

Marine Painting Manual

A. M. Berendsen

*TNO Paint Research Institute
Delft, The Netherlands*



*Netherlands Organization for
Applied Scientific Research, Delft*



*National Foundation for the
Co-ordination of Maritime Research,
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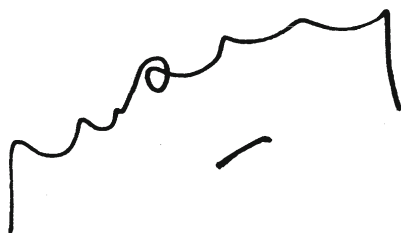
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PREFACE

It is a pleasure to introduce to the reader this new Marine Painting Manual. The previous edition, entitled Ship Painting Manual, was published in 1975. Since then a number of new technological developments have taken place. Also, standards with regard to safety, health and the environment have become more severe.

These changes called for a thoroughly revised and updated Marine Painting Manual. I believe that the editor should be congratulated on having completed this task in such a commendable way.

I hope that this new volume will find as enthusiastic a response among those concerned with maritime affairs as its predecessor did some fifteen years ago.

A handwritten signature in black ink, consisting of a series of connected loops and a final vertical stroke, positioned above the typed name.

Dr. Jan Raat
Director
Netherlands Foundation for the
Co-ordination of Maritime Research

INTRODUCTION

The "Marine Painting Manual" sets out to provide clear guidelines for the effective protection of marine structures, ocean-going vessels and offshore platforms. Painting is a high cost procedure and is a crucial factor in determining the life and subsequent maintenance of steel structures in the marine environment.

The book is a follow-up to the "Ship Painting Manual" published in 1975. It has been completely revised, partly rewritten and an additional chapter on offshore structures included. The present volume contains detailed and up-to-date information on all aspects of the preparation and painting for the protection of marine structures.

The following chapters are included:

1. The protection of different parts of ships under construction.
2. The protection of different parts of offshore structures under construction.
3. Surface preparation.
4. Paints and paint systems.
5. Prefabrication (shop) primers.
6. Storage and application of paints.
7. Maintenance of paint systems.
8. Paint contracts and specifications.
9. Quality assurance, quality control, testing and inspection.
10. Cathodic protection.
11. Health, safety and the environment.

The "Marine Painting Manual" was commissioned by the Netherlands National Foundation for the Co-ordination of Maritime Research (CMO)* and has been compiled by the TNO Paint Research Institute**. The editor, Ing. A.M. Berendsen, was assisted

* Stichting Coördinatie Maritiem Onderzoek (CMO).

** The TNO Paint Research Institute forms part of the TNO Centre of Polymeric Materials.

by an advisory panel of representatives of ship yards, ship owners, paint manufacturers and painting contractors. The chairman was Drs. F.H. de la Court, Head of the Paint Research Institute. Chapter 11 has been drafted by another member of the Institute, Dr. T. Doorgeest.

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He also wishes to thank Dr. D.R. Houghton for his advice on the English text and for his useful comments.

COLOUR PLATES

- Plate 1.* Section building.
- Plate 2.* Transport of a ship's section to the slipway.
- Plate 3.* Hydro-blasting of a ship's hull.
- Plate 4.* Mobile machine for dust-free blast-cleaning of ship hulls.
- Plate 5.* Severe osmotic blister formation in a water ballast tank resulting from a porous tank coating system on top of a prefabrication primer containing water-soluble material.
- Plate 6.* Failing water ballast tank coating system resulting from tar exudation.
- Plate 7.* Pitting corrosion on the bottom of a cargo tank, promoted by the use of un-insulated heating coils.
- Plate 8.* Corn grains sticking to an overly thermoplastic coating system in a cargo hold.
- Plate 9.* New building of a small offshore jacket and helideck.
- Plate 10.* Cathodic protection of a jacket by large sacrificial anodes.
- Plate 11.* Tidal splash zone protection.
- Plate 12.* Preparation for expensive offshore maintenance.

Front cover photograph: Dock and Shipbuilding Company Wilton-Fijenoord, Schiedam, The Netherlands.

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CHAPTER I

THE PROTECTION OF DIFFERENT PARTS OF SHIPS UNDER CONSTRUCTION

1.1. Introduction

The construction of a new ship begins with the welding together of plates and profiles into *block sections*. Before being welded, the various parts have undergone mechanical treatments such as rolling flat, cutting to size, bending, stretching and drilling. The sections are usually built under cover, in the so-called section hall. They are transported to the slipway, where they are welded together.

Most slipways are not covered, although a growing number of yards in Western and Northern Europe build their ships completely under cover and consequently they are no longer dependent on the climate.

Before the ship is launched for fitting-out, after welding the sections together, it is always necessary to apply a protective paint system to the bottom, the boottop area and preferably to the entire outer hull. If the ship is to lie in sea water during fitting-out, it is recommended that one or more coats of antifouling paint should be applied to the underwater plating before launching.

1.2. Protective methods

Current practice is to blast-clean the steel plates and profiles that are to be assembled into sections and to coat them with a prefabrication primer (shop-primer, shop-coat, see 5.1). The main advantage is that for a considerable time during the construction period the steel is protected from corrosion and contamination by atmospheric pollution; an additional advantage is that workshops remain clean. This method is called *building in the shop coat*.

The classical method is the so-called *building-in-rust*, in which surface preparation and painting are deferred until the sections have been welded together on the slipway.

During construction, weathering will partially or completely remove the mill scale. This process, however, is often accompanied by more or less severe pitting, which can reduce the lifetime of paint systems considerably, even when the entire substrate is thoroughly blast-cleaned before painting. Also, it should be taken into consideration that large-scale blast-cleaning in the open air, is not always acceptable in view of the environmental pollution it causes.

For the above mentioned reasons the building-in-rust method is unattractive. In Europe, this method has not been practiced for a long time.

A variation of the building-in-rust method is to blast-clean the steel plates before fabricating the sections, and to carry out further surface preparation and painting after welding the sections on the slipway.

The time lapse between blast-cleaning and painting, however, allows fresh rust to form. Although this method, in comparison with that described above (removing of mill scale by weathering), has the advantage of reducing the risk of pitting, it is equally unattractive as regards protection unless the surface is blast-cleaned for a second time before painting. Moreover, in a heavily polluted (industrial/marine) atmosphere, the steel surface may become contaminated with soluble salts. These salts considerably reduce the lifetime of paint systems and are difficult to remove by blast-cleaning (see Part 3.2.4.5).

Building sections from unpainted blast-cleaned steel is of advantage to the shipbuilder because welding and flame-cutting operations can be carried out at the highest possible speed. On the other hand, the method is expensive as, for a good result, blast-cleaning must be carried out twice.

Still another variation is to blast-clean the plates and profiles, assemble them into sections, if necessary blast-clean them again, and apply the first coat of paint before they are welded together on the slipway.

By far the best method as regards protection is, undoubtedly, to build ships in completely sheltered and heated spaces. This method, although it requires high capital expenditure, has become more widely adopted by Western and Northern European yards, because of long periods during the year when weather conditions are unfavourable for outdoor work, including coating application.

Beside the considerable advantage of working in sheltered, heated and well lighted workshops, which makes it possible to work without interruption, there are, however, some disadvantages. The steel surfaces often become dirty due to dust and welding fumes. Welding zones, which can be alkaline, will not be neutralized (washed) by rain as would happen in the open air.

It will be clear from the foregoing that additional cleaning operations are necessary. When building under cover large scale blast-cleaning, apart from tank internals, is impractical; only vacuum- or mini-(pencil) blast-cleaning can be permitted. Furthermore, painting under cover causes problems such as fire (explosion) risk, unpleasant odours and health hazards through solvent vapours and spray mist.

Consequently, unless a very good ventilation system is installed, painting is mostly done during night when all other work is stopped.

As already stated, *current practice* is to blast-clean the parts to be assembled into sections and to provide them with a so-called prefabrication primer (shop-primer, shop-coat).

Surface preparation and application of the prefabrication primer are usually performed by the yards themselves. It is possible, however, to begin construction with steel plates

which are prepared in the same way by the steel supplier or specialized painting contractor. This is the usual practice for small yards.

The best way of preparing shop-coated steel is to blast-clean plates and profiles in an impeller machine and to auto-spray them immediately with a thin coat of prefabrication primer. This procedure will be dealt with in Chapter 5, together with details such as surface preparation grade, surface profile, types of prefabrication primer, dry film thickness, corrosion protection, recoatability and behaviour of prefabrication primers in welding and flame-cutting operations.

The shop-coated steel is subjected to the mechanical treatments described in section 1.1., after which the plates and profiles are assembled into sections by (automatic) machine- or hand-welding in the section hall.

In order to carry out the automatic welding at the highest possible speed and to obtain continuous (non-porous) welding, it will be necessary sometimes to remove the shop-coat from the welding areas. This can be done by grinding or by vacuum-blasting.

After assembly, the sections are painted as follows:

- As soon as possible, partly or completely (in the section hall or in an adjacent coating hall).
This method is called *painting in section building* or *block painting*,
- After a long period, e.g. after erection on the slipway.
This method is called *building in the shop-coat*.

The two methods are compared below:

Painting in section building (block painting) has the following *advantages*:

- it can be done under favourable conditions (i.e. under cover, which is especially attractive for two-pack paints).
- it avoids premature corrosion.

Some *disadvantages* are:

- during transport of the sections to the slipway and during fitting-out there is a risk of mechanical damage and burns, necessitating local repairs of the paint systems. Such damage, however, can be minimized by adequate planning of the construction phase.
- subsequent pretreatment and painting of the section welds is of course unavoidable. These areas must be left unpainted during block painting.
- those parts of sections where much welding and flame-cutting are to be expected during final fitting-out are not suitable for painting during section building.
- some kinds of two-pack paints, applied at the block stages, may have become very hard by the time the welded areas are painted on the slipway. In that case the surface should be slightly roughened or softened, before being touched-up, in order to ensure good adhesion of the touch-up coats. This should be done in accordance with the paint manufacturers recommendations.

When a ship is painted during section building, application of the last coat of the paint system is often deferred until the ship is on the slipway or has been launched. This practice prevents touched-up areas from showing up.

When painting during section building, adequate ventilation must be provided to prevent fire and health hazards of solvent vapours liberated during degreasing and painting.

Building in the shop-coat has the following *advantages*:

- no coating hall is required.
- the repair of damage, caused by transport of the sections or by welding and flame-cutting operations, takes much less time than in the case of block painting.

The main *disadvantage* of building in the shop-coat is that shop-coats (prefabrication primers) are liable to weathering during construction of the ship. This means that, before final painting, the steel surfaces should be properly cleaned and freed from possible corrosion products.

By building ships under complete cover, which is normally is done in the shop-coat, corrosion products are usually avoided. The steel surfaces, however, may be contaminated by welding fumes and dust.

Shop-coated surfaces may become contaminated with water soluble salts by exposure in an industrial/marine atmosphere. When these salts are not properly removed, premature failure of the paint systems is to be expected. Nowadays, to avoid this, for immersed parts of ships (bottom, tank interiors) there is a growing tendency to remove the shop-coat by blast-cleaning before the application of the final paint system. An additional advantage is that the corrosion-free steel surface with a sharp surface profile, obtained in this way, will promote paint adhesion. The blast-cleaning of shop-coated surfaces, however, does mean an extra operation.

Shop-coats (prefabrication primers) containing zinc dust pigment have the disadvantage of producing 'white salts' ('white rust') during weathering. These salts, which are partially soluble in water (hygroscopic), cannot be removed easily. Residues of these zinc salts may cause subsequently applied paint systems to blister, especially on the immersed parts (underwater hull and interiors of tanks). To prevent this, the shop-coat is sometimes removed by blast-cleaning (sweeping) or thoroughly scrubbed and subsequently rinsed with fresh clean water, before application of the final paint system.

The choice between painting in section building and building in the shop-coat depends on, among other things, the geographical situation of the yard, the equipment available, the time of the year in which the painting has to be carried out, the nature of the paint systems and the planning of the building. Since both methods are currently being widely used, they will be dealt with in more detail in the following sections (1.2.1. and 1.2.2)

1.2.1. PAINTING IN SECTION BUILDING (BLOCK PAINTING)

1.2.1.1 *Operations in the coating hall*

Of great importance is the treatment of the welding seams, especially in sections for the immersed parts of the ship, including the tanks. Special attention should be given to the removal of welding flux in crevices and the removal of possible alkaline material on and around the welding zones.

It is strongly recommended that welding spatters be removed by chipping, to smooth sharp parts of the welds by grinding and to make good porous parts of hand welds by rewelding.

After preparation as described above, the welding seams, burns and mechanically damaged spots should be blast-cleaned and immediately provided with the first coat of the paint system, applied by brush. Blast-cleaning can be done with a vacuum blasting machine. The burnt zones along the welds should not be overlooked.

Instead of blast-cleaning, mechanical cleaning is sometimes carried out by power tools with (flexible) emery discs, needle hammers or rotary steel wire brushes but the results are inferior to blast-cleaning. Therefore, welding seams and burnt areas should be cleaned mechanically only if the paint manufacturer agrees. When mechanical cleaning is executed, the preparation grade should be St3 according to ISO standard 8501 (see Part 3.2.3.3).

After touching-up of the weld seams, burns and mechanically damaged areas, the sections should be degreased where necessary with a suitable organic solvent or detergent as recommended by the paint manufacturer.

As soon as the surfaces of the sections are dry, the subsequent coats of the paint system are applied in accordance with the painting specification (painting list) and the paint manufacturers recommendations. Those edges which are to be the section welds in a later phase of the building should be left clear of paint for about 3 cm.

1.2.1.2 *Operations on the slipway and during final construction (fitting-out)*

After being painted, either wholly or partly, and after the paint systems have sufficiently cured, the sections are transported to the slipway and welded together. The welds between sections are called 'section welds'.

Any sections which, before being welded together on the slipway, have to be stored for long periods should be placed so that no pools of rainwater can collect on them. The transport and final building operations should be carried out so as to minimize the risk of mechanical damage and burns.

When the sections have been welded together, the section welds, burns and mechanical damages must be cleaned and touched-up.

By far the best method is to blast-clean these parts (after degreasing where necessary) and then apply the various coats of the paint system. In this touching-up no prefabrication primer should be used.

1.2.1.3 *Summary of painting in section building*

The operations of painting in section building may be summarized as follows:

- smoothing of welding seams (especially for immersed parts);
- local blast-cleaning or mechanical cleaning of welding seams, burnt areas and mechanically damaged spots, followed by local application of the first coat of the paint system;
- degreasing of the sections where necessary;
- application of subsequent coats of the paint system(s) according to the painting specification and the recommendations of the paint manufacturer; the edges to be joined should be left unpainted;
- transport of the sections to the slipway;
- welding together of the sections;
- local blast-cleaning or mechanical cleaning (after degreasing, where necessary) of the sections welds, burnt and mechanically damaged areas (if any), followed by local application of the successive coats of the paint system.

1.2.2. BUILDING IN THE SHOP-COAT

1.2.2.1 *Operations in the section hall*

The weld seams and burnt and mechanically damaged areas of completed sections should be touched-up with the first coat of the paint system in the way described in Part 1.2.1.1.

Parts of sections to which access will be difficult in later stages of the building procedure should have the complete paint system applied in the section hall, e.g. those areas of the underwater hull which will afterwards rest on blocks and sledges.

At this stage too, it is advisable to apply, by brush, an extra coat of (touch-up) primer to weld seams, sharp edges and other less accessible areas. A thin coat of quick drying (system) primer is sometimes applied to the whole surface of the section.

1.2.2.2 *Operations on the slipway and during final construction*

After the operations in the section hall, the sections are transported to the slipway, where they are welded together. Unless stated otherwise in Parts 1.3.1. to 1.3.9., the following work scheme is recommended.

Section welds and damaged or burnt areas are touched-up in the way described in Part 1.2.1.1. Blast-cleaning is strongly recommended, using an inert abrasive that needs not to be recovered.

Other areas beside weld seams, burnt and damaged spots, showing outbreak of rust, should be derusted and touched-up in the way described above before application of the final paint system.

On shop-coated surfaces where the steel *has corroded more or less uniformly* to a degree *Re 1* or more of the European rust scale (i.e. at least 0.05% of the surface covered with protruding rust) the shop-coat should be removed by blast-cleaning before application of the first coat of the paint system.

As mentioned previously, in order to avoid premature paint failure in critical locations like underwater plating, it is recommended that the shop-coat will be removed by blast-cleaning before the application of the paint system. This becomes more important when the building time of the ship is protracted.

Before applying the different paint systems, the surfaces should be degreased where necessary with a suitable organic solvent or detergent; it is sometimes sufficient to wash the surfaces manually or by spraying with clean fresh water. Surfaces which have been directly exposed to the atmosphere, such as the outer hull, decks, exterior of deckhouses, etc. should in any case be washed with water. Surfaces coated with a prefabrication primer containing zinc dust should be scrubbed thoroughly with nylon brushes, using an abundance of *clean fresh water*, or should be hydroblasted. If such a coat is heavily weathered, it should be removed by sweep-blasting.

After the surfaces are thoroughly dry, the paint systems for the outer parts (underwater hull, boottop zone, topsides) are applied on the slipway as soon as possible. When these coats have cured, the ship can be launched.

The remaining parts of the ship are partly painted on the slipway, and partly during final construction, depending on the building scheme and the planning.

Painting should be done in good weather and each coat should be checked for appearance and thickness.

If long intervals between the application of successive coats cannot be avoided, it is recommended that any dirt adhering to the previous coat is washed-off with clean fresh water and the surface allowed to dry before applying the next coat.

Some two-pack paints, particularly if allowed to harden for long periods, may provide a poor basis for adhesion of the next paint coat. These two-pack paints should be properly roughened or slightly softened with a strong solvent before the application of the next coat of paint.

1.2.2.3 *Summary of building in the shop-coat*

The operations during building in the shop-coat may be summarized as follows:

- repair by blast-cleaning or mechanical cleaning of weld seams, burnt and mechanically damaged spots, followed by local application of either a thin coat of primer or the first coat of the paint system;
- prepainting of sharp edges and inaccessible areas with the first coat of the paint system.
- transport of the sections to the slipway;
- welding together of the sections;
- touch-up blast-cleaning or mechanical cleaning of the section welds, burnt, damaged and slightly rusted areas, followed by application of the first paint coat to these areas; if more rust is present, the shop-coat is often removed by blasting prior to application of the first paint coat;
- where necessary, degreasing, washing or scrubbing the surface and allowing it to dry;
- application of the subsequent layers of the paint system according to the painting specification and the recommendations of the paint manufacturer.

1.3. **Paint systems for the separate parts of a ship in new construction** (see Appendix 1.A for a tabular summary)

1.3.1. UNDERWATER PARTS

1.3.1.1 *Requirements*

Paint systems for the underwater hull should be:

- corrosion-inhibiting;
- water-resistant;
- abrasion-resistant;
- anti-fouling;
- smooth;
- compatible with cathodic protection systems (i.e. resistant to alkaline conditions).

In order to keep bunker costs to a minimum, it is extremely important that the underwater parts are smooth and remain smooth during service. The coating system should be applied as evenly as possible and provide long-lasting protection against corrosion and fouling. Some additional information concerning hull roughness parameters is given in appendix 1.B.

1.3.1.2 Suitable paint systems

Paint systems for underwater parts usually consist of *several anti-corrosive coats* and an *anti-fouling paint system*.

In *conventional systems* corrosion protection is provided by *several coats of a bituminous paint* with a total dry film thickness of at least 150 micrometers (μm). If the system is thinner, its service life may be considerably shortened.

Bituminous aluminium paints (which can also be supplied as 'high-build' types) are particularly popular as conventional underwater paints.

The anti-fouling properties are provided by a *conventional (classical) anti-fouling paint*.

With *modern high-performance systems*, which must provide a very long lasting protection, corrosion protection is afforded either by at least *two coats based on coal tar epoxy or polyurethane tar*, with a total dry film thickness of at least 250 μm , or by *several coats of paints based on chlorinated rubber, vinyl copolymers or vinyl/tar*, with a total dry film thickness of at least 200 μm . These paints are often used in their 'high-build' modifications.

Two-pack paints are often preferred to chlorinated rubber or vinyl paints because of their better mechanical properties.

The anti-fouling properties are provided by *several coats of an anti-fouling paint of the contact matrix (longlife) or a self-erodable type*.

Sometimes a 'sealer' or 'tie coat' must be applied between the coal-tar epoxy or polyurethane tar paint and the anti-fouling paint.

The sealer prevents the tar from bleeding into the anti-fouling coating system, thereby improving its effectiveness; in addition a sealer improves the adhesion of the anti-fouling layer.

In order to avoid the use of a separate sealer, sometimes the second coat of coal-tar epoxy paint is a vinyl modified type, which remains easily recoatable without intercoat adhesion problems.

On special ships, like tugs, harbour and offshore craft, where a very high abrasion resistance is required because of fender damage, ice impact or shallow water grounding, the underwater part can be coated with a very thick abrasion resistance system. These systems, for instance, consist of *special epoxy coatings*, sometimes solvent-free, applied in (dry film) thicknesses of approximately 300-500 μm or consist of *solvent free epoxy or polyester resin coatings, reinforced with glass flakes*, applied in thicknesses of 500-2000 μm .

If the underwater hull is cathodically protected by means of an impressed-current system, the areas around the anodes are liable to be damaged by the current, and should be given extra protection. This protection as a rule consists of a special dielectric (anode) shield. Directly around this shield an *epoxy filler* of at least several millimeters thick is

often applied, or the anti-corrosive underwater paint system, provided this is based on coal-tar epoxy or polyurethane tar, is locally applied very thickly.

1.3.1.3 Procedures

To ensure adequate protection of areas that become inaccessible for painting during building, such as keel block areas, the complete paint system, including the anti-fouling layers, should be applied on those areas before the sections are placed on the blocks.

The first coat of anti-fouling paint normally is applied shortly before the ship is launched. For conventional types of anti-fouling paint this is a must, because they cannot be exposed to the atmosphere for long periods. Modern types have a better resistance. The paint manufacturers recommendations as to drying and exposure time should be followed closely. Sufficient time should always be allowed for the anti-fouling paint to dry thoroughly.

When a ship has been completed, it is taken into dry-dock, where its underwater parts are cleaned by scrubbing or hydro-blasting. Where necessary, the surfaces should be degreased by means of a detergent, followed by hosing with plenty of clean fresh water. The surface is then allowed to dry, and any mechanically damaged spot touched-up with the correct number of paint coats. As soon as the paint is dry, the anti-fouling is applied shortly before delivery of the ship.

1.3.2. THE BOOTTOP ZONE

1.3.2.1 Requirements

Paint systems for the boottop should be:

- corrosion-inhibiting;
- water-resistant;
- weather-resistant;
- impact-resistant;
- scratch-resistant;
- smooth;
- easy to clean;
- anti-fouling (especially resistant to growth of algae).

Since many harbours are heavily polluted with oil, the paint system should also be *oil-resistant*.

When applied to ships provided with cathodic protection, paint systems should be *compatible with cathodic protection systems* (i.e. resistant to alkaline conditions).

The continually alternating action of water and air, the possibility of mechanical damage by drifting ice and other floating objects, and the possibility of softening of the

paint from floating oil, add up to the boottop zone being one of the most severely exposed parts of the ship.

The protection of the boottop zone should be at least qualitatively equivalent to that of the underwater parts.

1.3.2.2 *Suitable paint systems*

Paint systems for boottops usually consist of several *anti-corrosive and one or two coats of boottopping paint* of the desired colour.

For the anti-corrosive coats the reader is referred to the section on underwater systems (1.3.1.2).

Conventional boottopping paints are based on *tung oil phenolic resin combinations or bitumen*. However, the tung oil phenolic resin based products, which are saponifiable, are now not used very often.

Modern high-duty boottoppings are based on *epoxy resin, polyurethane resin, chlorinated rubber or vinyl copolymers*. Sometimes, to obtain a high degree of abrasion resistance in the boottop zone, special abrasion resistance systems, as mentioned under Part 1.3.1.2, are applied.

Chlorinated rubber paints are not resistant to fuel oil residues floating on the water and consequently are less suitable as boottopping compositions.

The colour mostly preferred by shipowners are black, red, reddish or dark green, which are not visibly discoloured by possible bleeding of coal-tar epoxy, polyurethane/tar or bitumen from the anti-corrosive coats. If a light colour for the boottop zone is preferred, it is recommended that anti-corrosives containing tar should not be used, unless an efficient sealer is employed as an intermediate coat.

So as to limit the number of paint types and to simplify the planning and execution of the paint work, it is further recommended that the high-duty system of the boottop zone is similar to that applied on the bottom parts, in which case no special coloured boottopping is used. This avoids the use of a separate paint system for the boottop area.

1.3.3. TOPSIDES AND EXTERIOR PARTS ON DECK (SUPERSTRUCTURES)

1.3.3.1 *Requirements*

Paint systems for topsides and superstructures, including deck houses, hatch coamings, hatches, cranes, funnels, bulwarks, etc., should be:

- corrosion-resistant;
- weather-resistant;
- impact-resistant;

- scratch-resistant;
- easy to clean.

Particular the top coat should be *smooth and hard* to prevent soiling and to ensure easy cleaning. For aesthetic reasons, especially for certain parts like deck houses, most owners prefer *high-gloss paints of durable colour and gloss*.

1.3.3.2 Suitable paint systems

Paint systems for the topsides and exterior work on deck (superstructures) consists of *several anti-corrosive coats and one or more finishing coats* of the desired colour.

Conventional alkyd paints still find wide application because of their pleasing appearance and good application properties. They are easy to repair and therefore particularly suitable for smaller ships, the topsides of which are often damaged by river vessels or lighters moored along side. Alkyd paint systems, whose total dry film thickness should be at least 140 micrometers, usually consist of two coats of anti-corrosive primer (having a certain colour difference) and two coats of finishing paint. They can easily be touched-up by the crew using a brush or roller.

Because of the risk of toxic fumes, anti-corrosive primers containing red lead or chromates should not be used on parts which have to be welded.

The topsides and exterior surfaces on decks of larger ships are often painted with *high-duty paint systems* (primers and finishing coats) based on *epoxy resin, polyurethane resin, chlorinated rubber or vinyl copolymers*. These high-duty systems should be at least 200 µm thick after curing.

If a high-build system is applied, the final coat is usually not of a high-build type but a conventional paint which gives a more decorative and smoother finish which is easier to clean.

Very decorative and durable finishes for *deck houses* etc., are provided by *polyurethane paints based on aliphatic isocyanates or isocyanate (polyurethane) acrylic paints* which have a better gloss and colour stability than paints based on alkyd resins. However, pure polyurethane paints have the disadvantage of possible intercoat adhesion problems when recoating since the old coats are very hard and insoluble. In this respect the polyurethane acrylic paints are to be preferred.

Some parts of the superstructures may consist of *aluminium* (e.g. deck houses) or *galvanized steel* (e.g. railings, pipelines) which require special surface preparation before being painted and, as a rule, special types of primer. (see Parts 3.3.3.4 and 4.5.1.3).

The protection of *machinery on deck* depends on the material from which it is constructed, its function and especially on its accessibility for maintenance. Extra requirements for the paint system are that this should be resistant to lubricating oil and

grease and is sometimes required to be heat-resistant. Machinery is often supplied with a standard finish, for cosmetic purposes, which is totally unsuitable for service on deck where a high corrosion-resistance is required.

The best way to overcome this problem is to issue the supplier, in good time, with a realistic coating specification. The machinery can then be delivered either totally (adequately) coated, or properly pretreated and primed.

Life-boats, constructed from glass-reinforced polyester resin, normally are delivered with a surface consisting of a gel-coat which has been pigmented in the required colour (orange or white). These boats are only painted in cases of mechanical damage or during maintenance when the gel-coat is excessively weathered.

The surface should be degreased and cleaned, for instance by rubbing with wet pumice powder and a detergent. In this way weathered gel-coat, wax and mould release agent residues will be removed. After having rinsed the surface with clean fresh water and after having allowed it to dry it should be painted, e.g. with one or two coats of *isocyanate (polyurethane) acrylic paint*, preferably on top of a suitable *pretreatment primer*.

1.3.4. MAIN DECKS AND GANGWAYS

1.3.4.1 *Requirements*

Paint systems for decks should be:

- corrosion-inhibiting;
- weather-resistant;
- impact-resistant;
- abrasion-resistant;
- non-slip (even when the decks are wet);
- resistant to water, fuel oils, lubricating greases, detergents (cleaning agents);
- resistant to spillage of cargo.

1.3.4.2 *Suitable paint systems*

Paint systems for steel decks not otherwise coated (e.g. by asphalt) usually consist of *several anti-corrosive paint coats and one or more coats of deck paint* of the desired colour. Often special 'non-slip' paints are used on the deck parts with heavy foot traffic.

Conventional paint systems for steel decks usually consists of *two coats of anti-corrosive primer and two coats of deck paint*, all based on *alkyd resin*. Such systems, applied at dry film thicknesses of at least 140 µm, are only moderately wear-, impact- and scratch-resistant.

They are not fully resistant to aromatic and other strong solvents and only poorly resistant to acids and alkalis. They should therefore on no account be used on the decks of 'extended white product'- or chemical tankers.

High-duty paint systems for decks consist of paints based on *epoxy resin, polyurethane resin, chlorinated rubber, vinyl copolymers* or *zinc silicate*. With the exception of the last-mentioned, the high-duty systems should be at least 200 μm thick after drying.

Zinc silicate paints, when used without top-coat should have a dry film thickness of between 75 and 120 μm . Zinc silicate is very hard, scratch-, wear- and corrosion-resistant, but not resistant to acidic and alkaline liquids.

Systems based on epoxy or polyurethane resin or combinations of these have good resistance against wear, as well as against chemicals and solvents. These systems are therefore suitable for use on decks of solvent carriers as well as the decks of chemical tankers.

Paint systems based on chlorinated rubber and vinyl copolymers are less wear-resistant than two-pack systems. They are resistant to acids and alkalis, but not to strong solvents. Moreover, chlorinated rubber paint systems are only moderately resistant to oils. Accordingly, chlorinated rubber and vinyl paint systems should not be used on the decks of solvent carriers. The decks of crude oil tankers should preferably not be coated with chlorinated rubber systems. Both paint systems, however, are fast-drying, which is an advantage when painting ships' decks.

Pipelines on deck should be treated according to their operating temperature. It may be necessary to use more or less heat resistant paint systems.

Deck equipment, not directly delivered by the yard, often is very poorly painted. When necessary, the paint work on this equipment should be derusted, touched-up and given extra coats in order to obtain the desired dry film thickness (approximately 200 μm).

1.3.4.3 Procedures

Before delivery of a ship the decks often show many damaged and rusted areas. Remedial action is often difficult, since, at this late stage of construction, open blasting is not always permitted and it is also impossible to isolate these areas for long periods. To avoid open blasting, portable vacuum or impeller blast-cleaning machines can be used, which can be driven slowly over the deck. The surface is blast-cleaned while dust and contaminants are safely collected.

When, in countries having a wet climate, a ship is to be delivered in winter, the anti-corrosive coats for its decks should be applied in the section building stage otherwise they will suffer severe corrosion. Whilst one has to realize that repair to the damage is expensive this has to be weighed against the much higher cost of blast-cleaning the whole deck and to a considerable delay in commissioning the vessel.

Ships that are being built in the shop-coat, should preferably be treated with a shop (prefabrication) primer having a high corrosion-resistance, such as one containing zinc dust. 'Building in the shop coat' is the preferred method for ships with small deck spaces (e.g. freighters) which are liable to suffer considerable damage during construction.

The ideal working procedure if a ship is built in the shop-coat is to blast-clean the decks shortly before delivery and to apply the entire paint system immediately after blast-cleaning.

It should finally be stated that non-slip paints, which are applied to certain deck areas in order to provide a non-slip surface, should not be applied too thickly.

1.3.5. DRY-CARGO HOLDS

1.3.5.1 *Requirements*

Paint systems for dry-cargo hold should be:

- corrosion-inhibiting;
- wear-resistant;
- impact-resistant;
- scratch-resistant.

Paints for the holds of dry bulk cargoes such as iron ore and coal should be particularly abrasion- and impact-resistant.

Paint systems for holds which are used for transport of cereals etc., where the risk of contamination of the cargo is unacceptable, should therefore on no account tend to flake. If they do, the holds will not be accepted for the transport of cereals etc. Also *the systems should have official approval for use in contact with food.*

In the case where dry-cargo holds will sometimes be used as ballast tanks, the coating system must fulfil additional requirements (see Part 1.3.6.3) and the number of cargoes to be transported is limited.

Especially for cargoes like grain, which may cause a rise in temperature due to natural heating, the coating system should not be thermoplastic in order to avoid sticking of the cargo to it and damaging the coating system. For this reason, systems based on chlorinated rubber and vinyl copolymers are not recommended.

Water collecting at the bottom of holds is normally drained off via the bilges at the side of the hull. Hence, paint systems for the floors of holds should be water-resistant.

Bilges, in which moisture and dirt can accumulate should be very well protected during building, since in later stages it is nearly impossible to clean, dry and paint them adequately.

1.3.5.2 Suitable paint systems

Conventional systems for dry-cargo holds consist of *several coats of bituminous or alkyd paint* e.g. two coats of anti-corrosive primer and one or two coats of 'hold paint' of the desired colour. For refrigerated holds 'low odour paints' are sometimes supplied. The total dry film thickness should be at least 140 μm . Alkyd and bituminous paints, however, tend to be damaged easily and require a great deal of maintenance.

High-duty paint systems based on *epoxy resin, polyurethane resin or their combinations with coal-tar* are wear- and impact-resistant and give reasonable results in the protection of holds for ore, coal or scrap. These systems should have a dry film thickness of at least 200 μm .

In holds liable to suffer heavy damage, a coat of *zinc silicate paint* at a dry film thickness of 75-120 μm is the most satisfactory because of its very good corrosion protection, hardness and resistance to wear.

Bilges, where good water-resistance is of prime importance, are often coated either with a very thick coat of hot applied bitumen, several coats of coal-tar epoxy, or with a so-called 'grease paint', which is a corrosion-inhibiting grease based on petroleum wax and/or wool grease (lanoline). Disadvantages of these 'grease paints' are that dirt easily sticks to their surface and that they may give problems when it is decided to protect the bilges subsequently with another type of coating system.

1.3.6. TANKS

1.3.6.1 Introduction

All ships have tanks for *ballast water, fuel, lubricating oil, drinking water, deionized or distilled water* and *special materials* such as sludges and liquid detergents. All these substances are indispensable in the normal ship operation. Fuel tanks are sometimes also used as water ballast tanks; these tanks are known as *fuel oil/ballast tanks*. Tanks for ballast water only are called *segregated ballast tanks*.

In addition to these tanks there are the *cargo tanks*, intended for the transport of many kinds of product. These tanks are also sometimes filled with ballast water ('*cargo/ballast tanks*', '*crude oil/ballast tanks*').

Depending on the type of ship and kind of cargo, the tanks may be provided with heating facilities (coils).

Ships are often named after the kinds of cargo they carry such as *crude oil tankers, white oil or product carriers* (for refined fuels, lubricating oils and aromatic distillates such as toluene and xylene), *solvent carriers* (for strong solvents, such as esters and ketones), *chemical tankers* (for strong solvents, acids, lyes, latex, etc.), *wine tankers, gas (LNG/LPG) tankers* (for liquefied gases such as propane, butane, ethylene, ammonia).

Not all tankers are coated internally with a complete paint system. No painting is required for fuel and lubricating oil tanks, and large parts of crude oil tanks also can often be left unpainted but this is not a general rule.

It should be considered that, apart from *corrosion protection*, one of the advantages of the use of a coating system is that the *tanks can be cleaned more easily* and rapidly and permit rather quicker changes in the type of cargo carried. Also, *cargoes will be considerably less contaminated* than in uncoated tanks.

Sometimes tanks are only partially coated or are provided with a cathodic protection system, often in combination with a coating system. Inert gas systems, which were designed for prevention of explosions, contribute to the reduction of corrosion.

Shipping registries permit a reduction in plate thickness of cargo- and ballast-tanks when these are provided with a durable paint system. Conditions and permitted reductions differ somewhat among the various registries and can be found in:

- Lloyd's Register of Shipping. Rules and Regulations for the Construction and Classification of Ships
- Bureau Veritas. Rules and Regulations for the Classification of Steel Ships.

The above mentioned shipping registries publish a list annually of approved corrosion control coatings.

Also according to the registries, on ships intended for the carriage of oil cargoes having a flash point not exceeding 60°C (closed cup test), paints containing aluminium should not, in general, be used in positions where cargo vapours may accumulate, unless it has been shown by appropriate tests that the paint to be used does not increase the hazard of spark generation.

From the viewpoint of adequate protection, tanks in particular should be constructed as simply as possible. For that reason, in modern practice, stiffeners are fixed outside and the inside surfaces are kept as uncomplicated (smooth) as possible. Further constructional provisions should be made to facilitate staging and to avoid as far as possible local pools of water or (aggressive) cargo when the tanks are emptied.

1.3.6.2 *Procedures*

Like the other parts of a ship, tanks can also be painted in the section building stage, or being 'built in the shop-coat', the latter being the more usual procedure. Painting in section building requires very careful planning, since during final construction tanks may sustain burns or other damage as a result of installing heating coils, making passages between tanks, fitting steel ladders, etc.

In tanks for chemically aggressive cargoes, such as strong solvents, acids or alkalis, it is necessary to remove the shop-coat by blasting, even when it is still intact, before the application of a heavy-duty paint system (tank coating system). This is called in situ blasting and should be done very carefully.

In tanks for less critical cargoes, such as 'white oil products' a shop-coat, provided that it is in good condition and resistant to white oil products, need not to be removed, and thorough cleaning is sufficient. Rusted and burnt spots, however, should be blast-cleaned to a preparation grade of at least Sa 2^{1/2} prior to painting.

Especially in ballast tanks and tanks for aggressive cargoes, before blast-cleaning or further coating, welding spatters and deposits should be removed by grinding. Porous parts of welds should be cut out and re-welded. Sharp edges should be rounded by means of mechanical grinding to a radius of about 2 mm.

Any faults in the steel should be ground until a smooth surface is obtained. As some of these faults only become visible after blast-cleaning, it may be necessary to carry out the grinding operations subsequently.

With respect to tank coating procedures the following general information can be given. During pretreatment and coating operations and during initial curing of the coating system tank openings should be covered for protection against rain, snow, etc.

Adequate staging, enabling good access to the entire inside tank area is of prime importance; the staging planks (gratings) should be smooth and turnable for cleaning.

The distance between the gratings and the tank walls should be at least 0,50 and not more than 1 m, thus enabling free access for blast-cleaning and proper paint application without holidays, overspray, (dry spray) sagging, etc. The distance between each level of the staging should be about 2 metres.

Adequate safety (spark-free) lighting has to be installed inside the tanks, to provide optimal illumination of the surfaces.

All workers, engaged in blast-cleaning and painting operations in the tanks have to be equipped with fresh air masks and protective clothing. Such masks must also be worn when entering tanks while the paint is still drying, especially if the concentrations of solvent and thinner vapours still exceed the TLV (MAC)*.

All equipment should be properly earthed. For more details concerning safe working in tanks, the reader is referred to Part 11.6.3 and Appendix 11.C.

Before, during and after blast-cleaning and painting, condensation of water on the steel surfaces should be avoided. The risk of condensation is particularly great when the ship is lying in cold water which cools the outer walls of the tanks below the dew point of the internal air. Preferably, the painting of tanks should be completed before the ship is launched.

* see Part 11.2.6

Blasting and painting should only be allowed if the temperature of the coldest parts of the tanks is higher (preferably at least 3°C) than the dew point of the air inside the tanks and remains so during the whole operation.

Possible changes in relative humidity should be taken into consideration. This necessitates continuous monitoring of steel and air temperatures, humidity and determination of the dew point.

In the interest of health and safety and in order to create favourable working and painting conditions, tanks should be ventilated with dry, oil-free and, if necessary, heated air, before, during and after painting. If the air has to be dried, this may be done in special dehumidifiers, e.g. by passing the air over silica-gel.

When heated, the air should not be allowed to pick up excess moisture.

For this reason electrical heating is preferred. Hot air guns are unsuitable because their combustion gases raise the humidity and reduce the oxygen content of the air. Normally, driers are used which both dry and heat the air.

For blast-cleaning, only suitable uncontaminated inert abrasives are allowed.

In order to obtain a sufficiently rough steel surface with a sharp edged anchor pattern, (steel) shot abrasives are not acceptable. Generally, no *recycling of used abrasive is permitted*, especially in cargo tanks.

Unless otherwise specified, the blast-cleanliness should be at least Sa 2¹/2 at the moment the first paint coat is applied. The surface roughness** should be about 50-80 micrometers.*

During blast-cleaning, oil and/or water contamination of the cleaned surfaces must be avoided. For that reason compressors should be fitted with coolers and adequate oil- and water separators which should be drained-off regularly.

After the blast-cleaning operation, the steel surfaces and scaffolding should be thoroughly cleaned by means of industrial vacuum cleaners. Special attention should be paid to corners where excessive amounts of dust may collect. Staging planks should be vacuum-cleaned, both top and bottom. Finally, after blast-cleaning, dust must be completely removed.

To prevent dust/grit contamination of blast-cleaned or painted surfaces, the following measures should be taken:

- the area on the main deck surrounding the entrance coaming should be kept in a clean condition;
- workers in tanks should wear soft soled shoes;
- fibre mats, for wiping feet, should be placed at coaming entrances.

* see Part 3.2.4.4

** Ry₅ or Rz (see Part 3.2.4.3)

The coating system should be applied according to the paint manufacturers instructions. *The first paint coat should be applied as soon as possible after cleaning. All sharp edges, irregular/rough welds, inaccessible areas and horizontal girders, where liquids may remain after emptying the tank, should be stripe-coated before spray application of each coat.* Premature corrosion of these susceptible areas is thus prevented.

Excessive high film thicknesses which may lead to cracking, for instance in corners of stiffeners etc., however, should be avoided. *Tank coating systems for instance should nowhere have a dry film thickness of more than 50% above that prescribed.*

The lower parts/bottoms of the tank should be done last.

Spraying equipment should be in good order and the nozzle dimensions and pressure should be in accordance with the applicable data sheets.

Under no circumstances should paint be applied at lower temperatures or at higher relative air humidities than those specified by the paint manufacturers' data sheets.

After completion of the paint application, staging damage, including staging marks on the bottom, should be touched-up. This should be done by vacuum-blasting or mechanical grinding and building up the coating system again by brush and/or roller.

Mechanical grinding should not result in too smooth (polished) a surface. When touching-up the paint system by brushing or rolling, sometimes more coats are needed than with spray application in order to obtain the prescribed dry film thickness.

During touch-up activities special attention should be paid to avoid damage to intact parts.

Adequate prevention of fire and explosion hazards requires a high air ventilation capacity. This high capacity is needed to prevent concentrations of flammable vapours of solvents/thinners building up to more than 10% of the lower explosion limit. This capacity can be calculated when the volatile matter content of the paint and the lower explosion limit (LEL) of the volatile matter is known. An example of such a calculation is given in Part 11.5.9.

It is very important to install the ventilation exhausts at or near the bottom of the tanks, because this is where solvents, being heavier than air, usually collect. Ventilation through man holes only is certainly not sufficient.

In view of the increased fire and explosion hazard in tanks and its surroundings, the use of paints with a high flash point is often specified. Fire, explosion and health hazards can be further minimized by the use of quick-drying high-solid paints and preferably by the use of those that are solvent-free. *As a general rule, ventilation should be continued for a long time after application of the final paint coat.*

Tanks should not be closed too early and not be filled with cargo or ballast water before the interior coating system is completely cured, i.e. before the evaporation of

solvents/thinners and the chemical drying (curing) are complete. *Incomplete curing can seriously impair the resistant properties of the coating.*

Too early a loading of freshly coated tanks may cause the system to soften, blister and flake, leading to premature corrosion and contamination of the cargo. Before loading the tank it is therefore strongly recommended that the paint suppliers' advice is sought on whether the system has sufficiently cured.

Aggressive cargoes can only be carried when the tank coating system is fully cured. Full cure may be obtained by transporting a hot, non-aggressive cargo for a few days. For this purpose, for instance lubricating oil at 60°C can be used.

Critical parts of coated surfaces should be checked for the presence of holidays and pinholes by visual examination and holiday detectors (see Part 9.4.7.4). All defective areas should be properly repaired (derusted and recoated) before the staging is removed.

For a final check on the presence of possible holidays it is good practice to fill the tank with sea water. After about 24 hr the tank is emptied and the inside allowed to dry. Holidays are revealed as rust spots.

1.3.6.3 Requirements

Paint systems for the interiors of tanks should be:

- corrosion-inhibiting;
- free from pores;
- smooth (easy to clean);
- very resistant to the cargo to be transported;
- resistant to substances as may be released by the cargo;
- resistant to tank cleaning procedures;
- resistant to a sequence of different cargoes and cargo/cleaning procedures.

When cathodic protection is applied, the paint systems should also be unsaponifiable.

As a general rule, paint systems for tanks *should not develop substances that may contaminate the cargo*. This is particularly important for cargoes intended for human consumption and pure chemical cargoes.

Paint systems for tanks for edible and potable cargoes must not develop toxic substances or substances affecting colour or taste. For this reason they need to be officially approved.

1.3.6.4 Suitable paint systems

a. Water ballast tanks

Conventional systems for water (segregated) ballast tanks consists of *several coats of bituminous paint* with a total dry film thickness of at least 300 μm . High-build modifications of these paints are also used.

As an alternative, *solventless bituminous compositions* are often employed. These compositions must be heated to prepare them for airless spraying (dry film thickness 300-500 μm) or application by brush in very thick coats (dry film thickness a few millimeters).

If necessary, the solidified brush coats can be smoothed by flame. To ensure good adhesion of the bituminous compositions, a so-called *bituminous solution* must be applied beforehand as a 'key-coat'.

To effect repair, *water-based bituminous or epoxy coal-tar dispersions* are sometimes used. This has the advantage that paint application is already possible during welding operations.

Less durable products for water ballast tanks are the *grease paints* (anti-corrosive grease, based on petroleum products or non-oxidising animal products) and *float coats* (low-viscosity non-drying anti-corrosive petroleum or wool fat derivatives).

Grease paints and float coats need no thorough surface pretreatment and the tanks can be ballasted shortly after application.

A float coat is applied by floating it on the surface of the water, filling the tank slowly and then emptying it, so that the product is deposited on the walls (flotation method). The procedure is cheap because it saves labour and material, but it has to be repeated several times. There is a risk, however, of contaminating the harbour water. Float coats can easily be applied by airless spraying, some of them in a thick layer.

The flotation method does not always give satisfactory results. Suppliers sometimes recommend applying the float coat to the upper parts of the tank and to the more inaccessible parts by airless spraying, and to the remaining parts by flotation. This method gives better results. If the tanks contain much sludge, the value of the treatment with a float coat is questionable.

The use of grease paints or float coats may give rise to problems when tanks are subsequently protected with another coating system. The reason being that it is very difficult to remove the grease paint or float coat to the extent necessary for obtaining adequate surface-cleanliness.

High-duty systems for water ballast tanks usually consist of *several coats of paint based on coal-tar epoxy, epoxy resin, polyurethane tar or vinyl tar*; their dry film thickness should be at least 250 μm for the epoxy and polyurethane systems and at least 200 μm for the vinyl systems. Sometimes *epoxy resin/bleached tar combinations* are used for which a dry film thickness of at least 300 μm is recommended.

Some of the epoxy-, coal-tar epoxy or polyurethane products are solvent-free and can be applied in one layer with a dry film thickness of at least 250 μm .

Water ballast/fuel oil tanks should not be coated with bituminous, coal-tar epoxy, grease paints or float coats because these products would soften or even dissolve in the fuel.

Water ballast/crude oil tanks are left in a shop-coated condition (after thorough cleaning) or are completely or partly (bottom + horizontal parts) coated with a *(coal-tar) epoxy or polyurethane paint* system with a dry film thickness of at least 250 μm .

As water ballast tanks are very prone to corrosion, pitting can occur due to irregularities (pores, mechanical damages) in the coating system. Therefore, *sacrificial anodes* are sometimes installed in the bottom area to provide cathodic protection.

b. Fuel tanks

Since liquid fuel prevents the rusting of steel and will emulsify considerable quantities of water, the interior of liquid fuel tanks need not be painted.

After mechanical cleaning, these tanks are filled with fuel oil as soon as possible. If a long delay is unavoidable, the interior of the tanks should be oiled.

The bottoms and horizontal parts of *diesel oil tanks* are usually protected by several coats of *epoxy paint* to a total dry film thickness of at least 250 μm .

Gas turbine fuel tanks should be completely coated with a well-adhering paint system, since contamination of such fuels with solid particles (e.g. dirt, rust, or zinc particles) would severely damage the turbines. Gas turbine fuel systems have very elaborate filtering systems which should not be blocked. As gas turbine fuels are chemically active, and also because contamination with paint particles must be avoided, gas turbine fuel tanks have to be treated in the same way as those for chemicals (see Part 1.3.6.4f). The preparation of the inner tank surfaces includes 'in situ' blasting, followed by application of *several coats of epoxy paint*. The paint system should be at least 250 μm thick and should be free from metallic pigments.

c. Lubricating oil tanks

Since lubricating oils contain inhibitors preventing the rusting of steel, it is not strictly necessary to paint the interior of the tanks in which they are carried. If such tanks are not painted, however, it is of *vital importance that all dirt, rust particles and pieces of metal are thoroughly removed*. Any solid contaminants in lubricating oil may clog the system. Many classification bureaus and shipowners require the interior of the tanks to be delivered at silver brightness. After mechanical treatment and thorough cleaning the tanks should be filled with lubricating oil, as soon as possible, or otherwise be oiled.

To prevent contamination of the lubricating oils and corrosion (pitting) by condensed water on the upper parts of the tanks, present practice is often to paint these parts of the

tanks during building. For this purpose at least two coats of epoxy paint are applied. Sometimes, however, the whole tank interior is painted.

d. Drinking (potable) water tanks

The oldest method of protecting the interior of drinking (potable) water tanks is to give them a *cement wash*. This treatment is cheap, but should be frequently repeated. Moreover, cement wash is likely to attack zinc containing shop-coats.

Another cheap method of protection, which also requires frequent repetition, is to apply an *odourless and tasteless preserving grease*.

More durable *conventional systems* usually consist of several coats of a special *odourless and tasteless bituminous paint*, or of similar compositions that can be applied hot in very thick layers (a few millimeters) to a thin key coat of bituminous solution. An advantage of such compositions is that they do not contain slowly evaporating solvents that might impart a disagreeable taste of drinking water.

The usual *high-duty systems* for protecting drinking water tanks consist of *one or several coats of epoxy paint* with a total dry film thickness of at least 250 μm or *several coats of vinyl paint* with a total dry film thickness of at least 200 μm .

The use of coal-tar epoxy paints is less attractive and even forbidden in some countries, because these paints may give off unpleasant tasting or even toxic substances. In many countries, paints for drinking water tanks are subject to approval of official bodies, for example the Food and Drug Administration (FDA) in the United States of America.

Before being put into service, drinking water tanks should be ventilated for a long period so as to remove any solvent vapours that might taint the water.

e. Water tanks other than ballast water or drinking water tanks

High-duty systems for such tanks usually consist of *several coats of epoxy paint* with a total dry film thickness of at least 250 μm . In order to reduce the risk of blister formation, the tanks should be blast-cleaned shortly before the application of the paint system when the shop-coat, if present, should also be removed. At the time the first coat of paint is applied, the blast-cleanliness should be at least Sa 2^{1/2}.

Hot water tanks, in which the risk of blistering is greatest, should preferably be given a paint system of at least three or more coats so as to ensure that the substrate is well sealed.

For this purpose 'high-build' paints are not always suitable, because of their tendency to retain solvents which makes them particularly likely to blister.

f. Cargo tanks

General

In the cargo tanks a wide variety of cargoes is shipped. While some tanks are always used for the same product, other tanks are used for different commodities. It may be necessary to wash the tanks insides thoroughly (for instance by butterworthing) when changing cargoes.

Consequently, *the coating system should not only be resistant to the separate cargoes but also to the alternating action of different cargoes and cargo/cleaning procedures.*

While two successive cargoes may be individually compatible with a tank coating system, a mixture of the two, due to residues of the first cargo, may cause damage. For instance when a vinyl acetate monomer (VAM) cargo is followed by a water containing cargo, residues of the vinyl acetate monomer in the tank lining (coating) will hydrolyse. By this process acetic acid is formed which will cause corrosion and attack the coating.

It may be necessary to clean and/or ventilate cargo tanks or to wait a certain time when changing cargoes from one to another.

Extensive information about the resistance of tank coating systems to a great variety of cargoes is given by coating manufacturers in their *commodity- or resistance list*. An example of a part of such a list is given in Appendix C of this chapter.

Special attention must be paid to the additional notes, containing warnings/restrictions, for instance concerning acidity/alkalinity, presence of water in the tanks, cleaning chemicals, cargo residues, etc.

Especially in the case of the transport of cargoes which cause swelling, such as certain solvents, tank coating systems based on organic coatings should not be too thick (e.g. not thicker than 500 µm).

As many cargoes are very corrosive, the inside of cargo tanks should contain no (poorly covered) sharp edges etc. Beside rounding the sharp edges and stripe-coating these before application of each coat, there is nowadays a tendency to construct tanks without internal sharp edges by placing the stiffeners outside the tanks (see also Part 1.3.6). Beside the advantage of avoiding sharp edges on the inside, the inner surface area, which must be protected by an expensive tank coating system, is reduced.

Heating coils of stainless steel or aluminium brass are often fitted in the cargo tanks in order to decrease the viscosity of some cargoes, thus facilitating pumping.

Electrical connection of these heating coils to the hull should be avoided by insulating them well from their supports. If there should be electrical contact between the coils and the hull, rapid corrosion will take place. Especially as in the bottom area of the tanks coating irregularities often occur, due for instance to mechanical damage, severe pitting may be the result. In order to avoid damage to the coating system as a result of overheating and to make touch-up painting under the coils possible the distance between the coils and the tank bottom should not be less than 10 cm.

Coating systems

Crude oil tanks are usually protected by *high-duty paint systems* based on *coal-tar epoxy, polyurethane/tar or epoxy resin*; the total dry film thickness should be at least 250 μm .

The cargo tanks of very large tankers (VLCC's), including crude oil/ballast tanks, are often only partially protected. In such cases, only the bottom (on which acidic water settles), the deckheads including a zone of about 2 metres downward on vertical walls and bulkheads (on which water condenses), a similar zone from the bottom upwards, and the upper side of the horizontal stringers, are painted. Coating damage should be avoided as this will result in severe pitting corrosion. The remainder of the plates and profiles of the tanks consist of blast-cleaned steel which is not shop-coated and painted. Often the bottom part of the tank is protected from excessive rapid corrosion by a cathodic protective system using *sacrificial anodes*.

This method is unsatisfactory for crude oil/ballast water tanks, and for adequate protection they should be painted completely; this point will be dealt with in more detail in Part 10.9 (cathodic protection of tanks).

Tanks for white oil products (refined fuels and aromatic distillates such as toluene and xylene) are generally protected by an *epoxy or polyurethane coating system* with a total dry film thickness of at least 250 μm , or by a *zinc silicate paint coat* with a dry film thickness between 75 and 120 μm . Before application of a zinc silicate paint, the tanks should be thoroughly blast-cleaned; no other shop-coat, except zinc silicate, should have been used previously. At the time of application the blast-cleanliness should be at least Sa 2^{1/2}. *When using zinc silicates it is extremely important to avoid rough layers*, for instance due to dry (over) spray, because it is extremely difficult to clean such areas when changing cargo.

If no zinc silicate paint is used, but an epoxy or polyurethane paint system, shop-coated surfaces of the tanks are often blast-cleaned to a cleanliness of Sa 2^{1/2}, but sometimes ordinary cleaning will suffice.

Whether or not (re-)blast-cleaning is required depends on the aggressiveness of the future cargoes and on the extent of breakdown of the shop-coat; this should be judged by the paint supplier.

It is not permitted to transport some types of fuel, such as kerosines for jet aircraft, in tanks treated with zinc containing paints. The slightest contamination of these fuels by zinc (zinc pick-up) is unacceptable, which means that even the shop-coat under the paint system must be zinc-free.

Tanks for strong solvents (esters, ketones) are painted like those for 'white products'. Any shop-coat should first be removed by blast-cleaning.

Chemical tanks (acids, lyes, latex, etc.) are (after in situ blast-cleaning) usually treated with a chemically resistant paint system consisting of *several coats of epoxy, epoxy*

phenolic or polyurethane paint with a total dry film thickness of at least 300 µm. The degree of blast-cleanliness should be at least Sa 2^{1/2} when the first coat is applied. Any shop-coat should be removed by blast-cleaning. Material coated with a zinc containing shop (prefabrication) primer should not be used. Zinc residues remaining in the pores of the steel after blast-cleaning may reduce the chemical resistance of tank coating systems. In chemical tankers, in the wing tanks often one bulkhead consists of stainless steel, which also forms part of a centre tank. In order to prevent (galvanic) corrosion, this bulkhead should also be properly blast-cleaned and coated, in the same way as the other (mild steel) parts of the tank. In order to obtain an optimum coating adhesion, the profile of the blast-cleaned stainless steel surface should be sharp.

Tanks for liquid consumer goods (edible oils, wines etc.) are treated like tanks for chemicals, additional requirements being that the paints must be odourless and must not develop substances that are toxic, coloured, or liable to cause tainting of the cargoes. In most countries the required paints are subject to approval by official bodies.

1.3.7. ENGINE ROOMS

1.3.7.1 Requirements

Paint systems for the engine room *above the floor plate* should be:

- corrosion-inhibiting;
 - oil-resistant;
 - easy to clean;
 - not (or only slightly) subject to yellowing;
 - fire-retarding (in many countries).
- Yellowing is undesirable because it reduces the efficiency of the lighting.

Since polluted water, dirt and acid-contaminated lubricating oil will collect *under the floor plate*, paint systems for this space should be:

- corrosion-inhibiting;
- water-, acid- and oil-resistant.

1.3.7.2 Suitable paint systems

The usual paint systems for engine rooms *above the floor plate* consist of *alkyd resin based paints* e.g. *one or two coats of anti-corrosive primer, one coat of undercoating, and one coat of non-yellowing light-coloured finishing paint*. To ensure easy cleaning and colour retention, the finishing paint should be high gloss and based on *non-yellowing alkyd resins*. For this purpose, *polyurethane resin based paint systems*, which are very easy to clean, may also be used. The top coat of such systems should be based on *non-yellowing aliphatic polyurethane- or polyurethane/acrylic resin*.

For the spaces *under the floor plate*, where esthetic appearance is not important but where corrosion prevention is imperative, *coal-tar epoxy, polyurethane tar, or straight epoxy paints* with a total dry film thickness of at least 200 μm may be used.

1.3.8. 'WET' ACCOMODATION AND SERVICE SPACES

1.3.8.1 *Requirements*

Paint systems for 'wet' accomodation spaces, such as bath rooms, showers, galleys and toilets should be:

- corrosion-inhibiting;
- water-, soap- and scratch-resistant;
- easy to clean;
- non-yellowing.

For reasons of hygiene, the systems should be light-coloured.

1.3.8.2 *Suitable paint systems*

Alkyd resin paint systems (dry film thickness of at least 120 μm) consisting of, e.g., *two coats of anti-corrosive primer, an undercoat and a white gloss finishing coat*, satisfy these requirements, provided that they are allowed to cure for a long period and are not permanently exposed to water. However, preference is to be given to paint systems based on *epoxy and polyurethane resins* with a thickness of, e.g. 200 μm , since these are better impact-, scratch- and water-resistant and easier to clean than alkyd paints.

A high-gloss surface is preferred because this facilitates cleaning.

The floors of 'wet' accomodation and service spaces often are coated with *solvent-free epoxy compositions* with a thickness of a few millimeters.

1.3.9. DRY ACCOMODATION SPACES

1.3.9.1 *Introduction*

In dry accomodation spaces, a great variety of substrate materials are used. Of these, wood, chipboard, other kinds of board and insulating materials may be mentioned.

The insulating materials may consist of mineral or glass wool packed in gauze and levelled with a coat of cement.

1.3.9.2 Requirements

Paint systems for dry accommodation spaces should have *lasting adhesion to the various substrates*, be *easily recoatable* and *usually decorative*.

Many countries will also require the paints to be *fire-retarding*.

The painting work in dry accommodation spaces is not particularly difficult, since there is no direct action of sunlight, moisture or salt.

1.3.9.3 Suitable paint systems

Wood, after having been sanded, is usually painted with *one primer coat or undercoat*, and *one or two finishing coats* of the desired colour, all these paints being based on an *alkyd resin*. If a very smooth surface is required, a *knifing filler* is applied after application of (thinned) primer; when the filler coat has been sanded or rubbed down, the undercoat and finish are applied.

Hardboard is treated like wood, but the first coat should be a *thinned primer/undercoat*, which prevents the absorption of subsequent coats. Highly absorbent types of hardboard should be pretreated with a *sealer coat* of a water-soluble cellulose derivative ('cellulose size').

Chipboard is treated like hardboard. If a smooth surface is required, several coats of *brush or spray filler* (primer surfacer) are applied on top of the (thinned) primer before top coating.

Hard wood objects (furniture and decorative linings) are usually treated with several coats of *varnish*.

Insulating materials (lagging) are usually painted with several coats of *water-based emulsion paint*. If the material is cement-coated, the paint should be an *unsaponifiable* one (e.g. based on chlorinated rubber).

APPENDIX 1.A. - SUMMARY OF THE PROTECTION OF THE SEPARATE PARTS OF A SHIP UNDER CONSTRUCTION

Part of the ship	Recommended substrate condition prior to painting	Paint systems requirements	Suitable paint systems or other forms of treatment	Remarks
Underwater parts (see Part 1.3.1)	<ul style="list-style-type: none"> - blast-cleaned (Sa 2 1/2) - intact cleaned shop-coat - derusted shop-coat, e.g. blast-cleaned (Sa 2 1/2) or power-tool cleaned (St3) 	<p>Corrosion-inhibiting Water-resistant Abrasion-resistant Anti-fouling Smooth Compatible with cathodic protection systems</p>	<ul style="list-style-type: none"> - <i>High-duty systems</i>, consisting of <i>corrosion preventing paints</i> based on <i>coal-tar epoxy</i> ($\geq 250 \mu\text{m}$), <i>polyurethane tar</i> ($\geq 250 \mu\text{m}$), <i>vinyl tar</i> ($\geq 200 \mu\text{m}$), <i>chlorinated rubber</i> ($\geq 200 \mu\text{m}$) or <i>vinyl copolymers</i> ($\geq 200 \mu\text{m}$) + two or more coats of <i>contact matrix</i> or <i>self-erodablenanti-fouling paint</i>. - <i>Conventional systems</i>, consisting of <i>corrosion preventing paints</i> based on <i>bitumen</i> ($\geq 150 \mu\text{m}$) + two coats of <i>conventional anti-fouling paint</i>. 	<p>On special parts of the ship (or on special ships), where a very high abrasion-resistance is required, underwater parts may be coated with very thick, <i>abrasion resistant (glass-flake) coatings</i>. When cathodic protection by means of impressed current is used, the zones near the anodes must be given extra protection.</p>
Boottop zone (see Part 1.3.2)	- as foregoing	<p>Corrosion-inhibiting Water-resistant Weather-resistant Impact-resistant Scratch-resistant Smooth Easy to clean Oil-resistant Algicidal Compatible with cathodic protection systems</p>	<ul style="list-style-type: none"> - <i>High-duty systems</i> consisting of <i>corrosion preventing paints</i> as described under <i>underwater-parts</i> + one or two coats of a so-called <i>boottopping</i> of the desired colour based on <i>epoxy resin</i>, <i>polyurethane resin</i>, <i>chlorinated rubber</i> or <i>vinyl copolymers</i>. - <i>Conventional systems</i>, consisting of <i>corrosion preventing paints</i> as described under <i>underwater-parts</i> + a <i>boottopping</i> based on <i>alkyd phenolic resin</i> or <i>bitumen</i>. Nowadays the practice for many ships is that the boottop system is quite similar to the system for the underwater parts. The top-coat then is an anti-fouling paint. 	<p>Chlorinated rubber systems, however in use, are not oil-resistant. If a light-coloured boottopping is used, no bitumen or tar containing anti-corrosive layers should be used. For a high abrasion-resistance, boottop areas are sometimes treated with very thick, abrasion resistant (glass flake) coatings.</p>

APPENDIX 1.A. - SUMMARY OF THE PROTECTION OF THE SEPARATE PARTS OF A SHIP UNDER CONSTRUCTION (continued)

Part of the ship	Recommended substrate condition prior to painting	Paint systems requirements	Suitable paint systems or other forms of treatment	Remarks
Topside + exterior parts on deck (see Part 1.3.3)	- as foregoing	Corrosion-inhibiting Weather-resistant Impact-resistant Scratch-resistant Easy to clean Decorative (more or less)	<ul style="list-style-type: none"> - <i>High-duty systems</i>, consisting of paints based on <i>epoxy resin</i> ($\geq 200 \mu\text{m}$), <i>polyurethane resin</i> ($\geq 200 \mu\text{m}$), <i>chlorinated rubber</i> ($\geq 200 \mu\text{m}$) or vinyl copolymers ($\geq 200 \mu\text{m}$) - <i>Conventional systems</i>, consisting of paints based on oil-modified <i>alkyd resins</i> ($\geq 140 \mu\text{m}$) 	The finishing coat of a high-build system often itself is not a high-build type in order to obtain a smooth (easy to clean) and decorative paint system. Especially for deck-houses the system should have a good colour and gloss stability. Care should be taken that suppliers equipment (like deck machinery) will be adequately coated.
Weather decks (see Part 1.3.4)	- as foregoing	Corrosion-inhibiting Weather-resistant Impact-resistant Abrasion-resistant Scratch-resistant Non-slip Resistance against water, oils, lubricating greases, detergents (cleaning agents) and cargo spillage	<ul style="list-style-type: none"> - <i>High-duty systems</i>, consisting of paints based on <i>epoxy resin</i> ($\geq 200 \mu\text{m}$), <i>polyurethane resin</i> ($\geq 200 \mu\text{m}$), <i>chlorinated rubber</i> ($\geq 200 \mu\text{m}$) or <i>zinc silicate</i> (75-120 μm); the top coat is often a <i>non-slip paint</i>. - <i>Conventional systems</i>, consisting of <i>alkyd resin paint</i> ($\geq 140 \mu\text{m}$); the top coat is often a non-slip paint 	The decks of tankers for chemical products or solvents should not be treated with conventional systems. The decks of solvent carriers should preferably be treated with systems based on <i>epoxy resin</i> , <i>polyurethane resin</i> or <i>zinc silicate</i> .
Dry cargo holds (see Part 1.3.5)	- as foregoing	Corrosion-inhibiting Wear-resistant Impact-resistant Scratch-resistant No flaking Officially accepted in holds for consumer goods	<ul style="list-style-type: none"> - <i>High-duty systems</i>, consisting of paints based on <i>coal-tar epoxy</i> ($\geq 200 \mu\text{m}$), <i>polyurethane tar</i> ($\geq 200 \mu\text{m}$), <i>epoxy resin</i> ($\geq 200 \mu\text{m}$), <i>polyurethane resin</i> ($\geq 200 \mu\text{m}$) or <i>zinc silicate</i> (75-200 μm). - <i>Conventional systems</i>, consisting of paints based on <i>bitumen</i> ($\geq 140 \mu\text{m}$) or <i>alkyd resin</i> ($\geq 140 \mu\text{m}$). 	For ore, coal and scrap holds, high-duty systems are particularly recommended. When dry cargo holds are used as ballast tanks, the coating system must fulfil additional requirements (see Part 1.3.6.3). For consumer goods an official acceptance is required.

APPENDIX 1.A. - SUMMARY OF THE PROTECTION OF THE SEPARATE PARTS OF A SHIP UNDER CONSTRUCTION (continued)

Part of the ship	Recommended substrate condition prior to painting	Paint systems requirements	Suitable paint systems or other forms of treatment	Remarks
Water ballast tank (see Part 1.3.6.4a)	- as foregoing	Corrosion-inhibiting Free from pores Water-resistant Compatible with cathodic protection (if installed) Resistance against fuel and crude oil when used in fuel-ballast or crude oil-ballast tanks	- <i>High-duty systems</i> , consisting of paints based on <i>coal-tar epoxy</i> ($\geq 250 \mu\text{m}$), <i>epoxy resin</i> ($\geq 250 \mu\text{m}$), <i>polyurethane tar</i> ($\geq 250 \mu\text{m}$), <i>vinyl tar</i> ($\geq 200 \text{mm}$) or <i>bleached tar/epoxy resin combinations</i> ($\geq 300 \mu\text{m}$). - Conventional systems, consisting of <i>bituminous paints</i> ($\geq 300 \mu\text{m}$) or <i>solvent-free bituminous compositions</i> (some mm's). Sometimes water ballast tanks are treated with less durable (cheaper) products like <i>grease paints</i> and <i>float coats</i> .	Treatment with float coats present a risk of harbour water contamination.
Fuel tanks (see Part 1.3.6.4b)	- clean	..	Fuel tanks generally need no extra protection. Gas turbine fuel tanks, however, are treated like tanks for chemicals (see Part 1.3.6.4f) in order to prevent possible contamination of the fuel.	Any possible contamination of gas turbine fuel must be avoided.
Lubricating oil tanks (see Part 1.3.6.4c)	- 1. very clean (silver bright) - 2. as underwater parts	.. Resistant against lubricating oil	1. No further protection 2. Total or partial protection (upper parts) with a <i>high duty epoxy paint system</i> ($\geq 200 \mu\text{m}$).	..
Drinking (potable) water tanks (see Part 1.3.6.4d)	- as underwater parts	Corrosion-inhibiting Free from pores Water-resistant Free from toxic substances and from substances liable to discolour or taint the water	- <i>High-duty systems</i> , consisting of paints based on <i>epoxy resin</i> ($\geq 250 \text{m}$) or <i>vinyl copolymers</i> ($\geq 250 \text{m}$). - <i>Conventional systems</i> , consisting of odourless and tasteless <i>bituminous paints</i> ($\geq 300 \mu\text{m}$) or <i>solvent-free bituminous compositions</i> (several mm's thick). Sometimes <i>cement-wash</i> or odourless and tasteless <i>grease</i> is applied.	The coating systems <i>must be officially accepted for use in drinking water tanks</i> . Treatment with cement-wash or grease should be frequently repeated.

APPENDIX 1.A. - SUMMARY OF THE PROTECTION OF THE SEPARATE PARTS OF A SHIP UNDER CONSTRUCTION (continued)

Part of the ship	Recommended substrate condition prior to painting	Paint systems requirements	Suitable paint systems or other forms of treatment	Remarks
Other water tanks (no ballast or drinking water tanks) (see Part 1.3.6.4e)	blast-cleaned (Sa 2 1/2); any shop-coat should be removed	Corrosion-inhibiting Free from pores Resistant against (deionised) hot water Free from tainting substances	<i>High-duty systems</i> ($\geq 250 \mu\text{m}$) consisting of <i>epoxy paints</i> ($\geq 250 \mu\text{m}$)	So as to ensure good sealing of the substrate and reduce the risk of blistering, hot water tanks should preferably be treated with 3 or more coats of paint (no high-build type)
Crude oil tanks (see Part 1.3.6.4f)	- as underwater parts	Corrosion-inhibiting Free from pores Water-resistant Resistant to crude oil Compatible to sacrificial anode cathodic protection systems	<i>High-duty systems</i> ($\geq 250 \mu\text{m}$) consisting of paints based on <i>coal-tar epoxy resin, epoxy resin or polyurethane tar</i>	In large tankers often only the bottom + deckheads (including about 2 m on vertical surfaces from the bottom upwards and the top downwards), and the upper side of the horizontal stringers are fully painted. The greater part of the bulkheads consists of unpainted blast-cleaned steel with cathodic protection in the bottom parts of crude oil ballast tanks
Tanks for white oil products (see Part 1.3.6.4f)	- as underwater parts - blast-cleaned (Sa 2 1/2) when a zinc silicate tank lining is used (any shop-coat must be removed)	Corrosion-inhibiting Free from pores Resistant to white oil products Free from cargo contaminating substances	<i>High-duty systems</i> , consisting of paints based on <i>epoxy resins</i> ($\geq 250 \mu\text{m}$), <i>polyurethane resins</i> ($\geq 250 \mu\text{m}$) or <i>zinc silicate</i> (75-120 μm)	The use of prefabrication primers and paints containing zinc is prohibited for jet fuel tanks
Tanks for strong solvents (see Part 1.3.6.4f)	blast-cleaned (Sa 2 1/2); any shop-coat should be removed	Resistant to strong solvents + requirements as given under tanks for white oil products	As tanks for white oil products	--
Tanks for chemicals (see Part 1.3.6.4f)	blast-cleaned (Sa 2 1/2); any shop-coat should be removed	Corrosion-inhibiting Free from pores Resistant to chemicals Free from cargo-contaminating substances	- <i>High-duty systems</i> , consisting of paints based on epoxy-, epoxy phenolic- or polyurethane resins ($\geq 300 \mu\text{m}$)	--

APPENDIX 1.A. - SUMMARY OF THE PROTECTION OF THE SEPARATE PARTS OF A SHIP UNDER CONSTRUCTION (continued)

Part of the ship	Recommended substrate condition prior to painting	Paint systems requirements	Suitable paint systems or other forms of treatment	Remarks
Tanks for liquid consumer goods (see Part 1.3.6.4f)	blast-cleaned (Sa 2 ^{1/2}); any shop-coat should be removed	Corrosion-inhibiting Free from pores Resistant to liquid consumer goods Free from toxic substances liable to discolour or taint the cargo	<i>High-duty systems</i> , consisting of paints based on <i>epoxy resins</i> ($\geq 300 \mu\text{m}$)	The coatings must be officially accepted for use in tanks for consumer goods
Engine room (see Part 1.3.7)	Above the floor plating: - blast-cleaned (Sa2) - intact cleaned shop-coat - derusted (blasted Sa 2 ^{1/2} or power-tool cleaned S12) Under the floor plating: - as underwater parts	Corrosion-inhibiting Oil-resistant Easy to clean Non-yellowing Corrosion-inhibiting Water-resistant Oil-resistant	- <i>High-duty systems</i> , consisting of paints based on <i>polyurethane resin</i> ($\geq 150 \mu\text{m}$) - <i>Conventional systems</i> , consisting of paints based on alkyd resins ($\geq 100 \mu\text{m}$) - <i>High-duty systems</i> , consisting of paints based on <i>coal-tar epoxy resin, polyurethane tar or epoxy resin</i> ($\geq 200 \mu\text{m}$)	The top coat must be based on a non-yellowing <i>aliphatic-polyurethane or polyurethane/acrylic resin</i> . The top coat must be based on a non-yellowing type of alkyd resin. In many countries paints for engine rooms should be fire-retarding.
Wet accommodation spaces (see Part 1.3.8)	- as underwater parts	Corrosion-inhibiting Water-resistant Soap-resistant Scratch-resistant Easy to clean Non-yellowing	- <i>High-duty systems</i> , consisting of paints based on epoxy of polyurethane resins ($\geq 200 \mu\text{m}$). - <i>Conventional systems</i> , consisting of paints based on alkyd resins ($\geq 120 \mu\text{m}$)	The top coat should be of the non-yellowing type. 'Wet' accommodation spaces include laundries, drying rooms, toilets, showers, bathrooms, galleys, butcheries and pantries.

