

CLASS GUIDELINE

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Corrosion protection of ships

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FOREWORD

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CURRENT – CHANGES

This is a new document.

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SECTION 1 GENERAL

1 Introduction

The aim of this guideline is to indicate different recognised methods for corrosion protection and surface preparation of ships and systems installed on ships, with emphasis on tanks and holds. For ballast tanks, double side skin space of bulk carriers, void space, cargo oil tanks and permanent means of access, this guideline refers to the IMO and IACS regulations, resolutions, circulars and interpretations.

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

The guideline is not mandatory for classification use but for assisting in the selection of effective corrosion protection systems by shipyards and owners.

Definitions and terms, properties and standards for protective 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.

2 Limitations

Corrosion as a mechanism cannot be prevented entirely as such; it is merely possible to minimize the corrosion rates and the effects of the corrosion.

The aim should be to reduce the corrosion rate to an acceptable level for a certain area by means of corrosion protection measures, e.g. an appropriate selection of materials, application of the corresponding design principles, suitable coating systems, through cathodic protection or a combination of several measures. The result is that, with a high degree of probability, the specified lifetime of the structure is ensured and no corrosion damage will occur, provided that no external event damaged the corrosion protection measures.

The corrosion and the corrosion rate depend on many different parameters. Application and environmental conditions, material properties, stress and strain states, as well as the effectiveness and efficiency of protective measures, surface preparation and surface cleanliness, all have an influence on corrosion.

Damage by corrosion can certainly be prevented. The principles and information given in the guideline is based on normative standards and values from experience which, applied correctly, will assure an adequate degree of corrosion protection for ships and components subjected to seawater and a marine atmosphere, if the measures are applied with care and follow the recommendations from the manufacturers e.g. regarding surface preparation, climatic condition during coating and production control and documentation of all processes.

However, this does not release the operators/owners and designers from the obligation to assess properly the features of each particular system, structural part or component and to consider the relevant corrosion hazard. In particular, the corrosion protection measures which are applied, their maintenance, repair and the servicing activities shall be coordinated to suit the component or the structure and also the specified lifetime.

In designing the corrosion protection, the specific contractual conditions and agreements between the purchaser/owner and the manufacturer/shipyard shall always be taken into account.

For the design of the corrosion protection, the relevant normative references shall also be considered. Upon request, DNV GL can act in an advisory capacity.

The guideline is aiming at being easy to use. No subject is treated in great depth or detail. Recommendations given in the guideline shall not replace instructions or recommendations given by the manufacturers of protective coating systems or cathodic protection systems.

3 Definitions

Table 1 Definitions

Term	Definition
alkyd	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. Usually they are not suited for submerged service as they absorb too much water leading to swelling of the alkyd paint film
anode	the corroding part of an electrochemical corrosion cell (sacrificial anode or impressed current anode)
anti-fouling coating (or paint)	coating for use on under water areas on hulls to prevent growth of living organisms, usually containing toxic agents (biocides). Fouling release coatings on the other side do usually not contain any biocides. Fouling release coatings have a smooth where organisms have difficulties to attach to
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. Main properties of paint will be decided by binder, it describes the type of paint/coating
cathode	the non-corroding or protected part of an electrochemical cell
cathodic protection	<p>protecting a metal surface from corrosion by making it a cathode in an electrochemical corrosion cell</p> <ul style="list-style-type: none"> — 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
coat (coats)	short expression for coating layer(s)
coating system (protective coating system)	the total sum of the coats of paints (or materials) which are applied to the substrate to provide corrosion protection
conductivity	the inverse of the resistivity (ohm cm). In the guideline: Conductivity, i.e. specific electrical conductance, of an electrolyte, usually water or 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

<i>Term</i>	<i>Definition</i>
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. Due to health problems with coal tar, these coatings are now prohibited in most countries and no longer recommended
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 sometimes 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
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 (definition according to IMO Resolution A.798(19)). 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
hardener	hardener is the B component in an epoxy coating. Epoxies are amide or amine cured
hold paint (holding primer)	applied after welding, intended to stay under full epoxy coats
inhibitor	chemical having an inhibiting effect on corrosion, usually added to a closed liquid or gaseous system
lining	are commonly of higher thickness than coatings, most often above 1 mm, and are usually applied internally in tanks, pipes or vessels, but they can also be applied externally for example on pipelines. 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
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
mechanical cleaning	power tool cleaning, by means of grinding disc, wire brush, or similar
MEK test	solvent rub test usually performed using methyl ethyl ketone (MEK) as the solvent. The MEK test indicates resistance or degree of cure of zinc silicate shop primers
paint	pigmented coating materials in liquid, paste or in powder form that, when applied to a substrate, forms an opaque film having protective, decorative or specific technical properties
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)

Term	Definition
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 (ISO 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 2½)	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 (pre-fabrication primer, pre-construction primer)	thin (approximately 15 – 25 microns) primer coating applied for temporary protection of steel plates in automatic plants. The main function is to protect the steel against corrosion and pollution during the building stage
soft coating	coating that remains soft so that it wears off when touched; often based on oils or sheep wool grease. Please see Sec.3 [2.3] for additional notes
semi-hard coating	coating which dries in such a way that it stays soft and flexible although hard enough to touch and walk upon. Please see Sec.3 [2.3] for additional notes
solvent	dissolves the binder and defines the application properties for brush, roller or spray (viscosity). Typical solvents are water, white spirit, xylene, toluene, alcohols, and glycols. Single or blended solvents may be used for a paint system
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 (ISO 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. The surface preparation is 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 the guideline, if not a more precise definition is given, steel means carbon steel including hull structural steel

<i>Term</i>	<i>Definition</i>
stripe coating (stripe coat)	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
sweep blasting	surface treatment by quickly passing a jet of abrasive across surface. It is typically used as a treatment to get some surface roughness on an existing, firm adhering coating in order to facilitate inter coat adhesion
thinner	are used to lower the viscosity of the paint mixture. May be necessary to adjust viscosity for ambient temperature or application method (brush, spray and roller)
ultra-high pressure water jetting	is cleaning with water pressures above 1,700 bar (definition by SSPC and NACE) or above 1,400 bar (definition by ISO 8501-4)
vinyl	binder in paints or coatings based on dissolved or emulsified vinyl chloride or vinyl acetate polymers (Vinyl chloride: $\text{CH}_2 = \text{CHCl}$). Vinyl paints are of one-component, air drying type
zinc rich coating (or paint 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

4 Abbreviations

Table 2 Abbreviations

<i>Abbreviation</i>	<i>Description</i>
ASTM	American Society for Testing and Materials
BS	British Standard
DIN	German Standard
EN	European Standard
ISO	International Standardization Organization
NACE	National Association of Corrosion Engineers (USA)
SIS	Swedish Standard
SSPC	Steel Structures Painting Council (USA)

SECTION 2 NEWBUILDINGS – CORROSION PROTECTION OF SHIPS

1 General

This section aims at indicating coating systems for ships. The present IMO standards are:

- IMO Resolution MSC.215(82) *Performance standard for protective coatings for dedicated seawater ballast tanks in all types of ships and double-side skin spaces of bulk carriers*. Hereafter called IMO-PSPC-WBT.
- IMO Resolution MSC.288(87) *Performance standard for protective coatings for cargo oil tanks of crude oil tankers*. Hereafter called IMO-PSPC-COT.
- IMO Resolution MSC.244(83) *Performance Standard for Protective Coatings for Void Spaces on Bulk Carriers and Oil Tankers* (not mandatory). Hereafter called IMO-PSPC-VS.

In addition to the standards above, both IMO and IACS have published a number of documents regarding the interpretation of these standards. Those documents are listed in [Sec.11 \[1\]](#).

2 Structural design

Ships, systems and components should be designed with the aim of ensuring optimum corrosion protection through the application of suitable structural measures. Amongst others, the following measures have proven their worth in practice:

- The structural design should be such that subsequent activities for the passive and active corrosion protection, such as surface pre-treatments, coating work, inspections, maintenance and repair, can be performed in an good manner, e. g. by ensuring good accessibility.
- The surfaces shall be designed to be as flat as possible. Any stiffeners, internal parts and piping, etc. should, wherever possible, be arranged in areas less at risk from corrosion.
- Shadow effects, which impede the coating work (such as open, deep gaps) shall be avoided.
- Burrs and sharp edges should be rounded off, in order to facilitate the coating work and to increase the durability of the coating.
- Areas where moisture tends to collect, thus facilitating the origination and propagation of corrosion, e. g. gaps and sumps, shall be avoided as far as possible.
- Accumulations of condensed water in steel structural elements can be avoided by providing sufficient venting possibilities.
- The possibility of performing a proper cleaning and pickling, especially in the case of passivable materials, e. g. austenitic steels, shall be provided after the welding process.
- Mixed construction using different materials should, if possible, be avoided; otherwise suitable insulating measures shall be applied.

3 Planning

To obtain long life protection, the application or installation of corrosion protection systems (coatings and anodes if present) should be a well-planned activity, integrated in the shipyard's construction plans. Care should be taken to avoid conflicts with other shipyard operations, notably piping installations and welding. Damages of the corrosion protection system due to welding activities after the coating system was applied are typical starting points for corrosion later in the service life of the vessel, even if these coating defects are repaired.

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.

4 Surface preparation of unalloyed and low-alloy steel

The preparation of steel surfaces is of greatest importance for the durability of a coating system. It may be more important than the selection of the specific 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.

4.1 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 2½ according to ISO 8501-1.

The MEK test method is used to determine the degree of cure of shop-primer film by the paint film resistance to a specified solvent. The solvent rub test is usually performed using methyl ethyl ketone (MEK) as the solvent. The MEK test method indicates the resistance or degree of cure of applied shop-primer (See ASTM D4752).

The best shop-primers from a corrosion protection point of view are those containing zinc (Zn), preferably inorganic silicate based. 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 ($> \approx 1700$ bar) with equipment free from back thrust and combined with chloride control (maximum conductivity corresponding to ≈ 20 -50 mg/m² sodium chloride (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 shipyard) 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.

The three IMO-PSPC's have the same requirement for the primary surface preparation and shop-primer: Blasting and profile: Sa 2½; with profiles between 30-75 µm, Water soluble salts: ≤ 50 mg/m² of NaCl and shop-primer: Zinc containing silicate based shop-primer compatible with the main coating system.

4.2 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 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.

