FOREWORD

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DET NORSKE VERITAS AS (DNV AS), a fully owned subsidiary society of the foundation, undertakes classification and certification and ensures the quality of ships, mobile offshore units, fixed offshore structures, facilities and systems, and carries out research in connection with these functions. The society operates a world-wide network of survey stations and is authorised by more than 120 national administrations to carry out surveys and, in most cases, issue certificates on their behalf.

Recommended Practices

Recommended Practices (RP) are issued as a supplement to DNV Rules for Classification or DNV Offshore Standards and other recognised codes used by the industry. RPs form a part of the technical basis for DNV classification and verification services as well as offering DNV’s interpretation of good engineering practice for general use by the industry.

An updated list of Recommended Practices is available on request. The list is also given in the latest edition of the Introduction-booklets to the “Rules for Classification of Ships”, the “Rules for Classification of Mobile Offshore Units” and the “Rules for Classification of High Speed, Light Craft and Naval Surface Craft”.

In “Rules for Classification of Fixed Offshore Installations”, only those Recommended Practices that are relevant for this type of structure have been listed.

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1. Introduction

1.1 General

The aim of these guidelines is to indicate different, recognised methods for corrosion protection of ships, with emphasis on tanks and holds. General specifications of coating systems I, II and III of different target useful life or durability 5, 10 and 15 years, respectively, are indicated. The useful life is dependent mainly on steel surface preparation and cleanliness.

Use of cathodic protection is recommended in combination with coating on surfaces submerged in seawater, e.g. sacrificial anodes in ballast tanks.

The guidelines are primarily not intended for classification use but for assisting in the selection of effective corrosion protection systems by yards and owners, especially for newbuilding. However, the additional voluntary class notations COAT-I and COAT-2, refer to these guidelines. A summary of the classification requirements related to corrosion protection is included.

Definitions and terms, properties and standards for coatings, a check list for coating inspectors, materials and corrosion resistance, surface preparation of steel, and coating condition evaluation on existing ships are briefly reviewed.

1.2 Limitations

The guidelines cover protection of common carbon steel hull structures against seawater and the marine environment.

Ballast tanks, oil cargo tanks and holds of bulk carriers or OBOs are known to be most susceptible to corrosion and are thus of prime concern. Other materials and subjects are briefly reviewed for the sake of completeness.

The guidelines do not address protection against corrosive cargoes or chemicals.

The guidelines are aiming at being easy to use. No subject is treated in great depth or detail.

1.3 Definitions and description of terms

Alkyd: Alkyds are synthetic resins of polyester type used as binders in paints or coatings. The name "alkyd" is derived from the parent chemicals alcohol + acid → ester. Alkyd paints cure by air-drying and oxidation.

Anode: The corroding part of an electrochemical corrosion cell (sacrificial anode or impressed current anode).

Anti-fouling paint: Paint for use on under water areas on hulls to prevent growth of living organisms, usually containing toxic agents (e.g. tin or other biocides).

Binder: The component in paint or coating binding its constituents together and fixed to the surface. Common binders are epoxy, chlorinated rubber, vinyl, and alkyd.

Cathode: The non-corroding or protected part of an electrochemical cell.

Cathodic protection: Protecting a metal surface from corrosion by making it a cathode in an electrochemical corrosion cell.

Cathodic protection of a steel surface is obtained by installing sacrificial anodes or impressed current anodes in metallic, electrical contact with the steel within the same electrolyte (sea water) system. Protective current passes from the anode through the electrolyte to the steel surface.

The term "anodic protection" is not to be used for common anode systems on ships, either based on sacrificial anodes or impressed current. These systems belong to the concept "cathodic protection systems". "Anodic protection" is another, special technique used in chemical industry.

Chlorinated rubber: Binder in paints or coatings based on dissolved or emulsified (un-vulcanised) rubber polymers saturated with chlorine. Chlorinated rubber paints are of one-component, air drying type.

Coating: There is no generally valid definition of coating.

Coating is often synonymous with painting, i.e. a protective film of thickness usually about 0.2 - 0.5 mm. Coatings or paints are usually sprayed on the metal surface.

Conductivity: The inverse of the resistivity (ohm cm). In these guidelines: Conductivity, i.e. specific electrical conductance, of an electrolyte, usually seawater.

Corrosion: Chemical degradation of solid material by influence from its environment.

Corrosion rate: The rate, usually in mm/year, at which the corrosion process proceeds. The corrosion rate is always to be calculated from metal loss on one surface, even when occurring on both sides of a steel plate, etc. (Corrosion rate is not to be confused with "steel thickness reduction rate").

Dew point: The temperature at which air is saturated with moisture.

Electrochemical cell: See electrolytic corrosion.

Electrolytic corrosion: Corrosion occurring in an electrolyte, i.e. an electrically conductive liquid such as seawater. Anodes and cathodes formed on the steel surface, together with the electrolyte, constitute electrochemical cells.

Epoxy: Common binder type in paints or coatings for marine use. Epoxies are normally of two component type, epoxy resin (A component) chemically cured with a hardener (B component, e.g. amine), resulting in a relatively hard film.
**Epoxy coal tar (coal tar epoxy):** Epoxy mixed with coal tar, constituting a part of the binder in paints or coatings for marine use. Chemical curing is accomplished by means of a hardener, as for pure epoxy. The tar component acts as pigment and influences the flexibility and water resistance of the cured coating film.

**Film thickness:** The thickness of a coating layer or a multi-layer coating system. Dry film thickness DFT is measured for cured coatings, in shipbuilding some times specified as average thickness. Minimum and maximum thickness can also be specified. Wet film thickness is usually controlled only during application by the coating applicator.

**General corrosion:** Relatively evenly distributed corrosion attacks on a steel surface.

**Guidelines (DNV definition):** Guidelines are publications which give information and advice on technical and formal matters related to the design, building, operating, maintenance and repair of vessels and other objects as well as the services rendered by the Society in this connection. Aspects concerning classification may be included in the publication.

**Hard coating:** Chemically cured coating normally used for new construction, or non-convertible air drying coating such as used for maintenance purposes, organic or inorganic (according to IMO (12)). The hard coating concept covers typical marine coatings such as those based on epoxy, coal tar epoxy, polyurethane, chlorinated rubber, vinyl, zinc epoxy, zinc silicate.

**Inhibitor:** Chemical having an inhibiting effect on corrosion, usually added to a closed liquid or gaseous system.

**Lining:** Linings are commonly of higher thickness than coatings, most often above 1 mm, and are usually applied internally in tanks, pipes or vessels. Linings may be applied in sheets or built up with reinforcements.

**Localised corrosion:** A concept comprising various kinds of more or less concentrated or spot-wise corrosion attacks:
Typically pitting, corrosion in way of welds, crevice corrosion, stress corrosion cracking, etc. Localised corrosion can proceed rapidly and can be dangerous, e.g. in case of loss of weld metal or penetration of a pressure vessel by pitting.

**Mechanical cleaning:** Power tool cleaning, by means of grinding disc, wire brush, or similar.

**Marine environment:** In this context used in its widest sense, comprising basically sea water and marine atmosphere, including contaminants from cargoes, industry, harbours, wave and weather actions, and operational factors specific for each ship.

**Pigments:** Powders added to the coating in liquid condition to obtain colour. Pigments also influence the coating's viscosity, application and protective properties.

**Primer coating:** First layer of a coating system applied in the shipyard (also called touch up primer, to differentiate from shop-primer).

**Recommended Practice (DNV definition):** Recommended Practices (RP) are issued as a supplement to DNV Rules for Classification or DNV Offshore Standards and other recognised codes used by the industry. RPs form a part of the technical basis for DNV classification and verification services as well as offering DNV's interpretation of good engineering practice for general use by the industry.

**Resin:** Material used as a binder constituent forming a non-crystalline film when dried or cured.

** Resistivity:** Specific electrical resistance (ohm cm).

**Sa 1:** Light blast cleaning. Loose mill scale, rust and foreign matter shall be removed. The appearance shall correspond to the standard photos designated Sa 1. (This originally Swedish standard SIS 055900-1967 is adopted as ISO standard 8501-1. It is a pictorial surface preparation standard for painting steel surfaces. The pictures showing the surface appearance are not reproduced in this guideline. Grades Sa 1 - Sa 3 describe blast-cleaned surfaces.)

**Sa 2:** Thorough blast cleaning. Almost all mill scale, rust and foreign matter shall be removed. Finally, the surface is cleaned with a vacuum cleaner, clean, dry compressed air or a clean brush. It shall then be greyish in colour and correspond in appearance to standard photos designated Sa 2. (See parenthesis, Sa 1.)

**Sa 2,5 (Sa 2 1/2):** Very thorough blast cleaning. Mill scale, rust and foreign matter shall be removed to the extent that the only traces remaining are slight stains in the form of spots or stripes. Finally, the surface is cleaned with a vacuum cleaner, clean, dry compressed air or a clean brush. It shall then correspond to standard photos designated Sa 2,5. (See parenthesis, Sa 1. It should be noted that Sa 2,5 is closer to Sa 3 than to Sa 2. Sa 2,5 corresponds to NACE grade No. 2 (near white) and SSPC grade SP 10 (near white).)

**Sa 3:** Blast cleaning to pure metal. Mill scale, rust and foreign matter shall be removed completely. Finally, the surface is cleaned with a vacuum cleaner, clean, dry compressed air or a clean brush. It shall then have a uniform metallic colour and correspond in appearance to standard photos designated Sa 3. (See parenthesis, Sa 1. Sa 3 corresponds to NACE grade No. 1 (white metal) and SSPC grade SP 5 (white).)

**Shop-primer:** Thin (approximately 15 - 25 microns) primer coating applied for temporary protection of steel plates in automatic plants.

**Soft coat:** Coating that remains soft so that it wears off when touched; often based on oils or sheep wool grease.

**Semi hard coating:** Coating which dries in such a way that it stays soft and flexible although hard enough to touch and walk upon.
St 2: Thorough scraping and wire brushing - machine brushing - grinding - etc. The treatment shall remove loose mill scale, rust and foreign matter. Finally, the surface is cleaned with a vacuum cleaner, clean, dry compressed air or a clean brush. It should have a faint metallic sheen. The appearance shall correspond to standard photos designated St 2. (This originally Swedish standard SIS 055900-1967 is adopted as ISO standard 8501-1. It is a pictorial surface preparation standard for painting steel surfaces. The pictures showing the surface appearance are not reproduced in this guideline. Grades St 2 - St 3 describe mechanically cleaned surfaces.)

St 3: Very thorough scraping and wire brushing - machine brushing - grinding - etc. Surface preparation as for St 2, but much more thoroughly. After removal of dust, the surface shall have a pronounced metallic sheen and correspond to standard photos designated St 3. (See parenthesis, St 2.)

Steel: In these guidelines, if not a more precise definition is given, "steel" means carbon steel including hull structural steel.

Stripe coating: Application, normally by brush, of one or more coating layer on edges, welds or similar to build up adequate total dry film coating thickness at the actual locations.

Vinyl: Binder in paints or coatings based on dissolved or emulsified vinyl chloride or vinyl acetate polymers (Vinyl chloride: CH₂ = CHCl). Vinyl paints are of one-component, air drying type.

Zinc rich paint or coating or primer: Products containing usually > 85 % of metallic zinc powder in the dry film. The high amount of zinc provides a sacrificial anode effect. The binder usually is on epoxy or (inorganic) silicate basis.

2. Newbuildings - Corrosion Protection of Ships

This chapter aims at indicating coating systems of varying quality and target useful life or durability levels.

Systems of three target useful life or durability levels are indicated for ballast tanks, oil cargo tanks and holds in bulk carriers or OBOs:

System I: Target useful life 5 years (± 3 years)

System II: Target useful life 10 years (±3 years)

System III: Target useful life 15 years (± 3 years).

The useful life of a coating is considered to be until 3 % breakthrough of rust on the coated surface areas: Welds' and edges' areas, respectively plain and large surface areas, considered separately. (ISO Standard 4628/3 rust scale = Ri 3-4, or Rust Grade 5, ASTM D 610, Appendix 5). Reasons: See 2.4 and 3.1.1.

The above coating quality or durability levels should be read as target useful lives, estimated based on literature data and experience, with great uncertainties and variations. The useful life will be prolonged if maintenance coating according to principles outlined in these guidelines is carried out.

Some users may find the indicated durability possibly too optimistic, others the opposite. As further elaborated below, the useful life of corrosion protection systems is dependent on many factors and circumstances, including those related to the ship type, trade and operation.

2.1 Planning

To obtain long life protection, the application or installation of corrosion protection systems (coatings and anodes) should be a well planned activity, integrated in the shipyard's construction plans. Care should be taken to avoid conflicts with other yard operations, notably piping installations and welding.

Corrosion protection works include

- staging
- steel surface preparation, e.g. grinding of edges and welds, blast cleaning, mechanical cleaning
- partitioning of suitable areas for blast cleaning and coating, e.g. block building
- coating application
- installation and masking off of anodes
- shielding off already painted areas from blasting operations in other areas
- cleaning operations
- control of humidity and temperature of the air in relation to the steel temperatures
- control of coating curing conditions
- avoidance of damage to finished coating and installed anodes.