APPENDIX I.A. - SUMMARY OF THE PROTECTION OF THE SEPARATE PARTS OF A SHIP UNDER CONSTRUCTION (continued)

Part of the ship	Recommended substrate condition prior to painting	Paint systems requirements	Suitable paint systems or other forms of treatment	Remarks
<p>Dry accommodation spaces (see Part 1.3.9)</p>	<p>- dry - clean - sometimes sanded</p>	<p>Lasting adhesion Easy recoatable Usually decorative</p>	<p>Wood : 1 coat of primer + 1 or 2 coats of finishing paints based on non-yellowing <i>alkyd resin</i> ; if necessary filled with knifing filler.</p> <p>Hardboard : as wood; to be sealed first with thinned primer or <i>cellulose size</i> to prevent paint sinking in.</p> <p>Chipboard : as hardboard; a <i>brushing or spray filler</i> should be applied on top of thinned primer.</p> <p>Hardwood : several coats of varnish.</p> <p>Insulating covers : several coats of <i>emulsion paint or chlorinated rubber paint</i> (when the substrate is alkaline).</p>	<p>Many painting operations are done in the prefabrication stage.</p>

APPENDIX 1.B. - HULL ROUGHNESS

1. Introduction

The surface roughness of the underwater hull has a large influence on its resistance and consequently on the engine power needed to maintain a certain speed.

As an increase in engine power means an increase in fuel consumption, i.e. higher bunker costs, every shipowner is strongly recommended to keep the hull surface roughness as low as possible during building as well as throughout the lifetime of the ship.

In this respect it has to be born in mind that fouling causes a very large friction increase, especially animal fouling such as barnacles and algal fouling, e.g. Enteromorpha.

Friction increase due to the paint system alone is much lower, but can still be of importance when fuel costs are high.

According to investigations of the Royal Institute of Naval Architects, for every 10 micrometers increase in surface roughness an increase in engine power of 0.5-1% is required to maintain a given speed. The actual figure depends on the initial roughness and the hull form.

The following formula can be used to estimate the percentage change in power:

$$\frac{\Delta P}{P} \times 100 = 5.8 * [(r_2)^{1/3} - (r_1)^{1/3}]$$

where:

ΔP = change in power

P = power required for roughness 1

r_1 = roughness 1 (initial roughness)

r_2 = roughness 2 (present roughness)

2. Hull roughness measurements

Hull roughness measurements are normally carried out by means of roughness gauges, the probe being moved over 50 mm of the rough surface for each determination.

The commercially available instruments register the maximum peak to valley value. Normally, the *mean hull roughness (MHR)* is calculated from a dozen determinations of the maximum peak-to-valley value at about 100 positions, evenly spread over the underwater hull. By averaging the MHR-values, the *average hull roughness (AHR)* is determined.

To obtain more accurate information, TNO modified one of the commercially available instruments in such a way that the roughness profile is registered on magnetic tape so that it can be reproduced and analysed at a later stage. The *root mean square value (RMS)* of each profile is calculated by computer, which gives information about the roughness perpendicular to the surface. The RMS-value is the standard-deviation of all deviations of the roughness profile around its mean. Roughly estimated, the AHR is about 5-6 times the RMS.

For a carefully coated new ship the value for the AHR may be for example 75-100 micrometers. This initial roughness depends on the quality of the steel, the construction, the blast-cleaning, the coating system and the coating application.

Normally ships hulls roughen during service. The rate of roughening depends on the way they are protected from corrosion and fouling, the frequency and quality of the underwater hull maintenance and on the initial roughness. It was found that ships with a higher initial roughness roughen at a higher rate than ships with a low initial roughness. For old ships with a rough hull the AHR for instance may well be 500-600 micrometers.

3. Hull roughness parameters

3.1. INITIAL ROUGHNESS

The initial roughness of the underwater hull depends mainly on the quality of the steel, the construction, the coating system and the coating application. With reference to the quality of the steel, it will be clear that the initial condition of the steel surface is the prime importance.

Condition A* (intact mill-scale) is a much better starting point than condition D (pitted steel). The roughness will also be determined by the condition of the welds, which should be as smooth as possible and by the presence of any laminations and weld spatter which should be removed before coating.

With reference to the contribution of the coating system to the roughness, the orange peel effect, solvent-popping and sags have to be considered. Coatings should be such that with normal application the orange peel effect is minimal and there should be no sags or solvent popping.

With reference to coating application, roughness promoting factors are:

- inclusion of dirt, debris and grit particles;
- poor application techniques resulting in film-irregularities such as sags, dry-spray, overspray, pinholes, uneven areas etc.

* According to ISO standard 8501-1 (see Part 3.2.3.3)

Poor application techniques arise from insufficiently stirred settled paint, incorrect mixing of paint and hardener, inclusion of air, the use of the wrong thinner or incorrect degree of thinning, the use of inappropriate or worn-out nozzles, a wrong spraying distance, angle or pressure etc. Apart from sagging, roughness due to coating application will not normally exceed 30 micrometers.

3.2. ROUGHNESS INCREASE DURING SERVICE

As mentioned under Part 2, ships' hulls will roughen during service. The main causes are:

- mechanical damage, followed by corrosion, for instance caused by anchors chains, contact with jetties, other ships etc.;
- corrosion;
- fouling;
- overcoated fouling remnants;
- coating defects such as flaking and blistering;
- uneven areas due to build-up of old coating residues at places during maintenance;
- coating detachment due to the build-up of so-called 'sandwich coatings' (alternate layers of primer and leached-out anti-fouling; see Part 7.2.2);
- cold flow (plastic deformation of the paint surface due to the water velocity).

Roughness due to mechanical damage, corrosion, fouling, blistering and flaking may be considerably higher than the roughness due to coating application.

After dry-docking, hull roughness should be considerably lower than before and some owners put exact requirements on the maximum allowable limit.

APPENDIX 1.C. - PART OF A RESISTANCE (COMMODITY) LIST*

Introduction

This resistance table applies only to the following system(s):

System sheet number	Specification number	System name	Surface preparation standard
A	1	Epoxy phenolic	Near SIS-SA3
B	1	Isocyanate cured HB epoxy	Near SIS-SA3
C	1	HB epoxy	SIS-SA2 ^{1/2}
D	1	HS epoxy	SIS-SA2 ^{1/2}
E	1 and 2	Zinc silicate	Near SIS-SA3

Substrate and curing

System(s) applied directly to the steel structure which has been blasted in situ, freed from rust and scale and cured under the correct conditions for at least the minimum period stipulated.

Exposure to an aggressive cargo before the coating has had the minimum curing time can permanently affect its properties of resistance.

This list is not valid when prefabrication primers have been used under the system, except system E specification 2, whereby coating manufacturers approved zinc silicate primer may be accepted under restrictions.

In the case of stainless steel tank walls, the blasting profile of the substrate should be the same as for mild steel, specified in the relative product system sheet.

Validity of this table

It is important to check that this resistance table is the latest issue, particularly if it is more than one year old.

* Courtesy Sigma Coatings B.V.

Explanation of data

RC = Resistance code	+	Suitable
	+ 1,2,3 etc.	Suitable, subject to reference notes 1,2,3 etc.
	+ T (degrees C)	Suitable up to T degrees Centigrade
	-	Unsuitable

A blank in this column indicates that the product has not been tested.

Transport and storage duration

The resistance code refers to bulk storage or transport of cargoes for a maximum period of 6 months.

For extended storage or transport times please refer to the coating manufacturer.

Maximum temperature in degrees Centigrade

Some cargoes are so viscous that they need to be heated to reduce their viscosity so that they can be pumped. The relevant temperatures have been obtained from organizations in the transport and manufacture of chemicals.

For these highly viscous cargoes storage temperatures are indicated in degrees Centigrade. Loading and discharge temperatures may be as much as 10 degrees Centigrade higher. But the time at these higher temperatures must be kept as short as possible and should not exceed 48 hours.

For less viscous cargoes that do not need be heated to reduced viscosity and allow pumping, no maximum temperatures are stated. This means that in such cases the coating system is resistant to temperatures up to 30 degrees Centigrade.

All cargoes having reference notes 4, 7, 8 or 11 should not be carried in tanks in contact with adjacent tanks containing cargoes at higher temperatures than allowed for other specific cargo.

Cargo and product conformity

When identical products or chemicals but with different trade or chemical names are offered, these may be carried at the defined conditions provided it is established by the shipowner and/or the shipper that the cargo does meet the chemical description give in the list.

The list is based on products or commodities of normal composition (e.g. natural materials).

Variation in composition can affect performance and the coating manufacturer cannot accept responsibility for any such effects.

Non-listed cargoes and temperature deviations

For cargoes not included in the list, or in cases when the owners have to deviate from maximum temperatures, the coating manufacturer must be consulted before a cargo is accepted or transported.

Inorganic acids and alkalines

Although the coatings themselves are resistant to several inorganic acids in various concentrations we do not accept these chemicals as cargoes.

This is because of the very serious pitting of the steel and undercutting of the coating system in the event of mechanical and other forms of damage of the coating prior to loading of the inorganic acid.

System E, being a silicate zinc-rich coating is not resistant to strong acids or alkalines. Its suitability is limited to products in the pH-range between 5 and 9. The use of acidic or alkaline tank cleaning products must also be avoided. Slight zinc pick-up by the cargo is possible, depending on the cargo in question.

Reference notes

Reference notes have a fixed number. This means that although a reference note may be revised or extended its original intention will be the same.

Cleaning chemicals

A list of accepted tank cleaning materials is available on request.

Note 1

Certain products, such as esters (acetates, phthalates, etc.) and chlorinated or brominated materials can react with water to form acidic compounds. Thus, although these products are suitable for storage in coated tanks when dry, the presence of water may make them aggressive or totally unacceptable. Such products must, therefore, be dry, carried in

completely dry tanks, and water leaks must be avoided. Water contents should not exceed 0.002% (200 ppm).

Note 2

These products may cause some discolouration of the coating. Subsequently cleaning of the tanks may be difficult so that contamination of susceptible cargoes could occur. These products are variable in composition, depending on source, and consequently the effects on the coating can also differ.

Note 3

Vegetable and animal oils, fats, greases and waxes are esters of polyols and various fatty acids, and contain mostly free fatty acid as well.

If in contact with water at higher temperatures these esters can saponify, resulting in increased free fatty acid content. These free fatty acids, especially the short chain types, can be very aggressive to tank coatings. Thus, during loading, storage and discharge the acid values should not exceed the maximum values given in the table.

System	Maximum acid value	Maximum free fatty acid content (approximately)
Epoxy phenolic	No limit	No limit
Isocyanate cured HB epoxy	No limit	No limit
HB epoxy	40	20%
HS epoxy	20	10%
Zinc silicate	5	2.5%

The fatty acids accepted in this list can be transported only if they are of normal composition and do not contain more than 2% short chain organic acids (below C6). The acid values of specific types should not be more than 10% higher than the approximates and constants for those types. The water contents must be limited to 0.75% maximum.

Note 4 (steel temperature)

These aggressive cargoes can only be carried when the coating is fully cured. Full cure will be obtained after transport of a hot cargo such as lubricating oil, animal oil or

vegetable oil at temperatures of 60 degrees C for 5 days, or 50 degrees C for 10 days for double-skin vessels. For single-skin vessels and seawater temperatures below 15 degrees C, the cargo temperature should be raised to 80-90 degrees C (lubricating oils or mineral oils). Full cure will also be obtained after a service period of 3 months with non-aggressive cargoes (cargoes without any special note).

However, for caustic soda or caustic potash cargoes in isocyanate epoxy coated tanks, a hot cargo cure is essential and cannot be substituted by a service period of 3 months with non-aggressive cargoes.

After transport of caustic soda or caustic potash in isocyanate epoxy coated tanks, no low concentrates of these cargoes should be left.

For transport of methanol and ethanol cargoes in epoxy phenolic coated tanks, a hot cargo cure is essential and cannot be substituted by a service period of 3 months with non-aggressive cargoes.

After transport of note 4 marked cargoes it is essential to restore its original condition.

This can be obtained by carrying non-aggressive cargoes (without remarks 4, 7, 8 or 11) for a period of at least 30 days or by a hot cargo of lubricating oil, vegetable oil, animal oil or molasses for a period of at least 5 days at 50 degrees C or 3 days at 60 degrees C.

Note 5

Products in this class are proprietary materials and can be transported, provided that the pH is within the range 5.0-9.0.

Note 6

These cargoes should not be transported in tanks adjacent to tanks containing hot cargoes (above 35 degrees C).

Note 7

Carriage of this cargo must be restricted to 30 days. Before another cargo with notes 4, 7, 8 or 11 is transported, it is essential to restore its original condition. This can be obtained by carrying non-aggressive cargoes (without remarks 4, 7, 8 or 11) for a period of at least 30 days or by a hot cargo of lubricating oil, mineral oil, vegetable oil, animal oil or molasses for a period of at least 5 days at 50 degrees C or 3 days at 60 degrees C.

Note 8

Carriage of this cargo should be restricted to 90 days. Before another cargo with notes 4, 7, 8 or 11 is transported, it is essential to restore its original condition. This can be

obtained by carrying non-aggressive cargoes (without 4, 7, 8 or 11) for a period of at least 30 days or by a hot cargo of lubricating oil, mineral oil, vegetable oil, animal oil or molasses for a period of at least 5 days at least 50 degrees C or 3 days at 60 degrees C.

Note 9

Lubricating oil, excluding chlorinated, brominated, phosphated and ester types, may be carried at temperatures up to 70 degrees C (80 degrees C for loading or discharge). It is necessary to establish that cargoes of lubricating oils are not of the types listed as exclusions.

Note 10

Molasses can be carried when the pH of the product is between 4 and 11. Diluted solutions of molasses should be removed within 24 hours after tank cleaning or, when acidic, be neutralized by an alkaline tank cleaning product.

Note 11

Before loading these aggressive water miscible cargoes it is essential to remove all traces of water from the tanks.

Tanks having carried these cargoes should not be brought into contact with water. No steam, ballast water, or aqueous cargoes must come into contact with the coating before its original coating condition is restored. This can be obtained by carrying non-aggressive cargoes (without remarks 4, 7, 8 or 11) for a period of at least 30 days or by a hot cargo of lubricating oil, mineral oil, vegetable oil, animal oil or molasses for a period of at least 5 days at 50 degrees C or 3 days at 60 degrees C. In case of residual cargo removal by means of water flushing in the bottom-area is unavoidable, please contact your coating manufacturers representative.

Concerning the quality of the methanol-ethanol, this must be pure (i.e. no contamination with formaline, acetone, acetic acid and others) and completely water free (max. 0.06 per cent water acceptable). Samples have to be sealed, properly marked and dated and maintained onboard for minimum 6 months after discharge of the methanol/ethanol cargo.

Note 12

Amines can be transported, when free from moisture. If water is present the alkalinity may increase to a pH of more than 9. To prevent contamination by water, both the cargo and the tank must be completely dry at the time of loading and preferably, the cargo

should be transported under a dry nitrogen gas-blanket. Maximum water contents 0.05% (500 ppm).

Note 13

Well cured zinc silicate is resistant to phenols and cresols. Tanks should be ballasted or water-cleaned at least once before transporting these products.

Note 14

Crude oils can normally be transported and stored in zinc silicate coated tanks. Some crude oils, however, are very acidic and thus aggressive to zinc silicates, especially when heated and in the presence of water. Acid values above 0.4 are not permitted. The pH of water concentration should not be outside the range 5 to 9.

Note 15

These products can be carried only in completely dry tanks without any leakage. Maximum water contents 0.015% (150 ppm).

Note 16

This is a generic name. Most of these cargoes can be transported, but it should be established that no notes are included under the specific type name of this cargo elsewhere in the list.

Note 17

If zinc silicate coated tanks are also available, it is recommended that they should be used to carry this product.

Note 18

Storage of this cargo should be restricted to 90 series days. Before carriage of another water cargo, the coating must be restored to its original condition. This can be obtained by drying the tanks thoroughly and adequate ventilation during 72 hours thereafter or by a hot cargo of lubricating oil, mineral oil, vegetable oil, animal oil or molasses for a period of at least 5 days at 50 degrees C or 3 days at 60 degrees C.

Extended service life for very aggressive cargoes will be obtained by avoiding ballasting.

Note 20

The coating is resistant, but possible cargo contamination by the coating should be considered (e.g. zinc pick up from zinc silicates).

RESISTANCE REGISTER

IM CO	PROD CODE	SQ NR	CARGO	EPOXY PHENOLIC		ISOCYANATE CURED HB EPOXY		HB EPOXY		HS EPOXY		ZINC SILICATE	
				R C	Ref.Note Max. TMP	R C	Ref.Note Max. TMP	R C	Ref.Note Max. TMP	R C	Ref.Note Max. TMP	R C	Ref.Note Max. TMP
02	0008	03	A.C.H.	+		+		-		-		+	
	1894	01	A.C.45C Shell lube oil additive	+	70	+	70	+	70	+	70	+	70
	5889	01	Absorbent A1	+		+							
	5890	01	Absorbent A3	+		+							
	5891	01	Absorbent A4	+		+							
	5892	01	Absorbent A6	+		+							
	5893	01	Absorbent E1	+		+							
	5894	01	Absorbent E2	+		+							
	3381	02	AC-45-C	+	70	+	70	+	70	+	70	+	70
	4228	01	Acajounut oil	+	60	+	60	+	60	+	60		
	4515	02	Acede Cresylique	-		-		-		-		-	13
	0003	01	Acetal	-		-		-		-		+	
	0004	02	Acetaldehyd	-		-		-		-		+	1, 8
	0004	01	Acetaldehyd	-		-		-		-		+	1, 8
	0004	03	Acetaldehyd (dot)	-		-		-		-		+	1, 8
03	0099	03	Acetate d'amyle	+	1	+	1	+	1	+	1	+	1
	0899	03	Acetate d'isopropyle	+	1	+	1	+	1	+	1	+	1
	4414	03	Acetate de butyle	+	1	+	1	+	1	+	1	+	1
	0993	03	Acetate de methyle	+	1, 4, 11	+	1, 4, 11	+	1, 4	+	1	+	1, 8
	5240	03	Acetate de propyle normal	+	1	+	1	-		-		+	1
03	1831	03	Acetate de vinyle	+	4	+	4	-		-		+	1, 8
	0671	03	Acetene	+		+		+		+		+	
03	0005	01	Acetic acid	-		-		-		-		+	
03	0005	02	Acetic acid (dot)	-		-		-		-		-	

RESISTANCE REGISTER

IM CO	PROD CODE	SQ NR	CARGO	EPOXY PHENOLIC		ISOCYANATE CURED HB EPOXY		HB EPOXY		HS EPOXY		ZINC SILICATE	
				R C	Ref.Note Max. TMP	R C	Ref.Note Max. TMP	R C	Ref.Note Max. TMP	R C	Ref.Note Max. TMP	R C	Ref.Note Max. TMP
2505	12		Glycol alcohol	+		+		+		+		+	
0776	01		Glycol alkyl ethers	+	16	+	16	-		-		+	
1787	08		Bis(hydroxyethyl)ether	+	60	+	60	+	60	+	60	+	
4412	18		Glycol butyl ether	+	4, 11	+	4, 11	-		-		+	1
4783	01		Glycol chlorohydrin	-		-		-		-		-	
2503	05		Gyanohydrin	-	1	-	4, 8	-		-		-	1
2599	01		Glycol diacetate	-		-		-		-		+	1
0676	20		Glycol dibromide	-	1, 4	-	1, 4	-		-		+	1
2504	26		Glycol dichloride	+	4, 11	+	4, 11	-		-		+	8
2292	14		Glycol ether	+	4, 11	+	4, 11	+	4	+	4	+	8
2292	15		Glycol ethyl ether	+	4, 11	+	4, 11	+	4	+	4	+	8
0683	08		Glycol monobutyl ether acetate	+	1, 4	+	1, 4	-		-		+	1
0001	01		Glycol monoethers	+	4, 11	+	4, 11	-		-		+	
4742	08		Glycol monomethyl ether	+	4, 11	+	4, 11	-		-		+	
4742	09		Glycolmonomethyl ether	+	4, 11	+	4, 11	-		-		+	
4784	01		Glyconic acid 50% in water	+		+	8	-		-		-	
0773	08		Glycol alcohol	+	60	+	60	+	60	+	60	+	8
2600	01		Glyoxal		16	+	16	+	16	+	16	+	16
3917	01		Glyoxal solutions		16	+	16	+	16	+	16	+	16
4786	01		Glyoxal 25% in water	+		+		-		-		-	
4787	01		Glyoxal 40% in water	+		+		-		-		-	
2601	01		Grain	+		+		+		+		+	
2475	27		Grain alcohol	+	4, 11	+	4, 11	-		-		+	

RESISTANCE REGISTER

IM CO	PROD CODE	SQ NR	CARGO	EPOXY PHENOLIC		ISOCYANATE CURED HB EPOXY		HB EPOXY		HS EPOXY		ZINC SILICATE		
				R C	Ref.Note TMP	Max. TMP	R C	Ref.Note TMP	Max. TMP	R C	Ref.Note TMP	Max. TMP	R C	Ref.Note TMP
	5526	01	Water, main	+		70	+	18	+		+		+	20
	1688	05	Water, potable	+			+	18	+		+		+	20
	1431	03	Water, sea-	+		70	+	18	+		+		+	
	1431	04	Water, salt-	+		70	+	18	+		+		+	
	1688	06	Water, tap	+			+	18	+		+		+	20
	5530	01	Waterglass	+			+	4, 8	+		+		+	
	2653	07	Waterstperoxyde 3%	+			+		+		+		+	
	5531	01	Wattle extract	+			+		+		+		+	
	3668	01	Wax	+	16	60	+	16	+	16	+		+	16
	4212	01	Wax petroleum	+		80	+	80	+	70	+		+	90
	1851	01	Wax, paraffin	+		80	+	80	+	70	+		+	90
02	0061	16	Weed drench	+	4, 11		+	4, 11	-		+		+	8
	2145	15	Weeviltox	+			+		-		+		+	
	2145	16	Wegla Dwustiarczek	+			+		-		+		+	
	2980	16	Welcoline do	+			+		-		+		+	
	5451	65	Westrosol	+	1, 4	60	+	1, 4	-		+		+	1
	5532	01	Whale fat	+		60	+	60	+	3	+		+	3
	1854	01	Whale oil	+		60	+	60	+	3	+		+	3
	4213	01	Whey	+			+		+	3	+		+	3
	3670	01	Whiskey	+	4, 11		+	4, 11	-		+		+	
	5533	01	Whitco Petroleum sulphonate	+		40	+	40	+		+		+	5
	2130	14	White comphor oil	+			+		+		+		+	
	3671	01	White gasoline	+			+		+		+		+	
	5534	01	White mineral oil	+		60	+	60	+		+		+	60

CHAPTER II

THE PROTECTION OF DIFFERENT PARTS OF OFFSHORE STRUCTURES UNDER CONSTRUCTION

2.1. Introduction

Broadly, offshore structures can be divided into two groups, e.g. *floating* and *fixed structures*.

Examples of *floating structures* are jack-up rigs, semi-submersible drilling platforms, drilling vessels for exploration, drilling and heavy lift barges, diver support vessels, pipe laying barges etc.

Fixed structures comprise sub-sea well-head structures, sub-sea manifolds, well-head and production platforms, sub-sea pipelines etc.

Ships, barges and floating structures can be brought to shore into a dock or at least into sheltered water for repair, modification and maintenance. For this type of structures high-duty ship painting systems can be used. They generally give adequate performance for the relatively short working life of this type of equipment.

Fixed installations on the sea bottom such as well-head structures, sub-sea manifolds, pipelines and support structures (jackets) for production platforms (apart from modules) cannot be transported to shore for repair or maintenance and most parts cannot be replaced without extreme difficulty and heavy cost if they should fail due to corrosion. Consequently, fixed offshore structures may be expected to have a service life of 25 years or more, which puts extremely heavy requirements on corrosion control.

This chapter mainly deals with corrosion protection by means of paint systems. As offshore floating equipment can be dry-docked and maintained like a ship, this chapter deals only with *fixed offshore structures* which cannot be transported onshore for maintenance.

As (fixed) offshore platforms form a large part of such structures, their corrosion protection will be dealt with under Parts 2.2 to 2.5.

2.2. Building/Painting of fixed offshore platforms

2.2.1. INTRODUCTION

Offshore platforms operate as complete gas and/or oil production and processing units. Consequently they have to accommodate drilling-, processing- and control equipment

and have to provide safe accommodation for the crew. The support structure of a platform is the jacket. This structure, built in tubular steel is positioned on the seabottom and the superstructure, consisting of the deck, drilling-, processing- and accommodation modules, is mounted on the jacket to form the complete platform. The building of these offshore structures is a highly specialized operation where much use is made of prefabricated sections and building takes place under cover.

As offshore structures, which must enable safe and economical oil and gas production in a very corrosive and often rough environment, represent very large capital investments, adequate corrosion control is of the utmost importance.

Due to factors like poor weather conditions, poor access, interference with other activities etc., offshore painting or other corrosion combating operations are often impossible or at least very difficult and expensive*. Moreover, it is very difficult to obtain the desired high protection quality offshore. Therefore, *corrosion protecting operations must be executed onshore as completely as possible and under adequate conditions.*

In order to postpone difficult and expensive maintenance as long as possible, *corrosion protection must be of the highest quality.* Good planning and quality control during build is essential. Also *design features, that will simplify corrosion control, are strongly recommended.* Some recommendations, as given in NACE Standard RP-0176-83**, are given in Appendix 2.A. of this chapter.

2.2.2. PROTECTIVE METHODS (see Appendix 2.B. for a summary)

In order to obtain a high quality product, there is a tendency to build offshore structures under cover as far and as completely as possible. Depending on the building contract, shop-coated or untreated hot-rolled steel tubular members, plates and beams are used. For shop-coats and their behaviour, the reader is referred to Chapter I, Part 1.2 and to Chapter 5. When untreated steel is used, the original condition should be preferably be A or B according to ISO standard 8501 (Swedish Standard SS 05 59 00-1988)***. This means that severely corroded pitted (polluted) steel, with conditions C and D, should not be used.

The *jacket* normally is constructed under cover or in the open air. Welds are tested by X-ray scanning and repaired where necessary. After approval of the welds, the part of

* It is estimated that offshore maintenance is at least three times as expensive as onshore maintenance.

** NACE Standard RP-0176-83, "Recommended Practice, Corrosion Control of Steel, Fixed Offshore Platforms Associated with Petroleum Production".

*** see Part 3.2.3.3.

the jacket which has to be coated (see 2.3.3.1 and 2.3.3.2) is normally blast-cleaned (cleanliness at least Sa 2^{1/2}) and provided with the subsequent layers of the paint system. Welds should be given particular care to ensure that weld spatter, weld flux residues and soluble salt contaminations are properly removed. Welds and edges are stripe-coated before the application of each layer of the paint system.

When the jacket is constructed in the open air it is advisable to use (temporary) shields to protect the environment against blasting and paint dust and the paint work against rain etc.

The *deck and superstructure* normally are constructed from prefabricated sections which are assembled to form *modules* which are mounted on the jacket structure after this has been brought offshore.

In modern offshore module construction, all operations up to the time of load-out and transport are normally executed under cover in large workshops. Often there are separate workshops for prefabrication of sections, blasting/priming and module construction/final painting; these workshops should preferably be heated and well-ventilated. For the advantages and disadvantages of building/coating under cover, the reader is referred to Part 1.2 of this manual.

If there is no full facility for building/coating under cover and part of this work has to be done outside in the open air, care should be taken to touch-up corroded spots before paint application and to remove, by fresh water washing/brushing, all possible weathering and air pollution products from the surfaces before a subsequent paint layer is applied.

Before being welded into sections, the various parts have undergone mechanical treatment such as cutting to size and bending. Also with respect to the very high quality desired, before welding all welding areas (section welds) are freed from corrosion products and/or shop-coat. This is preferably done by blast-cleaning; the blast-cleanliness should be at least Sa 2^{1/2} according to ISO standard 8501.

After welding into sections and subsequent removal of welding spatters by chipping, the welds must be smoothed by grinding.

Also the welds are tested by X-ray scanning and repaired where necessary. It is strongly recommended that all sharp edges be rounded by mechanical grinding to a radius of at least 2 mm.

After these operations, the sections are often precoated, which means that they are blast-cleaned (cleanliness at least Sa 2^{1/2}) and provided with the first coat (anti-corrosive primer) of the paint system. When this is a zinc-rich primer and the following layer is a sealer, the sealer is also applied at this stage.

It is strongly recommended that all welds, edges and corners be stripe-coated before the application of each layer of the paint system. Stripe-coating with a zinc-rich primer should result in a thin coat (dry film thickness under 25 µm), avoiding thick drops and

runs. Instead of stripe-coating with a zinc-rich primer a non-zinc touch-up primer may be used.

All areas to be welded at a later stage (connections between sections) are left free from paint. This is done by masking them with adhesive tape before coating starts. This tape should not leave behind residues of adhesive on the substrate as this might impair paint adhesion.

After transport to the assembling facility, the sections are assembled into modules.

The welds between the sections will again be smoothed etc., as previously described and subsequently cleaned, preferably by (vacuum, pencil) blast-cleaning.

If this is not longer permitted because of the risk of damage to and/or contamination of vulnerable equipment, power tool-cleaning will be employed; the cleanliness should then be St3 according to ISO standard 8501.

After approval, the welds will be primed and if necessary sealed. If in the painting specification a zinc-rich primer is prescribed for the priming of these welds, a special non-zinc containing touch-up primer is often used. In this way undesired overlaps with zinc-rich primers will be avoided; this is especially important when using zinc silicate primers.

After construction of the modules and installation of the equipment, final painting should be undertaken. Before it can start, all burnt areas and mechanically damaged and/or corroded spots should be blast-cleaned (cleanliness at least Sa 2^{1/2}) or thoroughly power tool-cleaned (cleanliness St3) and touched-up (primed and sealed). After curing of the touch-up paints, all surfaces should be rendered dust-free, thoroughly degreased where necessary (for instance by hot water/steam-cleaning) and coated with the final layers of the paint system. Also at this stage, all (rounded) edges should be stripe-coated before application of each layer.

It is recommended that final painting be undertaken at an earlier stage on surfaces that will become difficult to access during construction of the modules.

The jacket and modules, fabricated as described above, are transported to the offshore location, installed and assembled to form a complete platform. Before transport, all paint layers should be allowed to cure sufficiently in order to prevent unnecessary mechanical damage.

Prior to welding, the welding areas are freed from paint by blast-cleaning (cleanliness Sa 2^{1/2}). Mechanical damage and/or corroded spots originating during transport are also treated in this way. Care should be taken to protect the surrounding surfaces against damage by abrasive; if such damage is unavoidable, power tool-cleaning should be used as an alternative cleaning method (cleanliness St3).

After smoothing and approval of the welds, these and the pretreated mechanically damaged and/or corroded spots should be primed and coated with the different layers of the paint system. As there is a risk of contamination of prepared surfaces by sea water

mist before coating application, it is strongly recommended that the paint system be applied within the shortest possible period and to wash the surfaces with clean fresh water between application of the subsequent layers.

The building operations for the jacket and modules as described above are summarized in the flow sheet represented in Appendix 2.B.

2.3. Protective systems for the separate parts of offshore platforms in new construction

2.3.1. GENERAL

For the reasons set out under Part 2.1 it is of vital importance that corrosion protection measures should be of the highest possible quality. This can only be achieved by executing the corrosion protection operations, as complete as possible, onshore under well-defined conditions. Good planning and quality control, before and during execution, is essential.

Consequently, the right high-quality system must be applied during new construction and easy maintenance of these systems must be possible under adverse (offshore) conditions.

The systems described under Parts 2.3.2 up to and including 2.3.11 are examples of common systems of good quality. *No attempt has been made to produce a list of all possible systems.*

2.3.2. UNDERWATER (SUBMERGED) ZONE

Although some offshore platforms support structures are constructed from concrete, this manual deals only with jackets constructed from tubular steel, which form the majority of the support structures.

2.3.2.1 Requirements

As the supporting structure of the platform, continuously submerged in salt water, the jacket should be *effectively protected against corrosion. Any coating system applied should be compatible with the cathodic protection system* (alkali resistant and resistant to cathodic disbonding).

2.3.2.2 Suitable protective systems

Corrosion protection systems for the underwater part of offshore structures usually consist solely of cathodic protection systems, either by *sacrificial anodes* or by *impressed current systems*.

The cathodic protection system, sometimes, is combined with a coating system, applied to the whole or part of the underwater area. The reasons for this can be:

- cost reduction, due to reduced current requirements in the case of impressed current systems;
- better corrosion protection of areas with complex steel configurations where adequate current distribution is difficult to achieve;
- weight reduction, in case of sacrificial anodes, which deserves special consideration when the platform is situated in deep water.

When a coating system is added to a cathodic protection system, the steel substrate should be thoroughly blast-cleaned to a cleanliness of at least Sa 2^{1/2} and the coating system may consist of 2 or 3 layers of coal-tar epoxy or polyurethane tar paint with a total dry film thickness of at least 400 µm.

2.3.3. TIDAL AND SPLASH ZONE

2.3.3.1 Requirements

The tidal/splash zone can extend from 3-8 metres below Lowest Astronomical Tide (LAT) to 5-10 metres above LAT, depending on the location and size of the structure. *The tidal/splash zone, which is the most difficult to reach for maintenance painting, and which is exposed to the severe continually alternating action of sea water, salt spray and the atmosphere (tidal movement, wave action), is considered to be the most corrosive zone of the platform (see Appendix 2.C).*

Due to heavy marine fouling (sea weed) inspection of the surface for corrosion is impossible or at least extremely difficult. Moreover, in this zone, being only partly immersed for regular periods, cathodic protection systems will not give satisfactory protection.

Also, there is a strong possibility of mechanical damage of the protective system by workboats, floating ice, etc.

With reference to the above mentioned, paint systems in the splash/tidal zone should be:

- highly corrosion-inhibiting;
- resistant to mechanical damage;
- capable of local (patch) repair after spot blasting or power-tool cleaning;
- anti-fouling (although the existing anti-fouling compositions are not durable enough);
- resistant to the mechanical action of fouling.

2.3.3.2 Suitable protective systems

To compensate for the extreme corrosive environment, sufficient *extra steel to provide a corrosion allowance* and *heavier wall tubular members* may be provided as well as *steel wear plates* and *rubber boat fenders* which can provide extra resistant to mechanical damage.

The tidal/splash zone of offshore structures normally is protected by a high-quality anti-corrosive coating system. These systems usually consist of *2 or more coats of coal-tar epoxy or coal-tar polyurethane paint* to give a dry film thickness of at least 500 μm , over *blast-cleaned steel* (cleanliness $\geq \text{Sa } 2^{1/2}$) or over *blast-cleaned steel, primed with a zinc-rich primer* (zinc epoxy, 25-35 μm or zinc silicate, 50-75 μm) or a *zinc-free anti-corrosive epoxy primer* (30-40 μm).

When a zinc-rich primer is used, this is often sealed with an epoxy micaceous iron oxide (MIO)-pigmented sealer coat (50-75 μm).

As repair of coating systems near the water line is extremely difficult and costly, *there is a growing tendency to use special coatings or other systems of high durability for tidal/splash zone protection*. Some of these special coatings or systems are described in the following paragraphs; the protective systems mentioned under parts a and b are the most commonly used.

- a. **Silica-filled (flint-reinforced) compounds** are mainly solvent-free epoxy claddings which are applied by spraying or troweling directly to blast-cleaned steel (cleanliness $\geq \text{Sa } 2^{1/2}$) in a dry film thickness of 3-5 mm. Special attention should be paid to the surface profile of the blast-cleaned steel which should be at least 75 μm . The epoxy claddings are very durable and highly resistant to impact and wear.
- b. **Monel 400 (nickel-copper alloy) sheeting**, thickness 1-5 mm, is attached to the tubular steel either by bonding or by welding. Welding is preferred because by this method the gap between steel substrate and sheeting is sealed. On the other hand, however, welding can introduce problems arising from the fusion of dissimilar metals which can form a corrosion cell. In order to avoid hidden corrosion, the sheeting is sometimes applied over a protective coating system. In order to facilitate sheeting, all members in the splash zone should be smooth vertical cylinders; avoidance of cross and diagonal bracing and nodes is strongly recommended.
- c. **Glass-flake reinforced epoxy coatings** are high-build or high-solid coatings which are applied to blast-cleaned steel (cleanliness $\geq \text{Sa } 2^{1/2}$) by spraying in one or two layers with a dry film thickness of at least 500 μm per layer. These coatings are tough, very durable and highly resistant to impact and abrasion. The application is easier than the application of the silica-filled epoxy claddings (a). When only one

layer is applied, this may be top coated with a non-glass flake containing epoxy or polyurethane paint.

- d. **Thick rubber or neoprene (synthetic rubber) coatings** are applied in thicknesses of about 6 to 13 mm. Since these coatings cannot be applied after assembly, the application is restricted to straight parts of tubular members. This means that the ends of these members should be left uncoated to prevent damage during welding.
- e. **Bituminous wrappings** from which the wrapping material usually is glass fibre. Before application of the wrappings, the steel is cleaned and given one coat of coal-tar of bitumen primer.

2.3.4. UNDERDECK AREA

2.3.4.1 *Requirements*

As the zone between the splash zone and the decks is not in direct contact with sea water, corrosion attack may be expected to be less severe than in the tidal/splash zone. However, the steel surfaces are difficult to get at for maintenance and will be salty, from sea spray, which is strongly corrosion promoting.

The most severely exposed areas are the undersides of the decks, due to severe condensation as a result of poor ventilation and the low temperature of the steel. In addition, coating systems on the undersides of drilling decks may be attacked by spillage of oil, mud and chemicals.

Paint systems for the splash zone to underdeck areas should be:

- highly corrosion-inhibiting;
- resistant to weathering;
- resistant to spillage of oil, drilling mud and (process) chemicals;
- capable of local (patch) repair after spot-blasting or power-tool cleaning for instance during the offshore hook-up phase of the platform;
- lightly coloured in order to facilitate inspection in the dark underdeck areas.

2.3.4.2 *Suitable protective systems*

Depending on the view of the platform operator and/or paint manufacturer concerned, protective systems for the area between the splash zone up to and including the underside of the decks are often similar to the paint systems for the tidal/splash zone or for the topside facilities, for which the reader is referred to Part 2.4.5.

It is also possible to extend the special high-durability systems of the tidal/splash zone, as mentioned under Part 2.3.3.2a-e, all the way up to the deck level. These protective

systems, however, are not always suitable for completion and repair during the hook-up phase of the platform. When a system is chosen similar to the paint system used on upper parts, it is strongly recommended that an extra (intermediate) layer be applied to the deck undersides. The bearing (supporting) parts of the structure in the underdeck areas often are coated with a fire-resistant cement-based system, reinforced by means of a coated galvanized mesh which is fixed to the steel substrate. The fire-resistant system is very thick and is applied on top of an inorganic anti-corrosive paint system (see also Part 4.5.3.6).

2.3.5. ATMOSPHERIC ZONE (TOPSIDE FACILITIES)

The exterior of the topside facilities comprise all the steel exposed to the atmosphere above the lowest deck (cellardeck) level, with the exception of special surfaces such as decks, walkways, high-temperature areas, module sidings, tank interiors etc.

2.3.5.1 Requirements

Paint systems for the exterior of the topside facilities should be:

- highly corrosion-resistant (resistant to chloride contamination and condensation);
- resistant to weathering (ultra-violet radiation);
- more or less aesthetic;
- capable of local (patch) repair after spot-blasting or power tool-cleaning.

2.3.5.2 Suitable protective systems

Because subsequent maintenance is much easier than for the other parts of the platform, originally air-drying alkyd coating systems were widely used.

Due to the extremely aggressive atmosphere, however, nowadays only high-duty coating systems, totally based on unsaponifiable binders, starting with a high-quality two-component anti-corrosive primer are used.

A large variety of coating systems is suitable for topside steel protection. Generally, they consist of a *2-component anti-corrosive primer* (often a zinc-rich type, based on an epoxy- or silicate binder), a *tie-coat or sealer coat*, one or two *intermediate build coats* (for building-up thickness) and a, more or less, aesthetic or identification *top coat*.

Apart from the primer, which often is a zinc-rich epoxy or zinc silicate, the other layers of the system are based on epoxy resins, polyurethanes, combinations of the foregoing types, chlorinated rubber (modified chlorinated rubber) or vinyl copolymers.

Insulated parts should be given a full anti-corrosive coating system under the insulation material.

A few *examples* of current coating systems of good quality are given in Appendix 2.D).

Similar to those of the underdeck areas, the supporting parts of the topside are often coated with a thick cement-based fire resistant system. Paint systems for the interiors of the topside facilities are often similar to those described for the exteriors, although dry film thicknesses are sometimes lower in dry spaces. On the inside of accommodation modules, decorative top coats and fire-retardant coating systems are often used.

For walls and roofs of modules, coil coated corrugated panels (sidings) are often used. Most of these materials are hot dip zinc or zinc/aluminium coated, chemically pretreated, primed and coated with an organic coating in continuous (coil coat) processes. After fabrication, the coated coils are cut to size and corrugated. Although a lot of coating systems are in use, for offshore conditions it is advisable to use only materials with a thick coating system (thickness $\geq 100 \mu\text{m}$) such as a plastisol system or systems consisting of an epoxy coating, with PVDF (polyvinylidene fluoride) or polyurethane top coats.

Special attention should be given to the desired protection of the back of the panels, proper attachment to the main structure, avoidance of damage during installation and adequate protection of the (cut) edges. Materials showing cracks in the organic and/or zinc coating should not be used.

2.3.6. DECKS (WORKING DECKS AND HELIDECKS)

2.3.6.1 *Requirements*

Deck areas are subjected to heavy traffic and other mechanical influences. In addition, they are exposed to the marine environment and, in some areas, to salt water and spillage of drilling mud, chemicals, hydraulic oil and diesel fuel. Moreover, deck areas cannot remain inaccessible for long periods.

With reference to the above, and in order to obtain a rough surface and to enable safe working, protective systems for decks should be:

- corrosion-resistant;
- weather-resistant;
- resistant to abrasion, impact and scratching;
- resistant to salt water;
- resistant to spillage of drilling mud, chemicals, hydraulic oil and diesel fuel;
- non-slip (non-skid);
- fast drying;
- "easy" to clean.

2.3.6.2 Suitable protective systems

Coating systems for decks often consist of a *zinc silicate primer* (dry film thickness 50-75 μm) with or without a sealer (depending on the paint manufacturers recommendation) and *one or more layers of a high-solid or high-build epoxy paint*. The total dry film thickness should be at least 300 μm .

The top layer of the system should be *non-skid (non-slip)*.

Coating systems for decks may be similar to those described for the top sides, but with a non-skid top coat. If such a system is chosen, the chlorinated rubber and vinyl copolymer based types should not be used on helidecks and other areas where hydrocarbon spillage may be expected.

For decks which will be subject to heavy wear and damage, walkways and helidecks, the protective system often consists of a *non-skid, silica-filled (flint-reinforced) epoxy cladding*, directly applied on the blast-cleaned substrate, with a dry film thickness of ≥ 3 mm. Also *glass-flake reinforced epoxy coating systems* (thickness 1 mm) are suitable for such decks.

2.3.7. HIGH TEMPERATURE AREAS

2.3.7.1 Requirements

(Hot) piping, flare stacks and gas turbine exhaust stacks are subjected to elevated temperatures, sometimes intermittently. Protective systems for such surfaces should be:

- heat-resistant (resistant to alternating temperatures);
- corrosion-resistant;
- weather-resistant;
- resistant to intermittent condensation.

2.3.7.2 Suitable protective systems

For operating temperatures up to 150-200°C, paint systems consisting of *one coat of zinc silicate primer* (dry film thickness 75 μm) and *two coats of aluminium pigmented silicone alkyd* (dry film thickness 25 μm per coat) or *silicone acrylic resin* (dry film thickness 50 μm per coat) are often used. *Aluminium pigmented epoxy coating* can also be used as a top coat (for instance 2 layers, dry film thickness 40 μm per layer).

For operating temperatures up to about 400°C, current systems normally consist of *one coat of zinc silicate primer* (dry film thickness 75 μm) and *two coats of heat-resistant aluminium silicone paint* (dry film thickness 25 μm per coat). For an adequate film

development the silicone top coat should be heated gradually to the maximum possible temperature.

For operating temperatures up to about 600°C current systems consist of one coat of zinc silicate primer (dry film thickness 75 µm) and one coat of silicate finish (dry film thickness approximately 75 µm).

With regard to corrosion protection under offshore conditions, the above mentioned paint systems of low thickness cannot be considered to be very effective. Corrosion protection by these systems cannot be upgraded by the use of higher film thickness without losing part of their heat resistance. Therefore it is recommended that elevated temperature surfaces be treated by *metal spraying*.

A suitable system is to blast-clean (cleanliness \geq Sa 2^{1/2}) the surfaces and to metal spray these with *two layers of high purity aluminium* (purity \geq 99.5% Al). The dry film thickness should be at least 100 µm per layer. The metal sprayed coating may be sealed by the application of one coat of heat resistant silicone paint (dry film thickness 25 µm), pigmented with aluminium or stainless steel.

2.3.8 TANKS

2.3.8.1 Requirements

For the outside of the tanks the reader is referred to Part 2.3.5 (topside facilities), for the requirements and suitable protective systems.

Paint systems for the interiors of tanks (tank linings) should be:

- corrosion-inhibiting;
- free from pores;
- smooth (easy to clean);
- highly resistant to the liquid to be held in storage, including such substances as may be released by this liquid;
- unsaponifiable, especially when cathodic protection is applied.

Beside these requirements, coating systems for tanks should not develop substances that may contaminate the liquid to be stored. Especially for drinking water tanks, coating systems must not contain toxic substances or substances affecting colour or taste. They must receive official approval.

2.3.8.2 Procedures

Tank coating procedures are described under Part 1.3.6.2.

2.3.8.3 Suitable protective systems (see also Part 1.3.6.4d)

a. Drinking (potable) water tanks

The insides of drinking water tanks are usually coated with:

- one or more coats of *high-build, high-solid or solvent-free epoxy paint*, total dry film thickness at least 250 µm);
- several coats of *vinyl paint*, total dry film thickness at least 200 µm.

Before application of these systems, the substrate should be 'in situ blasted' to a cleanliness of at least Sa 2^{1/2}. The coating systems should be certified for suitability in potable water tanks.

b. Tanks for crude oil/ballast water/drilling mud/drilling water/fresh water

The interiors of these tanks are usually coated with:

- one or more coats of *high-build, high-solid, or solvent-free epoxy paint*, total dry film thickness ≥ 300 µm;
- two or more coats of *coal-tar epoxy paint*, total dry film thickness ≥ 300 µm.

Depending on the paint manufacturers recommendations these systems should be applied on 'in situ blasted' steel or on top of intact, thoroughly cleaned (shop) primer.

c. Tanks for fuel oil/white petroleum products

The interiors of these tanks are usually coated with:

- one or more coats of *high-build, high-solid or solvent-free epoxy paint*, total dry film thickness ≥ 300 µm.

In the case of fuel oil only, the interior of the tanks need not be painted (see also 1.3.6.4b).

d. Tanks for chemicals and solvents

Suitable systems for the interiors of these tanks are:

- several coats of *epoxy, modified epoxy phenolic or polyurethane paint*, total dry film thickness ≥ 300 µm.

Before application, the steel substrate should be 'in situ blasted' to a cleanliness of at least Sa 2^{1/2}.

e. Tanks for methanol (and other strong solvents)

The inside of tanks for methanol and strong solvents should be coated with one coat of *zinc silicate paint*, dry film thickness 75-100 μm .

Directly before application of the coating, the steel substrate should be blast-cleaned to a cleanliness of at least Sa 2^{1/2} and a surface profile (*Ry5*) of at least 50 μm .

2.3.9. RISERS

Oil or gas from a well below a production unit (platform) ascends via the drill pipe, protected by a so-called conductor. After processing and separation of gas, oil and water, the oil and/or gas leaves the platform via a so-called "riser".

The riser is the vertical part of a pipeline coming from the sea-bottom and may lead to a loading buoy, another platform or to the shore. Pipeline risers, which may operate at internal temperatures up to about 100°C and pressures up to about 500 KPa, pass through the sea, tidal, splash and atmospheric zone. The risers are therefore subjected to extreme corrosive conditions.

Internal corrosion, which will not be dealt with in this manual, is caused by (dissolved) hydrogen sulphide (H₂S), carbon dioxide (CO₂) and free water in the oil or gas transported.

External corrosion will be strongly promoted by the high temperature of the oil or gas. Moreover, expansion of the risers during testing and service causes severe strains on any coating system, particularly in the area where the riser passes through cold sea water. The part of the riser which is most vulnerable to external corrosion, is without doubt the splash zone portion. Sometimes, risers are subjected to the corrosive effects of stray currents from welding operations that take place after the offshore installation has been completed. The only way to avoid this is proper earthing of the welding equipment.

2.3.9.1 Requirements

For the submerged-, splash/tidal- and atmospheric zone, any corrosion protection system for (hot) risers must meet the requirements set out for the jacket and platform construction under Parts 2.3.2.1 (submerged zone), 2.3.3.1 (tidal/splash zone) and 2.3.5.1 (atmospheric zone) respectively.

Moreover, coating systems should be *resistant to elevated temperatures and to the extension and contraction of the riser pipes*, in other words be permanently flexible. Also, for the tidal/splash zone, coating systems should *be resistant to warm/hot water*.

2.3.9.2 Suitable protection systems

The *submerged zone* of risers normally is protected solely by means of a *cathodic protection system* (see Part 2.3.1.2).

The *splash/tidal zone*, after blast-cleaning (cleanliness \geq Sa 2^{1/2}), for instance, may be coated with one of the following systems:

- *Monel metal sheeting*, of at least 2 mm thickness;
- two or more coats of *coal-tar epoxy* or *coal-tar epoxy/urethane paint*, sometimes over a *zinc-rich primer*, total dry film thickness at least 400 μm);
- one or two layers of *glass-flake reinforced epoxy-* or *polyester paint*, dry film thickness at least 1 mm;
- *Neoprene sheet wrappings*.

Considering possible coating systems it should be stated that highly pigmented, solvent-based epoxy coatings (like tank linings) should not be used due to their limited water resistance at higher temperatures. Also sand or quartz-filled solvent-free epoxy compositions and solvent-free coal-tar epoxy compositions should not be used because these materials contain constituents which may become more or less volatile on heating and become slightly soluble in warm water.

The Monel sheet is attached to the risers by tack welding or by incorporating water and air tight joints at both ends (top and bottom). Welding, although to be preferred, can introduce problems arising from the fusion of dissimilar metals which can form a corrosion cell. If the water and air tight joints are not incorporated properly, corrosion will take place unnoticed behind the sheeting.

As the resistance of Monel sheeting to impact is relatively poor, special care must be taken when handling during 'hook-up'.

The *atmospheric zone* of the (hot) risers may be treated like the atmospheric zone of the platform (see Part 2.3.5). Chlorinated rubber or vinyl paints however should not be used due to their limited temperature-resistance.

There is a growing tendency to use special (stainless) steels (such as duplex steel) for risers, which makes protection by coating systems unnecessary.

2.3.10. SEA WATER PIPING SYSTEMS

Sea water piping systems are used to transport sea water to the fire main systems or for cooling purposes, for instance for gas turbines or centrifugal pumps. The pumped sea water is very corrosive and by its high velocity has a strong eroding effect on internal linings. For these reasons conventional pipe coating systems have been observed to fail quickly.

2.3.10.1 Requirements

For the external corrosion protection requirements the reader is referred to Part 2.3.5.1 (requirements for coating systems for the atmospheric zone).

Internal corrosion protection systems should be:

- highly corrosion-resistant (resistant to aerated sea water);
- highly erosion-resistant (resistant to the eroding action of high-velocity sea water);
- resistant to impingement attack.

2.3.10.2 Suitable protective systems

External

The reader is referred to Part 2.3.5.2 (atmospheric zone).

Internal

- *thick PVC-lining* on properly pretreated (preferably blast-cleaned) steel;
 - *a glass-flake reinforced unsaturated polyester or epoxy system* on blast-cleaned steel.
- As coating integrity at joints and welds always represents a problem, the trend nowadays is towards the use of *stainless steel* or *cupro-nickel alloy* pipelines.

2.3.11 SUPPLIERS EQUIPMENT

Suppliers equipment, such as cranes, turbines, motors, valves etc., is often supplied with a standard finish, for cosmetic reasons, which is totally unsuitable for service offshore where a perfect corrosion-resistance is required.

This problem could be solved by issuing the main equipment supplier with a realistic coating specification. It is essential that the equipment be coated properly by the vendor onshore. In the long-term, saving on maintenance costs should more than compensate for increased initial expenditure.

**APPENDIX 2.A. - PART OF NACE-STANDARD RP-0176-83,
RECOMMENDED PRACTICE, CORROSION CONTROL
OF STEEL, FIXED OFFSHORE PLATFORMS
ASSOCIATED WITH PETROLEUM PRODUCTION***

SECTION 3: STRUCTURAL DESIGN FOR CORROSION CONTROL

3.1. Introduction

3.1.1. This section recommends design features that will simplify corrosion control of structural steel in the atmospheric, splash, and submerged zones of offshore platforms. The structural design parameters that must be considered for a platform to resist the dynamic and static loads are the responsibility of civil and structural engineers and are not a part of this Recommended Practice.

3.2. Splash zone

3.2.1. This is the zone of a platform that is alternately in and out of the water because of the influence of tides, loads, and seas. Excluded from this zone are surfaces that are wetted only during major storms. In the Gulf of Mexico, the splash zone typically covers an interval of about 6 feet (2 metres); in Cook Inlet, Alaska, the interval approaches 30 feet (9 metres); while during winter storms the splash zone in the North Sea can be 33 feet (10 metres).

3.2.2. The structure should be designed to minimize the surface area of steel in the splash zone. Intersecting 'T', 'K' or 'Y' joints should be avoided in the splash zone.

3.2.3. Methods for controlling corrosion in the splash zone are presented in Section 10.

3.2.4. Sufficient added thickness (typically, in the Gulf of Mexico, 0.5 to 0.75 inches = 13 to 19 mm), either as a weld-applied wrap or heavier-wall tubular member, may be provided to compensate for the anticipated splash zone corrosion during the life

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of the platform. Steel wear plates can provide adequate resistance to damage by work, boats, or ice.

3.3. Atmospheric zone

3.3.1. This zone of the platform extends upward from the splash zone. It is exposed to sun, wind, spray, and rain.

3.3.2. Corrosion in this zone is typically controlled by the application of a protective coating system (see Sections 12 and 13). Steel surface areas requiring coating can be minimized and made accessible by:

3.3.2.1 Substituting tubular members for other structural shapes.

3.3.2.2 Seal welding and boxing-in of structural units.

3.3.2.3 Eliminating skip welding.

3.3.2.4 Eliminating close fitting and faying surfaces.

3.3.2.5 Providing padeyes to make scaffolding and maintenance painting easier.

3.3.3. Nonferrous materials minimize atmospheric corrosion problems. For example, quarters modules and life boats are available in polyester materials. Other types of corrosion-resistant materials can be used for handrails, electrical conduit, stair treads, and deck plates in light traffic areas. When using dissimilar metals, care must be taken to prevent galvanic corrosion of the active component.

3.3.4. Drilling fluids can damage protective coating systems and nonferrous metals such as aluminium and zinc. Solid decks, splash walls, and a good drainage system will minimize coating damage and pollution caused by drilling fluids.

3.4. Submerged zone - external areas

3.4.1. This zone extends downward from the splash zone and includes that portion below the mudline. Corrosion control for the external areas of the submerged zone is achieved through the application of cathodic protection or by cathodic protection in

conjunction with coatings. To simplify the application of effective cathodic protection, the following design features are recommended.

3.4.1.1 Use tubular members wherever possible. Recessed corners in channels and 'I' beams are more difficult to protect. The crevice formed by placing angles or channels back to back cannot be reliably protected, and such construction should not be used.

3.4.1.2 For platforms to be installed under conditions where fatigue or corrosion fatigue is an important factor in structural design, stress relief of weld will reduce the likelihood for corrosion in the heat affected zone and reduce the possibility of cracking. This is particularly important in cold-water environments where polarization tends to develop slowly (see API)¹ RP 2A.

3.4.1.3 Welded joints should be continuous. Skip and tack welding should not be used. If lap joints are used, both edges should be welded. Bolted and riveted fittings should be avoided.

3.4.1.4 Ballast control valve reach rods should be designed so that they can be removed after the platform has been set, where practical. If left in place, they may shield the adjacent structural members from the cathodic protection current. Loose reach rods can cause chafing damage to the platform.

3.4.1.5 Piping such as grout lines, well cutting lines, discharge lines, water supply casings, and pipeline risers, if clustered around a platform leg, can cause shielding and interfere with the flow of cathodic protection current. Piping not needed for platform operations should be removed if economically feasible. Lines not removed should be located to avoid shielding. Provide a minimum clear spacing of 1¹/₂ diameters of the smaller pipe. Pipe coatings can also be used to minimize shielding.

3.4.1.6 Supplemental or replacement impressed current anodes are sometimes required after a platform has been placed in service. Designers should consider providing spare 'J' tubes for pulling cables from add-on anodes and/or providing other types of brackets, guides, or clamps to facilitate anode additions or replacement.

3.4.1.7 The steel below the mudline consists of the platform pilings. Piles driven through the jacket legs are normally bonded to the jacket by welding and thus receive cathodic protection. Skirt piles are typically driven inside submerged piling grout tubes and then grouted in place. Skirt piles may be electrically connected to the jacket by

¹ American Petroleum Institute (API), 2101 L St., N.W. Washington, DC 20037

means of guide shoes, centralizers, or other acceptable bonding methods. However, corrosion rates below the mudline are low. Because of the low corrosion rates and the thick sections, bonding of grouted piles is not required.

3.4.1.8 Where the well casing conductors are considered necessary to the integrity of the well casings, the conductors should be electrically connected to the platform.

3.5 Submerged zones - internal areas

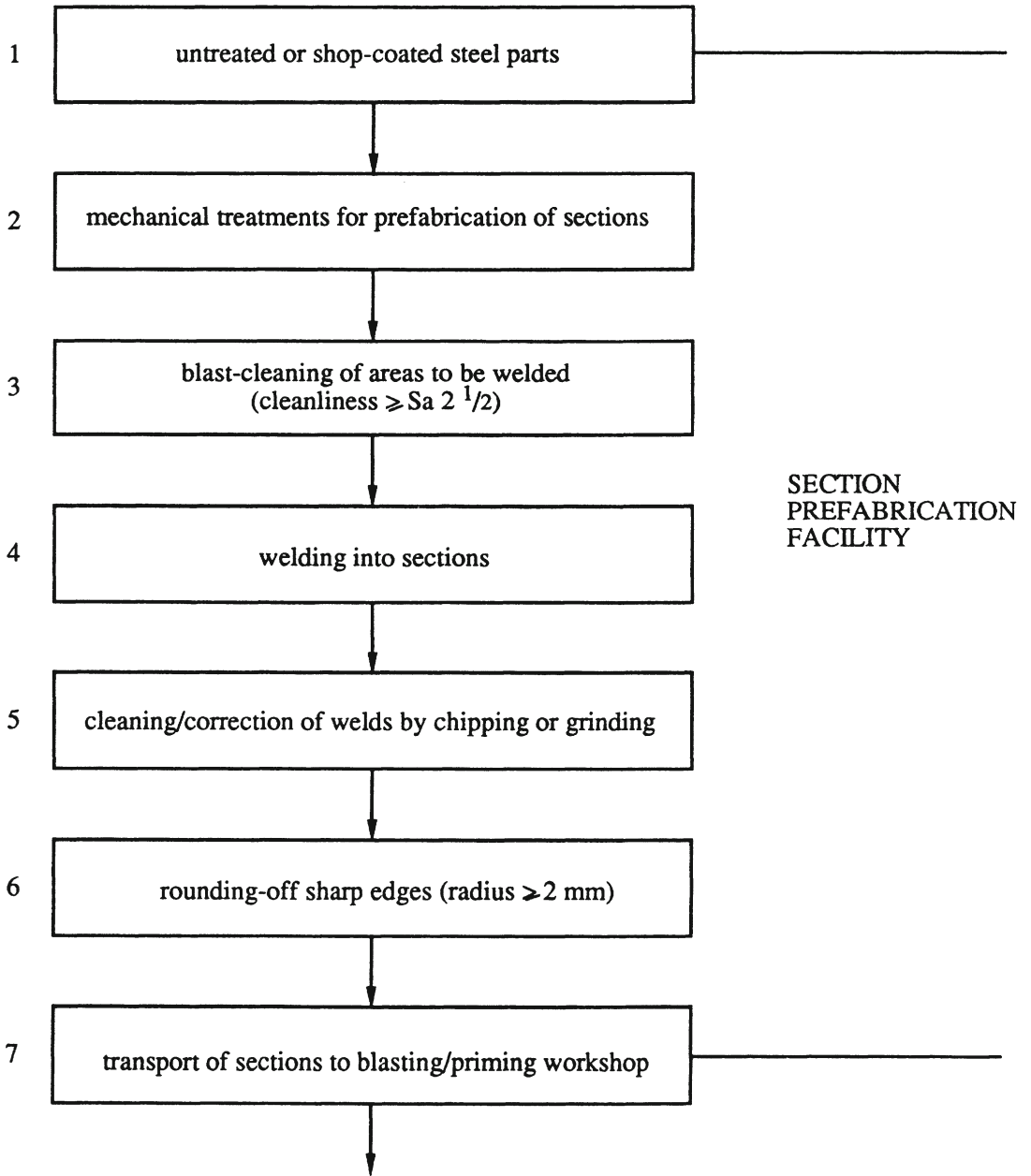
3.5.1. Corrosion will be negligible on the internal surfaces of structural members or in compartments that are sealed and have no contact with either the atmosphere or the seawater. Wherever possible, the design should provide for sealed compartments.

3.5.2. During the platform launching and tilt-up operation, some structural members are flooded and remain flooded for the life of the platform. To prevent internal corrosion, the flooding valves should be closed to isolate the flooded chambers from contact with atmospheric oxygen. In compartments where circulation of seawater is not prohibited, provisions should be made to curtail internal corrosion. Cathodic protection using anodes or a combination of anodes and coating should be used.

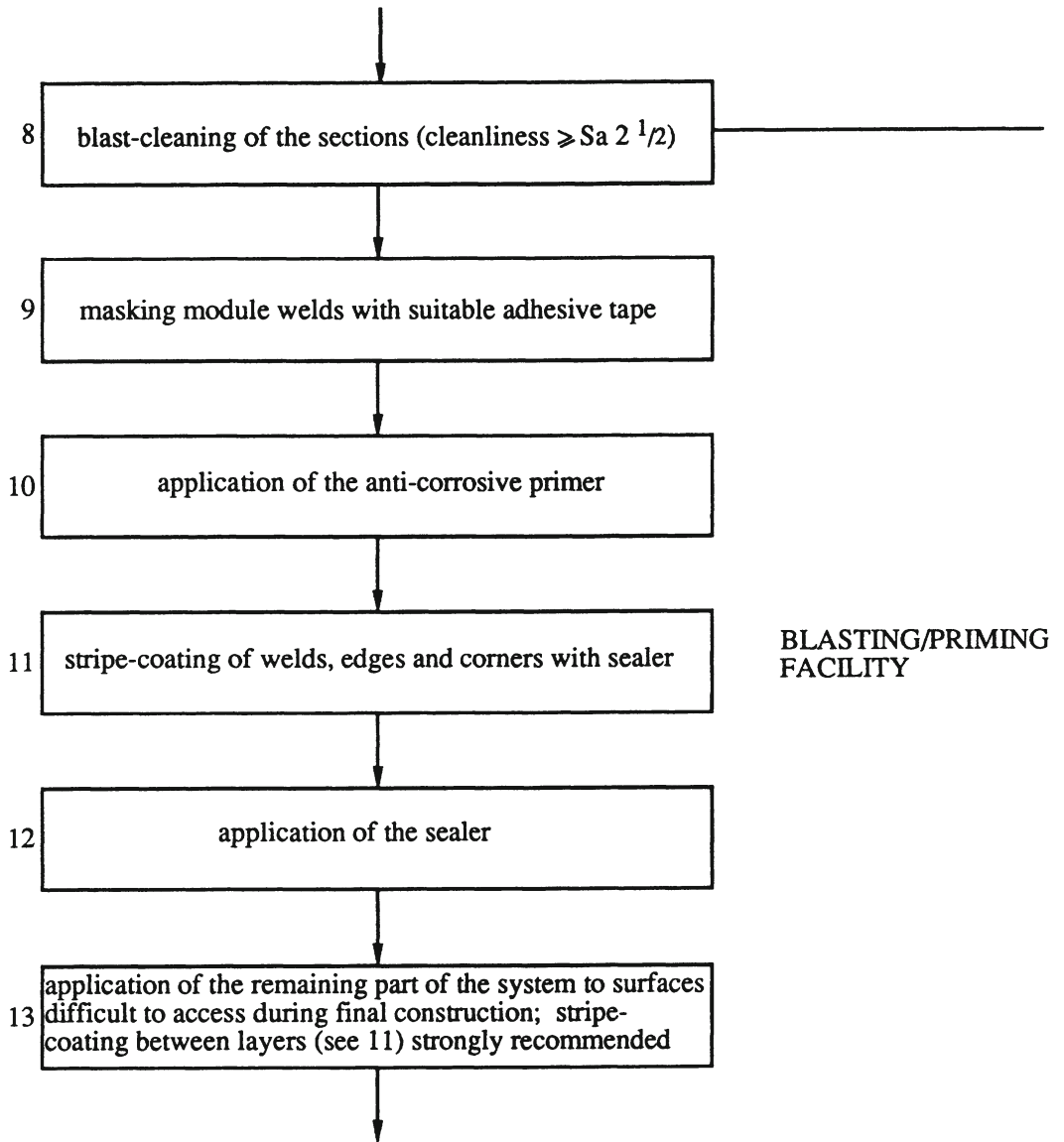
3.5.3. Pipelines are sometimes installed in pull tubes, or 'J' tubes. In order to restrict contact with seawater and atmospheric oxygen, the pull tube annulus should be sealed at the above-water end and a suitable nonwicking packing after the lines have been pulled into position.

3.5.4. In closed, flooded compartments, bacteria may develop that can cause corrosion. Bacteria related corrosion can be controlled by the use of internal cathodic protection, chemicals to raise the pH, and/or bactericides. In thick sections such as those used for pilings, the resultant corrosion may not be significant.