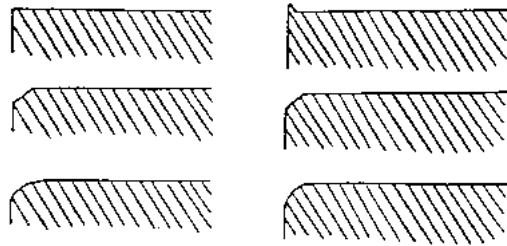


Figure 1 Edges on steel plates, enlarged, cross section.

Upper case: Sharp. Middle case: Broken, after one pass of grinding tool. Lower case: Rounded after blast cleaning.

Edges from gas and/or plasma cutting are often sharp, though not necessarily always so. Edges of rolled sections may more often than not be well rounded, though not always, depending on types of sections, profiles, and rollers. A definition of sharp edges may be: Edges with radius $r < 2$ mm (in some paint specifications, e.g. IMO-PSPC requirements, rounded edges are defined as with $r \geq 2$ mm).

Welds should be ground where necessary, so that weld beads, weld spatter or other surface irregularities that can reduce the coating's useful life are removed. See [Sec.10](#).

If the above treatment of edges and welds is not carried out, coatings will be:

- applied too thin, and
- easily damaged by light mechanical impact and flowing liquids.

The consequence will be that the coating's effective lifetime is reduced to a fraction of what it could have been.

It is difficult to measure coating film thickness on edges by non-destructive methods, even when rounded to $r = 2$ mm. Stripe coating is a common means of obtaining the same film thickness on edges as on plain surfaces.

4.3 Blast cleaning and inspection

Zinc rich shop-primer is generally recommended. Compatibility with Zn rich primer and coating system must be ensured by the coating manufacturer. In case of IMO-PSPC, compatibility with shop primers is mentioned on the type approval certificate of the main coating systems.

After finishing operations [\[4.1\]](#) to [\[4.2\]](#), 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 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.

To prevent impairments by dust or blasting agents, the blasting activities should not be performed at places near which coating work is being done or near which coatings have not yet dried properly. Local regulation regarding work conditions for the involved personnel as well as environmental legislation must be considered as well.

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 or the owner. Sa 2.5 is recommended to obtain 15 years useful life. Other, equivalent cleanliness standards are stated in [Sec.7](#). Blasting abrasives and dust shall be completely removed after finished blasting operations, e.g. by means of vacuum cleaning, compressed air and brushes.

As the blasting agents, copper works' slag, fused corundum as well as iron or steel blasting agents can be considered. The use of silica sand shall be avoided

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 shipyard and owner and coating manufacturer.

Indications of a coating inspector's duties are given in [Sec.8](#).

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

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. It should also be noted that power tool cleaning is generally less effective and more time consuming than blast cleaning.

Ultra high pressure water jetting ($> \approx 1700$ bar) with equipment free from back thrust and combined with chloride control (e.g. maximum conductivity corresponding to $\approx 20, 30$ or $50 \text{ mg/m}^2 \text{ NaCl}$) 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, hydro blasting, wet sand blasting, etc. also on newbuildings may possibly be realistic, subjected to specific conditions. Environmental concerns in some countries related to mechanical surface blasting may increase the interest in water jetting in future.

4.4 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 should be St 3 (ISO 8501-1) or equivalent standard (for comparison with blast cleaning, see [\[4.3\]](#)) and minimum $25 \mu\text{m}$ surface profile.

Mechanically cleaned steel (wire brushing and similar) is really not adequate for a long expected lifetime of the coating system but may have to be accepted in shipbuilding on block joints and on a minimum of spots of damaged coating, for practical reasons.

5 Surface preparation of cast iron

For cast iron as a coating substrate, the same prerequisites as for steel apply in principle. However, in contrast to rolling scale, the relatively thin casting skin need not be removed. The surface roughness is greater than for steel.

6 Surface preparation of stainless steel

Blasting shall be performed with ferrite-free blasting agents (proportion of metallic iron: max. 0.1%). The blasting agents shall not have been used on ferritic materials beforehand. All adherent welding spatters, welding beads and welding cinders shall be removed. Brush, pick hammers, spatulas and scrapers shall be made of stainless austenitic steel. Non-metallic brushes are permissible. Abrasive media shall be ferrite-free and shall not contain an insert of steel wire.

Abrasive disks or belts shall not have been used on ferritic components beforehand. For the purity not achieved by blasting, a metallic smooth surface on the basis of surface quality grade "St3" or "P St3" is required.

Annealing colours shall generally be removed by pickling or blasting. Grinding is permissible in exceptional cases. The pickling solution shall not contain any hydrochloric acid. After pickling, the surface shall be neutralized by thorough washing with fresh water, especially in crevices. As a matter of principle, it shall be ensured that components that are no longer to be subjected to surface treatment are protected against ferritic abrasion, e.g. during storage: rust films, sparks from flame-cutting, welding or grinding.

If foreign contamination cannot be removed by the above-mentioned procedures and agents, suitable measures shall be taken after agreement has been reached.

For the primer, the average surface roughness R_z shall be 30–45 μm . In confined spaces for which this surface roughness can only be achieved with difficulty, owing to the polishing effect of the blasting agent, metal sheets with a defined surface roughness of 50 μm can also be used. This parts shall be cleaned thoroughly before the coating is applied, e.g. by dry-ice blasting. For surfaces which are to remain uncoated, the roughness should be as low as possible.

The blasting agent grain size and shape shall be selected so that sharp-edged surface is attained for the components to be coated, and a smooth, fine surface for components which are to remain uncoated.

7 Surface preparation of copper alloys and of materials with metallic coatings of zinc or aluminium materials

The components shall be thoroughly cleaned and degreased. The cleaning procedure shall be coordinated with the coating manufacturer.

The following procedures are permissible:

- cleaning with cold detergent and subsequent washing with fresh water
- steam jet cleaning with dosing of chemicals
- high-pressure cleaning with dosing of chemicals
- light blasting
- dry-ice blasting.

Immediately after cleaning/degreasing and drying, the components shall be treated with a wash primer or with a suitable coating material which acts as an adhesion promoter and finish coat at the same time.

All surfaces shall be thoroughly degreased. For this purpose, chlorine-containing detergents shall be avoided, as they can lead to corrosion problems.

7.1 Cleaning

The cleaning procedure shall be compatible with the corresponding coating material.

7.2 Pickling

An acidic pickling solution shall be applied uniformly to all surfaces to be treated. After application, the detergent shall be left to act on the material surface for the reaction time specified by the manufacturer, which is usually 20–30 minutes. Then the surface shall be washed thoroughly with fresh water, until the pH value of the washing water corresponds to that of the fresh water.

7.3 Grit-blasting

Only ferrite-free special fused alumina shall be used as the blasting agent. Blasting agents which have already been used for metals other than aluminium shall be avoided, owing to the risk of pitting corrosion. The surface roughness R_z should lie between 25 and 50 μm . The prepared surfaces should be thoroughly freed from dust and coated as soon as possible, since the newly formed oxide layer tends to generate a porous hydrous covering layer under the influence of the weather.

7.4 Mechanical grinding

Mechanical grinding is limited to smaller areas at which coating damage has to be remedied or where, because of the local conditions, no blasting or pickling can be performed. A coarse-grained grinding disc should be used, in order to achieve a suitable surface condition in accordance with the specifications of the coating manufacturer. The blasting should extend at least 25 mm into the adjacent coated surfaces

8 Protective coatings – general

8.1 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 [4] for details. 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.

8.2 Coating specification

A coating specification should be mutually agreed between shipyard and owner and coating manufacturer. Coating 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 manufacturer's accepted for delivery
- shipyard'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.

8.3 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%. Testing should be carried out on adequately aged coating, not only on new, fresh coating.

8.4 Coating application and curing

Coatings, including shop-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 stripe coating is recommended for edges and welds.

Clean conditions: See [4.1] to [4.2].

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.

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 (profiles, inside edges, holes, notches, corners, angles, weld seams, etc.)
- stripe coats shall be applied by brush or roller. Roller to be used for scallops, rat holes, etc. only. Roller application will not force the paint into the profile of the substrate, but rather deposit it over the peaks.
- the dry film thickness should be as recommended by the coating system manufacturer, this is valid for minimum and maximum DFT
- 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).

9 Coating systems for ballast tanks

The indicated surface preparation in the tables is the minimum surface quality required by IMO-PSPC.

The estimated target useful life is meant an indication of durability, based on collected experience and information. It shall 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.

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 de-ballasting 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.

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 D610, or \approx rust scale Ri 3, ISO 4628-3).

The above definitions are chosen as practical compromises among several possible alternative definitions. Light coloured coatings have to be used to facilitate inspections.

DFT means dry film thickness in microns ($= 0,001 \text{ mm}$).

In case the average thickness is used, it should be specified sufficiently high to obtain a target minimum DFT. E.g. minimum 90% of all thickness measurements should be \geq the specified DFT. Of the remaining 10% of the measurements, none should be below 90% of specified DFT (90/10 rule). E.g. for ballast tanks, required DFT of $320 \text{ }\mu\text{m}$, 10% of the thickness measurements can be between 288 ($= 0.9 \cdot 320 \text{ }\mu\text{m}$) and $320 \text{ }\mu\text{m}$.

As for most coating types, it may be important that a maximum thickness specified by the coating manufacturer is not exceeded. Coating manufacturer's recommendations should be followed, please refer to relevant TDS and/or application instructions.

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.

Comment regarding the estimated 15 target useful life:

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.

The requirements mentioned in IMO-PSPC for seawater ballast tanks are minimum requirements. Better standards, for example a lower value for the salt concentration, can be used in order to achieve a longer target useful life.

Table 1 Coating system for seawater ballast tanks (IMO-PSPC)

Target life time	15 years
Coating system ¹⁾	Epoxy based, type approved. Other hard coating with type approval certificate for PSPC seawater ballast tanks.
Coats and thickness	Minimum two (2) coats. ²⁾ Total nominal dry film thickness (NDFT) minimum $320 \text{ }\mu\text{m}$. ³⁾
Primary surface preparation	Zinc containing, silicate based pre-fabrication primer on surface blast cleaned to minimum Sa 2,5.
Secondary surface preparation	Sharp edges to be rounded to 2 mm radius. Damaged shop primer blast cleaned to Sa 2½, including welds and burns. Sa 2 removing at least 70% of intact shop primer, which has not passed a prequalification. Intact shop primer to be sweep blasted. Mechanical cleaning to St 3 acceptable on block joints and damages to the applied coating system. Surface treatment after erection: Butts St 3 or better or Sa 2½ where practicable. Small damages up to 2% of total area: St 3. Contiguous damages over 25 m^2 or over 2% of the total area of the tank, Sa 2½ shall be applied.