2.2 Steel surface preparation

The preparation of steel surfaces is of greatest importance for the durability of a coating. It may be more important than the selection of coating type. Use of a high quality and technically sophisticated coating is useless if the steel surface preparation is neglected. The potentially best coatings may be the most dependent on adequate surface preparation. Early coating failures are often caused by inadequate surface preparation.

2.2.1 Shop-primed steel

Steel ships are normally built of shop-primed plates. The plates are automatically cleaned by shot blasting or similar and the shop-primer applied immediately afterwards in the same plant. The cleanliness standard for application of shop-primer should be near white metal or equivalent, i.e. Sa 2.5 according to ISO 8501-1.
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The best shop-primers from a corrosion protection point of view are those containing zinc Zn, preferably inorganic silicate based. Notably on surfaces not continually submerged, e.g. ballast tank top and internal splash zone areas, zinc containing shop-primers should be used.

Sweep blasting of the whole or parts of shop-primed surfaces may be relevant, dependent on their condition, type of shop-primer and coating system to be applied.

Ultra high pressure water jetting (≥: 1700 bar) with equipment free from back thrust and combined with chloride control (maximum conductivity corresponding to = 20-50 mg/m² NaCl, depending on various conditions) may be a possible, alternative method of cleaning shop-primed surfaces, for specially designed coatings, subject to coating manufacturer's recommendation.

Contamination as mentioned below on shop-primed or blast cleaned surfaces may result in early blistering and considerably reduced coating lifetime. There are indications that the negative effect of surface contamination with small amounts of salts may be larger than traces of grease.

When relevant, cleaning should be carried out before application of the first coating layer (primer coat applied in the yard) to shop-primed surfaces.

Any salt contamination, oil, grease, dust, weld smoke, metallic or other particles should be removed, e.g. with solvent cleaning, or washing with fresh water containing detergent followed by rinsing with fresh water and drying. Such degreasing, washing and drying of shop-primed surfaces shall, if required, be carried out before final blast cleaning operations. The blasting abrasive should not contain contaminants.

2.2.2 Treatment of sharp edges, welds and burns:

All sharp edges on cut or burnt steel plates should be rounded or broken before blast cleaning operations. A minimum of rounded edges is obtainable by means of a single pass of a grinding tool over the steel edge, braking up one 90 degrees or sharper edge into two, each approximately 90 + 45 = 135 degrees, as illustrated in figure 2.1. After finished blast cleaning, the edge may become sufficiently rounded for application of coating.

Rounding of sharp edges can also be specified more accurately, e.g. to a minimum radius, e.g. r = 2 mm.

All edges, including cut-outs, rat holes, etc. should be included in the above treatment.

2.2.3 Blast cleaning and inspection

In the normal shipbuilding situation, i.e. for internals and externals of the hull (except cargo tanks for chemicals, etc.) the coating system is built up on intact, clean shop-primed surfaces.

Zinc rich shop-primer should be used for System II and III and is generally recommended. Compatibility with Zn rich primer and coating system must be ensured by the coating manufacturer.
After finishing operations 2.2.1 to 2.2.2, blast cleaning should be carried out on all welds, burns and where the shop-primer otherwise is damaged.

When blast cleaning is finished, broken edges should appear sufficiently rounded for coating.

Inspection for acceptance of rounded edges, weld surfaces and other possible surface irregularities should be carried out at this stage. After any required re-grinding or breaking of edges the inspector will accept the surfaces for final blast cleaning and coating.

Final blast cleaning should be carried out only when the air and steel temperatures and air humidity is under control, i.e.
- the air humidity shall not be above 85%  
- the steel temperature shall be 3°C or more above the dew point.
- the above, dry conditions shall be maintained, so that no trace of moisture condensation on the steel occurs before the primer yard coat is applied.

Dry conditions are obtainable in tanks and closed compartments by means of heating and ventilation. On sections or blocks in ship newbuilding, dry conditions are obtainable in heated and ventilated buildings or tents.

The steel temperature may vary considerably in the same tank, e.g. condensation of moisture more easily occurs on cool steel surfaces deep down in the tanks than in upper, warmer areas.

The cleanliness of blast cleaned surfaces should be Sa 2,5 according to ISO 8501-1, or better if required by the coating manufacturer. Close to Sa 3 is recommended to obtain 15 ± 3 years useful life, System III. Other, equivalent cleanliness standards are stated in Appendix 2. Blasting abrasives and dust shall be completely removed after finished blasting operations, e.g. by means of vacuum cleaning, compressed air and brushes.

The surface roughness profile, see e.g. ISO 8503, should be according to the coating manufacturer's recommendations. (The surface roughness profile after blast cleaning is less important than the surface cleanliness.)

Inspection and acceptance of the surfaces after primer coating should be carried out.

Acceptance criteria, authority, scope of work and reporting lines for the coating inspector should be clearly defined. Inspection should be carried out according to specifications mutually agreed between builder and owner and coating manufacturer.

Indications of a coating inspector's duties are given in 7.

Blast cleaning as described above may not be the normal shipyard practice.

The minimum surface treatment for System I is shop-primer of unspecified type and St 3 on welds and burns. System I, with target useful life 5 years, is not recommended for ballast tanks.

The minimum surface treatment for System II is Zn containing, silicate based shop-primer, broken edges, Sa 2,5 on welds and burns, mechanical cleaning to St 3 on block joints and damages in coating only, and dry conditions.

The minimum surface treatment for System III is rounded edges, Zn containing, silicate based shop-primer, blast cleaning to Sa 2,5 or better on all surfaces (including plates, welds, burns and edges, except block joints and a minimum of spots of damaged coated surface), clean conditions (surfaces not contaminated with salts, dust, hand marks, grease, particles, etc., see 2.2.1) and dry conditions (see 2.3.4) during blast cleaning and coating application. The chloride content on surfaces to be coated shall be <50 mg/m².

Blast cleaning to Sa 2 is considered a better surface treatment for coating application than mechanical cleaning to St 3. St 3 may be equivalent to blast cleaning to somewhere between Sa 1 and Sa 2 regarding coating performance. This is due to that by brushing, dust and loose rust particles are worked into and fill up surface pores and irregularities. These become future spots of osmosis activity and early coating blisters.

Ultra high pressure water jetting (>≈1700 bar) with equipment free from back thrust and combined with chloride control (e.g. maximum conductivity corresponding to ≈20, 30 or 50 mg/m² NaCl) may be a possible, alternative method of cleaning, for specially designed coatings, subject to coating manufacturer's recommendation. Water jetting is relevant primarily for maintenance coating on ships in operation. When more experience is gained, water jetting, hydroblasting, wet sand blasting, etc. also on newbuildings may possibly be realistic, subjected to specific conditions.

2.2.4 Mechanically cleaned steel

If blast cleaning of welds and other areas of non-intact shop-primer is not obtainable, efforts should be made to make the surfaces as clean and dry as possible before application of touch up primer. Mechanical cleaning by means of e.g. wire brushes is commonly used.

Rotating wire brushes may polish welds and other steel surfaces, resulting in reduced coating adhesion compared with that obtained on blast cleaned surfaces.

The minimum cleanliness standard for any coating application according to System I and System II should be St 3 (ISO 8501-1) or equivalent standard (for comparison with blast cleaning, see 2.2.3).

Mechanically cleaned steel (wire brushing and similar) is really not adequate for System III but may have to be accepted in shipbuilding on block joints and on a minimum of spots of damaged coating, for practical reasons.
2.3 Coatings - general

2.3.1 Coating selection
Coating types adequate for the intended service should be selected in co-operation with the chosen coating manufacturer, which should have products of documented good performance records. The coating manufacturer or his representative should be capable of rendering adequate advisory and inspection services, if such are not covered by other parties.

Due concern should be given to the obtainable steel surface preparation in the shipyard, see 2.2.2. to 2.2.4. If blast cleaning, dry conditions, clean conditions, etc. are not specified, coating systems made to be tolerant of the expected surface condition should be selected.

Light coloured coatings should be used where relevant to facilitate inspections, e.g. in ballast tanks.

Coatings for ballast tanks should be chosen with due regard to that the water quality may be bad, e.g. acidic or otherwise contaminated, notably in harbours.

The below examples of simplified coating specifications are based on general experience and published literature, see e.g. reference (8).

2.3.2 Coating specification
A coating specification should be mutually agreed between builder and owner and coating manufacturer. Inspectors' duties and reporting line should be defined. The specification should describe:

- which coating systems (types of coating, thicknesses and number of coats) to be applied where
- coating manufacturers accepted for delivery
- yard's coating facilities
- equipment for control of air humidity, temperatures, ventilation
- coating applicator's duties and application equipment
- steel surface treatment
- coating application and curing
- repair procedures for damages
- test methods, equipment and acceptance criteria.

2.3.3 Hot surfaces - High strength steels
Coatings for application underneath sun heated decks or on warm bulkheads adjacent to e.g. the engine room should be able to withstand constant or repeated heating without becoming brittle. Documentation of the coating's long term high temperature stability should be requested from the coating manufacturer. Brittleness (ageing) may result from light components in the coating evaporating with time.

Coating to be applied on high strength steels should have adequate relative elongation to cope with increased strains and movements in ships built from such steel. As above, the long term ability of the coating to stay flexible is important. Documentation of relative elongation should be requested from coating manufacturers.

A relevant minimum figure for the relative elongation of a coating film may be about 4 per cent. For test method, see Appendix. Testing should be carried out on adequately aged coating, not only on new, fresh coating.

2.3.4 Coating application and curing
Coatings, including primers and intermediate coating layers, should be applied on dry, clean surfaces (i.e. blast cleaned, shop-primed, mechanically cleaned, washed and dried if necessary) and according to the coating manufacturer's recommendations. The degree of cleanliness and dryness will be varying according to the alternative quality levels System I, II or III. Stripe coating is recommended for edges and welds.

Clean conditions: See 2.2.1 to 2.2.2.

Dry conditions means:

- the air humidity shall not be above 85 %.
- the steel temperature shall be 3 °C or more above the dew point.
- the above dry conditions shall be maintained so that no condensation of moisture occurs on any surface when a new coating layer is applied. They are also valid for shop-primer application.

For System III, clean and dry conditions are required.

For System II, dry conditions are required. Clean conditions are necessary in the sense that intact shop-primer, welds and edges should be cleaned if contaminated with salts, weld smoke, etc. impairing coating adhesion.

For System I, dry, clean conditions are not required (but recommended).

In general, for application of coatings the following is valid:

- coatings should be applied by spraying, except "stripe coats" applied to build up thickness on edges not properly rounded and in areas difficult to access
- the dry film thickness should be as recommended by the coating system manufacturer
- each coating layer should be adequately cured before application of the next coat. The time required for curing will generally be longer at lower temperatures. Coating must not be applied below the manufacturer's recommended minimum temperature.
- intermediate coats should not be contaminated with dirt, grease, dust or salts
- for curing of zinc silicate based primers, the air humidity must be brought above a certain minimum percentage (contrary to other coatings - though not until the application process is finished).

2.4 Coating systems for ballast tanks (Tables 2.1 - 2.3)
In Tables 2.1 - 2.3 are indicated three alternative coating specifications for ballast tanks, System I, II and III.
The indicated surface preparation in the tables is the minimum surface quality needed to obtain the stated target useful coating life. It is a shorthand summary of the detailed description under 2.2.1 - 2.2.4.

For clarification: Touch-up priming of areas with non-intact shop-primer is not intended in these guidelines, but may be advantageous, depending on the coating manufacturer's recommendation.

The estimated target useful life span ranges (durability ranges) are meant to be rough indications of durability, based on collected experience and information. It is to be taken into consideration that the durability of coatings and the susceptibility to corrosion of different surfaces within the same tank may vary widely. Maintenance of the coating will increase the useful life. Notably the area underneath sun-heated decks, at warm bulkheads and internal splash zones are representing severe exposure conditions for coatings. See 2.3 and 8.

There are indications that the useful life of coating may be reduced in deep water ballast tanks e.g. in very large crude oil carriers, due to increased tendency to blistering with increasing hydrostatic pressure. The explanation may be that rapid decompression during deballasting causes small or premature blisters to grow and large blisters to break. This process may proceed at an increasing rate with increasing depth in deep water ballast tanks.

Useful life of a coating is considered to be until 3 % breakthrough of rust on the coated surface areas: Welds' and edges' areas, respectively plain and large surface areas, considered separately. (ISO Standard 4628/3, rust scale = Ri 3-4, or Rust Grade 5, ASTM D 610, 9). See also 3.1.1.

Maintenance coating should be carried out before breakthrough of rust reaches 1 % of the surface area: Welds' and edges' areas, respectively plain and large surface areas, considered separately. (Rust Grade 6, ASTM D 610, or ≈ rust scale Ri 3, ISO Standard 4628/3).

The above definitions are chosen as practical compromises among several possible alternative definitions.

The coating systems indicated in these guidelines may be considered as general coating types, commonly used. They are not meant to exclude other recognised or newly developed systems.

Light coloured coatings should be used where possible to facilitate inspections.