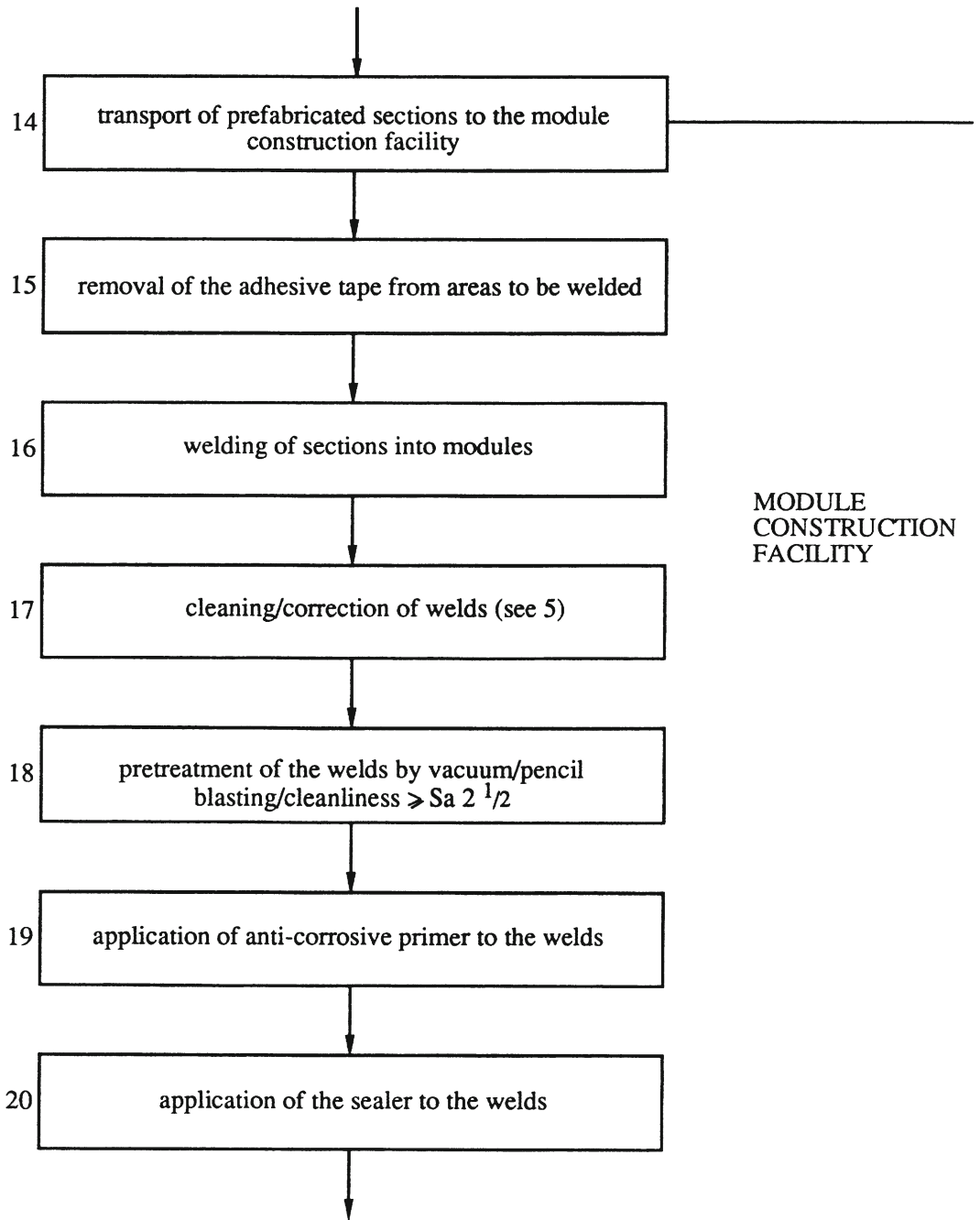
Appendix 2.B - BUILDING/PAINTING OPERATIONS FOR MODULES
(example of current practice)



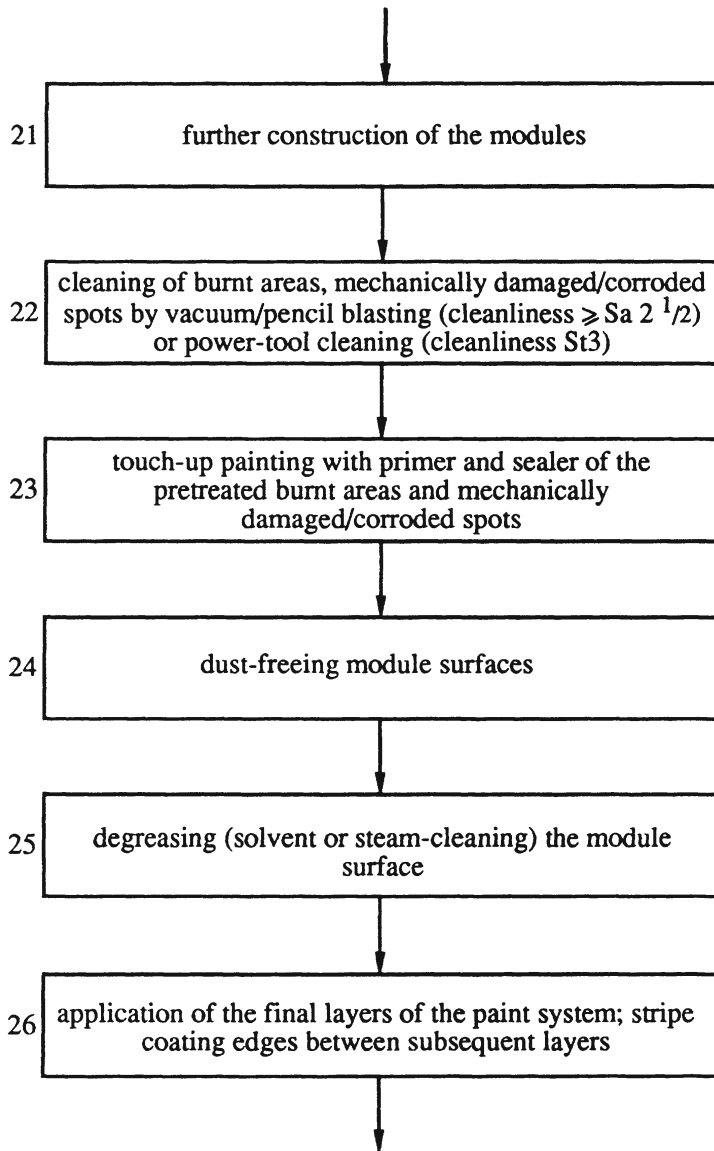
Appendix 2.B - Continuation



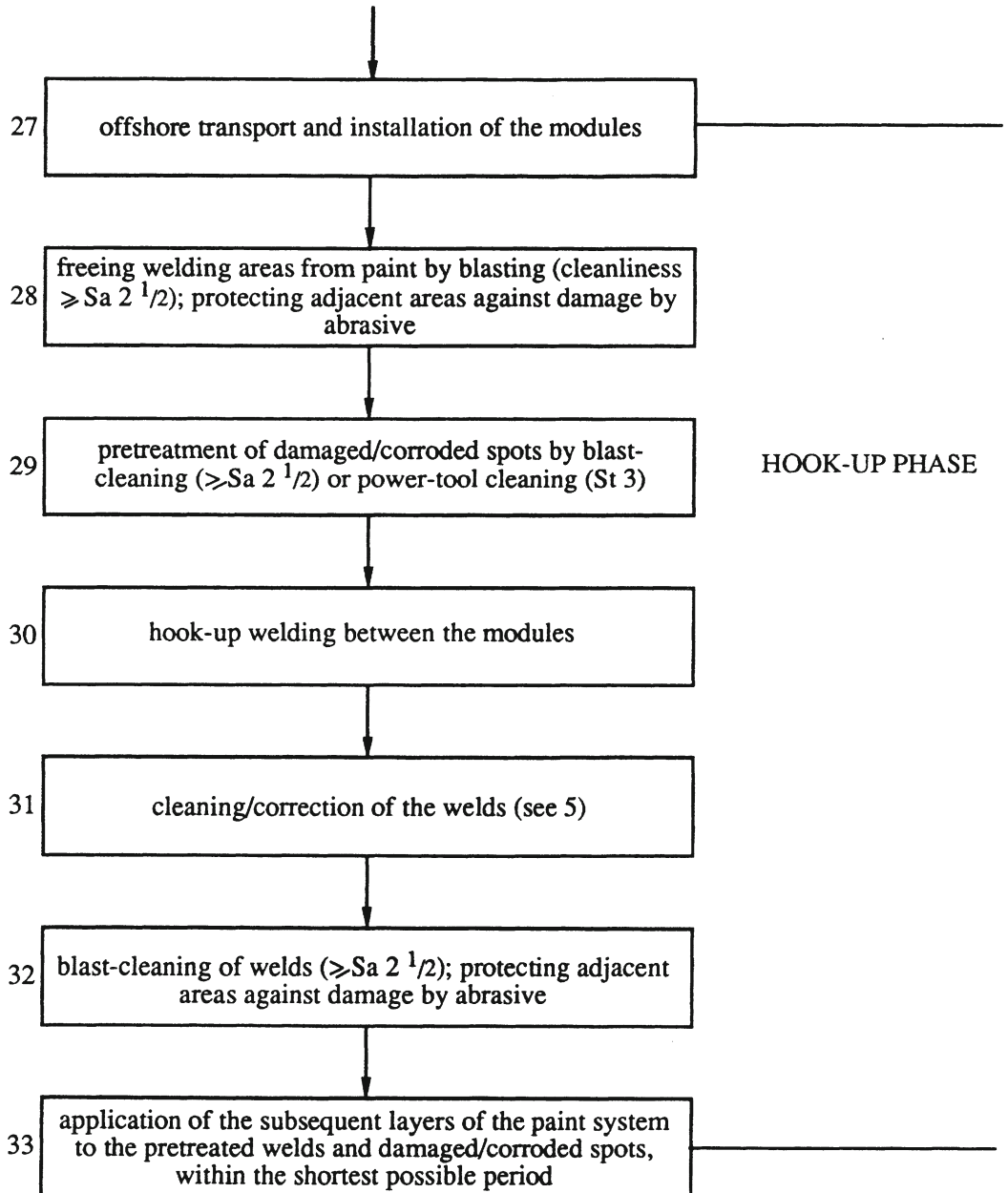
Appendix 2.B - Continuation



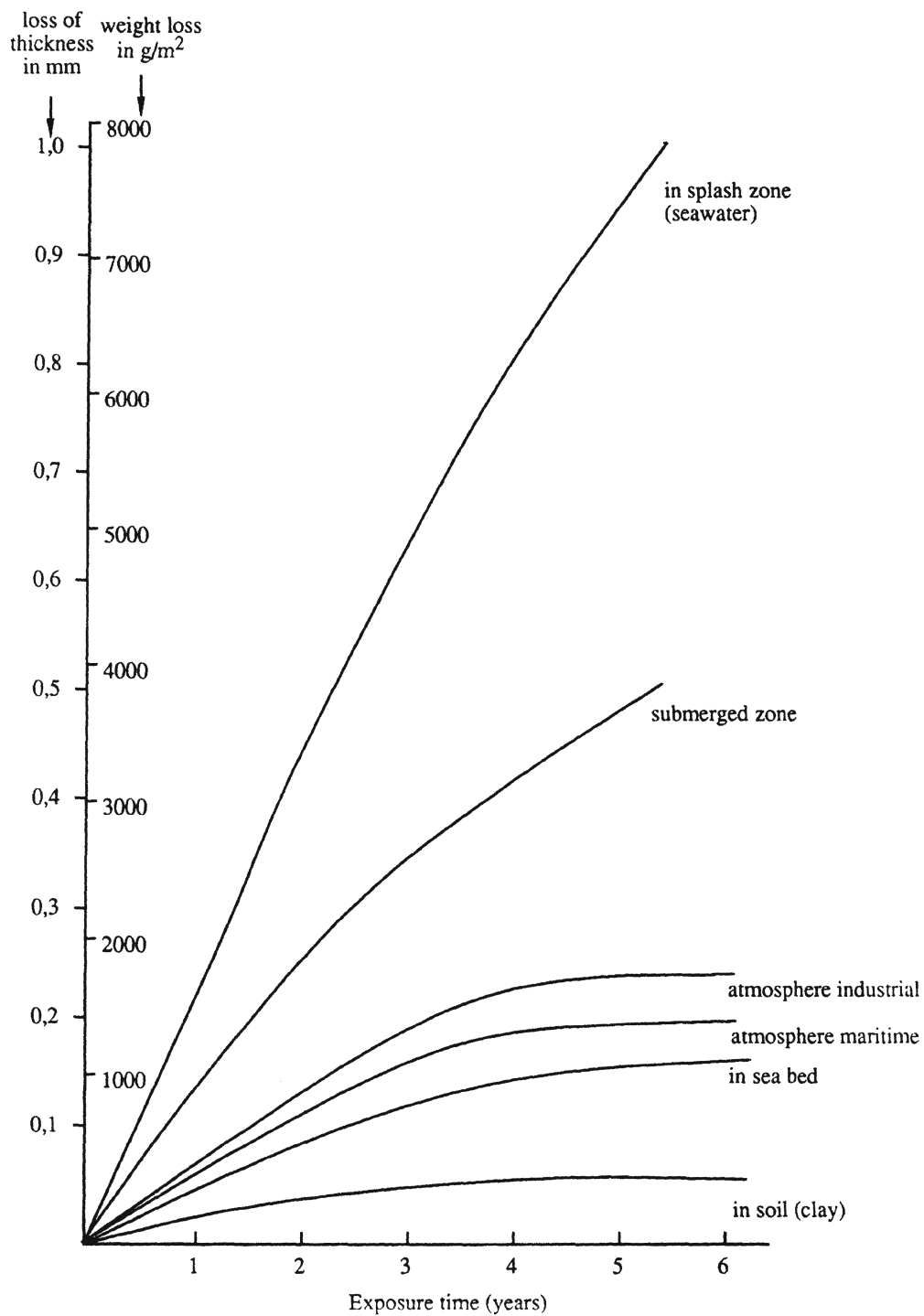
Appendix 2.B - Continuation

MODULE
CONSTRUCTION
FACILITY

Appendix 2.B - Continuation



Appendix 2.C - WEIGHT LOSSES OF STEEL 37 DUE TO CORROSION IN VARIOUS ENVIRONMENTS



APPENDIX 2.D. - EXAMPLES OF CURRENT SYSTEMS FOR THE ATMOSPHERIC ZONE

Epoxy system on zinc silicate primer

• blast-cleaned steel (cleanliness \geq Sa 2 ^{1/2} , profile depth Ry5 50 μ m)		
• inorganic zinc silicate primer	, dry film thickness (dft.)	75 μ m
• micaceous iron oxide (MIO) epoxy sealer	, dry film thickness	50 "
• high-build MIO epoxy coat	, "	100 "
• recoatable high-build epoxy top coat	, "	100 "
	total average dry film thickness	<hr/> 325 μ m

Epoxy system with aesthetic or identification top coat

• blast-cleaned steel (cleanliness \geq Sa 2 ^{1/2} , profile depth Ry5 approximately 50 μ m)		
• zinc-rich epoxy primer	, dry film thickness	25-40 μ m
• high-build MIO epoxy sealer	, "	100 "
• recoatable high-build epoxy coat	, "	100 "
• aesthetic isocyanate (polyurethane) acrylic top coat	, "	50 "
	total average dry film thickness	<hr/> 275 μ m

Chlorinated rubber/vinyl systems on zinc silicate primer

• blast-cleaned steel (cleanliness \geq Sa 2 ^{1/2} , profile depth Ry5 50 μ m)		
• inorganic zinc silicate primer	, dry film thickness	75 μ m
• chlorinated rubber, vinyl or epoxy tie coat	, "	25-50 "
• high-build chlorinated rubber or vinyl intermediate coat	, "	100 "
• chlorinated rubber or vinyl top coat	, "	50 "
	total average dry film thickness	<hr/> 250-275 μ m

CHAPTER III

SURFACE PREPARATION

3.1. General

Adequate surface preparation is of vital importance for the optimum service life of the object to be painted. Surface preparation means thoroughly freeing the surface from all contaminants that might impair the performance of the paint system. The surface should be so treated that it ensures good and permanent adhesion of the paint system. Only in this way can long-term protection be ensured.

For a lasting adhesion, it is necessary to clean the surface thoroughly and, for certain paint systems, to roughen it, e.g. by blast-cleaning.

The importance of adequate preparation cannot be over-emphasized. The paint system and surface preparation should always be related to one another.

3.2. Surface preparation of steel

Surface preparation of steel involves freeing it from mill scale, rust, soluble (iron) salts, grease and any other impurities. In addition, the steel surface should preferably be slightly roughened to ensure good adhesion of the paint system. The methods of surface preparation dealt with in the following sections are: *degreasing, weathering to remove mill scale, mechanical cleaning, blast-cleaning, flame-cleaning and pickling.*

3.2.1. DEGREASING

Large amounts of oil and/or grease should be removed by scraping-off as much as possible. For the removal of the remainder use can be made of *organic solvents*, e.g. recovered paint thinners, or of *detergents* (in aqueous solution, sometimes combined with emulsifying organic solvents).

Solvent degreasing of a surface is usually accomplished by wiping it with rags dipped in a solvent. A common error is to use one and the same rag for cleaning a large surface, and to dip it repeatedly in the same can of solvent. The result is that a thin film of oil or grease is spread-out over the surface. A better practice is to use a can with a spout for the solvent, so that the rag cannot be dipped into it, and to take a new rag at short intervals. When using organic solvents, one has to bear in mind that they may differ considerably in their capacity to dissolve grease. Attention should also be paid to fire (explosion) and health hazards (inhalation, skin contact), especially when solvents are used in confined

spaces. Sensitive individuals may develop dermatitis, as well as other diseases, if exposed to liquid solvents and solvent vapours for prolonged periods (see Chapter XI). *Detergents* are usually applied to the surface by brushing or spraying. When during maintenance a painted surface has to be cleaned, *the paint system should not be affected by the detergent*. After a certain time (specified by the manufacturer) the detergent is removed, together with the emulsified grease and dirt, by brushing with clean fresh water or by (high-pressure) water spraying.

A variation of the above method is *steam cleaning*, in which a jet of steam is used to which a detergent can be added. This is often used during maintenance of offshore structures as is (high-pressure) *hot water cleaning*.

Residues of detergents may have an adverse effect on the adhesion of the paint, and should therefore be removed completely by a thorough fresh water wash.

If the surface is properly degreased, a drop of water will spread-out in a continuous film. If oil or grease is still present, the water contracts to form droplets (water-break test).

3.2.2. REMOVAL OF MILL SCALE BY WEATHERING

The oldest method of removing mill scale from steel plates was to *weather them on the stocks* in the open air. If the plates are weathered during assembly and erection, the process is called '*building in the rust*'.

Removal of mill scale by weathering should always be followed by further treatment to remove the remaining mill scale and rust, e.g. by mechanical or blast-cleaning.

The process of removing mill scale by weathering is erratic and time consuming; in an industrial environment it takes at least six months. It is sometimes accompanied by local *pitting*, even though in other places mill scale still adheres to the steel surface. Steel surfaces will also become contaminated by airborne salt particles originating from sea spray (yards near the coast, offshore structures) or from industrial activities. This results in the formation of hygroscopic (water-absorbing) ferrous salt particles. If the rust layer is not completely removed from the steel surface, such hygroscopic salt residues will remain on the surface, especially in the corrosion pits. Due to osmotic blister formation, followed by flaking and corrosion, their presence is highly detrimental to the durability of the paint system. Salt residues can never be removed completely from rusted steel by hand cleaning alone and even (dry) blast-cleaning does not always remove them to a sufficient extent.

3.2.3. MECHANICAL SURFACE PREPARATION*

3.2.3.1 *Hand-cleaning*

Hand-tool cleaning should always be preceded by degreasing the surfaces where necessary.

Common hand-cleaning tools are *chipping hammers, scrapers, chisels*, etc. When the surface has been freed from loosely adhering rust, loose paint and impurities, it is brushed with *wire brushes* or sanded with *non-woven abrasive pads* or *sand paper*.

The dust is then removed by suction, compressed clean air, or by brushing with a soft brush.

The first coat of paint should be applied as soon as possible after cleaning. Hand-cleaning is only suitable for the removal of loose rust, loose mill scale, paint flakes and other superficial contaminants. Because hand-cleaning is very labour-intensive and qualitatively inferior, it is used only for local repairs, or in places inaccessible to mechanical or blast-cleaning.

3.2.3.2 *Mechanical-cleaning (power-tool cleaning)*

Mechanical-cleaning should, as with hand cleaning, always be preceded by degreasing. Mechanical-cleaning is executed by means of pneumatic or electric-driven portable tools. The cleaning action is based on *impact, rotation* (abrasion) or *combined impact and rotation*.

The most common *impact-cleaning tools* are *chipping/scaling-* and *needle hammers*. When using impact-cleaning tools excessive, cutting into the steel surface should be avoided because it leaves sharp burrs where paint failure may be expected.

Impact-cleaning is a slow method which, unless very carefully carried out, leaves an unsatisfactory surface. The method is useful in removing rust, weld flux, slag and old paint, particularly in areas difficult of access.

Rotary-cleaning tools are straight (in line)- or vertical (right angle) machines.

The straight machines are used with radial wire brushes, coated abrasive flap wheels and non-woven abrasive wheels. By taking abrasive materials of different coarseness it is possible to remove rust and then to give the surface a certain roughness.

V-stones are used to remove corrosion from pits etc.

* For descriptions of surface preparation methods by hand and power-tool cleaning, see also ISO standard 8504-3, which still was under development at the time of completion of the Marine Painting Manual.

The vertical machines are commonly equipped with cup wire brushes or coated abrasive discs. Wire brushes should be made of steel because non-ferrous materials can produce deposits which promote galvanic corrosion.

Prolonged burnishing of the steel surface with rotary brushes should be avoided because this produces a very smooth surface to which paint will not adhere satisfactorily.

Prolonged burnishing also tends to force rust particles into surface pores.

Rotary cleaning can be done with a higher productivity than impact cleaning but it does not remove intact mill scale satisfactorily.

Rotary impact (chipping) tools operate by centrifugal force where hammers or cutters are rotated at a high speed and thrown against the steel surface. Rotary impact tools use hardened steel cutter bundles of stars, swinging hammers or flexible flaps with tungsten carbide tips. With the latter it is possible to remove intact mill scale.

After mechanical-cleaning the surface should be rendered dust-free and the first coat of paint applied as soon as possible.

Mechanical-cleaning is much less time-consuming than hand-cleaning and gives a better result. Apart from certain types of rotary impact tools, tightly adhering mill scale, at best, can only partially be removed.

For large surfaces, mechanical-cleaning is more expensive than blast-cleaning. It is therefore used mainly for local repairs, removal of rust spots and treatment of damaged or burnt areas and welding seams.

3.2.3.3 Preparation grade

After mechanical surface preparation (hand- or power tool cleaning), the degree of preparation (surface finish, cleanliness) is very dependent on the original condition of the surface, the type and condition of the tool used and the duration of the cleaning operation.

The condition of the surface, before and after pretreatment, can be specified according to the *International Standards ISO 8501, 'Preparation of steel substrates before application of paints and related products - Visual assessment of surface cleanliness'*.

Part 1 of this standard, '*Rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings*', was issued on December 1988. Part 2 of the standard, dealing with the preparation grades of previously coated steel substrates after localized removal of previous coatings, had not yet been published at the time of completion of the Marine Painting Manual.

Part 1 of ISO 8501 is identical to the *Swedish Standard SS 05 59 00, 3rd edition (1988)* which supersedes the well-known SIS 05 59 00, 2nd edition 1967, which also has been issued by the American Society for Testing Materials as ASTM D2200-67 (1980) and by the Steel Structures Painting Council as SSPC-Vis 1-82T. British Standard BS 4232-

Four *rust grades* are specified, which correspond to four grades of the initial condition of hot-rolled steel. These rust grades are described, as well as illustrated by representative photographic examples. The descriptions of the four rust grades (original conditions) are as follows:

- A : Steel surface largely covered with adhering mill scale but little, if any, rust.
- B : Steel surface which has begun to rust and from which the mill scale has begun to flake.
- C : Steel surface on which the mill scale has rusted away or from which it can be scraped, but with slight pitting visible under normal vision.
- D : Steel surface on which the mill scale has rusted away and on which general pitting is visible under normal vision.

Apart from the description and photographic examples of the rust grades, the standard specifies a number of *preparation grades*, indicating the method of surface preparation and the degree of cleaning.

The preparation grades are defined by descriptions of the surface appearance after the cleaning operation, together with representative photographic examples.

Surface preparation by *hand or power tool cleaning*, such as scraping, wire-brushing, machine-brushing and grinding, is designated by the letters *St*.

Blast-cleaning and *flame-cleaning* is designated by the letters *Sa* and *F1* respectively (see parts 3.2.4.4 and 3.2.5).

Prior to hand and power-tool cleaning, any heavy layers of rust shall be removed by chipping. Visible oil, grease and dirt shall also be removed.

After hand and power tool cleaning, any loose rust and debris must be removed.

The following preparation grades are distinguished:

St 2* Thorough hand and power tool cleaning

When viewed without magnification, the surface shall be free from visible oil, grease and dirt, and from poorly adhering mill scale, rust, paint coatings and foreign matter.

St 3 Very thorough hand and power tool cleaning

As for St 2, but the surface shall be treated much more thoroughly to give a metallic sheen arising from the metallic surface.

For the description of surface preparation methods by hand and power tool cleaning, see also ISO standard 8504-3, which still had not been published at the time of completion of the Marine Painting Manual.

The condition of a steel surface after pretreatment is thus designated by a combination of letters and numbers. The designation B St 3 for instance means that the initial rust grade of the steel surface was B and that this surface was mechanically cleaned to the preparation grade St 3.

If not otherwise specified, mechanical cleaning must be pursued to a preparation grade equal to *St 3* (*not to be confused with Sa 3, which is a measure of blast-cleanliness*; see Part 3.2.4.4).

After mechanical surface preparation the steel surface often still shows residues of mill scale, rust, soluble salts etc., which are detrimental to the durability of the coating system.

Consequently, mechanical surface preparation is, apart from cases of minor repair, not acceptable for the underwater hull and boottop of ships, for submerged parts and tidal splash zones of offshore structures and for the insides of tanks.

3.2.4. BLAST-CLEANING**

Before any blasting operation, if necessary, the surface should be degreased. If much loose rust is present, this is often removed first by mechanical cleaning, especially if the abrasive is recoverable.

* Preparation grade St 1 is not included as it corresponds to a surface unsuitable for painting.

** For descriptions of surface preparation methods by blast-cleaning see also ISO standard 8504-2, which had not yet been published at the time of completion of the Marine Painting Manual.

For good quality work, welding spatters and deposits should be removed by grinding before blast-cleaning. Rough parts of welds should also be smoothed by grinding and porous parts of welds cut-out and rewelded.

Any faults should be ground until a smooth surface is obtained. As some of them only become visible after blast-cleaning, it may be necessary to carry out grinding operations afterwards.

Preferably, especially in tanks, sharp edges should be rounded to a radius of about 2 mm by means of mechanical grinding.

After blast-cleaning, the surface should be rendered dust-free (or allowed to dry completely in the case of water blast-cleaning)* and the first paint coat applied as soon as possible.

3.2.4.1 *Methods*

With blast-cleaning, use is made of the eroding action of a jet of particles (the abrasive) on the (steel) surface to be cleaned. The proper blasting method will remove all kinds of impurities, mill scale, rust and old paint coats and will roughen the surface to a specified standard.

Some factors, important for an adequate blasting job are:

- proper choice of abrasive (material, particle size, possible contamination);
- proper removal of dust and contaminants;
- proper blasting pressure;
- unabraded blasting nozzles;
- dry air (when air is used);
- proper oil/water separators (when air is used);
- proper ratio of abrasive/transport medium (air or water).

The most important blast-cleaning methods are *nozzle-blasting*, *impeller-blasting*, *vacuum-blasting* and *water blast-cleaning*.

Nozzle-blasting

In *nozzle-blasting* (abrasive air blast-cleaning) the abrasive is propelled by means of compressed air. When this type of blast-cleaning is done in the open air, cheap abrasives can be used which need not be recovered. Use of a cabinet, however, allows recycling of the abrasive.

On ships and offshore structures, nozzle-blasting is mainly used in the open air and in tanks, without recycling.

* A perfectly dry surface is no longer necessary for damp-tolerant (wet steel) primers (see Part 4.5.2.6)

Large scale blasting in the open air should, however, be avoided as much as possible because of the problems of the environmental pollution (dust) and noise it causes and because of the problems involved with the disposal of polluted abrasive.

Moreover, the large amounts of dust produced can be very disturbing to work which is carried out in the vicinity. Sometimes temporary shields (tarpaulins) are used to protect the environment against damage and pollution. Nearby vulnerable equipment should be adequately protected and care taken to ensure that blasting dust will not pollute freshly painted surfaces.

Recently developed nozzle-blasting methods are mainly based on systems which reduce the amount of dust, for example by adding water or steam in the air/abrasive stream or by shrouding the blasting nozzle with a water curtain.

A very light nozzle-blasting is called *sweep-blasting* (sweeping) or *brush-off blasting* and is used for superficial cleaning and roughening of, e.g. weathered (old) paint coats before recoating.

Small-scale nozzle-blasting with small equipment, for instance when carrying out spot repairs, is called *mini-blasting* or *pencil-blasting*.

A recently developed method is the *blast-cleaning/priming system*.

By this method, steel surfaces are blast-cleaned with an inert mineral abrasive and simultaneously coated with a very fast surface drying, zinc epoxy- or zinc silicate primer.

The advantage of the system is that it is suitable for blasting and priming damp/wet corroded steel surfaces under adverse weather conditions. Furthermore, corrosion of freshly blasted steel surfaces is avoided and on days with bad weather, more working hours are possible than with normal abrasive air blasting.

A disadvantage of this system is that the degree of surface-cleanliness cannot be checked. Moreover, the priming coat contains (inert) abrasive particles.

The blast-cleaning/priming system is especially suitable for flat surfaces. When priming sharp edges, profile edges etc., the paint supply is first switched-off which means that these parts are pre-blasted and then coated.

Impeller-blasting

In *impeller-blasting* (centrifugal blast-cleaning) the abrasive (mainly shot) is projected against the surface by means of centrifugal machines provided with impeller wheels. The steel is blast-cleaned while passing the machine.

Often the steel is preheated to a temperature of 35-40°C, and, immediately after leaving the machine, it is coated with a prefabrication (shop)-primer (see Part 5.1).

Spent abrasive is separated from contaminants in an air-wash separator and re-used, avoiding pollution of the environment.

The recirculated abrasive should be checked for specification regularly (size distribution, salt content, content of organic matter).

Dust is separated from the abrasive in a dust-collector, keeping adjacent areas clean and dust-free. Openings provided from transporting the steel to be cleaned through the impeller machine are equipped with seals to prevent flying abrasive and dust from escaping.

The degree of roughness (3.2.4.3) and finish (3..2.4.4) of the steel surface are, of course, determined by the speed at which the steel is passed through the machine and the nature and refreshment cycle of the abrasive.

Due to the nature of the abrasive (shot) impeller-blasting generally produces a much smoother (round) steel surface profile, compared to nozzle-blasting. The practice of adding grit to the abrasive, in order to obtain a sharper (anchor) profile, results in undesirable wear of the impeller wheels.

Special types of *portable centrifugal blast-cleaning machines* include, amongst others, units for ship sides and decks. The hull side types can be mounted on a mobile extensible crane system and reach the whole side of the largest ships. The advantages of the portable machines include pollution and dust-free operation, re-use of abrasive and no disturbance of other operations. The restrictions are their limited use where obstructions, corners or fillets are encountered, frequent maintenance and clumping of abrasives in wet conditions.

Vacuum-blasting

In *vacuum-blasting*, the air and abrasive are propelled in a rubber-hooded enclosure.

The abrasive and all the dust are drawn back into the blast unit where re-usable abrasive is separated and recycled.

The dust- and pollution-free process is limited to the use of re-usable abrasives. As with impeller-blasting, the recirculated abrasive should be regularly checked for specification. Vacuum-blasting is more time-consuming than other blasting methods but the degree of cleaning achieved is satisfactory. It is, however, a slow method and working with portable equipment is very fatiguing. Another disadvantage is that corners present considerable difficulties. For these reasons vacuum-blasting is used mainly for minor repairs and the cleaning of welding seams.

Special types of large portable equipment for horizontal surfaces, can be used for the blast-cleaning of decks. By these machines, which can be driven slowly over the deck, the surface is blast-cleaned while dust and contaminants are collected.

Water blast-cleaning

Hydro-blasting, which means *high-pressure water-washing*, is mainly used in maintenance work on ships' hulls. A high-pressure water jet (pressure about 150-300 bar) is used. Fouling (except 'hard fouling'), poorly adhering paint, loose rust and water-

soluble salts are removed from the surface. Hydro-blasting cannot replace blast-cleaning as it does not 'etch' the steel surface.

When hydro-blasting is carried out by the use of special equipment at very high pressures, for instance up to 3000 bar, the process is called *hydro-jetting*. With this process, beside poorly adhering paint and loose rust, even tightly adhering rust and intact coating systems can be removed from the substrate.

A considerable advantage of this process, however, is that, if desired, only a part of the coating system can be removed, for instance a defective topcoat, without causing serious damage to underlying layers. Especially thermoplastic materials, which are difficult to remove by ordinary blast-cleaning, can adequately be removed by hydro-jetting.

Hydro-jetting can also be carried out with the addition of abrasive in the water stream which means that tightly adhering mill scale can also be removed and the surface roughened. The hydro-jetting system incorporates a mechanical metering device, controlled by the operator at the nozzle, which enables him to regulate the quantity of abrasive in the water.

In *wet-abrasive blast-cleaning*, ('*wet-blasting*') compressed air, water and abrasive can be combined. The transport medium is the air.

The air/water pressure at the nozzle is about 7 bar. Newer systems involve pressures up to 20 bar, and are fully adjustable up to this pressure-level. The system incorporates a mechanical metering device, remotely-controlled by the operator, to enable him to regulate the quantity of abrasive fed into the air/water mixture. During operation, the air/water/abrasive is thoroughly mixed and projected onto the surface.

By wet-abrasive blast-cleaning, a cleaning-degree to white metal is achievable.

In order to prevent steel from flash-rusting, inhibitors are sometimes included in the water when executing wet-abrasive blast-cleaning or hydro-jetting with abrasive. These inhibitors must be compatible with the paint system to be applied, otherwise failure by blistering may occur, especially on the immersed parts of ships and offshore structures.

Water blast-cleaning is by far the best method for removal of salts from contaminated surfaces. The flash-rust which is the consequence of not including an inhibitor can be removed by brush-off blasting afterwards.

The *advantages* of wet abrasive-blasting (wet-blasting) and hydro-jetting, with or without abrasive, can be summarized as follows:

- cleaning can be carried out under humid conditions;
- large quantities of abrasive dust and hazard by flying abrasive are avoided;
- removal of salt contaminants from corrosion pits, especially when the blasting process is followed by a fresh water wash;
- greatly reduced sparking hazard;
- possibility of selective removal of single paint layers and feathering of edges when spot repairs are carried out, especially with the hydro-jetting process.

Some *disadvantages* of the above mentioned processes are:

- after cleaning, the surface is wet or damp which is not ideal for paint application; for damp surfaces however, special moisture-tolerant primers are available;
- the working rate is somewhat slower than for dry blast-cleaning; this refers especially to the hydro-jetting process;
- the wet abrasive sludge collecting below surfaces being cleaned can cause a disposal problem. This problem is greater for wet-blasting than for hydro-jetting;
- especially when using a small amount of water, fine abrasives may remain stuck to the substrate;
- residuals of corrosion inhibitors, used to avoid flash-rusting of the steel, may have detrimental effect on the behaviour of the coating system;
- when no inhibitors are used, flash-rusting may be removed by brush-off blasting afterwards, but this involves an extra operation.

3.2.4.2 *Abrasives*

Currently used abrasives can be divided into two groups, e.g. *metallic* and *mineral abrasives*.

Metallic abrasives have a long service-life because their particles can resist many hundreds of impacts before their size is so reduced that the abrasive must be discarded.

Cast-iron abrasives, however, are relatively short-lived, because they degrade more rapidly. Since metallic abrasives are expensive, they are used exclusively in installations from which they can be recovered and re-used, such as impeller installations and blasting booths.

According to particle shape, metallic abrasives can be subdivided into *shot* (spherical particles), *grit* (angular particles) and *cut steel wire* (cylindrical particles of nearly equal diameter and length). Cut steel wire, however, is not very widely used.

Shot abrasives are mainly used for cleaning new hot-rolled steel in impeller blasting machines.

The choice of abrasive is a matter of matching size, shape and hardness in relation to the surface finish and roughness required. The price and recycling possibilities are also determining factors.

The most widely used *metallic abrasives* are:

- steel shot : spherical particles of hardened steel
- steel grit : angular particles of hardened steel
- cast-iron shot : spherical particles of cast iron
- cast-iron grit : angular particles of cast iron.

Mineral abrasives are cheaper than metallic ones. Their shape is usually irregular and angular.

Mineral abrasives have a short life, being pulverized after only a few operations. They are not worth recovering and are generally used in nozzle-blasting operations.

In view of the risk of silicosis, the use of silica containing abrasives (sand) is forbidden by law in many countries.

Mineral abrasives must be inert; otherwise they can act as sources of corrosion.

They should not introduce a spark hazard during use.

Currently used mineral abrasives are:

- corundum* : angular particles of aluminium oxide
- silicon carbide : angular particles of silicon carbide
- industrial by-products** : angular particles of e.g. copper slag, blast-furnace slag, mineral slag etc.; these abrasives should not contain heavy metals.

Sometimes, *zinc-coated mineral abrasives* are used. When blasting with these materials, the steel surface is covered with a very thin layer of zinc which prevents rusting of the steel after blasting for a certain time, depending on the environment (about 4 hours in the North Sea splash zone).

Most abrasives can be supplied in a range of particle sizes. Cut steel wire is very uniform in dimension, steel and cast iron slightly less so. The size distribution of grit and mineral abrasives is still less regular and depends on the care taken in manufacture and sieving.

According to *specification J 444a of the Society of Automotive Engineers (SAE)*, the type and size of metallic abrasives is classified by a notation consisting of the letters *S (shot)* or *G (grit)* and a number for the particle size. For the blasting of structural steel the shot quantities S70, 110, 170, 230, 280, 330 and 390 are commonly used, corresponding with particle sizes (diameter) ranging from about 0.2 to 1.2 mm.

For the same purpose, the grit abrasives G 325, 200, 120, 80, 50, 40, 25 and 18 are used, with particle sizes roughly corresponding to about 0.1 to 1.2 mm.

According to *German Standard DIN 8201*, all abrasives are classified by:

- their standard name;
- a letter combination for the type of abrasive;
- a letter for the particle shape;
- two figures, representing the minimum and maximum particle size (one figure in case of cut steel wire);
- if desired, a letter/number combination for the hardness.

An example of such a classification is:

Blastman GS - K - 0.9 - HV 650 - DIN 8201, where:

Blastman = trade name of the abrasive

* corundum is sometimes recycled.

** or materials based on industrial by-products

GS	= Stahlguss (cast steel, hardened)
K	= kantig (angular)
HV650	= Härtebereich (average hardness according to DIN 50311)
DIN 8201	= according to DIN 8201

In order to minimize wear of the blade wheels in impeller-blasting machines, shot is mainly used as an abrasive. The resulting steel roughness profile is round-shaped and does not show the sharp-edged 'anchor-pattern', which is required for optimal mechanical bonding between coating and steel substrate.

During use the shot becomes more or less angular but not really sharp. An improvement of the roughness profile can be obtained by adding a small amount of steel grit to the shot abrasive. This, however, may result in undesirable wear of the impeller wheels.

As mineral (slag) abrasives can be derived from a great variety of sources, it is of utmost importance to test them for the presence of (water soluble) contaminants that might adversely affect paint adhesion, particularly in underwater areas and tank interiors.

By testing a pure water slurry of mineral abrasives for instance on acid value (pH), chloride content and electrical conductivity an assessment can be made of the extent to which the abrasives are contaminated with soluble salts that might adversely affect a freshly blasted steel surface.

A low pH, the presence of chlorides and a high electrical conductivity as well, might tend to initiate premature surface corrosion or cause subsequent blistering of the coating system.

Besides checking on the above mentioned properties, abrasives should be regularly checked for the presence of oil or grease, particle size, dust content (reduction of health hazard) and residual contaminations like heavy metals. For more details concerning the testing of abrasives, the reader is referred to Part 9.4.5.

The behaviour of an abrasive during use is largely determined by its nature. Since steel is tough, steel particles do not easily break up, being merely deformed and slowly worn down. Sharp-edged particles of steel wire and steel grit become rounded off. Cast-iron abrasives, however, are brittle and break easily, though the particles remain sharp.

Special heat-treated cast iron abrasives are less brittle, but their service life is much shorter than that of steel abrasives. Mineral abrasives also break down rapidly while remaining sharp.

Angular abrasive particles are more likely to be trapped by the metal surface than spherical particles. Although there is no proof that embedded abrasive particles act as centres of corrosion, paint manufacturers sometimes prescribe the use of specific abrasives for special cases.

3.2.4.3 *Surface roughness*

Blast-cleaning imparts a certain roughness to the steel surface which, in perpendicular sections, is seen as a succession of peaks and valleys, the so-called *roughness profile*. The difference in height between the two and the shape of the profile depends on the kind of abrasive used, the duration of the blasting and the working conditions.

Shot abrasives produce a more or less rounded-off regular surface profile. Coarse abrasives produce a high roughness. An example of the roughness which may be expected when using some types of abrasive is given in Appendix 3.A of this chapter.

Adequate protection against corrosion can only be provided by a paint system that covers the highest peaks of the roughness profile sufficiently. The rougher the surface, the more paint is needed.

A particularly important factor is the maximum distance (amplitude) between peaks and valleys. This amplitude is more precisely defined as the maximum distance, perpendicular to the surface, between a peak and an adjacent valley; it is also called the *maximum roughness*.

Exact determination of the surface profile is time-consuming and requires skilled personnel and expensive equipment such as the Talysurf or Perth-0-meter. With these laboratory instruments it is usual to measure the blasted surface in some arbitrarily chosen spots along a certain distance. Sometimes replicas of the blasted surface are made, which are subsequently measured in the laboratory.

Nowadays some types of smaller (piezo electric) roughness gauges are available, which can be used in practice (see also Part 9.4.6.2). The stylus of such an instrument traverses the blasted surface and its vertical displacement measures the peaks and valleys in the direction of travel over a stipulated length. Thus, the maximum and average peak-to-valley height is determined and recorded.

For the correct understanding of roughness definitions and parameters the reader is referred to Appendix 3.B.

An impression of the surface roughness and the shape (sharpness) of the roughness profile can be obtained by the so-called *comparator procedure* (see also Part 9.4.6.2).

A comparator consists of a number of test plates of differing surface roughness. Well-known ones are the so-called 'Rugotest' and 'Keane-Tator'. In 1988, a comparator has been issued by the ISO.

As already mentioned, a rough surface requires more paint for a certain degree of protection than a surface that is less rough. Blasting should therefore not be pursued too far. The average roughness should be in the range of 50-75 micrometers. Rogue peaks are acceptable up to a maximum of 100 micrometers.

Old steel, roughened by corrosion, inevitably shows a coarser profile. Allowance should be made for local upward deviations from this value caused by trapped particles of abrasive. For some types of paint, e.g. zinc silicates, manufacturers sometimes prescribe a minimum roughness for maximum adhesion.

3.2.4.4 Preparation grade

Like surface roughness, the degree of preparation (surface finish, cleanliness) depends on the original surface condition, the kind of abrasive used, the duration of the blasting and on other working conditions.

As already mentioned under Part 3.2.3.3, according to the ISO Standard 8501-1 (Swedish Standard SS 05 59 00-1988), the initial condition of the steel (rust grades) is indicated by the characters A, B, C or D, illustrated by colour prints.

Apart from these pictures, the ISO Standard provides photographs of the different grades of preparation as achieved by blast-cleaning.

It is assumed that prior to treatment the steel surface has been cleaned of dirt and grease and that the heavier layers of rust have been removed by chipping. After blast-cleaning, the surface shall be cleaned from loose dust and debris.

The preparation grades are designated by *Sa 1 (light blast-cleaning) to Sa 3 (blast-cleaning to visually clean steel)*.

The exact descriptions are as follows:

Sa 1 Light blast-cleaning

When viewed without magnification, the surface shall be free from visible oil, grease and dirt and from poorly adhering mill scale, rust, paint coatings and foreign matter* . See photographs B Sa 1, C Sa 1 and D Sa 1.

Sa 2 Thorough blast-cleaning

When viewed without magnification, the surface shall be free from visible oil, grease and dirt, and from most of the mill scale, rust, paint coatings and foreign matter. Any residual contamination shall be firmly adhering**. See photographs B Sa 2, C Sa 2 and D Sa 2.

Sa 2^{1/2} Very thorough blast-cleaning

When viewed without magnification, the surface shall be free from visible oil, grease and dirt, and from mill scale, rust, paint coatings and foreign matter. Any remaining

* Foreign matter may include water-soluble salts and welding residues. These contaminants cannot be completely removed from the surface by dry-blasting, hand and power tool cleaning or flame-cleaning; wet blast-cleaning should be used.

** Mill scale, rust or paint (coating) is considered to be poorly adhering if it can be removed by lifting with a blunt putty knife.

traces of contamination shall show only as slight stains in the form of spots or stripes. See photographs A Sa 2^{1/2}, B Sa 2^{1/2} and D Sa 2^{1/2}.

Sa 3 Blast-cleaning to visually clean steel

When viewed without magnification, the surface shall be free from visible oil, grease and dirt, and shall be free from mill scale, rust, paint coatings and foreign matter. It shall have a uniform metallic colour. See photographs A Sa 3, B Sa 3, C Sa 3 and D Sa 3.

The condition of a steel surface is thus designated by a contamination of characters and numbers. *The characters A-D refer to the original condition of the surface (rust grade) and the numbers (Sa) 1, 2, 2^{1/2} or 3 to the grade of preparation.* For instance the designation B Sa 2^{1/2} means that the initial rust grade of the surface was B and that it has been blast-cleaned to the preparation grade Sa 2^{1/2}.

During building of ships and offshore structures one has mainly to deal with initial rust grades A and B, and the preparation grades Sa 2, 2^{1/2} and 3. For superstructures a minimum preparation grade Sa 2 is sometimes sufficient, but for submerged parts and tank interiors a minimum of Sa 2^{1/2} is generally required. Theoretically Sa 3 would be preferable, but in practice this requires costly cleaning operations and produces an increase of surface roughness.

Preparation grades specified by paint manufacturers for special applications should always be followed carefully.

The table in Appendix 3.C gives the correspondence between designations in the ISO standard of surface preparation and some other important standards.

With reference to the preparation grade, special attention needs to be paid to the pictorial standard issued in 1975 by the Shipbuilding Research Association of Japan (JSRA).

According to this '*Standard for the Preparation of Steel Surface prior to Painting*' (SSPS), surface preparation consist of the following two steps:

- *Primary surface preparation* which aims to remove mill scale, rust and foreign matter from steel surfaces prior to the application of a prefabrication (shop) primer.
- *Secondary surface preparation* which aims to remove rust and foreign matter, if any, from steel surfaces coated with a shop-primer to the application of an anti-corrosive paint.

In *primary surface preparation* the Japanese Standard refers to:

- surfaces of hot-rolled steel in *two different rust grades* (JA, JB).
- the same surfaces prepared by *shot-blasting to three grades of surface quality* (Sh1, Sh2, Sh3)*.

* the Sh and Sd-grades are not exactly similar to the Swedish Sa-grades.

- the same surfaces prepared by *sand-blasting*** to three grades of surface quality (Sd1, Sd2, Sd3)*.
- the same surfaces in two different rust grades (Sh0, Sd0)***.

In *secondary surface preparation* the standard refers to:

- surfaces *coated with the following shop-primers* (wash primer W, zinc primer Z, inorganic primer I), *classified into five types of breakdown or damage* (HO, AO, FO, DO, RO), due to welding, burning, weathering, etc.
- the same surfaces prepared by sand-blasting to three grades of surface quality (Ss, Sd2, Sd3).
- the same surfaces prepared by power-tool cleaning to three grades of surface quality (Pt1, Pt2, Pt3).

As treatment for the secondary surface preparation the standard refers to:

- *sand blast-cleaning* for preparation grades Sd2 and Sd3;
- *sweep sand blast-cleaning* for preparation grade Ss;
- *disc-sanding* for preparation grades FPt1, FPt2, FPt3 and DPt3, where F represents shop-primed steel exposed to gas-burning and D represents shop-primed steel showing white zinc salts;
- *wire-brushing/disc sanding* for preparation grades HPt2, HPt3 and APt3, where H represents hand-welded and A automatic-welded shop-primed steel;
- *wire-brushing* for other preparation grades obtained by power-tool cleaning.

The Japanese Standard, like the ISO and Swedish, represents rust and preparation grades by colour prints.

3.2.4.5 Surface contamination by water soluble salts

Water soluble salts are formed during the corrosion of steel in an industrial and/or marine environment, for instance during exposure of the steel, used for ships and offshore structures, in open stock yards and during the service life of ships and offshore structures.

* the Sh and Sd-grades are not exactly similar to the Swedish Sa-grades.

** Probably this should be 'abrasive' blast-cleaning, as the use of sand is forbidden in Japan because of the risk of silicosis.

*** JA Sh0 is similar to JA
 JB Sh0 " " " JB
 JA Sd0 " " " JA
 JB Sd0 " " " JB

The soluble salts are mainly *chlorides*, e.g. sea salt and *sulphates*, originating from sulphur dioxide discharged from industrial sources.

These chlorides and sulphates particularly initiate and accelerate the corrosion of steel and become deeply embedded within the iron corrosion products. The corrosion of aluminium is also strongly promoted by damp salt residues, especially chlorides.

Remnants from water soluble salts on the substrate under a paint system or in between subsequent paint layers may lead to (osmotic) blister formation and subsequent flaking of the paint system, leading to premature corrosion.

This process occurs especially on the immersed parts of ships and offshore structures.

It is clear that soluble salts deposited on metal surfaces can increase both the corrosion rate and coating breakdown.

As the presence of these hygroscopic (water attracting) salts, which are mainly present in the bottom of rust pits, cannot be traced easily by visual means, they form a real danger to the durability of the paint system.

A *quantitative* indication of the presence of water soluble salts may be obtained by washing test areas on the steel surface with distilled water and collecting the washings. The salts can be determined in the washings by chemical analysis or by conductivity measurements.

The presence of water soluble salts can also be detected by the potassium ferricyanide test, which is very sensitive but provides only *qualitative* results; it indicates the presence of soluble ferrous salts by varying degrees of intensity of the blue colouration of test papers. For the qualitative and quantitative determination of the presence of water soluble salts on the steel surface, the reader is referred to Part 9.4.6.3.

Like other surface contaminants (mill scale, rust etc.), soluble salts are best removed from the steel surface by thorough blast-cleaning (cleanliness Sa 2^{1/2} or better).

When, however, the steel is severely corroded, e.g. deeply pitted, it is very difficult, or almost impossible, to remove the salts sufficiently by normal blast-cleaning. Repeated blast-cleaning will finally remove the salts from the pits, but it involves high costs and a considerable increase of the surface roughness.

This means that with steel showing rust grades of C and D according the ISO standard described under Part 3.2.3.3, preparation grades of Sa 3 or Sa 2^{1/2} cannot be achieved by normal dry abrasive-cleaning. The best way to treat such surfaces is by wet-abrasive blasting, followed by dry (sweep) blasting, or by hydro-jetting with the addition of an abrasive.

Due to the practical difficulty of obtaining a sufficient preparation grade for pitted (contaminated) steel it is strongly recommended that steel showing rust grades of C or D is not used for the building of ships and offshore structures.

Storage of steel in open stocks should be avoided as far as possible.

3.2.4.6 Working conditions

The quality of blasting can be improved and the service life of the abrasive can be prolonged by removal of loose rust, oil and/or grease from the steel surface before blasting (see also Part 3.2.4).

The compressed air used for nozzle- and vacuum-blasting should be dry and free from oil. For that purpose, adequate oil and water separators should be present in the blast-cleaning equipment. Regular purging is necessary to avoid accumulations of water and oil. The air pressure and the amount of abrasive per m³ of air should be properly adjusted. The dust content of the abrasive should be kept at an acceptable (low) level.

Blasting nozzles should be discarded and replaced when the nozzle diameter has increased or the blasting pressure is unacceptable low (50% or less).

The best angle of impact for the removal of mill scale is about 45°. Rust is removed most effectively when the angle of impact is perpendicular to the surface. The most effective distance between nozzle and surface is from 55 to 75 cm.

Blasting on the slipway or on offshore platforms generates thick clouds of dust that may damage vulnerable equipment and enter hull openings if they are not protected. Care should be taken to prevent abrasive from being deposited on freshly painted surfaces.

In humid conditions a freshly blasted steel surface will quickly begin to rust. For this reason, blasting in the open air should be avoided in wet weather. The same is true if the surface is damp with dew or if the air is so humid that water will condense on the steel or in the blasting nozzle.

Whether or not condensation of water will occur depends on the temperature differences between the steel surface and the surrounding air, and on the relative humidity of the air (see Part 6.4.1). In maintenance work, large temperature differences between ships' hull and the surrounding air may develop when tanks inside the hull are filled with relatively cold liquids and the atmospheric temperature is rising.

As a general rule blasting (and painting) should be undertaken only when there is no risk of condensation. Therefore it is often prescribed that the temperature of the steel surface should be at least 3°C higher than the dew point of the surrounding air. Attention should always be paid to possible changes in the weather that may cause differences in temperature between the surface and the surroundings.

3.2.5. FLAME-CLEANING

In flame-cleaning oxy-acetylene flames are passed over the steel surface. The difference in thermal expansion between the steel surface and mill scale or rust causes the latter to spall off. Flame-cleaning does not remove all the mill scale and rust and the final result is relatively poor.

Prior to flame-cleaning, any heavy rust layers shall be removed by chipping. After flame-cleaning, the surface shall be cleaned by power tool wire-brushing.

Because of fire hazard, flame-cleaning is not permitted on offshore structures.

In view of its relatively poor effectiveness, flame-cleaning is unsuitable when high-duty paint systems are to be used. It should be employed if for any reason blast-cleaning is not possible or not permissible, e.g. when the treatment or the painting has to be done in humid weather.

The effectiveness of the flame-cleaning process depends on the original condition of the steel surface; some preliminary weathering may promote a faster and more complete loosening of the mill scale.

The speed of traverse of the flame over the surface depends on the condition of the surface and may vary from 1 to 5 m/min. Slow rates must be used for heavily rusted plates or plates with much adhering paint.

Flame-cleaning is not suitable for the removal of intact paint systems. The heat of the flame may cause steel plates to buckle; consequently, plates thinner than 6 mm should not be flame-cleaned.

The ratio of acetylene to oxygen should be adjusted to avoid deposition of soot on the plates. It is recommended that the first paint coat be applied before the plates have cooled to ambient temperature, i.e. whilst the surface is still absolutely dry.

According to ISO standard 8501-1 (1988) the preparation grade achieved by flame-cleaning is given by the following description:

F1 Flame-cleaning

When viewed without magnification, the surface shall be free from mill scale, rust, paint coatings and foreign matter. Any remaining residues shall show only as a discolouration of the surface (shades of different colours). See photographs A F1, B F1, C F1 and D F1.

3.2.6. PICKLING

In pickling, mill scale and rust are removed by means of acids. An inhibitor is added to avoid attack the metal itself by the acid.

Before pickling, the steel must be thoroughly degreased and freed from dust. Degreasing and pickling is usually performed in a warm bath.

Pickling finds little if any application in shipyards because of the need for large and deep baths, the development of noxious and corrosive vapours, and the technical and financial problems posed by the necessity for disposal of strongly acid and oxygen demanding waste water. Pickling usually is carried out by specialized firms, for instance for pipes and tubes.

The use of acid pickling pastes, intended for use at ambient temperatures, is not recommended.

Immediately after pickling the steel is rinsed with clean fresh water to remove residues of acid. If this is not done thoroughly, the paint system may fail through premature

blistering and flaking. After being rinsed, the steel is generally 'passivated' in warm 2% phosphoric acid.

The acid reacts with the iron to give a very thin layer of iron phosphate, which provides protection against flash-rusting. When the steel is to be coated with an epoxy primer, lower concentrations of phosphoric acid (for instance 0.5%) are used for passivating purposes. The various stages of the pickling are carried out in successive baths. It is recommended that the first coat of paint be applied before the dry steel has cooled immediately.

Pickled steel is much smoother than blasted steel. For good adhesion blasting is preferred to pickling, especially for high-duty paint systems.

In the following text, the more usual pickling methods are briefly described.

3.2.6.1 *Sulphuric acid/phosphoric acid method*

- pickling in 5-25% (by weight) sulphuric acid at 50-65°C; the concentration depends on the condition of the metal to be pickled.
- rinsing in clean fresh water at 60-65°C.
- passivation in 2% (by weight) phosphoric acid at 80-90°C.

3.2.6.2 *Hydrochloric acid/phosphoric acid method*

- pickling in 15% (by weight) hydrochloric acid at room temperature.
- rinsing in clean fresh water at 60-65°C.
- passivation in 2% (by weight) phosphoric acid at 80-90°C.

3.2.6.3 *Phosphoric acid/phosphoric acid method*

- pickling in 10-20% (by weight) phosphoric acid at 60-85°C.
- passivation in 2% (by weight) phosphoric acid at 80-90°C.

3.2.7. THE USE OF RUST CONVERTORS

Rust convertors or rust stabilizers are products which convert rust into harmless iron compounds such as tannates or phosphates. *Modern types of rust convertors are film forming* and can be overcoated by most current types of paint.

As rust convertors (stabilizers) do not remove or convert the corrosion promoting salts (sulphates, chlorides) of the rust layer their protective value is limited. Because of this, careful derusting, preferably by blast-cleaning, is strongly preferred.

In practice, rust convertors can be used for non-immersed parts of ships and offshore structures in places where blast-cleaning is not possible or not permitted.

Before application, all loose rust should be removed by mechanical cleaning, thus ensuring that the rust convertor (stabilizer) will be applied on a well adhering rust layer. Their performance is not always favourable and sometimes better results can be achieved by using conventional (red lead) primers based on drying oils or long-oil alkyd resins.

Also *rust-penetrating products*, based on low-viscous drying oils may be used for painting rusty surfaces which, for some reason, cannot be blast-cleaned.

3.2.8. COMPARISON OF PRETREATMENT METHODS FOR STEEL

By comparing the pretreatment methods for steel, the following comments can be made:

Only by blast-cleaning and pickling can mill scale and rust be completely removed from steel surfaces. Pickling is not widely used because of its impracticability for use in yards and the smooth steel surface (without 'anchor pattern') which is obtained.

When the steel is heavily corroded (pitted) and consequently contaminated by corrosion promoting salts, *wet abrasive-blasting (wet-blasting)*, followed by sweep blasting or *hydro-jetting with addition of an abrasive*, is strongly recommended.

Flame-cleaning is inferior to blast-cleaning and pickling and results in a lower degree of surface cleanliness, which is less suitable for high-duty paint systems. Its most important advantage is that it provides a warm and dry steel surface, this being particularly useful when surface preparation and painting have to be done in humid weather.

Mechanical cleaning (power-tool cleaning) is more time-consuming than blast-cleaning and generally results in a lower degree of cleanliness. Apart from certain types of rotary impact tools, tightly adhering mill scale cannot be removed.

Mechanical cleaning is mainly used for local repairs (maintenance operations) and pretreatment of damaged or burnt areas and weld seams.

Removal of mill scale by weathering, followed by mechanical cleaning, is a slow and erratic process and is least satisfactory for the durability of the paint system.

Neither this method nor mechanical cleaning is recommended for surface preparation when high-duty paint systems have to be applied. For conventional paints, such as alkyd resin and bituminous paints, these preparation methods are acceptable because, for these products, the cleanliness of the substrate is less critical. Nevertheless, also for these paints, blast-cleaning is to be preferred.

3.2.9. RECENT ISO STANDARDS

During 1988, a number of new international standards, concerning the preparation of steel substrates before application of paints, have been prepared.

Some of them have been issued in 1988, some of them will be issued in the following year(s).

At the time the Ship Painting Manual was completed (March 1989), the situation was as follows:

- ISO 8501* - Visual assessment of surface cleanliness
 Part 1 : issued in December 1988 (mentioned in this chapter)
 Part 2 : soon to be expected (mentioned in this chapter)
- ISO 8502* - Test for the assessment of surface cleanliness
 Not yet issued
- ISO 8503* - Surface roughness characteristics of blast-cleaned steel substrates; issued in February 1988
 Part 1 : Specifications and definitions for ISO surface profile comparators for the assessment of abrasive blast-cleaned surfaces
 Part 2 : Method for the grading of surface profile of abrasive blast-cleaned steel - Comparator procedure
 Part 3 : Method for the calibration of ISO surface profile comparators and for the determination of surface profile - Focusing microscope procedure
 Part 4 : Method of the calibration of ISO surface profile comparators and for the determination of surface profile - Stylus instrument procedure
- ISO 8504* - Surface preparation methods
 Not yet issued.

3.3. Surface preparation of galvanized steel

In order to obtain a good and lasting paint adhesion on galvanized steel (hot-dip galvanized steel or sprayed-zinc coatings) the following must be realized:

- proper removal of flux, grease (oil) or other contaminants from the surface;
- proper removal of zinc salts formed during weathering;
- no application of (drying oil containing) paints that can react chemically with the zinc surface, leading to embrittlement and/or saponification.

The most common pretreatments of galvanized steel are described under parts 3.3.1-3.3.3.

3.3.1. SWEEP-BLASTING (for hot-dip galvanized steel)

After having degreased where necessary, the galvanized steel surface is sweep (brush-off) blasted using a low blasting pressure and a fine mineral abrasive. For the pretreatment of galvanized steel surfaces this method is strongly preferred because of the high degree of cleaning and the (adhesion promoting) surface roughness which is obtained.

Care must be taken that, when using this cleaning method, the zinc layer is not damaged too much and that only the contaminated upper part is removed.

3.3.2. CHEMICAL PRETREATMENT

Chemical pretreatments of galvanized steel surfaces are generally carried out with liquids containing phosphates or chromates. These pretreatments are called '*phosphatizing*' and '*chromating*' and result in the formation of a so-called *conversion coating* on the metal surface. The best results are obtained when galvanized steel parts are dipped in hot pretreatment liquids. As this, in normal yard practice and during maintenance is not possible, cold processes have been developed where the pretreatment liquids* are (cold) applied by brushing or spraying. After the specified contact time the surfaces must be rinsed thoroughly with clean fresh water and allowed to dry completely before being painted.

The method described above for chemical pretreatment is only valuable when the galvanized steel surface is first degreased and freed from excessive corrosion, for instance by mechanical cleaning (see Part 3.2.3).

As (cold) chemical pretreatments do not fit in very well with normal yard practices and involve certain risks when not properly carried out, their use is not recommended in ship- and offshore structure building and maintenance.

3.3.3. MECHANICAL CLEANING

The galvanized steel surface is degreased where necessary and subsequently cleaned mechanically and rinsed, for instance by brushing with steel wire- or nylon brushes and the use of abundant clean fresh water. For degreasing, no alkali-based materials should be used.

* British standard BS 5493 describes a special phosphating liquid for the pretreatment of galvanized steel surfaces.

3.4. Surface preparation of aluminium

Before being painted, aluminium must be degreased and freed from dirt and corrosion products. For degreasing, no alkali-based materials should be used. For the removal of dirt and corrosion products aluminium can be cleaned mechanically, e.g. by brushing with aluminium wool or by blast-cleaning with a fine, *inert* abrasive. When cleaning mechanically, steel wire brushes should not be used because of the risk of galvanic corrosion when steel particles might be retained on the surface.

To ensure adequate adhesion of paints on aluminium, special primers must be used, e.g. wash (etch) primers (see Part 4.5.1.3), or the surface should be pretreated chemically. The latter is usually done with chromate containing liquids and is therefore called 'chromating'.

With respect to the execution of cold chemical pretreatment processes and the incompatibility with normal yard practices, the reader is referred to Part 3.3.2.

APPENDIX 3.A. - PROFILES (ROUGHNESS) PRODUCED BY SOME ABRASIVES*

Type of abrasive	Particle size		Typical profile height**	
	Maximum U.S. sieve size	Main particle size (mm)	Maximum	'Average maximum'
Metallic				
Shot S - 230	20	0.85 - 1	74 + 5	56 + 8
" S - 280	18	1 - 1.2	89 + 8	64 + 10
" S - 330	16	1.2 - 1.4	97 + 10	71 + 13
" S - 390	14	1.4 - 1.7	117 + 13	89 + 18
Grit G - 50	30	0.2 - 0.6	56 + 8	41 + 8
" G - 40	20	0.3 - 0.85	86 + 10	61 + 13
" G - 25	16	0.7 - 1.0	117 + 13	9 + 18
" G - 14	12	1.4 - 1.7	165 + 20	130 + 23
Mineral				
Heavy Mineral Sand		Medium fine	98 ± 10	66 ± 10
Flint Shot		Medium fine	98 ± 10	69 ± 10
Silica Sand		Medium	101 ± 13	74 ± 10
Boiler Slag		Medium	117 ± 13	79 ± 13
Boiler Slag		Coarse	152 ± 18	94 ± 18

* This table is an elaboration of Table 1 (page 20) of Chapter 2.0 of Volume 1 of Good Painting Practice (2nd edition) of the Steel Structures Painting Council (SSPC).

** It should be borne in mind that the figures given are mainly of comparative value and that the profile height is very much determined by factors like the original surface condition, blasting-pressure and duration of the blasting.

APPENDIX 3.B. - SURFACE PROFILE (ROUGHNESS) OF ABRASIVE BLAST-CLEANED SURFACES

According to standard ISO 8503-4, the surface profile of blast-cleaned surfaces is measured with a stylus apparatus over an evaluation length of 12.5 mm, consisting of 5 adjacent sampling lengths of 2.5 mm each. The rate of traverse of the diamond stylus, having a tip radius of 5 ± 1 micrometer, shall not be greater than 1.0 mm/s.

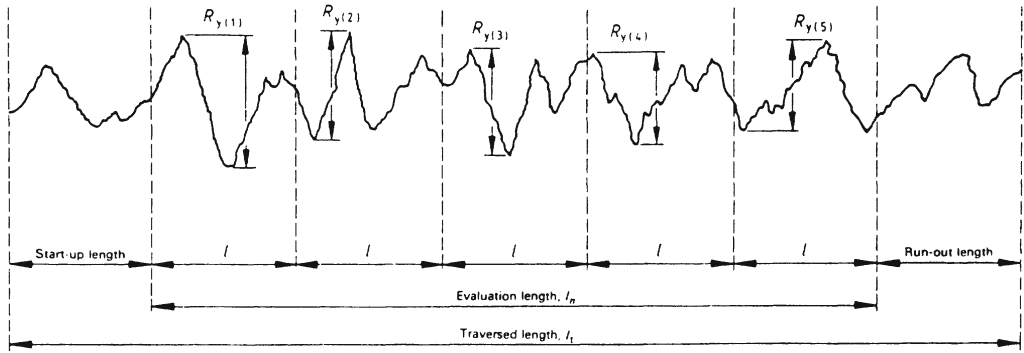
From the roughness profile obtained (see page 104), the following parameters are determined:

- a. **Maximum peak-to-valley height, R_y**
The largest single peak-to-valley height occurring over the sampling length l (2.5 mm).
- b. **Mean maximum peak-to-valley height, R_{y5}**
The arithmetic mean of peak-to-valley heights R_y of 5 adjoining single sampling lengths, l .
 R_{y5} is also known as R_z (R_{tm}) according to DIN 4768/1.
- c. **Grand mean maximum peak-to-valley height $\overline{R_{y5}}$**
 $\overline{R_{y5}}$ is the arithmetic mean of a number (not less than 10) determinations R_{y5} .

A roughness parameter which is often used is *the Ra or CLA-value* (CLA = centre line average). This parameter is defined in the standards ISO 4287/1, DIN 4768/1, DIN 4762/1 and BS 1134.

The roughness value R_a (CLA) is determined on the basis of a median line (centre line) drawn through the surface profile (see page 104). This centre line intersects the profile so that the total surfaces on either side of it are equal (the algebraic sum of the surfaces then is a minimum). *The roughness value is then defined as the mean distance of all points on the profile to the centre line.* The maximum roughness is generally 4-5 times the R_a (CLA)-value.

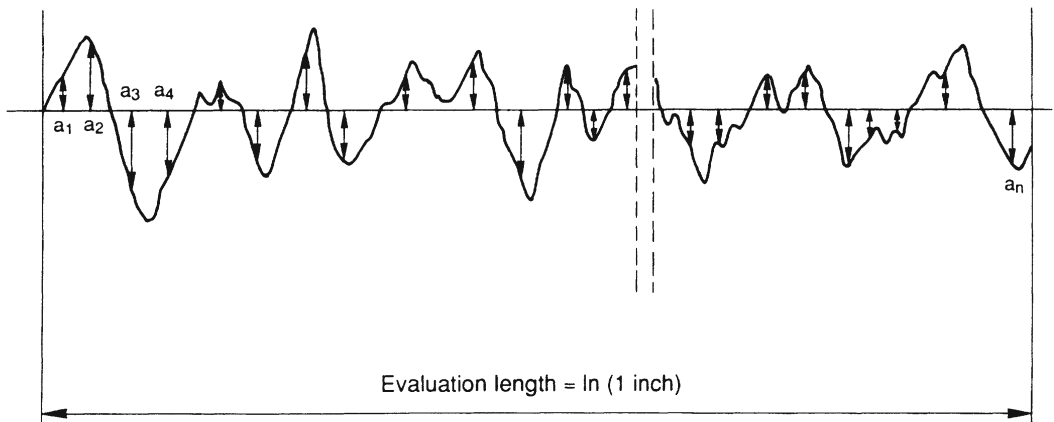
APPENDIX 3.B. - CONTINUATION



$$R_{y5} = \frac{R_{y(1)} + R_{y(2)} + R_{y(3)} + R_{y(4)} + R_{y(5)}}{5}$$

l = Sampling length

Significant features of a typical blast-cleaned surface profile measurement (ISO 8503-4)



$$Ra (CLA) = \frac{\sum a}{n} = \frac{a_1 + a_2 + a_3 + \dots + a_n}{n}$$

APPENDIX 3.C. - GRADES OF SURFACE PREPARATION BY BLAST-CLEANING

ISO 8501-1, 1988	BS 4232-1967** British standard	SSPC, Vol 2, 3rd edition Steel Structures Painting Council (USA)	NACE TM-01-70 Nat. Assn. of Corr. Engineers (USA)
SS 05 59 00-1988* Swedish scale			
DIN 55928 (Teil 4) 1977 (Germany)			
Sa 1	--	SSPC-SP 7 Brush-off blast- cleaning	NACE No. 4 Brush-off blast
Sa 2	Third quality	SSPC-SP 6 Commercial blast-cleaning	NACE No. 3 Commercial blast
Sa 2 ^{1/2}	Second quality	SSPC-SP 10 Near-white blast-cleaning	NACE No. 2 Near white
Sa 3	First quality	SSPC-SP 5 White metal	NACE No. 1 White

* Formerly SIS 05 59 00 - 1967

** Under revision (March 1989)

In the German Standard DIN 55928, additional (secondary) preparation grades *P* Sa 2 and *P* Sa 2^{1/2} are described; the latter is illustrated by some colour prints. The addition *P* means that well-adhering parts of the paint system during maintenance are not removed from the corroded steel surface. Edges between the remaining parts must be smoothed before further painting is undertaken.

The preparation grades of previously painted steel surfaces after only localized removal of paint coatings also form the subject of ISO Standard 8501-2, which still had to be published at the time the Marine Painting Manual was completed.

As described in Part 3.2.4.4, also the "Japanese standard" deals with preparation grades of previously primed and painted steel surfaces.

CHAPTER IV

PAINTS AND PAINT SYSTEMS

4.1. Definitions; aims of painting

The standardization institutes of several countries have published definitions of the terms used in the field of paints and varnishes. Unavoidably, they differ slightly in the different languages, because similar terms do not always have the same meaning. In this chapter the definitions are based on ISO standard 4618/1 (Paints and Varnishes - Vocabulary - Part 1: General terms). Most of them are substantially the same as those used in many other countries.

*Paint** is a product, liquid or in powder form, containing pigment(s), which, when applied to a substrate, forms an *opaque film* having *protective, decorative or specific technical properties*.

Varnish is a product which, when applied to a substrate, forms a solid, *transparent film* having *protective, decorative or specific technical properties*. In fact, varnish (clear coating) is substantially the same as a paint, the difference being that *varnishes contain no pigments*.

Medium or *vehicle* is the sum of the constituents of the liquid phase of paint.

Binder is the non-volatile part of the medium which *forms the film and binds the pigment*.

Solvent is a liquid, single or blended, volatile under normal conditions and in which the binder is completely soluble.

The solvent evaporates from the layer after application of the paint or varnish.

Diluent is a volatile liquid, single or blended, which, while not a solvent for the non-volatile constituents of a paint or varnish, may be used in conjunction with the solvent without causing any deleterious effects.

Normally, a diluent is mixed with the binder solution (vehicle) to obtain special effects, e.g. regulation of the evaporation pattern, adjustment of the paint viscosity** or cost reduction of the volatile part of the paint.

* In practice, paint is often referred to as a *coating*.

** Viscosity is a measure of the 'thickness' of a liquid; with paints it is also called *consistency*; the thicker the paint, the higher the viscosity.

Thinner is a volatile liquid, single or blended, added to a product to lower the viscosity. Normally, thinners are either solvents or diluents or mixtures of both.

Pigment is a substance, generally in the form of fine particles, which is practically insoluble in media and which is used because of its *optical, protective or decorative properties*.

A pigment gives a paint colour, covering power and often also protective properties.

Extender is a substance in powder form, which is practically insoluble in media, usually white or slightly coloured, having a refractive index usually less than 1.7. It is used because of its physical or chemical properties. The function of extenders, having a white or pale colour and a limited covering power, is to impart certain desirable properties to the paint. Thus, the purpose of using extenders may be to stabilize the paint, to prevent it from sagging, to make it matt, or to improve its rheological properties etc. It will be clear that the conventional use of extenders for reducing the price of paints is no longer the main reason.

*Additive** is a substance added in small quantities to paint formulations, its function being to improve certain properties of the paint or to facilitate its preparation. Examples are viscosity modifiers, anti-settling agents, anti-skin agents, driers, etc.

From the foregoing it is clear that *the main purpose of applying paints or varnishes is to provide protection, decoration or both. In addition some kinds of paint have special functions*. Examples are anti-fouling, non-slip and fire-retardant paints.

4.2. Paint systems

Good paint work should provide long lasting protection of metals from corrosion, of wood from rot and should have decorative properties (colour, gloss). For some parts of ships and offshore structures (e.g. interiors of tanks) only the protective function of the paint is important.

A single coat of paint cannot usually fulfil both requirements (protection and decoration) or indeed either of these to an optimum degree. It is therefore necessary to apply more than one coat giving rise to a *paint system*.

Paint systems for wood may consist of a *primer*, an *undercoat* and a *finishing coat or top coat*.

A conventional system for steel may consist of one or several coats of an *anti-corrosive primer*, an *undercoat (intermediate coat)* and a *finishing coat (the top coat)*. As a rule,

* No definition present in ISO 4618/1.

such a system should have a dry film thickness of at least 120 micrometers (μm^*). Normally, the dry film thickness of conventional systems does not exceed 180 μm .

Modern, chemical resistant paint systems, which are also known as *high-duty or high-performance paint systems*, have fewer coats than conventional systems; the separate coats are applied at a greater thickness by the use of so-called *high-build paints*. By virtue of their special composition these paints can be applied in thick coats without sagging on vertical surfaces. If this is the result of the paint containing a high proportion of pigments and extenders, it is called a *high-filled paint*. Thick layers can also be obtained by using *solvent-free, solventless or high-solid paints***.

Each coat of a paint system has a definite function.

A *primer for steel* must provide good adhesion to the substrate, must be actively corrosion-inhibiting (anti-corrosive) and must form a good basis for the next layer of the coating system.

Most primers for steel contain anti-corrosive pigments like red lead, zinc powder (zinc dust), zinc chromate, zinc phosphate or calcium phosphate. Due to their toxicity, red lead and zinc chromate nowadays are used less frequently and certainly not in prefabrication (shop) primers in order to avoid the evolution of noxious or toxic fumes during welding and flame-cutting.

Primers and undercoats have a mainly protective function, and need not be decorative.

Undercoats, often also called *intermediate or body coats* must adhere well to the primer; they are essential for obtaining a sufficient 'build' of the paint system. Furthermore, they should have good covering power and their colour should preferably be nearly the same as that of the top coat, but sufficiently different to allow the contrast to be obvious when applying the final coat.

Undercoats usually add to the overall protection of the paint system.

Especially when they incorporate lamellar pigments (see Part 4.3.2), they significantly reduce the oxygen and moisture permeability of the system.

The *finishing paint or top coat* has many functions. Beside being decorative, it should be weather-resistant. This means that the finishing paint must have good colour-retention and not lose its gloss or chalk in bright sunlight. It should also not lose adhesion under humid conditions.

Moreover, the finishing paint may be required to have good mechanical properties, i.e. scratch, impact and abrasion resistance and may be resistant to highly polluted atmospheres and mould-growth.

* 1 micrometer (μm) = 10^{-3} mm = 10^{-6} m
1 mil = 10^{-3} inch = 25.4 μm

** Roughly estimated, solvent-free paints contain not more than 0.1% volatile constituents by volume, solventless paints not more than 5% and high-solid paints not more than 20%.

The fact that a paint system consists of several coats reduces the risk of pore formation and thus improves its protective power.

The various coats of each paint system should be compatible and adhere well to one another. The neglect of compatibility and intercoat adhesion is likely to cause problems. When e.g. an epoxy paint, which contains strong solvents, is applied on top of a dried alkyd paint coat, the latter is liable to soften and wrinkle. This phenomenon is called 'lifting'. On the other hand, when an alkyd paint, containing weak solvents, is applied on top of a chemical resistant epoxy coating, no wrinkling or other defect of the latter will occur.

When a dried coat of coal-tar epoxy paint is top coated with a light coloured coating, some of the tar may diffuse into and discolour the top coat. This phenomenon is known as 'bleeding'. It may be prevented by the application of a 'sealer coat', through which the tar cannot penetrate. The sealer often also serves to promote adhesion between the coal-tar epoxy and the top coat; the sealer is then called 'tie-coat' or 'key-coat'.

It is strongly recommended that paint systems be built up with products from a single manufacturer. If for any reason the paints of a system have to be procured from different manufacturers, advice should be sought from all the manufacturers concerned.

4.3. Composition of paints

The most important constituents of paints are *binders*, *pigments* and *extenders*, *solvents/diluents/thinners* and *additives*. As was noted in Section 4.1., varnishes do not contain pigments.

4.3.1. BINDERS

The binder is that component of a paint which, after drying, forms a coherent layer, adhering to the substrate; the pigment particles are distributed more or less uniformly in this layer.

The type of binder to a large extent determines such properties as adhesion, hardness, elasticity, gloss and resistance to weathering, water, chemicals etc. These properties also depend on the pigment composition.

Many binders for paints are based on bitumen, coal-tar pitch, drying oils, synthetic resins, polymers, or combinations of these constituents. In addition, natural resins or modified natural resins are used to a limited extent, e.g., in conventional (classical) anti-fouling paints.

The choice of the binder is in large measure determined by the purpose for which the paint is intended. The various kinds of binders and the properties which they impart to the paint, will be dealt with in Sections 4.5.2.1 - 4.5.2.14.

4.3.2. PIGMENTS AND EXTENDERS

Many pigments have a mainly *decorative function*, which means that they impart *colour* and *covering power* to paints. Sometimes, however, they have a mainly *protective function*, like rust-inhibiting (anti-corrosive). Some have a very *special function*, e.g. cuprous oxide for anti-fouling paints, and 'leafing' aluminium flakes for use in paints which reflect sunshine so as to reduce the heating of some parts of the ship or offshore structure. Paints pigmented with aluminium flakes and other *laminar pigments*, like micaceous iron oxide and glass flakes, also have a very low water and water vapour permeability.

As already described under Part 4.1 (definitions), pigments are often combined with extenders. These are sometimes used to partially replace expensive colouring and covering pigments in order to obtain an optimal price-setting. Nowadays, however, they are mostly used to improve the quality of the paint, e.g. to prevent sedimentation of pigments, or to improve the mechanical properties and the resistance of the paint to water and chemicals. Moreover, extenders are often used to impart structural consistency to paint materials, enabling application of thick coats, and also to reduce gloss.

The most important pigments and extenders are listed in Appendix 4.A.

4.3.3. SOLVENTS AND THINNERS

Solvents, diluents and thinners are liquids used to dissolve the binder, to adjust the viscosity of the binder solution (vehicle) and to reduce the viscosity of the paint, for instance to spraying consistency. Certain binders, such as drying oils, themselves have a low viscosity and therefore do not need to be dissolved.

Most binders, however, are either solid materials or highly viscous liquids, and must therefore be dissolved in organic solvents. A few types of binder, such as certain silicates are dissolved in water. Binders for so-called 'dispersion paints' are dispersed as small spherical particles, for instance in water, with which they can be diluted.

Whether a given liquid e.g. xylene, is a solvent or a diluent, is determined by the nature of the binder. Xylene is a solvent for alkyd and chlorinated rubber paints, whereas for nitrocellulose and vinyl paints it is a diluent.

Many paint formulations contain mixtures of solvents and diluents; the latter can be regarded as liquid extenders for reducing the cost. A typical example of such a mixture is the thinner used for vinyl paints. It usually contains esters and/or ketones as solvents and aromatic (or occasionally aliphatic) hydrocarbons as diluents.

Solvents, diluents and thinners evaporate during drying and are therefore lost. Their function is temporary and may be regarded as a means of transport.