Target life time	15 years
Clean conditions	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. The chloride content on surfaces to be coated shall be less than 50 mg/m ² (as NaCl) according to Bresle conductimetric method, or an equally recognized method.
Thermal and hygrometric conditions	Air humidity \geq 85% and steel temperature \pm 3°C above the dew point during blast cleaning and coating application operations.
Comments (for complete specification check IMO resolution and corresponding IMO/IACS interpretation): 1) Light colored coatings are required 2) One stripe coat to be applied prior to each full coat on edges, welds and in areas where spraying may not be fully effective 3) Nominal dry film thickness shall follow the 90/10 rule and is defined as follows: The average DFT based on measurements shall always be equal to or larger than the NDFT. Up to 10% 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. The measured DFT shall not exceed the maximum dry film thickness defined by the paint manufacturer.	

10 Protective coating systems for cargo oil and slop tanks

Cargo oil tanks of crude oil tankers shall be protected against corrosion by either coating (IMO MSC.288(87)) or by using corrosion resistant steel (IMO MSC.289(87)). For current valid interpretation of this resolution and possible exemptions check relevant IMO/IACS interpretation. The requirements listed below are again minimum requirements. Better standards can be used.

Table 2 Coating system for cargo oil tanks (IMO-PSPC)

Target life time	15 years
Coating system ¹⁾	Epoxy based, type approved. Other hard coating with type approval certificate for cargo oil tanks.
Coats and thickness	Minimum two (2) coats. ²⁾ Total nominal dry film thickness (NDFT) minimum 320 μ m).
Primary surface preparation	Zinc containing, silicate based pre-fabrication primer on surface blast cleaned to minimum Sa 2,5
Secondary surface preparation	Sharp edges to be rounded to 2 mm radius. Damaged shop primer blast cleaned to Sa 2½, including welds and burns. Sa 2 removing at least 70% of intact shop primer, which has not passed a prequalification. Intact shop primer to be sweep blasted. Mechanical cleaning to St 3 acceptable on block joints and damages to the applied coating system. Surface preparation after erection: For inner bottom St 3 or better, small damages up to 20% – St 3, contiguous damages over 25 m ² or over 20% of the area to be coated – Sa 2 ½. For underdeck: St 3 or better, small damages up to 3% – St 3, contiguous damages over 25 m ² or over 3% of the area to be coated – Sa 2½.

Target life time	15 years
Clean conditions	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. The chloride content on surfaces to be coated shall be less than 50 mg/m ² (as NaCl) according to Bresle conductimetric method, or an equally recognized method.
Thermal and hygrometric conditions	Air humidity $\geq 85\%$ and steel temperature $\pm 3\text{ }^{\circ}\text{C}$ above the dew point during blast cleaning and coating application operations
Areas to be coated	Minimum: <ul style="list-style-type: none"> — deckheads — longitudinal and transverse bulkheads to uppermost means of access — bulkheads without uppermost means of access – 10% of tank height at centreline, not more than 3m down from deck — flat inner bottom + up to 0.3m above inner bottom.
Comments (for complete specification check IMO Resolution and corresponding IMO/IACS interpretation): 1) Light colored coatings are required 2) One stripe coat to be applied prior to each full coat on edges, welds and in areas where spraying may not be fully effective 3) Nominal dry film thickness shall follow the 90/10 rule and is defined as follows: The average DFT based on measurements shall always be equal to or larger than the NDFT. Up to 10% 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. The measured DFT shall not exceed the maximum dry film thickness defined by the paint manufacturer.	

11 Coating specification in void spaces

IMO has issued a standard regarding corrosion protection in void spaces (IMO MSC.244(83)). This standard has not been made mandatory by IMO.

Target life time	15 years
Coating system ¹⁾	Epoxy based or other hard coating, type approved.
Coats and thickness	Minimum one (1) coat. ²⁾ Total nominal dry film thickness (NDFT) minimum 200 μm . ³⁾
Primary surface preparation	Zinc containing, silicate based pre-fabrication primer on surface blast cleaned to minimum Sa 2,5
Secondary surface preparation	Sharp edges to be removed. Damaged shop primer blast cleaned to Sa 2 including welds and burns. Surface treatment after erection: Butts St 3 or better or Sa 2 where practicable.
Clean conditions	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. The chloride content on surfaces to be coated shall be less than 100 mg/m ² (as NaCl) according to Bresle conductimetric method, or an equally recognized method.
Thermal and hygrometric conditions	Air humidity $\geq 85\%$ and steel temperature $\pm 3^{\circ}\text{C}$ above the dew point during blast cleaning and coating application operations.

Target life time	15 years
Comments (for complete specification check IMO Resolution and corresponding IMO/IACS interpretation): 1) Light colored coatings are required 2) One stripe coat to be applied prior to each full coat on edges, welds and in areas where spraying may not be fully effective 3) Nominal dry film thickness shall follow the 90/10 rule and is defined as follows: The average DFT based on measurements shall always be equal to or larger than the NDFT. Up to 10% 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. The measured DFT shall not exceed the maximum dry film thickness defined by the paint manufacturer.	

12 Coating specification for holds in bulk carriers or OBOs

Examples for coating systems are given in [10] and may be modified as regards coating thickness and number of coats, if relevant. The coating shall 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 shall be coated. Internal and external surfaces of hatch coamings and hatch covers are also to be coated

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 coloured coating with one (1)–two (2) coats of hold paints (holding primer) 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.

13 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 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. Coating manufacturers should be consulted for selecting the appropriate coating system and surface preparation

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 over-thickness. The coating manufacturer's recommendations shall generally be followed as regards surface preparation, coating application, coating intervals and curing.

Table 3 Basic coating system: Tanks and miscellaneous areas

<i>Location</i>	<i>Surface preparation</i>	<i>Coating type</i>	<i>Nominal DFT microns</i>	<i>Number of coats minimum</i>
Oil cargo tanks ¹	Sa 2,5	Epoxy based or other qualified	300-400	2-3
Fresh water tank	Sa 2.5	Epoxy	200	2
Product tanks	Sa 3	Epoxy	300-350	2-3
		Phenolic epoxy	300-350	2-3
		Zinc silicate	75 – 100	1
Accommodation and engine rooms	Sa 2 – St 3	Alkyd, etc.	100 – 150	2
Reefers, underneath thermal insulation on tank top or inner bottom plate	Sa 2.5	Epoxy	300	2
Void spaces (except dry, sealed-off compartments), see [11] for details	Sa 2.5 – St 3	Epoxy based	200-300	1-2
Exposed decks	Sa 2.5	Epoxy based with topcoat	300 – 350	2-3
Voids in connection with spherical tanks, LNG carriers	Sa 2,5	Epoxy	300	2
1) Cargo oil tanks of crude oil carriers to be coated according to IMO-PSPC-COT requirements. The measured DFT shall not exceed the maximum dry film thickness defined by the coating manufacturer or as specified by the owner.				

14 Coating for external hull

A coating specification for the ship will include a description of the external hull coating.

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. This surface preparation will give the most durable coating.

The coating manufacturer's recommendations regarding surface preparation, cleanliness and coating application 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 4.

Table 4 Summary of the requirements: Coating system for external hull

Coating system ¹⁾	Epoxy (e.g., pure epoxy or modified epoxy) based. Other recognized hard coating which is pre-qualified. ²⁾
Coats and thickness	Two (2) to three (3) coats. ³⁾ Total nominal dry film thickness (NDFT) 300-400 microns. ⁴⁾
Primary surface preparation	Zinc containing, silicate based pre-fabrication primer on surface blast cleaned to minimum Sa 2.5 with surface roughness: ISO 8503 grade medium G (50 to 85 µm).

Secondary surface preparation	Sharp edges to be removed. Damaged shop primer blast cleaned to ISO 8501 Sa 2.5, including welds and burns. Intact shop primer to be sweep blasted. (Intact and sufficiently cleaned shop primer may be kept as the first coat in the paint system if recommended by the paint producer and accepted by the owner.) Mechanical cleaning to St 3 acceptable on block joints and damages to the applied coating system.
Clean conditions	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. The chloride content on surfaces to be coated shall be less than 50 mg/m ² (as NaCl) according to Bresle conductimetric method, or an equally recognized method.
Thermal and hygrometric conditions	Air humidity ≤ 85% and steel temperature ± 3°C above the dew point during blast cleaning and coating application operations.
Comments to coating system: <ol style="list-style-type: none"> 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 recognized coating system may depend on the type of compartment and its function. 3) One stripe coat to be applied prior to or after each full coat on edges, welds and in areas where spraying may not be fully effective. Stripe coating shall always be applied by brush. 4) Nominal dry film thickness shall follow the 90/10 rule defined as follows: <ul style="list-style-type: none"> — The average DFT based on measurements shall always be equal to or larger than the NDFT. Up to 10% 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. — The measured DFT shall not exceed the maximum dry film thickness defined by the coating manufacturer or as specified by the owner. 5) Only applicable for a reasonable amount of damages. Otherwise the basic surface preparation to be re-applied. 	

Table 5 External hull: Alternative coating systems

<i>Location</i>	<i>Coating type</i>	<i>Total average DFT microns</i>	<i>Number of coats</i>
External hull, under water including boot-top area up to ballasted water line ¹⁾	Abrasion resistant epoxy or aluminium pigmented epoxy or other epoxy anticorrosive +	300–450	2–3
	Anti-fouling coating ¹⁾	250–350	2–3
	Epoxy anticorrosive	200–300	1–2
	Aluminium pigmented vinyl	100	1
	Anti-fouling coating ¹⁾	250–350	2–3
External hull, adjacent to waterline in a zone of about +/- 2 m	Epoxy or polyester based glass flake or glass fibre reinforced ²⁾	600–1500	1–2
	Abrasion resistant epoxy or aluminium pigmented epoxy or other epoxy anticorrosive	300–350	2–3
External hull, above ballasted water, and deckhouse, superstructure	Zinc ethyl silicate or zinc epoxy	50	1
	Epoxy	200–300	1–2
	Polyurethane, acryl polyurethane or polysiloxan topcoat	50–100	1
	Zinc ethyl silicate or zinc epoxy	50	1

<i>Location</i>	<i>Coating type</i>	<i>Total average DFT microns</i>	<i>Number of coats</i>
	Polysiloxan ³⁾	200–300	2
	Epoxy	250–300	2
	Polyurethane, acryl polyurethane or polysiloxan topcoat	50–100	1
<p>Notes:</p> <ol style="list-style-type: none"> 1) The benefit of applying an anti-fouling coating needs to be evaluated. Alternatively fouling release coatings or hard coatings that require regular cleaning may be applied. 2) To provide a flexible heavy duty coating with resistance to some mechanical impact on the hull in a zone around the water line may be considered e.g. glass flake reinforced epoxy 500 µm DFT. 3) Polysiloxan may be applied in thicker coats. Consequently, a higher film thickness may be achieved with a reduced number of coats. 			