DFT means dry film thickness in microns (= 0.001 mm).

The total nominal dry film thickness NDTF is stated in these guidelines. However, the average DFT is also used in shipbuilding.

In case the average thickness is used, it should be specified sufficiently high to obtain a target minimum DFT. E.g. minimum 80 % of all thickness measurements should be ≥ the specified DFT. Of the remaining 20 % of the measurements, none should be below 80 % of specified DFT (80/20 practice). E.g. to obtain a minimum DFT of 200 microns, the average or nominal DFT should be about 250 microns.

For some coating types, it may be important that a maximum thickness is not exceeded. Coating manufacturer's recommendations should be followed.

In double bottom ballast tanks in bulk carriers, the coating on the tank top may be damaged by grab impact. It is important that the applied coating stays flexible. Relative elongation figures for the coating should be requested. See 2.3.3.

- System I for ballast tanks (not recommended)

Estimated useful life span range: 5 ± 3 years.

System I is not recommended for ballast tanks due to the short life expectancy. (It is, however, still in use, and may be suitable for some areas in oil cargo tanks and cargo holds in bulk carriers. See below.)

Surface preparation: Steel plates shop-primed on blast cleaned or equivalent surface to Sa 2 - 2.5. Welds and burns mechanically cleaned to minimum St 3. To obtain a coating durability ≥5 years the steel surface preparation for shop-primer should be Sa 2,5.

Coating application (Table 2.1): One stripe coat should be applied if necessary to obtain the stated thickness on edges, etc. Increasing of the average thickness to obtain 200 microns minimum DFT is recommended for a coating durability ≥ 5 years.

- System II for ballast tanks

Estimated useful life span range: 10 ± 3 years:

Surface preparation: Steel plates with Zn containing, silicate based shop-primer applied on surface blast cleaned to Sa 2,5 or better. Sharp edges broken or rounded. Damaged shop-primer blast cleaned to Sa 2,5, including welds and burns.

Dry conditions: Air humidity ≤ 85 % and steel temperature ≥ 3 °C above the dew point during surface preparation and coating operations.

Coating application: Stripe coating with brush should be applied as an additional coat where required to obtain the thickness specified.

- System III for ballast tanks

Estimated useful life span range: 15 ± 3 years.
Recommended Practice

Surface preparation: Steel plates with Zn containing, silicate based shop-primer applied on surface blast cleaned to Sa 2.5 or better, or, preferably, all shop-primer blasted off until fresh Sa 2.5 surface is obtained on all areas, including welds, burns and edges. Sharp edges rounded or broken.

Clean conditions: Any salt contamination, weld smoke, dust, particles, grease, oil, hand marks, etc. on shop-primed or other surface to be coated, to be removed by cleaning before final blasting operations (assuming that the blasting abrasive is clean).

Dry conditions: Air humidity ≤85 % and steel temperature ≥3 °C above the dew point during blast cleaning and coating operations.

Coating application: 2 stripe coats with brush should be applied where required to obtain the stated thickness. In way of suctions, erosion of the paint film should be taken into account. Heavy duty coating, e.g. glass flake reinforced epoxy 500 microns DFT and/or doubling plates may be applied.

Comment regarding the estimated 15 ± 3 years target useful life of System III:
Increased tendency to blistering of coatings with increasing depth of water ballast tanks is probably caused by increased osmotic pressure gradient and rapid de-pressurising when de-ballasting. Cleanliness of the surface underneath the coating is a necessary condition for good adhesion. Sufficient strength of the coating film is also necessary to obtain this coating life.

Table 2.1 Coating system No. 1 - Target useful life 5 years

<table>
<thead>
<tr>
<th>Target durability</th>
<th>5 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coating system</td>
<td>Epoxy based Other recognised hard coating</td>
</tr>
<tr>
<td>Coats and thickness</td>
<td>1 coat Total nominal dry film thickness (NDFT) 200 microns</td>
</tr>
<tr>
<td>Primary surface preparation</td>
<td>Steel plates shop primed on blast cleaned surface to Sa 2 - Sa 2.5 (Sa 2.5 recommended)</td>
</tr>
<tr>
<td>Secondary surface preparation</td>
<td>Welds and burns mechanically cleaned to minimum St. 3</td>
</tr>
<tr>
<td>Clean conditions</td>
<td>Any visible salt contamination, oil, grease, dust, weld smoke or dirt on shop primed or other surface to be coated, to be removed by cleaning</td>
</tr>
<tr>
<td>Thermal and hygrometric conditions</td>
<td>The thermal and hygrometric conditions related to air humidity and steel temperature shall be within the limits set by the coating manufacturer</td>
</tr>
</tbody>
</table>

Comments to system I:

1) Light coloured coatings are recommended. Tar containing coatings are dark.
2) The selection of a recognised coating may depend on the type of compartment and its function.
3) One stripe coat to be applied on edges, welds and in areas where spraying may not be fully effective.
4) Nominal dry film thickness shall follow the "80/20 rule" and is for system I defined as follows:
   - The average DFT based on measurements shall always be equal to or larger than the NDFT. Up to 20% of the area (measured points) may have a thickness between 100% and 80% of the NDFT, but the measured dry film thickness shall always be larger than 80% of the NDFT.
   - The measured DFT shall not exceed the maximum dry film thickness defined by the paint manufacturer.
Table 2.2 Coating system No. II - Target useful life 10 years

<table>
<thead>
<tr>
<th>Target durability</th>
<th>10 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coating system 1)</td>
<td>Epoxy based</td>
</tr>
<tr>
<td></td>
<td>Other recognised hard coating 2)</td>
</tr>
<tr>
<td>Coats and thickness</td>
<td>2 coats 3)</td>
</tr>
<tr>
<td></td>
<td>Total nominal dry film thickness (NDFT) 300 microns 4) 6)</td>
</tr>
<tr>
<td>Primary surface preparation</td>
<td>Zinc containing, silicate based pre-fabrication primer on surface blast cleaned to minimum Sa 2.5</td>
</tr>
<tr>
<td>Secondary surface preparation</td>
<td>Sharp edges to be removed</td>
</tr>
<tr>
<td></td>
<td>Damaged shop primer blast cleaned to Sa 2.5, including welds and burns. Intact shop primer can remain. Mechanical cleaning to St 3 acceptable on block joints and damages 5) to the applied coating system</td>
</tr>
<tr>
<td>Clean conditions</td>
<td>Any visible salt contamination, oil, grease, dust, weld smoke or dirt on shop primed or other surface to be coated</td>
</tr>
<tr>
<td></td>
<td>The chloride content on surfaces to be coated shall be within the limit set by the coating manufacturer, if any</td>
</tr>
<tr>
<td>Thermal and hygrometric conditions</td>
<td>Air humidity ≤ 85 % and steel temperature ≥ 3 °C above the dew point during blast cleaning and coating application operations</td>
</tr>
</tbody>
</table>

Comments to system II:
1) Light coloured coatings are recommended. Tar containing coatings are dark. If coal tar epoxy is used the epoxy to tar ratio shall normally not be less than 60 to 40. If paint with a less epoxy to tar ratio is used (less epoxy, more tar), the thickness of the coating may have to be increased.
2) The selection of a recognised coating may depend on the type of compartment and its function.
3) One stripe coat to be applied prior to each full coat on edges, welds and in areas where spraying may not be fully effective.
4) Nominal dry film thickness shall follow the "80/20 rule" and is for system II defined as follows: The average DFT based on measurements shall always be equal to or larger than the NDFT. Up to 20% of the area (measured points) may have a thickness between 100% and 80% of the NDFT, but the measured dry film thickness shall always be larger than 80% of the NDFT.
5) The measured DFT shall not exceed the maximum dry film thickness defined by the paint manufacturer.
6) Only applicable for a reasonable amount of damages. Otherwise the basic surface preparation to be re-applied.

Table 2.3 Coating system No. III - Target useful life 15 years

<table>
<thead>
<tr>
<th>Target durability</th>
<th>15 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coating System 1)</td>
<td>Epoxy based</td>
</tr>
<tr>
<td></td>
<td>Other recognised hard coating 2)</td>
</tr>
<tr>
<td>Coats and Thickness</td>
<td>2 to 3 coats 3)</td>
</tr>
<tr>
<td></td>
<td>Total nominal dry film thickness (NDFT) 300-400 microns 4)</td>
</tr>
<tr>
<td>Primary surface preparation</td>
<td>Zinc containing, silicate based pre-fabrication primer on surface blast cleaned to minimum Sa 2.5</td>
</tr>
<tr>
<td>Secondary surface preparation</td>
<td>Sharp edges to be removed</td>
</tr>
<tr>
<td></td>
<td>Damaged shop primer blast cleaned to Sa 2.5, including welds and burns. Intact shop primer to be sweep blasted. Mechanical cleaning to St 3 acceptable on block joints and damages 5) to the applied coating system</td>
</tr>
<tr>
<td>Clean conditions</td>
<td>Any visible salt contamination, oil, grease, dust, weld smoke or dirt on shop primed or other surface to be coated, to be removed by cleaning</td>
</tr>
<tr>
<td></td>
<td>The chloride content on surfaces to be coated shall be less than 50 mg/m² (as NaCl) according to Bresle conductimetric method, or an equally recognised method</td>
</tr>
<tr>
<td>Thermal and hygrometric conditions</td>
<td>Air humidity ≤ 85 % and steel temperature ≥ 3 °C above the dew point during blast cleaning and coating application operations</td>
</tr>
</tbody>
</table>

Comments to system III:
1) Light coloured coatings are recommended. Tar containing coatings are dark. If coal tar epoxy is used the epoxy to tar ratio shall not be less than 60 to 40.
2) The selection of a recognised coating may depend on the type of compartment and its function.
3) One stripe coat to be applied prior to each full coat on edges, welds and in areas where spraying may not be fully effective.
4) Nominal dry film thickness shall follow the "90/5 rule" and is for system III defined as follows: The average DFT based on measurements shall always be equal to or larger than the NDFT. Up to 5% of the area (measured points) may have a thickness between 100% and 90% of the NDFT, but the measured dry film thickness shall always be larger than 90% of the NDFT.
5) The measured DFT shall not exceed the maximum dry film thickness defined by the paint manufacturer.
6) Only applicable for a reasonable amount of damages. Otherwise the basic surface preparation to be re-applied.
2.5 Coating systems for oil cargo and slop tanks (Tables 2.1 - 2.3)

Three alternative coating specifications for oil cargo tanks, Systems I, II and III, are indicated in Tables 2.1 - 2.3.

The indicated surface preparation is the minimum level needed to obtain the stated potential useful coating life. It is a brief summary of the detailed description under items 2.2.1 - 2.2.4.

General about estimated life span ranges, definitions and explanations: See 2.4.

Coating is recommended in cargo oil tanks bottom plating and structures and underneath deck and deck-structures. System II is preferable for cargo tank inner bottom and deckhead, while System I may be sufficient on upper part of stringers.

On the bottom plating the coating is to prevent bottom pitting corrosion that can occur in sour, foul water precipitated from oil cargoes, from condensation of moisture in the air, etc. Bacterial corrosion attacks superposed on common electrolytic corrosion may give very high corrosion rates on bottom plates unless properly protected by coating, especially in double hull vessels due to elevated cargo temperatures being maintained for a prolonged time period (thermal isolation or "thermos bottle effect" of the double hull).

The top side of horizontal stringer decks should be protected with coating due to their susceptibility to pitting corrosion due to deposits settling out from the cargo, as for the bottom plating.

Plating and associated structures underneath deck are often susceptible to more or less uniform corrosion attacks due to cyclic sun heating and cooling, condensation water, abundant oxygen supply, washing and sloshing of cargo. Proper application of a suitable coating is recommended. Sacrificial anodes will not be effective due to that here is no bulk electrolyte for distribution of protective current.

The coating types suitable for cargo oil tanks must be oil resistant and will usually be epoxy based. The coating type should be selected in co-operation with coating manufacturers. Coal tar epoxies will usually not be oil resistant and may easily become brittle due to that light tar components may be washed away and/or evaporated due to cyclic sun heating.

Slop tanks should be coated on all surfaces with System II (or better).

2.6 Coating specification for holds in bulk carriers or OBOs (Tables 2.1 - 2.3)

The three alternative coating specifications Systems I, II and III as indicated in Tables 2.1 - 2.3 are applicable also for holds in bulk carriers and OBOs.

Surface preparation, estimated life span ranges, definitions and explanations: As for 2.4.

Coating systems I, II and III are generally applicable but may be modified as regards coating thickness and number of coats, if relevant. The coating is to be epoxy or equivalent, rendering adequate corrosion protection to the surfaces in question, considering the cargo type and mode of operation of the ship.

All internals of cargo holds except flat tank top areas, hopper tanks sloping plating and transverse bulkheads bottom stool approximately 300 mm below shell frame and brackets are to be coated. Internal and external surfaces of hatch coamings and hatch covers are also to be coated, referring to the current Rules for Classification of Ships (9).

Coating of the flat tank top areas and other surfaces exempted from the rule requirement (see above), is also recommended, provided a coating or floor covering can be found that is sufficiently tough to withstand the impacts, abrasion and generally rough treatment by grabs, bulldozers, etc. during loading and unloading.