Binders requiring only a small amount of volatile material (solvents etc.) to lower the viscosity are referred to as 'low viscosity' or 'high solid' binders. Paints containing these binders give rather thick dry films.

Binders requiring large amounts of volatile materials to lower the viscosity are called 'high viscosity' or 'low solid' binders. These binders give relatively thin dry film. Examples are chlorinated rubber and vinyl copolymers.

From the foregoing it will be clear that paint systems made up of paints based on low viscosity binders as a rule have a greater dry film thickness than those based on high viscosity binders, for the same number of coats.

As noted above, many solvents/diluents and thinners used in paints are mixtures.

If the composition is not chosen correctly, various kinds of difficulties may arise, such as too slow or too fast a drying, poor application properties, spraying defects, blushing, blistering and so on.

It is therefore of the utmost importance to use the specified type of solvent/diluent or thinner.

Solvents may differ considerably in solvent power. White spirit (mineral spirits) is a rather weak solvent whilst aromatic hydrocarbons, such as toluene and xylene are usually good solvents.

Solvents containing a large proportion of esters and/or ketones have still better solvent power and are called *strong solvents*. In this connection it must be emphasized that paints containing these solvents, e.g. epoxy and vinyl paints, should not be applied over paints sensitive to these solvents, such as alkyd paints as this may cause 'lifting' (wrinkling).

After drying, many paints tend to retain small quantities of solvent for a long time. This phenomenon, which is called *solvent retention* may lead to soft films having poor resistance to water or chemicals. Particularly with coating systems on the insides of tanks, this can have a disastrous effect, for instance leading to extensive blistering of the system.

Some solvents retained in the coating, can hydrolyse under the influence of water or certain cargoes, forming corrosion promoting products; examples are acetate-based solvents which may form acetic acid.

Solvents also must be water-repellent as otherwise water will be attracted which may lead to blister formation.

From the foregoing it is clear that well formulated solvents/diluents and thinners should contain no constituents likely to be retained by the binder.

Many solvents/diluents and thinners are flammable, a measure of their fire hazard being their *flash point* (see Part 11.2.1).

In addition, many solvents/diluents and thinners present a serious health hazard if their vapours are inhaled; the degree of toxicity on inhalation is expressed as their *TLV (MAC)* (see Part 11.2.6).

Fire and health hazards, arising during the application and drying of paints in confined spaces such as tanks, should be reduced to minimum by effective ventilation.

Solvent-free, solventless and high-solid paints are less hazardous in regard to fire and health than normal paints. Their high content of solids allows them to be applied in thick coats that do not sag on vertical surfaces.

Sometimes low-solvent paints contain a so called 'reactive diluent', which does not evaporate but reacts with the hardener or curing agent during drying of the paint.

Some solvent free two-pack paints are so viscous that they must be heated to obtain a suitable application consistency. Since their 'pot life' at higher temperatures is very short, this type of solvent-free two-pack paint can only be applied by means of twin-feed hot spray equipment.

The most important solvents/diluents and thinners in current use are listed in Appendix 4.B.

4.4. Classification of paints

Paints can be classified on the basis of different criteria, such as substrate, object, place in the paint system, kind of pigment or binder and special function.

One classification distinguishes between *conventional* and *high-duty (high-performance) paints*.

From a technical point of view a *classification according to the type of drying process is important*. Because of the significance of a good understanding of this classification it will be dealt with separately in Section 4.4.1.

Conventional paints are those which have been in use for several decades in shipbuilding practice. Examples are paints based on bitumen, drying oils and alkyd resins. With the exception of bituminous paints, all conventional paints contain saponifiable (alkali sensitive) binders which are not chemically resistant. Most oil-based and all alkyd resin paints are too water-sensitive to be used on the the underwater parts of ships and offshore structures. Bituminous paints are suitable for this purpose.

Tung oil/phenolic paints were used on ships in former days but these are saponifiable and are incompatible with cathodic protection systems. However, on well pretreated substrates, bituminous paints are compatible with cathodic protection.

Conventional paints are less critical than high-duty (high-performance) paints with regard to surface preparation; they can be used on surfaces which have not been blast-cleaned. It should be emphasized, however, that good surface preparation greatly prolongs their service life.

High-duty (high-performance) paints are very durable, mechanically strong and generally chemical and/or solvent resistant. Examples of such paints are products based on epoxy resin, polyurethane resin, chlorinated rubber, vinyl copolymers and (zinc) silicates. Broadly speaking, it should be mentioned, however, that chlorinated rubber and vinyl copolymers are chemical (alkali/acid) but not solvent resistant and that (zinc) silicates are solvent but not chemical resistant. Moreover, chemical as well as solvent resistant paints, differ in their degree of resistance.

The high price of high-duty paints and the thorough surface pretreatment they require, normally is more than compensated for by their better performance and durability, which results in a great reduction in maintenance costs. The advantages of high-duty paints become apparent only when they are applied to surfaces which have been well prepared, preferably by blast-cleaning.

High-duty paints are based on unsaponifiable (alkali-resistant) binders, and they can therefore be used for underwater parts, even when these are cathodically protected. Some types of high-duty paints, e.g. epoxy and polyurethane paints, are so highly resistant, that they are suitable for the protection of the interiors of tanks used for chemicals or solvents; zinc silicates are most suitable in tanks for strong solvents. On underwater parts of ships, high-duty paint systems retain their smoothness for much longer periods than do conventional systems, resulting in considerable savings in fuel consumption and operating costs.

4.4.1. CLASSIFICATION OF PAINTS ACCORDING TO DRYING MECHANISM

Paints can be divided into two groups according to their drying mechanism, e.g. *physically drying paints* and *chemically drying paints*.

A classification scheme of paints according to these criteria is given in Appendix 4.C.

4.4.1.1 *Physically drying paints*

The drying process of this type of paint consists exclusively of the evaporation of solvents/diluents and thinners. Since most are highly volatile, drying proceeds rapidly. *The dried coats can more or less be redissolved in the original solvent or attacked by other solvents*, even after long service periods.

The drying process is reversible. This means that the application of successive coats by brush causes difficulties. When the second coat is applied, the solvents will soften the first one and the two coats will be more or less mixed. When applied by spraying, the second coat is, so to speak, laid carefully on top of the first and a slight softening may then be favourable, as it promotes intercoat adhesion. On the other hand, it should be borne in mind that such softening may occasionally cause sagging on vertical surfaces

especially, when an (old) physically drying thick paint system, consisting of many layers, is overcoated with a fresh layer of paint.

Some kinds of paints are made up of combinations of physically and chemically drying binders, the aim being to obtain rapid initial drying (setting) and to make it possible to apply successive coats by brush, e.g. chlorinated rubber/alkyd resin paints.

Physically drying paints can be applied at low temperatures, provided that the solvents and thinners are sufficiently volatile. This property is very desirable when painting has to be done in winter. The substrate, however, should be dry and free from ice. Physically drying paints are not resistant to solvents; some are not even resistant to vegetable and animal oils.

Examples of physically drying paints are those based on bitumen, chlorinated rubber, vinyl resins and nitrocellulose.

4.4.1.2 *Chemically drying paints*

The drying of these paints, usually called *curing*, proceeds by chemical reaction of the binder, for instance with atmospheric oxygen, or with a so-called hardener (curing agent).

Of course volatile components, such as solvents and thinners also evaporate after application; their evaporation provides the *initial drying (setting)*, but the final drying (*curing, hardening*) is the result of a chemical reaction.

Paints that dry by *their binder reacting with atmospheric oxygen* are called *oxidatively drying paints*. Examples of such paints are found among those based on drying oils or alkyd resins.

Paints drying by *chemical reaction of their binder with a hardener (curing agent)* are called *two-pack paints (two-component paints, reaction paints)*. The *paint (base)* and *hardener (curing agent)* of two-pack paints are supplied in separate containers in the right proportions; the two components must be mixed in these proportions shortly before application.

Since curing starts immediately after mixing, the (mixed) paint can be used only for a limited time, called the *pot-life*. This is always stated by the manufacturer and it is absolutely necessary to apply the paint within this period. When the temperature increases the pot-life decreases.

Many two-pack paints are based on epoxy resins, polyurethane resins or unsaturated polyester resins.

Zinc silicate paints form a separate group of chemical drying paints. The pigment (zinc powder) and the silicate solution react with each other and the drying is accelerated by uptake of water vapour from the air.

Although their components are packed separately, these paints are not usually called two-component paints, since no special hardener is required.

The curing of chemically drying paints usually proceeds much more slowly than that of physically drying paints. The rate of curing depends greatly on temperature. At low temperatures they do not cure or cure very slowly.

The dried coats are insoluble in the original solvents, which means that *the drying process is irreversible*. It is therefore possible to apply successive coats by brush, provided of course that previous coats have cured sufficiently.

The hardness of two-pack paints, especially those for immersed parts of ships and offshore structures, which have had ample time to dry is usually very high. This may cause intercoat adhesion difficulties, e.g. in repair work. In order to obtain good adhesion of a repair coat, it may be necessary to roughen the old paint system thoroughly, e.g. by grinding, wet abrasive blast-cleaning or sweep-blasting, or to soften the old paint coat slightly with strong solvents. In addition, long periods between the application of successive coats of the paint system should be avoided.

4.5. Important types of paint used in the building of ships and offshore structures

In the following descriptions of the most important paint types, no attempt is made to provide a rigid classification. The place of the paint in the system or its function, has been taken as the primary criterion; sometimes a further subdivision being made according to the binder type.

The properties of the various paints and their advantages and disadvantages, are described in Sections 4.5.1. - 4.5.3.6. In Appendix 4.F. the properties of the paint types are summarized.

4.5.1. PRIMERS

4.5.1.1 *Common primers for steel*

Conventional anti-corrosive primers for steel are those based on (oil modified) alkyd resins pigmented with *active corrosion-inhibiting pigments* like *red lead, zinc (potassium) chromate* or combinations of these pigments with (red) iron oxide. Due to the toxicity of red-lead and zinc chromate, conventional primers have become unpopular.

Spray mist of these primers forms a potential health hazard when inhaled. Such health hazards are also present when inhaling grinding/blasting dust or welding and flame-cutting fumes of substrates coated with paint systems containing red-lead or zinc chromate primers.

The present situation is that zinc chromate primers are no longer used. Red-lead primers, however, due to their good corrosion resistance, are still widely used in maintenance painting where brush or roller application is usual.

Nowadays anti-corrosive primers for steel are often pigmented with active corrosion-inhibiting pigments like *zinc dust*, *zinc phosphate* or another non-toxic anti-corrosive pigment, sometimes in combination with (red) iron oxide. 'Zinc-rich' primers, containing more than 90% by weight of zinc in the dried coat, are very corrosion resistant due to the local cathodic protective function of the zinc pigment to steel. They require a thoroughly blasted substrate with an adjusted surface roughness. These primers, which are often based on epoxy or silicate binders, are mainly used in new construction. Zinc dust primers have better anti-corrosive properties than primers containing other anti-corrosive pigments.

A main disadvantage of *zinc dust* based primers is that, due to chemical reactions on their surface during outdoor exposure, zinc salts are formed, some of which are hygroscopic (take up water).

An additional complication in using water based zinc silicate primers is the formation of so-called 'curing salts' on the surface. Both water soluble and curing salts lead to intercoat adhesion problems after recoating. Particularly on submerged parts (underwater areas, tanks etc.) lack of adhesion may lead to blistering and flaking of the paint system. To prevent these defects, the zinc salts formed during weathering, as well as the reaction products formed during curing, must be carefully removed before overcoating a zinc dust primer. This is usually done by cleaning the surface thoroughly with nylon brushes, using an adequate supply of clean fresh water (e.g. tap water) and rinsing the surface thoroughly afterwards. Also high-pressure water-washing is a useful method for this purpose.

The primers based on *zinc or calcium phosphate* and *other modern non-toxic anti-corrosive pigments* are used in new construction as well as in maintenance operations. Their binders can be unsaponifiable e.g. epoxy resins and chlorinated rubber, for use on immersed surfaces, or saponifiable such as (oil modified) alkyd resins, for use in maintenance work on non-immersed parts of ships and offshore structures. However, these primers are less corrosion resistant than the corresponding conventional primers pigmented with red-lead or zinc (potassium) chromate.

4.5.1.2 *Special primers for steel* (see also Appendix 4.D.)

a. **Prefabrication primers** (see especially Chapter V)

Prefabrication primers, which are also called *shop primers* or *weldable primers*, are intended to protect plates and components against corrosion during the construction of the ship or offshore structure.

Prefabrication primers are applied in thin coats immediately after preparation of the surface, usually by (impeller) blast-cleaning.

They should not appreciably reduce the speed of welding and flame-cutting nor the strength of weld seams and they should not release noxious or hazardous fumes. Often, a prefabrication primer coat is not removed prior to application of the paint system.

In order to eliminate defects that can cause breakdown of the paint system, there is, however, a growing tendency to remove the (weathered) prefabrication primer coat, preferably by blasting, before final paint application.

For critical parts of ships and offshore structures, e.g. for underwater parts and ballast tank interiors, the removal of the weathered coat of prefabrication primer before final painting is strongly recommended.

In certain cases, however, the prefabrication primer coat *must* be removed, e.g. in tanks for strong solvents and chemicals (see Part 1.3.6.4).

It is imperative that a correct choice of the prefabrication primer be made in order to prevent corrosion of a ship or offshore structure under construction and to improve the durability of the paint system.

The important function of the prefabrication primers and the multitude of problems that beset their use, justify a separate chapter (Chapter V).

Prefabrication primers should not be confused with *pretreatment primers* or *wash primers* (see Part 4.5.1.3). The primary purpose of a pretreatment (wash) primer is to promote good adhesion of the paint system; its protective properties are of secondary consideration. Most of these primers, mainly used on aluminium or galvanized steel, have very limited protective properties and need to be overcoated within a few hours. A prefabrication primer, however, is intended to provide protection over the whole period (usually between three to nine months for shipbuilding) during which the material is being prepared and assembled in the workshops and exposed outdoors before final painting.

The distinction between prefabrication primers and pretreatment primers has become blurred because *modified pretreatment primers*, the so-called *reinforced wash primers*, have been developed. These modified pretreatment primers provide much longer protection than the original formulations and can be used as prefabrication primers, especially as the period over which protection is needed has been shortened by the introduction of speedier methods for the building of ships and offshore structures.

b. Touch-up primers

Touch-up primers, also known as *repair primers* are used for the repair of cleaned welds and damaged areas and for the upgrading of corroded prefabrication primed steel. Normally touch-up primers are compatible with weathered prefabrication primers and imperfectly cleaned steel.

c. Holding primers

Holding or blasting primers are used to protect 'in situ' blast-cleaned steel. Holding primers can be overcoated within a short time which makes it possible to shorten dry-docking times for ships.

They should also be overcoated within a relatively short time, for instance two weeks. The mechanical and chemical properties of holding primers are better than those of prefabrication primers, e.g. an improved resistance to the effects of cathodic protection.

d. System primers

A *system primer* is the first (anti-corrosive) coat of a paint system. Generally, such primers have very good anti-corrosive properties and can be exposed to the environment for relatively long periods. Very often they have long maximum overcoating times.

e. Universal primers

Universal primers are products which can either be used as a touch-up, holding or system primer. Such primers are flexible with regard to the thickness applied and normally need somewhat longer drying than holding primers.

Appendix 4.D. gives a summary of the properties of the special primers for steel.

4.5.1.3 Primers for non-ferrous metals

The surface of non-ferrous metals is frequently pretreated by blasting or chemically by the application of a so called conversion coating (see Parts 3.3 and 3.4). After this pretreatment, a *specially formulated, universally recoatable epoxy primer* is often applied.

If the surface of such metals is not treated as described above, it will often be coated with a *pretreatment primer*.

A pretreatment primer is often known as a *wash* or *etch(ing) primer*. As mentioned under Part 4.5.1.2, a pretreatment primer is primarily used to ensure a good adhesion of the paint system to the metal substrate. It usually is a two-pack paint containing phosphoric acid, based on polyvinyl butyral and pigmented with a small amount of zinc tetroxy chromate. The phosphoric acid serves as the hardener and also etches the metal substrate which results in a good adhesion of the primer.

Normally a pretreatment primer must be applied within eight hours of mixing with the acid hardener. Although, after this period, the mixture may show no apparent thickening, the properties of the dried coat will not be satisfactory. This type of primer should be applied in a very thin coat by spraying or brushing. The dry film thickness should not exceed about 12 micrometers at which thickness the layer is still transparent. Thicker coats impair adhesion. During curing, these primers are sensitive to moisture and should therefore not be applied at relative humidities higher than 80%.

So called *reinforced pretreatment (wash) primers* can be applied at dry film thicknesses of up to 25 micrometers without impairing adhesion. The binder of these products usually consists of a combination of polyvinyl butyral and phenolic resin. Reinforced wash primers are also used as prefabrication primers on steel. However, these products are saponifiable to some extent and are consequently unsuitable for cathodically protected underwater parts of ships and offshore structures.

It should also be mentioned that, especially on galvanized steel, the best adhesion will be obtained when the surface is pretreated by light blast-cleaning (see also Part 3.3.1). When blast-cleaning is not possible or permitted on weathered galvanized steel, reasonable results can be obtained by mechanical (hand) cleaning and the application of a (high build) micaceous iron oxide pigmented chlorinated rubber primer as the first coat.

4.5.2. PAINT MATERIALS, CLASSIFIED ACCORDING TO THE BINDER TYPE

4.5.2.1 *Paints based on drying oils*

Paints based exclusively on drying oils have almost gone out of use on ships and offshore structures.

Disadvantages of paints in which the binder is based solely on drying oils, which are saponifiable, are the slow (oxidative) drying, the poor mechanical properties and the poor resistance to water, solvents and chemicals.

In contrast, paints whose binders consist partially of drying oils are used widely, the most prominent being the (oil modified) alkyd resin paints which will be dealt with in Section 4.5.2.3.

Typical conventional underwater paints are those based on tung oil/phenolic resin, which are mainly used on wooden yachts. These products are oxidatively drying, water resistant paints which nevertheless are saponifiable.

4.5.2.2 *Bituminous paints*

Bituminous paints are physically drying paints based on *asphalt, bitumen* or *coal-tar pitch*.

Especially those based on coal-tar pitch show a high water impermeability. Pigmentation with laminar (plate-like) pigments improves the impermeability still further.

For paints based on asphalt and bitumen, aliphatic hydrocarbons are mainly used as solvents and thinners, but for coal-tar pitch paints, aromatic hydrocarbons are employed. Bituminous coatings are resistant to weak acids, alkalis, sea water, salts and aggressive atmospheres but are not resistant to vegetable oils, hydrocarbons and other solvents.

Coal-tar pitch coatings show the best water resistance and asphaltic coatings the best chemical resistance.

Bituminous aluminium paints are widely used in conventional underwater paint systems. They are also available as 'high-build' types which do not sag when applied as thick coats in a single operation.

The so-called 'black varnish', which is a solution of coal-tar pitch in solvent naphtha or other suitable solvent, is widely used for the protection of the outer hull of non sea-going ships.

When exposed to the atmosphere, coal-tar paints are subject to 'alligating' (a kind of crazing that produces a pattern resembling the skin of a crocodile).

When overcoated with other kinds of paint, coloured constituents of bituminous paints will sometimes 'bleed', i.e. bitumen or coal-tar diffuses into the subsequent paint coat.

Considering their properties and dark colour, bituminous paints are most useful for application on underwater parts, in water ballast tanks and in drinking water tanks.

For water ballast tanks *solvent-free bituminous compositions* are sometimes used. At normal temperatures these are solid and they require to be melted before being applied in very thick coats by brush or by hot airless spraying. If necessary, the solidified coats are smoothed by flaming.

Before being painted with these bituminous compositions, surfaces should be treated with a thin coat of bituminous paint (bituminous solution), which act as a key-coat.

For potable-water tanks special odourless and tasteless bituminous compositions have been developed. These types of composition may also be used in cooled or refrigerated holds or behind insulation sheets.

Bituminous materials may be reinforced with glass fibre or other *wrapping*, especially for the protection of pipelines and certain parts of offshore structures.



1.



2.

Plate 1. Section building.

Plate 2. Transport of a ship's section to the slipway.



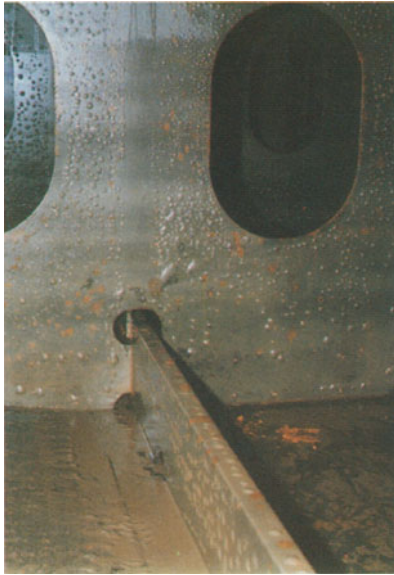
3.



4.

Plate 3. Hydro-blasting of a ship's hull.

Plate 4. Mobile machine for dust-free blast-cleaning of ship hulls.



5.



6.



7.



8.

Plate 5. Severe osmotic blister formation in water ballast tank as a result of a porous tank coating system on top of a prefabrication primer containing water-soluble material.

Plate 6. Failing water ballast tank coating system resulting from tar exudation.

Plate 7. Pitting corrosion on the bottom of a cargo tank, promoted by the presence of un-isolated heating coils.

Plate 8. Sticking of corn grains in a overly thermoplastic cargo hold coating system.



9



10.



11.



12.

Plate 9. Newbuilding of a small offshore jacket and helideck.

Plate 10. Cathodic protection of a jacket by large sacrificial anodes

Plate 11. Tidal/splash zone protection.

Plate 12. Preparation for expensive offshore maintenance.

By polymerisation of certain coal-tar fractions, *coumerone-indene resins* are manufactured. As they are practically colourless and derived from coal-tar, they are sometimes called *bleached tar*.

In certain paint products these resins are used as a substitute for coal-tar (see for instance Part 4.5.2.6).

The so-called *coal-tar resin paints* are made by cooking drying oils with coumerone-indene resins.

4.5.2.3 Alkyd resin paints

Alkyd paints are oxidatively drying (air drying) paints. Since most of the alkyd resins contain compounds of phthalic acid, they are also called 'phthalic resins'. As they contain fatty acids of drying oils, they are often called (drying) oil modified alkyd resins. They usually contain fatty acids of linseed, soyabean, dehydrated castor or safflower oil. Properties such as drying time, elasticity, tendency to yellowing and outdoor durability depend particularly on the kind and amount of fatty acids present. For example, a linseed oil based modified alkyd resin paint shows a marked yellowing tendency when used for interiors. Soyabean oil alkyd paints yellow considerably less and are therefore preferentially used in engine rooms and in dry accommodation spaces.

Those alkyd resins containing a large amount of fatty acids are called 'long-oil alkyds'.

Alkyd paints are saponifiable, soften easily in water and are therefore unsuitable for underwater parts and tank interiors. Moreover, they are not resistant to chemicals and solvents. Because of their tendency to saponify, alkyd paints should never be applied directly to the alkaline surface of galvanized steel or zinc silicate paint in a humid environment.

Alkyd paints are easy to apply and have good levelling properties. The dried coats are decorative and show good outdoor durability, although over long periods they lose their gloss and show a degree of chalking.

They are used particularly for those parts which require a decorative appearance, such as the superstructures, including deck houses and accommodation spaces.

As oil based materials (alkyds) tend to wet metal surfaces effectively and are able to penetrate wire-brushed rusted surfaces to a much greater degree than other coating materials, 'long-oil' alkyd primers may be applied to such surfaces without further extensive pretreatment. 'Long-oil' alkyd red lead primers have been and still are popular as a first coat on hand-cleaned surfaces. Also modern anti-corrosive pigments like zinc phosphate are often combined with 'long-oil' alkyds.

Due to their ease of application and good recoatability, alkyd paints are very popular as maintenance paints.

Alkyd paints are not suitable for application in very thick coats. Since they dry oxidatively by reaction with atmospheric oxygen, thick coats tend to dry only on the surface, leading to wrinkling of the film.

They are usually thinned with aliphatic hydrocarbons, such as mineral spirit (white spirit). If desired, aromatic hydrocarbons can also be used, but these are in fact 'strong' solvents for most alkyd resins.

Alkyd paints should be stored in tightly closed cans, preferably at temperatures below 25°C, so as to prevent severe skinning, gelation and settling.

Alkyd resins can be chemically or physically modified with a large number of other binders. Each of these provide some specific property to the alkyd. By this means the paints are upgraded.

The most important combinations are:

- *Vinyl alkyd paints*, which have shorter drying times, improved adhesion and a better chemical and water resistance than the conventional alkyd paints.
- *Chlorinated rubber alkyd paints*, which show shorter drying times and a better chemical and water resistance than the conventional alkyd paints.
- *Silicone alkyd paints*, which show shorter drying times and better temperature and weather resistance. These paints are increasingly used under offshore conditions where moderately high temperatures are involved.
- *Urethane alkyd (uralkyd) paints*, which have very short drying times and improved abrasion resistance and are often used as floor- and deck coatings.

4.5.2.4 Chlorinated rubber paints

Chlorinated rubber paints are of the physically drying type; as a vehicle they contain chlorinated rubber and unsaponifiable plasticizers.

These paints are water-resistant, unsaponifiable and resistant to acids and alkalis. They are not resistant to solvents and vegetable and animal oils.

Paints based on chlorinated rubber are classed as high-duty, chemical resistant paints, although their mechanical strength is less than that of epoxy and polyurethane paints. Like other high-duty compositions, they require careful surface preparation (preferably by blast-cleaning). If more than one coat is to be applied, this should preferably be done by spraying or rolling instead of brushing.

Suitable solvents and thinners are aromatic hydrocarbons such as xylene.

Chlorinated rubber paints can be divided into *high and low molecular types*.

The 'high molecular' types are mechanically strong and show the best chemical resistance and aesthetic appearance. They need a large amount of solvent/thinner to reach application viscosity and consequently give thin films.

The 'low molecular' types are mechanically weaker and show a lower chemical resistance and aesthetic appearance. These paints, often formulated as high-build products, can be applied in thick layers in one operation.

At low temperatures and high winds, e.g. under offshore conditions, with high-build chlorinated rubber paints the surface may dry very quickly, leading to solvent retention. In view of their excellent water resistance, chlorinated rubber paints are particularly suitable for underwater parts. Chlorinated rubber is used in both anti-corrosive- and anti-fouling paints. If desired, chlorinated rubber paints can also be used on parts exposed to the atmosphere.

A further important property is that chlorinated rubber paints are self-extinguishing which make them suitable as fire-retardants (see also Part 4.5.3.6).

Since chlorinated rubber paints have a poor gloss retention and tend to yellow on exposure, their decorative properties are inferior to those of the alkyd paints. This is especially so for the low molecular (high-build) types. 'High-build' chlorinated rubber paints are generally so heavily pigmented that they soon tend to chalk when used exteriorly. To improve the outdoor durability of chlorinated rubber paint systems the usual practice is to apply a standard (high-molecular) chlorinated rubber, alkyd, or compatible vinyl paint as the top coat.

4.5.2.5 Vinyl paints

Like chlorinated rubber paints, (poly)vinyl paints are of the physically drying high-duty type, resistant to acids and alkalis. In addition, they resist mineral oils and aliphatic hydrocarbons, but not strong solvents like esters and ketones.

Most of the currently used vinyl paints are based on vinyl chloride/vinyl acetate (PVC/PVA) copolymers. In addition vinyl chloride/acrylic resin copolymers are used to a limited extent.

Like chlorinated rubber paints, vinyl paints can be divided into *high and low molecular types*. The 'high molecular' vinyl paints (mainly American types) are mechanically strong and show the best chemical and weather resistance. These products are based on high-viscosity vinyl binders. They need a large amount of strong solvent/diluent for reduction to application viscosity and give thin films. The 'low molecular' vinyl paints (mainly European types) are mechanically weaker and show a lower chemical and weather resistance. They are based on low-viscosity vinyl binders. These paints, often formulated as high-build products, however, can be applied in thick layers in one operation.

When a high molecular type of vinyl paint, containing a large amount of strong solvents, is applied on top of a low molecular vinyl paint system, the latter will soften and on vertical surfaces sagging of the total paint system may occur.

Although they are very similar in properties and use to chlorinated rubber paints, vinyl paints are tougher, more durable and slightly more decorative. The most suitable solvents for these paints are esters or ketones; diluents are aromatic hydrocarbons such as xylene and toluene. Of great importance is a well balanced mixture of solvent and

diluent. If the mixture is too strong, there is a risk of the previous paint coats being softened or dissolved, resulting in sagging on vertical surfaces.

Due to the high volatility of the solvents and thinners, dry spray (the paint particles being dry before reaching the substrate) is formed in hot and windy conditions. When application is performed during windy weather, quick drying of the surface may prevent solvents from evaporating from the underlying layers. This results in solvent retention, pinholing and reduced water and chemical resistance. Too rapid an evaporation of the volatile constituents, results in moisture condensation and may also cause 'blushing' or 'blooming' of the paint film; for this reason vinyl paints should not be applied at high relative humidities, e.g. not above 80%.

For underwater parts and ballast tanks of ships and offshore structures so-called *vinyl tar paints* are available.

Compared to the pure bituminous underwater coatings these vinyl tar types are faster drying and have an improved hardness.

Special products based on polyvinyl chloride (PVC) form the so-called *plastisols* and *organosols*, where PVC is emulsified in a plasticizer or organic solvent/plasticizer mixture. The plastisols are especially used as thick linings on corrugated sidings, for instance for use under offshore atmospheric conditions.

Also based on vinyl resins are the so-called *PVDF (polyvinylidene fluoride) coatings*. They have excellent gloss and colour retention on outdoor exposure. They are mainly used on coil-coated corrugated sidings. As these coatings can only be applied in thin layers, they need a good (thick) primer if a high corrosion resistance is required, for instance under offshore conditions.

4.5.2.6 Epoxy paints

Most epoxy paints for marine and offshore structures are of the chemical resistant two-pack type. They dry (cure) by mechanical reaction of the binder (epoxy resin) with a special hardener. The most common hardeners are polyamines or amino/polyamides (polyamide resins).

When cured properly, epoxy paints adhere very well, are very hard, show good mechanical properties, have a good resistance to water and an excellent resistance to chemicals, oil and many solvents.

For a good chemical resistance, of course the pigments, extenders and additives of these paints must also be chemically resistant.

The epoxy coatings cured with polyamine hardeners show a better chemical resistance, especially with respect to acids and solvents, than those cured with amino/polyamide hardeners.

The best chemical resistance however, is shown by the so-called *epoxy phenolic coatings*, which are used in tanks for extremely aggressive cargoes such as methanol and

fatty acids. For proper curing, epoxy phenolic coatings generally need somewhat higher temperatures than the straight epoxy coatings.

Amino/polyamide cured epoxy paints are more or less *tolerant to damp steel surfaces*. Special *primers for damp steel surfaces*, also known as *wet steel primers*, intended for use under humid weather conditions or in combination with wet-abrasive blast-cleaning, are based on these resins.

Some amino/polyamide curing epoxy resins are formulated so that they have *water-displacing properties*. They are used for epoxy coatings which can be applied on wet surfaces or even under water.

Coatings with water-displacing properties are used for offshore maintenance and maintenance in water ballast tanks.

Beside being more tolerant of damp surfaces, amino/polyamide cured epoxy coatings are easier to recoat, show better corrosion resistance and better resistance to atmospheric influences than the polyamine cured epoxy coatings. The latter, however, have a faster curing time and better chemical resistance.

Polyamine curing epoxy coatings are mainly applied in tanks carrying aggressive cargoes.

Polyamine curing epoxy coatings often suffer from exudation of hardener from the curing film, resulting in a sticky surface layer, which can cause intercoat adhesion problems. To avoid this, so-called 'adduct hardeners' can be used. In these hardeners, all the polyamine is prereacted with a part of the epoxy resin.

Like other high-duty paints, epoxy paints require careful preparation of the substrate; steel should preferably be blast-cleaned to a cleanliness of at least Sa 2^{1/2}.

After being mixed with the hardener (curing agent), the paint should be applied before its pot-life, as specified by the manufacturer, expires.

Epoxy paints can readily be applied by brush or spray in fairly thick coats. Suitable solvents are ketones or glycol derivatives; as thinners, blends of aromatic hydrocarbons and alcohols can be used.

Even at ambient temperatures epoxy paints cure rather slowly and due to their slow curing at low temperatures, conventional two-pack epoxy paints are in general not recommended for application below 10°C. With special 'adduct' hardeners however, curing down to -5°C is possible.

Special *low temperature curing epoxy coatings*, which cure with e.g. isocyanate hardeners, can cure at temperatures down to about -10°C. However, at low temperatures curing times will be very long.

Application of epoxy paints at relative humidities above 90% is not recommended since this may result in a non-homogeneous structure of the paint film.

When exposed to the atmosphere, epoxy paints lose their gloss rapidly and tend to chalk; the most sensitive are the polyamine cured types.

These defects however do not appreciably affect their protective properties.

The excellent hardness and solvent resistance of epoxy paints, especially of the polyamine cured types, is a disadvantage in maintenance work. For proper adhesion of the maintenance system a thorough roughening (or slight softening) of the old paint prior to the application of the repair paint is necessary.

Nowadays however, modified epoxy paints are available which, even after long exposure times, show a good recoatability and which do not tend to chalk as quickly as conventional types.

These *easily recoatable epoxy paints*, however, show a somewhat reduced resistance to chemicals and solvents and are mainly used for those parts of ships and offshore structures exposed to atmospheric conditions.

Epoxy paints are suitable for many parts of ships and offshore structures, in particular for the underwater areas, boottop zone, tidal and splash zone, underdeck areas, decks, holds and many types of tanks.

Zinc epoxy primers (including zinc epoxy prefabrication primers) are used extensively by virtue of their excellent anti-corrosive properties.

In the building of ship and offshore structures frequent use is made of epoxy paints of the *high-build type*, which can be applied in thicker coats than the corresponding high-build chlorinated rubber and vinyl paints.

For the protection of the insides of tanks, *solvent-free, solventless or high-solid epoxy coatings* are sometimes used. They contain little or no flammable solvents, thus reducing fire and health hazards.

The application of chemically resistant solvent-free epoxy tank coatings is mainly accomplished by twin-feed airless spraying.

Some types of epoxy resins can be modified (esterified) with fatty acids or drying oils to give (saponifiable) oxidatively drying *epoxy esters*. The properties and application of the one-component *epoxy ester paints* are comparable to alkyd resin paints, although epoxy ester paints have a somewhat lower chalking resistance and colour retention. The epoxy ester paints, however, can be applied in somewhat thicker layers and show somewhat better resistance to industrial atmospheres.

As they are saponifiable, they are not chemically resistant.

Especially for offshore structures some special products, on the basis of two-component epoxy resins are in use. Examples are:

- *Epoxy compounds (claddings)*, which are solvent-free, two-pack, fast-curing compounds, which are applied at thicknesses up to about 6 mm by pouring, spraying, hosing or trowelling. These compounds provide an impact, abrasion and corrosion resistant barrier in the tidal and splash zone areas and a non-skid coating on (heli)decks, floors and walkways of offshore structures.

- *Underwater repair coatings*, which are solvent-free, two-pack epoxy coatings, applied under water by brush, glove or putty knife. These coatings, which must have very good water-displacing properties, are designed as repair coatings for steel or concrete parts of offshore structures permanently submerged or in the tidal zone.

4.5.2.7 *Coal-tar epoxy paints*

A special group of epoxy paints is represented by the so-called coal-tar epoxy paints (coal-tar pitch epoxy resin combinations). Like other two-pack epoxy paints, they cure by chemical reaction between the epoxy resin and an added hardener (polyamine or amino/polyamide). Apart from being much cheaper, coal-tar epoxy combinations have a better water resistance than 'straight' epoxy paints without coal-tar pitch. However, they show a reduced chemical resistance and their resistance to solvents is poor.

Similar to the 'straight' epoxy, some types of coal-tar epoxy paints are formulated to provide water-displacing properties.

Coal-tar epoxy paints are suitable for the protection of underwater parts and water ballast tanks. Their chemical resistance is such that they can also be used in, for instance, cargo/storage tanks for (sour) crude oil.

The risk of 'bleeding' when overcoating coal-tar epoxy paints can be minimized to some extent by prior application of a *sealer*, e.g. before treating the underwater hull of a ship with anti-fouling paint. The use of a sealer has the additional advantage of improving the adhesion of the anti-fouling paint, thus serving as a *tie-coat*. Sometimes, instead of a special tie-coat, use is made of a *vinyl modified coal-tar epoxy paint*, which is partly physically drying, as the last layer of the anti-corrosive paint system to which the anti-fouling paint will adhere adequately.

In cases where a dark colour is undesirable, sometimes coatings based on epoxy- and coumerone-indene resin (*bleached tar*) are used (see also Part 4.5.2.2). Beside the advantage of a lighter colour, these coatings are more readily recoated than coal-tar epoxy combinations. Epoxy resin/bleached tar coatings are mainly used in water ballast tanks.

Like other epoxy paints, coal-tar epoxy combinations should not be applied at low temperatures; the limit is about 2°C. This restriction does not apply to certain special *low-temperature curing types*, employing poly-isocyanates as a hardener. These will cure at temperatures down to about -10°C. They are also referred to as *polyurethane-tar* coatings.

4.5.2.8 Polyurethane paints

Polyurethane paints, like epoxy paints, belong to the group of high-duty chemical resistant paints. They cure as a result of a chemical reaction between the binder (a polyester or polyether with free hydroxyl groups) and a hardener (poly-isocyanate).

Dependent on the choice of binder and hardener (curing agent), polyurethane coatings are capable of being made into soft, rubbery materials, as well as into hard, tough, chemically resistant products.

With regard to pot-life, surface preparation, adhesion, mechanical strength, hardness and resistance properties, two-pack polyurethane coatings are comparable to epoxy paints.

Polyurethane paints can be based either on *aromatic or aliphatic poly-isocyanates*.

Aromatic polyurethane paints show a poor gloss retention and yellow on prolonged exposure to sunlight.

The considerably more expensive *aliphatic polyurethane paints* show very good gloss and colour-retention on outdoor exposure and do not chalk.

In this respect they are superior to most other paints, including alkyd paints. These properties make the aliphatic polyurethane paints particularly suitable for the painting of objects requiring a decorative appearance, such as deck houses and accommodation areas.

Polyurethane paints are thinned with mixtures of esters, ketones and aromatic hydrocarbons.

In order to prevent undesirable chemical reactions, the paint, solvents and thinners must be absolutely free from water and/or alcohols, with which the isocyanate hardener reacts faster than with the binder component, forming carbon dioxide. This results in foamy, porous paint layers.

The isocyanate hardener also reacts with the water vapour from the air and with any moisture on the substrate. *Polyurethane paint containers therefore should not be left open for long periods and substrates should be dry.*

The sensitivity to moisture during drying precludes the application of polyurethane paints at relative humidities above 85%.

In view of their poor curing properties at lower temperatures, the application of polyurethane paints at temperatures below about 5°C is not recommended unless the manufacturer agrees. Polyurethane paints, however, are more tolerant in this respect than epoxy paints, which should not be applied at temperatures below about 10°C.

A disadvantage of polyurethane paints in maintenance work, as with certain types of epoxy paints, is their great hardness and resistance to softening by solvents, which may result in a poor adhesion of the repair paint. However, when using *polyurethane-acrylic paints*, which are combinations of acrylics (containing free hydroxyl groups) and poly-isocyanate hardeners, there are no adhesion problems. When these paints are based on an

aliphatic isocyanate, they are especially suitable where aesthetic appearance is required. Their chemical resistance, however, is less than that of straight polyurethane paints.

A special group of polyurethane paints is represented by the *moisture-curing types*.

Moisture-curing polyurethane coatings are one-component products, containing isocyanate groups bearing polymers, which cure by reaction with the moisture from the atmosphere to form the final crosslinked coating. Consequently, curing times are strongly influenced by the extent of air humidity.

Broadly speaking, the properties of the moisture-curing (one-component) polyurethane coatings are similar to those of the two-component products. Beside the advantage of being one-component products, moisture-curing polyurethane coatings can cure at temperatures down to about 0°C. Their recoatability however is more problematic than that of two-component polyurethanes.

4.5.2.9 Polyurethane tar paints

Like the corresponding epoxy products, polyurethane coal-tar combinations are mainly used for the protection of underwater parts and water ballast tanks. Although their application is somewhat more difficult, polyurethane tar paints have the advantage of curing more rapidly at slightly lower temperatures than the corresponding epoxy products.

Special polyurethane tar coatings can cure at very low temperatures (see also Part 4.5.2.7).

Moisture-curing polyurethane tar (one-component) products can be applied to damp (but not wet) surfaces and at high humidities.

4.5.2.10 Zinc silicate paints

In zinc silicate paints, the binder is a silicate and the pigment is zinc powder. These components are supplied separately in the correct proportions. The usual binders of the *self-curing zinc silicates*, which are mainly used nowadays, are *alkali silicates* (sodium, potassium, lithium or ammonium silicate) or *partially hydrolysed ethyl silicate*.

Paints based on an *alkali silicate* (water glass) contain water and can be thinned with it. Likewise, paints based on *ethyl silicate* contain alcohols, with which they can be thinned. The ethyl silicate paints have a very short setting time.

All types of zinc silicate paint cure as a result of:

- a. evaporation of water or solvent;
- b. formation of an *insoluble silica oxygen zinc polymer* (zinc silicate matrix), by reaction between the silicate, zinc particles (pigment) and iron (steel substrate);
- c. formation of zinc carbonate and zinc hydroxide on and within the film.

By the reactions b and c, which proceed during the lifetime of the coating and by the uptake of water and carbon dioxide from the air, the initial porosity of the paint film is gradually decreased.

The ethyl silicate paints show an especially rapid initial setting.

Full curing of zinc silicate paints requires a considerable time, depending on the temperature and relative humidity.

Most zinc silicate paints require a minimum relative humidity of 50% for proper curing. Especially inside buildings, structures and tanks, where humidities are often low, this may cause problems. During curing in these spaces, humidity should be closely followed by constant monitoring.

The curing of zinc silicate paints is accelerated by high humidity, high temperature and by spraying the set paint film with water. During application, however, the substrate should be dry.

For good adhesion, zinc silicate paints require a high degree of surface preparation which can only be obtained by thorough blast-cleaning; the blast cleanliness should be at least Sa 2^{1/2} at the time of paint application.

Also, a certain minimum roughness of the steel surface is recommended; for instance *the roughness (Ry5)* should be about 50 micrometers (see Appendix 3.B.).

After mixing the zinc dust and silicate, the paint should be used within the pot-life specified by the manufacturer.

The most suitable application method is pneumatic (air) spraying. Airless spraying is also possible, but it is less reliable because the pump suffers heavy wear from the zinc which deposits on the plunger. This is less serious in airless spraying zinc silicate prefabrication primers because of their reduced zinc content (low-zinc types).

During curing the (water based) alkali silicates form alkali hydroxides which remain in the film giving it an alkaline nature. This alkalinity decreases as the hydroxides react with atmospheric carbon dioxide forming the so-called 'curing salts'.

When overcoating, the alkalinity of the water-based zinc silicate paints can cause problems such as blistering, unless they are weathered for some weeks or hosed with fresh water to remove the alkali. For this reason, solvent-based (ethyl) silicates are favoured when zinc paints are to be overcoated.

Another advantage of solvent-based zinc silicate paints is that they may be applied at temperatures, down to about -10°C. The water-based types, however, do not give satisfactory films below 1°C.

Thick coats of zinc silicate paints are liable to suffer from *mud-cracking* (the appearance of hairline cracks). Accordingly, they should not be applied at thicknesses exceeding 120 micrometers, unless manufacturers' specifications state otherwise. As mentioned above, zinc silicate paint layers are always more or less porous after application. To avoid 'bubbling or pinholing' when overcoating, it is strongly recommended that a thin

'mist coat' of the subsequent paint be applied before the full coat, or alternatively to apply a special 'sealer coat'. Zinc silicate paints preferably should only be overcoated with unsaponifiable paints, such as those based on chlorinated rubber, vinyl copolymers, epoxy resins or polyurethane resins.

Before being overcoated, the surface should be completely freed from zinc salts (formed by weathering) by vigorous brushing with nylon brushes and hosing with an excess of fresh water or by (high-pressure) water spraying.

The anti-corrosive properties of zinc silicate paints are somewhat superior to those of zinc epoxy paints.

After appropriate curing, zinc silicate paints become very hard, wear resistant, heat resistant (being inorganic) and resistant to water and solvents. The alkali zinc silicates show the highest solvent resistance of all and therefore are frequently used as linings in tanks used to carry strong solvents.

Like other metallic zinc containing paints, zinc silicate paints are not resistant to acids and alkalis. They are also not resistant to organic substances which form acids on hydrolysis, such as esters and some types of oils and fats.

When (alkali) zinc silicate paints are used as tank coatings it is extremely important that these are sufficiently cured before loading cargo. This normally requires a few weeks. When not sufficiently cured, the initial porosity of the film enables the cargo to penetrate the coating and makes it extremely difficult to clean the tank when changing to another cargo. Also for this reason clean cargoes, e.g. solvents, should be the first to be carried and not cargoes which are difficult to remove, such as vegetable oils. To ensure adequate cleaning, it is extremely important to avoid rough layers, for instance due to dry (over) spray. The cleaning of a zinc silicate tank lining showing dry spray is very difficult and a subsequent cargo will readily be contaminated by remnants of the previous cargo.

Zinc silicate paints are mainly used to protect tanks for 'white oil products', holds and decks and they also find application as heat-resistant paints.

Another important application is their use as a prefabrication primer, which will be covered fully in Chapter V.

4.5.2.11 *Acrylic paints*

Acrylic paints are based on polymers or copolymers of (meth)acrylate esters. On ships and offshore structures, the following types of acrylic paints are used:

- *aesthetic two-component coatings*, for instance as top coat for deck houses, where the acrylic resin is cured by means of an aliphatic isocyanate hardener; these products are often called *isocyanate or polyurethane acrylic paints*. Compared to the straight polyurethane coatings, based on polyalcohols and isocyanates, the acrylic types show a better recoatability but a reduced chemical resistance (see also Part 4.5.2.8).

- *water dispersible physically drying wall paints*, less correctly called *emulsion or latex paints* (see also Part 4.5.2.14).

4.5.2.12 *Unsaturated polyester resin coatings*

These coatings consist of an unsaturated linear polyester (mostly obtained by reaction of glycol and maleic acid) and styrene. The mixture cures rapidly when brought into contact with a (peroxide) catalyst and a so-called accelerator. As the mixture of polyester and styrene is liquid and of the correct viscosity, no extra solvent needs to be added.

Unsaturated polyester coatings are solvent-free, fast curing products, which can be applied in thick layers. The coatings are slightly sensitive to saponification, especially under alkaline conditions.

On ships and offshore structures, unsaturated polyester coatings are mainly used as glass flake reinforced products for parts which are subject to severe abrasion. These may be underwater parts of (special) ships, fender areas and some parts of decks with heavy traffic. Glassflake reinforced epoxy coatings, which are still more resistant to mechanical damage and chemical influences, are also used for these parts.

4.5.2.13 *Silicon resin paints*

Paints based on silicon resins show good heat and weather resistance. Upon heating above about 280°C, silicon resins lose their organic structure and become inorganic (silicate structures).

Often silicon resins are used in heat-resistant paints (see Part 4.5.3.5) or are combined with other resins to upgrade their heat resistance. Examples are combinations with acrylic or alkyd resins. Moreover, combination of alkyd with silicon resins improves the outdoor durability of the alkyd paints.

4.5.2.14 *Dispersion paints*

A special group of paints is represented by the so-called *dispersion* or *emulsion paints*. The binder is not dissolved, but dispersed or emulsified as fine spherical particles in a medium, which often is water. Naturally, the paints also contain pigments, extenders and additives (such as a suitable plasticizer).

After evaporation of the water, the film is formed by the coalescing of the binder particles into a more or less continuous film. Because they contain water, emulsion paints should be stored under frost proof conditions.

For ships and offshore structures, water dispersible coatings based on bitumen, epoxy resins, coal-tar epoxy resin combinations, vinyl copolymers and acrylates are used.

Water dispersible bituminous and coal-tar epoxy coatings for instance can be used as maintenance coatings in water ballast tanks. Water dispersible epoxy paints are also sometimes used for decks.

When using water dispersible coatings, fire, explosion and health hazards are greatly reduced.

Painting and welding operations in tanks can be carried out simultaneously during maintenance.

Another advantage is the possibility of the application of water dispersible paints to damp surfaces. However, if applied to bare steel, these paints should contain suitable corrosion inhibitors.

It should be noted that during curing, adequate ventilation is essential for proper evaporation of the water from the coating.

Water dispersible *wall paints*, based on vinyl acetate copolymers or polyacrylates, are often used for interior work for instance on hardboard, chipboard and wood. These paints are often called *latex or emulsion paints*.

Dispersion wall paints of good quality are washable when dry, i.e. they can be cleaned with soap and water without being attacked.

Emulsion wall paints are usually easy to apply by brush and roller and the dry coats are readily permeable to water vapour. Depending on their composition, the dried films show an eggshell gloss or give a completely flat finish. They are easy to recoat, provided that the old coats are properly cleaned.

Water dispersible wall paints to be used in humid or wet accommodation and service spaces, should contain suitable biocides to prevent mould growth.

4.5.3 SPECIAL PRODUCTS, CLASSIFIED ACCORDING TO THEIR FUNCTIONS

4.5.3.1 *Varnishes (clear coatings)*

Varnishes are used for the transparent finishing of decorative woods. They are usually based on *alkyd resins, tung oil/phenolic resin or polyurethane resins*.

Varnishes based on alkyd resin and tung oil/phenolic resin are saponifiable. Those based on tung oil/phenolic resin or polyurethane resin are highly water-resistant and find application as e.g. yacht varnishes.

Polyurethane varnishes also are very abrasion resistant and resistant to chemicals and solvents. They are used, inter alia, as floor coatings and as a sealing coat which prevents the natural colouring matter of certain tropical wood species from migrating into the subsequent paint layers and discolouring them.

Varnishes based on tung oil/phenolic resin and those based on polyurethane resins curing with aromatic isocyanates tend to yellow but those curing with aliphatic isocyanates do not.

Alkyd resin and tung oil/phenolic resin varnishes are easy to apply by brush and are therefore widely used. Durable exterior work requires at least three or four coats. An advantage of these varnishes is that in maintenance work, old coats can easily be removed by means of paint strippers. Polyurethane varnishes are at a disadvantage in this respect unless the urethane alkyd combinations are used (see Part 4.5.2.3).

4.5.3.2 *Anti-fouling paints*

(see also Appendix 4.G. for detailed information)

If not properly treated, the underwater parts of ships and offshore structures are subject to fouling by species of the marine fauna and flora. The initial settlement is a slime deposit consisting of bacteria, diatoms and other micro-organisms.

The (macro)fouling organisms are generally divided into two major types, e.g. *grasses* and *shells*.

Grass fouling consists of seaweeds, mainly green and brown and occasionally red algae.

Shell fouling comprises barnacles (acorn and goose), tubeworms, polyzoans, mussels etc.

The degree of fouling depends considerably on the temperature of the water. In colder regions fouling occurs only in summer. In tropical waters however, fouling is extensive and may occur during the whole year.

Other factors influencing the degree and type of fouling are light, salinity, nutriment, remains of older fouling etc.

The variation in fouling conditions throughout the world makes the degree and type of fouling, to be expected on a ship, to a large extent dependent on its sailing routes.

Although algal spores are capable of settling at water speeds up to 10 knots, fouling mainly occurs in relatively static conditions on offshore structures and on ships at anchor or moored at a berth. Ships that stay in port for short periods will therefore foul less severely than those that spend more time there. If a ship is idle for one day only, both algae and animal species may settle on the hull. However, whilst the algal spores will remain attached when the vessel goes to sea, the animal species will not have become sufficiently firmly attached and will be swept off as the speed of the vessel increases. The algae will continue to grow and produce a, usually, green 'beard' near the waterline. Although some species of barnacle can tolerate salinities down to 5 ppt, most cannot and react to fresh water by closing their shell and waiting for more congenial conditions. In contrast some species of algae are able to tolerate fresh water. In general the algae settle in the most highly illuminated parts i.e. near the surface of the water whilst animal fouling tends to settle in the less well lit regions mainly towards the deeper parts of the hull.

Fouling considerably roughens the underwater hull of a ship, thereby lowering its speed or increasing its fuel consumption due to higher frictional resistance which, on a slow moving ship can amount up to 80% of the total resistance.

On offshore structures fouling considerably increases the surface area of the supporting construction, leading to a considerable increase in the forces acting on it by tidal flow and wave action. This, and also the increase in weight of the structure, has a considerable influence on the design and the financial consequences. Moreover, fouling makes adequate underwater inspection of nodes impossible.

From the foregoing it will be clear that for *economic reasons* underwater parts of ships must be kept fouling free as long as possible. For reasons of *safety and economy* this also applies to the underwater parts of offshore structures.

Fouling prevention normally is obtained by the application of *anti-fouling paints*.

These paints function by a *slow release of toxins* into the laminar sub-layers around the underwater surfaces and thus prevent the settlement or development of marine organisms. A drawback of this system for ships is that most of the toxin is released when the ship is sailing and is least in need of protection.

The main toxic materials nowadays used in anti-fouling paints are *cuprous oxide and/or organometallic compounds* such as *tributyl tin oxide (TBTO)*, *tributyl tin fluoride (TBTF)* or *triphenyl tin fluoride (TPTF)*. In fresh water hardly any cuprous oxide is released.

In the past many other toxic materials were developed which, due to their health and environmental problems, are no longer used or are already banned. Recently, the use of TBTO and related tin compounds have been withdrawn or had their use restricted by legislation in a number of countries (see Parts 4.5.3.2d and 11.7).

Cuprous oxide contains some free copper, and for this reason anti-fouling paints based on cuprous oxide should never be applied directly to metal since contact corrosion would occur.

When the available toxin is exhausted, or when the release falls below the minimum lethal dose for marine organisms, fresh anti-fouling paint layers are applied.

On offshore structures where recoating is not possible, fouling will periodically be removed by underwater scraping.

If the underwater parts of ships or offshore structures are painted with coal-tar epoxy or polyurethane-tar, sometimes a so-called 'sealer' or 'tie-coat' is applied before the application of the anti-fouling paint. This sealer prevents the tar from bleeding into the anti-fouling coating system, thereby maintaining its effectiveness; in addition, a sealer or tie-coat improves the adhesion of the anti-fouling paint system. Nowadays however, the second coat of the anti-corrosive system (coal-tar epoxy or polyurethane tar) is often specially formulated for this purpose by the incorporation of some physically drying binder components such as vinyl resins.

Anti-fouling paints (anti-fouling) can be divided into the following types:

a. Soluble-matrix anti-fouling paints

In soluble-matrix anti-fouling paints, based on rosin (natural resin), the binder as well as the poison gradually dissolves in the water. Such paints, which are called *conventional (classical) anti-fouling paints* are very sensitive to alkali and should preferably not be used in combination with cathodic protection.

Because of the risk of cracking, soluble matrix (rosin-based) anti-fouling paint layers should not be allowed to stand unimmersed (exposed to the atmosphere) for long periods after drying. They should be applied shortly before the ship is launched, allowing sufficient time for drying before launching.

Naturally dependent on the factors mentioned above, the service life of conventional anti-fouling tends to be shorter than that of other formulations.

Commercially available conventional anti-fouling normally have a service life of 6-12 months.

b. Contact-matrix anti-fouling paints

In so-called *contact-matrix anti-fouling paints*, also called *long life anti-fouling paints*, the vehicle is based on insoluble and semi-soluble binders.

The name of the anti-fouling paint is based on the insoluble part of the binder which is very often chlorinated rubber or vinyl resin. In contact with sea water the toxic material and soluble part of the binder (rosin) leach-out from the paint film, leaving behind an empty skeleton (matrix) of the insoluble part of the binder on top of a still unleached part of the anti-fouling paint layers. The diffusion of toxins through this growing 'empty matrix' gradually decreases with time. Finally, the leaching-rate of the underlying anti-fouling is reduced to such an extent that fouling will occur. The empty matrix will also provide a certain roughness of the underwater surface (see also Part 7.2.2).

As the leaching is not linear with time, in the early days of the anti-fouling the toxin will leach rapidly and at the end of the service life there will still be a residue of toxic material in the depth of the coating.

The maximum service life of commercially available longlife anti-fouling is about 16-24 months at dry film thicknesses of about 150 micrometers, normally obtained by the application of two (high-build) paint layers. If thicker layers are used, adequate diffusion of toxic material may become too difficult due to clogging of the residual insoluble binder skeleton.

Special types of the longlife compositions form the so-called *reactivable anti-fouling*. With this type of paints, the 'skeleton', formed when the soluble matter leaches out, changes colour. The 'skeleton' is removed by special brushes. This operation is referred to as 'reactivation'. By this process, the discoloured leached-out part of the anti-fouling

paint layer is removed and a fresh red-brown active layer is exposed as if a new layer of anti-fouling paint has been applied. Moreover, this tends to improve the smoothness of the hull.

Also no excessive build-up of coating layers occurs so that at the subsequent dry-docking no sealer coat is required before application of a fresh coat of anti-fouling paint. Such reactivation should be repeated about once a year and, if initially sufficient anti-fouling is applied, it is possible to keep the ships' underwater parts clean and smooth for up to 5 years.

In order to avoid mechanical damage of the underwater coating system and subsequent corrosion, the brushing operation must be carried out very carefully and in case there is accidental removal of the whole anti-fouling system in some areas it is very important that the ships underwater hull is protected by a high-performance (mechanically strong) anti-corrosive system.

c. Self-erodable (polishing, ablative) anti-fouling paints

This type of anti-fouling paint consists of high-build coatings based on organometallic polymers, very often tributyl tin acrylate copolymers. In sea water the organotin moiety is released, leaving behind acidic groups, making the polymer soluble in the slightly alkaline sea water. Thus a situation is created where *the anti-fouling paint gradually erodes, giving protection against fouling growth and keeping the underwater hull smooth*. As no leached-out matrix remains, the availability of fresh toxic material is quaranteed continuously.

The erosion with this type of paint proceeds at a rate roughly linear with time and is about 0.2-0.3 micrometers a day (73-100 $\mu\text{m}/\text{year}$). For a service life of 3-5 years, which is possible, thick layers have to be applied, often realized by at least two coats of different colour with a dry film thickness of 150 μm each.

During subsequent dry-dockings no excessive build-up of the coating occurs and no sealer is required before the application of a fresh coat of anti-fouling paint.

d. Future anti-foulings

Since present anti-fouling paints are toxic due to the incorporation of toxins (biocides), they form a substantial hazard for workers (inhalation of spray mist or blasting dust) and for the environment (water pollution).

One of the least hazardous toxins is cuprous oxide, which has been used since very early times.

Anti-foulings containing DDT, mercury and arsenic must not be used. For the future it is to be expected that legislation, as already realized in for instance England, France and Sweden, will be introduced in many countries. This will restrict the use of organotin anti-foulings, for instance on small craft and yachts smaller than 25 meters.

For the above mentioned reasons, current research is focused on the development of anti-fouling which do not present health hazards or environmental pollution and on the development of fouling prevention by means other than coatings.

Some experiments, already performed, employ special anti-adhesive coatings based on Teflon-filled fluorinated polyurethanes or epoxies and the use of certain silicones.

For more information concerning fouling prevention by paints the reader is referred to Appendix 4.G.

4.5.3.3 *Non-slip/non-skid paints*

Non-slip or non-skid paints are used on main decks, helidecks, walkways and other areas with heavy traffic on ships and offshore structures. They are intended to render the surface rough, even when wet or when oil has been spilled on it.

Non-slip and non-skid paints contain a quantity of coarse material, the *aggregate*, such as non-sparking materials like aluminium oxide, glass beads and vegetable shells and other materials like sand (silica), pumice powder, slags etc. The aggregates, which can be obtained in different particle sizes, should not be so sharp that personnel are hurt, who might fall on surfaces coated with non-slip or non-skid paint.

Non-slip paints are intended for pedestrian areas and must provide a finish which is rough enough to minimize slipping and falling.

Non-skid paints are intended for areas for wheeled transport.

The aggregate for non-skid paints generally is coarser and harder than the aggregate for non-slip paints.

For offshore structures the requirements are for a non-iron containing quartz-free, non-spark or low-sparking aggregate with a sparking intensity below that of carbon steel.

Sometimes the aggregate is sprinkled on to the paint coat when it is still wet, alternatively the material is incorporated into the liquid paint. Thorough stirring before use is then extremely important.

To ensure proper adhesion of the embedded anti-skid material, often an extra aggregate-free top coat is applied after the application of the non-skid paint but this must not detract from the non-skid property of the system.

Although non-skid (non-slip) paints can be based on a variety of binders, those based on epoxy and polyurethane resins, are preferred. These paints are resistant to abrasion, water, oil and spillage of chemicals.

4.5.3.4 *Paints with laminar (flake) pigments*

In the dried layers of such paints the laminar pigment particles (flakes) are distributed parallel to the surface and overlap, thus forming a barrier to water (vapour) and chemicals.

Moreover, laminar pigments form a barrier to ultraviolet light and consequently reduce its influence on the degradation of paint binders. Also, the mechanical properties of paint layers are improved by the use of these pigments.

The most common laminar pigments are *micaceous iron oxide (MIO)*, *aluminium (leafing and non-leafing)*, *glass*, *mica* and *stainless steel*.

Micaceous iron oxide is the most widely used and acts mainly as a barrier (sealer) against water (vapour) transmission. Micaceous iron oxide paints therefore, are mainly used as sealers in coating systems for under and above water exposure.

Especially by glass flake, mica and micaceous iron oxide mechanical properties of paint layers like scratch, impact and abrasion resistance are improved. For this reason, glass flake coatings nowadays are often applied on for instance bulbous bow, anchor chain area, fender areas and special deck areas of ships and in the splash zone and on special deck areas of offshore structures.

Glass flake coatings are high-solid or solvent-free products, mainly based on epoxy or unsaturated polyester resins. They are applied in thicknesses ranging from about 0.5 to 2 mm. The epoxy based coatings are advantageous with respect to the ease of application and chemical resistance.

Apart from aluminium, which is not chemical resistant, the laminar pigments are chemically inert and can be successfully used in chemical resistant coatings (tank linings). When a high acid resistance is required, glass flake coatings are to be preferred. Coatings containing leafing aluminium flakes, strongly reflect sunshine and may be successfully applied on the outside surfaces of storage tanks for volatile products and thus considerably reduce the heating of these product.

It must be noted, however, that during exposure in industrial environments, the aluminium pigmented coatings lose their brilliance and consequently their heat reflecting properties are reduced. In these environments, therefore, so-called 'self-cleaning coatings' pigmented with titanium dioxide, a part of which consists of the anatase modification, are to be preferred.

4.5.3.5 *Heat resistant paints*

Most paint products will, apart from some discolouration (yellowing), be unaffected when used at temperatures up to about 80-100°C. Those used for the outside of hot water water containers and central heating units, require a temperature resistance up to 120°C and are often based on *soya oil alkyd resins*. When this type of paint is pigmented

with aluminium, it will be resistant to temperatures up to about 170°C. Epoxy or polyurethane aluminium paints are heat resistant even up to about 200°C.

Paint products to resist temperatures of about 200-250°C for longer periods are often based on *silicon/alkyd* or *silicon/acrylic resin* combinations.

When a higher temperature resistance is required, so-called *high-heat resistant paints* are used which, depending on the actual circumstances, can withstand temperatures up to 500-600°C. This type of paint is normally based on *silicon resins*, pigmented with titanium dioxide or aluminium, or is based on (*zinc*) *silicate*.

For these circumstances also the so-called *zinc graphite stack paints* can be used which are mixtures of zinc dust, graphite powder and stand oil; at high temperatures they sinter on their substrate and are resistant up to about 450°C.

In order to obtain an optimum temperature resistance, heat resistant paints should be heated very gradually to the maximum temperature they can withstand.

4.5.3.6 *Fire-retardant and fire-resistant paints*

Fire-retardant paints are defined as paints that prevent combustible substrates from catching fire and retard spread of flame along the surface. These paints are mainly used on wood, board etc., in order to prevent these materials from catching fire.

Fire-resistant paints or compounds should protect a structure, in case of fire, from spread of flame, from a rapid rise in temperature and from loss of strength.

Fire-resistant paints or compounds are used principally on steel structures in order to keep the temperature of the steel as low as possible, thus protecting it against loss of strength.

Fire-retardant and fire-resistant paints are based on binders that are difficult to ignite or are self-extinguishing. Pigments are specially selected and sometimes salts (for instance phosphates) having a specific action are added.

A possible combination is a binder containing chlorine (e.g. chlorinated rubber) with antimony oxide as pigment. When heated, such paints evolve self-extinguishing gases, which, however, are hazardous.

The most effective types of fire-retardant and all fire-resistant paints are intumescent, i.e. on heating they form a thick heat-insulating layer of foam consisting mainly of carbon. Such fire-resistant paints should be applied in thick layers (e.g. 1-2 mm) so that thick foam coats are formed which withstand high temperatures for a long time.

Especially on offshore structures *fire-resistant cement based compounds* are used. These compounds, which are applied in thicknesses of a few centimeters on an inorganic anti-corrosive coating system and which can be top coated, are reinforced by means of a coated galvanized mesh which is fixed to the steel substrate. These fire-resistant systems

are designed to provide sufficient time for fire-fighting and for the complete evacuation of offshore platforms.

In several countries fire-resistant and fire-retardant paints and compounds are subject to standards containing requirements concerning resistance to flame-spread and flame-propagation, the time they protect structural steel against loss of strength and (toxic) smoke generation etc.

An international organisation that is active in this field is the IMO (Intergovernmental Maritime Organisation).

4.5.4. DATA SHEETS

Data sheets serve to inform painting contractors and users of a paint product about its properties. Data sheets should therefore contain *all* relevant information that owners of ships and offshore structures, yards and painting contractors need for the correct and safe use of the paint material concerned.

In order to facilitate comparison of products of different origin, a uniform drafting and arrangement of data is strongly recommended. In order to facilitate calculations by the paint users, statements of all technological properties, wherever applicable, should be given in volume and in weight units.

Data sheets should contain the following items:

a. **Name, supplier, type**

- trade name of the paint product;
- name and address of supplier (and if necessary, that of his representative in the country concerned);
- type of material, with a short description of its main characteristics.

b. **Delivery form**

c. **Available colours and gloss values (if applicable)**

d. **Composition**

QUALITATIVE DATA

- main pigments and extenders (if applicable);
- type of binder;

- type of hardener (if applicable);
- type of solvent and thinner (if applicable).

QUANTITATIVE DATA

- total non-volatile content of the mixed paint* in % by weight and by volume (volume solids);
- content of pigment in the dried paint film in % by weight for anti-corrosive primers (only when relevant).

e. **Physical properties**

- density (specific gravity) of the mixed paint.

f. **System specification**

- systems where the paint is used and its place in these systems.

g. **Application data**

- substrate(s) for which the paint is intended and method and degree of surface preparation;
- ratio of paint base to hardener, by volume and by weight (only for two-pack products);
- induction time (only for two-pack products);
- pot-life at different temperatures (only for two-pack products);
- application methods;
- recommended thinner(s);
- alternative thinner(s);
- cleaning solvent(s);
- spraying pressure, type of spraying equipment, orifice (nozzle) and spraying viscosity;
- approximate quantity of thinner needed to bring the paint to spraying - viscosity, in % by weight and by volume;
- maximum allowable amount of thinners to be added in % by weight and by volume;
- minimum, maximum and preferred wet film thickness of a single coat;
- minimum, maximum and preferred dry film thickness of a single coat;

* The mixed paint is the product supplied, including when appropriate, the correct amount of hardener, but excluding any thinner needed for application.

- theoretical spreading rate in m^2/l and m^2/kg of the mixed paint, when applied at the desired film thickness;
- ranges of temperature and relative humidity within which the paint should be applied;
- relevant drying characteristics including recoatability, in relation to temperature, relative humidity or both;
- relevant curing times (in relation to temperature) before a coating system is allowed to be taken into service (for instance for tank coating systems and anti-foulings);
- storage stability at different temperatures.

h. Special properties of the dried paint coat (if applicable) e.g.:

- resistance properties; for tank coatings refer to a 'commodity list';
- fire-resistance;
- non-slip properties;
- resistance to cathodic protection;
- heat-resistance, etc.

i. Safety and health

- hazard code;
- flash point of the ready-mixed paint (including test method);
- presence of hazardous substances;
- special health and/or safety measures to be taken during application; if necessary, TLV (MAC) should be quoted for the solvents;
- special health measures to be taken when welding or flame-cutting plates treated with the paint in question.

An example of a data sheet for a coal-tar epoxy paint is given in Appendix 4.E..

4.5.5. TABULAR COMPARISON OF THE DIFFERENT PAINT TYPES

Appendix 4.F. compares the different paint types, classified according to their binders. It should be noted, that the figures given in this table are merely typical values, and that the exact properties of a paint material depend not only on the binder type, but also on the type of pigment and other constituents.

For example, a two-component epoxy paint pigmented with titanium dioxide has excellent resistance to chemicals, whereas one containing zinc as the pigment is sensitive to acids and alkalis, although this type of paint has an optimum corrosion resistance.

For maximum chemical resistance it is essential to combine chemically-resistant binders with chemically-resistant pigments. Different pigments may give totally different properties with the same type of binder.

APPENDIX 4.A. - PIGMENTS AND EXTENDERS

A. Pigments mainly used in primers

Pigments	Characteristics
Red lead (orange)	typical conventional anti-corrosive pigment; toxic; often used in combination with iron oxide.
Zinc (potassium) chromate (yellow)	typical conventional anti-corrosive pigment; slightly carcinogenic; welding vapours maybe harmful to health; slightly water-soluble, which inhibits corrosion but may also cause blistering of paint systems in immersed areas.
Zinc tetroxy chromate (yellow)	type of zinc chromate with low water-solubility; slightly carcinogenic; mainly used in pretreatment (wash) primers.
Zinc phosphate (white) Calcium phosphate (white)	modern anti-corrosive pigments; non-toxic; corrosion-resistance less than red lead, zinc chromates and zinc dust.
Zinc dust (grey)	anti-corrosive pigment with excellent anti-corrosive properties; local cathodic protective function when used in 'zinc-rich' primers; soluble zinc salt formation when exposed to marine/industrial atmospheres.
Metallic lead (dark grey)	not widely used; toxic; as being cathodic to steel, no local cathodic protective function; sometimes used in primers for direct application to galvanized steel.
Iron oxide (red, brown or yellow)	not an anti-corrosive pigment itself; inert; has good weather-resistance and good covering power; iron oxide pigments are often combined with typical anti-corrosive pigments; red oxide primers may mask initial breakdown by rusting.

Appendix 4.A. - Continuation

B. Laminar pigments, mainly used for undercoats and finishes

Pigments	Characteristics
Aluminium - leafing - non-leafing	<p>in the dried paint layers the leafing pigment particles lie parallel to the surface and overlap, thus forming a barrier to water vapour and moisture and improve the tensile strength; leafing-aluminium reflects sunshine so as to reduce the heating of, for instance, storage tank surfaces.</p> <p>non-leafing aluminium is not often used in paints for ships and offshore structures.</p>
Micaceous iron oxide (MIO) Mica Glass flake Stainless steel	<p>especially by glass flake, mica and micaceous iron oxide (MIO), mechanical properties like scratch- and impact resistance are improved.</p> <p>unlike aluminium, which is not chemically resistant, laminar pigments are chemically inert</p>

Appendix 4.A. - Continuation

C. White pigments, mainly used for undercoats and finishes

Pigments	Characteristics
Titanium dioxide - rutile - anatase	rutile titanium dioxide is the most widely used white inert pigment; the anatase type of titanium dioxide chinks severely on exposure of UV-light and is, for this reason, sometimes combined with the rutile type to obtain the so-called self-cleaning (tank) paints (top coats with controlled rate of chalking).
Zinc oxide	zinc oxide may be used, in combination with other pigments, for its fungicidal properties
Antimony oxide	antimony oxide may be used in fire-retardant paints.

Appendix 4.A. - Continuation**D. Coloured pigments for undercoats and finishes**

Colour	Pigment	Characteristics
Red	- toluidine red	organic pigment; rather poor covering power
	- molybdate reds	toxic; good covering power; good colour and gloss retention
Orange	- molybdate orange	toxic; good covering power; good colour and gloss retention
Yellow	- lead chromates	toxic; good covering power; good colour and gloss retention
	- hansa yellow	organic pigment; rather poor covering power; good colour and gloss retention
	- yellow iron oxide undercoats	inert; unattractive colour; mainly used in primers and undercoats
Green	- chrome greens	toxic; good covering power; good colour and gloss retention
	- chrome oxide green	unattractive colour; good covering power; good temperature and chemical resistance
	- phthalocyanine green	organic pigment; good covering power; good colour and gloss retention; chemically resistant
Blue	- phthalocyanine blue	see phthalocyanine green
	- iron blue (Prussian blue)	toxic; good covering power; moderate weather resistance; poor chemical resistance
Black	- black iron oxide	inert; moderate covering power; mainly used in undercoats
	- carbon black	inert; good covering power; good colour and gloss retention

Appendix 4.A. - Continuation

E. Anti-fouling pigments and biocidal agents (poisons)

Cuprous oxide (red pigment) and certain *organometallic compounds*, such as *tributyl tin oxide (TBTO)*, *tributyl tin fluoride (TBTF)* and *triphenyl tin fluoride (TPTF)*.

TBTO is often used as a moiety in acrylate copolymers for self-erodable anti-fouling paints.