SECTION 3 MAINTENANCE OF CORROSION PROTECTION SYSTEMS

1 General

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.

2 Ballast tanks and hull internals

2.1 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 D610 (9) or \approx rust scale Ri 3, ISO 4628-3. The ASTM D610 has a very simple and useful figure for estimation of area percentages and is reproduced as [Figure 1](#) in this guideline. More standards on evaluation of the condition of worn or damaged coatings may be found in [Sec.7](#).

Regarding ballast tanks and cargo oil tanks, IMO has published recommendations for maintenance and repair procedures see IMO Guidelines MSC. 1/Circ. 1330 and MSC.1/Circ. 1339. Maintenance and repair procedures shall be included in the coating technical file (CTF) that every PSPC compliant vessel is required to have on board.

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 [Sec.2 \[4\]](#).

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 owner has two options for maintenance coating:

- dry-dock repairs, or
- repairs at sea.

For ballast tanks and cargo oil tanks, according to IMO (PSPC-WBT and PSPC-COT), maintenance procedures of the corrosion prevention system shall be included in the CTF and any maintenance or repair work related to the coating in ballast tanks or cargo oil tanks shall be recorded in the CTF.

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 1](#) are listed examples of paint coating systems designed for maintenance coating. The list is not meant to exclude other recognized 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 80 mg/m². A recognized 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 1 Maintenance coating

<i>Location</i>	<i>Coating type</i>	<i>Total average DFT micron</i>	<i>Number of coats minimum</i>
Hull internals	Epoxy based, surface tolerant, high tech, mastic, etc., preferably light colored	300–350	1–2
As above	Other recognized system	300, or as recommended by manufacturer	1–2
<p>Notes:</p> <ul style="list-style-type: none"> — The use of aluminium coatings containing greater than 10% aluminium (Al) by weight in the dry film is prohibited in cargo tanks, cargo tank deck area, pump rooms, cofferdams or any other area where cargo vapour may accumulate (i.e. gas hazardous areas), ref. IACS UR F2. — 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. <p>General guidelines for inspection may be found in Sec.8 and Sec.10.</p> <p>Regarding selection of coatings sufficiently flexible on sun heated or hot surfaces and coatings for high strength steels, see Sec.2 [4].</p>			

Recommendations for repair of ballast tank coatings (IMO 1330).

[Table 2](#) describes the recommended medium and long-term repair to restore "GOOD" coating conditions. Coating repair should be inspected by qualified inspectors certified to NACE coating inspector level 2, FROSIO inspector level III or equivalent as verified by the administration.

Table 2 Recommended medium and long-term repair

Purpose	Preparation	Coating system		Dry film thickness (DFT)
Repair of affected area — POOR to GOOD — FAIR to GOOD	— Removal of mud, oil, grease, etc. — Fresh water hosing. — Drying. — St 3 or Sa 2.5* for FAIR condition. — Sa 2.5* for POOR condition. — Intact coating next to damaged area should be feathered. — Total soluble salts, calculated as sodium chloride, according to manufacturer's recommendation, but not more than 80 mg/m ² . — Climatic control.	Medium term (ten (10) year target life) (not recommended for ships of less than five (5) years of age)	— Coating system approved according to Resolution MSC.215(82). — The same coating system as was originally employed, or a coating system compatible with the original system, or equivalent according to manufacturer's recommendation.	— 250 µm DFT**. — Minimum two (2) spray coats with two (2) stripe coats.
		Long term (more than ten (10) years' target life)	— Coating system approved according to Resolution MSC.215(82)	— 320 µm DFT — Minimum two (2) spray coats with two (2) stripe coats

* Refer to standard: ISO 8501-1:1988/Suppl:1994. Preparation of steel substrate before application of paints and related products Visual assessment of surface cleanliness.

** Coating used approved at 320 µm DFT, according to IMO Resolution MSC.215(82), is satisfactory for medium-term at 250 µm DFT.

2.2 Surface preparation

Several methods of surface preparation are relevant:

- 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 descaling
- 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 two (2)–five (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 five (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 ten (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 five (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 ten (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 two (2)–five(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, two (2)–five (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.

2.3 Soft and semi-hard coatings

This category of products is of different chemical origin and they have different properties. Terms such as 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.

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 second 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 (IACS UR Z7) has issued a recommendation that rules 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 addressed/checked before application in ballast tanks, considering that sun heating, adjacent cargo tanks and engine room may cause elevated temperature.

Semi-hard coatings and soft coats will not qualify for relaxation of requirements for annual examination of water ballast tanks (see IACS UR Z7). It is also decided (1995) that DNV GL 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 shall normally be properly cleaned before tank surveys, e.g. the coating shall 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 External hull

3.1 Maintenance coating

External hull coatings should be renewed when necessary. When the necessary control with blast cleaning, humidity and temperature conditions during coating application cannot be obtained, special coating systems designed for maintenance may be used. Examples of such systems are indicated in [Table 3](#).

Table 3 Maintenance paint coating systems – external hull

<i>Coating system</i>	<i>Coating type</i>	<i>Nominal DFT micron</i>	<i>Number of coats minimum</i>
Option A	Epoxy based, surface tolerant, high tech, mastic, etc.,	300–350	1–2
	Anti-fouling coating	Varying	Varying
Option B	Other recognized system,	300, or as recommended by manufacturer	1–2
	Anti-fouling coating	Varying	Varying
Notes: - On submerged areas anti-fouling coating should be applied			

3.2 Cathodic protection – maintenance – renewal

Sacrificial anode systems should be renewed in accordance with the principles outlined in [Sec.6](#).

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

4 Assessment of coating condition (GOOD, FAIR, POOR)

Ballast tank coatings will be assessed by the 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 Society may be reduced.

If the coating is found in POOR condition, or where coating has not been 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.

The condition of the coating in ballast tanks is assigned and categorized as "GOOD", "FAIR" or "POOR", based on visual inspection and estimated percentage of areas with coating failure and rusty surfaces.

The definitions of coating conditions "GOOD", "FAIR" and "POOR" in the guideline on the enhanced programme of inspections during surveys of bulk carriers and oil tankers (based on IMO Resolution A.744(18)) are as follows:

— GOOD: Condition with only minor spot rusting.

- FAIR: Condition with local breakdown of coating 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.

This guideline clarifies the above definitions in order to achieve unified assessment of coating conditions as follows, see also [Table 3](#) below:

- GOOD: Condition with spot rusting on less than 3% of the area under consideration without visible failure of the coating. Rusting at edges or welds, should be on less than 20% of edges or weld lines in the area under consideration.
- FAIR: Condition with breakdown of coating or rust penetration on less than 20% of the area under consideration. Hard rust scale should be less than 10% of the area under consideration. Rusting at edges or welds should be on less than 50% of edges or weld lines in the area under consideration.
- POOR: Condition with breakdown of coating or rust penetration on more than 20% or hard rust scale on more than 10% of the area under consideration or local breakdown concentrated at edges or welds on more than 50% of edges or weld lines in the area under consideration.

Table 4 IMO definition of “GOOD”, “FAIR” and “POOR” coating conditions

	<i>GOOD (3)</i>	<i>FAIR</i>	<i>POOR</i>
Breakdown of coating or area rusted ⁽¹⁾	< 3%	3 – 20%	> 20%
Area of hard rust scale ⁽¹⁾	-	< 10%	≥ 10%
Local breakdown of coating or rust on edges or weld lines ⁽²⁾	< 20%	20 – 50%	> 50%
Notes: 1) % is the percentage calculated on basis of the area under consideration or of the critical structural area 2) % is the percentage calculated on basis of edges or weld lines in the area under consideration or of the critical structural area spot rusting, i.e. rusting in spot without visible failure of coating			

SECTION 4 METAL COATINGS

1 Hot dip galvanizing

Hot dipped galvanizing shall be in accordance with ISO 1461. Minimum thickness for structural items and outfitting steel shall be 125 μm and 900 g/m^2 . Structural items shall be blast cleaned before hot-dip galvanizing. When coating is considered to be required for the galvanized item an epoxy system may be used as a topcoat.

In conjunction with cathodic protection the galvanizing will not provide any benefits as the zinc layer provide a limited anode capability (the zinc represents a very limited anode weight). Consequently, there is no practical benefit to use galvanizing on submerged items.

2 Thermally sprayed coatings

2.1 Surface preparation and application conditions

The surface preparation of the steel surfaces shall comply with the requirements set by the supplier. Further notes and recommendations are given in EN 13507 *Pre-treatment of surfaces for thermal spraying*.

With regard to the application conditions, the following points shall be observed:

- The interval between preparation and spraying shall be selected so that the surface to be coated remains clean and dry and does not visibly oxidize. This interval should be less than four (4) hours.
- The steel temperature shall be at least 3°C above the dew point.

2.2 Materials for metallic coatings

As suitable materials for metal spraying,

- Aluminium: Al99,5 and
- Al-Mg alloy: AlMg5

as per ISO 14919 or an equivalent quality grade can be considered.

The following information shall be available with regard to the filler metal that is used:

- material datasheet
- material test certificate
- manufacturer's designation
- standard used
- production or batch number
- chemical analysis
- wire diameter
- net weight
- production date.

2.3 Spraying technique

Each layer shall be applied uniformly to the entire surface. The metallic coatings shall be applied in several crossed layers. Equipment and units for thermal spraying should comply with the requirements set out in EN 1395 or similar standards. For parts which shall be welded after spraying, an area 5–10 cm around the welding groove shall remain uncoated.