Due concern should be given that coating used for grain or other edible cargoes is properly certified for the purpose by the responsible authorities. The inner bottom should be coated, covered by a wooden deck, or similar.

Floodable cargo holds for harbour filling should be coated with due regard to that harbour ballast water may be polluted and corrosive.

For some dry cargoes, light coating with 1 - 2 coats of hold paints may be useful. A variety of hold paints (epoxy and non-epoxy based) and surface preparation methods are available. Especially ultra high pressure water jetting may be useful in cargo holds.

2.7 Coating for miscellaneous areas

For the sake of completeness, a few examples of coating systems for accommodation areas, engine rooms and fresh water and petroleum product tanks are listed below. The suggested systems for use underneath thermal isolation in reefer tanks and for voids in LNG tankers are practically the same as System II, Table 2.2. For other allocations, special systems are suggested that are more or less different from the Systems I-III presented in Tables 2.1 - 2.3.

The durability level or estimated useful life of the coating is dependent on wear and tear as well as on maintenance coating. The corrosion protection of these areas is, however, usually not critical for the operation or safety of the ship.

No coating systems are indicated for corrosive cargoes, chemicals or gases.
For coating or lining of tanks for chemical cargoes, shop-primer should be removed before application of the primer yard coat. The cleanliness of blasted surfaces should be Sa 2.5 - Sa 3. Some of the coatings may be very sensitive to overthickness. The coating manufacturer’s recommendations should generally be followed as regards surface preparation, coating application and curing.

Table 2.4 Coatings for miscellaneous areas

<table>
<thead>
<tr>
<th>Allocation</th>
<th>Surface preparation</th>
<th>Coating type</th>
<th>Nominal DFT microns</th>
<th>Number of coats minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh water tanks</td>
<td>Sa 2.5</td>
<td>Epoxy</td>
<td>200</td>
<td>2</td>
</tr>
<tr>
<td>Product tanks</td>
<td>Sa 3</td>
<td>Epoxy</td>
<td>300-350</td>
<td>2 - 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Phenolic Epoxy</td>
<td>300-350</td>
<td>2 - 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Zinc silicate</td>
<td>75-100</td>
<td>1</td>
</tr>
<tr>
<td>Accommodation and Engine rooms</td>
<td>Sa 2 - St 3</td>
<td>Alkyd, etc.</td>
<td>100-150</td>
<td>2</td>
</tr>
<tr>
<td>Reefers, underneath thermal insulation on tank top or inner bottom plate</td>
<td>Sa 2.5</td>
<td>Epoxy</td>
<td>300</td>
<td>2</td>
</tr>
<tr>
<td>Voids in connection with spherical tanks, LNG carriers</td>
<td>Sa 2.5</td>
<td>Epoxy</td>
<td>200-300</td>
<td>1 - 2</td>
</tr>
<tr>
<td>Void spaces (except dry, sealed-off compartments)</td>
<td>Sa 2.5 - St 3</td>
<td>Epoxy based</td>
<td>200-300</td>
<td>1 - 2</td>
</tr>
</tbody>
</table>

2.8 Coating for external hull

A coating specification for the ship will include a description of the external hull coating. The general contents of a coating specifications is described under 2.3.

For the hull a coating specification with two alternative steel surface preparations is indicated below:

Surface preparation alternative 1:

Shop-primed steel, shop-primer applied on plate surface blast cleaned to Sa 2.5 and preferably of Zn containing type. All welds and other areas of damaged shop-primer blast cleaned to minimum Sa 2.5. The coating should be applied under dry and clean conditions and as indicated under 2.2.1, 2.2.3 and 2.3.4. This surface preparation will give the most durable coating.

Surface preparation alternative 2:

Shop-primed steel, preferably Zn containing shop-primer, and mechanical cleaning, e.g. wire brushing, of welds and other areas of damaged shop-primer to St 3.

The durability of a coating on areas with surface preparation alternative 2 will be considerably reduced compared with the same coating applied on a surface according to alternative 1.

The coating manufacturer’s recommendations should generally be followed.

Anti-fouling coating should likewise be applied in accordance with the manufacturer’s recommendation, also considering the target lifetime.

Indications of hull coating systems are given in Table 2.5.
Table 2.5 Hull coating systems and allocation

<table>
<thead>
<tr>
<th>Allocation</th>
<th>Coating type</th>
<th>Total average DFT microns</th>
<th>Number of coats</th>
</tr>
</thead>
<tbody>
<tr>
<td>External hull, under water including boot-top* area</td>
<td>Epoxy or Epoxy coal tar + Anti-fouling paint</td>
<td>300-350</td>
<td>2-3</td>
</tr>
<tr>
<td>* between loaded and ballasted water line</td>
<td></td>
<td>250-350</td>
<td>2-3</td>
</tr>
<tr>
<td>As above</td>
<td>Vinyl tar + Anti-fouling paint</td>
<td>300-350</td>
<td>2-3</td>
</tr>
<tr>
<td>As above</td>
<td>Chlorinated rubber + Anti-fouling paint</td>
<td>300-350</td>
<td>3</td>
</tr>
<tr>
<td>External hull, in ice</td>
<td>Epoxy, hot applied, solvent free</td>
<td>600-1500</td>
<td>1-2</td>
</tr>
<tr>
<td>External hull, above water, and deck, deckhouse, superstructure</td>
<td>Chlorinated rubber</td>
<td>250-300</td>
<td>3</td>
</tr>
<tr>
<td>As above</td>
<td>Epoxy</td>
<td>250-300</td>
<td>2-3</td>
</tr>
<tr>
<td>As above</td>
<td>Vinyl</td>
<td>250-300</td>
<td>3</td>
</tr>
<tr>
<td>As above</td>
<td>Epoxy Mastic + Topcoat</td>
<td>300-350</td>
<td>2</td>
</tr>
</tbody>
</table>

Note:
Stripe coating of insufficiently rounded edges, etc. should be carried out to build up coating thickness.

2.9 Cathodic protection of ballast tanks

Cathodic protection is recommended in ballast tanks in combination with coating, as no coating will be free of pores and defects. Notably in the bottom areas of tanks which are seldom completely dried, sacrificial anodes installed as close as possible to the bottom plates can prevent or reduce pitting corrosion starting from local coating defects.

To obtain full cathodic protection in large, uncoated tanks may be difficult in practice due to the often complex structure of tanks and great number of anodes required to cover all surfaces.

Cathodic protection systems are without effect when the tanks are empty, and it will take some time (1/2 day or more) to obtain full effect (polarisation) of submerged steel surfaces after filling with sea water. In the ullage space or under deck area on top of tanks sacrificial anodes will not be effective unless the tank is completely filled.

Sacrificial anode systems designed according to the below principles will prevent corrosion on surfaces during submersion in ballast water (minus the time needed for repolarisation after refilling).

2.9.1 Cathodic protection system design basis - ballast tanks

2.9.1.1
The tanks' size, shape and areas to be protected should be presented accurately and in detail to the cathodic protection system supplier.

2.9.1.2
Areas coated, respectively uncoated should be specified.

2.9.1.3
The ballasting routines, including the percentage of the total time the tanks will likely be filled with ballast water, the probable duration of ballasted periods, and quality of ballast water should be indicated, if possible.

2.9.1.4
The criterion of cathodic protection is that the potential of the protected surfaces shall be - 0.80 V or higher negative values measured with a silver or silver chloride Ag/AgCl reference electrode, or equivalent potential with other reference cell. For ballast tanks, the goal of the cathodic protection designer will be to obtain this condition as quickly as possible after each ballasting and during ballasted periods for a defined lifetime of the anodes.

Cathodic protection may induce hydrogen stress cracking in extra high strength steels with specified minimum yield strength > 550 MPa, which are not used in common shipbuilding. Potentials more positive than - 1.05 V Ag/AgCl are generally recommended.

2.9.1.5
The average current density demanded to obtain full cathodic protection according to 2.9.1.4 may be as given in Table 2.6.
The current density demand to horizontal upwards facing surfaces in combined oil cargo or ballast tanks can be higher, e.g. up to 200 mA/m² and more.

For short ballast voyages the current densities should be increased by installing more anodes, e.g. for voyages shorter than 5 days, the above current densities should be increased by 25 % (if the future trade routes of the ship are known the cathodic protection system may to some degree be designed for specific ballasting routines).

### 2.9.2 Sacrificial anodes - ballast tanks

#### 2.9.2.1 Anode alloy materials based on aluminium or zinc are acceptable. Magnesium based alloys are not acceptable.

Ballast tanks adjacent to tanks for liquid cargo with flash point < 60 °C are considered as gas dangerous areas according to the DNV Rules for Ships. Aluminium alloy anodes are to be so located that a kinetic energy of ≤ 275 J is developed in case of their loosening and falling down, i.e.

\[ H \leq 28/W, \]

where \( H \) (m) is the height above tank bottom, deck or stringer, \( W \) (kg) is the anode gross mass.

It is a presumption for the above calculation of \( H \) that the largest diameter of holes or scallops in deck or stringer is less than 1/2 of the anode length. From corrosion and safety point of view, welded anodes are preferable. Bolted aluminium alloy anodes with at least 2 through-bolts per anode and double locking nuts (for easy renewal) are, however, acceptable.

See also 5.

---

### Table 2.7 Current capacities and consumption rate

<table>
<thead>
<tr>
<th>Anode and environment</th>
<th>Current capacity Ah/kg</th>
<th>Consumption rate kg/A year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al based anodes in sea water</td>
<td>2300 - 2650</td>
<td>3.3 - 3.8</td>
</tr>
<tr>
<td>Al based anodes in marine sediments</td>
<td>1300 - 2300</td>
<td>3.8 - 6.7</td>
</tr>
<tr>
<td>Zn based anodes in sea water</td>
<td>760 - 780</td>
<td>11.2 - 11.5</td>
</tr>
<tr>
<td>Zn based anodes in marine sediments</td>
<td>750 - 780</td>
<td>11.2 - 11.7</td>
</tr>
</tbody>
</table>

#### 2.9.2.2

Al or Zn based anode alloys should be of recognised type, known to be efficient in ships. The current capacities and consumption rates, respectively should be as given in Table 2.7.
Anode renewals should be carried out well in time before the old anodes are fully consumed. The design of renewal systems should be based on the above principles modified according to experience gained with the actual ship.

Inspection of sacrificial anode installations can be carried out by the coating inspector, see 2.3 and 7.

Immersed current systems should not be used in ballast tanks due to development of chlorine and hydrogen, which can result in an explosion hazard.

All external hull items in electrical contact with the hull shall be included in the cathodic protection system. The propeller will be insulated from the hull when rotating. Recognised slip-rings and brushes should be installed to include the propeller in the cathodic protection system.

The criterion of cathodic protection is as per 2.9.1.4.

Average current densities needed to obtain full cathodic protection of well coated ships' hulls will usually be about 10 mA/m² or more. In special cases, e.g. on ice breakers, up to about 60 mA/m² may be needed. The current density demand will vary depending on factors mentioned under 2.10.1.1, and will be different at different locations of the hull and its accessories such as propeller, rudder, and sea chests.

Water resistivities: See 8.

Aluminium or zinc anode materials should be used.

Typical current capacity or consumption rate figures, lifetime and current output capacity calculations are described under 2.9.2.

Anode size and distribution should be based on the information provided from 2.10.1.1 and calculations as indicated in 2.9.2.3 - 2.9.2.4. The anode distribution, type, weights and dimensions should be shown on drawings.

Anode renewals should be carried out well in time before the old anodes are fully consumed, preferably during docking.

The size, number of and distribution of impressed current anodes should be based on information as per 2.10.1.

The impressed current system design and installation, including anode alloy type, design, location and distribution, reference electrodes, rectifiers, cabling, hull penetrations, cofferdams, monitoring units, anode shields, etc. should be delivered by a recognised specialist company with good references.

Impressed current systems should be checked and adjusted by the supplier regularly for proper functioning, e.g. every 2nd year.

Ships of some age can have corrosion prevention systems in varying condition. Systems suitable for newbuildings may not be so for ships in service. In the following some methods for prevention or limitation of corrosion attacks are suggested for ships in service.

Maintenance coating - general

Maintenance coating should be carried out before breakthrough of rust reaches 1% of the surface area: Welds' and edges' areas, respectively plain and large surface areas, considered separately. This corresponds to Rust Grade 6, ASTM D 610 (9) or ¿ rust scale Ri 3, ISO Standard 4628/3. The ASTM D 610 has a very simple and useful figure for estimation of area percentages and is reproduced as figure 9.1 in these guidelines. More standards on evaluation of the condition of worn or damaged coatings may be found in Appendix 2.
When rust is breaking through on as much as 1 % of the coated area, much of the remaining coated surface is soon due for the same. When possible, maintenance coating should be started earlier.

Often those areas which are most in need of protection will suffer the hardest from coating breakdown: Welds, burns and edges of cut-outs, etc. The reason is the commonly occurring substandard surface preparation of welds, burns and edges, see 2.2.

Maintenance coating may be carried out with the same coating system as originally used on the newbuilding. The surface treatment and humidity or temperature conditions required for a satisfactory result are, however, not always practically obtainable.