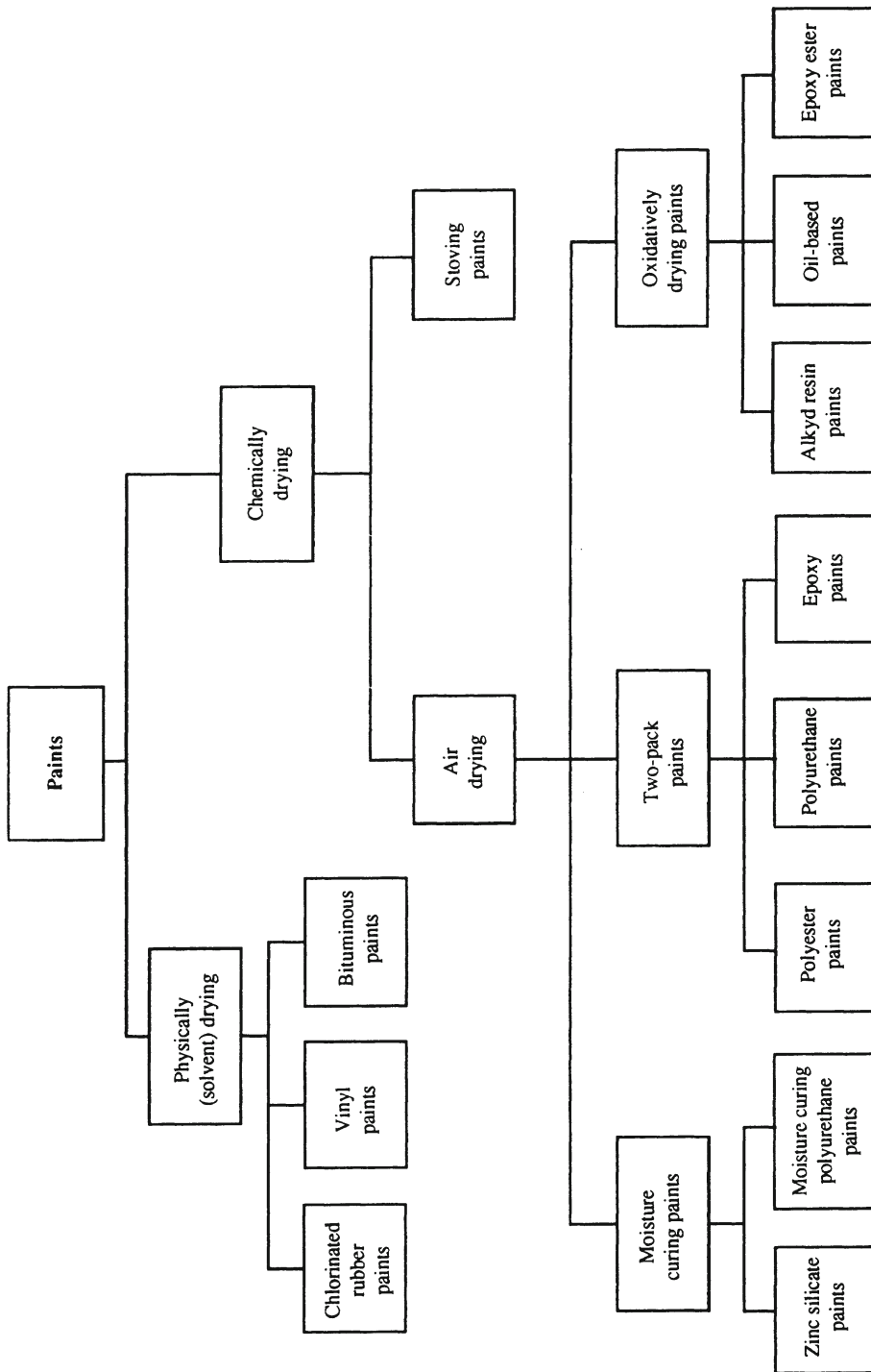
F. Extenders

Main group	Extenders	Some characteristics
Silicas (SiO ₂)	<ul style="list-style-type: none"> - quartz - diatomaceous silicas (kieselguhr) 	<ul style="list-style-type: none"> suitable for non-slip paints suitable for gloss reduction
Silicates	<ul style="list-style-type: none"> - aluminium silicates (china, clay, mica, bentonite) - calcium silicates - magnesium silicates (talc, e.g.) 	<ul style="list-style-type: none"> anti-settling and reversible (thixotropic) gel producing properties stabilization of emulsion paints anti-settling properties
Sulphates	<ul style="list-style-type: none"> - barium sulphate (barytes and blanc-fixe) - calcium sulphate (gypsum) 	<ul style="list-style-type: none"> inert; insoluble; very useful extender in high-duty coatings water sensitive; not suitable for high-duty coatings
Carbonates	<ul style="list-style-type: none"> - calcium carbonate (chalk, whiting) - calcium magnesium carbonate (dolomite) 	<ul style="list-style-type: none"> cheap extenders; not acid-resistant; not to be used in high-duty coatings and in coatings exposed to industrial atmospheres

APPENDIX 4.B. - SOLVENTS AND DILUENTS (THINNERS)

CLASS	MAIN TYPES	BOILING POINT OR BOILING RANGE, °C	FLASH POINT (CLOSED CUP), °C
Aliphatic hydrocarbons	<ol style="list-style-type: none"> special boiling point spirits, free from aromatics aromatic-free mineral spirit (odourless white spirit) mineral spirit (white spirit); contains about 15% aromatics aromatic white spirit; contains about 40% aromatics 	e.g. 80/110 to 140/160 187-212 160-200 160-200	- 20 to 27 58 39 41
Aromatic hydrocarbons	<ol style="list-style-type: none"> toluene xylene high-boiling aromatics (solvent naphthas), such as 'Aromasol H' and 'Solvesso 150' 	111 144 170-200 and 195-215	6 27 47 and 66
Alcohols	<ol style="list-style-type: none"> ethanol isopropanol (isopropyl alcohol, IPA) isobutanol (isobutyl alcohol) butanol (butylalcohol) methoxypropanol (MP) 	78 82 108 118 117-125	12 12 27 35 35
Esters	<ol style="list-style-type: none"> ethyl acetate butyl acetate isobutyl acetate methoxy propylacetate (MPA) ethoxypropylacetate (EPA) 	77 127 118 140-150 156-162	- 4 25 18 50 54
Ketones	<ol style="list-style-type: none"> methyl ethyl ketone (MEK) methyl isobutyl ketone (MIBK) 	80 117	- 4 15
Glycol derivatives	<ol style="list-style-type: none"> ethyl glycol (glycol monoethyl ether, 'Cellosolve', 'Oxitol') butyl glycol (glycol monobutyl ether, 'Butyl Cellosolve', 'Butyl Oxitol') ethyl glycol acetate ('Cellosolve acetate', 'Oxitol acetate') 	135 171 156	40 61 51

APPENDIX 4.C CLASSIFICATION OF PAINTS ACCORDING TO DRYING MECHANISM



APPENDIX 4.D. - SPECIAL PRIMERS FOR STEEL

TYPE	USE	SOMETIMES CALLED	GENERAL PROPERTIES	GENERIC BINDER TYPE	SPECIFIC PROPERTIES
<i>Prefabrication Primer</i>	On wheel-abraded steel (automatically) sprayed	Weldable primer Shop-primer Prefab primer	<i>High</i> pigment load; no optimum in chemical or mechanical resistance can be expected. <i>Very thin film</i> (20-25 μm) giving limited corrosion resistance. <i>Very fast drying</i> (less than 3 min.). <i>May not be recoated with itself</i> (no strength). Compatible with many paint systems. Can be welded and cut. Very fast evaporating solvents.	Alkyd P.V.B. (polyvinyl butural) Zinc Epoxy Zinc Silicate Epoxy	For atmospheric exposure only (not immersed). To be overcoated with alkyd paint system. Not to be used for underwater paint systems exposed to cathodic protection. When exposed, zinc salts are formed. Good corrosion resistance. Most often used.
<i>Touch-up Primer</i>	For spotwise repairs of cleaned welds and damage. For upgrading of prefabrication primed steel	Repair primer	<i>Medium</i> pigment load. <i>Not too fast</i> evaporating <i>mild</i> solvents. Therefore compatible with <i>weathered prefabrication primer</i> and <i>imperfectly cleaned steel</i> . Drying time is normal, <i>overcoating time relatively long</i> . Dry film thickness 50-70 μm . Good wetting properties.	Epoxy	Can be used on top of, or in connection with weathered zinc silicate or zinc epoxy prefabrication primers.
<i>Holding Primer</i>	On in situ blast-cleaned steel, in or outside the shop.	Blasting primer	<i>Medium</i> pigment load, medium fast drying solvents and relatively <i>low solid content</i> . It dries and <i>cures very well</i> . No dust pick up. Can be overcoated quickly to shorten dry-docking times, but should also be <i>overcoated within a relatively short time</i> (2 weeks). Dry film thickness 35-50 μm .	Epoxy (zinc epoxy) Zinc silicate	Mechanical and chemical properties are much better than those of prefabrication primers, e.g. improved resistance to cathodic protection.
<i>System primer</i>	On in situ blast-cleaned steel, in or outside the shop.	Primer	<i>First</i> coat (anti-corrosive) of paint system based on various binders and <i>normal solvents</i> . Drying time <i>not very critical</i> . Dry film thickness 50-100 μm .	Alkyd, Epoxy, Vinyl, Chlorinated rubber, PUR, etc.	Generally the primer has very good properties when exposed for longer time. <i>Very often</i> also long maximum overcoating times.
<i>Universal Primer</i>	Either as Touch-up primer, Holding primer or System primer	-	<i>Flexible in applied thickness, overcoating time and drying</i> (depending on thickness). <i>Curing proceeds slowly</i> compared to a holding primer	Epoxy	The properties should cover those of <i>touch-up primer</i> and <i>system primer</i> . Drying time is a bit longer than holding primer but the applied film thickness can be 2 to 3 times as high.

APPENDIX 4.E. - EXAMPLE OF A DATA SHEET FOR A COAL-TAR EPOXY PAINT

Trade name	Eptar-1											
Manufacturer	Formulator Ltd., Paint City											
Description	Coal-tar pitch epoxy resin combination with excellent water and crude oil resistance; particular suitable for underwater (submerged) parts of ships and offshore structures, water ballast tanks, lock gates, crude oil tanks, concrete sewage pipes etc.; fully compatible with cathodic protection											
Delivery form	separate containers of base and hardener, in correct mixing ratio											
Colours and gloss	black and brown, eggshell											
Composition	pigments/extenders : silicate extenders binder : epoxy resin/coal-tar pitch hardener (curing agent) : aliphatic polyamine solvent/thinner : alcohols/aromatic hydrocarbons											
- qualitative												
- quantitative (mixed product)*	total solids	:	70% by weight abt. 60% by volume									
	density (23°C)	:	1.36									
System specification	- underwater hull systems	:	see system sheet 100									
	- offshore submerged parts	:	see system sheet 200									
	- tank coating system	:	see system sheet 300									
	- pipeline system	:	see system sheet 400									
Application data												
- substrates	steel steel with intact, unsaponifiable shop-coat, approved by Formulator Ltd. concrete											
- surface preparation	steel	:	thorough blast-cleaning; blast-cleanliness at least Sa 2 ^{1/2} (ISO 8501)									
	shop-coat	:	- mechanical cleaning and degreasing where necessary; cleanliness at least Pt3 (SSPS) - sweep-blasting; cleanliness at least Ss (SSPS)									
	concrete	:	brushing for removal of loose particles									
- mixing ratio			<table style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th></th> <th style="text-align: center;"><i>parts by weight</i></th> <th style="text-align: center;"><i>parts by volume</i></th> </tr> </thead> <tbody> <tr> <td>base</td> <td style="text-align: center;">90</td> <td style="text-align: center;">85</td> </tr> <tr> <td>hardener</td> <td style="text-align: center;">10</td> <td style="text-align: center;">15</td> </tr> </tbody> </table>		<i>parts by weight</i>	<i>parts by volume</i>	base	90	85	hardener	10	15
	<i>parts by weight</i>	<i>parts by volume</i>										
base	90	85										
hardener	10	15										
- induction time	paint not to be applied within 1/2 hour after mixing of base and hardener											
- potlife	10°C : approx. 24 hrs. 15°C : approx. 12 hrs. 20°C : approx. 8 hrs. 25°C : approx. 4 hrs.											
- application methods	brushing, rolling, air spraying, airless spraying (brushing and rolling only for touch-up and spot repair)											

* mixture of base and hardener

APPENDIX 4.E. - Continuation

- thinner	thinner A			
- alternative thinner	xylene/sec. butanol 1/1			
- cleaning solvent	thinner Sc or alternative thinner			
- quantity of thinner to be added to mixed paint at 20°C		<i>% by weight</i>	<i>% by volume</i>	
	brushing	max. 3	max. 5	
	rolling	max. 3	max. 5	
	air spraying	3-7	5-10	
- air spraying data	airless spraying	max. 7	max. 10	
	nozzle orifice	: 1.5 - 3 mm		
	nozzle pressure	: 0.2 - 0.4 MPa (about 2-4 at; 28-56 p.s.i.)		
- airless spraying data	nozzle orifice	: 0.38 - 0.53 mm (0.015 - 0.021 inch)		
	nozzle pressure	: 12 - 15 MPa (about 1680 - 2100 p.s.i.)		
- film thickness	dry coat	: 125 - 250 micrometers (µm)		
	wet coat	: 200 - 400 µm		
- theoretical spreading rate	125 µm dry coat	: 5 m ² /l (3.7 m ² /kg)		
	250 µm dry coat	: 2.5 m ² /l (1.8 m ² /kg)		
- application temperature and humidity	temperature range	: 5-30°C		
	relative humidity	: not over 90%		
- curing data up to 250 µm dry film thickness, approximate times	<i>temperature (°C)</i>	<i>touch dry after</i>	<i>recoat after</i>	<i>fully cured after</i>
	5	16 hrs	36 hrs	20 days
	10	10 hrs	24 hrs	15 days
	15	8 hrs	20 hrs	10 days
	20	6 hrs	16 hrs	7 days
	25	4 hrs	12 hrs	4 days
- storage stability	30	3 hrs	8 hrs	2 days
	15°C	: 2 years		
	20°C	: 1 year		
	25°C	: 6 months		
	30°C	: 3 months		
Safety health	(see separate safety sheets)			
- E.E.C. directive coding	base	: symbol Xn R10, R20/21/22, R43 S23, S38, S36/37/39 P52		
	hardener	: symbol Xn R10, R20/21/22 S23, S36/37/39		

APPENDIX 4.E. - Continuation

- flash point (closed cup, DIN 53213) - ventilation requirements, air quantity for 1 litre	base and hardener : 26°C mixed paint : - 10% of lower explosion limit (LEL) 70 m ³ : - threshold limit value (TLV) 1000 m ³ thinner A : - 10% of LEL 180 m ³ : - TLV 2000 m ³ thinner Sc : - 10% of LEL 180 m ³ : - TLV 2000 m ³
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APPENDIX 4.F. - COMPARISON OF PAINT TYPES ACCORDING TO THEIR BINDER COMPOSITION*

Paint type (according to binder)	Delivery forms (most common)	Drying (curing) mechanism	Solvents thinners	Minimum surface preparation	Drying times at 20°C (normal paint)		Dry film thickness (µm)	Mechanical strength	Gloss and colour retention	Anti-corrosive properties	Resistance to				Recoat-ability of old (hard) paint coats
					recoat-able after	fully cured after					water	acid	alkali	solvents	
Tung/oil/phenolic resin (4.5.2.1)	normal paint (solvent-based)	oxidative	aliphatic hydrocarbons	hand-tool cleaning	16 hr	1 week	30	fairly good	moderate	fairly good	very good	moderate	poor	moderate	good
Bitumen (4.5.2.2)	normal paint high-build solvent-free	physical	aliphatic or aromatic hydrocarbons	hand-tool cleaning	8 hr	24 hr	30-100	moderate	poor	fairly good	very good	fairly good	fairly good	very poor	good
Alkyd resin (4.5.2.3)	normal paint	oxidative	aliphatic hydrocarbons	hand-tool cleaning	8-24 hr	2 weeks	30-40	fairly good	good/very good	good	moderate	poor	poor	moderate	good
Chlorinated rubber (4.5.2.4)	normal paint high-build	physical	aromatic hydrocarbons	blast-cleaning (Sa 2 1/2)	4-8 hr	24 hr	30-100	fairly good	fairly good	good	very good	good	good	poor	very good
Vinyl copolymers (4.5.2.5)	normal paint high-build	physical	esters, ketones/aromatic hydrocarbons	blast-cleaning (Sa 2 1/2)	2-6 hr	24 hr	30-100	good	good	good	very good	good	good	poor/moderate	very good
Vinyl/ter (4.5.2.5)	normal paint high-build	physical	esters, ketones/aromatic hydrocarbons	blast-cleaning (Sa 2 1/2)	6 hr	24 hr	30-100	fairly good	poor	good	very good	good	good	poor	good

* This table should be used for comparative purposes only. Deviations from the listed data are likely.

APPENDIX 4.F. - CONTINUATION

Paint type (according to blinder)	Delivery forms (most common)	Drying (curing) mechanism	Solvents thinners	Minimum surface preparation	Drying times at 20°C (normal paint)		Dry film thickness (µm)	Mechanical strength	Gloss and colour retention	Anti-corrosive properties	Resistance to				Recoat-ability of old (hard) paint coats
					recoat-able after	fully cured after					water	acid	alkali	solvents	
Epoxy resin (4.5.2.6)	normal paint high-build solvent-free	chemical (with hardener)	esters, ketones, glycol derivatives/ aromatic hydrocarbons	blast-cleaning (Sa 2 1/2)	8-24 hr	7-10 days	30-500	very good	poor	good	very good	very good	very good	poor	
Epoxy resin, recoatable type (4.5.2.6)	normal paint high-build	chemical (with hardener)	esters, ketones, glycol derivatives/ aromatic hydrocarbons	blast-cleaning (Sa 2 1/2)	6 hr	1 week	40-100	good	fairly good	good	fairly good (spillage)	fairly good (spillage)	fairly good	good	
Epoxy/phenolic resin (4.5.2.6)	high-build	chemical (with hardener)	esters, ketones, glycol derivatives/ aromatic hydrocarbons	blast-cleaning (Sa 2 1/2)	24 hr	7-10 days	100	very good	irrelevant	good	excellent	excellent	excellent	poor	
Epoxy ester resin (4.5.2.6)	normal paint	oxidative	aliphatic hydrocarbons	hand-tool cleaning	8-24 hr	2 weeks	40-60	fairly good	fair	good	poor	poor	moderate	good	

APPENDIX 4.F. - CONTINUATION

Paint type (according to blinder)	Delivery forms (most common)	Drying (curing) mechanism	Solvents thinners	Minimum surface prepa- ration	Drying times at 20°C (normal paint)		Dry film thick- ness (µm)	Mechan- ical strength	Gloss and colour retention	Anti- corro- sive propert- ies	Resistance to				Recoat- ability of old (hard) paint coats
					recoat- able after	fully cured after					water	acid	alkali	solvents	
Coal-tar polyure- thane resin (4.5.2.9)	high-build	chemical (with hardener or atmo- spheric moisture)	esters, keto- nes/aro- matic hydro- carbons	blast- cleaning (Sa 2 1/2)	16 hr	1 week	100- 250	good	moderate	very good	very good	very good	fairly good	poor	poor
Zinc silicate (alkali silicate) (4.5.2.10)	normal paint	chemical (with atmo- spheric humidity)	water	blast- cleaning (Sa 2 1/2)	24 hr	2 weeks	75-125	very good	irrele- vant	excellent	very good	very poor	very poor	excellent	very poor
Zinc silicate (ethyl silicate) (4.5.2.10)	normal paint	chemical (with atmo- spheric humidity)	alcohols (glycols)	blast- cleaning (Sa 2 1/2)	8-24 hr	2 weeks	75-125	very good	irrele- vant	excellent	very good	very poor	very poor	excellent	very poor

APPENDIX 4.G. - FOULING AND ANTI-FOULING

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TNO Paint Research Institute, Delft, The Netherlands*

For settling of barnacle larvae, algal zoospores and other organisms living in the sea to occur, the water flow rate along the immersed substrate is of the utmost importance. Roughly speaking two practical situations in this respect are possible:

- static substrate (oil rig, ship lying stationary); in which case the flow rate is determined by the tidal movement, wind etc.
- moving substrate (ship), when it is determined by the speed. In that case the flow is turbulent.

In the latter case the organisms are normally not able to attach. Algal spores can apparently settle on substrates over which there is a turbulent flow pattern, but usually settlement of fouling organisms occurs under conditions, where the flow rate is low.

To prevent settling on immersed substrates, paints containing toxins still offer the most practical solution. The toxins must dissolve from the paint film into the sea water from where the organisms pick them up in the dissolved state at the paint film/sea water interface. Subsequently they will die.

For this to occur a minimum (lethal) concentration of the toxin must be maintained at the interface, which on the one hand is decreased mainly by diffusion to the bulk of the sea water, on the other hand increased by dissolving of the toxicant from the paint film (Fig. 1).

The lethal concentration differs from toxin to toxin and from organism to organism and for all kind of reasons, it is difficult to determine.

Therefore as a measure of toxic efficiency the 'critical leaching rate' is used, which is the lowest toxic leaching rate necessary to prevent fouling.

In Figure 2 the critical rates are given for some of the most important toxins, with regard to prevention of algal and barnacle settlement.

In the table of Figure 2 the amount of toxins are given and not the amount of metal, as is usually done (Cu₂O contains 88% copper, TBTF 38.5% tin, TPTF 31.5% and TBTO 38.2%).

These toxins are 'broad spectrum' types, which means that they are efficient against a large range of organisms.

Basically, two kinds of commonly used paint formulations can be distinguished:

- contact-leaching types;
- self-polishing (ablative, eroding) types.

Contact-leaching types

In these paints the toxin and other water soluble pigments are embedded in the paint matrix in close contact. The paint matrix consists of a mixture of different kinds of paint resins and additives, which are mainly insoluble in water. On immersion in sea water the toxin dissolves at the surface of the paint film, and the water penetrates, dissolving the next layer of toxic particles. These diffuse the surface of the paint film and the process is repeated. Thus, in the matrix a network of interconnected holes develop, through which the toxin is transported to the paint film surface but the matrix remains intact (Fig. 3).

The diffusion process, by which the toxin is transported, is dependent on the difference in the toxin concentration in the paint film/sea water interface and the sea water. The higher the difference, the higher the leaching rate. On a active ship, under turbulent conditions, the concentration in the sea water is always very low and therefore the toxin leaches rapidly from the paint. Due to this fact and also because diffusion from the inside of the film is slow, the concentration of toxin in the outer layer of the paint film decreases gradually and therefore the leaching of toxin from the paint decreases as is shown in Figure 4. It can be seen that, the leaching rate (the slope of the curve) decreases quickly with time and will soon be lower than the critical value (Fig. 2). This applies not only to Cu_2O , but also to other toxicants like TBTF etc. This means that paints containing these toxicants age relatively fast and that their lifetime is restricted. A period of 1-2 years as a maximum was achieved in the past.

An exception in this respect is triphenyl tin fluoride, which is barely soluble and leaches slowly at a constant rate. Apart from those already mentioned, other organotin derivatives are in use as toxins as well as different algicides and herbicides. No hazardous materials such as mercury and organometals based on arsenic, lead and antimony are found in present day anti-foulings.

Self-polishing paints

It was recognized at an early stage that if the outer layer of contact-leaching anti-foulings, devoid of toxin, could be removed preferably by dissolution, the performance time could be extended. Only when organotin acrylate copolymers became available, was this achieved.

The chemical structure of these polymers is given schematically in Figure 5.

As soon as they come in contact with sea water the tributyl tin (SnBu_3) moiety splits off, leaving behind the polymer backbone with water soluble carboxyl groups. Due to these groups, the backbone dissolves gradually in the sea water and thus the paint film disappears, layer by layer. An example of this phenomenon is given in Figure 6 in which the erosion (in μm), as measured when rotating the paints in sea water, is plotted against time. As will be seen the erosion rate is constant.

It must be noted that, though the SnBu_3 moiety itself is an active toxicant, additional toxicants have to be added to the paint formulation, to increase its performance. Anti-

fouling lives of up to 5 years have been achieved. The additional toxicants are the same as those used in the contact-leaching paints.

Though the erosion rate is constant in time, it is not independent of the seawater flow rate. This is shown in Figure 7. In this figure the erosion rate is plotted for four different paints against the frictional force along the surface. As can be seen, the erosion rate decreases slowly when the flow rate and therefore the frictional force decreases but remains rather high at low rates. From experiments under raft conditions it has been shown that the erosion is much lower and has an average value of about $0.04 \mu\text{m}/\text{day}$. It is obvious that the critical leaching rate also determines the performance for these kinds of paints. The leaching rate is given by:

$$\text{Leaching rate} = \text{Concentration in paint} \times \text{Erosion rate}$$

The concentration of toxin in the paint and the erosion rate can be varied as long as their product remains above the critical value. Increasing the erosion rate is, however, restricted to certain practical limits. When it is increased to compensate for a lower toxin concentration, the total thickness of the paint must be increased to obtain the same anti-fouling life. When for instance a life of three years is required and the erosion rate is $0.1 \mu\text{m}/\text{day}$, the dry film thickness needs to be about $110 \mu\text{m}$. When, however, the erosion rate has to be increased to $0.3 \mu\text{m}/\text{day}$ the thickness to be applied for the same protection time is $330 \mu\text{m}$. This can be done but may give rise to application difficulties and it is costly. Still higher thicknesses will most certainly cause greater problems.

APPENDIX 4.G (Continuation)

BIOCIDECONC. (C_0) DEVELOPMENT IN BOUNDARY LAYER

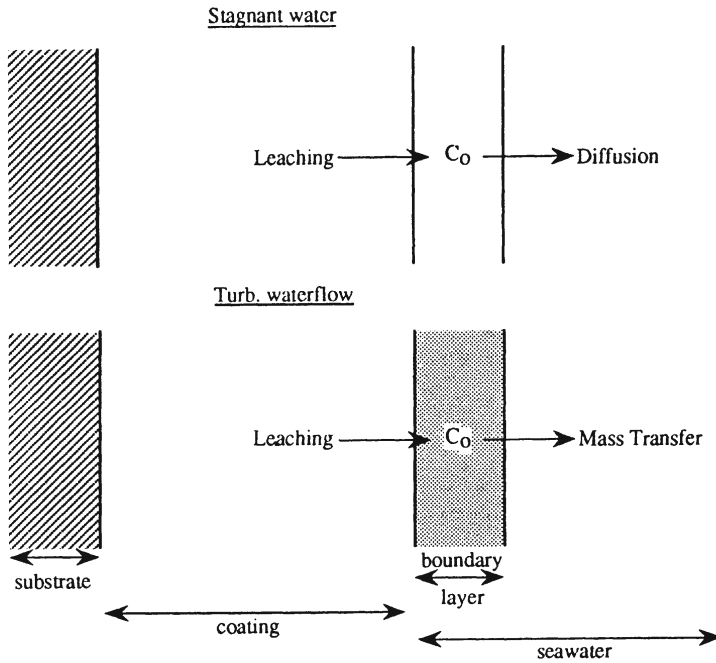


FIG. 1

CRITICAL LEACHING RATES TO PREVENT FOULING*)

	Algae	Barnacles
Tributyltinfluoride (TBTF)	24	10,5
Triphenyltinfluoride (TPTF)	16	6
Tributyltin oxide (TBTO)	>>16	>>16
Cuprous oxide (Cu_2O)	25	18

*) $\mu\text{g toxin}/\text{cm}^2/\text{day}$ ($0,12 \mu\text{g}/\text{m}^2/\text{sec}$)

FIG. 2

APPENDIX 4.G (Continuation)

CROSS SECTION OF A LEACHED PAINT FILM (C REFERS TO COPPER CONCENTRATION)

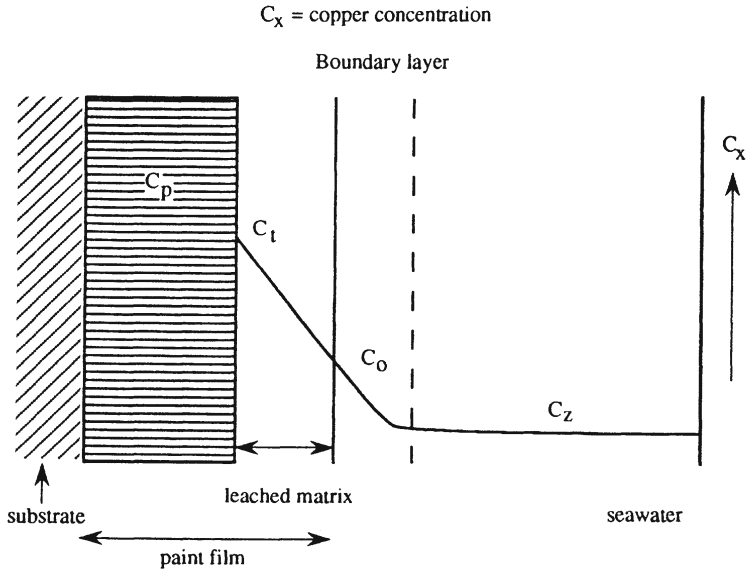


FIG. 3

LEACHING CURVE OF A CUPROUS-OXIDE PAINT

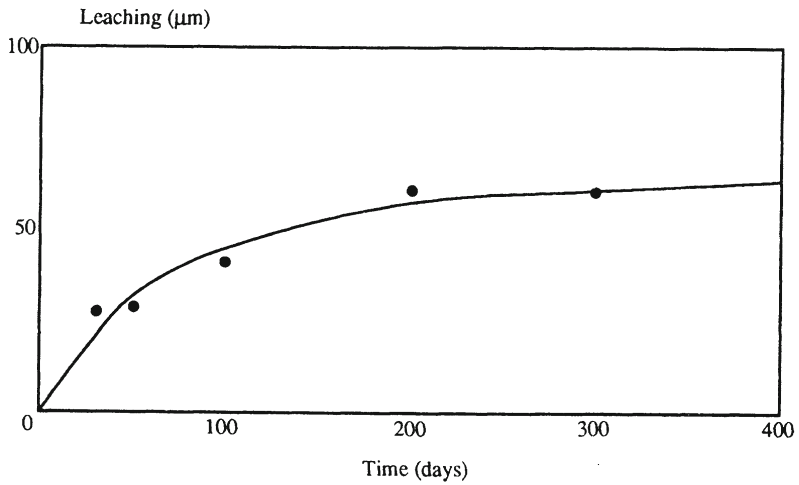


FIG. 4

APPENDIX 4.G (Continuation)

REACTION OF POLYTRIBUTYLTIN-ACRYLATE IN SEAWATER

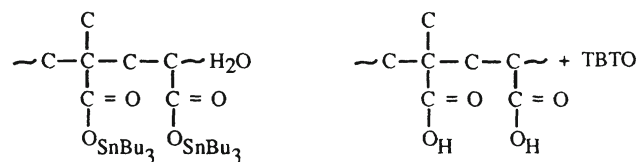


FIG. 5

EROSION OF PAINT VERSUS TIME (DAYS)

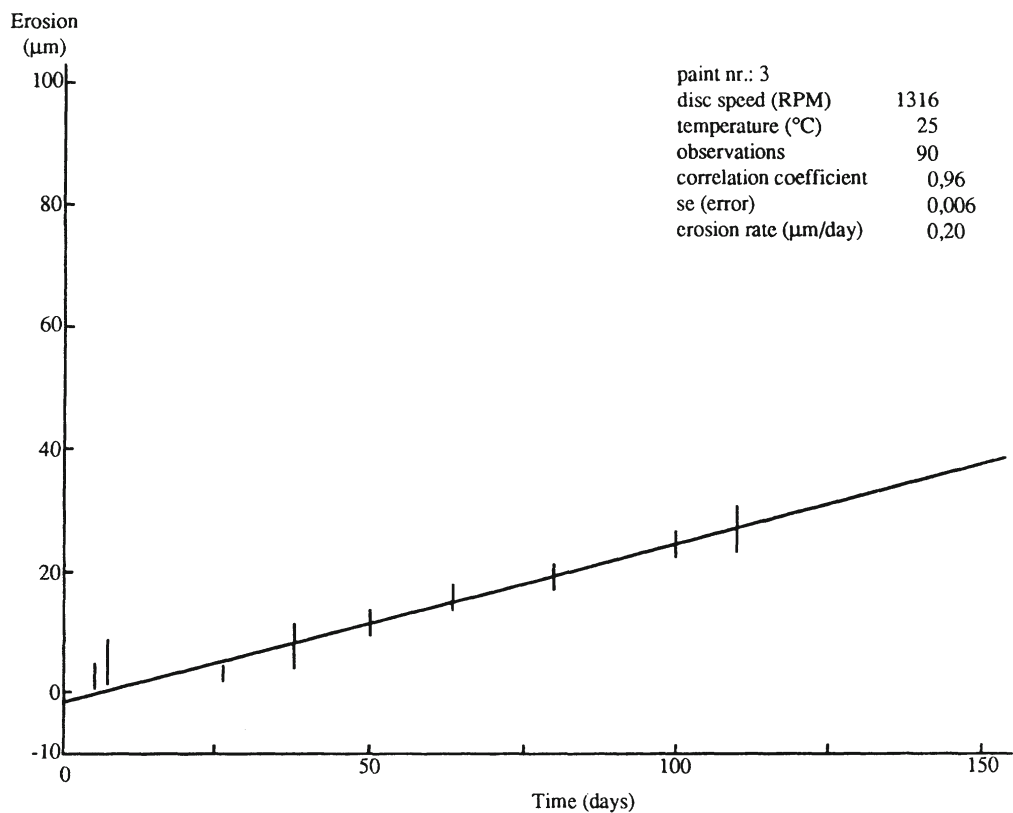


FIG. 6

APPENDIX 4.G (Continuation)

EROSION ON SMOOTH DISC

Circumferential speed : 26.8 knots
 Temperature : 20°C

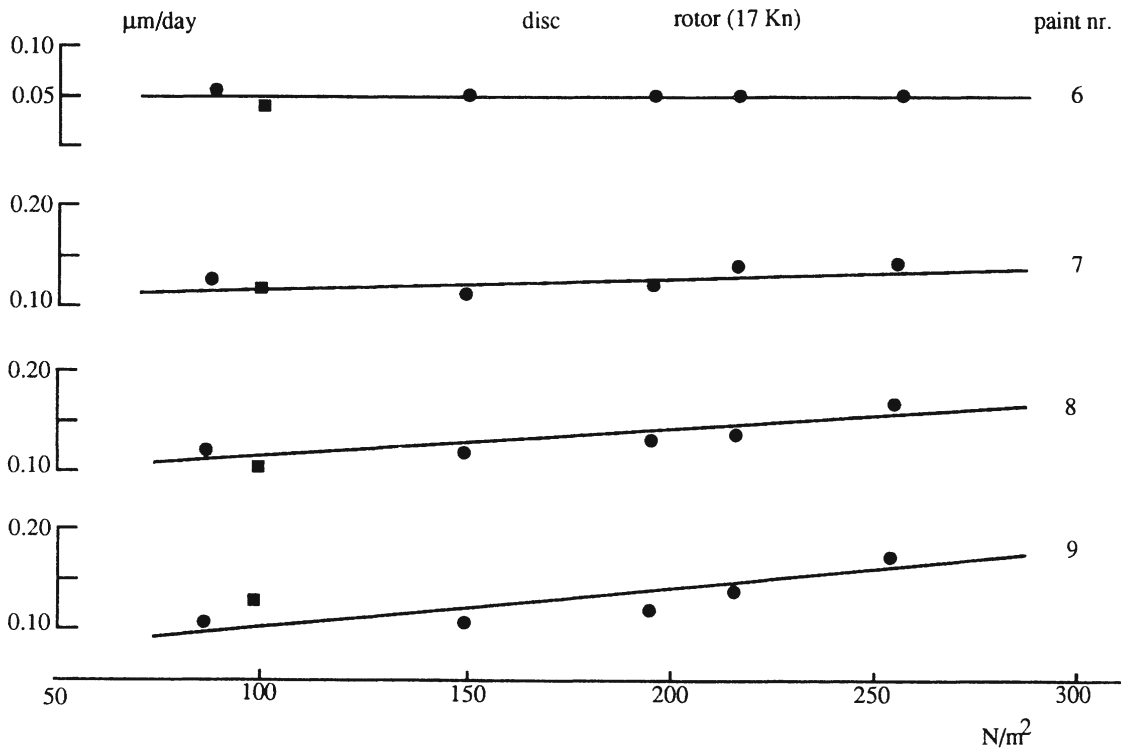


FIG. 7

CHAPTER V

PREFABRICATION (SHOP) PRIMERS

5.1. Introduction

The main function of *prefabrication primers* or *shop primers*, is to protect steel plates against corrosion during the building of ships and offshore structures. In many cases the prefabrication primer (shop-coat) also functions as a base for the final paint system. Sometimes however, the shop-coat is removed by reblasting before the paint system is applied. Removal is required when the sections have rusted badly before the final painting, or when the shop-coat underneath a tank coating system is not resistant to the cargoes to be transported.

To improve the performance of the paint systems, nowadays there is a tendency to remove the weathered/contaminated prefabrication (shop) primer from the underwater parts of ships and offshore structures by blast-cleaning before painting is undertaken.

When using a prefabrication primer, the preferred procedure is to blast-clean the plates and components to be used in building the sections, in a centrifugal (impeller) blasting machine (wheelabrator) and to apply a thin coat of prefabrication (shop) primer by automatic spraying immediately afterwards.

It is recommended that the steel be preheated to a temperature of 35-40°C prior to blast-cleaning. This is usually accomplished by means of gas burners. In this way a dry surface is obtained, and in addition the rate of drying of the primer is increased considerably.

Usually it is necessary for the primed steel plates and components to be transportable within a few minutes after application of the prefabrication primer.

In the case of inadequate preheating, the primer will dry too slowly, which may result in damage to the shop-coat e.g. by the rollers of the conveyor or by the cranes lifting the plates. If, on the contrary, overheating takes place, the primer dries too fast, and there is insufficient flow and leveling; this results in a discontinuous, porous coat which fails to protect the steel adequately against corrosion.

Several types of prefabrication (shop) primer are used in the building of ships and offshore structures. They will be dealt with in Section 5.6.

A proper choice of both prefabrication primer and application method is essential in order to obtain effective protection of the steel. This choice will be greatly influenced by the anti-corrosive properties, weldability and recoatability of the prefabrication primer.

5.2. Requirements for prefabrication (shop) primers

Prefabrication primers must meet the following requirements:

- Provide adequate protection against corrosion during the building of the ship or offshore structure.
If the ship or offshore structure is built from shop-primed steel, the requirement is very onerous; complete protection in the open, during building for periods of 6-9 months, can only be realized by the use of zinc-rich prefabrication primers.
- Be applicable by spray to give a thin, continuous film of uniform thickness.
- Have a short dry-to-handle time; the primed objects must be transportable within three minutes without damage to the shop-coat from conveyor rollers, magnetic cranes or vacuum hoists.
- Have little or no effect on the speed of welding and cutting and preferably be suitable for automatic welding processes.
- Have little or no effect on the homogeneity and strength of welds.
- Not evolve noxious or toxic fumes during welding and flame-cutting. This requirement can only be met if the prefabrication primer does not contain toxic elements such as arsenic, antimony, lead, cadmium and chromium; concentrations of hazardous fumes evolved should not exceed the corresponding TLV (MAC)*; a certificate from a health authority is generally required.
- Be able to withstand rough handling including bending of the steel.
- Be suitable as a base for the final paint system.
As the paint systems on the different parts of ships and offshore structures vary considerably, prefabrication primers should be compatible with a great variety of paints, ensuring that good intercoat adhesion is obtained.
- Be highly water-resistant and compatible with cathodic protection systems (resistant to alkaline conditions)**.
- Be approved by the classification societies.

From a practical point of view, it is strongly recommended that only one type of prefabrication (shop primer) is used on all parts of the ship or offshore structure including cathodically protected parts such as the underwater areas and certain tanks.

* TLV = Treshold Limit Value (MAC = Maximum Allowable Concentration): see Part 11.2.6.

** To fulfil these requirements the binder of prefabrication primers should be unsaponifiable and the pigments should contain no or only a very low content of water soluble constituents. If this content exceeds a value of 0.1% by weight, it is strongly advised that the shop-coat from underwater surfaces and tank interiors be removed by blast-cleaning before the application of the paint system.

5.3. Blast-cleanliness and surface roughness

5.3.1. BLAST-CLEANLINESS (see also 3.2.4.4)

Unless otherwise specified in the building specification, the blast-cleanliness should be at least Sa 2^{1/2} immediately before the application of the prefabrication primer. Due to the practical difficulty of obtaining this preparation grade with pitted (contaminated) steel it is strongly recommended that steel showing rust grades C or D according to ISO standard 8501* is not used. For that reason storage of steel, prior to blast-cleaning, in open stocks should be avoided.

During blasting operations the blast-cleanliness should be checked frequently. The recirculated abrasive should be checked regularly for size distribution, salt content etc. If the required cleanliness is not obtained, either the speed of the plates through the centrifugal blasting machine should be reduced, or an improved grade of abrasive should be used. If the machine is a horizontal one, special attention should be paid to the cleanliness of the underside of the plates.

5.3.2. SURFACE ROUGHNESS (see also 3.2.4.3)

During blast-cleaning care should be taken to see that the surface is not unduly roughened. An excessive roughness involves the risk that the primer will not completely cover the peaks of the blast-cleaned surface. This defect may result in rapid formation of rust, especially with prefabrication primers not containing zinc dust.

On the other hand, the surface roughness should not be too small as this might impair the adhesion of the primer coat. An average roughness ($Ry5$, ISO 8503-4) of 50-75 micrometers is recommended.

In impeller blasting machines shot is mainly used as the abrasive. This implies that the resulting roughness profile is round and does not show the sharp-edged anchor pattern, which is required for optimal mechanical bond between the coating and the steel. This is not only a disadvantage for the shop-coat but also for the final paint system. An improvement of the sharpness of the roughness profile can be obtained by adding a small amount of steel grit to the shot abrasive. This however, causes extra wear in the impeller blasting machine.

In addition to the blast-cleanliness, the surface roughness should also be checked frequently. A simple method of judging (maximum) roughness is to make use of the comparator procedure (3.2.4.3/9.4.6.2). Somewhat more complicated but more accurate is measurement of the roughness with a (portable) stylus instrument. If the surface

* Swedish standard SS 05 59 00-1988 (formerly SIS 05 59 00-1967).

5.4. Dry film thickness of the prefabrication (shop) primer

For maximum corrosion protection a thick coat of prefabrication primer is desirable. Thick coats, however, are undesirable from the point of view of other requirements, e.g. drying time, welding speed, weld quality, amount of welding fumes and resistance to damage. Therefore, the dry film thickness has to be a compromise between the various requirements.

In practice zinc-dust containing prefabrication primers should be applied at a dry film thickness not exceeding 20 micrometers. In the case of a zinc-dust free prefabrication primer coat it should not exceed 25 micrometers.

The dry film thickness should be checked periodically. This is done by measuring the thickness of the coat on small smooth metal or glass plates, attached to the blast-cleaned surface prior to the spraying of the shop primer. Glass plates are to be preferred as the homogeneity of the shop-coat can be checked by looking through the back of the panels. *Measurement of the dry film thickness of prefabrication primers on blasted steel by means of magnetic thickness gauges should be discouraged because these measurements are subject to large errors (see Part 9.4.7.1e).*

5.5. Behaviour during automatic welding and flame-cutting

In shipbuilding, manual (MMA*) welding is increasingly replaced by cost-saving automatic (MIG/MAG**) welding procedures. In these automatic processes the welding speed is decreased and the porosity of the welds is enhanced by the presence of the prefabrication primer.

Primers based on organic binders cause more porosity than those based on inorganic binders. The same goes for primers containing zinc (pigment) versus zinc dust-free types.

For the above reasons, the areas to be welded automatically are often freed from shop primer by mechanical cleaning (grinding) or by vacuum-blasting. This, however, introduces an extra operation and increases the cost.

Developments are still being made in the field of automatic welding processes for shop-coated steel. Welding procedures, as well as the type of prefabrication primer should be adjusted so as to give optimal economical results.

Normally, when building offshore structures, all areas to be welded are freed from the shop-coat. This should be done because of the very high quality requirements for welds in this field.

* MMA = manual metal arc

** MIG/MAG = metal inert gas/metal active gas

Normally, when building offshore structures, all areas to be welded are freed from the shop-coat. This should be done because of the very high quality requirements for welds in this field.

The speed of flame-cutting is also influenced by the presence of a prefabrication primer. Especially the zinc dust pigmented types seem to have an adverse effect, which lessens when the zinc dust content or the dry film thickness is decreased. This can be done, without the risk of premature corrosion, when building is carried out under cover.

5.6. Common types of prefabrication (shop) primers

In ship and offshore structure building, two types of prefabrication primers are mainly used. These are the *zinc dust based* and the *zinc-free prefabrication (shop) primers*. They will be dealt with in Sections 5.6.1. and 5.6.2. respectively.

5.6.1. ZINC DUST CONTAINING PREFABRICATION PRIMERS

5.6.1.1 *Composition*

Zinc dust containing prefabrication primers are usually based on the following, non-saponifiable, binders:

- epoxy resin
- partially hydrolized ethyl silicate.

Zinc epoxy based primers are two-component products. The two components, zinc dust pigmented epoxy resin solution and hardener, are mixed in the specified ratio shortly before use, preferably by means of a mechanical stirrer.

The components of *zinc silicate primers* (silicate solution and zinc dust or zinc paste) are also supplied in separate containers and mixed shortly before use.

Prefabrication primers based on zinc dust can be divided into two groups: *zinc-rich primers* and *primers with a reduced zinc content*. Dry coats of zinc-rich types contain at least 90% zinc by weight. The excellent corrosion-inhibiting properties of these primers is due to the local cathodic protective action of the zinc particles.

The types with reduced zinc content have reduced anti-corrosive properties, but their recoatability and welding properties are better and, in addition, less zinc fumes are evolved during welding and flame-cutting. Zinc-rich shop-coats show the typical grey colour of zinc dust. Those with reduced zinc content often show other colours due to the incorporation of pigments such as red iron oxide.

5.6.1.2 *Dry film thickness, anti-corrosive properties, recoatability*

As a rule, zinc dust based prefabrication primer coats have a dry film thickness of 15-20 micrometers. Thicker coats not only adversely affect the weldability of the steel and the adhesion of subsequent paint coats, but also increase the amount of welding fumes. Moreover, with thicker coats cohesive failure in the layers itself may occur. Zinc dust based prefabrication primer coats thinner than 15 micrometers do not provide adequate corrosion protection.

Regarding corrosion protection, zinc dust based prefabrication primers are superior to those free from zinc dust (usually the red-brown types, Part 5.6.2). The better anti-corrosive properties of the zinc dust based types are primarily due to the local cathodic protection action of the zinc particles; by this action damaged spots (e.g. scratches) in the primer coat are protected against corrosion for a considerable time.

Zinc silicate prefabrication primers have still better anti-corrosive properties and are mechanically stronger than those based on zinc epoxy. Particularly when 'building in the shop-coat', the use of zinc dust based prefabrication primers is definitely preferred.

A main disadvantage of zinc dust based primers is the formation of zinc salts during atmospheric exposure. These salts, some of which are hygroscopic (take up water from the air), are formed on the surface of the primer coat due to chemical reactions. This frequently results in intercoat adhesion problems following recoating. Particularly on submerged parts (underwater areas, tanks etc.) such lack of adhesion may result in blistering and flaking. To prevent this, the zinc salts formed during weathering have to be removed before the next paint layer is applied over the shop-coat. Removal of zinc salts is usually done by cleaning the weathered surface thoroughly with nylon brushes, using an adequate supply of abundant *clean fresh water* (e.g. tap water) and rinsing the surface thoroughly afterwards. High-pressure water washing can also be used to remove the zinc salts. A much better method, however, is to clean the surfaces by wet abrasive-blasting or sweep-blasting before final painting.

As a rule, prefabrication primers with a reduced zinc content form less (hygroscopic) zinc salts during weathering than the zinc-rich types and this results in easier cleaning and an improved intercoat adhesion.

It is emphasized that zinc-dust containing primers should be recoated with paint systems having negligible water permeability. Such (thick) paint systems largely reduce the risk of blistering and peeling.

As the surface of zinc dust containing primers is slightly alkaline, the top coats should preferably be unsaponifiable.

5.6.1.3 *Welding (flame-cutting) fumes*

During welding or flame-cutting of steel coated with a zinc dust based prefabrication primer, fumes containing zinc oxide are generated. Inhalation of such fumes may cause temporary malady, called 'zinc fever'. The risk is of course greater with thick primer coats, inadequate ventilation or a combination of both.

The threshold limit value (TLV) of zinc fumes is given in Appendix 11.A.

5.6.1.4 *Comparison of zinc-epoxy and zinc silicate prefabrication (shop) primers*

Zinc silicate shop primers are more critical in respect to surface preparation, application and recoatability than zinc epoxy shop primers. However, if the best performance with respect to corrosion prevention, hardness and abrasion resistance is required, zinc silicate shop primers are to be preferred. As mentioned above, zinc-epoxy primers contain an organic binder, and as a result relatively large amounts of fumes are generated and a relatively large area is burnt alongside welds and flame-cutting edges. Also the heat-affected zone, adjacent to the burnt areas and on the back of the steel, forming an unreliable base for a paint system, is large. In this respect zinc silicate primers, which are inorganic, are to be preferred.

5.6.2. ZINC-FREE PREFABRICATION PRIMERS

5.6.2.1 *Composition*

Zinc-free prefabrication primers are usually based on the following binders:

- epoxy resin
- combinations of polyvinylbutyral/phenolic resins.

As a rule these primers are supplied as two-pack products.

Prefabrication (shop) primers based on combinations of polyvinylbutyral/phenolic resin are sometimes called *reinforced wash primers*. They show a very limited resistance to the side effects (alkaline formation) of cathodic protection systems, which may lead to blistering of underwater coating systems applied over such primers. For this reason, they are not now very often used as prefabrication primers.

Epoxy resin based zinc-free prefabrication primers are usually pigmented with red- or yellow iron oxide in combination with an anti-corrosive pigment.

The use of the yellow types is strongly recommended for the following reasons:

- the yellow colour has a greater light reflection property than the dark brownish colour of the red iron oxide; as a result, surfaces coated with the yellow iron oxide primers stand out better which makes coating easier, especially inside sections;

- first stages of breakdown by rusting are much easier to detect when using the yellow oxide primers;
- when welding or flame-cutting, the yellow iron oxide changes into red oxide in the heat affected zone, clearly showing where the prefabrication primer has been destroyed.

The anti-corrosive pigment used in prefabrication primers formerly was often zinc (potassium) chromate.

Notwithstanding its superior anti-corrosive properties, this pigment has been gradually superseded by modern anti-corrosive pigments like zinc phosphate and calcium phosphate because zinc chromate containing primer coats evolve hazardous fumes during welding and flame-cutting. Also, due to the water solubility of zinc (potassium) chromate, this type of primer promotes blistering of paint systems on immersed parts of ships and offshore structures, especially when they are cathodically protected.

Reinforced wash primers usually contain, in addition to iron oxide pigment, a small percentage of zinc tetraoxochromate or strontium chromate which show a much lower water solubility than zinc (potassium) chromate. However, as already stated, this type of prefabrication primers is not very often used anymore.

5.6.2.2 *Dry film thickness, anti-corrosive properties, recoatability*

Zinc dust-free prefabrication primers are applied in a dry film thickness of 20-25 micrometers. Their protective properties are inferior to those of the zinc dust based types. It should be mentioned, however, that zinc dust-free primers based on epoxy give a better corrosion resistance than reinforced wash primers.

When using red-brown coloured prefabrication primers, slight rusting of the steel is difficult to detect. Therefore, the use of yellow iron oxide pigmented primers is strongly recommended. *Dark coloured areas on steel coated with a red-brown prefabrication primer indicate appreciable corrosion.* If the paint system is applied on such a surface, poor durability will result, especially on immersed parts and in tanks.

Steel coated with a zinc dust-free prefabrication (shop) primer as a rule corrodes during building of the ship or offshore structure.

In practice, corrosion can only be prevented by applying the first coat of the final paint system at an early stage of the building procedure, preferably immediately after fabrication of the sections.

If rust has formed during building in the shop-coat and a high-performance paint system is to be applied, it is, as a rule, necessary to remove the shop-coat by blast-cleaning before the paint system is applied. If a conventional paint system has to be applied, mechanical derusting is often permitted by the paint supplier.

In comparison with zinc dust based prefabrication primers, the use of zinc dust free types generally results in better adhesion of the final paint system. This is due to the absence of hygroscopic zinc salts which are formed on zinc dust based shop-coats during

weathering. Nevertheless, it should be mentioned that some zinc dust free epoxy shop-coats, which are very hard and smooth after complete curing, may also give rise to intercoat adhesion problems.

5.6.2.3 *Welding (flame-cutting) fumes*

During welding and flame-cutting of steel primed with prefabrication primers containing chromate pigment(s), hazardous fumes may be evolved. Inhalation of such fumes, which are carcinogenic, may affect workers' health. For this reason *it is very strongly recommended that prefabrication primers containing chromate pigment(s) should not be used.*

For the maximum allowable concentration of chrome containing vapours in confined spaces see Appendix 11.A..

5.6.2.4 *Comparison of zinc dust free epoxy prefabrication primers with reinforced wash primers*

Zinc dust free prefabrication primers based on epoxy resin have better anti-corrosive properties and are moreover mechanically stronger than reinforced wash primers based on combinations of polyvinylbutyral and phenolic resin. Prefabrication primers based on epoxy resin are resistant to cathodic protection provided that they do not contain chromate pigments, which show a high water solubility, especially under neutral and alkaline conditions. As polyvinylbutyral is slightly saponifiable, reinforced wash primers are insufficiently resistant to cathodic protection. In fact, these products should not be recommended for underwater parts that are provided with a cathodic protection system.

5.7. Summary

Prefabrication (shop) primers are used to prevent corrosion of blast-cleaned steel plates and components during building of ships and offshore structures. The period during which they are capable of completely protecting the blast-cleaned steel is limited.

Zinc dust based prefabrication primers, which have the best anti-corrosive properties, within a short period show weathering phenomena which may adversely affect the adhesion of the paint system applied at a later stage.

For these reasons, *prefabrication primer coats should not be exposed to the atmosphere longer than strictly necessary or should be removed by (sweep) blasting directly before the application of the paint system.*

The exposure time to the atmosphere can be limited by applying one of more coats of the paint system at an early stage of the building procedure, e.g. by applying the first coat of the paint system immediately after construction of the sections.

In the building of ships and offshore structures mainly three types of prefabrication (shop) primers are used. These are: *zinc-epoxy*-, *zinc silicate*- and red-brown or yellow *epoxy primers*.

A fourth (red-brown) type, based on *polyvinylbutyral/phenolic resin (reinforced wash primers)*, is no longer used on a large scale.

The most important properties of the four types of prefabrication (shop) primer are summarized in the table in Appendix 5.A. of this chapter.

APPENDIX 5.A. - PROPERTIES OF THE MAIN TYPES OF PREFABRICATION (SHOP) PRIMERS

Properties	Type of prefabrication (shop) primer		
	Zinc-epoxy (5.6.1)	Zinc/silicate (5.6.1)	Red-brown or yellow epoxy (5.6.2)
Delivery form	two-pack system: - epoxy resin solution containing zinc dust - hardener (polyamine or polyamide resin solution)	two-pack system: - ethyl silicate solution - zinc dust or zinc dust paste	two-pack system: - epoxy resin solution containing iron oxide and anti-corrosive pigment - hardener (polyamine or polyamide resin solution)
Solvents/thinners	alcohols/ketones/aromatic hydrocarbons	alcohols/aromatic hydro- carbons	alcohols/ketones/aromatic hydrocarbons
Dry film thickness (micrometers)	15-20	15-20	15-25
Anti-corrosive properties	very good ¹⁾	excellent ¹⁾	fair
Mechanical strength	good	excellent	good
Health hazards of welding fumes	temporary effect	temporary effect	slight ²⁾
Recoatibility	critical (zinc salts) ¹⁾	critical (zinc salts) ¹⁾	good
Resistance to cathodic protection	good	good	poor

1) Prefabrication primers with a reduced zinc dust content are less anti-corrosive, but their recoatability is somewhat better.

2) Prefabrication primers containing chromates may evolve hazardous welding fumes.

3) The chromate pigment content of reinforced wash primers is so low that welding fumes are only hazardous to a limited degree.

4) For a good resistance to cathodic protection, the pigment should contain no or only a very low content of water-soluble material.

CHAPTER VI

STORAGE AND APPLICATION OF PAINTS

6.1. Storage

The containers (tins, cans, drums, etc.) in which paints are stored should be sealed tightly in order to prevent the paint from thickening, skinning and evolving solvent vapours giving rise to a fire hazard. After use, containers, should be resealed hermetically.

They should not be filled completely, and sufficient ullage (free space between paint surface and lid) should be left to allow the paint to be stirred without risk of spillage.

Paint containers should be stored in dry stores provided with adequate ventilation. Switches and other electrical equipment should be explosion-proof, and the thresholds should be high enough to hold back large amounts of spillage. A sufficient number of fire-extinguishers should be kept in readiness on the spot and in the immediate vicinity. Further details on fire prevention regulations for storage rooms will be found in Part 11.6.1.

The preferred temperature of paint stores is 15 to 25°C.

At *lower temperatures*, paints become too viscous and as a result difficult to apply by brush, roller or spray. Moreover, a cold paint takes a long time to attain a satisfactory working temperature.

Water-based products, such as certain dispersion paints, should not be exposed to temperatures below freezing since this may cause the coagulation of the binder and render the paint unfit for use.

Storage at *higher temperatures* may lower the viscosity of some paints to a point where the pigment settles rapidly. Other types of paint tend to thicken and become unusable. At higher temperatures the increased solvent vapour pressure in a container may blow off the lid, creating a risk of fire or explosion.

The fact that application of paints at too high or too low a temperature is always difficult is another reason why they should be stored at temperatures that do not differ too much from those at which they are ordinarily applied.

Excessive humidity of the air in the storage room is likely to cause corrosion of metal containers, and labels may become illegible.

In order to prevent corrosion, metal containers should not be placed directly on the floor, but on platform or racks.

Formation of a thick skin on a paint that dries by oxidation (air drying) in a partly used container can be minimized by closing the container tightly and inverting it for a few moments before replacing it on the rack. Any minute leaks between lid and container are

thereby sealed by paint. If the container is so large that it cannot be turned upside down, the remedy is to pour a thin layer of solvent (thinner) on the paint surface. The solvent will prevent skinning for some time, but not indefinitely.

When paint is taken from the store, the oldest or partly used containers should always be taken first. Paints which have been in store for a time exceeding that indicated as 'the maximum storage time' on the data sheet should not be used without obtaining the advice of the manufacturer. Paints which have become excessively thick or which contain a sediment that cannot be resuspended by stirring, should never be used.

6.2. Preparation before application

All coating materials should be supplied to the worksite in their original, unopened and clearly identifiable containers. No mixing of different brands or types of paint should be permitted.

Before using a paint, the directions on the label of the container should first be read, making sure that the paint is the right one for the work in hand. As a rule, the label gives information on the mode of application and any precautions to be taken.

Before a container is opened, any dust, dirt or water should be removed from the cover and the rim. When it has been opened, any skin on the paint should be cut loose and carefully removed. On no account should skin fragments be stirred into the liquid paint. After removal of the skin (if any), the paint should be mixed (homogenized) thoroughly with a clean tool, e.g. a flat paddle or spatula. If the container is large (5 litres or more) and/or if there is a heavy sediment on the bottom, a mechanical mixer should be used. For thorough mixing the stirrer must be moved up and down or be placed at an angle. Stirring must be continued until the mixture is completely homogeneous. If a coating material contains heavy (metallic) pigments, that have a tendency to settle, these should be kept in suspension during application by a mechanical stirrer.

The hardener of two-component paints should be added with continuous stirring to the paint component in the correct proportion, in accordance with the manufacturer's directions. Likewise, the zinc powder of zinc silicate paints should be added with continuous stirring to the silicate vehicle.

Two-pack paints should be prepared by mixing the entire contents of the containers and the practice of mixing only part of their contents should be discouraged since it frequently leads to errors. The pot-life of two-component paints should be clearly indicated on the label of the container.

If the pot-life has expired, the paint should no longer be used, even if it shows no apparent signs (such as thickening) of deterioration.

If during mixing/stirring air is entrapped in the paint, sufficient time should be allowed for air bubbles to escape before application.

This reduces the risk of pinholing and the occurrence of vacuoles in the applied paint layer.

Some types of two-component paints should be applied before the lapse of a certain 'induction time', specified by the manufacturer.

Brushing paints should be supplied at the correct viscosity (consistency). Paints which have thickened slightly during storage or use, can be restored to brushing consistency by the addition of a small quantity of the appropriate thinner. If the amount of thinner needed is more than 5% by volume, the paint should not be used without seeking advice from the manufacturer.

Spraying paints should be brought to spraying viscosity with a certain quantity of thinner, as specified by the manufacturer. The spraying viscosity is sometimes specified very precisely. It can be measured by means of flow cups (efflux cups, consistency cups), of which there are several types.

However, flow cups cannot be used to measure the viscosity of thixotropic paints (e.g. high-build paints). These are often supplied at the correct spraying viscosity.

In pouring paint from a container, care should be taken to prevent it from soiling the labels, thus making them illegible.

Before use, spraying paints should be strained in order to prevent clogging of the nozzle of the spraying equipment. Straining is particularly important with zinc dust containing paints, especially when these are to be applied by airless spray.

Before being used, paints which have been stored at temperatures below 15°C or above 25°C should be allowed to attain the proper working temperature. This rule does not apply, of course, to paints specially made for application at lower or higher temperatures.

As a rule, cold paints should not be thinned to restore them to working consistency as this practice would result in an insufficient dry film thickness.

6.3. Application methods

During the building of ships and offshore structures, paints are applied mainly by *brushing, rolling or spraying* (pneumatic or airless). In the following sections these methods will be discussed briefly but without details of the equipment used and the operative techniques.

6.3.1. BRUSHING

Application of paints by brushing is labour-intensive and consequently time-consuming and expensive.

The paint layers obtained by brushing can vary greatly in thickness, depending on the painter and access to the site of application. For reasons of economy, more rapid

methods are to be preferred. However, brushing is still indispensable when painting small surfaces (e.g. in spot repairs) or when painting places inaccessible to spraying. Similarly, brushing is one of the few methods for painting spaces where, for safety reasons, spraying is prohibited (e.g. accommodation and engine rooms), or where ventilation is difficult, particularly when using paints with constituents that form a hazard to health (e.g. lead pigments).

Brushing is also used for the *stripe painting* of parts which are difficult to protect, such as (sharp) edges, angular parts and weld seams, when these are given an extra coat of paint.

It is generally believed that brushing gives a better penetration of paint into pores, cracks and crevices than do other modes of application.

Any moisture on the surface is displaced more effectively (or emulsified) by brushing than by spraying or rolling. *Therefore, application by brush is preferred for the application of primers on (moist) weathered and hand-cleaned steel. Another advantage of brushing is that wastage is very low.*

Very fast-drying products such as vinyl paints should preferably not be applied by brush; because of their rapid drying brush marks remain visible, and the resulting paint film is very uneven. Similarly, the layers on successively treated areas will not coalesce, so that overlaps remain visible.

With some types of physically drying paints it is also difficult to apply two or more coats by brush. When the second coat is brushed on top of the first, the latter is softened by the solvent of the fresh coat and becomes mixed with this coat.

For painting relatively large areas, wide flat brushes are most suitable; their width, however, should not exceed 120 mm. For irregular surfaces, bolts, rivets and rough or pitted steel, round and oval brushes are considered more suitable.

Brushing should be carried out in such a way that a smooth coat, as uniform in thickness as possible, is obtained. No deep brush marks should be present after drying. When brushing a layer of primer, the paint material should be worked into all corners, crevices etc.

Runs and sags should be brushed out. The use of extending handles for paint brushes should be avoided as much as possible.

After use, brushes should be cleaned thoroughly with an appropriate solvent, and stored dry, preferably in dust-free containers. During short breaks, brushes may be put in a can containing water or solvent.

6.3.2. ROLLING

Application of paint by roller is a method that is particularly suitable for treating large flat surfaces which for some reason cannot be sprayed.

Painting by roller is about five times as fast as by brush. However, an additional coat of paint should be applied by brush in corners and on edges, welds, protruding parts etc.

A normal paint roller cannot be used for painting small surfaces or objects such as frames and profiles, pipes or gauze. For these, specially designed rollers are available. The material of the roller must be resistant to the solvents and thinners in the paint. Paints containing very strong solvents should not be applied with foam plastic rollers, but with rollers covered with lamb's wool or special solvent-resistant synthetic material.

As with brushing, the loss (wastage) of paint with rolling is small. Generally speaking, vinyl lacquers and other fast-drying products cannot be applied with a roller because the air bubbles squeezed out of the roller are trapped in the rapidly drying paint layer. After use, rollers should be cleaned thoroughly by washing in solvent and stored dry, preferably in a dust-free container or wrapping.

6.3.3. CONVENTIONAL SPRAYING (AIR SPRAYING)

In conventional spraying the paint is forced from a container to the spray gun by pressurized air or by a pump. As the paint passes through the orifice of the fluid nozzle, it is mixed with air and atomized at pressures of about 0.2-0.4 MPa (2-4 bar).

Spray guns can be equipped with fluid nozzles or different orifice sizes and the appropriate air caps. The pressurized air is supplied by a compressor with sufficient extra capacity to compensate for the pressure drop in the (long) hoses. The air is freed from oil, moisture and dust by means of an oil-water separator.

Painting by air spraying can be carried out much faster than by brushing or rolling. An additional advantage is that sprayed paint layers are more uniform in thickness. On the other hand, *losses of paint are considerably higher than in brushing or rolling*, because part of the paint is lost by *overspray*, i.e. paint missing the object being coated. This, of course, strongly depends on the shape and size of the object and on such factors as spraying pressure, spraying distance and paint characteristics, as well as the skill of the operator. Overspray can cause contamination and damage to objects in the neighbourhood and can create a rough surface on already painted surfaces.

Another cause of paint loss is the *rebound* of the air containing paint spray mist from the surface of the object. This rebound effect makes it difficult to direct sufficient paint into corners, holes, hollows etc.

Paint losses are excessively high when spraying is done outdoors in strong winds, e.g. on slipways.

Directions for spraying consistency, spraying pressure and nozzle type should always be followed accurately.

Normally, the spray gun is held about 45-60 cm from the surface to be coated and perpendicular to it. Uniform parallel passes are made each of which should overlap the previous one by about 50%.

The surfaces to be coated normally receive passes in two directions at right angles to each other. Each paint layer should be applied uniformly over the entire surface. Runs

and sags should be brushed-out immediately or the paint should be removed with a suitable solvent and the surface resprayed.

If the paint gun is held too far from the substrate, the paint droplets are already (surface) dry when reaching the surface and will not aggregate. This phenomenon, which is called *dry spray*, results in a discontinuous, porous film. It may be expected, especially with highly pigmented products, such as zinc silicates or with paint products containing very volatile solvents and thinners, such as vinyl paints. Dry spray may also be expected when the paint material is unsufficiently thinned or when spraying during hot and/or windy weather, without adequate adjustment of the quantity or type of thinner.

Minimizing dry spray for instance is very important during application of a cargo tank coating and particularly important for zinc silicate tank linings.

The cleaning of a zinc silicate tank lining showing dry spray is very difficult and a subsequent cargo will easily be contaminated by remnants of the previous cargo.

Immediately after use, the spray gun and hoses should be flushed with a suitable solvent (cleaning thinner). The spray gun should be taken apart, cleaned thoroughly and reassembled. Maintenance of the equipment should always conform to the directions of the supplier.

6.3.4. AIRLESS SPRAYING

In airless spraying the paint is brought at a high pressure (7.5-30 MPa; 75-300 bar) by means of a pump, and forced through a narrow orifice (nozzle, tip) which atomizes the paint. Most pumps are driven by air pressure, but some types are electrically powered.

The equipment supplied with airless spray guns usually comprises a set of nozzles of various orifice sizes and spray angles. The angle determines the width of the spray stroke. The type of nozzle or tip to be used depends, inter alia, on the viscosity of the paint, the shape and size of the object to be sprayed and the kind of paint. The relevant directions should be provided by the paint manufacturer in his data sheets.

In airless spraying the paint is not atomized by air, and hence, the amount of spray mist, overspray and rebound are much less than in air spraying. It is also easier because the gun is fed by a single hose (the paint hose), whereas an air spray gun needs two (paint and air hose).

Since the paint is not mixed with air, there is little risk of contamination with impurities such as oil or water droplets. Further advantages of airless- over air spraying are:

- significantly higher production rates which makes faster spraying possible;
- paints can be generally sprayed at a somewhat higher viscosity, resulting in higher dry film thicknesses;
- the loss of solvents and thinners by evaporation in airless spraying is much lower than in air spraying. This allows the use of more volatile solvents, with less risk of sagging.

Since airless spraying is particularly suited to rapid application of paint to large surfaces, the method is widely used in building of ships and offshore structures.

Disadvantages of airless spraying compared to air spraying are:

- the high rate of deposition requires that the painter has to work very fast and concentratedly;
- the high rate of deposition makes it unsuitable for spraying small objects. Since with a given nozzle the spray rate cannot be decreased, it is difficult to control the thickness of the paint layer; the application of thin coats requires use of spray nozzles with very narrow orifices;
- the spray orifices are narrow, and become worn during prolonged use, particularly by paints which contain hard pigments or extenders. Therefore, spray tips must be regularly checked and replaced if necessary;
- the jet of paint, at a short distance from the nozzle (tip), has such a high velocity that it can easily pierce the skin.

If in airless spraying the pattern is irregular, (e.g. tailing), the paint should not be thinned, since this may cause it to sag; one should check the equipment paying attention to pressure drops through leaks and to possible clogging of filters and spray nozzles before thinning the paint.

The use of so-called 'reversible tips' is recommended, because when clogged, they can be cleaned without being taken apart.

After use of the airless spray equipment should be cleaned thoroughly. The paint should be returned to the container, the pump disconnected, and the nozzle removed. Filters and nozzle should be cleaned with a small soft brush, using a solvent, and blown dry. It is particularly important to clean the connecting rod between the air-driven motor and the pump, because dried paint can damage the packings. To prevent the hoses from becoming contaminated, it is recommended that they should be disconnected but kept filled with thinner.

A modification of ordinary airless spraying is *hot airless spraying*, in which the paint is heated before being sprayed. As the viscosity decreases at higher temperatures, paints with a higher viscosity can be sprayed, resulting in higher dry film thicknesses and less risk of sagging. Hot airless spraying is also used in the building of ships and offshore structures and is utilized, inter alia, for spraying certain bituminous compositions in water ballast- and potable water tanks.

Some solvent-free two-component coatings need to be heated to obtain a proper spraying viscosity. For this type of coating, having a very short pot-life at elevated temperatures, hot airless twin-feed spraying equipment is available. The equipment is electrically heated, including the (long) hoses for the paint and hardener. This type of equipment is mainly used in tanks, where it is attractive to apply a thick coat in only one operation, without introducing harmful and explosive solvent vapours. A disadvantage of this equipment is its vulnerability and the relative high price. Beside that, nowadays, a

lot of solvent-free two-component coatings is available that need no heating for proper spraying. These types of product are normally twin-feed airless sprayed at very high pressures.

6.4. Application conditions

6.4.1. ATMOSPHERIC HUMIDITY

The quality of the paint work depends, amongst other things, on the humidity of the air during application. *When the humidity is high there is a risk of water condensing on the surfaces to be painted.* Any moisture on such surfaces can initiate corrosion of the steel and reduce the adhesion of the paint. The properties of the paint film itself can also be impaired by a high humidity during drying. For example the drying may be retarded, enamels sometimes get a frosted appearance, and the chemical resistance of two-pack paints may be reduced. Some paint products, however, are more or less tolerant to a high air humidity and damp surfaces such as polyamide curing epoxy paints and specially formulated primers (damp-tolerant or wet steel primers).

The humidity of the air is usually expressed in terms of the *relative humidity* (R.H.). This is the ratio of the amount of water vapour present in a given volume of air at a given temperature and the maximum amount of water vapour which this volume of air can hold at that temperature (see Appendix 6.A.). The relative humidity is often expressed as a percentage. When it is 100%, the air is said to be saturated. The relative humidity of air ordinarily varies from 50 to 90%. When unsaturated air is cooled its relative humidity rises. The temperature at which the air becomes saturated (RH = 100%) and at which water begins to condense, is called the *dew point*.

Appendix 6.B. gives the dew point at different relative humidities for a number of temperatures. Using the figures of Appendix 6.B., a graph can be drawn which gives the relationship between air temperature, relative humidity and dew point. This graph is shown in Appendix 6.C.

It should be noted that at high relative humidities, only a slight lowering of the temperature leads to condensation.

Water which condenses by cooling of the air is deposited on all surfaces, including those which have to be painted and those which are freshly painted. Condensation is particularly likely on calm and clear evenings, when there is a large decrease in air temperature. Any condensed water may persist for a long time, sometimes far into the following morning, depending on the season and the weather conditions. Condensation can also take place on cold surfaces (e.g. steel) surrounded by warmer air of high humidity.

The chance of condensation is highest when the weather is changeable. Also, water will sometimes condense on those parts of a ship's hull which form part of tanks containing cool liquids. Similarly, the lower parts of the hull may be cooled when the ship is lying in cold water.

Before painting is undertaken, the existing weather conditions should be assessed for the risk of condensation. If the temperature of the steel is likely to fall below the dew point, condensation is certain to occur.

For large painting jobs it is strongly recommended that the trend in humidity/dew point be continuously monitored.

For successful painting it is essential that during and several hours after paint application, the substrate temperature should remain above the dew point of the surrounding air.

In order to be safe, in painting specifications it is often prescribed that:

- painting should not be undertaken when the relative air humidity exceeds 85% (unless the paint manufacturer considers it safe or when special, damp-tolerant, products are used);
- painting should be undertaken only when the substrate temperature is at least 2 or 3°C higher than the dew point.

For the measurement of humidity, air and steel temperatures, the reader is referred to Part 9.4.4. For the dew point calculation see appendices 6.A. and 6.B.

When painting the interior of tanks the air is often dried to lower its dew point and thereby reduce the risk of condensation.

The only correct way of drying the air is by means of dehumidifiers. It should be noted, that drying by simple heating procedures is not effective when the steel surface is at a low temperature (e.g. when a ship lies in cold water). Although heating of air lowers its relative humidity, its dew point does not change as long as its water content remains unchanged.

Heating by means of hot-air guns is, apart from fire hazard, unacceptable because it increases the water content.

It is obvious that painting in the open should never be done in rain, snow, frost, fog or heavily polluted air. Under these conditions painting should be suspended.

Painting schedules for new construction and repair work often take insufficient account of high humidities that prevail during the winter months, when blast-cleaning and painting is often impossible. In particular the onset of thaw is accompanied by marked condensation.

Since the steel only slowly rises in temperature due to its high heat capacity, condensation sometimes persists for several days. It will be clear that in planning painting operations in the open, careful note should be taken of weather forecasts.

6.4.2. TEMPERATURE

Like humidity, temperature is an important factor in paint application. In warm weather, solvents and thinners evaporate quickly, and fresh coats of paint set rapidly. In extreme cases, surface drying proceeds so fast that the solvents at lower levels have not evaporated completely, which leads to solvent retention.

Occasionally this results in wrinkling or in the formation of blisters. Also the formation of 'dry spray' is strongly promoted by paint application during high temperatures, producing rough and porous paint layers. Too rapid setting occurs particularly on hot days with strong winds, which rapidly carry away the solvent vapours.