The protective film shall adhere properly. Spraying layers shall exhibit a uniform surface appearance that is not too coarse. They shall be free from bubbles, voids, loosely adherent spray metal, discolorations,

damages and uncoated spots. Before a subsequent layer is applied, any damage that may have occurred to the previous layer shall first be repaired.

A sealer may be applied on the thermally sprayed coating. The objective of the sealer is to fill the porosity of the thermally sprayed coating. The sealer should be applied to the absorption is complete. There should be no measurable overlay of the sealer on the metallic coating after the application. Sealing can be achieved either by a chemical transformation (through phosphatizing, reactive compacting agents, etc.) or through the use of a suitable painting system which covers up the pores.

2.4 Minimum film thickness

The minimum thickness of the metallic coatings shall not be less than the values as given in [Table 1](#):

Table 1 Minimum thickness of sprayed metallic coatings

<i>Spraying material</i>		<i>Minimum film thickness [μm]</i>	
		<i>without painting</i>	<i>with painting</i>
Aluminium	Al99,5	200	150
AlMg alloy	AlMg5	250	200

2.5 Quality assurance for spraying

The testing of thermal spraying layers should be performed on the basis of DVS Work Sheet 2301 and 2304 or similar.

The responsible personnel should be checked according to ISO 14918.

Spraying shops in the sense of this guideline can apply for approval by the Society. Through personnel with suitable training and equipment that is in good working condition, the shop shall ensure that the requirements for the processing of the thermal spray materials are met. An existing quality management system with defined working sequences and the envisaged company-internal quality checks shall be verified. The examination of the conditions existing on site, with a positive result, shall be viewed as a fundamental requirement. This examination shall be carried out before work starts; spot checks should also be made during the application process, to confirm the initial conditions. If all requirements are met and if the examinations yield a positive result, a certificate is issued by the Society.

SECTION 5 ASSESSMENT OF COATING WORK

1 General

The application process of coating systems is generally not included in the DNV GL's classification scope of work, but the process may be assessed by DNV GL on request.

2 Assessment procedure

Written application of the client (owner, shipyard, coating manufacturer, applicator, etc.) shall be sent to DNV GL local office and forwarded to the responsible technical unit at the approval centre. The scope of the assessment has to be defined by stating the areas to be coated and monitored. The technical basis shall be provided by the coating specification. On the basis of this information, an offer will be made to the client by DNV GL. Usually a report will be issued based on the assessment.

3 Elements of the assessment

3.1 Comparison with the coating specification

The items described in the coating specification determine all the resulting requirements and measures.

- The completeness of the requirement catalogue and the fulfilment of the requirements shall be checked.
- Elements of the coating specification, such as instructions of the coating material supplier as well as of other subcontractors of the shipyard, shall be coordinated and harmonized.

3.2 Quality assurance of the coating manufacturer

An examination/analysis of the quality assurance system at the coating manufacturer shall be carried out. Perusal of the relevant documents regarding the manufacturing processes and their monitoring, as well as the subsequent quality tests at the manufacturer, shall be made possible. If the coating manufacturer is regularly checked for during the issuance or renewal of type approval certificates, this step may be omitted. A site visit may be necessary to perform this step.

3.3 Acceptances of the steel structure and surface preparation

The correct structural execution shall be verified.

- Welding seams shall be examined to make sure that weld reinforcements, weld toes, surface condition and welding spatter conform to the specification.
- The surface preparation shall be performed in accordance with the specification and the standard contained therein and is checked by the surveyor for compliance with the instructions.

The decisive parameters for surface preparation

- For instance, the initial and continuously monitored blasting-medium quality, blasting pressure, and environmental conditions when blasting (steel and air temperature, air humidity, dew point, etc.) – shall comply with the specifications, and the actual conditions encountered shall be documented.
- In addition, the surface preparation grade achieved shall be documented for all relevant surfaces (and accepted by the parties involved).

3.4 Quality assurance of the coating applicator (persons, equipment, procedure)

- The applicator shall ensure, through personnel with suitable training and equipment that is in good working condition, that the demands set for the processing of the coating materials are satisfied.
- An existing quality management system with defined working sequences and the envisaged company-internal quality checks shall be verified.
- The examination of the conditions existing on site, with a positive result, shall be viewed as a fundamental requirement. This examination shall be carried out before work starts; spot checks should also be made during the application process, to confirm the initial conditions.
- If necessary, unsuitable personnel or equipment shall be changed, even when production is already under way.

Application conditions:

- The environmental conditions (such as air and steel temperature, air humidity, dew point, retouching intervals, coating thicknesses achieved, intermediate inspections, etc.) shall be continuously recorded and documented.
- The protocol and assessment of the essential data and results is performed by the responsible surveyor.
- Suitable measurement and documentation equipment shall be available.

4 Trials, repair

The specified post-treatment, such as hot curing of the tank coating, as well as the relevant final tests, e.g. the seawater test, are also documented and accepted by the surveyor, as are any retouching activities.

SECTION 6 CATHODIC PROTECTION

1 General

In the following section some initial guidance regarding cathodic protection is given. For more detailed information, the following DNV GL documents should be considered:

- DNV-RP-B401 – *Cathodic Protection Design*
- [DNVGL-RP-B101](#) – *Corrosion protection of floating production and storage units*

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 re-polarisation after refilling).

2 Cathodic protection system design basis – internal tanks

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

Areas coated, respectively uncoated should be specified.

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.

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.

The average current density demanded to obtain full cathodic protection may be given in [Table 1](#).

Table 1 Average current density

Area	Current density mA/m ²
Clean ballast tanks (bare steel)	100–110
Upper wing tanks (bare steel)	120
Fore and aft peak tanks (bare steel)	100–110
Lower wing tanks and double bottom tanks (bare steel)	80–90
Cargo or dirty ballast tanks (bare steel)	40–60
Paint coated surfaces (in intact condition)	5–10

Area	Current density mA/m ²
Soft coats (see Sec.3 [2.2] , in intact condition)	20–40

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 five (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).

For cathodic protection current output calculations a resistivity of 25 ohm cm can be used as an average figure for sea water ballast. For brackish or river water, the resistivity can be 100–200 ohm cm (allowance for increased resistivity can be made if the trading routes are known).

3 Sacrificial anodes – ballast tanks

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 rules for ships. Aluminium alloy anodes shall be 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 two (2) through-bolts per anode and double locking nuts (for easy renewal) are, however, acceptable.

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](#).

Table 2 Current capacities and consumption rate

Anode and environment	Current capacity Ah/kg	Consumption rate kg/A year
Al based anodes in sea water	2300–2650	3,3–3,8
Al based anodes in marine sediments	1300–2300	3,8–6,7
Zn based anodes in sea water	760–780	11,2–11,5
Zn based anodes in marine sediments	750–780	11,2–11,7

The anode lifetime can be calculated from:

$$L = \frac{W}{EI}$$

L = effective life of the anodes (years)

W = net mass of one anode (kg)

E = consumption rate (kg/A year)

I = mean current demand per anode (A) during the lifetime, based on mean current density.

Sacrificial ballast tank anode systems should be designed to last for minimum the planned docking interval and can be designed for 3, 4, 5 years or more effective life, according to need.

The current output capacity i of the anode should be calculated from Ohm's law

$I = U/R$

U = the driving voltage difference between anode and cathodically protected steel

R = the anodic resistance, to be calculated based on the anode geometry by a recognised formula.

Anode size and distribution should be based on the above information and calculations. The anode distribution, type, weights and dimensions should be shown on drawings. Sacrificial anode systems should be delivered by a recognised company with good references.

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.

4 Sacrificial anodes – cargo oil tanks

Magnesium or magnesium alloy anodes are not permitted in oil cargo tanks and tanks adjacent to cargo tanks (see IACS UR F1).

5 Impressed current cathodic protection systems

Impressed current cathodic protection (ICCP) systems shall not be used in ballast tanks due to development of chlorine and hydrogen, which can result in an explosion hazard.

Impressed current cathodic protection (ICCP) systems are not permitted in oil cargo tanks (see IACS UR F1)

More information regarding ICCP systems can be found in [DNVGL-RP-B101](#).

6 Cathodic protection of external hull

6.1 Cathodic protection system design basis – external hull

The following should be specified:

- size, shape and area of the external hull
- speed and probable trade or trading routes, including time in harbours
- propeller(s)' type, size, speed, materials and location(s)
- propeller shaft material, and if grounded to the hull
- rudder and rudder accessories
- sea water intakes, sea chests, and any other hull accessories.

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. Recognized slip-rings and brushes should be installed to include the propeller in the cathodic protection system.

The criterion of cathodic protection is as per [\[2\]](#).

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 above, and will be different at different locations of the hull and its accessories such as propeller, rudder, and sea chests.

6.2 Sacrificial anodes – external hull

Aluminium or zinc anode materials should be used.

The material of the anodes to be installed should be considered. The US vessel general permit (VGP) requirements, *Cathodic Protection* (VGP 2.2.7), are valid for anodes on external hull and sea chest (and most like also thruster tunnels), and not those anodes located in e.g. water ballast tanks.

From the VGP requirements it could be concluded that the use of aluminium anodes are expected when vessel operates in seawater (or magnesium when vessel operates in freshwater), indicating that any zinc anodes installed or intended to be installed should be changed to aluminium.

Typical current capacity or consumption rate figures, lifetime and current output capacity calculations are described under [2] and [3].

Anode size and distribution should be based on the information provided from [1] and calculations as indicated in [3]. 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.

6.3 Impressed current cathodic protection systems

The size, number of and distribution of impressed current anodes should be based on information as per [1].

The design of an impressed current cathodic protection (ICCP) system should be carried out in accordance with a recognised standard. The design standard shall be stated in an ICCP manual. The impressed current cathodic protection (ICCP) 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 recognized specialist company with good references.

ICCP systems should be checked and adjusted by the supplier regularly for proper functioning, e.g. every second year.

Further information can be found in [DNVGL-RP-B101](#) *Corrosion protection of floating production and storage units*.

6.4 Marine growth prevention systems

These systems are installed with the intention to limit the growth of marine organisms in sea chests, seawater inlets etc.

The arrangement of these anti-fouling protection systems are not subject to class review.

There are several concepts and terms in daily use. Electrolytic anti-fouling may also be called:

- marine growth prevention system – MGPS,
- impressed current antifouling system – ICAF,
- electrolytic antifouling – EAF,
- cuproban, copper ionization and copper dosing system.