The shipowner has to options for maintenance coating:
- dry-dock repairs, or
- repairs at sea.

For ballast tanks, according to IMO (12), maintenance of the corrosion prevention system shall be included in the ship’s overall maintenance scheme.

Mud, sludge and foul water in the bottom of tanks should be removed on a planned and continuous basis in order to prevent pitting corrosion, bacterial growth and development of bacterial corrosion. If bacterial corrosion is superposed on the common electrolytic corrosion, the corrosion rate can be very high. This phenomenon is especially relevant in double hull tankers’ cargo tanks, due to prolonged period of elevated cargo temperature (isolating effect of empty ballast tanks).

Special coating systems designed to be more tolerant of lower quality surface treatment and humidity or temperature conditions may be more effective. In the Table 3.1 are listed examples of paint coating systems designed for maintenance coating. The list is not meant to exclude other recognised or new developed systems. Documentation of obtained results should be requested before selection of coating type.

The steel surface cleanliness should be minimum St 3 according to ISO 8501-1, or degreased, clean, sound coating or shop-primer, and as dry conditions as practically possible.

Salt contamination is a common problem in maintenance coating. Salts on surfaces underneath applied coating will promote early blistering due to osmosis. Salt should be removed as far as possible by means of fresh water washing. The salt content on surfaces to be coated should at least be below 60 and preferably below 30 mg/m² (as NaCl). A recognised test method for salt is ISO 8502-9.

The significance of condensation of moisture on steel surfaces and its relation to air humidity and temperature conditions must be understood by the personnel involved, so that adequate ventilation, and dehumidification if necessary, is provided.

It is important that repaired, welded or heat affected zone areas are given adequate surface preparation and are properly coated, otherwise accelerated galvanic corrosion attack may occur.

The ship’s safety and tank entry procedures must be strictly adhered to during work in connection with maintenance coating, Personnel must be adequately trained in safe usage of all equipment.

### Table 3.1 Maintenance coating

<table>
<thead>
<tr>
<th>Allocation</th>
<th>Coating type</th>
<th>Total average DFT micron</th>
<th>Number of coats minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ballast tanks and hull internals</td>
<td>Epoxy based, &quot;surface tolerant&quot;, &quot;high tech&quot;, &quot;mastic&quot;, etc., preferably light coloured</td>
<td>300 - 350</td>
<td>1 - 2</td>
</tr>
<tr>
<td>As above</td>
<td>Other recognised system</td>
<td>300, or as recommended by manufacturer</td>
<td>1 - 2</td>
</tr>
<tr>
<td>As above</td>
<td>Semi hard or similar coating, approved</td>
<td>According to manufacturer’s recommendation</td>
<td>1 - 2</td>
</tr>
</tbody>
</table>

Notes to Table 3.1:
- Coatings with aluminium Al content above 10 % in the dry film shall not be used in gas hazardous areas.
- Maintenance coating systems should be specially developed for use on non-blast cleaned surfaces.
- Cargo holds for clean cargo should be maintenance coated with the same system as used originally, and the coating must be compatible with the original coating and the cargo.

General guidelines for inspection may be found in 2.2.4 and 7.
Regarding selection of coatings sufficiently flexible on sun heated or hot surfaces and coatings for high strength steels, see 2.3.

#### 3.1.2 Surface preparation

Several methods of surface preparation are relevant, and in 1999 the preferred of these seem to be:
- power tool cleaning (rotary grinders, wire brushes, needle gun, etc.)
- hydro-jetting (grit injection available)
- ultra-high pressure hydro-jetting (grit injection available)
- slurry blasting
- grit blasting
- magnesium de-scaling
2000

hydrochloric acid descaling
- sponge-jet blasting.

*Power tool cleaning* is suitable for small repairs. A realistic useful life span range obtainable with a good coating may be about 2 - 5 years.

*Hydro-jetting* with water pressure above about 100 MPa will give varying results depending on nozzle design, speed of operation, etc. Loose rust, scale and coating will generally come off, while mill-scale and hard, black rust (magnetite-scale) will not be removed. Expected useful life for good, surface tolerant coatings can be 5 years or more. (So called "moisture tolerant" coatings may not yet be sufficiently developed to be successful for such use.)

*Ultra-high pressure hydro-jetting* with pressures above about 200 MPa gives faster and usually better results than the above method. Depending on the cleanliness achieved, the expected useful life of good coatings applied on surfaces prepared by means of this method may be varying but in some cases up to 10 years.

*Slurry blasting* is similar to dry grit blasting but water is used as propellant instead of air. The advantages are reduced dust and salt levels, the disadvantage is that the surface is wetted, which implies re-rusting. The expected useful life of a good coating may be about 5 years but strongly dependent on the degree of re-rusting.

*Grit blasting* is technically the best method for obtaining a durable coating. However, grit-blasting may often not be feasible for maintenance coating. Special grit blasting units suitable for maintenance work are, however, available; e.g. vacuum, back-pack, mini-pot, etc. equipment. Expected useful life of a good coating applied on grit blasted surface in a maintenance-situation may be 10 years or more.

*Magnesium descaling* may give a surface suitable for a surface tolerant coating if white calcium/magnesium carbonate powder formed during descaling is quickly removed by fresh water washing. Large amounts of hydrogen gas formed during descaling can represent a safety hazard if not properly ventilated, and magnesium metal itself is a very reactive metal, e.g. thin flakes or chips may catch fire. Expected useful life of a good coating may be 2 - 5 years.

*Hydrochloric acid descaling* (diluted HCl) may be used for descaling. Hydrochloric acid represents also a potential safety hazard. All traces of acid must be removed by fresh water washing before coating. Expected useful coating life may be about as for magnesium descaling, 2 - 5 years, depending on e.g. re-rusting and dryness of surfaces during coating application.

*Sponge-jet blasting* is a newly developed method that may possibly be used for preparing block joint surfaces and similar. No records giving indications on expected useful coating life are available.

### 3.1.3 Soft coats, semi hard coatings, inhibitors

This category of products is of different chemical origin and have different properties. Terms such as for example "soft coats", "semi hard" coating and "inhibitors" may occur. Soft and semi hard coatings may be based on for example petroleum oils, vegetable oils or wool grease (lanolin).

The basic idea of soft and semi hard coats or coatings is usually that they shall be able to penetrate rust and adhere to non-blast cleaned steel, due to their content of surface active chemicals. They should stay soft or semi hard, i.e. flexible and non-brittle. The corrosion protection mechanism may be due to chemical constituents acting as corrosion inhibitors and/or in combination with a barrier effect. They are usually intended primarily for maintenance coating.

- "Soft coat" may be defined as: Coating that remains soft so that it wears off when touched; often based on oils or sheep wool grease.
- Semi hard coating" may be defined as: Coating which dries in such a way that it stays soft and flexible although hard enough to touch and walk upon.
- "Inhibitors" for corrosion protection are generally chemicals having an inhibiting effect on corrosion and can be of film forming (i.e. coating), anodic or cathodic type.

Soft and semi hard coatings will normally be of shorter durability than common paint coatings and will normally have to be renewed annually or every 2nd year. Manufacturers of such coatings should normally have ready made procedures for re-coating.

A drawback with some of these coatings, notably wool grease based soft coats, is that hot work or welding on the outside or inside of coated plates may cause fire or explosions due to gas development from the coating when heated. Careful removal of the coating is thus necessary before any hot work is carried out.

Another drawback, also most significant with wool grease based soft coats, is that the coated surfaces stay soft and slippery and make inspection work e.g. in ballast tanks difficult and dirty. For this reason IACS (13) has issued a recommendation that practically will rule out the use of soft coats in ballast tanks.

Some soft coat products are applied in relatively high thickness, e.g. 1 mm and above. These will impose the greatest difficulties with respect to cleaning, hot work, access and possibilities for inspection.

The heat resistance of the coating products should be carefully checked before application in ballast tanks, considering that sun heating, adjacent cargo tanks and engine room may cause elevated temperature.

Semi hard coatings approved by DNV will be accepted for avoidance of annual survey of ballast tanks. However, soft coats will not qualify for relaxation of requirements for annual examination of water ballast tanks. It is also decided (1995) that DNV approval will no more be issued for soft coat products, due to the drawbacks described above.
Classification survey with steel thickness measurements if necessary should be carried out after cleaning but prior to application of any maintenance coating, in order to verify that the hull structure is in sound condition.

Coated tanks will normally have to be properly cleaned before tank surveys, e.g. the coating is to be removed in critical areas. The extent of cleaning will be to the discretion of the surveyor. It should be considered that some coatings might be more difficult to clean off steel surfaces than others.

3.1.4 Other coatings
Several coatings have been marketed for application to non-blast cleaned surfaces but with little documented success. Relatively new products within the groups "surface tolerant epoxies" and "rust converter + " may seem promising.

Documentation of obtained results should be requested before taken into use.

3.1.5 Cathodic protection
Sacrificial anodes of zinc or aluminium may effectively reduce corrosion in the under water region of ballast tanks for the ballasted periods. They can prevent pitting corrosion in tank bottom areas mostly flooded with water. Sacrificial anodes will not have any effect on areas not submerged in water. They should preferably be used in combination with coating, to reduce the protective current demand and increase anode life (care is to be taken such that anodes are not covered by coating).

Sacrificial anode systems installed in ships in service should be designed in accordance with the principles of these guidelines as described in 2.9. (Too few and/or too small anodes have often been installed in ships tanks.)

Impressed current systems should not be used in ballast tanks, see 2.9.

Generally, anodes should be renewed before the sacrificial material has disappeared. If designed for a defined useful life, anodes should be renewed in accordance with the predetermined schedule.

3.2 External hull

3.2.1 Maintenance coating
External hull coatings should be renewed when necessary. When the necessary control with blast cleaning, humidity and temperature conditions during coating application can not be obtained, special coating systems designed for maintenance may be used. Examples of such systems are indicated in Table 3.2.

3.2.2 Cathodic protection - maintenance - renewal
Sacrificial anode systems should be renewed in accordance with the principles outlined in 2.9 and 2.10.

Impressed current cathodic protection systems need regular specialist survey by the supplier for maintenance of proper functioning.

<table>
<thead>
<tr>
<th>Table 3.2 Maintenance paint coating systems - external hull</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allocation</td>
</tr>
<tr>
<td>External hull</td>
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<tr>
<td></td>
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<tr>
<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td>External hull</td>
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</tbody>
</table>

Notes to Table 3.2:
- On submerged areas anti-fouling paint should be applied
- Tar containing coatings have shown good performance as corrosion protection in under water applications but are now prohibited in several countries due to their carcinogenic properties.

* Development are in progress and will continue due to restrictions on the use of antifouling containing tin.

3.3 Assessment of coating condition in ballast tanks (Good, Fair, Poor)
Ballast tank coatings will be assessed by the classification surveyor as being either in Good, Fair or Poor condition.

If the coating is found in Good condition, the extent of close-up examination and steel thickness measurements required by the classification society may be reduced.

If the coating is found in Poor condition, or where coating was not applied (relevant for some ships built before the general requirement of coating ballast tanks was introduced), retention of class will be subject to the tank in question being examined at annual intervals.

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To avoid the requirement of annual examination, the ballast tanks with coating in Poor condition will have to be recoated. Due to high costs of carrying out proper surface preparation for application of an epoxy based, hard coating, semi-hard or similar coating materials have been especially developed for the maintenance coating market of ageing ships' ballast tanks. In ships classed with DNV, such coatings (other than hard coats) are required to be Type Approved.

Type Approval is offered as a service to coating manufacturers. The criterion for Type Approval is, briefly, satisfactory performance in either actual field exposure (ballast tank) for a minimum of 2 years, or laboratory testing by approved methods. Coating materials that are Type Approved by DNV are thus products of a high and defined quality (7, 14).

A simplified interpretation for practical purposes may be that condition Good can be given if all observed coating damages and rust spots added together make less than 1% of the surface area considered when compared with the ASTM D 610 figure, reproduced as figure 9.1 in these guidelines, Appendix 5.

Condition Poor should be given if all observed areas of coating damage and rust added together make more than 20% of the area under consideration when compared with the same Figure 9.1 in these guidelines. Accordingly, condition Fair can be given for corresponding area percentages 1-20%.

### Table 3.3 Coating conditions

<table>
<thead>
<tr>
<th>Item considered or comparable standard</th>
<th>Coating condition (Limit for rating)</th>
<th>Good</th>
<th>Fair</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spot rust</td>
<td>minor (1%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light rust (surface rust)</td>
<td>minor (1%)</td>
<td>20%</td>
<td>&gt;20%</td>
<td></td>
</tr>
<tr>
<td>Edges and welds, coating breakdown</td>
<td>minor (1%)</td>
<td>20%</td>
<td>&gt;20%</td>
<td></td>
</tr>
<tr>
<td>Hard Scale</td>
<td>minor (1%)</td>
<td>10%</td>
<td>&gt;10%</td>
<td></td>
</tr>
<tr>
<td>General coating breakdown</td>
<td>minor (1%)</td>
<td>20%</td>
<td>&gt;20%</td>
<td></td>
</tr>
<tr>
<td>ASTM D 610 (all coating breakdown and rust added, see fig. 9.1)</td>
<td>1%</td>
<td>20%</td>
<td>&gt;20%</td>
<td></td>
</tr>
<tr>
<td>ISO 4628/3 (area rusted)</td>
<td>Rust Scale</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ri 3 (1%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rust Scale</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ri 4 (8%)</td>
<td></td>
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</tbody>
</table>

The three main coating conditions are commonly defined by the classification societies as follows:

- **Good**: Condition with only minor spot rusting.
- **Fair**: Condition with local breakdown at edges of stiffeners and weld connections and/or light rusting over 20% or more of areas under consideration, but less than as defined for Poor condition.
- **Poor**: Condition with general breakdown of coating over 20% or more of areas or hard scale at 10% or more of areas under consideration.