When paint is sprayed on a warm surface, it sometimes sets so rapidly that the paint droplets fail to coalesce, resulting in a porous coat. In brush application it is sometimes difficult to spread the paint over the surface in a uniform thickness.

For all these reasons, painting at air temperatures higher than 30°C should be discouraged, unless paints are specially made for application at higher temperatures. Likewise, steel surfaces which have become hot from exposure to sunshine should not be painted. Paint under such circumstances should only be applied if the surface is in shadow.

With falling temperatures the viscosity of paints increases, resulting in poor applicability. Sometimes an extra amount of thinner has to be added to obtain good application properties. This practice, however, leads to thinner dry paint films. Thinning, exceeding 5% by volume, is only allowable if the paint manufacturer agrees.

Low temperatures may considerably retard setting and curing of paint coats which may show sagging on vertical surfaces.

At lower temperatures, some two-pack paints will not harden at all, because under these circumstances chemical reactions between binder and hardener almost cease. At low temperatures, sometimes, special types of hardeners may be used. As a rule and apart from some special types, epoxy paints should not be used below 10°C and polyurethane paints not below 5°C, unless the manufacturer advises otherwise.

In view of the poor application properties and slower drying, *as a general rule painting at temperatures below 5°C should be discouraged.*

Painting at temperatures below 1°C should never be allowed, since the possible presence of ice in the pores of the steel surface would obviously result in poor adhesion and reduced corrosion protection.

6.4.3. OTHER CONDITIONS

After the correct surface preparation (Chapter III), the first coat of paint should be applied with the shortest possible delay. Premature corrosion or contamination by impurities from the air (dust, salts, sulphur dioxide) is thereby prevented. The first paint coat should in any case be applied before discolouration of the steel surface (appearance

of coloured corrosion products) starts. At the beginning of the application, the blast-cleanliness should be as prescribed.

With high-duty paints in particular the presence of even small amounts of corrosion products, salts and foreign matter (impurities) adversely affects adhesion and durability of the paint system. If present, the preferred pretreatment is wet abrasive blast-cleaning, followed by dry sweep-blasting.

In view of possible contamination of the surface, the subsequent paint layers should also be applied with the shortest possible delay. If the painting schedule does not allow for this and longer intervals (e.g. a few months) cannot be avoided, it will often be necessary to clean the surface by thoroughly washing it with clean fresh water or by hot water- or steam-cleaning.

When a following coat is applied, the preceding one should be sufficiently dry, but not completely hardened through. Some types of two-pack paints (underwater paints, tank linings) in particular are very critical in this respect, unless special easy recoatable types are used in which a small amount of physical drying binder is incorporated. The application of a new coat on an old two-component system sometimes results in a poor adhesion of the new coat.

If time intervals between application of successive coats of two-pack paints considerably exceed those specified by the paint manufacturer, it is advisable to roughen the surface before application of a new coat; some manufacturers supply special 'key-coats'.

The intercoat adhesion of physically drying paints is better, since the solvents of the new coat will soften the previous coat slightly, thus resulting in good adhesion.

It is always advisable to purchase the separate coating materials, needed for the complete paint system, from one and the same manufacturer. It is equally important to use the correct application technique, and to apply the paints as uniformly as possible and at the correct film thickness. Methods of measuring film thickness are dealt with in Section 9.4.7.1.

The building schedule should be planned so that paint work cannot be ruined by welding or cutting operations, or by blasting-dust falling on freshly painted wet surfaces.

Painting in high winds should be avoided, since there is risk of contamination of wet paint layers with sand, dust etc. and moreover because the rapid setting of the paint may cause defects as described under Part 6.4.2.

When spraying is done in high winds, spray mist may be carried over long distances, causing damage and nuisance elsewhere.

Whenever necessary, good illumination during application and surface preparation should be provided, not only in tanks, but also under the (flat) bottoms of ships and decks of offshore structures.

When coating tank interiors, proper ventilation is of the utmost importance (see also Part 11.5.9).

6.5. Supervision/Inspection

The quality of paint work, in new construction as well as maintenance, always depends strongly on the quality of the supervision, which therefore should be well-organized.

Regulations on supervision and inspection duties and rights, which, especially in building/coating of offshore structures form part of *quality plans* (Part 9.2), should be laid down in the *contract painting specification* (Part 8.2). The following parties are involved:

- *the owner* (of ship or offshore structure), who has the right of inspecting all operations and requiring inspection reports from the yard and/or the painting contractor;
- *the yard* (quality department), which is in charge of supervising/inspecting all operations and has the right of requiring inspection reports from the painting contractor;
- *the painting contractor*, who has the right of inspecting pretreatments (blast-cleaning + application of prefabrication primer) carried out by the yard and who often must provide inspection reports of his own work (paint application) on behalf of the yard and/or owner;
- *the paint manufacturer*, who has the right of inspecting the work of the yard (blast-cleaning + prefabrication primer application) and the work of the painting contractor (pretreatment + coating application).

Before, during and after the application of the subsequent layers of the coating system, normally frequent checks are made on:

- environmental conditions (monitoring air/substrate temperature and relative humidity for dew point calculations), with respect to the possibility of condensation;
- type/condition of pretreatment, paint preparation and paint application equipment;
- type/quality of pretreatment operations (degreasing, blast-cleaning etc.) and paint preparation/application (mixing, stirring, spraying etc.);
- substrate condition (cleanliness, roughness etc.);
- wet and dry film thickness of the subsequent paint layers;
- appearance (visual defects) and recoatability of the subsequent paint layers;
- curing of the complete system;
- adhesion (after full cure of the coating system);
- presence of holidays (after full cure).

APPENDIX 6.A. - RELATION BETWEEN AIR TEMPERATURE AND MAXIMUM WATER VAPOUR CONTENT

Degrees Centigrade	Maximum water vapour content g/m³
0	4.8
5	6.8
10	9.5
15	12.8
20	17.3
25	23.0
30	30.4
35	39.6
40	51.1
45	65.0

APPENDIX 6.B. - RELATION BETWEEN DEW POINT, AIR TEMPERATURE AND RELATIVE HUMIDITY

Air temperature, °C	Dew point (°C) at a relative humidity of:								
	50%	55%	60%	65%	70%	75%	80%	85%	90%
5	-4.1	-2.9	-1.8	-0.9	0.0	0.9	1.8	2.7	3.6
6	-3.2	-2.1	-1.0	0.1	0.9	1.8	2.8	3.7	4.5
7	-2.4	-1.3	-0.2	0.8	1.8	2.8	3.7	4.6	5.5
8	-1.6	-0.4	0.8	1.8	2.8	3.8	4.7	5.7	6.5
9	-0.8	0.4	1.7	2.7	3.8	4.7	5.7	6.6	7.5
10	0.1	1.3	2.6	3.7	4.7	5.7	6.7	7.6	8.4
11	1.0	2.3	3.5	4.6	5.6	6.7	7.6	8.6	9.4
12	1.9	3.2	4.5	5.6	6.6	7.7	8.6	9.6	10.4
13	2.8	4.2	5.4	6.6	7.6	8.6	9.6	10.6	11.4
14	3.7	5.1	6.4	7.5	8.6	9.6	10.6	11.5	12.4
15	4.7	6.1	7.3	8.5	9.5	10.6	11.5	12.5	13.4
16	5.6	7.0	8.3	9.5	10.5	11.6	12.5	13.5	14.4
17	6.5	7.9	9.2	10.4	11.5	12.5	13.5	14.5	15.3
18	7.4	8.8	10.2	11.4	12.4	13.5	14.5	15.4	16.3
19	8.3	9.7	11.1	12.3	13.4	14.5	15.5	16.4	17.3
20	9.3	10.7	12.0	13.3	14.4	15.4	16.4	17.4	18.3
21	10.3	11.6	12.9	14.2	15.3	16.4	17.4	18.4	19.3
22	11.1	12.5	13.8	15.2	16.3	17.4	18.4	19.4	20.3
23	12.0	13.5	14.8	16.1	17.2	18.4	19.4	20.3	21.3
24	12.9	14.4	15.7	17.0	18.2	19.3	20.3	21.3	22.3
25	13.8	15.3	16.9	17.9	19.1	20.3	21.3	22.3	23.2
26	14.8	16.2	17.6	18.8	20.1	21.2	22.3	23.3	24.2
27	15.7	17.2	18.6	19.8	21.1	22.2	23.2	24.3	25.2
28	16.6	18.1	19.5	20.8	22.0	23.2	24.2	25.2	26.2
29	17.5	19.1	20.5	21.7	22.9	24.1	25.2	26.2	27.2
30	18.4	20.0	21.4	22.7	23.9	25.1	26.2	27.2	28.2

CHAPTER VII

MAINTENANCE OF PAINT SYSTEMS

7.1. General

In the long run, all paint systems develop defects. Examples are mechanical damage, loss of gloss, chalking, discolouration, cracking, flaking and chemical and biochemical degradation. Such defects are caused either by atmospheric attack (including attack by pollutants), or attack by water (e.g. sea water), chemical and mechanical influences. They cause degradation of the substrate, such as corrosion of metals, which, if no specific measures are taken, can even lead to mechanical failure of the (coated) structure.

In order to prevent paint systems failing in their purpose (protection, decoration, special purpose), in the long term, periodic maintenance should be undertaken. The aim of maintenance is to keep the coated structure free from deterioration and the need for repair, so that *it performs its required function safely, efficiently and economically throughout its designed life*. Moreover, proper maintenance should *preserve its appearance*.

The interval between building and the first maintenance operation, as well as the intervals between subsequent maintenance operations must be extended for as long as possible by adequate pretreatment of the substrate and the use of high-quality paints. This is extremely important as maintenance can often involve considerable expense.

Ships for instance, must dry-dock frequently and on offshore structures extremely expensive scaffolding has to be installed in order to make the most corrosion-sensitive areas accessible for maintenance operations. Moreover, the result of these operations is often doubtful.

Permission for longer maintenance intervals for ships is usually granted by classification societies to shipowners who protect the underwater hull by means of a cathodic protection system based on impressed-current, in combination with a high-performance paint system.

Maintenance, however, should not be postponed until serious defects occur such as flaking, blistering and corrosion, since this will considerably increase long-term costs. Preferably, repainting, should always be carried out before finishing coats have ceased to protect the priming coat, or before they have degraded to such an extent that they no longer provide suitable base for the new paint. If maintenance is undertaken at the right time, it should not be necessary to strip all the old coatings before repainting.

Generally, preventive maintenance is to be preferred above curative maintenance. This means that small defects should be corrected as soon as possible.

For ships and offshore structures the need for maintenance should be established by properly planned regular inspections and by keeping reliable records.

As corrosion induced failure is nearly always caused by severe corrosion at some especially vulnerable parts, maintenance procedures should pay particular attention to these parts. Consequently, it will be clear that often it is not necessary to recoat the entire surface area.

The decision whether to patch-paint or to recoat completely is largely an economic one. If, for instance, very complicated expensive scaffolding is needed (e.g. for under deck areas of offshore structures), so that the cost of access forms a high proportion of the total costs, it may be economical to recoat the entire area while on site. This should also be done when an excessive amount of patch-painting of small areas, for instance upwards of 10%, is involved.

Correct planning of maintenance painting work is no less important than that of painting during build.

Although in maintenance work it is usually not necessary to remove the entire paint system, local repair cannot be pursued 'ad infinitum'; even the best system has to be renewed completely after a number of years. This will eventually become necessary when repeated local repainting has ultimately produced extremely thick, cracked layers, or if severe corrosion occurs in places that are difficult to access.

A coating system with excessive thickness has a greater tendency to pull away from the substrate or delaminate between coats than a thinner system of the same generic (binder) type.

Physical drying paint systems which show an excessive coating thickness due to repeated maintenance, can show sudden sagging from vertical surfaces when a new (maintenance) layer is applied.

In the case of local damage, it is often difficult to estimate the total area to be repaired.

Any surface on which maintenance work has to be carried out should first be cleaned thoroughly (e.g. by hydro-blasting or hot water/steam-cleaning).

The extent of any defects can be estimated only after thorough cleaning and close inspection, particularly in the case of underwater parts and tank interiors.

The amount of maintenance work required is usually very much in excess of the visual estimated area of rust spots and other defects. Moreover, it depends heavily on the distribution of these defects over the surface (see Appendix 7.A.).

When using official pictorial standards, like those for the estimation of the degree of rust or blistering (see Part 9.4.8), one should be aware that it is only the part or percentage of the surface covered with (protruding) rust or blisters that is estimated and not the percentage of the surface which needs to be repaired.

The estimation of the extent of maintenance requires considerable skill and experience.

It is important to remove completely not only the clearly visible defects but also any underrust and poorly adhering paint surrounding these defects, before touching-up the paint system (see Appendix 7.B.). Preferably, patches to be repaired should be defined

by 'chalking' in the boundaries, which aids identification and measurement of the areas. Rust staining may be misinterpreted as indicative for coating breakdown.

The owner (operator) and yard manager must agree on the extent of the maintenance work before it is started.

If a ship or offshore structure is painted under guarantee, a distinction should be made between defects originating from mechanical damage and those resulting from imperfections in the paint system itself, e.g. improper pretreatment, insufficient dry film thickness or solvent retention. It is general practice to exclude from the guarantee defects caused by damage during service.

As in building, the best method of surface preparation for maintenance work is blast-cleaning; this also being the cheapest method if the surfaces to be treated are large. If a high-performance paint system is to be used, blast-cleaning is the only acceptable pretreatment method.

Materials like bituminous, chlorinated rubber or vinyl tar paint systems sometimes are difficult to remove by blasting, due to their thermoplastic behaviour.

If localized- or spot-blasting is undertaken the following dangers exist:

- The surrounding paint can be undercut by the abrasive particles, causing damage and loss of adhesion (see Appendix 7.C.). If this occurs, the detached edges should be removed by thorough scraping, using a rotary disc, or by feathering (feather edging).
- The surrounding area will be peppered by stray abrasive particles, which reduces the protective value of the coating system. Therefore it is extremely important to repair the damaged area around the blasted spot.
- Damage can also occur in the areas between the defective (corroded) spots when the jet of abrasive particles is moved over the surface from one spot to another. Preferably, blasting must be discontinued whilst moving the blasting nozzle from spot to spot. Any damage caused between defective areas should also be repaired.

In order to minimize the risk it is recommended that a fine abrasive be used, to blast at low pressure at a small angle to the surface and to use a low viscosity primer, preferably applied by brush (good penetration of possible minor cracks). The method described above is called 'feather edging'. Also special rotary cleaning tools can be used for local repairs, thus minimizing the risk to surrounding (intact) areas.

On pitted (severely corroded) steel surfaces, special attention should be given to the bottom of pits, where water soluble iron salts or other contaminants are present. It is practically impossible to remove these corrosion promoting materials sufficiently by normal (dry) blast-cleaning.

After blasting, these substances (especially soluble iron salts like chlorides and sulphates) are sometimes still present, causing discolouration of the steel surface immediately after blasting. This phenomenon is called *steel bleeding*. The application of paint systems on such a substrate is very risky and may result in poor adhesion, followed by blistering/flaking, due to osmosis and corrosion.

Sometimes, the blasting operation has to be carried out several times to obtain a clean surface. In doing so, however, the steel surface will become extremely rough.

The use of a fine abrasive is helpful in cleaning pitted areas. The best way, however, is to treat such surfaces by wet abrasive blast-cleaning, followed by dry sweep-blasting to remove the flash rust.

Also dry blast-cleaning, followed by water-washing (hydro-blasting) or hot water (steam)-cleaning and dry sweep-blasting can be used.

With local repair (for instance at damaged spots) it is essential to rebuild the paint system to a sufficient thickness; this is of special importance for the anti-corrosive coats. In carrying out local repairs each new coat of paint should overlap the previous one. Often, after the primer and intermediate coats have been applied, the last coat (finishing coat) is applied over the whole surface. This prevents the touched-up parts from lifting and being too noticeable ('patchwork').

When deterioration of the paint system has reached the stage of loss of gloss and chalking, and the aim is to restore its decorative function, treatment can be confined to one finishing coat. Of course, the surface should be cleaned, e.g. by hosing with clean fresh water and degreased where necessary, or by hot water (steam)-cleaning. In this way dirt, grease and soluble salts are removed from the surface.

In order to obtain good adhesion of the repair coat it is sometimes necessary to roughen the existing paint system either mechanically by sanding, sweeping or wet abrasive-blasting or chemically by softening it slightly with a strong solvent. Such roughening or softening is particularly necessary when the old system is built up from certain types of two-pack materials (for instance underwater coatings or tank linings). The directions of the paint manufacturer should be carefully followed.

Maintenance painting work generally poses more problems than painting during building. Surface preparation operations preceding maintenance work are often more difficult, the result depending on e.g. the weather conditions. Also, it is not always possible to use blast-cleaning as a pretreatment because of the damage, noise and pollution it causes.

Problems arise when the paint system of a ship's hull must be repaired during a very short period during dry-dock in cold damp weather. In such cases maintenance paints should be quick-drying and at the same time tolerant to high atmospheric humidity and low temperatures.

For offshore structures in the North Sea, especially in the northern part, maintenance painting is possible only during a few months of the year.

Maintenance paints for local repairs should always be compatible with the existing paint system. In many cases, the same paints as those used for new ships and offshore structures can be applied. Sometimes, however, the paint manufacturer has to modify the paints slightly in order to make them suitable for application over old (hard) existing paint systems or for application under unfavourable weather conditions.

Quite often the decision is made to upgrade an old conventional coating system that appears to be in good condition, with a 'higher-performance system'. Especially if the application is made over a very thick multicoat conventional coating system, this decision is often disastrous. Delamination of the new coating system from the old one or delamination of the old system from the substrate (or at the weakest link between coats) can occur due to differences in thermal expansion and contraction properties or due to the cohesive forces in the high-performance system. Depending on the film thickness, adhesion and exposure conditions of the old coating system, it is normally better to touch-up and top coat with the same generic coating system.

In maintenance work for ships the usual practice is that the paints are supplied by the owner. Sometimes this practice gives rise to problems if the painting contractor has no previous experience with the type of paint and its application properties.

In maintenance work, good supervision is at least as important as with new build.

7.2. Maintenance operations on the various parts of ships

7.2.1. GENERAL

Most of the paint maintenance work on ships is done during obligatory dockings. As a ship out of service constitutes a considerable expense, shipowners endeavour to keep docking times to a minimum. However, for optimum protection, the docking time should not be too short, since paints should be allowed to dry-through sufficiently.

There is an increasing practice of removing fouling and applying fresh anti-fouling paint, during short dockings (e.g. one day) interposed between dockings for extensive maintenance. Such rapid maintenance is possible only if the painting contractor is fully equipped for it, having at his disposal enough equipment such as scaffolding, cherry pickers, compressors, etc.

The data needed for the maintenance work should preferably be available before the ship goes into dry-dock. Ship reports (including photographs) and reports about previous dockings may provide useful information. Immediately after arrival of the ship in the yard, the parts where maintenance is deemed to be necessary should be inspected.

On the basis of this inspection, it should be decided, as quickly as possible, which parts of the ship need maintenance and how it is to be performed. Repair of these parts should either be local or total, depending on the extent of the damage.

All maintenance work concerning the painting of the different parts of the ship involves the following operations:

- cleaning and, where necessary, degreasing the surface;
- removal of corrosion products (rust) and/or defective paint coats by blasting or mechanical cleaning;
- sanding of boundary zones;
- removal of dust;

- roughening or slight softening of the old paint, where needed; any roughening should be followed by removal of dust;
- application of the required repair paint coats.

It is not proposed to deal in detail with the maintenance operations for all parts of the ship, but restrict it to those parts which give most trouble in maintenance, namely the underwater hull and the tanks.

7.2.2. MAINTENANCE OF THE UNDERWATER HULL

Maintenance of the underwater hull involves:

- removal of fouling, leached-out anti-fouling layers, defective paint layers, rust, salt, slime and oil;
- renewal of the paint system on the defective areas;
- *restoring the smoothness of the underwater surface by the methods described above to keep the frictional resistance to a minimum.*

Normally, the barnacles (hard fouling) are removed by scraping.

The underwater hull then is cleaned by means of high-pressure water jetting (hydro-blasting). This removes, algae (grass) small shells, flaking and poorly adhering paint and loose rust.

Sometimes the underwater areas are covered with a very thin, hardly visible hygroscopic slime film or, when a self-erodable anti-fouling paint is used, with a very thin soft eroded layer. In order to remove these films, which can later cause loss of adhesion of the paint system, the hydro-blasting operation should be carried out using the highest (reasonable) possible pressure.

Where necessary the underwater hull should be degreased, this usually being carried out by the application of a suitable detergent, followed by spraying with clean fresh water. Sometimes this is necessary for the entire underwater area when, during emptying the dry-dock, it has been contaminated by the deposition of a thin oil film* .

As soon as the hull is dry, it should be freed from any adhering rust, leached-out anti-fouling layers and defective (blistered/cracked) paint layers. The extent of these defects is assessed by careful inspection of the underwater parts.

The choice of the necessary cleaning method depends on the type and extent of the defective areas and on the type of repair system to be applied. The choice is usually between nozzle-blasting with a cheap abrasive that does not need to be recovered, sweep-blasting, wet abrasive blast-cleaning or mechanical (power tool) cleaning. As in other cases, blast-cleaning is the most effective and economical method. When sweep-

* In the Netherlands, for naval ships, the underwater areas are brushed using a special cleaning agent which subsequently is removed by fresh water cleaning.

blasting, the abrasive to be used should be very fine (diameter ≤ 0.5 mm) in order to prevent damage to underlying paint (primer) layers.

Before blasting and painting, the vessel should be deballasted completely to prevent condensation on the hull.

Also before blasting starts, appropriate measures should be taken to protect the propeller, the anodes + reference electrodes of the cathodic protection system and the echo-sounding elements against mechanical damage and paint.

Before painting, all scupper holes should be closed and all drain pipes temporarily plugged to avoid premature defects in the paint layers.

The anti-corrosive coats should be touched-up, as soon as possible, after removal of fouling, corrosion products and defective parts of the paint system. Zinc-rich primers should not be used for this purpose as no adequate adhesion will be obtained at overlaps. As soon as the touched-up areas are dry the necessary coats of anti-fouling paint should be applied. Conventional (classical) anti-fouling, however, should never be applied a long period before undocking the ship.

After removing of leached-out anti-fouling, rust and poorly adhering paint coats, the underwater hull sometimes still shows very rough parts. If this roughness is the result of repeated maintenance operations, the areas concerned should be cleaned to bare metal (preferably by blasting), and the paint system completely renewed.

On ships with a long-life (contact matrix) anti-fouling system the leached surface of old anti-fouling paint (depleted matrix) should be removed or sealed with a special sealer before application of the new anti-fouling paint. The old anti-fouling system should be removed in cases of excessive thickness and roughness, due to the build-up of alternating sealer and leached-out anti-fouling layers as a result of repeated previous maintenance*. Removal should be by sweep (brush-off)-blasting or wet abrasive-blasting, using a very fine abrasive.

If, due to this blasting, the anti-corrosive system is damaged, it should be touched-up and brought to the original film thickness before application of the new layers of anti-fouling paint.

Bare steel surfaces should not be treated with anti-fouling paints containing cuprous oxide, since this is likely to cause contact corrosion.

In order to avoid unnecessary roughness of the underwater hull, i.e. no overspray of paint droplets on the anti-fouling paint, all painting of topside and boottop has to be completed before commencing anti-fouling paint application. Also, no blasting activities

* The build-up of alternating primer and anti-fouling layers leads to a so-called sandwich structure and is a serious cause of increase in roughness. When such systems are exposed to sea water and, even worse, to fresh water, the old anti-fouling layers (depleted matrixes) will absorb a lot of water, swell and become weak links in the paint system. After a few dry-dockings, peeling-off and flaking will occur resulting in a tremendous increase in roughness.

should be executed in the vicinity. Overspray should be removed as quickly as possible by means of nylon brushes.

If the underwater hull is cathodically protected by an impressed-current system, the paint system around the anode shields often is severely attacked. The cleaning of these areas and the removal of remnants of paint from them generally poses no special problems. After hydro-blasting and local abrasive-blasting, around the anodes a thick (epoxy) filler or mastic is applied in accordance with the advice of the anode supplier.

7.2.3. MAINTENANCE OF TANKS

Tanks are usually cleaned by specialized contractors, generally associated as sub-contractors to the yard. The cleaning procedures will not be discussed here. Before being painted, tanks must be gas-freed and tank surfaces must be dry and clean.

As with other parts of the ship the maintenance of paint systems involves local derusting and removal of defective paint coats, followed by touching-up of the paint system. For procedures of surface preparation, conditions of painting and safety measures, the reader is referred to Section 1.3.6.2 (building). Apart from these, the maintenance of tanks poses several special problems, which will be discussed in the following paragraphs.

Proper painting of a tank in the time available for maintenance requires very close cooperation between yard management, painting contractors and other sub-contractors. Although for surface preparation blast-cleaning is strongly recommended and is indeed the only acceptable method in tanks carrying chemicals, it suffers from the disadvantage that in local repairs intact areas of the coating system are likely to be damaged by abrasive particles. Shielding vulnerable parts or vacuum-blasting may reduce the extent of the damage.

If corrosion has set in, certain constituents of cargoes (ballast water, fuel) may have penetrated into the pits of the corroded steel, causing 'steel bleeding'. For the proper treatment of such surfaces, the reader is referred to Part 7.1.

Adhesion of paint is particularly poor if a tank has contained oils or greases, because the solvents of the paint will 'extract' grease from the pits in the steel surface.

It should finally be said that tanks (for instance water ballast tanks) treated in build with a 'grease paint' (rust-inhibiting grease) or with a 'float-coat' (non-drying mineral oil or lanoline derivative), cannot be cleaned adequately, even by blasting, without great difficulty.

7.3. Offshore maintenance

As set out already in Part 2.1, offshore maintenance painting is often very difficult and always expensive*. This is due to factors, like poor weather, poor access, undesired interference of maintenance operations with other activities, etc. *Therefore it is extremely important to evaluate which protective systems have failed prematurely and why.*

As moreover, it is very difficult to obtain the desired high-quality corrosion protection by painting offshore, it must be clear that *during building of offshore structures corrosion-protecting activities must be of the highest possible economical quality and be executed onshore as complete as possible.* Such a high quality can only be achieved when a proper line of communication exists, based on regular meetings, between operator (owner), builder (yard), coating manufacturer, painting contractor and coating inspector(s).

It is of the utmost importance to avoid coating damage during building, handling, transport, load-out, hook-up and erection of the offshore structure or parts of it. Any damage should be rectified completely and as soon as possible. With respect to avoidance of premature (expensive) maintenance, proper treatment of field welds is of prime importance.

As mentioned previously, maintenance painting is difficult, subject to several limitations and extremely expensive. Significant points in this respect are:

- For certain areas like the northern part of the North Sea, maintenance painting can only be undertaken during a short period of the year (the summer months), due to high humidity and low temperatures.
- The need to transport all equipment, materials and personnel (painting operators, supervisors, inspectors etc.) to the offshore structures and find accommodation.
- Poor access and limited working space. Often expensive and time-consuming scaffolding is required; especially the tidal/splash zone and underdeck areas form notoriously difficult areas to maintain. In the initial design of the structure, provision should be built in to provide adequate access any time, especially at critical node points and weld areas.
- Contamination of surfaces with salt, oil and/or chemicals.
- Frequent shortage of fresh water for washing-down operations.
- Limitations on dry blasting-operations due to poor access, safety considerations for personnel, spark hazard, generation of static electricity and possible damage to adjacent equipment and instruments. In such circumstances, vacuum-blasting, wet abrasive-blasting or hydro-jetting may be advantageous.

* Offshore maintenance may well be five times as expensive as onshore maintenance, apart from underwater coating repairs which are even more so!

- The use of coating systems of low tolerance to offshore application conditions. The use of damp-tolerant (wet steel) primers and moisture-curing coating systems should be considered.
- Undesired interference of paint maintenance operations with production requirements and other maintenance programmes.
- Lack of labour and supervising continuity, due to the necessary changes of crew.

Offshore coating maintenance operations should be properly planned and based on comprehensive surveys by a coating specialist to establish precise areas requiring treatment.

Usually, offshore coating maintenance activities are divided into two groups:

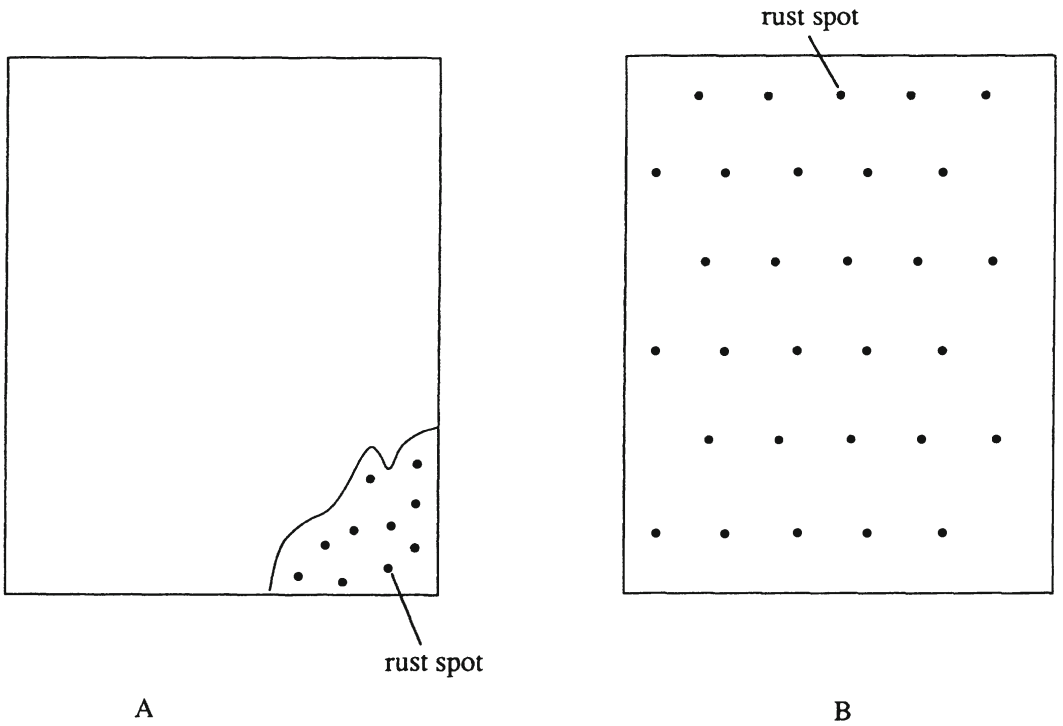
- *frequent touch-up work* (for instance annually) to repair any damage of the coating system originating from mechanical causes and from installation and equipment modifications;
- *large-scale maintenance*, necessary because the existing coating system has failed or reached the end of its economic life, or because the degree of damage to the system is such that local repairs are not economically justified.

The maintenance programme should be closely integrated with other on-going offshore activities to ensure absence of undesired interference and availability of essential services such as power and water and also to ensure optimum use of services required by other contractors, e.g. scaffolding or other access equipment.

To eliminate wasteful duplication of work, coating maintenance should follow and not precede any essential structural modifications, maintenance welding or equipment replacement.

The maintenance coating systems should be selected with due regard to complete compatibility with the existing systems to be overcoated. Preferably, the maintenance systems should also have tolerance to the lower standards of surface preparation, which are the rule rather than the exception offshore. Hot water (steam)-cleaning, wet abrasive-blasting and hydro-jetting (with the addition of a fine abrasive), in combination with damp tolerant primers are increasingly used under offshore maintenance conditions.

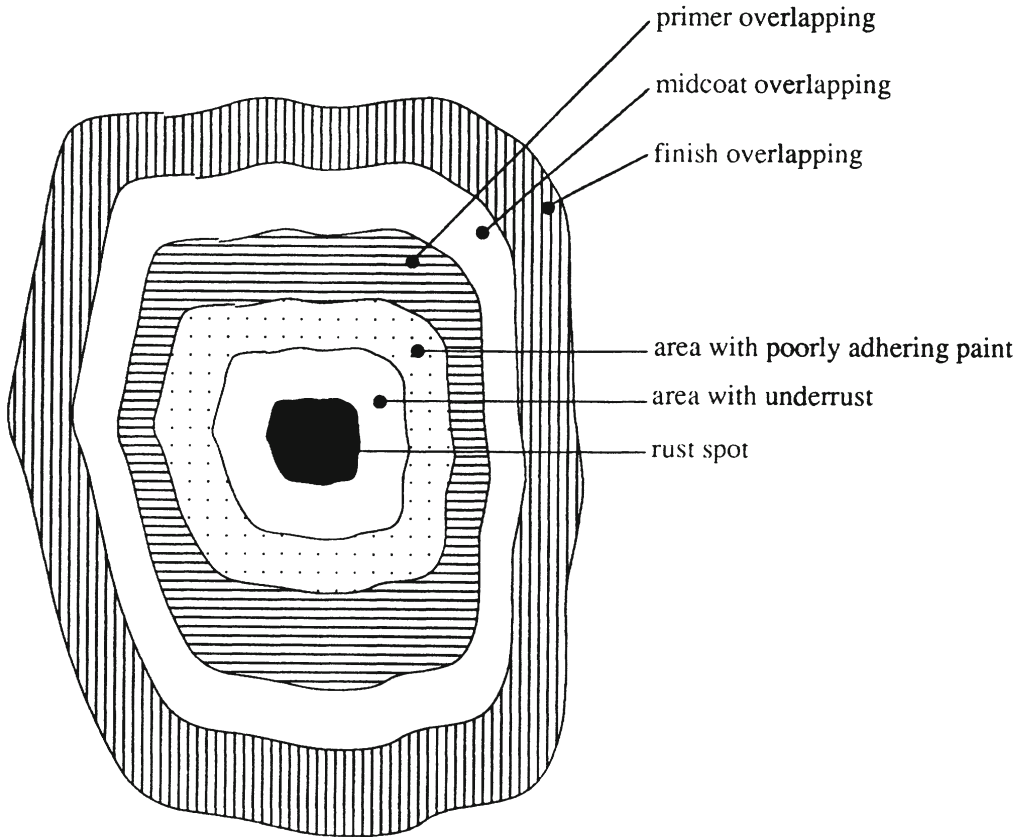
APPENDIX 7.A - RELATION BETWEEN THE DISTRIBUTION OF RUST SPOTS AND THE AREAS TO BE REPAIRED.



% rust: A 1% (Re 3 acc. to European rust reale)
B 1% (Re 3 acc. to European rust reale)

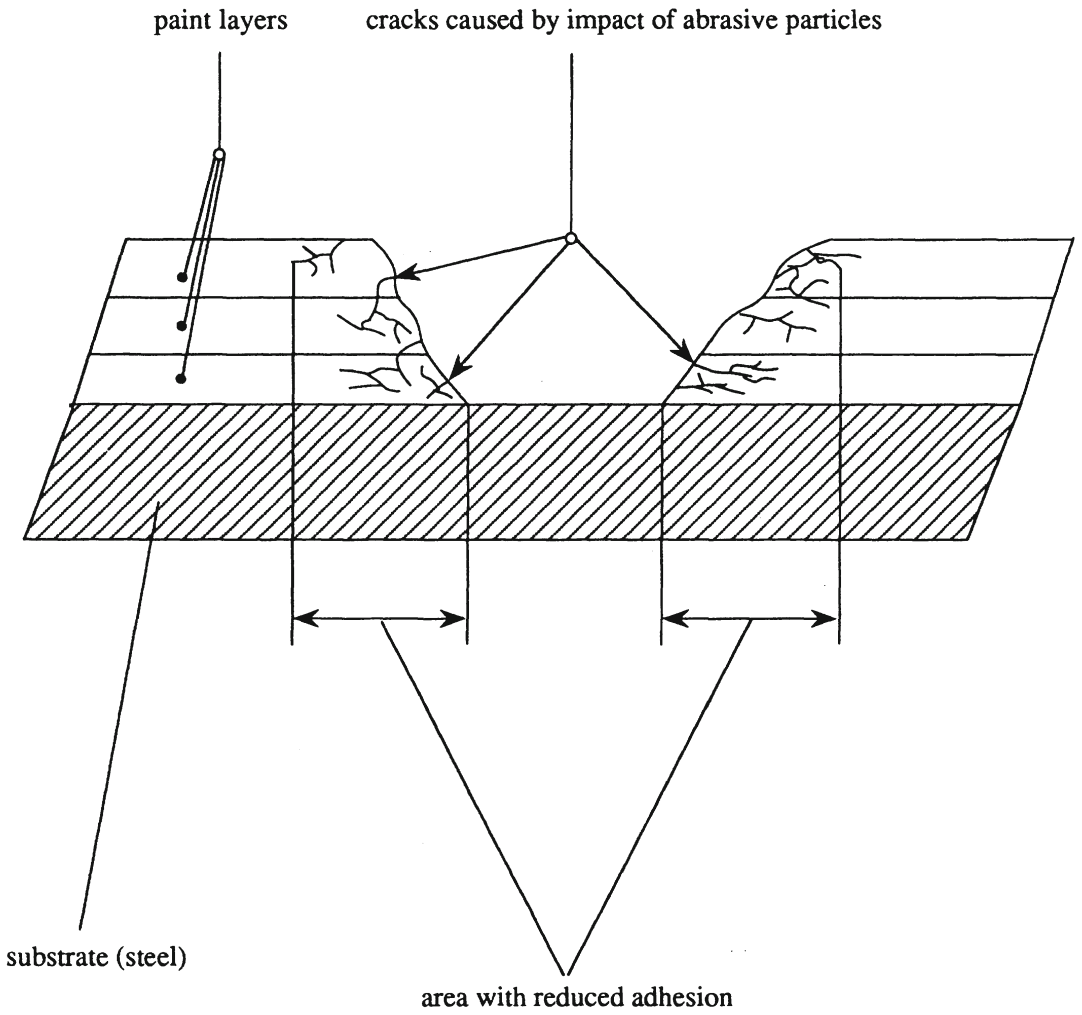
Area to be repaired A: approx 10%
B: 100%

APPENDIX 7.B - AREA INVOLVED WHEN TOUCHING-UP A RUST SPOT



Area to be painted is much larger than area to be blast-cleaned.

APPENDIX 7.C - DAMAGED AREA CAUSED BY SPOT-BLASTING.



CHAPTER VIII

PAINT CONTRACTS AND SPECIFICATIONS

8.1. Introduction

Although practice in matters of contracts and specifications, which may refer to new build or to maintenance work, naturally varies from country to country, a general outline will be given in this chapter.

When ordering a ship or offshore structure, the owner or operator usually makes an *outline specification* constituting a general indication of the paint systems to be used. Based on this outline specification the owner or operator requests a cost estimation from one or several yards (builders). These yards work up the outline specification into a more detailed one, called the *tender specification*, which is the basis for their price quotations.

When agreement has been reached, the owner (operator) and the yard (builder) draft a *contract specification*, which is more detailed than the tender specification. For maintenance work on a ship, this document will be drafted after the ship has dry-docked.

The contract specification is a very important document which is legally binding on the parties concerned.

In order to avoid differences of opinion on technical and commercial matters, the parties to the contract should draft the specification with the utmost care and in close cooperation.

The contract painting specification (painting schedule), which is a part of the complete contract specification, has to be adapted to local circumstances such as the geographical situation of the yard, the available working facilities (blast-cleaning hall, section hall) and the processes available in the yard concerned.

It is essential for owner, yard, paint supplier and painting contractor to establish and maintain, before and during the building of the ship or offshore structure, a close cooperation particularly as regards the planning of the painting work.

The contract painting specification should not contain contracts between yards and sub-contractors. These separate contracts are called *agreements*, which describe for instance details of providing power supplies, auxiliary equipment, financial matters etc.

It is essential that in the agreements no points are inserted contrary to the contract painting specification.

Further detailing of the contract painting specification (painting schedule) leads to the so-called *paint list* which is dealt with in Section 8.3.

8.2. The contract painting specification (painting schedule)

The contract painting specification comprises a number of *basic clauses* and a number of *supplementary clauses*. These will be dealt with in the following sections.

8.2.1. BASIC CLAUSES

Basic clauses are items that should at all events be incorporated in the contract painting specification.

Examples of basic clauses are:

- names of the parts of the ship or offshore structure to be painted;
- methods and standards of surface preparation and, where necessary, roughness of substrates (steel, aluminium etc.), for the various parts;
- type and trade name of prefabrication primer (if required) and its dry film thickness;
- whether the painting is to be carried out on sections after prefabrication or whether construction occurs 'in the shop-coat';
- method of cleaning and touching-up of the shop-coat or prefabrication primer (if such a product is specified), before application of the paint system;
- whether or not the shop-coat must be removed from certain parts of the ship or offshore structure before final painting (if one is specified); if applicable, the method of removal and the desired cleanliness of the substrate should be prescribed;
- the methods to be used for cleaning and touching-up weld seams, burnt spots, mechanical damage and rust spots, including the required cleanliness of these areas;
- description of the various paint systems, with specifications of colours, dry film thickness of separate coats and total dry film thickness. Appendix 8.A gives an example of a part of a painting schedule for the construction of a ship;
- regulations concerning quality control, testing and inspection; with respect to the importance of quality control and proper testing/inspection, these subjects are dealt with separately in Chapter IX.

8.2.2. SUPPLEMENTARY CLAUSES

In addition to the basic clauses dealt with in the previous section, the contract painting specification for new construction comprises a number of agreements or arrangements aimed at ensuring good progress of the painting work, and avoiding misunderstandings between the parties concerned.

Examples of such supplementary clauses are:

- plates with a shop-coat (prefabrication primer) should only be rolled and bent by means of clean, smooth rollers;
- sections should not be taken out of doors until weld seams, burnt spots and mechanical damage have been touched up;
- paint suppliers should agree that their paints are to be applied over the yard's prefabrication primer (shop-coat);
- all products to be used should be approved by the owner (operator) and their colours should be to the owners choice;
- all painting work should be carried out by qualified personnel and in accordance with the specifications;
- the painting work should be so timed as not to interfere with the building of the ship or offshore structure, and so planned as to prevent needless damage from bending, blast-cleaning, flame-cutting, welding, foot traffic etc.;
- weld spatter should be removed and rough parts of welds should be smoothed before painting;
- butt welds of underwater plating should be smoothed by chipping;
- instruments and vulnerable equipment should be protected against damage by abrasive and paint particles;
- during the paint application on the underwater parts or in tanks, the anodes of the cathodic protection system should be temporarily masked;
- section welds should be masked with adhesive tape of about 5 cm wide before paint application;
- surfaces to be painted should be marked with materials agreed upon by the paint manufacturer and the owner (operator); no chalk and no wax pencils, or other materials liable to bleed (ink crayons), should be used for this purpose;

- the actual condition of substrates should be approved by the owner (operator) and paint manufacturer before painting starts;
- all surfaces to be painted should be dry and free from grease, dirt, dust, corrosion products, etc.;
- during paint application the surfaces concerned should be at a temperature that ensures that no condensation can take place; preferably their temperature should be at least 2°C above the dew point of the ambient air;
- during paint application the temperature of the surfaces concerned should be at least 1°C;
- in bad weather (rain, mist, frost) all exterior painting should be suspended;
- in order to remove zinc salts properly, surfaces treated with a zinc-rich paint (e.g. shop-coat) should be thoroughly brushed and rinsed with clean fresh water and allowed to dry before application of the next coat of paint;
- unless otherwise stated in the painting schedule, paints should be applied as specified in the manufacturer's data sheets; special attention should be paid to sufficient drying time; thinning of paints, otherwise than specified by the manufacturer's data sheets or separate instructions, is not allowed;
- whenever there is any doubt about the type of paints systems, application method, recoatability etc., the owner and/or paint manufacturer should be consulted;
- successive anti-corrosive primer coats should be sufficiently different in colour;
- no subsequent paint coat should be applied without the approval of the inspectors of the owner (operator) and paint manufacturer; if the inspectors consider it necessary the paint system first should be touched-up (with all coats already applied) on all damaged, burnt spots etc.;
- tanks should be pressure-tested only when painted completely, but not before permission from the Classification Society's office has been obtained;
- the painting work should be so planned that spaces which will become difficult of access, such as tunnels for piping, tanks for storing lubricating oil and cofferdams, are painted in an early stage, whilst still easily accessible and clean;
- before starting paint application in tanks and other confined places adequate lighting- and ventilation equipment should be installed;

- in order to avoid dew point conditions when the ship is berthed in relatively cold water, double bottoms and peak tanks should be painted before launching the ship;
- the painting process must be supervised by qualified paint inspectors and not be retarded by unreasonable demands of the inspectors.

8.3. The paint list

The *paint list*, mentioned in Section 8.1, is an elaboration of the painting schedule (contract painting specification). *It comprises the basic and supplementary clauses of the painting schedule worked out in detail. It also serves as a working document for the yard and painting contractor* and it should therefore list all operations relating to painting, including the planning of these operations in the course of the processing in the yard. Appendix 8.B. gives an example of part of such a painting list. This example corresponds to Appendix 8.A., which is a more general survey of the painting schedule.

8.4. The checklist

In drafting the final painting schedule and the paint list, it is recommended that reference is made to a *checklist* for the appropriate details, so that no parts of the ship or offshore structure are overlooked.

A checklist enumerates all parts that have to be protected by paint, classified in groups and subgroups. The painting schedule (8.2) only mentions the more important parts of the ship or offshore structure, whereas the paint list (8.3) mentions all parts of the checklist, together with the operations to be carried out. Appendix 8.C. is an example of a ships checklist.

8.5. The maintenance painting schedule

The *maintenance painting schedule* is based on the schedule for new building. The items are much the same as those described in Sections 8.2 and 8.3.

In the maintenance painting schedule, however, the following points are of prime importance:

- *surface preparation*, which includes the method of cleaning (including that of the weathered paint coats), the method of removing corrosion products and defective paint coats, and the desired grade of surface preparation after these treatments;
- *types of paint to be used*; it is important to consider the recoatability of the existing paint systems with the maintenance paints (special attention should be paid to the avoidance of poor adhesion, bleeding, wrinkling, etc.).

The maintenance schedule should contain a clause stating that the paint schedule used for the new building is to be in the possession of the owner or operator and also a copy held aboard the ship. On board, the new build paint schedule should be available on request to the yard management and the painting contractor. The maintenance schedule should also incorporate a clause requiring the owners of ships and operators of offshore structures to keep records stating:

- when and where previous maintenance systems have been applied, as well as the extent of the maintenance (areas where maintenance has been carried out) and, if possible, the method of surface preparation and the weather conditions during application;
- trade names, types, and if available, data sheets of the paints used in new building and maintenance.

APPENDIX 8.A. - EXAMPLE OF A CONTRACT PAINTING SPECIFICATION (PAINTING SCHEDULE) FOR A SHIP'S NEW BUILD

Part of the ship	Surface preparation	Prefabrication (shop) primer	Paint system						Special remarks	
			1st coat	2nd coat	3rd coat	4th coat	5th coat	Total dry film thickness in μm (without shop-coat)		
Flat bottom to bilgekeel	blast-cleaning Sa 2 $\frac{1}{2}$	red brown epoxy, 20 μm *	coal-tar epoxy 125 μm	coal-tar epoxy 125 μm	coal-tar epoxy 125 μm	--	--	--	250	--
Underwater hull from bilgekeel to light load-line	blast-cleaning Sa 2 $\frac{1}{2}$	red brown epoxy, 20 μm	coal-tar epoxy 125 μm	coal-tar epoxy 125 μm	vinyl-based sealer, 50 μm	anti-fouling vinyl based, 35 μm	anti-fouling vinyl based, 50 μm		385	Areas around anodes to be blasted and treated with epoxy filler or mastic
Boottop/topside	blast-cleaning Sa 2 $\frac{1}{2}$	red brown epoxy, 20 μm	high build epoxy paint, 100 μm	high build epoxy paint, 100 μm	glossy epoxy finish light green, 40 μm	--	--	--	240	--
Main decks	blast-cleaning Sa 2 $\frac{1}{2}$	red brown epoxy, 20 μm	high build epoxy paint, 100 μm	high build epoxy paint, 100 μm	non-slip epoxy paint, grey, 50 μm	--	--	--	250	--
Deck houses	blast-cleaning Sa 2 $\frac{1}{2}$	red brown epoxy, 20 μm	high build epoxy paint, 100 μm	high build epoxy paint, 100 μm	glossy aliphatic polyurethane finish white, 40 μm	--	--	--	240	--
Superstructure	blast-cleaning Sa 2 $\frac{1}{2}$	red brown epoxy, 20 μm	high build epoxy paint, 100 μm	high build epoxy paint, 100 μm	glossy epoxy finish, selected colours, 40 μm	--	--	--	240	Deck machinery and cranes to be power tool cleaned and painted with an alkyd paint system (dry film thickness approx. 150 μm)
Swimming pool	blast-cleaning Sa 2 $\frac{1}{2}$	red brown epoxy, 20 μm	high build epoxy paint, 100 μm	high build epoxy paint, 100 μm	high-build epoxy paint blue-green, 100 μm	--	--	--	300	Shop-coat to be removed by blast-cleaning before application of the paint system

APPENDIX 8.A. - CONTINUATION

Part of the ship	Surface preparation	Prefabrication (shop) primer	Paint system						Special remarks
			1st coat	2nd coat	3rd coat	4th coat	5th coat	Total dry film thickness in μm (without shop-coat)	
Engine room	blast-cleaning Sa 2 1/2	red brown epoxy, 20 μm	alkyd primer, 35 μm	alkyd under-coating light grey, 35 μm	non-yellowing engine room alkyd paint white, 30 μm	--	--	100	--
Fuel tanks	blast-cleaning Sa 2 1/2	red brown epoxy, 20 μm	--	--	--	--	--	--	After mechanical cleaning to be filled with fuel as soon as possible or to be oiled
Crude oil/ ballast tanks	blast-cleaning Sa 2 1/2	red brown epoxy, 20 μm	high-build epoxy paint, 100 μm	high-build epoxy paint, 100 μm	--	--	--	200	Only deck heads + 2 m down, bottom parts + 2 m up and upper side of horizontal stringers to be painted; bottom parts to be cathodically protected by zinc anodes
Drinking water tanks	blast-cleaning Sa 2 1/2	red brown epoxy, 20 μm	bituminous solution, 20 μm	taste- and odourless bituminous paint, 80 μm	taste- and odourless bituminous paint, 80 μm	taste- and odourless bituminous paint, 80 μm	--	260	Shop-coat to be removed by blast-cleaning before application of the paint system
Lubricating oil tanks	blast-cleaning Sa 2 1/2	red brown epoxy, 20 μm	--	--	--	--	--	--	Shop-coat to be removed by blast-cleaning. After thorough removal of grit and dust, to be filled with lubricating oil as soon as possible

etc.

etc.

* With the exception of the thickness of the shop-coat, all thicknesses are to be considered as minimum dry film thickness.

etc.

APPENDIX 8.B. - EXAMPLE OF A PART OF A PAINT LIST FOR SHIPS' NEW BUILD

MAIN PART	PART	SURFACE PREPARATIONS FOR PLATES AND COMPONENTS	SHIP-PRIMER FOR PLATES AND COMPONENTS	FURTHER TREATMENTS			PAINT SYSTEM						SPECIAL REMARKS	
				In the fabrication hall	On the slipway	On the fitting-out quay	In dry-dock	1st coat (C1)	2nd coat (C2)	3rd coat (C3)	4th coat (C4)	5th coat (C5)		6th coat (C6)
HULL EXTERIOR PARTS	Flat bottom to bilge	bl.cl. Sa 2 1/2	Shoppox 20 µm (sp or asp)	tur.m.cl. S13 + Primex 30 µm* (br)	a. degr.as required b. w.w. as required c. let dry d. tur.bl.cl. Sa 2 1/2+ C1 (br, r or asp) e. C1+C2 (asp)	--	a. degr. as required b. hb c. let dry d. tur.bl.cl. Sa 2 1/2+ C1+C2 (br, r or asp)	Epistar black 125 µm	Epistar brown 125 µm	--	--	--	250	
	Under-water part from bilge to light load-line	bl.cl. Sa 2 1/2	Shoppox 20 µm (sp or asp)	tur.m.cl. S13 + Primex 30 µm (br)	a. degr.as required b. w.w. as required c. let dry d. tur.bl.cl. Sa 2 1/2+ C1 (br, r or asp) e. C1-C4 incl. (asp)	--	a. degr. as required b. hb c. let dry d. tur.bl.cl. Sa 2 1/2+ C1-C4 incl. (br, r or asp) e. C5 (asp)	Epistar black 125 µm	Epistar brown 125 µm	Tie-Co L.L. grey 35 µm	Zero-foul L.L. red-brown 75 µm	Zero-foul L.L. red-brown 75 µm	435	
	Sea inlets + rudder exterior	bl.cl. Sa 2 1/2	Shoppox 20 µm (sp or asp)	tur.m.cl. S13 + Primex 30 µm (br)	a. degr.as required b. w.w. as required c. let dry d. tur.bl.cl. Sa 2 1/2+ C1 (br, r or asp) e. C1-C5 incl. (br, r or asp)	--	a. degr. as required b. w.w. as required c. let dry d. tur.bl.cl. Sa 2 1/2+ C1-C5 incl. (br, r or asp) e. C6 (asp)	Epistar black 125 µm	Epistar brown 125 µm	Tie-Co L.L. grey 35 µm	Zero-foul L.L. red-brown 75 µm	Zero-foul L.L. red-brown 75 µm	560	

APPENDIX 8.B. - CONTINUATION

MAIN PART	PART	SURFACE PREPARATIONS FOR PLATES AND COMPONENTS	SHIP-PRIMER FOR PLATES AND COMPONENTS	FURTHER TREATMENTS				PAINT SYSTEM						SPECIAL REMARKS	
				In the fabrication hall	On the slipway	On the fitting-out quay	In dry-dock	1st coat (C1)	2nd coat (C2)	3rd coat (C3)	4th coat (C4)	5th coat (C5)	6th coat (C6)		Total dry film thickness in micr. (without shop-coat)
HULL EXTERIOR PARTS	Areas around anodes (approx. 40 m ²)	b.cl. Sa 2 1/2	Shoppox 20 µm (sp or asp)	tu.m.cl S13 + Primex 30 µm (br)	a. b.cl. Sa 2 1/2 b. C1 (k) + C2 (asp)	--	a. degr. as required b. C3 (asp)	Epfill paste 3-5 mm	Zero-foul L.L. red-brown 75 µm	Zero-foul L.L. red-brown 75 µm	--	--	--	3-5 µm	
				tu.m.cl S13 + Primex 30 µm (br)	a. degr. as required b. w.w. as required c. let dry d. tu.b.cl. Sa 2 1/2 +C1 (br, r or asp) e. C1+C2 (asp)	--	a. degr. as required b. hb c. let dry d. tu.b.cl. Sa 2 1/2 +C1+C2 (br, r or asp) e. C3 (asp)	Epcoat H.B. brown 100 µm	Epcoat H.B. grey 100 µm	Epcoat Gloss light green 40 µm	--	--	--	240	
SUPER STRUCTURE + DECKS	Anchors and anchor chains	--	--	--	--	a. m.cl. S12 b. C1 (br)	a. m.cl. b. C1 (br)	TarcoA black 50 µm	TarcoA black 50 µm	--	--	--	--	100	
		--	--	--	--	a. degr. as required b. C1+C2 (br)	--	Markpa white 30 µm	Markpa white 30 µm	--	--	--	60		
		tu.m.cl S12 + Primex 30 µm (br)	--	a. b.cl. Sa 2 1/2 b. C1-C3 incl. (asp)	a. degr. as required b. tu.b.cl. Sa 2 1/2 +C1-C3 incl. (br, r or asp)	Epcoat H.B. red-brown 100 µm	Epcoat H.B. light grey 100 µm	Epcoat non-slip dark grey 50 µm	--	--	--	250			

APPENDIX 8.B. - CONTINUATION

MAIN PART	PART	SURFACE PREPARATIONS FOR PLATES AND COMPONENTS	SHIP-PRIMER FOR PLATES AND COMPONENTS	FURTHER TREATMENTS			PAINT SYSTEM						SPECIAL REMARKS	
				In the fabrication hall	On the slipway	On the fitting-out quay	In dry-dock	1st coat (C1)	2nd coat (C2)	3rd coat (C3)	4th coat (C4)	5th coat (C5)		6th coat (C6)
SUPER-STRUCTURE + DECKS	Deck-houses winch-houses and inside bullwarks	b.cl. Sa 2 1/2	Shoppox 20 µm (sp or asp)	t.u.m.cl S12 + Primex 30 µm (br)	--	a. degr. as required b. w.w. c. let dry d. tu.m.cl. S12+C1 (br, r or asp) e. C1-C3 incl. (asp)	a. degr. as required b. tu.m.cl. S12+C1 incl. (br, r or asp)	Epocoat H.B. red-brown 100 µm	Epocoat H.B. light grey 100 µm	Epuran Gloss white 40 µm	--	--	240	
				t.u.m.cl S12 + Primex 30 µm (br)	--	a. degr. as required b. w.w. c. let dry d. tu.m.cl. S12+C1 (br, r or asp) e. C1-C3 incl. (asp)	a. degr. as required b. tu.m.cl. S12+C1 incl. (br, r or asp) c. C4 (br, r or asp)	Epocoat H.B. red-brown 100 µm	Epocoat H.B. light grey 100 µm	Epuran Gloss light green 40 µm	Epuran Gloss light green 40 µm	--	--	280

etc.

etc.

etc.

etc.

Meaning of abbreviations:

- asp = airless spraying
- kn = application by knife (knifing)
- C1 = first coat of paint system
- C2 = second coat of the paint system
- tu = touching up of welds (sections welds inclusive), mechanical damage, burned spots and rust spots

- b.cl. = blast cleaning
- Sa = mechanical cleaning (ISO 8501)
- m.cl. = mechanical cleaning (sanding, brushing, rotary disc cleaning)
- St = degree of cleanliness after mechanical cleaning (ISO 8501)
- degr = degreasing
- hb = hydroblasting

- w.w. = water washing
- br. = brushing
- r = rolling
- sp = spraying (pneumatic)

* With the exception of the shop-primer, all film thicknesses represent the *minimum* dry film thickness.

APPENDIX 8.C. - CHECKLIST OF A SHIP**A. Hull exterior**

1. Keel plate
2. Flat bottom to bilge keel
3. Sides from bilge keel to light load-line
4. Sea inlet chests
5. Sternpost
6. Rudder
7. Area around anodes
8. Boottop
9. Topside (to top of railing)
10. Bulwark
11. Topsides above rail
12. Anchors
13. Anchor chains
14. Marks: Plimsoll-, draught-, tank- and sternmarks
15. Name of ship, port of registry
16. Hawse pipes
17. Scupper pipes
18. Tube for bow thrust

**B. Superstructure and deck, exterior
(weather-exposed surfaces)**

1. Walking decks, platforms
2. Main deckhouse, winch deckhouses, bulwarks inside, bulkheads and overheads
3. Woodwork
4. Swimming pool
5. Deck machinery, cranes, etc., e.g.:
 - a. Derricks
 - b. Winches
 - c. Mooring equipment
 - d. Cranes
 - e. Transport installations
6. Pipelines and valves, if necessary specified for different materials and operation temperatures
7. Miscellaneous on deck:
 - a. Hatch caomings
 - b. Tank tops
 - c. Hatches
 - d. Deck ladders (steel)

- e. Rails and stanchions
- f. Masts
- g. Funnel
- h. Ventilation ducts
- i. Foundations and scuppers
- k. Davits
- l. Platforms
- m. Helidecks
- n. Gratings
- etc.

C. Tanks, cofferdams and other closed spaces

- 1. Cargo holds
- 2. Cargo tanks
- 3. Ballast tanks
- 4. Deep tanks
- 5. Tanks for different purposes:
 - a. Ballast/fuel oil
 - b. Ballast/cargo
 - c. Ballast/drilling mud
 - d. Ballast/potable water
- 6. Slop tanks
- 7. Heeling tanks
- 8. Fuel-oil tanks
 - a. Heavy oil
 - b. Diesel oil
- 9. Cofferdams
- 10. Freshwater tanks:
 - a. Potable water
 - b. Feed water
 - c. Distilled water
 - d. Fresh water
- 11. Lubricating oil tanks:
 - a. Storage tanks
 - b. Drain tanks
 - c. Lubricating oil-sludge tanks
- 12. Hydraulic oil tanks
- 13. Faeces tanks
- 14. Void spaces (incl.echo-sounder and log compartment)
- 15. Chain lockers
- 16. Bilges and bilge wells
- 17. Rudder, interior

18. Box-beams, interior
19. Ventilation ducts, interior
20. Masts, derricks and bollards, interior

D. Engine room, steering gear compartment, pumproom etc.

1. Tanktop and remaining steel below lowest floor, incl. pipelines, foundation and underside of floor plates
2. Bilges and bilge wells
3. Drip trays
4. Upper sides of decks and floors
5. Steel behind sheating or insulation
6. Plating and/or covering over heating- and/or sound-damping insulation
7. Unsheated steel

E. Cooling and refrigeration rooms

F. Accommodations, stores and workshops

1. Dry spaces (cabins, passages, public rooms, pantries etc.)
 - a. Steel behind sheating or insulation
 - b. Unsheated steel
 - c. Groundwork and back of sheating
 - d. Woodwork visible
2. Wet spaces (bath-room, lavatories, galleys, laundries, drying rooms etc.)
 - a. Steel behind sheating and insulation
 - b. Unsheated steel

CHAPTER IX

QUALITY ASSURANCE, QUALITY CONTROL, TESTING AND INSPECTION

9.1. Introduction

In the case of new construction and maintenance, the painting specification (8.1) is used by the owners (operators) to achieve high-quality coatings and to avoid unnecessary delays, for instance by misinterpretation of the exact requirements by the paint supplier or painting contractor.

As set out under Part 8.2.1, regulations concerning quality assurance, (quality control), testing and inspection form an essential part of the basic clauses of the contract painting specification. Particularly in those for offshore structures, regulations concerning quality assurance etc., are described in detail. Operators of offshore structures and owners of ships normally have a quality department, whose main activities are:

- assisting the project department to evaluate the quality plans of potential painting contractors.
- carrying out regular spot checks during the work in order to determine whether the work is being executed according to the specification and whether the quality control by the painting contractor is adequate.
- participating in the final inspection and approval of completed parts of the work.

9.2. Quality plans

Operators of offshore structures especially require that all main and sub-contractors submit a written quality plan for approval. The quality plan of the painting contractor should include:

- a time schedule for the various pretreatment and painting activities.
- a description of the paints, thinners and other materials to be used.
- a description of all available equipment used in surface pretreatment and paint application activities.
- a description of the qualification of the personnel involved, together with a clear definition of their responsibilities and lines of communication.
- a description of the inspection equipment, including calibration methods and procedures for quality control, testing and inspection, including their methods and frequency.
- details of proposed hold points for operators inspections, after which continuation of the work is allowed only with the operators written approval.

When main and subcontractors have an adequate quality assurance system (plan) this will guarantee the quality of the work, reduce of the number of rejections and makes frequent testing/inspection by the owner (operator) unnecessary.

9.3. Quality control

The most stringent regulations are given in the painting specifications of operators of offshore structures and owners of chemical tankers, who sometimes have direct contracts with the painting contractors. Some of the most frequently occurring regulations are given in the following paragraphs.

- No pretreatment and paint application activities shall be carried out without owners (operators) knowledge and consent.
- During the work the inspector on behalf of the owner (operator) or painting contractor shall submit daily reports including details of weather conditions, air temperature and humidity, substrate temperature, dew point, pretreatment and application details, film thicknesses, progress and any deviations from the approved plan etc.
- Deviations to the prescribed working methods are only allowed with owners (operators) written approval.
- All quality control tests may be witnessed by the owner (operator) or his representative. This includes control of calibration of instruments and measurement of environmental conditions.
- Before testing is carried out, the owner (operator) must have the opportunity to inspect the testing procedures and equipment.
- The owner (operator) has the right to inspect, at all times, all equipment, materials, testing and control equipment, staging/scaffolding, personnel- and equipment protective devices etc., needed to perform the work.
Equipment and materials not in accordance with the painting specification will be rejected.
- The owner (operator) has the right to inspect any surface pretreatment and any paint and application activities at all times. For this purpose, all parts of the work must be made accessible.
- Pretreatment and application activities not in accordance with the painting specification will be rejected.
- Where the assembling of separate parts of the structures will prevent subsequent inspection of certain areas, the owner (operator) shall be warned in time, making it possible for him to inspect those specific areas and repair to be made if necessary, before assembly proceeds.
- All rejected equipment, surface preparation, coating application, applied coating system and test procedures shall be replaced or rectified to an acceptable level in accordance with the painting specification.
- All inspected and accepted or rejected areas shall be given a clear identification mark, with a marker which does not damage the coating system (fatty markers are not acceptable).

In the *building and maintenance of offshore structures*, coating inspections should be carried out by the painting contractor. The operator and the yard have the right of inspection. Normally the operator carries out a considerable amount of inspection. When there is a direct contract concerning the painting work between the operator and the painting contractor, no coating inspection will be undertaken by the yard.

In *building ships*, the paint is delivered by the yard. Normally coating inspections are done by the yard/paint supplier and the owner.

When *maintenance work* is carried out on *ships*, the paint is delivered by the owner. Coating inspections then are normally done by the yard and by the paint supplier on behalf of the owner.

9.4. Testing (inspection) methods

9.4.1. GENERAL

In the following, a number of testing/inspection methods are briefly described, including some relevant standards.

The testing/inspection methods can be used during coating without the need of laboratory facilities.

It should be taken into consideration that the tests to be undertaken depend upon the type of work to be carried out. For instance, a test for the presence of water soluble salts on the steel substrate is very useful after blast-cleaning of strongly corroded and pitted steel, but not after blast-cleaning of steel with intact mill scale.

The inspection/testing tools described are typical 'field instruments'.

9.4.2. INSPECTION OF EQUIPMENT

Prior to the commencement of any surface preparation or coating application, the *equipment* to be used should be inspected so as to ensure adequate operation. This means that *blast-cleaning, paint spraying, heating, ventilation and dehumidification equipment*, including hoses and other accessoires, should be clean and in good condition.

Paint spray nozzles should be in good order and not be worn-out.

Scaffolding should be safe and provide access to all areas of the structure to be coated.

Compressed air for abrasive blast-cleaning, paint spraying and dust removal, should be clean and free from moisture and oil. This can be controlled by regular checking the water and oil separators and directing the compressed air against a white cloth.

9.4.3. SUBSTRATE INSPECTION PRIOR TO SURFACE PREPARATION

Prior to the commencement of any surface preparation or coating application, the *substrate* should be inspected to determine if it is ready to be pretreated and painted. Heavy deposits of grease, oil, dust, dirt, cement spatter and other contaminants should first be removed. To avoid contamination of the abrasive, removal of oil and grease deposits is particularly important when abrasive recycling blast-cleaning methods are used, since the contamination tend to be deposited onto any (steel) surface that will be subsequently blast-cleaned.

The steel substrate should also be inspected for the presence of weld spatter, which must be removed, and the presence of laminations. Rough welds should be ground smooth or rewelded. All laminations should be removed and the areas ground smooth with the surrounding steel surface.

9.4.4. MEASUREMENT OF AMBIENT CONDITIONS AND SUBSTRATE TEMPERATURES

Surface preparation and coating application should be done under suitable ambient conditions of temperature, humidity and dew point.

Weather forecasts should be taken into account by painting contractors and inspectors. Ambient conditions that might impair painting operations are rain, extremely low or high temperatures, strong winds, dust, leakage of steam or water and air pollution.

During the execution of a coating job, *air temperature, relative humidity and substrate (steel) temperature* should be measured and the dew point calculated. This should be done each day before starting work and periodically throughout the day, as prescribed in the painting contractor's approved quality plan. For large coating jobs it is strongly recommended that the above mentioned data be monitored continuously.

For the determination of the *air temperature*, either mercury thermometers or digital electronic thermometers may be used.

The *relative humidity* (and air temperature) can be determined by means of a *psychrometer* through measurement of the 'dry- and wet bulb' temperature or directly by means of (digital) electronic hygrometers. Psychrometers can be divided into *aspirated* and *whirling (sling) types* (hand or fan operated).

With the sling psychrometer, dry and wet bulb temperatures are recorded when three consecutive measurements give the same wet-bulb temperature. The air temperature is recorded by the dry-bulb.

When using the fan-operated psychrometer about two minutes are needed, after starting the fan, for stabilization. Both temperatures are recorded when the wet-bulb temperature remains steady.

On the basis of these temperatures a so-called *psychrometer chart or table* is used to determine the relative humidity and dew point.

For monitoring purposes, a *recording hygrometer* can be used, which records humidity and air temperature continuously to provide daily or weekly records.

For the determination of (*steel*) *surface temperatures*, two types of instruments are used. One of the most common instruments is a *surface temperature thermometer*, which consists of a bimetallic sensing element that is shielded from drafts. Attachment to ferrous substrates is achieved by two magnets on the sensing side. Several minutes are required for the instrument to stabilize, which is very time-consuming.

The other type of instrument is a *direct reading thermocouple/thermistor*. The sensing probe is placed on the surface, resulting in a direct temperature read-out. The sensing probe does not require shielding from drafts.

The reading of ambient conditions and surface temperatures should be taken at the actual locations of the structure to be coated. For general readings, however, the coldest areas of the structure should be considered because condensation problems will occur there first.

For ships these areas may be unventilated compartments, loaded tanks or underwater areas. To ensure that coatings are applied within their temperature limitations, air and surface temperature measurements should be made at the coolest and warmest areas.

9.4.5. ABRASIVES

When blast-cleaning, the type, grade and quality of the abrasive determines the degree of surface cleanliness and roughness (anchor pattern). Abrasives should be of good quality, of the right particle size and be free from fine dust and contaminants such as oil or grease, water soluble salts, organic material (paint particles) and other foreign matter.

Abrasives can be inspected visually for their grade, appearance (e.g. extent of wear) and the presence of dust, clay, chalk, organic contaminants (paint particles) and other foreign materials. The inspection should be carried out using a magnifying glass of at least 10.

It is of the utmost importance to sample the abrasive on a regular basis for laboratory tests on particle size (sieve analysis), moisture content, presence of oil or grease, acidity (pH) and for corrosion promoting water soluble salts (e.g. chlorides).

It is outside the scope of this manual to describe the laboratory tests in detail. For further information the reader is referred to the publication: 'A tentative Specification for Mineral Slag Abrasive' (Journal of Protective Coatings and Linings, November 1984).

9.4.6. STEEL SURFACE CONDITIONS

9.4.6.1 *Surface cleanliness (finish)*

For the assessment of *surface cleanliness after blast-cleaning or mechanical pretreatment*, (pictorial) standards like ISO 8501 (SS 05 59 00, Swedish scale) may be used. Such standards are described under parts 3.2.3.3 and 3.2.4.4.

As the appearance of a blast-cleaned or mechanically pretreated steel surface depends on its original condition and, in the case of blasting, on the abrasive used, agreement on surface cleanliness sometimes is achieved by preparing a '*job-site standard*' which serves as a reference.

9.4.6.2 *Surface roughness* (see also part 3.2.4.3)

For the determination of the roughness of a blast-cleaned steel surface, the *surface profile* should be measured or estimated.

For typical field service, the following instruments (devices) are available:

- surface profile comparators.
- depth micrometers.
- replica tape.
- portable piezo-electric roughness gauges (stylus instruments).

Of these instruments, the *piezo-electric roughness gauges* are the most accurate, but they are also the most vulnerable and expensive. However, they are the only instruments which measure the surface profile accurately under field conditions. ISO Standard 8503-4 describes the stylus instrument method for roughness measurement. The principle is the measurement of the peaks and valleys by vertical displacement of a stylus traversing the test surface in the direction of travel over a specified traversing length.

The most common *profile comparators* are the so-called Rugotest no. 3 and the Keane Tator surface profile comparator. A similar device has been developed by ISO in 1988 (ISO standards 8503-1 and 8503-2). The comparators consists of a number of reference areas with different roughness and profile sharpness. Comparison with the surface to be assessed is made visually and by touching with the fingertips. The comparator method is more or less subjective and gives no accurate figures. There are often large differences between these figures and those obtained with the piezo-electric roughness gauge.

Another type of field instrument which determines average profile depth is a *depth micrometer*; it measures the depths of the valleys of the surface profile by means of a thin needle. Nevertheless, if blasting is carried out using a fine abrasive, the needle does not reach the deepest parts of the valleys and consequently an artificially low roughness is measured. If the surface is irregular or wavy, the base of the instrument is held slightly above the plane of the profile, resulting in too high a reading.

The average profile depth can also be measured by using *replica tape* which is pressed on to the blasted surface and from which, after removal, the thickness increase due to the roughness can be measured by means of a portable micrometer. The replica tape cannot be used for profiles exceeding 4½ mils (approx. 115 micrometers).

Replicas can also be made by using two-component silicone rubber products which, after curing, can easily be removed from the surface and from which the roughness can be measured microscopically afterwards.

9.4.6.3 *Water soluble salts*

The possible presence of *blister and corrosion promoting water soluble iron salts*, for instance after pretreatment of severely corroded steel or as a result of contamination of the steel substrate in a marine atmosphere, can be detected according to Appendix G of B.S. 5493: 1977, using ferricyanide test papers. Typical blue dots (Prussian blue) show the presence of contaminated pits on the steel substrate. The test paper should not be pressed for longer than 5 seconds on the substrate.

The test is very sensitive but only provides *qualitative* results.

A *quantitative indication* of the presence of water soluble salts can be obtained by washing test areas of the steel surface with distilled water, collecting the washings and determining the amount of salts such as chlorides and sulphates, by *chemical analysis*.

For the *semi-quantitative* determination of chloride, special paperstrips can be used, which are dipped into the solution obtained by washing a certain area of the steel surface with distilled water. This test can be used as a field test.

Another rapid field test is to measure the *conductivity* of the washing water and to reject the steel surface when the conductivity exceeds a certain specified value.

For field testing, a 'soluble salt detector' may be used. With this instrument, which can be magnetically attached to steel surfaces, a certain area is washed with demineralized water and the conductivity of the water measured on site.

Concerning the amount of water soluble salts permitted on a steel substrate, the following remarks are pertinent.

The corrosion rate of contaminated steel in a humid environment increases with increasing amount of sodium chloride (sea salt), especially above 10 mg per square meter. Below this concentration corrosion proceeds very slowly. A contamination of 10 mg/m² of sodium chloride will result in conductivity value of 1 mS/m when 250 cm² of the steel surface has been washed with 50 ml of distilled water.

Because local concentrated chloride deposits are always present, it is in fact impossible to give a definite threshold below which chloride deposits do not affect corrosion.

Also qualitative and quantitative tests have been developed for the detection of (blister promoting) water soluble zinc salts on (weathered) galvanized steel or zinc dust containing paint layers.