SECTION 7 PROPERTIES AND TEST STANDARDS FOR COATINGS

1 General

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.

2 Quality control tests for steel surface treatment and coating application

2.1 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 D3359, BS 3900 part E6.

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

2.2 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 [Sec.2](#) of these guidelines.

2.3 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, ASTM D1005, SIS 184160, SSPC-PA2.

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

2.4 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.

ISO 12944 is a standard 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 Sa 2,5 approximately correspond to, respectively,

- 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.

2.5 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, etc.

2.6 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:

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

Relevant standards for measurement of WFT:

— ASTM D1212, BS 3900 Part C5, BS 5493.

2.7 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 SP0274-2011. Useful advice is also given in BS 6374.

3 Coating materials' testing – thermal, mechanical and physical properties

3.1 General

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

3.2 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, ASTM D2485.

3.3 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 D2370.

Cupping of coated plates (Erichsen test):

- ISO 1520, BS 3900 Part E 4

Bending over mandrel:

- BS 3900 Part E 1, ASTM D522.

3.4 Abrasion resistance

For floor coatings and traffic paint abrasion resistance is important. Relevant test standards may be:

- ASTM D968.

3.5 Drying time of coatings

Test standards:

- ASTM D3732, ASTM D1640, ASTM D711, ISO 1517, SIS 184207.

3.6 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 D2697, ASTM D2832, ASTM D1259, ASTM D2621, ISO 3233.

3.7 Impact resistance

Relevant test standards (to be chosen according to type and thickness of coating):

- BS 3900 Part E3 and E7, ASTM G14, D2794.

3.8 Hardness

If hardness testing is relevant, due concern must be given to the type and thickness of coating. Relevant test standards:

- ASTM D2134, ASTM D2240, BS 4164.

3.9 Flash point

The flash point of a liquid coating may be determined by e.g. tests:

- ASTM D93, ASTM D3278, ASTM D56, ASTM D1310, DIN 51755.

3.10 Viscosity

Relevant tests:

- ASTM D1200, DIN, 53177.

3.11 Gloss

Tests for gloss of architectural paints, etc.:

- ASTM E430, BS 3900 Part D 50, ISO 2813.

SECTION 8 COATING INSPECTOR'S DUTIES – CHECKLIST

1 General

The status and authority of the coating inspector or team of inspectors should be stated in the contract between shipyard 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 cathodic protection systems should be surveyed by a representative from the supplier.

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

- planning
- steel surface preparation
- coating selection and application
- coating quality control and testing (of the tests mentioned in [Sec.7](#) only a few of those mentioned under [Sec.7 \[2\]](#) 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, see [\[2\]](#) to [\[4\]](#).

2 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.

3 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, which shall be in accordance with specifications, calculations and drawings.

4 Inspection equipment

The coating applicator or coating subcontractor should normally have the necessary inspection equipment on site and the equipment shall be calibrated regularly (if applicable). 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.

SECTION 9 CORROSIVITY AND CORROSION RESISTANT MATERIALS – A BRIEF REVIEW

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 (references /1/ and /2/):

- 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.

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 increase 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 H_2S (Caution: H_2S 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.

3 Factors influencing steel corrosion rates in ships

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

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.

4 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.

5 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 1](#).

Table 1 Typical Al-alloys

<i>Alloy</i>	<i>Si</i>	<i>Mg</i>	<i>Mn</i>
AlMg2.5–AlMg4	maximum 0.5	2.2–4.6	maximum 0.4–0.8 *
AlMg3Mn	maximum 0.5	2.4–3.4	0.3–1.0
AlMg4.5Mn	maximum 0.5	4.0–4.9	0.3–1.0
AlMgSi1	0.6–1.6	0.4–1.4	0.4–1.0.
* maximum Mn content varying from 0.4 % for Mg 2.5 to 0.8% for Mg 4.			

Other elements in [Table 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 $> \approx 4.5\%$ 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.

6 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 rest
- 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 /3/) recognised flow velocities should not be exceeded to avoid corrosion attacks as given in [Table 2](#).

Table 2 Maximum flow velocities in heat exchangers

<i>Tube material</i>	<i>Maximum flow velocity, m/s</i>
Al-brass	2.1
Cu-Ni 90/10	2.4
Cu/Ni 70/30	3.0

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.

7 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 /4/) for relevant metals and alloys, with relative potential differences). 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.

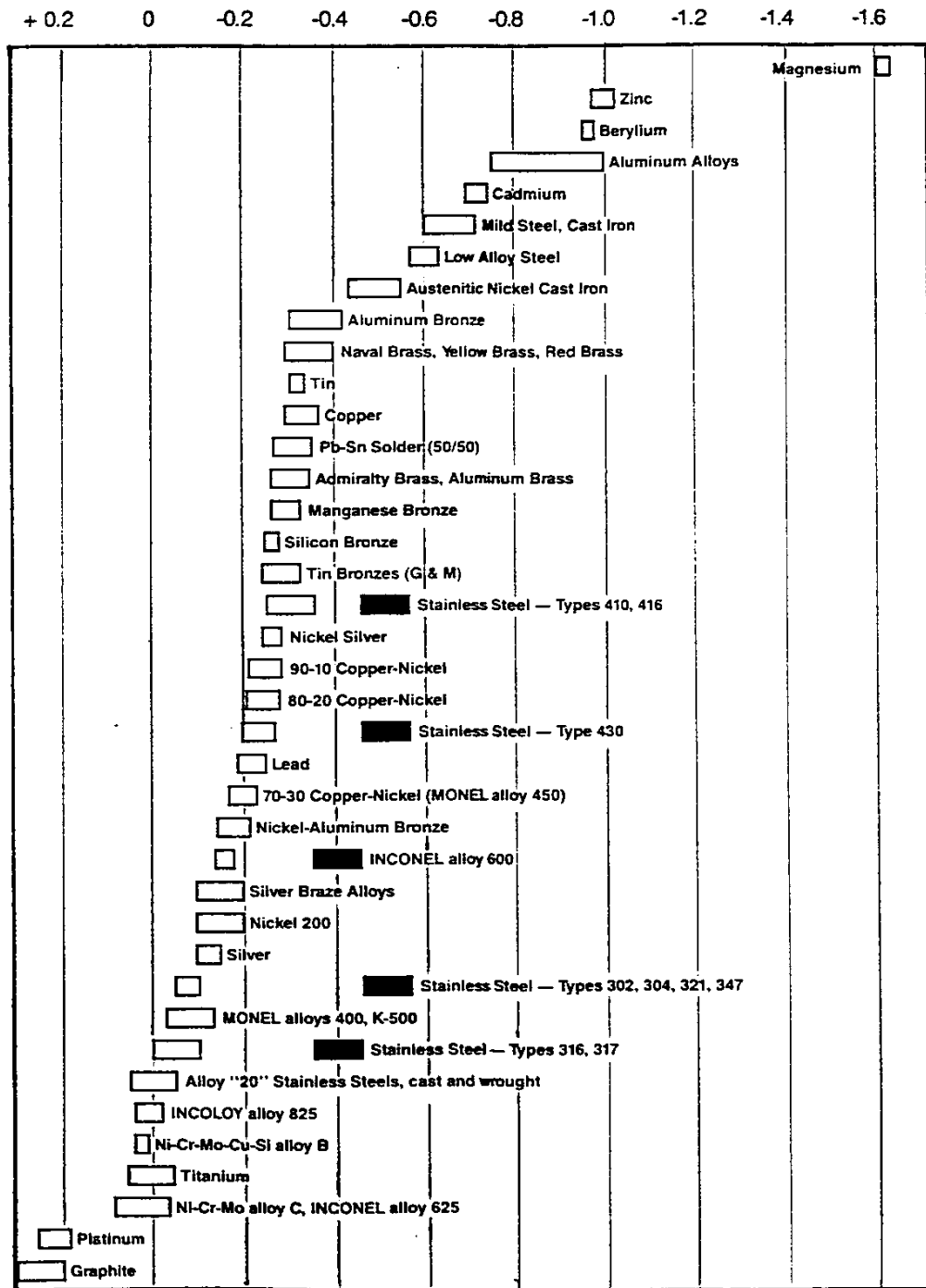


Figure 1 Galvanic series in sea water /4/

Note regarding Figure 1:

Volts: Saturated calomel half-cell reference electrode.

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 Cargo and ballast handling – design against corrosion

Ballast water and cargoes often promote corrosion, as in the typical cases of:

Tanker 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 carrier: Impacts from grabs may damage the corrosion protection systems on both sides of exposed plates.

Ore carrier: 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.

Measures to treat ballast water (see IMO International convention for the control and management of ships' ballast water and sediments, (BWM), 2004) may affect the corrosivity in positive (less corrosion: ballast water is filtered and hence cleaned for sand and larger organisms; less sediments in ballast tanks; oxygen may be removed from water) or negative way (chemical substances added to the water to kill bacteria and smaller organisms may have a negative effect on corrosion rate especially in tanks where the coating is damaged). Special consideration is necessary if existing vessels are retro-fit with such a system.

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.

SECTION 10 SURFACES – PREPARATION, COATING AND CORROSION

1 General

In Figure 1 are shown some figures illustrating various aspects of steel surface preparation and coating related to the subjects treated in this guideline.