The definitions of Good, Fair and Poor coating conditions can be interpreted as given in Table 3.3.

### 4. References

2. NTNF-prosjekt Extended Lifetime for Ships, DNV Report No. 89-0205 dated 5.5.91, NTNF MV.24918.
9. ASTM D 610 - 85, Evaluating Degree of Rusting on Painted Steel Surfaces. ASTM Annual Book of Standards, Vol. 06.01.

(13) International Association of Classification Societies IACS, Recommendation No. 44, Survey guidelines for tanks in which soft coatings have been applied, 1996.

5. Appendix 1: Brief Review of the DNV Rules for Ships (2000) and IMO Guidelines regarding corrosion protection of ships

5.1 Classification requirements

The below is a brief review of DNV class requirements for corrosion protection, presented in the same order of occurrence as the related subjects are treated in these guidelines. The detailed requirements are stated in the DNV Rules for Classification of Ships (See reference (6)).

<table>
<thead>
<tr>
<th>Guidelines, Chapter and subject</th>
<th>Item, briefly</th>
<th>DNV Rules for Ships, reference (2000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1, 2.2.3 Planning and access for inspection</td>
<td>Permanent and temporary staging and passages through hull structures to be provided.</td>
<td>Pt.5 Ch.3 Sec.3 D300 Pt.7 Ch.2 Sec.1 E200</td>
</tr>
<tr>
<td>2.2.1 Shop-primer</td>
<td>To be approved with respect to that it will have no detrimental effect on welds.</td>
<td>Pt.3 Ch.1 Sec.18 B201</td>
</tr>
<tr>
<td>2.3 to 2.7 Coating, newbuildings</td>
<td>All steel surfaces are to be coated, except in tanks other than ballast tanks.</td>
<td>Pt.3 Ch.1 Sec.18 B101 Pt.3 Ch.1 Sec.2 D201</td>
</tr>
<tr>
<td>2.3 to 2.7 Coating specification</td>
<td>Items to be described in a coating specification are outlined.</td>
<td>Pt.3 Ch.1 Sec.18 A200 Pt.3 Ch.2 Sec.14 A200</td>
</tr>
<tr>
<td>2.6 Coating, holds in bulk carriers</td>
<td>Corrosion protection to be specially considered. Details regarding coating of cargo holds.</td>
<td>Pt.3 Ch.1 Sec.18 B101 Pt.5 Ch.2 Sec.5 C500</td>
</tr>
<tr>
<td>2.3 to 2.7 Coating containing aluminium</td>
<td>Use in gas hazardous areas limited to Al content maximum 10 % by weight in the dry film, due to sparking hazard.</td>
<td>Pt.3 Ch.1 Sec.18 B202</td>
</tr>
<tr>
<td>2.9 Sacrificial anodes’ efficiency in ballast tanks</td>
<td>If anodes are to installed, calculation details and distribution drawings are to be submitted for, respectively, information and approval</td>
<td>Pt.3 Ch.1 Sec.18 A200</td>
</tr>
<tr>
<td>2.9 Sacrificial anodes’ fastening and installation</td>
<td>To be approved with respect to fastening in gas hazardous areas, e.g. tanks adjacent to oil cargo tanks. Maximum kinetic energy 275 J developed in case of anodes falling down.</td>
<td>Pt.3 Ch.1 Sec.18. B301 to B304</td>
</tr>
<tr>
<td>2.9 Gas produced by anodes</td>
<td>Vent pipes are to be installed both fore and aft in tanks where sacrificial anodes are installed.</td>
<td>Pt.4 Ch.1 Sec.4 K101</td>
</tr>
<tr>
<td>3.1 Coating, Ships in Service</td>
<td>Corrosion protection system definition. Definition of coating conditions Good, Fair, and Poor. Annual survey, coating. Intermediate survey, coating. Renewal survey, coating.</td>
<td>Pt.7 Ch.2 Sec.2 A108 Pt.7 Ch.2 Sec.2 A109 Pt.7 Ch.2 Sec.2 B601 Pt.7 Ch.2 Sec.2 C102, C303 and C400 Pt.7 Ch.2 Sec.2 D100</td>
</tr>
</tbody>
</table>

5.2 IMO Guidelines - Corrosion protection

Selected items of the IMO guidelines concerning corrosion protection in such forms as they appear in January 1996, are presented in the below table. The guidelines deal with technical aspects of corrosion protection as well as organisational matters concerning shipowners, shipyards, flag state administration, classification societies and others. The classification society’s involvement in follow-up of ships’ corrosion protection systems is currently being discussed.
Table 5.2 IMO Guidelines - Corrosion protection

<table>
<thead>
<tr>
<th>IMO reference</th>
<th>Guidelines - Heading and selected items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Res. A.798(19) adopted 23 Nov. 1995</td>
<td>GUIDELINES FOR THE SELECTION, APPLICATION AND MAINTENANCE OF CORROSION PROTECTION SYSTEMS OF DEDICATED SEA WATER BALLAST TANKS</td>
</tr>
<tr>
<td></td>
<td>- invites governments to apply the guidelines a.s.a.p. to new bulk carriers and oil tankers</td>
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<tr>
<td></td>
<td>- shipyard and/or its subcontractors should provide clear evidence of their experience in coating application</td>
</tr>
<tr>
<td></td>
<td>- coating standard, job specification, inspection, maintenance and repair criteria should be agreed by the shipyard and/or its subcontractors, owner and manufacturer, in consultation with the Administration or an organization recognised by the Administration</td>
</tr>
<tr>
<td></td>
<td>- multi-coat treatments with coating layers of different colours are recommended</td>
</tr>
<tr>
<td></td>
<td>- use of a hard coating is the most common practice</td>
</tr>
<tr>
<td></td>
<td>- the effectiveness of a hard coating can be achieved only if the manufacturer's technical product data sheet and job specification is carefully followed</td>
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<tr>
<td></td>
<td>- the last layer of each coat should preferably be of a light colour in order to facilitate in-service inspections</td>
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<tr>
<td></td>
<td>- due regard should be given to the possible poor edge covering of hard coatings with a high solids content</td>
</tr>
<tr>
<td></td>
<td>- the surface preparation should be in accordance with the coating manufacturer's specifications and recommendations</td>
</tr>
<tr>
<td></td>
<td>- the conditions under which blast cleaning is performed should preclude condensation</td>
</tr>
<tr>
<td></td>
<td>- it is not recommended to carry out blast cleaning when</td>
</tr>
<tr>
<td></td>
<td>- the relative humidity is above 85 %, or</td>
</tr>
<tr>
<td></td>
<td>- the steel surface temperature is less than 3 °C above the dew point, or</td>
</tr>
<tr>
<td></td>
<td>- there are traces of moisture, or condensation occurs before the primer coat is applied</td>
</tr>
<tr>
<td></td>
<td>- inspection relevant to surface preparation and coating application should be agreed upon between shipowner and shipyard under the manufacturer's advice</td>
</tr>
<tr>
<td></td>
<td>- activities that should be overseen, inter alia, are</td>
</tr>
<tr>
<td></td>
<td>- working conditions, e.g. illumination, access, staging, etc.</td>
</tr>
<tr>
<td></td>
<td>- environmental conditions, e.g. temperature and moisture</td>
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<tr>
<td></td>
<td>- removing of sharp edges</td>
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<td></td>
<td>- blast cleaning or mechanical cleaning</td>
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<tr>
<td></td>
<td>- cleaning up after blast cleaning</td>
</tr>
<tr>
<td></td>
<td>- shielding of painted surfaces from blasting operations</td>
</tr>
<tr>
<td></td>
<td>- coating application equipment</td>
</tr>
<tr>
<td></td>
<td>- curing times for intermediate coats in relation to temperature and humidity</td>
</tr>
<tr>
<td></td>
<td>- cleaning of coated surfaces before application of next coat</td>
</tr>
<tr>
<td></td>
<td>- handling or storing or transport of coated objects</td>
</tr>
<tr>
<td></td>
<td>- coating repairs, when damaged</td>
</tr>
<tr>
<td></td>
<td>- precautions are to be taken to reduce health, fire, explosion and other safety risks which should be in accordance with the regulations of the Administration</td>
</tr>
<tr>
<td></td>
<td>- cathodic protection by means of sacrificial anodes may be used in combination with coating to prevent or reduce pitting corrosion starting from local defects in the coating</td>
</tr>
<tr>
<td></td>
<td>- anodes should be designed in terms of size, weight, and distribution to give an adequate life commensurate with the service period</td>
</tr>
<tr>
<td></td>
<td>- anode design documents should be available for maintenance purposes</td>
</tr>
<tr>
<td></td>
<td>- alternative corrosion protection methods may be used, provided they give the same level of corrosion protection accomplished by means of hard coatings</td>
</tr>
<tr>
<td></td>
<td>- maintenance of the corrosion protection system should be included in the overall ship's maintenance schemes</td>
</tr>
<tr>
<td></td>
<td>- the effectiveness of the corrosion protection system should be verified during the ship's life by the Administration or an organization recognised by the Administration</td>
</tr>
</tbody>
</table>

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6. Appendix 2: Properties and Test Standards for Coatings

Some recognised standard methods for optional use in quality control, testing of properties and evaluation of the condition of coatings are listed below. Other test methods may be used as a well.

Abbreviations:
ASTM: American Society for Testing and Materials
BS : British Standard
DIN : German Standard
ISO : International Standardization Organization
NACE : National Association of Corrosion Engineers (USA)
SIS : Swedish Standard
SSPC : Steel Structures Painting Council (USA)

6.1 Quality control tests for steel surface treatment and coating application

Coating adhesion
Proper coating adhesion (bonding) to the steel surface and between individual coats is most important for the quality and durability of the coating. Inadequate adhesion results in a mechanically weakened coating layer which may soon be lifted, blistered or peeled off by moving water, weathering actions, impacts or traffic.

Proper adhesion is obtained by following the above guidelines for surface preparation and coating application.

Criteria for minimum acceptable adhesion may be specified, referring to either a cross cut test or pull-off test. Adhesion testing is, however, destructive and is normally used only in cases of complaint, not as a routine test.

Adhesion (bonding) may be tested by the pull-off method, cross cutting or tape test, manual peel testing, etc.

Standards for cross cut test, e.g.: ISO 2409, ASTM D 3359, BS 3900 part E6.

Standards for pull-off test: ISO 4624, BS 3900 part E10, DIN 53232.

Coating dry film thickness DFT
The minimum dry film thickness DFT should be stated for each coating layer and for the full coating system. If it is considered more practical to specify the average DFT, it should be increased so that it will comply with a stated minimum DFT. See examples discussed in 2.4 of these guidelines.

Dry film thickness DFT test methods:
Electromagnetic and magnetic type instruments are used for coatings on steel. Eddy current based instruments may be used on non-magnetic substrates.

Standards concerning dry film thickness measurements:
ISO 2808, BS 3900 Part C5, BS 5494, ASTM D 1005, D 1400, D 2691, SIS 184160.

Due consideration to surface profile should be taken when calibrating DFT measuring equipment.

Blasted steel surface cleanliness and profile
Visual, pictorial standards for surface cleanliness are usually sufficient, such as
- ISO 8501-1, with grades Sa 3 and Sa 2.5
- SIS 055900, with grades Sa 3 and Sa 2.5
- DIN 55928, with grades Sa 3 and Sa 2.5.

ISO 12944 is a relatively new standard, 1st edition 1998, comprising Paints and Varnishes for corrosion protection in general, consisting of 8 parts. The part no. 4 concerns steel surface preparation. National and EN standards are issued with the same number and same content.

The grades Sa 3 and 2.5 approximately correspond to, respectively,
- BS 4232, grades First Quality and Second Quality
- NACE, grades No. 1 (white metal) and No. 2 (near-white)
- SSPC, grades SP 5 (white) and SP 10 (near-white).

Surface roughness profile after blast cleaning can be checked with a surface profile gauge, or a "Rugotest" set or similar for visual comparison, commonly Rugotest no. 3. It is described in ISO 8503. Commonly used surface profiles for corrosion protection paint coatings are 60 - 90 microns R max, where R max is the peak to valley profile depth.

Mechanically cleaned steel surfaces
The common minimum cleanliness standard for mechanical cleaning is St 2.

The St 2 cleanliness standard is described in the above mentioned standards ISO 8501-1, SIS 055900, DIN 55928, etc.