9.4.6.4 Grease

If a surface is properly degreased, a drop of water placed on it will spread out in a continuous film. If oil or grease is still present, the water contracts in the form of droplets. This test is called the 'water-break' test. If an ultraviolet light source is available, the following procedure can be followed.

Wash a part of the surface with methylene chloride and collect the liquid. Apply a few drops to a clean glass panel and allow the solvent to evaporate. When exposed to ultraviolet light in complete darkness, the panel will show a blue fluorescence if mineral oil or grease is present.

9.4.6.5 Dust

The presence of (blasting) dust can be determined by applying transparent adhesive tape to the surface. After rubbing the tape thoroughly against the substrate, it is pulled off and applied to a surface with a contrasting colour to that of the dust and can be visually assessed.

9.4.7. PAINTS

Ship owners, platform operators and painting contractors normally do not have laboratory facilities for extensive paint testing. Only field testing is possible, which includes, amongst others, evaluation of the condition in the container, application properties, drying and appearance.

Heavily settled and/or non-homogeneous paints, which cannot easily be mixed by (mechanical) stirring, should not be used.

For large contracts, paint manufacturers can be requested to submit samples prior to the commencement of the work. After approval of the samples, paint manufacturers can be requested to provide a certificate for each subsequent batch stating that the paint has been made to the same formula as that already approved.

It is also possible to request an independent laboratory to test a sample of the paint for approval purposes according to a testing programme agreed between the ship owner (platform operator) and the paint manufacturer. For approval the testing programme may be rather comprehensive but more limited for regular batch control. The latter may include testing of the paint for condition in the container, density, volume of solids, presence of coarse particles, application properties, curing (drying) times, colour and gloss.

9.4.7.1 *Film thickness*

a. **Agreements**

In order to obtain long-lasting protection, *it is of prime importance to apply paints in uniform layers of the specified thickness and this should be checked regularly.* Methods for measuring the film thickness are described under sections 9.4.7.1c, d and e.

It is very important for the owner (operator), yard, painting contractor and paint supplier to agree upon the method of measurement, the number of measurements, as well as the interpretation of the results.

First of all, the parties should make it clear whether the specified film thickness is to be regarded as a *minimum thickness* or a *mean thickness*. The paint manufacturers data sheets should be clear on this point.

If the specified thickness is to be regarded as the minimum, the film thickness should nowhere be less than this value. Since variations in film thickness cannot be avoided, the mean thickness is necessarily considerably greater than the minimum thickness. Alternatively, the parties may agree that e.g. 90% of the measurements must be of at least the prescribed thickness.

If the specified thickness is to be considered as the mean thickness, it might in addition be agreed that 90% of the measured values should lie between agreed limits either side of the mean. Although other methods are possible, they are not dealt with here* .

It is essential that the agreement is set out in a contract, preferably in the painting specification, wherein the details of the measurements to be made may be laid down. Moreover, it is necessary to indicate clearly whether or not the prefabrication primer coat is to be regarded as part of the paint system in the measurement of the total system thickness.

b. **Calculation of the quantity of paint**

The quantity of paint necessary to coat any structure depends on its surface area, the prescribed dry film thickness, the volume solid content of the paint and on the paint losses. Since these paint losses depend on many factors and are subject to large variations, the amount is often unknown.

* Standards like SSPC-PA2, BS 5493, DIN 55928-Teil 5 and ISO 2808 give clear information concerning film thickness measuring systems.

In brushing large surfaces, paint losses may be less than 5%, whereas in spraying wire articles they may be as high as 80%. For many painting operations by airless spraying in ship and offshore construction paint losses vary from about 30 to 50%.

The quantity of paint (Q) needed for a coating job is given by the following equations:

$$Q_v = \frac{10 \cdot F \cdot l_d}{nv \cdot (100-x)}$$

$$Q_w = \frac{10 \cdot F \cdot l_d \cdot d}{nv \cdot (100-x)}$$

where:

- Q_v = volume of paint needed, litres
- Q_w = weight of paint needed, kilograms
- F = surface area to be painted, m^2
- l_d = dry film thickness, micrometers (μm)
- d = density of paint, g/cm^3
- nv = volume solids of paint, %
- x = paint loss, % of total amount used

c. Measurement of wet film thickness

The thickness of wet paint films can be measured by means of special *wet film thickness gauges*. They are the comb gauge (comb with teeth of unequal length) or the wheel gauge (steel wheel with three rims, of which the central one is smaller and eccentric with respect to the outer ones).

From the wet film thickness, the dry film thickness can be calculated by means of the following equation:

$$l_d = \frac{l_w \cdot nv}{100}$$

where:

- l_d = dry film thickness in micrometers (μm)
- l_w = wet film thickness in micrometers
- nv = volume solids of the paint, %

It is essential to measure the wet film thickness immediately after application of the paint, since it decreases rapidly due to the evaporation of solvents and thinners. Accordingly, if measurements are not made immediately, the recorded thickness will be less than the real value.

In measuring the wet film thickness of sprayed wet paint layers, the values are always inaccurate since the atomisation of the paint involves a considerable loss of volatile constituents. The measurements will be extremely inaccurate with thin films as a result of the very fast evaporation of solvents and thinners.

Calculations of the dry film thickness from the wet film thickness will therefore only be reasonably accurate if the films are thick and when the readings are taken immediately after application of the paint.

d. Measurement of dry film thickness on smooth substrates

These measurements can be made either by *destructive* or *non-destructive* means. The former require removal of a small area of the paint coat or system.

Destructive measurements are made by a *dial gauge* or by a *paint inspection gauge*. The dial gauge measures the local dry film thickness of a paint system. The paint inspection gauge additionally allows measurement of the thickness of the separate coats, provided that these differ sufficiently in colour.

An obvious disadvantage of destructive measurements is the necessity of repairing the test areas. They also usually take considerably more time to complete than non-destructive methods.

For *non-destructive measurements of dry paint film thicknesses on steel* a great variety of instruments is available. Their operation is usually based on the magnetic properties of the substrate. For non-destructive measurements on non-ferro metals (aluminium copper etc.) instruments operating on eddy currents are employed.

With dry film thickness gauges with digital read-out, a great number of measurements can be made within a short time and data like number of measurements, average, minimum, maximum thickness and standard deviation are immediately available. In order to obtain a print-out of all measurements, such instruments often can, after having carried out the measurements, be connected to a printer.

Reliable results can only be obtained if the paint coats are completely dried through. If they are not, the sensing head of the instrument sinks into the paint film or the sensor sticks in it, resulting in too low readings.

It is also essential to calibrate thickness gauges periodically by means of test sheets of known thickness, and if possible, by adjustment beforehand in the thickness range to be expected. Zero setting should preferably be made on a bare part of the substrate.

A possible source of error with magnetic gauges is the presence of certain iron oxide pigments (e.g. micaceous iron oxide) in the paint. These pigments may be weakly magnetic, and cause the meter to read a few percent too low.

e. Measurement of dry film thickness on blast-cleaned steel

In measuring dry film thickness on blast-cleaned steel with magnetic gauges, particularly *in the case of thin paint coats, inaccurate readings are obtained due to the roughness of the substrate*. Even on bare steel, a certain reading is obtained which is called the *pseudo dry film thickness*. This thickness depends on the degree of roughness of the blast-cleaned steel and can vary widely from one spot to another.

The mean dry film thickness should never be determined by subtracting the mean pseudo dry film thickness from the measured mean dry film thickness.

If the blast-cleaned steel is not unusually rough, magnetic thickness gauges always give too high a value in a range up to about 30 micrometers. The error decreases with increasing thickness and for coats thicker than 30 micrometers readings are reliable. The mean value of a number of readings above 30 micrometers may be regarded as the true mean thickness.

The procedure for taking measurements is:

- setting the zero of the thickness gauge on a flat polished (uncorroded) steel surface;
- calibrating the thickness gauge on test sheets of known thickness, preferably in the range to be expected, placed on the above mentioned steel surface;
- taking measurements on the coated blasted steel surface;
- the zero setting and calibration must be checked frequently.

Should it be necessary to measure thin coats on blast-cleaned steel (e.g. for checking prefabrication primer coats), this can be done by using small flat steel or glass panels attached to the substrate before application of the paint or by microscopic investigation of cross-sections of samples of the coated steel.

9.4.7.2 Cure

If a coating system is to be used on immersed parts, i.e. underwater or in the inside of tanks, it is extremely important that it is allowed to cure properly prior to be taken into service.

Because for most coatings hardness is not fully synonymous with the rate of cure, in practice it is not really possible to determine the curing rate.

As there is no reliable field test, it is extremely important to follow the coating manufacturers instructions implicitly with respect to curing times. As they are strongly temperature dependent, the coating manufacturers should include overcoating and final curing times at a number of relevant temperatures in their technical documentation (data sheets).

For the determination of the rate of cure in practice, sometimes *solvent rub*, as well as *sandpaper tests* are used. If a coating does not weaken or come off when rubbing with a solvent, prescribed by the coating manufacturer, it may be considered suitably cured. Sufficient degree of curing may also be indicated when a fine dust is produced by

sandpapering the coating. If the sandpaper gums up, the coating may not be properly cured.

When *hardness tests* are used to indicate the rate of curing, it should be realized that coating hardness strongly depends on temperature. Suitable field instruments are the Buchholz indentation tester (ISO 2815, DIN 53153 or BS 3900: part E9) and the Shore hardness tester.

9.4.7.3 Adhesion

The most simple field method of adhesion testing is the so-called *knife-test*. Generally, a cut is made with a knife blade through the coating (system) and an attempt made to lift it from the substrate in order to ascertain whether or not the adhesion is adequate. This (subjective) evaluation is normally based on previous experience with the coating system under test. Good adhesion is indicated by a coherent coating chip.

When, during cutting, the coating system detaches easily from the substrate and alongside the actual cut, adhesion is poor.

The most common type of adhesion determination is the *cross-cut tape test*. This test consists of making a number of small squares, by cutting through the coating system down to the substrate, after which tape is firmly stuck over the squares and subsequently pulled away quickly and firmly. The adhesion, or in fact the extent of detachment, then is visually assessed, using a standard scale.

The cross-cut tape test is described in many standards, among them ISO 2409, DIN 53151 and ASTM D 3359 (method B).

The spacing between the parallel cuts depends on the dry film thickness of the coating system. For the current standards the following is prescribed:

- | | | | | | | | | | | | |
|---|---|--|--|---|--------------|---|---|--------------|--|---|--|
| ISO 2409 | : | the choice of the spacing shall be subject of agreement between the interested parties. | | | | | | | | | |
| DIN 53151 | : | <table border="0"> <tr> <td>up to 60 μm dry film thickness</td> <td>:</td> <td>spacing 1 mm</td> </tr> <tr> <td>from 60 to 120 μm dry film thickness</td> <td>:</td> <td>spacing 2 mm</td> </tr> <tr> <td>more than 120 μm dry film thickness</td> <td>:</td> <td>spacing 3 mm</td> </tr> </table> | up to 60 μm dry film thickness | : | spacing 1 mm | from 60 to 120 μm dry film thickness | : | spacing 2 mm | more than 120 μm dry film thickness | : | spacing 3 mm |
| up to 60 μm dry film thickness | : | spacing 1 mm | | | | | | | | | |
| from 60 to 120 μm dry film thickness | : | spacing 2 mm | | | | | | | | | |
| more than 120 μm dry film thickness | : | spacing 3 mm | | | | | | | | | |
| ASTM D 3359 (method B) | : | <table border="0"> <tr> <td>up to and including 2.0 mil (50 μm) dry film thickness</td> <td>:</td> <td>spacing 1 mm</td> </tr> <tr> <td>between 2.0 mil (50 μm) and 5 mil (125 μm) dry film thickness</td> <td>:</td> <td>spacing 2 mm</td> </tr> <tr> <td>for coating thicknesses exceeding 5 mil (125 μm)</td> <td></td> <td>use method A, which describes the so-called <i>X-cut tape test</i>, where an X is cut through the coating system instead of small squares. The extent of detachment, especially originating from the intersection, is assessed.</td> </tr> </table> | up to and including 2.0 mil (50 μm) dry film thickness | : | spacing 1 mm | between 2.0 mil (50 μm) and 5 mil (125 μm) dry film thickness | : | spacing 2 mm | for coating thicknesses exceeding 5 mil (125 μm) | | use method A, which describes the so-called <i>X-cut tape test</i> , where an X is cut through the coating system instead of small squares. The extent of detachment, especially originating from the intersection, is assessed. |
| up to and including 2.0 mil (50 μm) dry film thickness | : | spacing 1 mm | | | | | | | | | |
| between 2.0 mil (50 μm) and 5 mil (125 μm) dry film thickness | : | spacing 2 mm | | | | | | | | | |
| for coating thicknesses exceeding 5 mil (125 μm) | | use method A, which describes the so-called <i>X-cut tape test</i> , where an X is cut through the coating system instead of small squares. The extent of detachment, especially originating from the intersection, is assessed. | | | | | | | | | |

A more complicated and time consuming test is the so-called *pull-off test*, mainly performed by means of a special adhesion tester. In this test the coated surface is degreased and lightly sanded after which small aluminium test dollies are cemented to it by means of an adhesive (two-component epoxy or fast drying one-component cyanoacrylate adhesive).

After curing of the adhesive, the paint system is cut through down to the substrate around the periphery of the dolly. The test instrument is then placed over the head of the dolly by means of a claw, and a steady increasing pulling force applied until the dolly is torn from the surface. The pulling force (tensile strength) needed for this detachment is read from the scale on the test instrument.

Not only the force required, but also the type of break is important.

The three possibilities are:

- a clean (adhesive) break to the substrate (detachment of the whole coating system)
- a (cohesive) break between coats
- a (cohesive) break between the adhesive and the remaining coating system.

In the last two cases it is established that the (remaining) coating adhesion strength is at least as good as the measured tensile strength. The test is described in ISO standard 4624 and ASTM standard D 4541.

As all adhesion tests are destructive, the number should be limited and the coating system repaired after such tests.

9.4.7.4 *Holiday (pinhole) detection*

Particularly for coating systems intended for use under immersed conditions, such as tank linings, it is extremely important that they should be free from pinholes, holidays, cracks, large vacuoles, too thin areas etc.

The investigation for the presence of holidays etc., is usually done by means of *holiday detectors*. These instruments can be divided into two groups, e.g. *low-voltage (wet sponge)* and *high-voltage holiday detectors*.

Low-voltage wet sponge holiday detectors consists of a sponge electrode, connected to a low-voltage source and a ground cable. After attaching the ground cable to the bare substrate, the sponge is saturated with a conductive liquid and slowly moved over the surface to be tested. If the conductive liquid makes contact with the (steel) substrate, via a pinhole or a crack in the coating system, a current will flow which is indicated by an audible signal.

The conductive liquid normally consists of a salt solution and a small amount of wetting agent (detergent).

With this type of equipment, operating at about 10 V, the test is limited to coating systems with dry film thicknesses up to about 200 micrometers. This limitation is due to the difficulty of the conductive liquid penetrating a pinhole within a reasonable time.

Another limitation is that with these detectors only true pinholes (penetrations to the substrate) can be detected.

High-voltage holiday detectors operate on the same principle as the low-voltage types, except that an electrode made of a conductive material such as carbon-filled neoprene or brass is employed. These (portable) instruments, which give an audible signal when a pinhole is detected, are available to operate up to about 40,000 Volts.

The person carrying out the inspection should be very experienced in the use of high-voltage detectors.

It is extremely important to choose the correct voltage for testing.

If too high a voltage is applied, the coating system can be seriously damaged as pinholes are created by voltages higher than the dielectric strength of the coating material.

No higher voltage levels than recommended by the coating manufacturer should be used. This voltage usually is 2-3 times the dielectric strength of air, which is about 6-9 Volts per micrometer dry film thickness at ambient conditions.

To be safe, it is recommended that the operating voltage is not more than 6 Volts per micrometer dry film thickness. Also it is recommended that the same area of a coated surface not should be measured more than twice as repeated measurements creates weak spots in the coating system.

High-voltage holiday detectors should not be used on paint layers containing electrically conductive pigments such as zinc dust, micaceous iron oxide and graphite.

For pore detection in tanks, reference is made to part 1.3.6.2, where a method is described based on keeping the tanks filled with sea water for 24 hr after which pores, holidays etc., show up like rust spots.

9.4.8. ASSESSMENT OF COATING DEFECTS

In order to assess the type and extent of coating degradation (defects, failures), use is often made of official (pictorial) standards. These standards contain photographic prints of certain types of defects of different size and quantity.

Sometimes the standards are used in guarantee certificates. For instance, the notation Re2 of the European rust scale is often used as the maximum allowable amount (0.5%) of protruding rust after a certain period of service (for instance 5 or 10 years) of the coated structure. When applying these standards it should however be realized, as already stated under Part 7.1, that *the amount of maintenance work has no direct relation to the number of defects but strongly depends on their distribution over the surface* (see also Appendix 7.A). The amount of maintenance work is always far in excess of that indicated by the official standards.

Some standards used for the assessment of paint defects (degradations) are mentioned in Appendix 9.A. A few examples of the photographic prints of these standards are given in Appendix 9.B.

APPENDIX 9.A. - CURRENT STANDARDS USED FOR THE ASSESSMENT OF COATING DEGRADATION (DEFECTS)

Degradation (defect)	Applicable standards				
	ISO	ASTM	BS	DIN	Other
General	4628/1	-	-	53210	-
Blistering	4628/2	D 714	3900-H2	53209	-
Rusting	4628/3	D 610	3900-H3	53210	European rust scale
Cracking	4628/4	D 661	3900-H4	-	TNO
Flaking	4628/5	D 772	3900-H5	-	TNO
Chalking	4628/6*	D 659 D 4214	-	53159	TNO
Erosion	-	D 662	-	-	-
Checking	-	D 660	-	-	-
Discolouration	105 Part AO2	D 2616	1006-AO2C	54001	-

* At the stage of draft (May 1989)

APPENDIX 9.B. - SOME EXAMPLES OF (PARTS) OF STANDARDS USED FOR THE ASSESSMENT OF COATING DEFECTS

*ISO standard 4628/1 - 1982**

Paints and varnishes - Evaluation of degradation of paint coatings - Designation of intensity, quantity and size of common types of defect - Part 1: General principles and rating schemes

0 Introduction

This International Standard is one of a series of standards dealing with the sampling and testing of paints, varnishes and related products.

The other parts of ISO 4628 already published or in course of preparation are :

Part 2 : Designation of degree of blistering.

Part 3 : Designation of degree of rusting.

Part 4 : Designation of degree of cracking.

Part 5 : Designation of degree of flaking.

Part 6 : Designation of degree of chalking.¹⁾

Parts 2 to 6 provide auxiliary pictorial or other reference scales for rating particular types of defect. As far as possible, the scales are based on existing well-established schemes.

The schemes given in this part of ISO 4628 are intended to provide a system for describing, in a standard manner, test areas showing the common types of defects of coatings, in particular the defects caused by ageing and weathering.

1 Scope and field of application

This part of ISO 4628 establishes a general system for designating the intensity, quantity and size of common types of defects of paint coatings and outlines the basic principles of the system in respect of designation of the intensity, quantity and size of defects.

2 Reference

ISO 4540, *Metallic coatings — Coatings cathodic to the substrate — Rating of electroplated test specimens subjected to corrosion tests.*

3 Designation of intensity and quantity of defects

A uniform convention has been adopted for designating the intensity and quantity of defects by means of ratings on a numerical scale ranging from 0 to 5; "0" denoting no defects, and "5" denoting defects so severe that further discrimination has no practical meaning.

The other ratings, corresponding to the numbers 1, 2, 3, and 4, are so defined that they give an optimal discrimination over the whole range of the scale.

The use of intermediate half-steps is permissible, if required, to give a more detailed report of the defects observed.

A general description of each of the ratings is given in tables 1 and 2.

Table 1 refers to defects consisting of a uniform deterioration of the visual appearance of the coating.

Table 2 applies to defects in the form of discontinuities or other local irregularities of the coating, scattered over the test area in a more or less even pattern.

NOTE — If appropriate, the quantity of small defects scattered over the test area can be assessed in terms of their frequency by means of a grid method. Details of such a method are described in ISO 4540.

1) At present at the stage of draft.

* Reprinted with permission of ISO/NEN.

ISO 4628/1-1982 (E)

Table 1 — Uniform deterioration — Rating scheme for designating the intensity of deterioration consisting of a uniform change in the visual appearance of the paint coating

Rating	Intensity of change
0	unchanged, i.e. no perceptible change
1	very slight, i.e. just perceptible change
2	slight, i.e. clearly perceptible change
3	moderate, i.e. very clearly perceptible change
4	considerable, i.e. pronounced change
5	severe, i.e. intense change

Table 2 — Scattered defects — Rating scheme for designating the quantity of defects consisting of discontinuities or other local imperfections of the paint coating

Rating	Quantity of defects (relative to a test surface area of 1 to 2 dm ²)
0	none, i.e. no detectable defects
1	very few, i.e. some just significant defects
2	few, i.e. small but significant amount of defects
3	moderate, i.e. medium amount of defects
4	considerable, i.e. serious amount of defects
5	dense, i.e. dense pattern of defects

Table 3 — Rating scheme for designating the size (order of magnitude) of defects

Class	Size of defect
0	not visible under X 10 magnification
1	only visible under magnification up to X 10
2	just visible with normal corrected vision
3	clearly visible with normal corrected vision (up to 0,5 mm)
4	range 0,5 to 5 mm
5	larger than 5 mm

4 Designation of size of defects

The average size of defects shall be designated, if required and meaningful, according to the classification given in table 3.

5 Rating

Rate the intensity or quantity of the observed defects on the basis of the schemes given in table 1 or 2, depending on the type of phenomenon in question.

If applicable, also rate the average size of the individual defects on the basis of the scheme given in table 3.

6 Test report

The test report shall contain at least the following information :

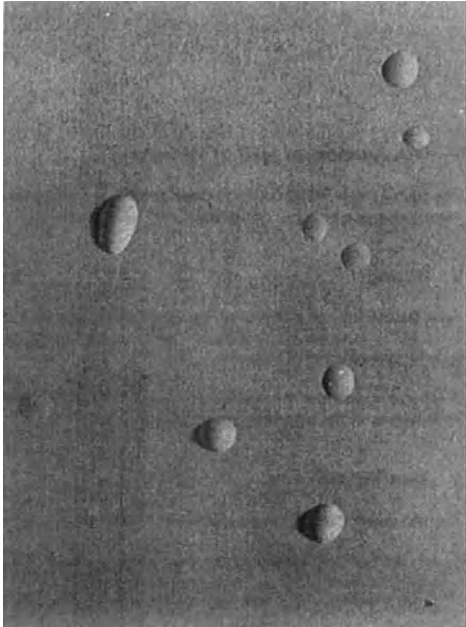
- a) the type and identification of the product tested;
- b) a reference to this International Standard (ISO 4628/1);
- c) the type of defect;
- d) the intensity of the defect (table 1) or,
- e) the quantity of the defect (table 2);
- f) the rating, if any, of the size of the defect in parentheses, preceded by the letter "S".

Examples : cratering of top coat : 2 (S3)
whitening : 4
rivelling : 3 (S2)

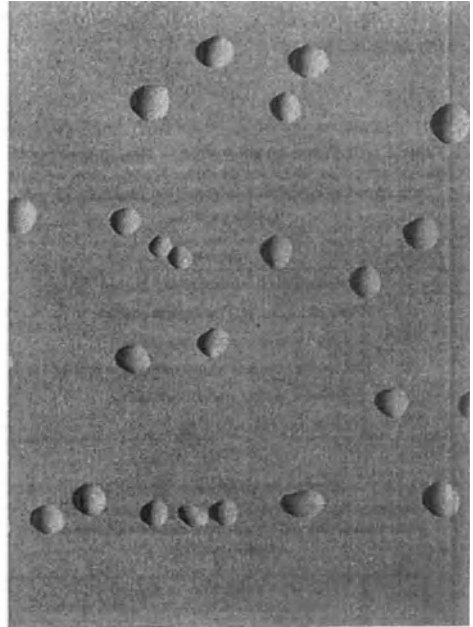
If necessary, the test report may be amplified in words, for example "confined to edges" or "blistering of top coat down to the undercoat". The use of such comments shall, however, be avoided wherever possible.

- g) the date of the examination.

**Part of ASTM D 714-56
(International Standard 4628/2 is identical)**

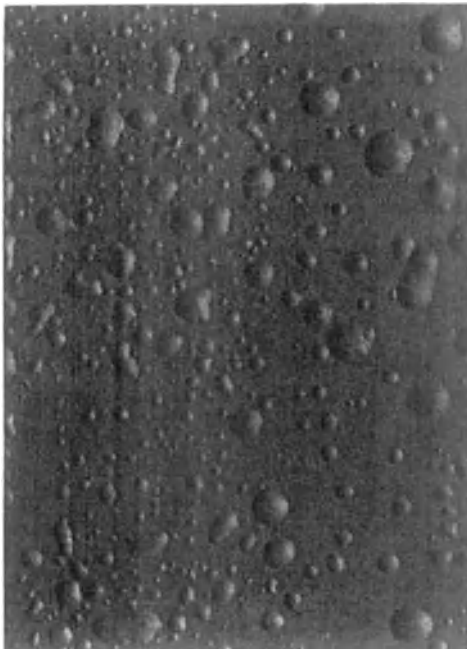


FEW



MEDIUM

BLISTER SIZE NO. 2

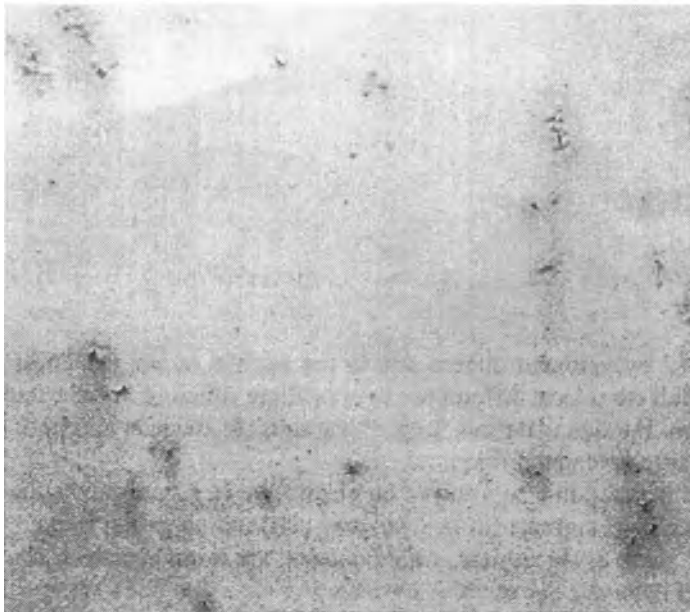


MEDIUM DENSE



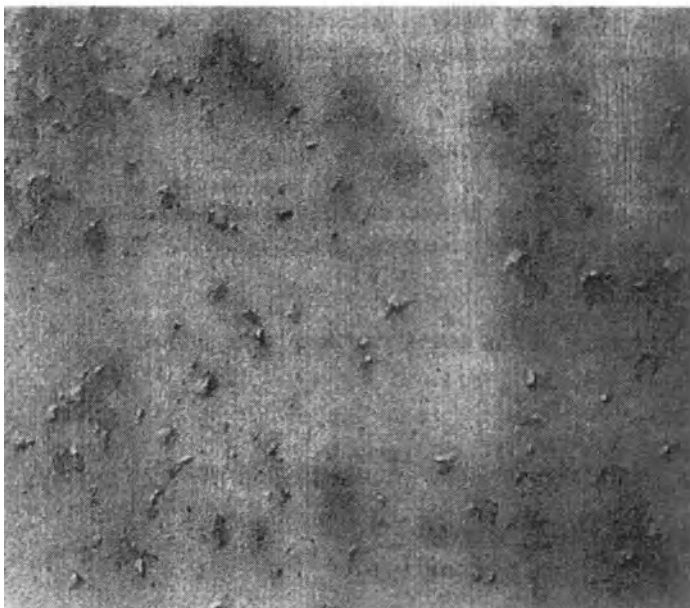
DENSE

Part of the European Scale of Degree of Rusting for Anti-corrosive Paints*



Re 3

⑦



Re 5

⑤

Re 0 - Re 9 = DEGREE OF RUSTING

Re 0 = rustfree

Re 9 = the whole surface rusty

⑩ - ① = DEGREE OF PAINT
PROTECTION EFFICIENCY

⑩ = rustfree

① = the whole surface rusty

* ISO standard 4628/3 - 1982 gives the photographic prints of the European Rust Scale but gives different rust figures.

CHAPTER X

CATHODIC PROTECTION

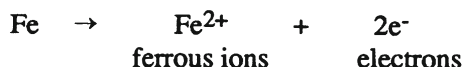
10.1. Corrosion

Corrosion is caused by potential differences in the surface of metals. These potential differences can result from local differences in crystalline structure, mechanical stress or differential aeration. Foreign materials (impurities, salts) or oxide layers (mill scale and welds) may also cause potential differences.

When a metal is immersed in a solution of an electrolyte (e.g. sea water), the potential differences generate local currents (as in a galvanic cell) and corrosion starts.

On the 'less noble' parts of the surface, called anodes, the metal dissolves. On the 'more noble' parts, called cathodes, the metal is protected.

The corrosion of steel, which is an electro-chemical process, occurs by the dissolving of iron at the anodes, giving rise to ferrous ions and electrons:



This reaction occurs readily in (conductive) electrolytes such as sea water. The electrons liberated by this process flow through the metal to the cathodes. This flow of electrons is known as the *corrosion current*.

At the cathode, the corrosion current causes two possible reactions:

- a. $2\text{H}^{+} + 2\text{e}^{-} \rightarrow \text{H}_2$
hydrogen ions hydrogen gas
(the hydrogen ions are produced by the ionization of water: $\text{H}_2\text{O} \rightarrow \text{H}^{+} + \text{OH}^{-}$)
- b. $2\text{H}_2\text{O} + \text{O}_2 + 4\text{e}^{-} \rightarrow 4\text{OH}^{-}$
oxygen hydroxyl ions

The main result of the above reactions is the formation of hydroxyl ions (alkali).

These hydroxyl ions react with the already dissolved ferrous (iron) ions to form ferrous hydroxide which is oxidized to rust.

In sea water with a low oxygen content black iron oxide (Fe_3O_4 , *black rust*, magnetite) is formed. Like mill scale, this type of rust is magnetic. At higher oxygen contents, for instance near the sea level, brown hydrated ferric oxide ($\text{Fe}_2\text{O}_3 \cdot n\text{H}_2\text{O}$, *brown rust*) is formed.

As long as this insolubilization of the iron ions proceeds, due to the presence of oxygen, there will be a continuous demand for iron ions and the corrosion process will continue. From the foregoing theoretical consideration it will be clear that the corrosion rate of steel in sea water decreases with increasing depth, due to the decreasing oxygen content. The corrosion process of steel with broken mill scale in sea water is illustrated schematically in Appendix 10.A.

When corrosion is widespread and uniform, with steel in sea water a metal loss of about 0.3 mm per year may be expected (see for instance Appendix 2.C).

However, if for some reason the corrosion process is concentrated (pitting corrosion), local metal losses up to 20 mm/year occur. Pitting corrosion for instance may be expected on poorly coated and/or mechanically damaged tank bottoms. Sometimes, this type of corrosion may proceed so fast that the safety of a construction is threatened.

10.2. Galvanic corrosion

All metals have a certain electrical potential when immersed in electrolyte solutions like sea water. Some of these potentials are given in Appendix 10.B. The most anodic (less noble) metals have the lowest (most negative) potentials.

When two different metals are electrically connected in an electrolyte, e.g. sea water, the anodic metal with the lowest potential corrodes at an increased rate and the cathodic metal will be protected. This process is known as *galvanic corrosion*.

When for instance stainless steel heating coils in ship tanks are electrically connected to the steel tank bottom, the latter tends to corrode at an increased rate. When the tank bottom is coated, the corrosion process will concentrate at discontinuities in the coating system such as pores, mechanically damaged and poorly coated areas and cause pitting corrosion.

To avoid this problem, heating coils should be electrically isolated from the steel of the tank.

10.3. Other forms of corrosion

Beside the corrosion mechanisms as described in the Sections 10.1 and 10.2, many other forms exist.

Some examples are:

- corrosion in (hydrogen) sulphide containing media, like crude oil, leads to the formation of iron sulphide and magnetite, which are both cathodic to steel (and consequently promote corrosion).
- bacterial corrosion, in which process the first step is the reduction to hydrogen sulphide by bacteria of any sulphate present in the water; this type of corrosion may

occur when the steel is in contact with mud (offshore structures; ships moored in shallow water).

- erosion corrosion, often encountered under conditions of high velocity, turbulence, impingement and where suspended solids are present in the water flow.
- cavitation corrosion, which is the wearing away of metal by mechanical damage resulting from repeated impact, produced by the collapse of (vapour) voids within a fluid; this type of corrosion sometimes occurs on ships' propellers.

10.4. Principles of cathodic protection

As described in Section 10.1, corrosion of steel at the anodic areas results from electric currents generated by potential differences between anodes and cathodes. The electrons (corrosion current) flow through the steel from anodes to cathodes ($\text{Fe} \rightarrow \text{Fe}^{2+} + 2e^-$).

This corrosion current can be suppressed by a current in the opposite direction by means of *external anodes*. This counter current has to exceed the corrosion current.

Because the whole metal structure to be protected then becomes a cathode, the process is called cathodic protection (see Appendix 10.C, figs. 1 and 2).

10.5. Potential and current density

Cathodic protection renders submerged steel parts cathodic. The *potential* of unprotected steel is about -630 mV relative to a silver/silver chloride (Ag/AgCl) sea water reference electrode. By changing the potential to a value lower than -800 mV* , complete protection against corrosion is achieved on all underwater parts.

At potentials between -630 and -800 mV the steel is partially protected. This is called *underprotection*. Lowering the potential to values under -900 mV leads to *overprotection*. When overprotection exists, an excess of *alkali is formed, electro-osmosis is increased* and, under certain circumstances, *hydrogen gas may be evolved* (see Part 10.12.1). *These phenomena may cause paint defects, such as blistering and saponification.*

The *current density* (expressed in mA/m²) required for adequate cathodic protection depends on the condition of the underwater paint system (if present) and on the salt and oxygen content, as well as the temperature of the water. In the case of ships, a dominant factor is also the speed.

* This potential corresponds to:

- 730 mV relative to a Ag/AgCl saturated KCl-electrode
- 780 mV relative to a saturated calomel electrode (SCE)
- 850 mV relative to a Cu/CuSO₄ (sat)-electrode
- + 250 mV relative to a zinc/sea water-electrode

A freshly painted surface in sea water at ambient temperatures as a rule requires a current density less than 5 mA/m^2 . If the paint system is damaged or porous, considerably larger current densities are necessary.

Calcareous deposits, formed as the results of the application of cathodic protection, however will reduce the required current density somewhat and improve current distribution (see also Part 10.12.1).

The following current densities are required for the protection of unpainted steel against corrosion in sea water:

- stationary steel, corroded : about 50 mA/m^2
- stationary steel, uncorroded : about 130 mA/m^2

- moving steel* , corroded : $300 - 400 \text{ mA/m}^2$
- moving steel, uncorroded : $1500 - 2000 \text{ mA/m}^2$

For painted steel which has to be cathodically protected by sacrificial anodes, for design purposes, a current density of 15 mA/m^2 is normal. For impressed current systems, the design current density will be about 33 mA/m^2 and for bronze propellers about 500 mA/m^2 .

Cathodic protection of moving unpainted steel requires such high current densities that it would be prohibitively expensive. From an economical point of view therefore, cathodic protection of the underwater part of a ship must be considered a method of combating corrosion that supplements to painting.

As the maintenance of coating systems on submerged parts of offshore structures is practically impossible and economically unattractive, these (stationary) parts are usually protected against corrosion by cathodic protection alone (see Part 2.3.2.2).

10.6. Cathodic protection systems

Two main types of cathodic protection systems are commonly used. They differ in the way in which the protective electron current is generated. These systems are:

- *Sacrificial anode systems*

In these systems the external anodes consist of a metal which is strongly anodic (less noble) to the metal to be protected. On connecting the external anodes with the metal to be protected, *a galvanic cell is formed*. The electrons flow directly from the anodes to the object to be protected. In supplying the protective current, the anodes are gradually consumed ($\text{Me} \rightarrow \text{Me}^{n+} \text{ne}^-$) and therefore they have to be renewed periodically. The principle of sacrificial anode systems is illustrated in Appendix 10.C, fig. 3).

* or steel in running (sea) water.

- *Impressed current systems*

In these systems the current is supplied by external anodes fed with direct current, usually provided from an alternating current source via a transformer/rectifier. The anodes are connected to the positive pole of the current source and the object to be protected to the negative pole. The anodes are usually made of an inert material and therefore have a long service life. The principle of impressed current systems is shown in Appendix 10.C, fig. 4).

Control and regulation of the potential is realized by reference electrodes (sensors); for ships, the underwater hull potential is also controlled and regulated whilst under way.

The sensors are often silver/silver chloride (Ag/AgCl) or zinc/sea water reference electrodes (see also Part 10.11).

The choice between the two systems of cathodic protection must be made in each case by considering their advantages and disadvantages. These are summarized in Appendix 10.D.

It should be noted that cathodic protection systems do not function well in fresh water and in brackish water with a specific resistance of more than 500-1000 Ω cm.

10.6.1. SACRIFICIAL (GALVANIC) ANODE SYSTEMS

Sacrificial (galvanic) anodes are made of metals less noble and consequently having a lower potential in sea water than steel. The anodes must have a long service life and a high capacity in ampere-hours per unit of weight. The current generated by sacrificial anodes should be constant and not be diminished by deposits of corrosion products on the anode surface. When in use, the anodes should be consumed uniformly, without 'necking' or disintegrating.

The metals commonly used for sacrificial anodes are: *zinc*, *aluminium* and *magnesium*. To meet the above mentioned requirements, aluminium and magnesium are alloyed with other metals. Zinc however, must be of a high purity with in particular a low iron content.

Magnesium has a very low potential, resulting in the formation of alkali and hydrogen gas (see Part 10.11.1). The anode efficiency is relatively low due to self-corrosion of this metal. For these reasons magnesium anodes are not used on ships and offshore structures.

Aluminium has the advantage of a high capacity and a low density, thus reducing the required number of anodes. For reasons of safety, the use of aluminium is restricted in certain tanks (see Part 10.9).

Zinc is by far the most widely used anode material.

It has a high efficiency, is reliable in use and has such a potential to sea water that it has the least possible adverse effect on underwater paint systems. Moreover, it can be used in tanks without restrictions.

Some properties of the anode materials are given in Appendix 10.E.

To deliver the protective current with optimum current distribution throughout their operating lives, sacrificial anodes are made in a great variety of shapes and sizes, usually castings and sometimes strips or wires. It should be noted that the shape of anodes must be such that their surface is large enough to provide the required current, taking into account the maximum possible anode current density.

The anodes should be fitted on the object to be protected so that all parts receive the desired current density. They are often provided with a strip of steel which allows them to be fixed securely. Usually the anodes are mounted by welding, occasionally, however, by means of clamps or bolts. The fastening must be such as to ensure permanent low resistance electrical contact with the steel parts to be protected. The anode cores must be structurally resistant to the mechanical forces to which they will be subjected. This is especially important in the case of platform setting and pile driving.

Accidental painting of the anodes should be avoided. During painting operations they must be covered with a material which is soluble in sea water (e.g. soft soap), or which can easily be removed in due course.

Expert guidance should be sought to determine the number and type of anodes required in each case. An estimate of the required quantity of anode material is given in Appendix 10.F.

The anodes must be inspected periodically; those attached to the hull of ships are usually inspected during dry-docking. On stationary offshore structures, underwater inspection is inevitable. Checks have to be made that all anodes are still present and connected properly to the steel.

Estimates should be made of the amount of consumed anode material and of the remaining service life of the anodes. If the estimated remaining life is insufficient to cover the period until the next dry-docking of the ship or the next regular inspection of the offshore structure, the anodes should be renewed or additional anodes mounted.

10.6.2. IMPRESSED CURRENT SYSTEMS

In these systems the protective current is supplied from the alternating current system of the ship or offshore structure via a transformer/rectifier. This current is supplied to the anodes mounted on the underwater parts requiring protection.

Impressed current anodes consist of highly conductive and chemically inert metals or metal alloys. They should not be attacked by the anodic current and should be resistant to mechanical influences. Anode materials now in use are for instance lead/antimony/silver alloys, platinized titanium, niobium or tantalum, titanium covered with mixed metal oxides, graphite, silicon-iron or scrap steel.

With present anodes a service-life of at least 15 years may be expected. Some data on non-galvanic anode materials are given in Appendix 10.E.

The anodes are connected, via electrically insulated conductors, single or in groups, to the positive terminal of the direct-current source and the area to be protected to the negative terminal.

Impressed current system anodes are fewer in number than galvanic anodes and designed for much larger current outputs (30 to about 200 A each). This results in a reduced current efficiency and overprotection of nearby surfaces. In order to prevent coating damage, hydrogen embrittlement of high-tensile steel and current wastage in the vicinity of the anodes, they are surrounded by a so-called *dielectric shield*.

These shields normally consist of (yard applied) very thick chemical resistant coatings, prefabricated plastic or elastomeric sheets.

As relatively few anodes are involved, impressed current systems are more vulnerable than sacrificial anode systems to mechanical damage. The loss of just one anode can seriously reduce the performance of the protective system.

10.7. Cathodic protection of ships' hulls

Cathodic protection of the underwater part of ships reduces corrosion and, as a consequence, dry-docking and repair costs. In particular, areas where the paint system has been mechanically damaged or has become more or less porous on ageing, are cathodically protected as the protective current passes through such areas. Roughening of the hull as a result of corrosion is also retarded by cathodic protection. This has an important economic advantage, because an increased surface roughness leads to a higher fuel consumption if the speed of the ship is to be maintained.

The choice between the two systems of cathodic protection has already been discussed in section 10.6. On very large ships in particular, impressed-current systems are economic and technically advantageous. For a new ship with a good underwater paint system, a current density of 2-3 mA/m² is sufficient. The current density increases gradually with increasing porosity and mechanical damage of the paint system.

As a rule it can be assumed that on a ship at sea a protective current density of about 10 mA/m² is needed for every 0.5% of bare, uncorroded surface. If the steel is already corroded, a current density of 10 mA/m² will protect up to 2.5% of bare surface area.

When the ship is lying idle, a current density of 10 mA/m² can protect about 5% of uncorroded, or about 20% of corroded bare surface area.

In order to prevent underprotection, the anodes should be spaced so that the potential of the plating is nowhere higher (i.e. more positive) than the required protective potential. This means that a certain degree of overprotection immediately around the anodes has to be accepted, especially with impressed current systems operating with a small number of anodes and a high output voltage.

Unless recessed into the hull, anodes should not be mounted in places where damage is likely, e.g. from anchor chains. To protect the propeller and to compensate for its corroding effect on the stern, it is connected conductively to the hull by means of a slip ring with brush gear on the propeller shaft.

In addition, the rudder has to be earthed to the hull. To this end the pintle is connected to the hull by means of a braided copper conductor.

Especially when welding galvanic anodes to the hub of the propeller, on the rudder plating, on stabilizers or other moving parts of the ship, the anodes must be earthed directly.

If not properly earthed, the welding return current may pass through vulnerable parts of the (earthed) ship, for instance propeller shaft bearings and steering gear and may cause enormous damage.

Because the fitting of anodes by welding presents a serious fire hazard, they must not be fitted in way of fuel tanks or tanks for flammable materials. For the same reason, cable runs are not permitted through such tanks.

Sacrificial anode systems are usually designed for an average current density of 15 mA/m^2 and a service life of two to four years.

In fitting the anodes around the underwater part of a ship, it should be borne in mind that the stern is more susceptible to corrosion than other underwater parts, owing to the presence of the unpainted bronze propeller and the rudder. Contrary to some statements, the stern requires a current density of at least 20 mA/m^2 , the rudder about 50 mA/m^2 and the propeller about 200 mA/m^2 , provided it is earthed. Also other parts susceptible to corrosion, such as sea water inlets, sea-cocks and hot water outlets are given special cathodic protection. The areas around the bow propellers, where a stainless steel housing is directly welded onto the mild steel hull, should be protected by extra anodes or by a thick layer of glass reinforced epoxy filler.

The anodes for the protection of the sides of the ship should preferably be fitted under the bilge keel.

Sacrificial anodes should not be fitted too close to the propeller, because in this position they would create turbulence and cause serious cavitation of the propeller. If the radius of the propeller is r , anodes may be fitted either within a distance of $0.4 r$, or at distances greater than $1.1 r$.

Good electrical contact between anodes and the underwater hull is essential. Anodes usually contain inserts of iron strip, which are fitted to the hull by welding. Although the anodes themselves should never be painted, it is vital to paint the plating underneath in order to prevent rapid consumption of the anodes.

Cathodic protection is sometimes limited to parts which are very susceptible to corrosion such as the stern, inlets, outlets, valves etc. Such local cathodic protection is almost always effected by means of sacrificial anodes.

Impressed current installations are usually designed for current densities of 30-40 mA/m². Impressed current systems have only a few anodes, usually mounted on the stern and amidship. However, with tankers, where anodes amidship are not permitted (10.9), they are mainly mounted near the stern, and smaller auxiliary anodes are sometimes placed near the bow.

In view of the risk of mechanical damage, e.g. by anchor chains, anodes near to the bow should, if possible, be mounted flush with the plating.

The anodes are fashioned into domes (round discs) or long rectangular strips, the base of which is often embedded in an epoxy or polyester resin. They are surrounded by an insulating screen (dielectric shield or anode shield), which ensures good current distribution. The shield should be able to withstand the high alkalinity around the anode. Also, it should be large enough to reduce the potential at the edges to a value which will not attack the underwater paint system. If the prefabricated screen is not large enough, the surrounding area of the hull is either treated with one or two coats of epoxy filler which is trowelled to a thickness of a few millimetres, or the underwater paint system is locally applied very thickly.

In order to ensure good adhesion, these materials should be applied directly to the blast-cleaned surface without an intermediate coat.

Much care should be given to the mounting of anodes and reference electrodes (sensors) in order to prevent mechanical or heat damage during welding them to the hull.

As the impressed current system cannot reach the inside of in and outlet chests, especially when they are provided with weed gratings, they must be protected by sacrificial anodes. The gratings should be painted on both sides.

10.8. Cathodic protection of fixed offshore structures

Protective current densities for submerged parts of open sea (offshore) structures range from about 60 to 440 mA/m².

For the North Sea this is about 85-215 mA/m², with mud-zone current densities of about 10-35 mA/m².

The cathodic protection of stationary offshore structures is specified by regulations and recommended practices in, among others, the following standards:

- NACE Standard RP-0176-83: Corrosion control of steel on fixed offshore platforms.
- NACE Standard RP-06-75: Corrosion control on offshore steel pipelines.
- (draft) Recommended practice for the cathodic protection of offshore steel structures, including pipelines (1981, Dutch).
- Code of Practice CP 1021: 1973 Cathodic Protection (BSI).

As mentioned previously, for economic reasons, coating systems are rarely applied to the underwater parts of offshore structures. If they are applied, the cathodic protection system should be designed so as to provide adequate protection of the structure when the coatings deteriorate. It should be realized, however, that cathodic protection produces

calcareous deposits (10.11.1) on the platform members which tends to decrease the protective current density.

A uniform current distribution can be promoted by making use of a large number of anodes, each emitting a low current. In view of the cost involved, such a system is only practicable when galvanic anodes are employed. A uniform current distribution may be obtained, for example, by installing galvanic anodes each producing some 5 A at a distance of at least 30 cm from the surface to be protected.

Since in the case of installations with an external impressed current source, in general fewer (non-galvanic) anodes are employed, each emitting high currents, the current distribution over the protected area is often rather poor.

The high current emitted by each anode (30 to 200 A) tends to overprotect the surfaces nearest to them. In view of the current wastage near the anodes, the cathodic protection system should be designed for a current output 25 to 50% higher than calculated.

With impressed current systems, the current distribution may be improved by installing the anodes at a distance from the structure or by the use of dielectric shields.

For stationary offshore structures, the life of the installed cathodic protection system should, if possible, be at least equal to that of the structure.

There may be considerable delay between the time an offshore structure (platform) is erected until permanent electric power becomes available. If cathodic protection by means of sacrificial anodes is applied, there will be no problem. If, however, cathodic protection by means of an impressed current system is intended, temporary power at an early stage should be made available or initial cathodic protection should be obtained by a short term sacrificial anode system. Otherwise, serious corrosion of platform members can occur.

To ensure adequate protection of the node welds, anodes should be fixed to an offshore structure as early as possible. These node welds, which are critical to the structural strength of offshore installations, are zones of high metal surface and complex geometry. Consequently, node weld areas require extra current density (protection) to overcome the effect of shielding. However, cathodic protection systems with excessive current densities or excessive earth (sea) potential gradients should be avoided as they may have a detrimental effect on coatings or on neighbouring submerged or buried structures.

10.9. Cathodic protection of tanks

Water ballast and cargo ballast tanks are often cathodically protected. It functions only when the tanks are actually in ballast.

Moreover, only the immersed parts of the surface are protected. As the tanks are not always in ballast and, if in ballast, not completely filled, *protection is best achieved by cathodic protection in combination with an unsaponifiable paint system.*

Cathodic protection is unsuitable for fresh water tanks (e.g. feed water tanks) because of the low electrical conductivity of the water (see also Part 10.6).

All cathodic protection systems must satisfy the requirements of the appropriate Classification Societies.

Under certain well defined conditions, a reduction in the size of scantlings is permitted for cathodically protected tanks.

Directions for the installation of cathodic protection systems are given, inter alia, in 'Guidance Notes on Application of Cathodic Protection' of Lloyd's Register of Shipping and in 'Code of Practice CP 1021: 1973 Cathodic Protection' of the British Standard Institution.

For the internal protection of tanks only sacrificial anodes are permitted. Impressed current systems are not allowed because they might ignite any flammable gases in the tanks. In case of malfunctioning, they might generate hydrogen gas, which is very explosive when mixed with air.

The use of magnesium and aluminium as anodes in tanks is subject to limitations. Magnesium anodes may generate hydrogen gas, which may cause explosions. Magnesium or aluminium anodes that become detached will fall to the bottom of the tank, causing sparks that may set off an explosion if flammable vapours are present. Magnesium anodes are not permitted in tanks for liquid cargoes that may develop flammable vapours, e.g. in crude oil tanks. They are only permitted in tanks intended solely for water ballast. In tanks for the carriage of oil, aluminium anodes are only permitted in the bottom parts or directly above horizontal surfaces such as large bulkhead girders. The aluminium anodes should be mounted only at locations where the potential energy does not exceed 275 J (28 kgf.m). Also aluminium anodes are not to be located under tank hatches or Butterworth openings unless protected by adjacent structure.

For the use of zinc anodes in tanks there are no restrictions.

Classification Societies demand a service life of cathodic protection systems for tanks of at least four years. The number and placing of the anodes depends on the ballast time and the depth to which the tanks are filled. The anodes should be placed so that they are easily accessible for cleaning and renewal. They should preferably be fixed by welding. If fixed by bolts or clamps on bars welded to the inner tank surface, good electrical contact should be ensured by tack welding.

Unpainted tanks require current densities of 80-120 mA/m², depending on the type of tank. The current density required for an unpainted sea water tank is about 100 mA/m². For tanks coated with a high-duty paint system, it can be reduced to about 5 mA/m². A slightly higher value should be applied if some degree of attack or mechanical damage to the paint system has to be taken into account. Current densities equal to that needed for unpainted steel are necessary if only a (prefabrication) primer has been applied.

As mentioned previously, tanks are fully protected only when they are completely filled. As this is seldom the case, in unpainted tanks the upper parts at deck level are often unprotected. It is recommended therefore that the deckheads at least are provided with a good paint system. Some shipowners habitually have the top part of the tank painted

down to about two metres and in addition all horizontal parts that may remain wet after emptying the tank, such as the bottom and the upper surfaces of the stringers and frames.

Painting the bottom only and failing to coat the vertical surfaces is not recommended for crude oil ballast tanks. The sludge adhering to the vertical bulkheads is likely to change their potential. In ballast, when the tanks are filled with sea water, the bulkheads act as large cathodes. This can cause severe pitting of the bottom and other horizontal surfaces where there are small defects in the paint system. If the horizontal parts are left unpainted the corrosion is spread more evenly and severe pitting is avoided. It is therefore recommended that either the whole internal surface of a tank be painted or only the bulkheads. Since painting of such large surfaces is expensive, mounting of anodes to both the vertical surfaces and to the bottom and horizontal members may suffice in crude oil ballast tanks.

In order to prevent severe corrosion of steel tanks by heating coils (often made from stainless steel) and pipes, they need to be insulated from the tank bottom and bulkheads. Preferably pipes should be coated with the same paint system used for the tank surface. If insulated mounting is difficult, protection can be obtained by supplementary sacrificial anodes on the tank bottom and bulkheads placed between the heating coils and pipes.

10.10. Damage by stray currents

For a ship being fitted out in a sea water berth, the application of cathodic protection is strongly recommended. If sacrificial anodes are to be used, these should either be mounted before the ship is launched, or suspended over the side afterwards and connected to the hull by means of electrically conducting cables. If the ship is to be protected by an impressed current system, this as a rule, cannot be used during fitting out. In this case a shore based installation may be used temporarily. Such an installation should preferably be fully automatic.

In a ship being fitted out, so-called *stray (interference) currents* can be generated by operations such as welding, particularly if the welding equipment is not correctly earthed or if cables are defective.

These stray currents are much stronger than the cathodic protection current and will therefore cause severe corrosion in areas where they leave the ship's hull, or cause damage to the paint (saponification) where they enter the hull. Stray currents may be detected by a voltmeter placed between a suitable reference electrode and the hull. It should be connected to a recorder and if stray currents are detected, cables of welding equipment and temporary lighting should be inspected for leaks and defective earthing. Sufficient return (earth) cables with a lower electrical resistance than the sea water-circuit should be connected to the welding equipment. Directions for correct earthing of welding equipment are given in Appendix 10.G.

When two ships that are both protected by an impressed current system are moored alongside each other, their hulls should be electrically connected and the potential adjusted to -800 mV relative to a Ag/AgCl sea water reference electrode. Often one installation will suffice to protect both ships. If one of the ships has no cathodic protection they should still be connected and the potential of the hull of the unprotected ship adjusted to 800 mV negative to the reference electrode.

When a ship, protected by an impressed current system, is moored alongside a jetty, the steel of the jetty and the hull of the ship should be connected electrically. The cathodic protection system of the ship should be adjusted in such a way that the potential of both the ship and the jetty are 800 mV negative to a Ag/AgCl sea water reference electrode. If this is impossible, because the underwater surface of the jetty is too large, the lowest possible potential should be taken. If the steel of the jetty itself is cathodically protected, the installation of the ship can be switched off. The ship will then be protected by the jetty, provided that the earthing is good.

On offshore structures, with respect to stray-current damage, situations similar to those affecting ships can occur, for instance when the welding machines are mounted on a barge and the welding operations find place on the structure.

10.11. Control and adjustment of cathodic protection systems

The most important criterion in cathodic protection is the potential of the underwater parts. This must be equal to the protection potential.

For ships and coated parts of offshore structures the potential should not be more negative than -900 mV relative to a Ag/AgCl sea water reference electrode, because otherwise the paint system may be damaged by overprotection (see Part 10.11.1).

The potential can be measured by means of a high-resistance voltmeter. The negative pole is connected to the steel substrate and the positive pole to a *reference electrode*, which is suspended alongside the ship or offshore structure. The desirable readings (see also 10.5) are: -800, -850 or +250 mV relative to respectively a Ag/AgCl sea water, Cu/CuSO₄, or Zn/sea water reference electrode.

In sacrificial anode systems the protective current cannot be adjusted, but overprotection can be avoided by correct calculation of the number (see Appendix 10.F) and spacing of the anodes.

In impressed current systems continuous control and adjustment of the protective current is essential. The required current varies with the immersed surface area (which depends on the load for ships), the conductivity (salt content) and temperature of the water, the speed (for ships) and the condition (porosity) of the underwater paint system. In order to meet the varying current demands the potential is measured continuously by permanent reference electrodes fitted to the underwater surface. The potential difference between the underwater structure and the reference electrodes is used as a control for the rectifier supplying the current to the anodes. Fully automatic adjustment of the potential is obviously preferable to manual adjustment, which requires constant attention.

Accurate control and adjustment of impressed current systems depends on the reliability of the permanent reference electrodes. The copper/copper sulphate (Cu/CuSO₄) electrode is unsuitable for prolonged use in sea water. Silver/silver chloride (Ag/AgCl) electrodes are suitable, but they have to be renewed periodically, e.g. once in five years. The robust zinc (Zn) electrodes are more durable and less sensitive to mechanical and chemical influences but especially at higher speeds, their potential is less constant than that of silver/silver chloride electrodes.

The places where the reference electrodes are mounted should be chosen carefully, because the potential varies slightly over the surface.

When a silver/silver chloride reference electrode is polluted, it will register an elevated potential. The result will be that the impressed current installation delivers more current and a situation of overprotection is created. This leads to a serious damage of the underwater coating system. When a zinc/sea water reference electrode becomes polluted, a depressed potential is registered and a situation of underprotection is created, which will not harm the underwater coating system. The underwater parts are then, however, insufficiently (cathodically) protected.

Because of the above effects, zinc/sea water sensors are to be preferred to silver/silver chloride sensors.

The maintenance of an impressed current system should be left to the supplier. When ships are dry-docking, the system must be switched off before pumping out the dock. It is strongly recommended that the sensors be cleaned during dry-docking of ships and underwater maintenance operations of offshore structures. Anodes and reference electrodes should be inspected and repaired or renewed when necessary.

10.12. Cathodic protection and paint

10.12.1. EFFECT OF CATHODIC PROTECTION ON PAINTS

As mentioned in Part 10.1, *alkali* is formed on cathodically protected surfaces ($2\text{H}_2\text{O} + \text{O}_2 \rightarrow 4 \text{OH}^-$).

Some (saponifiable) paint binders and some pigments can be attacked by this alkali, leading to degradation and blistering of the paint system.

Cathodic protection, also induces *electro-endosmosis** increasing the transport of water to the substrate, which may also cause *blistering* of the paint system.

Both phenomena (alkali information, electro-endosmosis) increase as the potential of the cathodic protection system is lowered and are severe under conditions of overprotection.

* electro-endosmosis is the movement of ions and molecules through a membrane (for instance a coating system) under the influence of an electrical potential.

At potentials lower than -1100 mV (relative to Ag/AgCl sea water), the above processes are accompanied by the generation of *hydrogen gas* ($2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$), which again may lead to *blistering* of the paint system. Beside which, hydrogen gas can cause *hydrogen embrittlement* of the heat affected zone of welds.

As sacrificial anodes of zinc and various aluminium alloys do not have potentials lower than -1100 mV, these materials do not give rise to hydrogen generation.

The increased alkalinity, mentioned previously, often leads to the formation of *calcareous deposits*, particularly around the anodes and on bare areas. These deposits, consisting of magnesium and calcium carbonates, are formed by precipitation of magnesium and calcium salts from the sea water. They are not harmful to paint systems but before recoating a bare area they must be removed completely in order to ensure good adhesion of the new paint system. This can only be done by blast-cleaning.

Due to the formation of the calcareous deposits the current demand will be reduced and the current distribution improved.

Near the anodes of impressed current systems *chlorine gas* may be generated by the electrolysis of chlorides present in sea water ($2\text{Cl}^- \rightarrow \text{Cl}_2 + 2\text{e}^-$). For ships under way this is not a serious problem, the chlorine being rapidly carried away by the sea water. With ships lying idle and with coated fixed offshore structures, however, the chlorine may attack and discolour the paint system around the anodes.

The relationship between potential, degree of corrosion and the secondary phenomena mentioned above, is represented in Appendix 10.H.

10.12.2. PAINTS SUITABLE FOR USE WITH CATHODIC PROTECTION

Paints to be used with cathodic protection must primarily be resistant to alkali.

Binders and plasticizers (if any) must be *unsaponifiable*; also pigments, fillers and additives must be sufficiently *resistant to alkali* (not be attacked at higher pH values).

When a coating system is defective, the cathodic protection current will concentrate at the discontinuities in the coating and produce highly alkaline conditions to which each of the layers of the coating system and the interface between them will be subjected.

In order to provide good resistance to electro-osmotic effects and to disruption by hydrogen gas, paint systems should be sufficiently water-impermeable (thick and free of vacuoles), and display good adhesion.

Paints based on saponifiable binders such as drying oils, alkyd resins and epoxy esters are unsuitable for use with cathodic protection.

Bituminous paints can be used in combination with cathodic protection by means of sacrificial zinc or aluminium anodes. However, conventional anti-fouling paints, usually applied over bituminous coatings, are less resistant to cathodic protection.

High-performance paints, based on epoxy resins, epoxy resin/coal-tar pitch combinations, polyurethane resins, polyurethane resin/coal-tar pitch combinations, vinyl resins, vinyl/tar combinations or chlorinated rubber are suitable for use with cathodic protection by impressed current and sacrificial anode systems. Paints based on epoxy resin, polyurethane resin and the coal-tar pitch combinations of both have the best resistance to cathodic protection and consequently are resistant to some degree of overprotection.

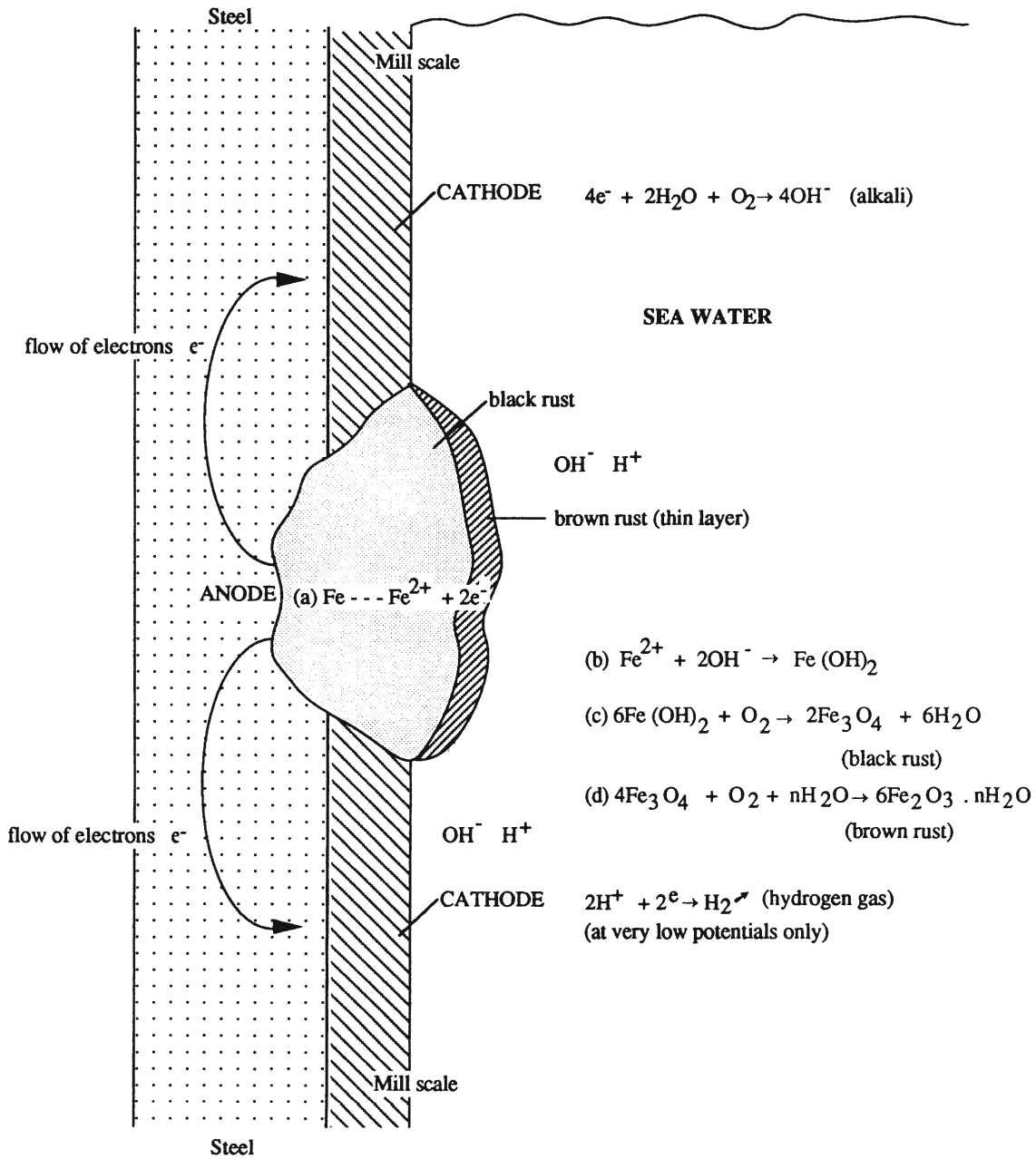
Strong retention of polar solvents considerably reduces the resistance of paint systems to cathodic protection.

Although aluminium powder or zinc dust can be used in paints for cathodically protected surfaces, these pigments diminish the alkali resistance. In particular, such paints will be attacked under conditions of overprotection.

For the same reason the use of zinc chromate, calcium phosphate, or other alkali sensitive anti-corrosive pigments in such paints is not to be recommended.

Paint systems on rusty substrates or on heat-affected shop-coats show a strongly reduced resistance to cathodic protection.

APPENDIX 10.A - CORROSION CELL (Steel with broken mill scale in sea water)



APPENDIX 10.B - POTENTIAL OF METALS IN SEA WATER
 source: 'Corrosion of stainless steels' (page 206)
 by A. John Sedriks
 Publisher: John Wiley & Sons

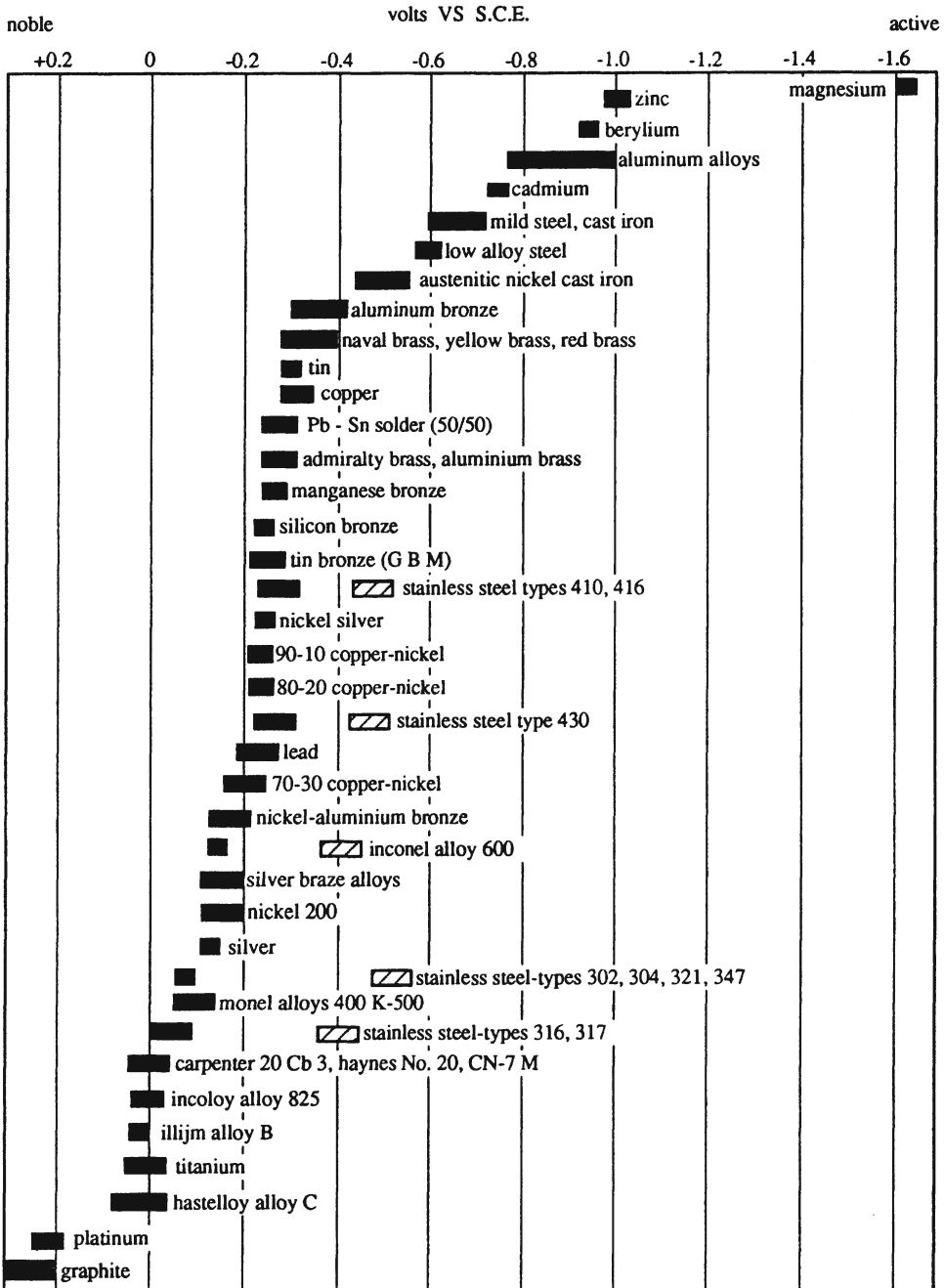


Figure 8-10 Corrosion potentials of various materials in flowing sea water (2.5-4 m/sec) at temperatures in the range 10-26°C. The hatched symbols indicate potentials exhibited by stainless steels in acidic water such as exists in crevices.

APPENDIX 10.C - PRINCIPLES OF CATHODIC PROTECTION

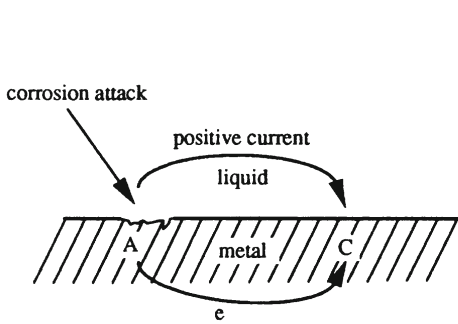


Fig. 1. Before cathodic protection (corrosion cell).

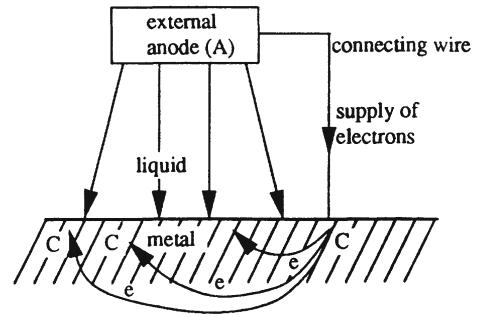


Fig. 2. With cathodic protection: the whole metal surface becomes a cathode; no corrosion attack.

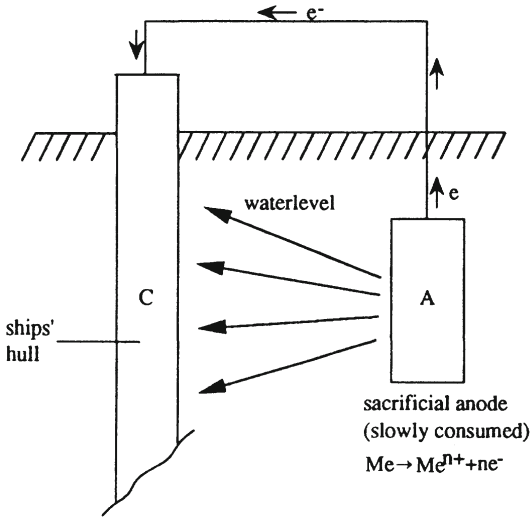


Fig. 3. Cathodic protection by sacrificial anodes.

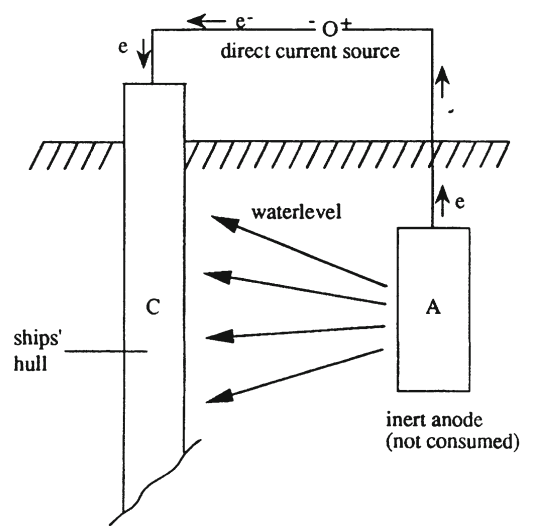


Fig. 4. Cathodic protection by impressed current.