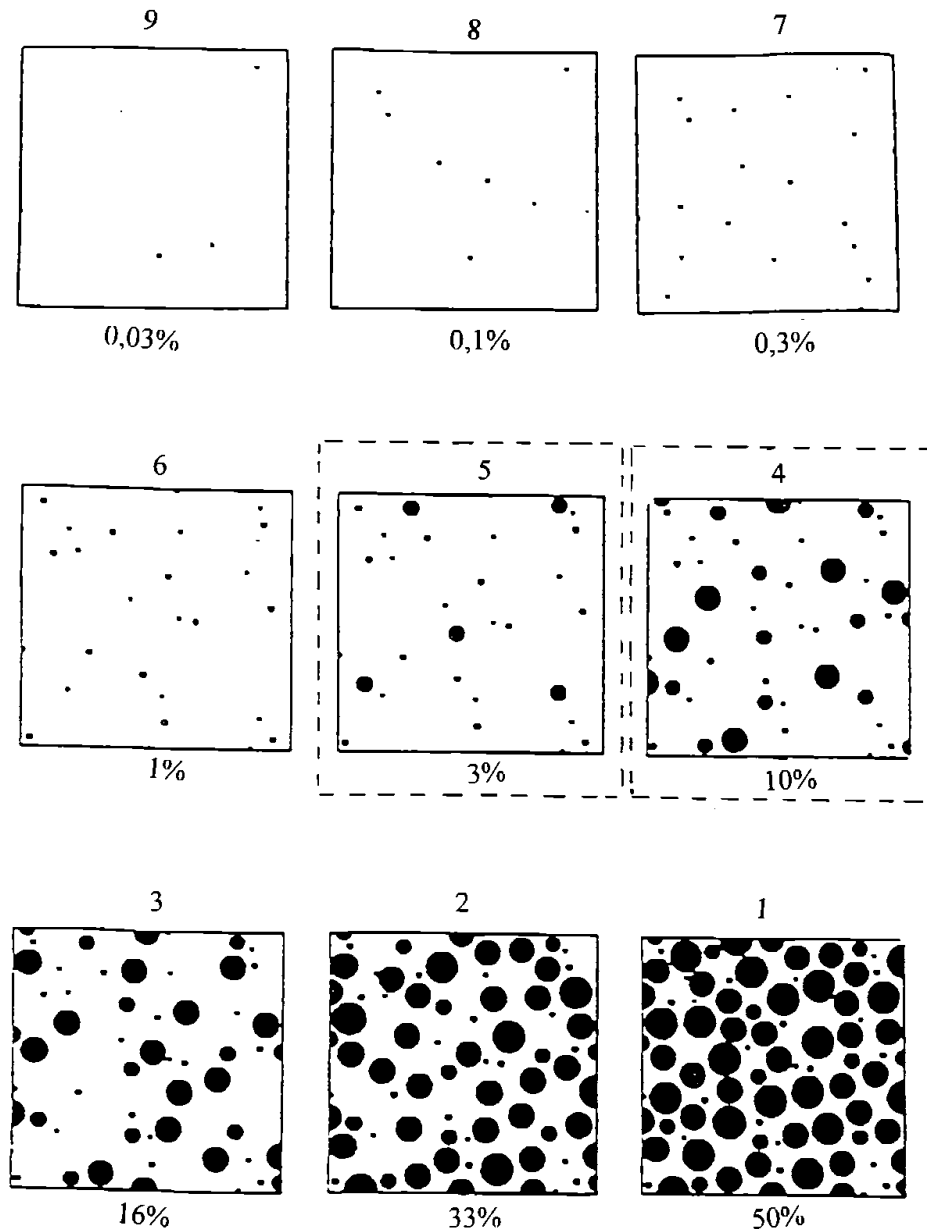


Figure 1 Examples of area percentages

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 /5/).

The figure is referred to in this guideline for defining:

- due time for maintenance coating (1% = rust grade 6), and
- useful life of a coating (3% = rust grade 5).

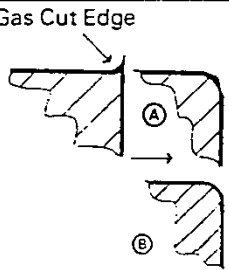
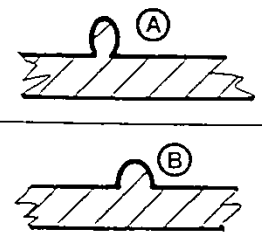
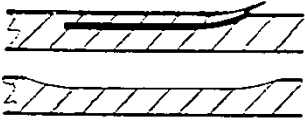
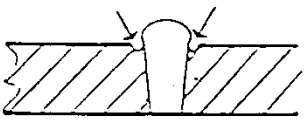
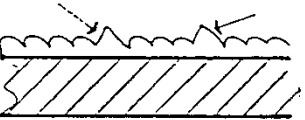
Sharp Edge		A. Remove by grinder or disc sander.
		B. Rolled steel sections normally have radiused edges. Therefore can be left untreated.
Weld Spatter		A. Remove spatter observed before grit-blasting with grinder or chipping hammer.
		B. For spatter not readily removed. Remove using grinder/disc.
Lamination		Remove using grinder.
Undercut		Undercuts exceeding classification ruling should be repaired by welding and grinding.
Manual Weld Bead		Sharp Profile peaks to be smoothed using grinder.

Figure 2 Preparation of steel

The figure (originally made by Camrex Limited (see reference /6/) illustrates important surface details to be prepared for coating application. All the above preparations should be carried out before blast cleaning.

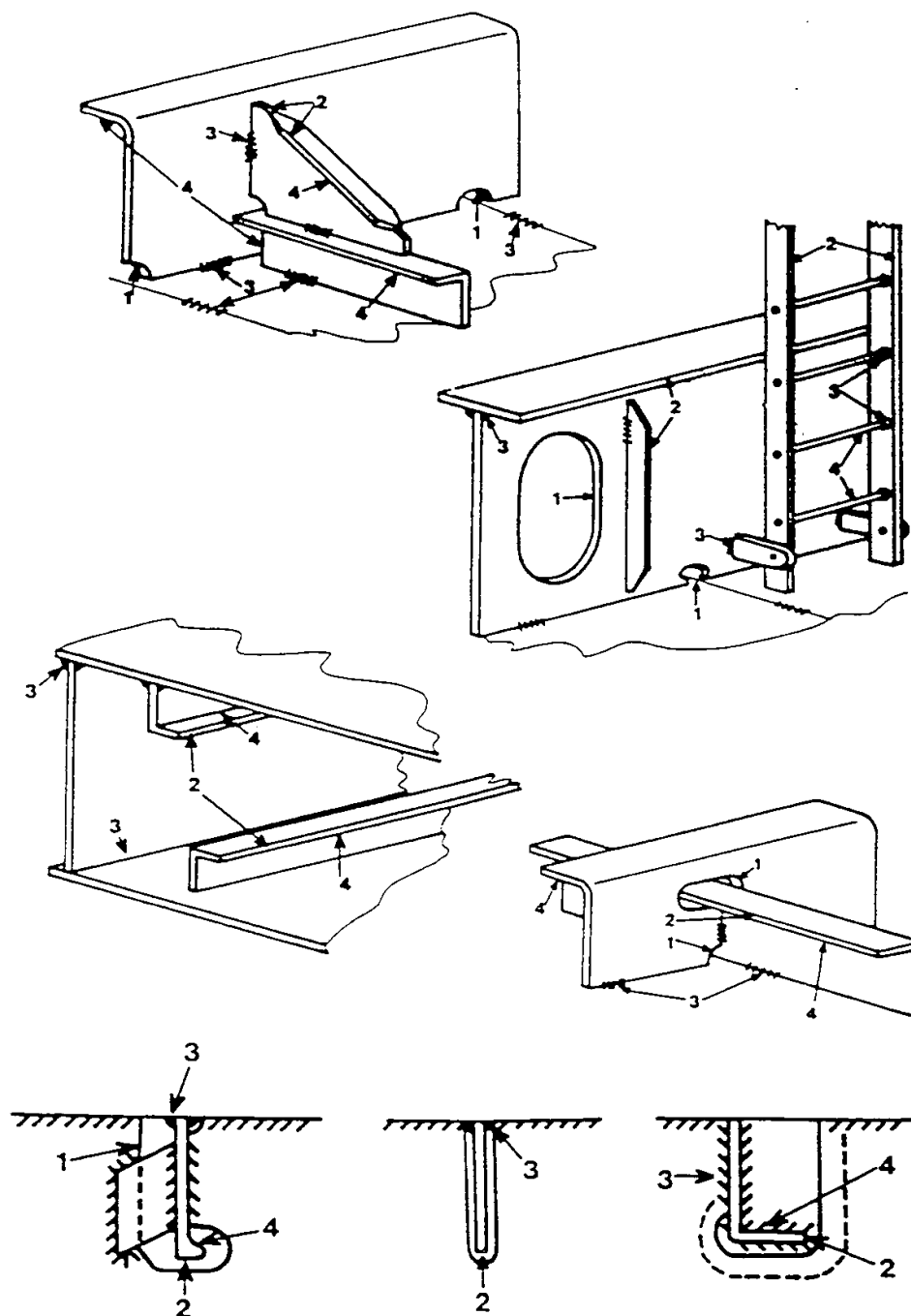


Figure 3 Stripe coating locations (from Camrex (see /6/))

- 1: Inside edge of cut outs.
- 2: Edge part of stiffeners.
- 3: Welding beads.
- 4: Where spraying is difficult.

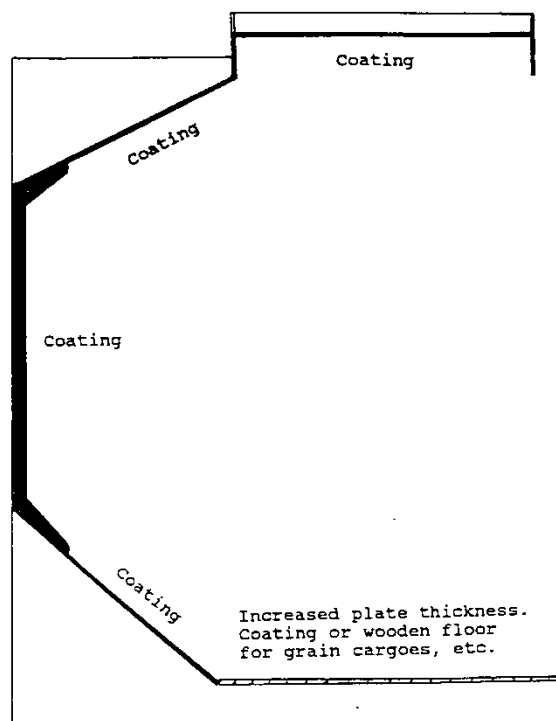


Figure 4 Recommended extent of coating in cargo holds on bulk carriers

Regarding the extent of coating, see also the IACS *Common Structure Rules for bulk carriers and oil tankers* (available at IACS homepage). 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.