Wet film thickness WFT
WFT is usually measured only by the coating applicator. Rollers and comb type of equipment are in use. The dry film thickness DFT can be estimated from the WFT:

\[ \text{DFT} = \text{WFT} \times \text{volume \% solids/100.} \]

Relevant standards for measurement of WFT:
ASTM D 1212, BS 3900 Part C5, BS 5493.

Holiday detection or spark testing
Holiday detection, or spark testing, or continuity testing, is not commonly used on paint coatings but can be essential for linings for chemicals, pipe coating, and other critical coating or lining applications. The equipment must be calibrated strictly according to the manufacturer's instructions and duly considering the coating or lining type and thickness. Low voltage equipment only is relevant for paint coatings.

A recognised standard indicating test voltages versus coating thickness is NACE RP-02-74. Useful advice is also given in BS 6374.
6.2 Coating materials' testing - thermal, mechanical and physical properties

The below tests for materials properties are listed for optional use and are not meant to exclude other test methods.

Heat resistance
Coatings with sufficient heat resistance should be selected for application to surfaces exposed to elevated temperatures, such as bulkheads against heated cargo and decks exposed to sunshine. For example, tar containing coatings may contain volatile components which tend to evaporate when heated, rendering the remaining coating less flexible and prone to cracking when aged.

Service temperature limits of coatings may be determined as softening point, or by means of registering signs of degradation or decomposition, e.g. change of colour.

Standards for heat resistance testing:
BS 3900 Part G 7, BS 4164, BS 4692, ASTM D 2485.

Flexibility or relative elongation
Coatings should have sufficient flexibility or relative elongation for the actual application. Loss of flexibility may result from prolonged exposure to elevated temperature. In general, the coating should have higher relative elongation than the steel it is applied to, considering even that some local deformation of the steel may occur. Coatings to be used in ships tanks should have minimum 4% relative elongation at relevant conditions of exposure (ageing effects and a safety factor taken into account).

Test standards for coating flexibility:
Tensile elongation, free film: ASTM D 2370.
Cupping of coated plates (Erichsen test):
ISO 1520, BS 3900 Part E 4, DIN 53156.
Bending over mandrel:
BS 3900 Part E 1, ASTM D 522, ASTM D 1737.

Abrasion resistance
For floor coatings and traffic paint abrasion resistance is important. Relevant test standards may be:
ASTM D 1395, D 658, 968, 821.

Drying time of coatings
Test standards:
ASTM D 3732, 1640, 1953, 711, ISO 1517, SIS 184153.

Binder/Pigment/Volatile/Solids content
The percentages of the respective components of a coating material may be determined by various standard tests, e.g.:
ASTM D 2697, 2832, 1259, 2621, ISO 3233.

Impact resistance
Relevant test standards (to be chosen according to type and thickness of coating):
BS 3900 Part E3 and E7, ASTM G 14, D 2794.

Hardness
If hardness testing is relevant, due concern must be given to the type and thickness of coating. Relevant test standards:
ASTM D 2134, 2240, BS 4164, SIS 162201.

Flash point
The flash point of a liquid coating may be determined by e.g. tests:
ASTM D 93, 3278, 56, 1310, DIN 53213, 51755, 51758.

Viscosity
Relevant tests:
ASTM D 1200, DIN 51550, 1342, 53177.

Gloss
Tests for gloss of architectural paints, etc.:
ASTM E 430, BS 3900 Part D 50, DIN 67530.

6.3 Documentation of coating performance properties - Type approval of coatings

Independent records of satisfactory performance as corrosion protection in a relevant environment should be requested and evaluated before selection of coating type and manufacturer.

DNV offers type approval of protective coating systems to the manufacturers, see Type Approval Programme. The type approval is mainly based on independent documentation of the coating's long-time durability in real life exposure. Type approved coatings, their areas of use and requirements to steel surface treatment are described in the DNV publications series Type Approved Products.

Standards which may be used in evaluation of coating performance or describing the condition of a coating:
ISO 4628, in which the part 3 is most useful, and ASTM D 610, D 659, D 661, D 714, D 772, D 1654, DIN 53209, NS 5400-5408, etc.
7. Appendix 3: Coating inspector's duties - Checklist

The status and authority of the coating inspector or team of inspectors should be stated in the contract between shipbuilder and owner. The following are indications of relevant tasks and equipment for the inspector that may be considered in such contract.

The coating inspector should have documented qualifications, including knowledge about health and fire hazards concerning this work. Certification arrangements for coating inspectors are established in some countries.

Sacrificial anodes' installation can be covered by the coating inspector. Installations of impressed current systems should be surveyed by a representative from the supplier.

The coating inspector should be involved in the following items described in the guidelines:

- planning
- steel surface preparation
- coating selection and application
- coating quality control and testing (of the tests mentioned in Appendix 2 only a few of those mentioned under 6.1 are normal routine tests for common paint coatings)
- sacrificial anodes installation, if any.

Details of testing and quality control to be carried out by the coating inspector should be defined. During coating operations the inspector's daily duties may be as follows:

**Practical inspection work**

Survey of:

- illumination, access, and compartments for conditioning of temperatures and moisture
- breaking or rounding of edges
- blast cleaning
- cleaning up after blast cleaning
- shielding off painted surfaces from blasting operations
- conditioning of steel temperatures and air temperature
- control of humidity and dew point calculation
- coating application equipment and methods
- dry film thicknesses
- curing times for individual coats in relation to temperature and humidity
- storing of coating materials and abrasives
- specified type of coating to be applied
- cleaning of coated surfaces before application of next coat
- handling or storing or transport of coated objects
- coating repairs, when damaged
- sacrificial anodes, installation in accordance with specification and drawings
- survey that sacrificial anodes are not coated or otherwise damaged.

**Paper work**

Reporting, including:

- documentation of the quality of coated surfaces versus the quality specified
- tests carried out (check of surface cleanliness, film thicknesses, air and temperature controls)
- deviations from specified quality
- documentation of installed numbers and locations of any anodes, to be in accordance with specification and drawings.

**Inspection equipment**

The coating applicator or coating subcontractor should normally have the necessary inspection equipment on site. The most important equipment for the coating inspector will be:

- specification or pictorial standards for steel surface preparation
- pocket knife
- psychrometer (for wet and dry air temperature measurement) or hygrometer
- dew point calculator, electronic type
- steel surface thermometer
- dry film thickness measuring equipment.

Useful additional equipment may be:

- inspection mirror
- pull-off adhesion test equipment
- Rugotest or surface profile gauge
- paint inspection gauge.
8. Appendix 4: Corrosivity and corrosion resistant materials - a brief review

8.1 The marine environment - corrosivity

The corrosivity of sea water varies relatively little in the oceans. Even in local areas like the Baltic Sea, where the salt content is considerably lower than in the large oceans, there is enough salt to make the water an electrolyte and thus corrosive. The resistivity of the water is a measure of its electrolytic properties. Typical resistivities are for example (see references (1) and (5))

- in open sea water, temperature about 25 °C, 20 ohm cm
- in open sea water, temperatures below 10 °C, 30 ohm cm
- in sea bottom mud or sediments, 75 - 150 ohm cm
- in brackish river water, 200 ohm cm
- in distilled water, 500000 ohm cm.

The corrosivity of sea water as regards general corrosion on steel increases with increasing temperature, oxygen content, water velocity, content of corrosive contaminants, eroding particles, and conductivity.

Localised corrosion, notably on stainless steels and aluminium alloys, will often be promoted by stagnant water low in oxygen.

Bacterial corrosion (also called micro-biological, anaerobic, etc.) may occur e.g. in ships' oil tanks, ballast tanks, cargo piping, etc., due to that local environments and conditions for bacterial activity are prevailing. These conditions are, briefly

- stagnant (anaerobic) water
- hydrocarbons nourishing bacteria, e.g. crude oil, possibly some coatings or soft coats, etc.
- sulphates present in sea water (the most common corrosion promoting bacteria utilise sulphate for "breathing" instead of oxygen)
- ideal temperatures for bacterial growth (about 20 to 40 °C)
- sufficient numbers of bacteria to flourish under above conditions are often present in water.

The corrosivity of the marine atmosphere is dependent on its content of chlorides, sulphates or sulphites and other air contaminants, including soot and dust particles. The corrosivity thus generally decreases with increasing height above sea level.

The corrosion promoting effect of salts, dust etc. in the marine atmosphere is due to, mainly

- increasing conductivity of moist film on metal surfaces
- prevention of a moist film on metal surfaces from drying out, and
- breaking up passive, oxide films on e.g. stainless steels and Al alloys.

8.2 Corrosion mechanisms on steel surfaces in ships

Common corrosion on steel in ships is of the electrolytic corrosion type. General-, pitting-, crevice-, galvanic- or bimetallic-, intercrystalline-, erosion-, etc.- corrosion are all variants of principally the same, electrolytic type. The smaller the anodic (corroding) surface in relation to the cathodic (non-corroding) surface, the more localised, concentrated and rapidly occurring is the corrosion process, e.g. pitting corrosion rates may be very high. Corrosion fatigue and stress corrosion cracking is also of the electrolytic type, though combined with mechanical action.

Dry, high-temperature corrosion may occasionally occur under special conditions, as in engines.

For steel submerged in sea water the accessibility of oxygen to the surface is governing the corrosion rate. This implies that the corrosion rate for different steel grades in submerged, static condition is approximately the same, independent of minor alloying elements.

High strength steels may more often than common steel be subject to high stress levels or cyclic stresses. This can imply increased corrosion rates, due to the stresses as such (stress corrosion cracking or corrosion fatigue), and also due to that a protective layer of rust is prevented from being formed at spots receiving high stress levels or fatigue loads. Fresh, unprotected metal surface is then continuously exposed to a corrosive environment.

Due to high local stresses and strains, the useful life of coatings may be reduced. If so, the corrosion process may get an early start.

Bacterial corrosion, if occurring, may proceed locally at high rates. Indications of bacterial activity are

- rotten smell of hydrogen sulphide H2S (Caution: H2S in high concentrations is odourless to humans. It is very poisonous and also explosive)
- corrosion may occur as smooth pitting
- corrosion products are initially black coloured by iron sulphides
- the black colour disappears rapidly in air due to oxidation of the iron sulphides.

For steel exposed to marine atmosphere the corrosion rate is governed by the rate of transfer of metal ions at the anode, which in its turn is dependent on the amount of contamination elements and alloying elements in the steel. The atmospheric corrosion rate will thus vary significantly with the steel type.

8.3 Factors influencing steel corrosion rates in ships

The corrosion rate on unprotected surfaces, like other chemical reaction rates, generally increases with the temperature.

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DET NORSKE VERITAS
The corrosion rates in a ship can, however, be constant, increase or decrease with the time, dependent on e.g. the following factors:

- a layer of built up corrosion products (rust) on a steel surface will have a protective (coating) effect by limiting the access of oxygen to the steel, thus lowering the corrosion rate
- a layer of corrosion products may render parts of the surface cathodic in relation to other, anodic, parts of the surface lacking such layer experiencing increased corrosion rate
- surfaces exposed to vibrations and/or high stress levels may have increased corrosion rates with time, due to that the thickness reduction of steel plates reinforces vibrations and stress levels
- macro-elements or large aeration cells caused by variations in the oxygen concentration, e.g. at different depth levels in a ballast tank and over or under sediments, may create anodic parts experiencing accelerated corrosion and other parts cathodic, non-corroding
- areas with locally degraded coating may become anodic compared with areas with intact coating, resulting in pitting corrosion.

Other, operational factors may also influence the corrosion rates in a ship, e.g.:

- percentage of time in ballast or ballasting routine
- moisture content of empty tanks
- temperature of cargo or fuel in adjacent tanks
- cathodic protection, application and design and anode distribution
- coating type and application, including steel surface preparation
- maintenance of corrosion protection systems
- structural design of ship and tanks
- frequency and method of tank washing
- clean or dirty ballast
- cargo type and composition, including contamination
- use and type of inert gas
- trade, speed and sailing route
- etc.

Depending on the above factors, unprotected steel internally in ships ballast tanks may typically, allowing for great deviations, experience average corrosion rates (see reference (2)) of the order of 0.2 - 0.4 mm/year. Local corrosion, e.g. pitting and corrosion in way of welds, may proceed at much higher rates.

8.4 Metallic materials other than steel

Significant features concerning the corrosion or protection aspects of a few important groups of metallic materials are briefly mentioned below:

8.4.1 Stainless steels

The so called stainless steels owe their corrosion resistance to a thin surface film of oxides, called a passive film. The oxide film is cathodic compared with the base metal, and when broken, the adjacent base metal exposed to sea water will act as a sacrificial anode. Pitting will occur, often at a high rate.

The passivity of the oxide film is dependent on oxygen supply and on the chemical-metallurgical composition of the base metal. Notably the content of molybdenum must be above a certain minimum to withstand depassivation by chlorides. Only a few types of "high molybdenum" type stainless steels are resistant to sea water, i.e. those with Mo-contents above about 6 %, e.g. 0.02 % C, 20 % Cr, 18 % Ni, 6,1 % Mo, 0,2 % N, 0,7 % Cu. At temperatures > 15 °C, however, the 6% MO stainless steels can suffer from crevice corrosion in sea water.