APPENDIX 10.D. - COMPARISON OF CATHODIC PROTECTION SYSTEMS

Sacrificial anode systems	Impressed current systems
Installation is simple	Installation requires expert knowledge
The anodes are designed to have a service life of 2-4 years for ships and about 25 years (the total lifetime) for offshore structures)	The anodes are designed to have a service life of at least 15 years for ships and 25 years for offshore structures (the total lifetime of both)
Efficient current distribution (many anodes)	Less efficient current distribution (few anodes)
Heavy weight, especially for offshore structures situated in deep water (implies structural adaptation)	Light-weight installation
Economically less attractive for the underwater hull of large ships and for large offshore structures	Economically attractive for the underwater parts of large ships and large offshore structures, provided the system functions well and is fully automatic
Require attention only during dry-docking of ships and underwater inspections of offshore structures	Require continuous regulation and adjustment
Practically no risk of damage to paint systems due to overprotection	Serious risk of damage to the paint systems in case of failure or malfunctioning of the installation
Permitted in tanks; in certain tanks the choice of the anode material is limited because of explosion hazard	Not permitted in tanks
If applied in combination with a high-duty paint system, no extension of ship-docking intervals is permitted	If applied in combination with a high-duty paint system, extension of ship-docking intervals may be permitted
If attached to the underwater hull, the resistance of ships is slightly increased (about 0.5%)	If attached to the underwater hull, the resistance of ships is not increased

APPENDIX 10.E. - CHARACTERISTICS OF SOME ANODE MATERIALS

GALVANIC ANODES

Anode material	Potential against a Ag/AgCl reference electrode,	Approximate anode efficiency, %	Output capacity, ampere hours per kg	Consumption rate, kg per ampere year
Magnesium alloys	-1500 to -1700	55-65	1200-1400	6.5-8
Aluminium alloys	-1000 to -1350	50-95	1500-2900	2.9-4.7
High purity zinc or zinc alloys	-1050 to -1100	approx. 95	780-810	approx. 11

NON-GALVANIC (IMPRESSED CURRENT) ANODES

Anode material	Permissible load, A/m ²	Consumption, kg/A.year	Note
Scrap steel	--	8.0	Permissible load and anode consumption dependent on environment and anode composition
Graphite	10 to 40	0.2 to 0.5	
High-silicon iron	10 to 40	0.2 to 0.5	
Lead alloys*	160 to 220	0.05 to 0.1	
Platinized titanium, tantalum and niobium	500 to 1000	negligible	

* For instance lead/silver (antimony) alloys

**APPENDIX 10.F. - QUANTITY OF ANODE MATERIAL TO BE USED
(GALVANIC CATHODIC PROTECTION SYSTEM)**

The *required current* is given by:

$$I = \frac{F \cdot I_a}{1000}$$

where:

I = required current, A

F = surface to be protected, m²

I_a = required current density, mA/m²

The *minimum quantity of anode material to be used* is given by the following formula:

$$G = \frac{a \cdot I \cdot t \times 100}{\eta \cdot C}$$

where:

G = minimum quantity of anode material, kg

a = desired service life, years

I = required current, A

t = total time of immersion (for tanks: time in ballast), hours/year

η = practical anode efficiency, %

C = capacity of anode material, Ah/kg

APPENDIX 10.G - AVOIDANCE OF DAMAGE BY STRAY CURRENTS

Connections for welding equipment with separate current supply for each ship

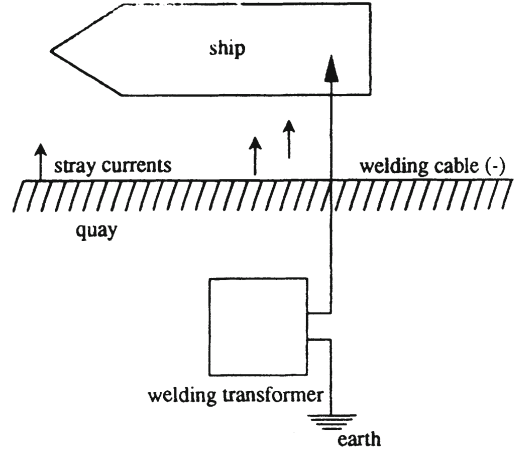
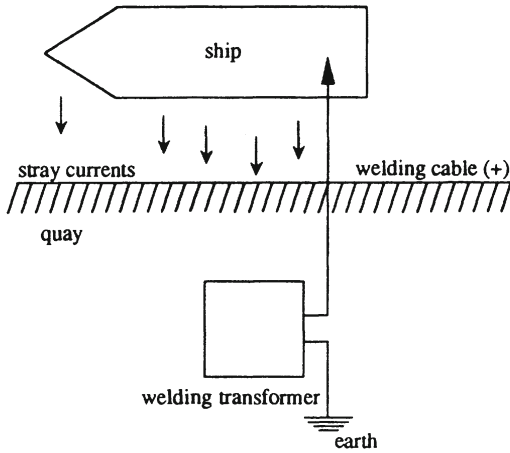


Fig. 1. Wrong!

If welding is done with a positive electrode and without a return cable, the ship's hull will become an anode, and the stray current will cause severe corrosion in places where it leaves the hull.

Fig. 2. Wrong!

If welding is done with a negative electrode and without a return cable the hull becomes a cathode; the paint will be saponified in places where alkalinity is high; bare spots will subsequently corrode.

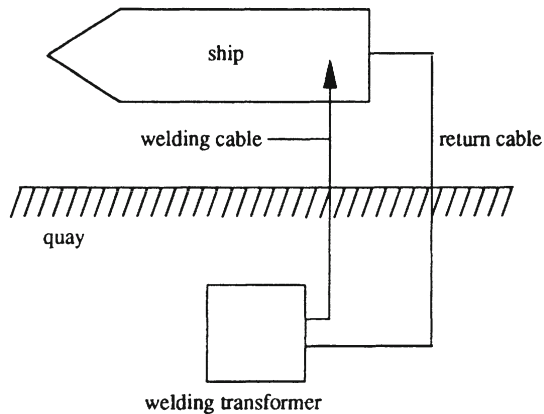


Fig. 3. Correct!

The welding transformer is not earthed; the return cable should have a large diameter (low resistance), so that the sea water and the quay cannot act as conductors for the return current; the welding transformer must not be used for welding operations on the quay, since this would cause earth contact (situation as in fig. 1 and fig. 2).

APPENDIX 10.G - AVOIDANCE OF DAMAGE BY STRAY CURRENTS (continued)

Connections for welding equipment with single current supply for two ships

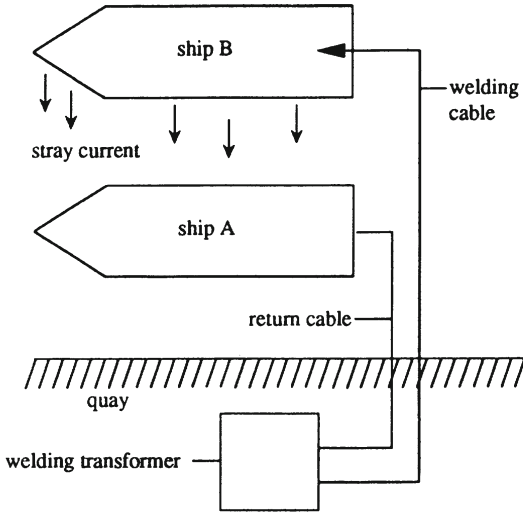


Fig. 4. Wrong!
 A single welding transformer for two ships and no return cable; the return current from ship B will pass to ship A. The hull of ship B will corrode and the paint on the hull of ship A will be damaged by saponification.

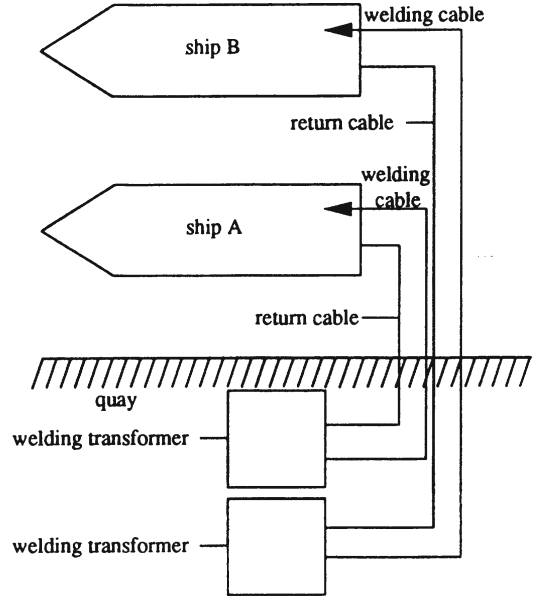


Fig. 5. Correct!
 Each ship has its own welding transformer with separate return cable.

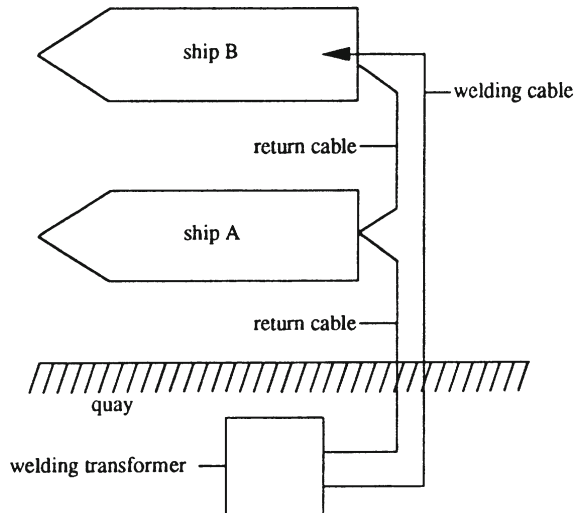


Fig. 6. Correct!
 The ships are connected electrically by a return cable.

APPENDIX 10.H. - RELATIONSHIP BETWEEN POTENTIAL, DEGREE OF CORROSION AND SECONDARY PHENOMENA

Corrosion and cathodic protection	Potential (mV) of the steel in sea water relative to:			Secondary phenomena of cathodic protection
	Ag/AgCl (Sea water)	Cu/CuSO ₄	Zn/Sea water	
<p>↑ Severe corrosion</p> <p>↓ Normal corrosion</p> <p>↑ No cathodic protection</p> <p>↓ Under-protection</p> <p>↑ Slight corrosion</p> <p>↓ Normal potential steel in sea water</p>	- 300	- 350	+ 750	<p>↑ Increasing alkalinity, calcareous deposit and electro-osmotic water transport; risk of coating blistering and saponification</p> <p>↓ Increasing generation of hydrogen; risk of local coating blistering and complete loss of adhesion; risk of hydrogen embrittlement of steel.</p> <p>↑ Flaking of paint layers, mill scale and rust</p>
	- 400	- 450	+ 650	
	- 500	- 550	+ 550	
	- 600	- 650	+ 450	
<p>↑ Cathodic protection</p> <p>↓ Correct protective potential</p> <p>↑ Overprotection</p>	- 700	- 750	+ 350	
	- 800	- 850	+ 250	
	- 900	- 950	+ 150	
	- 1000	- 1050	+ 50	
<p>↑ No corrosion</p> <p>↓ Overprotection</p>	- 1100	- 1150	- 50	
	- 1200	- 1250	- 150	
	- 1300	- 1350	- 250	
	- 1400	- 1450	- 350	

CHAPTER XI

HEALTH, SAFETY AND THE ENVIRONMENT

11.1. Introduction

Although coating materials are indispensable to any ship owner or operator of offshore structures, both the pretreatment of the substrate and the application of paints may involve *safety and health hazards*. Moreover, these activities may lead to *environmental pollution*. The same criteria apply to the scrapping of ships, offshore equipment and other steel structures.

Unsafe and unhealthy situations primarily can be prevented by the awareness of potential dangers (hazards) and risks. Therefore operators should be familiar with the materials and equipment they use and they should use it with proper care.

Much attention is paid nowadays to minimizing risks during surface preparation and paint application. Moreover, paint manufacturers have developed coating materials which are less hazardous than for instance the red lead paints and the reinforced wash primers which were used extensively in the past. It cannot be denied, however, that prevention of accidents, health risks and environmental pollution may contribute significantly to the cost in new building as well as during maintenance.

11.2. Some important characteristics

Prevention of fire and explosions are two major safety factors which require some understanding of the following characteristics:

- flash point
- lower explosive limit
- upper explosive limit
- explosive range
- self-ignition temperature.

Another important characteristic - which is actually not related to these hazards but to occupational health hazards - is the *Threshold Limit Value (TLV)*.

The Threshold Limit Value of a substance is defined as the concentration in the air of a specified substance (toluene, asbestos fibres, etc.) which will neither cause harm to the persons involved nor to their offspring, provided that the exposed persons are adults in good health and that they do not inhale the contaminated air for more than eight hours a day (i.e. five times eight hours a week). In some countries the expression *Maximum Allowable Concentration (MAC)* is used instead of Threshold Limit Value. It has to be stressed that the TLV/MAC of a specific substance may differ in different countries.

Consequently the relevant national list of TLV or MAC values has to be consulted. Some general information about these values is presented in Part 11.2.6.

11.2.1. FLASH POINT

The vapour pressure of any volatile substance is temperature dependent, i.e. a higher temperature is synonymous with a higher vapour pressure.

In gradually raising the temperature of a liquid which is both volatile and combustible (e.g. a flammable solvent), there is a minimum temperature at which the mixture of air saturated with (solvent) vapour can just be ignited by a flame or spark. That temperature is called the *flash point*. At temperatures below this point a mixture of the vapour and air cannot be ignited by any means. Thus, the flash point is a very important characteristic in selecting paints and thinners to be used in e.g. confined spaces.

For the sake of completeness it has to be mentioned that there are two basic methods for determining the flash point of a substance, viz. the open cup and the closed cup method. Both have been standardized by ISO (International Standardization Organization). Some examples of flash points are presented in the table of Appendix 11.A.

Occasionally the term *fire point* is used. Flash points and fire points are determined in a slightly different way. Usually a fire point is 1 to 3°C higher than the corresponding flash point.

11.2.2. LOWER EXPLOSIVE LIMIT

At the flash point, the pressure of the saturated vapour is just high enough to make it possible to ignite the mixture of vapour and air by a flame or a spark. The vapour content of that vapour-air-mixture is called the *lower explosive limit* (LEL). Examples are presented in Appendix 11.A.

11.2.3. UPPER EXPLOSIVE LIMIT

In raising the temperature of a flammable liquid gradually over its flash point, the vapour content of the explosive vapour-air-mixture also increases gradually. In passing a certain temperature the vapour content of the mixture reaches a limit at which it is no longer ignitable by a flame or a spark. The corresponding vapour pressure is called the *upper explosive limit* (UEL, see Appendix 11.A for examples). It must be borne in mind, however, that mixtures with vapour concentrations above the upper explosive limit may become explosive by the addition of air. The most likely places for this to occur are the transition zones between confined places and the open air, e.g. tank entrances and man holes.

11.2.4. EXPLOSIVE RANGE

The range between the lower explosive limit and the upper explosive limit is called the *explosive range*. It may be noted from Appendix 11.A that the explosive range of the various solvents differs considerably.

11.2.5. SELF-IGNITION TEMPERATURE

The occurrence of a fire or explosion requires not only the presence of a mixture of air and flammable vapour whose composition is within the explosion range, but also that the energy and temperature of the ignition source is large enough to ignite the mixture. The main sources of ignition are open flames, the flames and sparks from welding and cutting equipment, hot surfaces and sparks caused by switching of electric circuits. The minimum temperature required for the ignition by a hot surface is called the *self-ignition temperature*. It can be seen from the table in Appendix 11.A that the self-ignition temperatures of common solvents differ greatly.

11.2.6. TLV (MAC)

Some substances are harmful to health or even toxic. Others may smell so badly that even low concentrations in the respired air are unacceptable. Such aspects are of prime importance in setting up standards for acceptable concentrations for gaseous or finely divided solid substances in the air in the working environment. Such acceptable concentrations are known, in Anglosaxon countries, as *Threshold Limit Values (TLV)** and are listed in official and semi-official documents, e.g. in the List of Threshold Limit Values and Biological Exposure Indices, issued by the American Conference of Governmental Industrial Hygienists. The Dutch equivalent of that list is P-blad nr. 145, issued by Arbeidsinspectie (Labour Inspectorate). Similar lists are issued in Western Germany (Bundesrepublik) and the United Kingdom. Threshold Limit Values, in some countries are expressed as the *Maximum Allowable Concentration (MAC)*.

TLV/MAC's of finely divided solids are given in mg of substance per m³ of air, with the notable exception of asbestos fibres where the MAC/TLV is expressed in the number of fibres per cm³.

TLV/MAC's of volatile substances are expressed in ppm (one ppm is one ml of vapour in one thousand litres of air) as well as in mg/m³.

Obviously the more harmful the substance, the lower its TLV or MAC. Examples of substances with a very low TLV/MAC are isocyanates, organotin compounds, lead

* For the exact definition of TLV see Appendix 11.B.

compounds (e.g. red lead) and certain chromates (e.g. the pigment zinc chromate). Examples of solvents having a relative low TLV/MAC are benzene, ethylglycol acetate and methylglycol.

Responsible paint manufacturers aim at replacing all raw materials having a low TLV/MAC by less harmful substances. This, for instance, has resulted in a decreased use of lead pigments in anti-corrosive primers for structural steel. TLV/MAC's of some substances are presented in Appendix 11.A.

11.3. Safety hazards

The safety hazards to be discussed are:

- electrical hazards
- mechanical hazards (physical hazards)
- fire hazards
- explosion hazards.

If appropriate, some aspects of risk prevention will also be discussed. A more detailed discussion, however - which also involves prevention of health risks - is presented in Part 11.5.

11.3.1. ELECTRICAL HAZARDS

Both in surface preparation and paint application extensive use is made of electric equipment (abrading tools, chipping hammers, compressors, pumps, lightning, etc.). As hazards may arise the prevention of risk is an important item. For safety reasons, pneumatic equipment is to be preferred to electrical equipment.

Some important aspects are:

- If necessary the voltage has to be limited (to 50 V in using alternating current and 110 V in applying direct current).
- Colour codes of electric cables should be in accordance with the international standards (white/50 V; blue/220 V; red/380 V, etc.).
- Electrical equipment should only be installed and maintained by qualified electricians.
- Unsafe electrical equipment as well as damaged cables may lead to the electrocution of workers.
- Electric cables lying on the floor may be damaged by vehicles. Cables should be suspended so that they cannot be damaged by vehicles and other moving objects. (Or protected by ramps if they cannot be suspended).
- Electric cables should always be rigged so that they cannot be used as a safety rope or be pulled down accidentally.
- Switches, motors, and the breaking of electric circuits, may cause sparks which could ignite an explosive mixture.

- Various activities not only require explosion-proof switches, motors, lightning, etc. but also the proper earthing of equipment and substrates to remove static charges which may produce sparks.
- Abrasive blast-cleaning as well as airless spraying, may produce static charges, especially at relative humidities below 50 percent. An electric shock caused by static electricity may lead to a worker losing his footing. To avoid such accidents the electrical conductivity of the worker's protective clothing, gloves, footwear and underwear should be sufficiently to prevent any build-up of static charge.
- The electrical conductivity of hoses for abrasives and paints should be high enough to dissipate any charges that might accumulate during usage.

11.3.2. MECHANICAL (PHYSICAL) HAZARDS

The use of equipment in surface preparation and paint application involves various mechanical hazards. The prevention of risk is essential; to this end workers should familiarize themselves with their equipment and avoid carelessness in its use.

Some other important aspects are:

- Maintenance of equipment should be carried out by qualified personnel.
- The erection and removal of scaffolding should be carried out by properly trained and qualified workers.
- Directions regarding the maximum voltage or maximum number of revolutions of grinding discs should be faithfully adhered to.
- Portable scaffolding should be secured properly to prevent any undue movement.
- Footboards of scaffolding should be mounted so that it is impossible for them to move.
- Ladders are liable to break; therefore metallic ladders should be free from corrosion and wooden ladders free from cracks, burrs, knots and other weak points. To facilitate inspection, wooden ladders should not be painted, but there is no objection to them being varnished.
- Ladders should always be erected so that they cannot slip.
- High-pressure hoses should be laid smoothly, i.e. without sharp bends and kicks which may be subject to excessive wear with all the attendant risks.
- Connections of high-pressure hoses should be properly secured as a disconnected end moves violently and erratically, beating any object in its way. If it is used to transport water, paint or abrasive, the situation is made even more dangerous.
- High-pressure hoses should be inspected frequently and should be replaced at the slightest sign of damage.
- Operators of abrasive blast-cleaning equipment should take care not to be struck by the abrasive loaded air stream, as this will normally cause seriously bodily injury.
- Operators of airless spraying equipment should never put a finger on the nozzle tip as this causes paint to be injected into the flesh, which may ultimately result in the finger having to be amputated. Moreover, operators of airless spraying equipment should take care not to be hit by the spray.

- Paints or solvents spilled on the ground may cause workers to lose their footing. Any spillage should be cleared away immediately.
- Marked traffic ways must be kept free from obstructions.
- As the risk of falling objects and welding spatter is always present, safety helmets should be worn by all workers in ships, on slipways, in dry-docks and on offshore structures.
- Workers should wear protective clothing, safety footwear, eye protection, face/head protection and respiratory protection, as appropriate.

11.3.3. FIRE HAZARDS

11.3.3.1 *Solvents, ready-to-use paints, etc.*

Almost all solvents, thinners and diluents used in manufacturing and thinning paints are not only combustible but are also flammable. The same is true of ready-to-use paints, with the noticeable exception of water-borne products.

Solvent-free paints, as a rule, are combustible but not flammable.

It goes without saying that fire prevention is imperative in degreasing surfaces with flammable solvents as well as in applying flammable or combustible paints. The necessary precautionary measures are dealt with in Part 11.5.

11.3.3.2 *Deposits in dry spray-booths*

Dry spray-booths are equipped with filters on which substantial amounts of spray mist are deposited. Some deposits, e.g. those of air drying paints based on isocyanate modified alkyd resins, may reach a temperature which causes them to ignite spontaneously.

11.3.3.3 *Waste materials*

Some waste materials, e.g. rags soaked with linseed oil, may become spontaneously combustible.

11.3.4. EXPLOSION HAZARDS

11.3.4.1 *Mixtures of solvent vapour and air*

Mixtures of solvent vapour and air can be ignited by a flame, a hot surface, a spark or any other ignition source provided that the concentration of the vapour lies between the Lower Explosive Limit (LEL) and the Upper Explosive Limit (UEL).

The ignition of such a gaseous mixture is immediately followed by an explosion. The explosion is due to a very fast chemical reaction between the solvent and oxygen molecules. This results in an increase in the volume, the temperature and the pressure of the gaseous mixture. Moreover, the oxygen content of the air is diminished to a dangerous level for respiration. The ultimate result is casualties and loss of property.

11.3.4.2 *Spray mist and air suspended combustible dust*

Some activities, e.g. blast-cleaning of aluminium with soft abrasives (fragmented walnut shells, etc.) may give rise to high concentrations of combustible dust in the air. Such mixtures are liable to explode (dust explosions). Consequently, forced (mechanical) ventilation may be necessary.

Spray mists of non-aqueous solvent-free paints may also explode. Here again, forced ventilation may be required.

The spraying (atomisation) of a solvent based paint results in a fast evaporation of the solvent. It should be noted that in a confined space the solvent vapour concentration should not exceed 10 percent of the Lower Explosion Level (LEL).

11.4. Occupational health hazards

The items to be discussed are:

- asphyxiation.
- working at high temperatures.
- exposure to noise.
- exposure of the respiratory tract to harmful substances.
- exposure of the skin to harmful substances.
- exposure of the eyes to harmful substances.
- exposure of the digestive tract to harmful substances.

11.4.1. ASPHYXIATION

Asphyxiation (death due to a shortage of oxygen in the air) *takes place within seconds* if a unprotected person enters a confined space in which the oxygen content is under 16 percent.

When the oxygen concentration is between 16 and approximately 18.5 percent a worker is quickly exhausted when doing physical work, e.g. in climbing.

Consequently the allowable lower oxygen content is in practice 19 percent. Confined spaces should be ventilated properly and, moreover, *the oxygen content of the air must be measured before any unprotected person enters the confined space.*

11.4.2. WORKING AT HIGH TEMPERATURES

In ship building as well as dry-docking, the temperature in a ballast or a cargo tank may rise to over 50°C on hot days. Working at high temperature requires regular breaks from work, as specified in official regulations - in countries where such regulations do not exist - by a qualified medical doctor.

Forced (mechanical) ventilation is an important aid in keeping down the temperature to an acceptable level. It has to be stressed that solvents and other volatile constituents evaporate much faster at elevated temperatures than at e.g. 20°C. The implication is that extra ventilation is required in applying solvent borne paints in tanks on hot days.

11.4.3. EXPOSURE TO NOISE

In some activities, e.g. in abrasive blast-cleaning and in using air driven power tools, so much noise is generated that protection for the ears is necessary. In the Netherlands noise protection is *obligatory* at intensities above 90 dB(A). However, it is *recommended* for levels between 80 and 90 dB(A).

11.4.4. EXPOSURE OF THE RESPIRATORY TRACT TO HARMFUL SUBSTANCES

Inhalation of dust, fumes, spray mists or vapours may be harmful to health. Examples are, benzene (a solvent), zinc chromate (a pigment), finely divided lead compounds (e.g. the pigment red lead), volatile amines (used as hardeners in epoxy coatings), isocyanates (used as hardeners in polyurethane coatings) and organotin compounds (used in anti-fouling).

Safe levels in the air are provided by the list of TLV's (Threshold Limit Values) or MAC's (Maximum Allowable Concentrations).

Forced (mechanical) ventilation is the main technique to lower the concentration of harmful substances in the air. Respiratory protection is mandatory if forced ventilation does not bring the concentration down to a level below the TLV or MAC for the substance involved.

During welding and flame-cutting operations in confined spaces the risk of excessive concentrations of hazardous fumes arising is particularly high. Accumulation of such fumes should be prevented by adequate local ventilation.

Portable air suction hoses provide effective removal of fumes from the site of operations. If for some reasons this is impossible, welders should wear respirators.

11.4.5. EXPOSURE OF THE SKIN TO HARMFUL SUBSTANCES

Some common raw materials, e.g. amines, liquid epoxy resins, reactive diluents (glycidyl esters, glycidyl ethers, etc.), organotin compounds and most solvents irritate

the skin. Such materials are called skin irritants and repeated exposure may cause skin diseases. Moreover, repeated exposure of the skin to e.g. isocyanates, liquid epoxy resins, reactive diluents and aliphatic amines may ultimately lead to sensitization.

Most solvents can dissolve oils and fats from the skin. Excessive cleaning with solvents ultimately results in it becoming brittle and cracked. Micro-organisms may enter the skin via such cracks, and cause skin disease.

Some solvents are absorbed in the body via the skin and may be harmful to health.

Solvent resistant gloves made of e.g. nitril rubber (neoprene rubber) or polyvinyl alcohol are very useful in preventing exposure of the skin to solvents and other harmful substances. Such gloves should be used in combination with cotton gloves to prevent discomfort due to perspiration.

The so-called barrier creams, often used to protect hands and arms against contamination with paint, make it easier to clean the skin after painting, but do not provide protection against the absorbence of solvents etc.

11.4.6. EXPOSURE OF THE EYES TO HARMFUL SUBSTANCES

Splashes of solvents and other liquids entering the eyes may not only cause irritation but may also damage them. Moreover, solvent vapours and vapours of other volatile substances may cause irritation. A well-known example is n-butanol, a solvent present in a number of paints.

Irritation as well as damage to the eye can be prevented by the use of chemical goggles, a face shield or a fresh air hood.

11.4.7. EXPOSURE OF THE DIGESTIVE TRACK TO HARMFUL SUBSTANCES

Deliberate swallowing of a solvent, thinner or paint by a mentally sound person is highly improbable. However, accidental imbibition may occur. A classical example is the use by a worker of a beer bottle to provide a temporary store for a liquid hardener and the drinking of that fluid by a colleague by mistake.

A main cause of exposure of the digestive tract to harmful substances is the inhalation of small dust particles, present in the air. Particles deposited in the upper part of the respiratory tract are transported to the pharynx. Due to swallowing, they are passed to the digestive tract.

The process of inhaling and swallowing can be prevented by using a mask with a dust filter or a fresh air hood.

11.5. The prevention of risk

The prevention of risk - a better definition is the aim to minimize occupational health and safety risks in surface pretreatment and painting operations - requires a systematic approach. Important aspects are:

- organization of the work to be carried out;
- procedures;
- instruction and training of the workforce;
- selection, maintenance and use of equipment;
- selection of surface preparation techniques;
- selection of paints, thinners and other coating materials;
- selection of paint application techniques;
- elimination of ignition sources;
- ventilation;
- protective clothing, gloves, respirators, etc.;
- cloak rooms and sanitary facilities;
- personal hygiene;
- total abstinence at work;
- the safety organization.

11.5.1. ORGANIZATION OF THE WORK TO BE CARRIED OUT

Unnecessary (avoidable) improvisations in surface preparation and paint application increases the safety and health risks for the workers. It is essential that, wherever possible, all activities are properly prepared, organized, managed and controlled by the painting contractor, in close collaboration with the yard and owner.

11.5.2. PROCEDURES

Procedures should be clearly stated and made as simple as possible in order to minimize safety and occupational health risks, not only in surface preparation and paint application, but also in such activities as erecting, scaffolding, mixing two-component paints and the removal of waste material.

It is essential to draft clear and plain emergency procedures (i.e. procedures to be used after an accident).

11.5.3. INSTRUCTION AND TRAINING OF THE WORKFORCE

The prevention of risk includes instruction and training of the workforce, e.g. in the proper use of scaffolding, electrical equipment, power tools, blast-cleaning equipment, airless spraying equipment etc.

Items which are sometimes neglected are the need to read safety instructions attached to packages of coating materials and the need for proper personal hygiene.

11.5.4. SELECTION, MAINTENANCE AND USE OF EQUIPMENT

In selecting equipment, management should pay particular attention to safety aspects. Obviously, equipment to be procured has to meet the appropriate compulsory safety regulations. These may, however, differ from one country to another.

Expert advice on safety aspects may be needed in selecting e.g. scaffolding, electrical equipment for the lighting of confined spaces, power tools and pressurized equipment. Proper maintenance of equipment not only reduces safety risks, but also reduces running costs. Maintenance procedures for equipment should be supplied by the manufacturer. Proper use of equipment implies proper training of the workforce (see Part 11.5.3).

11.5.5. SELECTION OF SURFACE PREPARATION TECHNIQUES

In selecting a surface pretreatment technique for a specific job, attention should always be given to safety and health risks.

In a number of cases high-pressure water-jetting, steam-cleaning and solvent-degreasing are interchangeable as far as the ultimate degree of cleanliness of the surface is concerned. However, solvent-degreasing should be limited to exterior work to exclude explosion risks and to reduce the risk of exposure of workers to solvent vapour concentrations above their TLV or MAC.

Common techniques for the removal of mill scale are abrasive blast-cleaning and acid pickling, the former being the preferred method in most cases.

Acid pickling can be carried out under more controlled conditions which is, of course, an advantage from the point of view of improving industrial health. On the other hand, pickling finds little or no application in shipyards because of the need for large and deep baths, the development of noxious and corrosive vapours, and technical and financial problems posed by the necessity of disposing of the highly contaminated acidic waste water.

Removal of (partly degraded) paint coats is often done by dry abrasive blast-cleaning, a process which creates excessive amounts of dust, part of which is respirable. Dust production can be reduced significantly by injecting relatively small amounts of steam in the compressed air. Respirable harmful substances are almost absent if degraded paint coats are removed by high-pressure water-jetting or by wet abrasive blast-cleaning.

11.5.6. SELECTION OF PAINTS AND THINNERS

In selecting paints and the appropriate thinners attention should also be paid to safety and health hazards for the workers.

Safety hazards in paint application, in e.g. confined spaces, can be reduced by avoiding the use of paints with a flash point of under 40°C.

Safety risks in confined spaces can be made even smaller by using solvent-free and solventless paints instead of solvent-rich paints. However, *health risks* may increase when using solventless and solvent-free paints, due to the presence of reactive diluents.

Occupational hazards can be reduced by avoiding the unnecessary use of for instance zinc chromate primers, paints containing volatile isocyanates and lead based paints. Examples of lead based paints are red lead and calcium plumbate primers and finishes based on chrome yellow, molybdate orange and molybdate red. The use of leadless and lead-free paints is attractive as well as from an environmental point of view (Part 11.7). Moreover, *health risks* during flame-cutting are reduced if the steel is covered with a paint which is lead- or chrome-free (see Part 11.6.4).

11.5.7. SELECTION OF PAINT APPLICATION TECHNIQUES

In painting large areas of ships and offshore structures, airless spraying is common practice.

By using a large nozzle, 80 to 120 litres of paint can be applied by one worker in an hour. On average this quantity contains 50 litres of solvent which has to evaporate within one to three hours. This makes it abundantly clear that forced (mechanical) ventilation is a must in confined spaces, machine rooms and accommodation rooms.

It may be necessary to avoid airless spraying and to apply the paint by brush or roller if forced ventilation is impracticable.

Paint application by spraying on exterior work on a windy day results in excessive amounts of overspray, which is dispersed into the environment. This is not only objectionable, but may also be forbidden by compulsory regulations.

11.5.8. ELIMINATION OF IGNITION SOURCES

Explosion prevention implies:

- elimination of all ignition sources;
- limitation of the solvent vapour concentration, the spray mist concentration and the concentration of airborne combustible dust to a level sufficiently below the Lower Explosive Level (LEL).

Limitation of e.g. the solvent vapour concentration by forced or mechanical ventilation is discussed in Part 11.5.9.

The main sources of ignition sources are:

- open flames;
- burning cigarettes, cigars and pipes;
- hot surfaces;
- welding sparks, sparks from flame-cutting operations, etc.;
- sparks from switches, from the breaking of electric circuits, etc.;
- sparks from tools;
- sparks generated by static charges.

Open flames, burning cigarettes, cigars and pipes, as well as hot surfaces and sparks from welding operations and tools, can be prevented by proper management techniques. Sparks from switches etc. can be prevented by the use of explosion-proof electrical equipment. Electric lightning has to be considered, as most bulbs do not only have hot surfaces when in use, but may also produce a spark when they fail.

Sparks from e.g. chipping hammers can be prevented by using non-sparking tools.

The raising of static charges cannot be prevented in e.g. dry abrasive blast-cleaning and airless spraying. At relative humidities below approximately 50 percent static charges are almost persistent on materials of low electrical conductivity. These charges may generate sparks, which may ignite an explosive mixture of solvent vapour and air.

For safety reasons materials and equipment of a low electrical conductivity should not be present in areas where explosive mixtures of e.g. solvent vapour and air may be present. Moreover, all equipment should be properly earthed.

Clips used in earthing should be inspected to see that they make proper electric contact with the bare metal of the equipment involved, surfaces to be painted, etc. Consequently the clips should be free from corrosion products and foreign matter.

11.5.9. VENTILATION

It should be recognized that solvent-based coating materials as well as paint spraying techniques are indispensable. Consequently, in confined spaces, *forced ventilation is of utmost importance for the removal of volatile material (solvents) and in keeping down concentrations of harmful substances in the air to acceptable levels.* Proper forced ventilation is also important for the following reasons:

- in obtaining the right oxygen content of the air in confined spaces;
- in cooling spaces, in subtropical and tropical regions, to such a level that (painting) work can be continued without undue interruptions;
- in increasing the temperature in cool spaces to such a level that the drying/curing time of an applied paint coat decreases significantly.

In ventilating a space, an important characteristic is the *ventilation rate*. This is defined as the number of times per hour the air is replaced by fresh air. If the net volume of a space is e.g. 100 m³ and the supply of fresh air is 500 m³/hour, the ventilation rate is 5.

The basic ventilation techniques are:

- natural ventilation;
- forced (mechanical) ventilation.

In *natural ventilation* fresh air enters a space via apertures (openings), cracks, fissures and crevices. Main driving forces are the force of the wind and the temperature difference between the interior of the space and its environment. Due to various factors (e.g. the wind direction) the ventilation rate is quite uncontrollable. Consequently, natural ventilation is unacceptable if a confined space has to be properly ventilated during a painting operation.

In *forced (mechanical) ventilation* the main techniques are *exhaust ventilation* and *dilution ventilation*.

In the *exhaust process* the air loaded with dust, spray mist, solvent vapour etc., is sucked away at a well chosen location. In *dilution ventilation* compressed fresh air is blown into the space involved.

In most cases exhaust ventilation is much to be preferred over dilution ventilation. An example is the ventilation of a vertical tank during a painting operation. The solvent vapour tends to concentrate near the bottom of the tank. Consequently, maximum efficiency is obtained if the contaminated air is drawn off from this area. Exhaust ventilation is also to be preferred in removing spray mist and airborne dust. However, if the space to be ventilated has a relatively small height and a relatively large floor area, as a rule blowing the fresh air in at one side and letting the solvent vapour loaded air escape via openings in the opposite wall gives the best results.

In exhaust ventilation one has to make sure that sufficient fresh air can enter the space. An insufficient amount of 'make up air' results in a decreased pressure, which leads, as a rule, to a reduced capacity of the exhaust ventilation system.

Another important aspect of exhaust ventilation is that the 'make up air' does not normally pass through a filter. As a result, significant amounts of dust may enter a freshly painted compartment, leading to objectionable results.

Dilution ventilation is much more controllable than exhaust ventilation. If necessary, the fresh air can be preheated, dried and/or made dust-free. Moreover, spreading of the replacement air can be improved by using a plenum.

Proper ventilation means that concentration of volatile or finely divided hazardous substances is kept below their TLV or MAC.

The minimum quantity of air needed to reach the TLV is given by the following equation:

$$\text{RAQ (TLV)} = \frac{d_p \times \sum (q_s \times 10,000)}{\text{TLV}_s}$$

- RAQ = Required quantity of air = minimum quantity of replacement air to reach TLV, m³ per litre of applied mixed paint.
 d_p = density (specific gravity) of mixed paint.
 q_s = quantity of each solvent or diluent, kg per kg of mixed paint.
 TLV_s = Threshold Limit Value (Maximum Allowable Concentration) of each solvent and diluent, present in the mixed paint, mg/m³.

In airless spraying in confined spaces, such as tanks, where large volumes of paint are applied within a short time, it may be impossible or at least impractical to provide sufficient ventilation to maintain the concentration of solvent vapours below their TLV or MAC.

In such cases it is a prerequisite that ventilation be provided to reduce the concentration of vapour to less than 10% of its lower explosion limit (LEL).

The minimum quantity of replacement air required per minute can be calculated as follows:

$$\text{RAQ (10\% LEL)} = \frac{(P \times A) + (T \times B)}{t}$$

where:

- RAQ = Required quantity of air = minimum quantity of air to reach 10% LEL, m³ per minute.
 P = volume in litres of undiluted paint applied in t minutes.
 T = volume in litres of thinner added to the volume of paint (P) applied in t minutes.
 A = quantity of air for 1 litre of undiluted paint required to reach 10% LEL.
 B = quantity of air required for 1 litre of thinner to reach 10% LEL.
 t = time in minutes for the application of P litres of paint.

Leading paint manufacturers state in their product data sheets the minimum volume of air required for one litre of paint in order to reach the TLV and 10% of the LEL respectively.

A proper rate of ventilation does not mean, however, that each part of the space is sufficiently ventilated. Air streams are complex and zones where a low rate of ventilation is achieved are quite common. There may even be stagnant areas of (almost) zero ventilation. Using solvents with a low flash point, stagnant zones are extremely dangerous, as the solvent vapour concentration may locally exceed the Lower Explosive

Limit (LEL). So-called smoke candles are quite useful in controlling air streams in spaces which have to be properly ventilated.

It should be noted that even if ventilation in a confined space is sufficient to prevent a fire or an explosion, concentrations of hazardous compounds may still be well above their MAC (TLV). This means that operators must be protected by fresh-air masks or respirators when entering the confined spaces.

It is obvious that almost any freshly applied paint coat releases solvent vapour for a considerable time. Consequently, forced ventilation has to be continued for a considerable period after application of the paint.

11.5.10. PROTECTIVE CLOTHING, GLOVES, RESPIRATORS ETC.

Apart from the items mentioned below it should be clear *that workers always must wear hard hats and footwear provided with steel toe-caps*. A proper choice of clothing, gloves, footwear, etc. is quite important in preventing exposure of the body to harmful substances, noise and heat, radiation, etc. General information is provided in the following paragraphs.

11.5.10.1 *Clothing*

It is no exaggeration, and it has to be stressed that the worker's underwear is an important factor which has to be considered.

Underwear should not be highly combustible. Nylon is extremely dangerous as it is highly combustible. Moreover, it melts when it starts to burn and can fuse with the skin causing serious third degree burns.

Underwear should have good water absorption properties. Cotton normally provides the maximum comfort.

In airless spraying, as well as in dry blast-cleaning, underwear should exhibit an adequate electrical conductivity. By this means, large local electrostatic charges are avoided. Cotton is again suitable for this purpose.

Strong overalls made of cotton are satisfactory for most kinds of works. Overalls made of nylon or polypropylene are not recommended as these are highly combustible and are characterized, as a rule, by a low electrical conductivity. A highly contaminated overall should be changed for a clean one immediately if it cannot be excluded that harmful substances may reach the skin of the worker.

Disposable overalls made of suitable nonwoven materials are to be preferred if the work is such that they are seriously contaminated within a short period. In activities in which the worker may get soaked, e.g. in water-jetting, impermeable clothing should be used. In other types of work there is a risk that the clothing may be rapidly abraded, e.g. in grit-blasting if the grit loaded airstream touches the overall. In these cases it is strongly

recommended that an overall which sufficiently protects the legs and the abdomen should be worn. Leather clothing is preferred as it has a good wear resistance as well as a large water vapour permeability. In flame-cleaning operations, leather is also recommended, as it is almost inflammable and poorly combustible.

11.5.10.2 *Aprons*

It is good practice to wear an apron when handling solvents, aqueous sodium hydroxide solutions, aqueous solutions of hydrofluoric acid, pickling acids, etc.

The material of which the apron is made depends on the nature of the liquid involved. In handling solvents, aprons made of neoprene (nitril rubber) are preferred. Those made of polyvinyl alcohol have an even better resistance to solvents, but are not very pliable. Aprons made of rubber are most suitable for handling aqueous solutions of acids, alkalis, etc.

11.5.10.3 *Gloves*

Protective gloves are a great help in preventing exposure of the skin to solvents, alkalis, acids, etc. They can also prevent damage to the skin in e.g. abrading operations.

Protective gloves used in handling chemicals have to be both resistant and impermeable to the substance involved. Moreover, they should extend well above the wrist. Discomfort in wearing impermeable gloves can be limited to some extent by wearing cotton under-gloves.

In handling aqueous solutions of e.g. acids, rubber or PVC gloves are usually best. In handling solvents, neoprene (nitril rubber) or polyvinyl alcohol gloves are to be preferred, however, polyvinyl alcohol is not resistant to water. Protective gloves used in preventing mechanical damage of the skin have to be made of a strong, flexible material which should possess a high water vapour permeability. Leather will be suitable.

Protective gloves used in flame-cleaning operations should also be made of leather.

11.5.10.4 *Footwear*

Footwear is important in preventing accidents and in preventing exposure of the feet to harmful substances. All shoes and boots should contain steel toe-caps. However, they are banned by some platform operators because of the risk of sparking.

The specific demands made on the protective footwear depend largely on the type of work involved. In handling aqueous solutions of chemicals, knee-length rubber boots are best. Knee-length boots made of neoprene (nitril rubber) are preferred for handling solvents. Any discomfort due to wearing these boots can be alleviated by insoles made of felt or cork.

Soles and heels should be made from a material which does not slip when in contact with a spilled solvent. The electrical conductivity must ensure that static charges are discharged immediately.

In airless spraying and blast-cleaning operations, strong thick leather footwear should be worn. For flame-cleaning knee-length boots made of thick leather are essential.

11.5.10.5 *Respiratory protection*

Respirators contain cartridges filled with a suitable absorbent, e.g. activated carbon. They are used to prevent exposure of the pharynx, bronchial tubes and lungs to volatile irritating, harmful or toxic substances, e.g. solvents. Obviously, used cartridges have to be replaced as soon there is any sign of saturation of the absorbent.

Respirators must not be used when the oxygen content of the air is below 19%.

If the substance involved is a solvent vapour, both a *full face mask* and a *half face mask* fitted with an activated carbon filter give good protection. If the air contains a spray mist, an aerosol filter is needed as well in the protective mask.

If the substance involved is an airborne solid, a *dust mask* can be used for respiratory protection. These masks are supplied in different grades depending on whether the dusts are coarse and relatively harmless, fine and relatively harmless or are (quite) harmful to health.

A *fresh air hood*, which receives air via a hose, gives an excellent degree of protection, provided that the intake air is clean and has been freed from the tiny droplets of oil which are released by some compressors. Fresh air hoods not only provide protection for the respiratory tract, but also for the eyes and other parts of the head. Some types of fresh air hoods also provide noise protection.

When using *self-contained breathing equipment*, the air is supplied by one or two high pressure air cylinders, carried on the worker's back. This type of equipment is mainly used in cases of accidents, fire-fighting, etc.

In confined spaces only breathing equipment which is completely independent of the air in those spaces (fresh air hoods) should be used.

When there is lack of oxygen (concentration less than 19%) fresh air hoods or self-contained breathing equipment are obligatory.

11.5.10.6 *Eye protection*

Eye protection is a must in blast-cleaning, power-tool cleaning and in handling corrosive liquids when irritant vapours are being released, etc. A fresh air hood or full face mask

provide complete protection for the eyes. Usually a fresh air hood is preferred to a full face mask, as it provides better visibility for the worker.

Safety goggles give good protection in working with equipment such as sanding machines or abrasive discs.

In handling solvents, liquid chemicals or aqueous solutions of chemicals, the eyes should be protected against splashes by chemical goggles or a face shield. Chemical goggles also protect the eyes against irritating or corrosive vapours which a face shield does not. On the other hand a face shield protects all parts of the face against splashes.

11.5.10.7 *Noise protection*

Some activities, e.g. blast-cleaning operations, generate so much noise that the sound intensity exceeds 90 decibels which means that noise protection is *obligatory*. However, it is *recommended* at sound levels between 80 and 90 dB(A).

In selecting protective devices, it has to be borne in mind that the absorption characteristics depend as a rule on the audio frequency. Consequently, as a rule, the types of noise protection used in blast-cleaning is quite unsuitable in for example ultrasonic degreasing operations.

11.5.10.8 *Skin protection*

It is a common misconception that barrier creams ('fluid gloves') protect the skin against solvents, liquid hardeners, etc. (see Part 11.4.5). Protection is only provided by avoiding skin contact with such harmful substances by using gloves and protective clothing.

11.5.10.9 *Protection of the head*

In yards, on ships and offshore structures the use of a hard hat is normally obligatory and applicable to everyone entering the site.

Hard hats (protective helmets), which are usually fabricated from thermo-setting plastics, should be:

- mechanically strong, i.e. impact, penetration and scratch-resistant;
- temperature-resistance and fire-retardant;
- resistant to ultra-violet radiation;
- resistant to water, sweat, grease, oil, salt, detergents and disinfectants.

Internally, the protective helmet should be shock-absorbent, non irritant to the skin and easily cleanable. Protective helmets must retain the above mentioned properties over a long period. They should be discarded after five years.

11.5.11. CLOAK ROOMS AND SANITARY FACILITIES

Good cloak rooms are important, as they contribute to improvements in personal hygiene (see Part 11.5.12).

A cloak room should be equipped with two lockers for each worker, one for personal belongings and the other for protective clothing and footwear.

Toilets should be equipped with proper hand washing facilities, with a supply of non-abrasive soap or a suitable detergent for general cleaning, a slightly abrasive detergent to remove paint etc., and disposable tissues for drying.

Showers should be available with hot and cold water, for everyone involved in blast-cleaning, airless spraying and all other activities which, due to their nature, may lead to harmful substances being deposited on the skin, to excessive perspiration, or both. These facilities must be properly maintained.

11.5.12. PERSONAL HYGIENE

Personal hygiene should be encouraged by the employer for the workers own protection and may result in such benefits as a reduced absentee rate. Workers should be advised:

- not to wear rings, wrist-watches etc. as harmful substances may collect behind them, leading to problems such as skin irritation or sensitization. They may also get caught in machinery or other protrusions;
- to change their overall for a clean one if it has been contaminated so that contact of the skin with a harmful substance cannot be avoided;
- to remove any harmful substance that has been in contact with the skin immediately;
- to remove protective items in such a way that the skin is not contaminated with a harmful substance;
- to keep their finger nails short to prevent harmful substances collecting under the nails causing skin irritation or sensitization;
- to pay special attention to the finger nails when washing the hands;
- to wash their hands carefully before urinating or stooling;
- not to smoke, eat or drink whilst working;
- not to smoke, eat or drink at the work site during breaks;
- to eat and drink only in the work's canteen;
- to wash both their hands and face properly before smoking, eating or drinking;
- not to clean/wash their overalls with the family laundry.

11.5.13. TOTAL ABSTINENCE AT WORK

Most persons are quite sensitive to alcohol and drinking of just one glass of beer can result in a reduction of concentration. This leads to higher safety risks. Consequently total abstinence at work is a must for blast-cleaning operators, airless spraying operators and workers involved in scaffolding operations or other technical activities.

11.6. Some activities characterized by enhanced risks

11.6.1. STORAGE OF FLAMMABLE PAINTS AND THINNERS

For technical reasons as well as for safety requirements, (highly) flammable paints and thinners should be stored in properly ventilated warehouses. These should be heatable or coolable, depending on climatic conditions.

The height of the threshold of a stockroom for flammable paints and thinners should be such that, in case of fire, the burning liquid cannot escape. Moreover, the stockroom should be constructed of fireproof materials. Fire fighting equipment should be either permanently installed or be at hand. The person in charge of the paint and thinner store should make sure that all tins, drums etc. are undamaged and well-sealed to prevent leakage, spillage and fire risks.

Most ships have a limited store of paints and thinners for touch-up work during sailing or for maintenance work by a painting contractor whilst in harbour. For safety reasons flammable materials should be stored preferably in a relatively cool part of the ship, especially in tropical and subtropical regions. Relatively high storage temperatures may also have a detrimental effect on paint quality.

11.6.2. APPLICATION OF ANTI-FOULINGS

Anti-foulings are used to prevent the growth of algae and barnacles on ships' hulls, submerged parts of offshore structures, lock gates, buoys, etc. All common anti-foulings have a high toxicant content; those commonly used are cuprous oxide, tributyltin oxide (TBTO), tributyltin fluoride (TBTF), triphenyltin fluoride (TPTF) and organotin copolymers.

The so-called conventional anti-foulings are based on cuprous oxide which is relatively harmless to man. However, the toxicants used in the so-called modern anti-foulings (long life anti-foulings, self-polishing anti-foulings, etc.) are quite toxic.

Anti-foulings are usually applied by airless spraying. The atomisation of the paints greatly enhances the risk to the workers.

Applicators of anti-foulings should have complete body protection. The protective clothing has to provide a barrier between the atomized paint and the body and requires the use of a fresh air hood. The air must be drawn from a site which is uncontaminated by spray mist and other harmful substances. Moreover, any oil present in the airstream has to be removed usually by an oil filter.

Attention should also be paid to the health risks for persons working to leeward of the airless sprayers.

The same holds for the persons working at the same time as the anti-fouling sprayers in the lower parts of poorly ventilated drydocks. It may also be necessary for them to use respiratory protection.

Another important aspect is the pollution of the environment, e.g. of surface waters, due to dispersed spray mists of anti-foulings. This aspect is dealt with into some detail in Part 11.7.

11.6.3. WORKING IN CONFINED SPACES

Some of the hazards discussed in Parts 11.3 and 11.4 are of importance when working in confined spaces. In most industrialized countries, compulsory regulations regarding work in confined spaces are in force. As far as the author is aware, the compulsory regulations in the various countries are essentially the same.

The painting contractor should see that the confined space has been made:

- clean,
- dry,
- free from gas,
- free from excessive rust,
- free from oil, grease and fat,
- free from chemicals,

before his workers enter it.

As a rule, use is made of the services of specialized contractors to clean fuel and cargo tanks.

11.6.3.1 *The main hazards*

These are:

- asphyxiation (a sudden death, due to oxygen deficiency);
- intoxication, due to chemicals (e.g. lead compounds present in heavy dust deposits);
- narcosis, due to e.g. solvent vapour;
- explosions;
- fires;
- electrocution;
- injuries due to moving or rotating parts of machinery;
- undue effects of extreme temperatures on the human body.

These general hazards have been dealt with in Parts 11.3 and 11.4. Therefore, only those aspects which are directly related to working in confined spaces are dealt with in the next parts (11.6.3.2 to 11.6.3.7).

An illustration concerning safe working during application of tank coatings is presented in Appendix 11.C.

11.6.3.2 *Organization*

The Dutch Labour Inspectorate (Arbeidsinspectie) requires that a document ('the work permit') be produced by the employer before the work is started. In that document, all relevant matters such as the type of work to be carried out, the harmful substances which may be met with, the required forced ventilation, the materials and equipment to be used, have to be stated in plain language and easily understood by all persons involved. The document has to be signed by several persons, e.g. the safety engineer and the works supervisor. As the type of work to be carried out may differ from day to day, the Dutch Labour Inspectorate requires that a new work permit is produced daily. The workers should be instructed about the work to be done each day. In the first of the series of daily instructions, relevant information about communication procedures, the substances likely to be encountered, the rescue procedures and the personal protection equipment to be used etc., should also be presented.

Persons who suffer from claustrophobia or vertigo (fear of heights) are not fit to work in such places as ballast and cargo tanks. Consequently, proper selection of personnel is essential.

As long as workers are present within a confined space, another has to be stationed permanently near the entrance. The main duties of this attendant are to communicate with the workers inside and to raise the alarm if there is an accident. To facilitate rescue operations, all workers should be connected by a safety rope, connected to a suitable point external to the confined space.

11.6.3.3 *Accessibility*

A proper access to the confined space is of prime importance. It may be necessary to make a temporary entrance if the diameter of the manhole is relatively small.

For safety reasons any confined space which has to be painted should preferably have three entrances:

- the main entrance for the workers;
- the emergency exit;
- the entrance for electric cables, air, blasting, paint hoses etc.

However, quite a few confined spaces have only one entrance and the making of one or two temporary entrances is not always possible. Each worker should be able to move freely and easily within the confined space. Moreover, they should not meet excessive physical hindrance in entering or leaving the space.

11.6.3.4 *Procedures, measurements etc. before entering a confined space*

Proper (forced) ventilation with fresh air is necessary before entering a confined space and all pipes for gases and liquids must be shut from the outside.

Also, before entering, a representative sample of the air of the confined space should be investigated on oxygen content, combustible gases/vapours content and on the amount of airborne harmful or toxic substances.

The confined space may be entered without special measures only if the oxygen content is at least 19% by volume of the air, the content of combustible gases (vapours) is below 10% of the LEL (lower explosion limit) and the amounts of hazardous substances are below their TLV or MAC.

Special equipment is available for measuring the parameters mentioned above such as portable oxygen meters, explosion meters and gas detectors. *If the content of combustible gases (vapours) is higher than 10% of the LEL, the confined space is not be entered.* If the amount of substances constituting a health hazard is above the TLV/MAC, the confined space is to be entered only by persons wearing respirators or fresh air hoods. Likewise when the oxygen content is lower than 19% by volume, a fresh air hood or a self-contained breathing apparatus must be used.

11.6.3.5 *Temporary lighting*

Some confined spaces, e.g. cargo tanks and ballast tanks, are not provided with permanent lighting equipment. Consequently, temporary lighting is needed during scaffolding, abrasive blast-cleaning, painting, etc. Temporary lighting has to meet the compulsory regulations and these may limit the voltage allowed. For safety reasons, proper attention should be paid to luminous intensity, positioning of the electric cables, etc.

11.6.3.6 *Temporary heating*

It may be necessary to heat a confined space, during as well as after paint application, to accelerate paint drying and curing. Temporary heating is usually achieved by preheating the fresh air used in forced ventilation (dilution ventilation). For safety reasons, this should be done by means of a heat exchanger.

11.6.3.7 *Equipment*

To minimize safety risks, abrasive blast-cleaning equipment and airless spraying equipment, apart from the blasting- and spray guns, should be installed outside the confined space.

11.6.3.8 *Spot-cleaning*

Touching-up of damaged areas involves as a rule spot-cleaning. For safety reasons, highly flammable solvents should not be used for this purpose within enclosed spaces.

11.6.4. WELDING AND FLAME-CUTTING OF PAINTED STEEL

In welding and flame-cutting painted steel, the paint is heated locally to such a degree that fumes, vapours and gases are released which may be harmful to health.

Special attention must be paid to the fumes, vapours and gases released from paints containing red lead or any other lead compound, zinc chromate or any other anti-corrosive chromium pigment. Similar considerations hold for paints based on isocyanates (polyurethane paints), coal-tar pitch or chlorinated binders (chlorinated rubber).

It is obvious that prefabrication primers (shop-primers, welding primers) should be formulated so that they do not present enhanced health risks in welding and flame-cutting operations (see parts 5.6.1.3 and 5.6.2.3).

Any paint other than a prefabrication primer is preferably removed over a width of about 15 cm (6 inches) before the welding or flame-cutting operation is carried out. If this is impossible, proper local exhaust ventilation has to be provided as well as proper respiratory protection (preferable a fresh air hood).

11.7. Some environmental aspects

Surface preparation and paint application may lead to environmental pollution. Some examples are given below:

In dry abrasive blast-cleaning in the open air, for instance of a ship's hull, large amounts of fine dust are dispersed into the air which may settle afterwards on the surface of the water or the soil. Up to 40 kg of friable abrasive is needed to clean one square meter of steel.

The amount of paint to be removed does not normally exceed one kg per square meter. Consequently, the chemical composition of the spent abrasive is mainly determined by the abrasive itself. As some commercially available abrasives have a significant content of arsenic and copper, their chemical composition should be checked (see Parts 3.2.4.2 and 9.4.5). The removal of e.g. a thick red lead paint coat by blast-cleaning, in the open air, is also a cause of environmental pollution.

Spent abrasives can be disposed of as a rule on landfills for household refuse, industrial waste, etc. This does not involve high costs. However, the disposal costs are usually much higher if the spent abrasive contains significant amounts of e.g. lead, arsenic, chromium, copper or tin, as this must be disposed of on a landfill for hazardous waste ('chemical waste').

Solvent degreasing as well as application of solvent borne paints leads to the emission of solvent vapours. These are believed to contribute to the photochemical production of ozone in the lower levels of the air.

Emission of solvent vapours is under fire in some countries for instance in Western Germany, Denmark, France and the Netherlands. Such pressure leads to an increasing use of waterborne and solvent-free paints.

Application of an anti-fouling by airless spray on a windy day leads to dispersion of large amounts of atomized paint containing tin and/or copper compounds. This may settle on surface water and soil, thereby causing pollution.

In cleaning a ship's hull by hydro-blasting part of the old anti-fouling system is removed. Local pollution of the harbour bottom may occur if the debris is not collected.

Paints to be applied by airless spray are usually supplied in cans of a net content of 20 litres. Due to their thixotropic characteristic a significant amount is left when an 'empty' drum is exchanged for a full one. In most cases this residue remains unused. Consequently, a drum may contain up to a kg of semi-solid or solid waste when disposed in a landfill. Leaching by rain water of such compounds as tin and copper may lead to pollution of ground water and soil.

Solvent-cleaning of e.g. spraying equipment results in liquids containing significant amounts of binders, pigments, extenders, etc. These contaminated solvents (waste solvent) can be recycled by vacuum distillation. The semi-solid residue, up to 25 per cent of the original amount, may contain significant amounts of chromium, lead, zinc, copper and tin. Moreover, it may also contain 5 to 10 per cent of solvent. The residue is considered to be hazardous waste ('chemical waste') and has to be disposed of accordingly.

Perfectly dried or cured paint coats may cause pollution as well. Leaching of tin and copper compounds from anti-fouling on ships is known to cause pollution of surface water in regions characterized by intensive shipping and a low rate of flow (Suez Canal, Red Sea and the eastern part of the Mediterranean). Small amounts of organotin compounds, which leach from organotin anti-fouling, have a detrimental effect upon oysters.

As already mentioned under Part 4.5.3.2d, it is to be expected that regulations will be issued which restrict the use of organotin anti-fouling. In some countries regulations regarding their use on ships up to a certain length (for instance up to 25 metres) and on fish farming equipment are already in force.

11.8. Some relevant dutch compulsory rules and regulations

Over a long period of time an extensive range of *compulsory rules and regulations* have been issued in the Netherlands and other industrialized countries.

Compulsory regulations are part of the legislation. They are issued by the Dutch Administration or by authorized governmental agencies, e.g. the Labour Inspectorate (Arbeidsinspectie). Rules are also issued by employers' organizations such as the VNSI* (the Dutch Association of Ship Builders) and the VVVF (the Dutch Association of Paint Producers).

An increasing number of Dutch compulsory regulations are based on Directives which have been issued by the European Community (EC). For example the compulsory regulation regarding the labelling of dangerous substances (paints and other coating materials, chemical substances for pretreating substrates, adhesives, etc.).

The *EC labelling system* consists of:

- *Symbols* indicating the type of danger involved when using the product; the different symbols represent the following hazards: toxic, corrosive, highly flammable, explosive, harmful, irritant, oxidizing.
- *R-phrases* which give the specific dangers when using the product.
- *S-phrases* which give the measures to be taken in order to prevent risks when using the product.

It is outside the scope of this manual to provide a complete review of all the relevant Dutch compulsory regulations and rules in the field of safety, industrial health and environmental pollution. However, a number are set out below.

11.8.1. SAFETY AND INDUSTRIAL HEALTH

The all important Dutch act in the field of safety and industrial health is the *ARBO-Wet* (Act regarding safety, health and welfare in paid work). The ARBO-wet is a framework or skeleton act. Only the objectives, procedures, responsibilities of the Administration, employers and employees and the penalties are laid down. More detailed requirements are set out in *Implementary Orders* (Uitvoeringsbesluiten), which are legally part of the ARBO-wet. Examples are:

- Implementary Order regarding the safety in factories and shops (Veiligheidsbesluit voor fabrieken of werkplaatsen).
- Implementary Order regarding electric safety (Electrotechnisch Veiligheidsbesluit).
- Implementary Order regarding blasting with abrasives containing more than one percent of crystalline silica (Zandstraalbesluit)
- Implementary Order regarding repair and maintenance of tankers (Veiligheidsbesluit Tankschepen).

One of the duties of the *Labour Inspectorate* (Arbeidsinspectie) is to control the working conditions in factories, shops and other enterprises. But as a few technical details have

* Vereniging Nederlandse Scheepsbouw Industrie

not been laid down in *Compulsory Orders* the Dutch Labour Inspectorate has issued an extensive range of Publications (P-bladen). Examples are:

- P 22 Eye protection (Oogbeschuttingsmiddelen).
- P 69 Safe working conditions in enclosed spaces (Veilig werken in besloten ruimten).
- P 77 Skin protection (Het tegengaan van beroepshuidaandoeningen).
- P 112 Respiratory protection (Ademhalingbescherming).
- P 139 Paint storage and paint application (Verfverwerking).
- P 145 The Dutch MAC's (Nationale MAC-lijst).
- P 152 Labelling of dangerous substances (Etikettering en aanduiding van gevaarlijke stoffen en preparaten).
- P 166 Noise protection (Gehoorbescherming).

It should be noted that anti-foulings are not covered by the ARBO-wet but by the *Dutch Pesticides Act* (Bestrijdingsmiddelenwet). According to this act any product subject to this law must be officially approved before it is made commercially available. Such approval is granted only if the product is not highly toxic to the user, is effective, and does not cause unnecessary pollution of the environment.

Anti-foulings containing mercury compounds, organolead compounds or persistent organic biocides such as DDT are not approved. Consequently, they are not commercially available in the Netherlands.

11.8.2. PREVENTION OF ENVIRONMENTAL POLLUTION

The main Dutch acts are:

- Act regarding the *prevention of surface water pollution* (Wet verontreiniging oppervlaktewateren). According to this act, painting activities on the outside of movable objects such as ships are not permitted on open water. Exemption can only be obtained if the objects are pretreated and coated in such way that all arisings (blasting dust, spray mist etc.) are collected before they reach the water surface. When special permission is given, requirements are laid down concerning the execution of the painting activities.
- Act regarding the *prevention of air pollution* (Wet op de luchtverontreiniging).
- Act regarding the *prevention of soil pollution* (Wet bodembescherming).
- *Chemical (hazardous) waste act* (Wet chemische afvalstoffen).

To this should be added that the Dutch *pesticides act* (Bestrijdingsmiddelenwet) is used to limit environmental pollution due to the application and leaching of anti-foulings.

Each of the above mentioned acts is a framework (skeleton) act and additionally there are quite a few Implementory Orders. An example is the one regarding substances and processes (Stoffen- en processenbesluit) in which the Dutch definition of chemical waste (hazardous waste) is laid down.

The environmental pollution prevention acts have resulted in concerted activities and actions within the Dutch shipbuilding industry (VNSI) and the Dutch Paint Industry

(VVVF). The members of VVVF have agreed upon the abolition of mercury and its compounds. Moreover, agreement about reduction in the consumption of lead pigments, lead driers and organic solvents has also been reached.

The members of VNSI have agreed about a highly improved standard dry-dock/slipway discipline which aims to prevent environmental pollution during surface preparation and paint application. This discipline is in accordance with the act regarding the prevention of surface water pollution.

11.9. International compulsory regulations and rules

In Part 11.8 it has already been mentioned that the European Community issues EC-Directives (EG Directieven).

These are supernational laws. Any EC Directive has to be implemented within a specified period in the national legislation of each of the member states. Consequently, almost identical Acts and Implementary Orders are issued by the twelve EC countries. This is obviously a definite improvement compared with the situation in the past.

Ideally, a Compulsory Regulation is issued by the United Nations or one of its 'divisions'. Examples are the *IMO Code* (formerly IMCO Code) for the *International Convention for the Safety of Life at Sea*, and the *Merchant Shipping* (passenger ships construction) *Rules*.

Also quite effective are the rules issued by the leading classification societies (Lloyd's, Norsk Veritas, etc.).

APPENDIX 11.A - BOILING POINTS, FLASH POINTS, EXPLOSION LIMITS, IGNITION TEMPERATURES AND TLV's (MAC's) OF VARIOUS SUBSTANCES¹⁾

Substances	Applied as, or occurring in:	Boiling point (range), °C	Flash Point, °C	Explosive limits, vol. %		Self-ignition temperature, °C	TLV (MAC)-TWA	
				lower (LEL)	upper (UEL)		ppm	mg/m ³
Aliphatic hydrocarbons n-hexane n-heptane n-octane white spirit (stoddard solvent)	solvents and thinners	69	-23	1.2	7.5	225	50	180
		98	-4	1.1	6.7	223	400	1600
		126	13	1.0	4.7	220	300	1450
		150-200	40	1	6	230	100	525
Aromatic hydrocarbons benzene ²⁾ toluene xylene styrene monomer	solvents and thinners reactive solvent	80 111 144 146	-11 4 30 31	1.4 1.2 1.0 1.1	8.0 7 6 6.1	562 480 465 490	10 100 100 50	30 375 435 215
Alcohols methanol (methyl alcohol) ethanol (ethyl alcohol) propanol (propyl alcohol) iso-propyl alcohol (IPA) butanol (butyl alcohol) iso-butanol	paint strippers solvents and thinners	65 78 97 83 118 108	12 13 15 12 35 28	6.0 3.3 2.1 2.5 1.4 1.2	36.5 19 13.5 12 11.2 10.9	470 423 440 456 365 427	200 1000 200 400 50 50	260 1900 500 980 150 150
Esters ethyl acetate butyl acetate iso-butyl acetate	solvents and thinners	77 127 118	-4 22 18	2.2 1.4 2.2	11 7.5 11	427 425 423	400 150 150	1400 710 700
Ketones acetone methyl ethyl ketone (MEK) methyl iso-butyl ketone (MIBK)	solvents and thinners	56 80 118	-18 -5 17	2.6 1.8 1.4	12.8 11.5 7.5	465 516 459	750 200 50	1780 590 205
Glycol derivatives ethyl glycol (glycol mono-ethyl ether, 'Cellosolve', 'Oxitol') butyl glycol ('butyl Cellosolve', 'butyl-Oxitol') ethyl glycolacetate ('Cellosolve acetate', 'Oxitol acetate')	solvents and thinners	135	40	1.8	14	235	5	19
		170	61	1.1	10.6	240	25	120
		156	51	1.7	--	379	5	27
Chlorinated hydrocarbons trichloro-ethylene perchloro-ethylene carbon tetrachloride 1,1,1, trichloro-ethane methylene chloride	degreasing agents paint strippers	87 121 121 74 40	Non-flammable; thermal decomposition products are very poisonous				50 50 5 350 100	270 335 30 1900 350
Amines ethylene diamine (EDA) diethylene triamine (DTA)	epoxy hardeners	117 207	43 102	-- --	-- --	385 399	10 1	25 4
Isocyanates diphenylmethane diisocyanate (MDI) toluene-2,4 diisocyanate (TDI)	hardeners for polyurethane coatings	199 --	-- --	-- --	-- --	-- --	0.02 0.005	0.2 0.04
Organometallic compounds tributyltinoxide (TBTO) triphenyltinfluoride (TPTF)	anti-fouling agents	-- --	-- --	-- --	-- --	-- --	-- --	0.1 ³⁾ 0.1 ³⁾
Gases carbon monoxide carbon dioxide nitrogen dioxide	exhaust- and welding fumes	-191 -- 21	-- -- --	12.5 -- --	74.2 -- --	610 -- --	50 5000 3	55 9000 6
Fumes (oxides) of: chromium copper lead iron zinc	welding fumes	-- -- -- -- --	-- -- -- -- --	-- -- -- -- --	-- -- -- -- --	-- -- -- -- --	-- -- -- -- --	0.5 0.2 0.1 5 5 ⁴⁾

1) Sources: - Dangerous Properties of Industrial Materials, N. Irving Sox (6th edition), Van Nostrand Reinhold Company
- Threshold Limit Values and Biological Exposure Indices for 1987-1988 (American Conference of Governmental Hygienists)

2) Suspected carcinogenic substance

3) as Sn

4) as zinc oxide

APPENDIX 11.B - DEFINITIONS THRESHOLD LIMIT VALUES (TLVs)

According to the list of the American Conference of Governmental Industrial Hygienists, the following three categories of Threshold Limit Values are specified.

- a. *Threshold Limit Value - Time Weighted Average (TLV - TWA)* - the time-weighted average concentration for a normal 8 hour workday and a 40 hour workweek, to which nearly all workers may be repeatedly exposed, day after day, without adverse effect.
- b. *Threshold Limit Value - Short Term Exposure Limit (TLV - STEL)* - the concentration to which workers can be exposed continuously for a short period without suffering from
 - 1) irritation,
 - 2) chronic or irreversible tissue damage,
 - 3) narcosis of sufficient degree to increase the likelihood of accidental injury, impair self-rescue or materially reduce work efficiency, and provided that the daily TLV-TWA is not exceeded.

It is not a separate independent exposure limit, rather it supplements the time-weighted average (TWA) limit where there are recognized acute effects from a substance whose toxic effects are primarily of a chronic nature.

STELs are recommended only where toxic effects have been reported from high short-term exposures in either humans or animals.

A STEL is defined as a 15-minute time-weighted average exposure which should not be exceeded at any time during a workday even if the eight-hour time-weighted average is within the TLV.

Exposures at the STEL should not be longer than 15 minutes and should not be repeated more than four times a day. There should be at least 60 minutes between successive exposures at the STEL. An averaging period other than 15 minute may be recommended when this is warranted by observed biological effects.

- c. *Threshold Limit Value-Ceiling (TLV-C)* - the concentration that should not be exceeded during any part of the working exposure.

In conventional industrial hygiene practice if instantaneous monitoring is not feasible, then the TLV-C can be assessed by sampling over a 15-minute period except for those substances which may cause immediate irritation with exceedingly short exposures. For some substances, e.g., irritant gases, only one category, the TLV-Ceiling, may be relevant, depending on their physiological action.

It is important to observe that if any one of these three TLVs is exceeded, a potential hazard from that substance is presumed to exist.

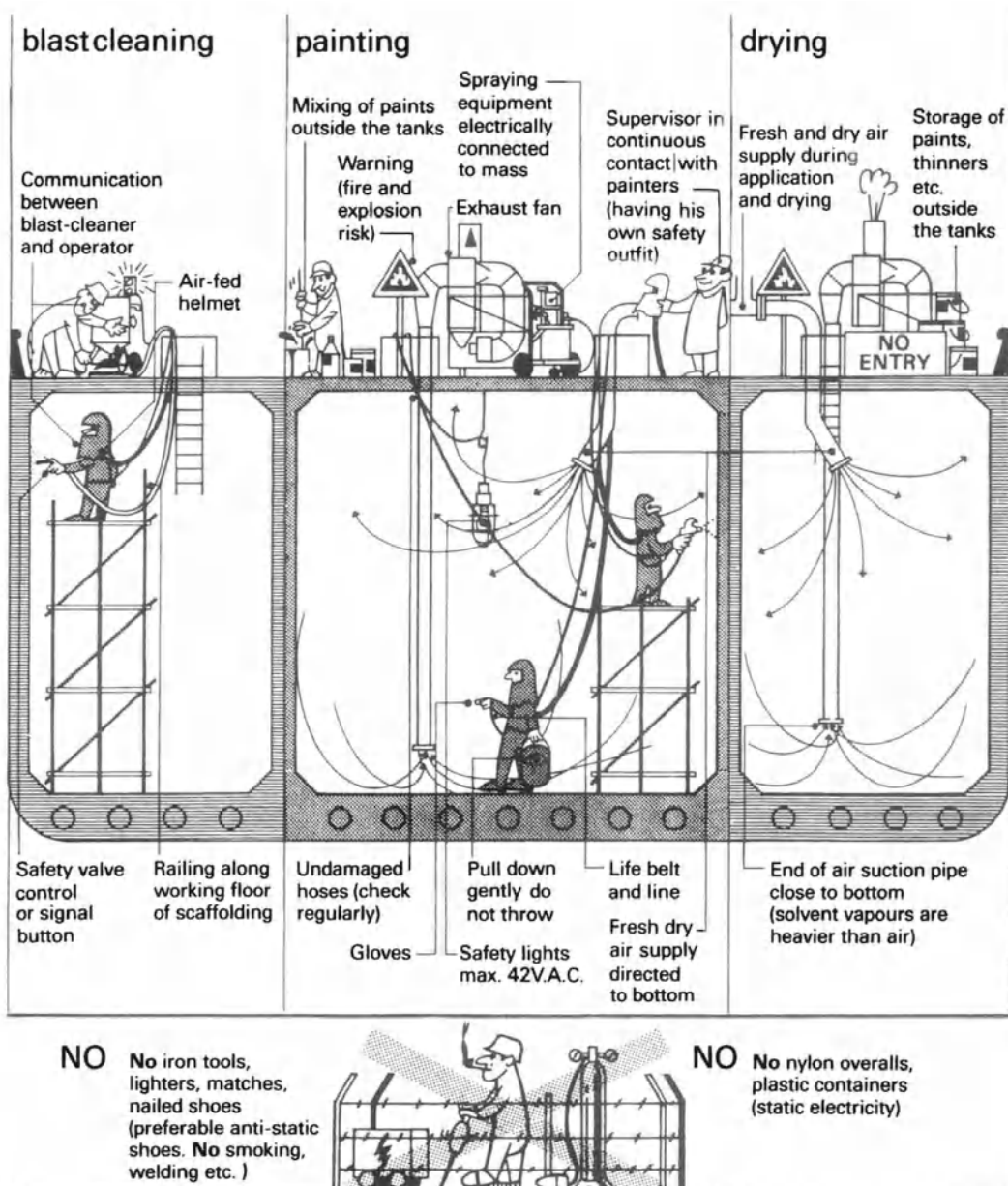
The Committee holds the opinion that limits based on physical irritation should be considered no less binding than those based on physical impairment. There is increasing

evidence that physical irritation may initiate, promote or accelerate physical impairment through interaction with other chemical or biological agents.

APPENDIX 11.C. - SAFE WORKING IN CONFINED SPACES*

Safe working is always of the greatest importance, but particularly during application of tank coatings.

The illustration on this sheet indicate the quite simple principal measures that will ensure safe working.



* Courtesy Sigma Coating BV

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