The most commonly used austenitic type stainless steels, e.g. 0,03 % C, 18,5 % Cr, 14,5 % Ni, 3,3 % Mo (AISI 316 and related products) are not resistant to sea water. Modern duplex steels may be somewhat more resistant.

Pitting or other localised attacks in stainless steels are thus often due to:

- lack of oxygen, e.g. in stagnant sea water, underneath debris or adherent particles
- local chemical or metallurgical surface defects, e.g. caused by welding.

It follows that success of stainless steels in sea water are dependent on a non-intermittent flow of water and of the surface being kept smooth and clean. Proper welding procedures must be strictly adhered to.

Further, stainless steels are more noble, i.e. of significant cathodic character compared with common ship construction steel. When sea water or moist marine air is present, unprotected black steel in electrical contact with stainless will corrode more quickly than if it were alone, due to galvanic corrosion.

Stainless steel types used for chemical cargoes should be selected based on a critical evaluation of information provided by the manufacturers of the steel and of the chemicals. Close attention should be given to the welding procedures, and to the contaminants of the cargo, which may be more corrosive than its main constituent.

8.4.2 Aluminium alloys

The sea water resistance of Al-alloys depends, as for stainless steels, of a thin, cathodic film of oxides. If the film is destroyed, the Al-alloy is likewise prone to pitting, according to the same mechanisms as stainless steels.

Contrary to stainless steels, Al-alloys are anodic, i.e. less noble, compared with black steel. In metallic, electrical contact and exposed to sea water or marine atmosphere, the Al-alloy will corrode, sacrificing itself and protecting the steel.
Typical Al-alloys used in marine construction are given in Table 8.1.

<table>
<thead>
<tr>
<th>Table 8.1 Typical Al-alloys</th>
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<tbody>
<tr>
<td>Alloy</td>
</tr>
<tr>
<td>AlMg2.5 - AlMg4</td>
</tr>
<tr>
<td>AlMg3Mn</td>
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<tr>
<td>AlMg4.5Mn</td>
</tr>
<tr>
<td>AlMgSi1</td>
</tr>
</tbody>
</table>

* maximum Mn content varying from 0.4% for Mg 2.5 to 0.8% for Mg 4.

Other elements in Table 8.1, maximum values, %: Cu: 0.10, Fe: 0.50, Cr: 0.35, Zn: 0.20, Ti: 0.20, Other: Each 0.05, Total 0.15.

Al-alloys, including the above, may suffer from localised corrosion such as pitting. Cast alloys of AlMgSi type are relatively prone to pitting corrosion. The general corrosion rate in sea water is, however, normally low, i.e. (0.005 mm/year). Pitting may be initiated on e.g. Al hulls of vessels when idle in harbours with stagnant sea water, underneath marine growth or anti-fouling coating.

The AlMg alloys may be subjected to stress corrosion cracking at contents of Mg > = 4.5 % in strain hardened and stabilised condition. Materials for bolts and rivets should have < 3.5 % Mg.

Galvanic corrosion is well known on Al alloys in the presence of an electrolyte such as sea water or a chloride containing film of moisture. Metallic contact between Al and e.g. copper, nickel, chromium, stainless steels and mild steel should be avoided in the presence of sea water or moist, marine atmosphere. Al/Zn (e.g. galvanised steel), Al/cadmium and usually Al/lead are harmless.

Stainless steel screws or bolts are often used in Al alloy constructions. When submerged in sea water or when a film of moisture will often be present at the surface, electrical insulation is necessary between stainless steel and Al. Metallic contact Al/stainless steel screw or bolt may be adequate in marine atmosphere at some height above the water level (e.g. some helicopter deck constructions) provided the surface connection is kept dry most of the time by abundance of fresh air. Al/stainless steel contacts are harmless in a dry, indoor atmosphere.

Copper content in Al alloys above the above limit of 0,10 % may initiate intergranular corrosion.

AlSiCu and AlCuTi cast alloys should thus not be used in marine construction.

AlZnMg alloys may be prone to stress corrosion cracking and should thus be avoided.

8.4.3 Copper alloys

Typical propeller casting materials are the Ni-Al-bronzes.

The typical composition of Ni-Al-bronzes is minimum 78 % Cu, 8 - 11 % Al, 3 - 6,5 % Fe, 3 - 6.5 % Ni, maximum 3 % Mn and total other elements maximum 0.5 %.

Ni-Al-bronzes are resistant to high water velocities and pure sea water. Like all other Cu-alloys, they are susceptible to sulphide polluted waters.

Filling of newly installed cuprous alloy piping systems with foul harbour water should be avoided.

Typical tube materials are

Al-brass : 76 - 79 % Cu, 0.02 - 0.035 % As, 2 % Al and Zn

Cu-Ni 90/10: 10 % Ni, 1.0 - 1.8 % Fe, 0.5 - 1 % Mn
Cu-Ni 70/30: 30 % Ni, 0.4 - 1.0 % Fe, 0.5 - 1.5 % Mn.

Copper has relatively low chemical reactivity and is cathodic, i.e. of noble or inert character compared with steel. The corrosion resistance of Cu-alloys, however, often depends on a thin film of surface oxides. If the protective surface oxide film on Cu-alloys are broken down by too high water velocity, erosion or contaminants in harbour waters, corrosion attacks may occur.

For tube materials in heat exchangers (see reference (3)) recognised flow velocities should not be exceeded to avoid corrosion attacks as given in Table 8.2.

<table>
<thead>
<tr>
<th>Table 8.2 Maximum flow velocities in heat exchangers</th>
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</thead>
<tbody>
<tr>
<td>Tube material</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Al-brass</td>
</tr>
<tr>
<td>Cu-Ni 90/10</td>
</tr>
<tr>
<td>Cu-Ni 70/30</td>
</tr>
</tbody>
</table>

Joining of tubes by welding or other methods may introduce local deviations from the base material composition of great consequence for the corrosion resistance. Proper procedures for joining and installation should be strictly adhered to.

8.4.4 Galvanic series of metals and alloys

Joining together different metals or alloys may result in rapid galvanic corrosion on the less noble alloy, which will act as a sacrificial anode relative to the nobler, cathodic alloy. Necessary conditions for such corrosion are that the two alloys stay in electrical contact and that sea water or a film of moisture is present. Insulating flanges and bolts, coating, or dry conditions, will prevent galvanic corrosion from occurring.
Below is inserted a table of galvanic series in sea water (see reference (4)) for relevant metals and alloys, with relative potential differences (from F. L. LaQue, Marine Corrosion - Causes and Prevention). For practical purposes, galvanic corrosion will usually not be significant at potential differences less than 50 - 100 mV.

Generally, the surface ratio between anodic (less noble) and cathodic (more noble) metals will influence the galvanic (bimetallic) corrosion attack on the anodic surface. Two common conditions are, however, worth considering: The fully submerged and the moist surface film condition, respectively:

**Fully submerged in bulk sea water (electrolyte):**

E.g. a stainless steel bolt (cathodic) with small surface area in contact with a large surface area of aluminium (anodic) is normally far less harmful than if the opposite situation should occur, because the corrosion attack on the Al alloy surface will be spread out evenly on a large surface.

**Moist surface film (electrolyte):**

Due to the low thickness of the moist film, the surface effect of a large anode versus a small cathode will be cancelled (no spreading effect of corrosion current through the bulk electrolyte). E.g. a stainless steel bolt in an aluminium alloy construction will give local corrosion attack on the aluminium adjacent to the bolt.
Figure 8-1 Galvanic series in sea water
Volts: Saturated calomel half-cell reference electrode

Note regarding Figure 8.1:
Alloys are listed in the order of the potential they exhibit in flowing sea water (2.4 - 4 m/sec, temperatures 10 - 27 °C).

Certain alloys indicated by black rectangles in low-velocity or poorly aerated water, and at shielded areas, may become active and exhibit a potential near -0.5 V.

8.5 Cargo and ballast handling - design against corrosion
Ballast water and cargoes often promote corrosion, as in the typical cases of:
Tankers for oil: Acid water containing sulphurous components from the oil may settle out in the bottom of cargo tanks, ballast tanks and cargo piping, causing corrosion problems.
Ore carriers: Impacts from grabs may damage the corrosion protection systems on both sides of exposed plates.

Ore carriers: Corrosion attacks may occur from water acidified by the ore.

Ballast tanks: Heavily exposed to sloshing sea water, cyclic changes of temperature and hydrostatic pressure, wetting and drying, often of intricate construction, with difficult access, inadequate drainage, etc., invite corrosion to unprotected surfaces.

In designing and constructing of the ship attention should be paid to cargo handling and ballasting operations, to facilitate drainage, cleaning and drying up of empty tanks and holds.

Access must be ensured for application of adequate corrosion protection systems where most likely needed. Details often overlooked are for instance small cut-outs in corners, which are made too small for proper surface treatment and for access of painters' spraying equipment. "Mice holes" should be enlarged to "rat holes" with diameter minimum 100 mm.
9. Appendix 5: Surfaces - Preparation, Coating and Corrosion

In Figure 9.1 are shown some figures illustrating various aspects of steel surface preparation and coating related to the subjects treated in these guidelines.

Figure 9-1 Examples of area percentages

The black spots of the figure representing 3% of the surface is denoted as Rust Grade 5, those representing 1% is denoted Rust Grade 6. Figure copied from ASTM (see reference (9)).

The figure is referred to in the guidelines for defining
  - due time for maintenance coating (1% = Rust Grade 6), and
  - useful life of a coating (3% = Rust Grade 5).
### Sharp Edge

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<table>
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<tr>
<td></td>
<td>Gas Cut Edge</td>
</tr>
<tr>
<td>A</td>
<td>Remove by grinder or disc sander.</td>
</tr>
<tr>
<td>B</td>
<td>Rolled steel sections normally have radiused edges. Therefore can be left untreated.</td>
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</tbody>
</table>

### Weld Spatter

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<tr>
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<tbody>
<tr>
<td>A</td>
<td>Remove spatter observed before grit-blasting with grinder or chipping hammer.</td>
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<tr>
<td>B</td>
<td>For spatter not readily removed. Remove using grinder/disc.</td>
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</table>

### Lamination

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<td></td>
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<td></td>
<td>Remove using grinder.</td>
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### Undercut

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<tr>
<td></td>
<td>Undercuts exceeding classification ruling should be repaired by welding and grinding.</td>
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</table>

### Manual Weld Bead

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<tr>
<td></td>
<td>Sharp Profile peaks to be smoothed using grinder.</td>
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</tbody>
</table>

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**Figure 9.2 Preparation of steel**

The figure (originally made by Camrex Limited (see reference (9))) illustrates important surface details to be prepared for coating application. All the above preparations should be carried out before blast cleaning.
Figure 9-3 Stripe coating locations
(from Camrex (see reference (9))

1: Inside edge of cut outs. 2: Edge part of stiffeners. 3: Welding beads. 4: Where spraying is difficult.
Regarding the extent of coating, see also the DNV Rules, reflecting IACS Unified Requirement. The inner bottom should have increased steel plate thickness due to susceptibility to corrosion and physical wear. Holds for grain and other cargoes to be kept clean should have coated inner bottom.

**Figure 9-4 Recommended extent of coating in cargo holds on bulk carriers**

Wing ballast tanks:

- a) Upper part of transverse and longitudinal bulkheads (not illustrated)
- b) Upper part of deck transverses
- c) Longitudinals
- d) Cut edge of slots and drain holes in transverses
- e) Block butts in internal members and in bulkheads
- f) Junction of cross ties to side transverses or vertical webs
- g) Bulkhead plate at the level of double bottom tank top (not illustrated)
- h) Upper surface of tank top plating incl. hopper tank plating
- i) Hold frames, particularly lower part, upper part and frame bracket at toe and HAZ
- j) At about 40% of height (normally top of cargo with cargoes not trimmed)

**Figure 9-5 Recommended extent of coating in cargo holds on bulk carriers**

Cargo holds:

**Figure 9-6 Parts liable to corrosion in bulk carriers or OBOs**

Holds and bulkheads:

- Lower end of hold frames
- Lower end of water tight bulkhead (not illustrated)
- Corners of lower decks
- Bilge wells
- Double bottom ballast tanks:
  - c) Corners of lower decks
  - d) Bilge wells
  - e) Upper surface of face plates of bottom and tank longitudinals
  - f) Floor plate around filler plates to slots
  - g) Upper surface of tank top plating

(from Y. Akita (see reference (11))

**Figure 9-7 Parts liable to corrosion in oil tankers**
Water ballast tanks:

a) Upper part of transverse and longitudinal bulkheads
b) Upper part of deck transverses
c) Deck longitudinals
d) Upper surface of horizontal stiffeners and brackets (not illustrated)
e) Cut edge of slots and lightening holes in horizontal girders

f) Upper surface of horizontal girders
g) Upper surface of shell and bulkhead longitudinals
h) Upper surface of face plate of bottom longitudinals, bottom girders and bottom transverses

Cargo tanks:
i) Structural members in vapour spaces of tanks (not illustrated)