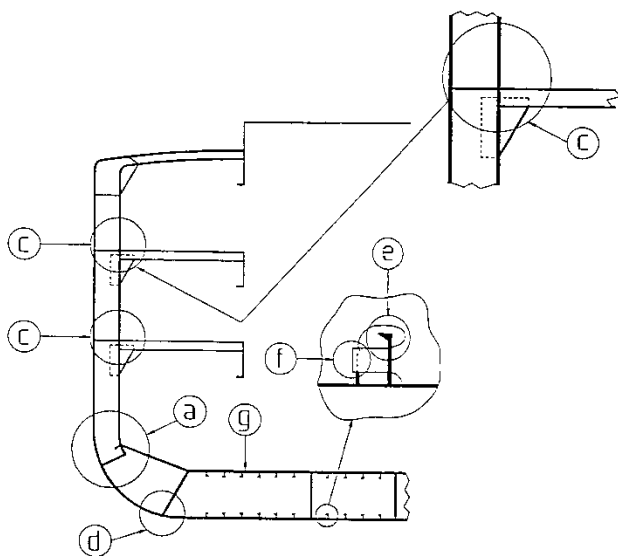


Figure 5 Parts liable to corrosion in general cargo ships

Cargo holds:

- a) lower end of hold frames
- b) lower end of water tight bulkhead (not illustrated)
- c) corners of lower decks
- d) bilge wells.

Double bottom ballast tanks:

- 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 /7/)).

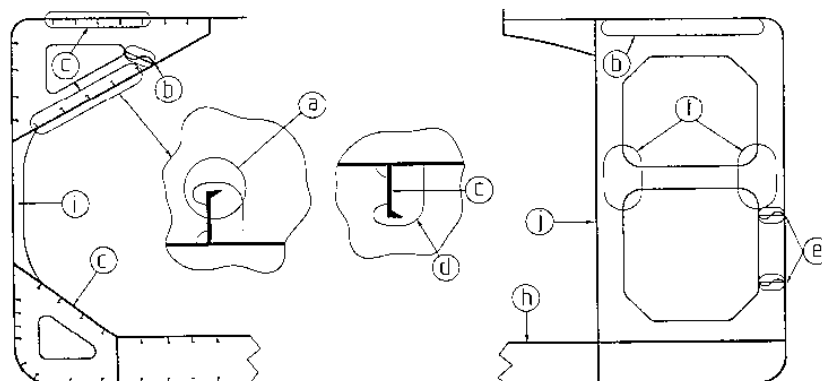


Figure 6 Parts liable to corrosion in bulk carriers or OBOs

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

Holds and bulkheads:

- 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).

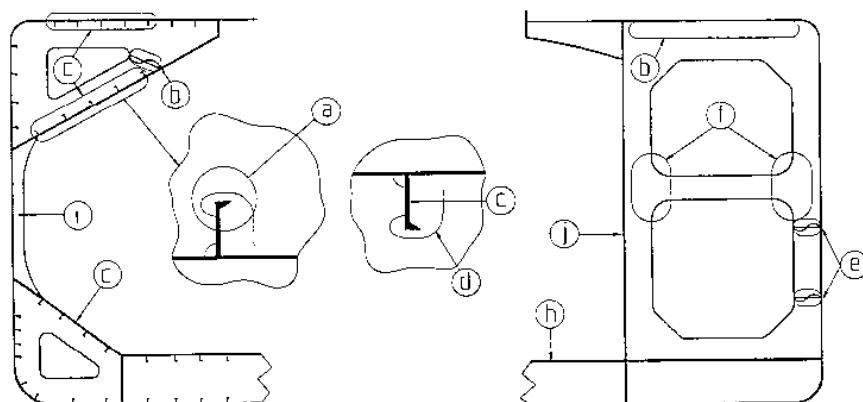


Figure 7 Parts liable to corrosion in oil tankers

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).

SECTION 11 REFERENCES

1 IMO/IACS documents

SOLAS Amendment, Regulation II-1/3-2 (December 2006) (IMO-PSPC-WBT)

SOLAS Amendment, Regulation II-1/3-11 (May 2010) (IMO-PSPC-COT)

IMO. Resolution A.798 (19) adopted 23 November 1995. *Guidelines for the Selection, Application and Maintenance of Corrosion Protection Systems of dedicated Sea Water Ballast Tanks.*

IMO Resolution MSC.215(82) (IMO-PSPC-WBT) *Performance standard for protective coatings for dedicated seawater ballast tanks in all types of ships and double-side skin spaces of bulk carriers*

IMO Resolution MSC.244(83) (IMO-PSPC-VS) *Performance standard for protective coatings for void spaces on bulk carriers and oil tankers*

IMO MSC.1/Circ.1279 (IMO-PMA-Guidelines) *Guidelines for Corrosion Protection of Permanent Means of Access Arrangements*

IMO Resolution MSC.288(87) (IMO-PSPC-COT) *Performance standard for protective coatings for cargo oil tanks of crude oil tankers*

IMO Resolution MSC.289(87) *Performance Standard for Alternative Means of Corrosion Protection for Cargo Oil Tanks of Crude Oil Tankers*

IMO Resolution MSC.291(87) *Exemption of combination carriers or chemical tankers from PSPC-COT*

IMO MSC.1/Circ.1421 *Guidelines on Exemptions for Crude Oil Tankers solely engaged in the Carriage of Cargoes and Cargo Handling Operations not causing corrosion*

IMO MSC.1/Circ.1465 *Unified Interpretations of the Performance Standard for Protective Coatings for Dedicated Seawater Ballast Tanks in all Types of Ships and Double-side Skin Spaces of Bulk Carriers (Resolution MSC.215(82))*

IMO Resolution A.1076(28) *Amendments to the survey guidelines under the harmonized system of survey and certification (HSSC), 2011*

IACS Unified Interpretations SC223 (IACS UI SC223) *For Application of SOLAS Regulation II-1/3-2 Performance Standard for Protective Coatings (PSPC-WBT) for Dedicated Seawater Ballast Tanks in All Types of Ships and Double-side Skin Spaces of Bulk Carriers, adopted by Resolution MSC.215(82) (regularly updated)*

IACS Unified Interpretations SC226.2 (IACS UI SC226.2) *regarding ballast tanks in conversion projects*

IACS Unified Interpretations SC227 (IACS UI SC227) *regarding combined tanks The dedicated seawater ballast tanks in SOLAS Chapter II-1 (Regulation 3-2) (regularly updated)*

IACS Unified Interpretations SC258 (IACS UI SC258) *For Application of SOLAS Regulation II-1/3-11 Performance Standard for Protective Coatings for Cargo Oil Tanks of Crude Oil Tankers (PSPC-COT), adopted by Resolution MSC.289 (87) The Performance Standard for Alternative Means of Corrosion Protection for Cargo Oil Tanks of Crude Oil Tankers*

IACS Unified Interpretations SC259 (IACS UI SC259) *For Application of SOLAS Regulation II-1/3-11 Performance Standard for Protective Coatings for Cargo Oil Tanks of Crude Oil Tankers (PSPC-COT), adopted by Resolution MSC.288(87) (regularly updated)*

IMO MSC.1/1479, *Unified Interpretation on the application of the Performance Standard for Protective Coatings for Cargo Oil Tanks of Crude Oil Tankers (Resolution MSC.288(87))*

IMO Guidelines MSC.1/Circ.1330 *Guidelines for maintenance and repair of protective coatings (Seawater Ballast Tanks)*

IMO Guidelines MSC.1/Circ. 1339 *Guidelines on procedures for in-service maintenance and repair of coating systems for cargo oil tanks of crude oil tankers*

IACS Unified Requirements F1, *Cathodic protection on oil tankers (Rev. 1, June 2002)*

IACS Unified Requirements F2, *Aluminium coatings onboard oil tankers and chemical tankers (Rev. 2, Nov 2012)*

IACS Unified Requirements Z7, *Hull classification surveys* (Rev 23, July 2015)
 IACS Unified Requirements Z23 *Hull Survey for New Construction* (Rev. 2, Apr 2009, Corr.1 August 2012)
 IACS, Recommendation No. 44, *Survey guidelines for tanks in which soft coatings have been applied*, 1996.
 IACS Recommendation 87, *Guidelines for Coating Maintenance and Repairs for Ballast Tanks and Combined Cargo/Ballast Tanks on Oil Tankers*, Revision 2, May 2015, IACS documents may be downloaded at <http://www.iacs.org.uk/>.

2 Standards

ASTM D56 Standard Test Method for Flash Point by Tag Closed Cup Tester
 ASTM D93 Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester
 ASTM D522 Standard Test Methods for Mandrel Bend Test of Attached Organic Coatings
 ASTM D610 Standard Practice for Evaluating Degree of Rusting on Painted Steel Surfaces
 ASTM D711 Standard Test Method for No-Pick-Up Time of Traffic Paint
 ASTM D968 Standard Test Methods for Abrasion Resistance of Organic Coatings by Falling Abrasive
 ASTM D1005 Standard Test Method for Measurement of Dry-Film Thickness of Organic Coatings Using Micrometers
 ASTM D1200 Standard Test Method for Viscosity by Ford Viscosity Cup
 ASTM D1212 Standard Test Methods for Measurement of Wet Film Thickness of Organic Coatings
 ASTM D1259 Standard Test Methods for Nonvolatile Content of Resin Solutions
 ASTM D1310 Standard Test Method for Flash Point and Fire Point of Liquids by Tag Open-Cup Apparatus
 ASTM D1640 Standard Test Methods for Drying, Curing, or Film Formation of Organic Coatings
 ASTM D2134 Standard Test Method for Determining the Hardness of Organic Coatings with a Sward-Type Hardness Rocker
 ASTM D2240 Standard Test Method for Rubber Property—Durometer Hardness
 ASTM D2370 Standard Test Method for Tensile Properties of Organic Coatings
 ASTM D2485 Standard Test Methods for Evaluating Coatings For High Temperature Service
 ASTM D2621 Standard Test Method for Infrared Identification of Vehicle Solids From Solvent-Reducible Paints
 ASTM D2697 Standard Test Method for Volume Nonvolatile Matter in Clear or Pigmented Coatings
 ASTM D2794 Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact)
 ASTM D2832 Standard Guide for Determining Volatile and Nonvolatile Content of Paint and Related Coatings
 ASTM D3278 Standard Test Methods for Flash Point of Liquids by Small Scale Closed-Cup Apparatus
 ASTM D3359 Standard Test Methods for Measuring Adhesion by Tape Test
 ASTM D3732 Standard Practice for Reporting Cure Times of Ultraviolet-Cured Coatings
 ASTM D4752 Standard Practice for Measuring MEK Resistance of Ethyl Silicate (Inorganic) Zinc-Rich Primers by Solvent Rub
 ASTM D7091 Standard Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals (replaced ASTM D1400)
 ASTM E430 Standard Test Methods for Measurement of Gloss of High-Gloss Surfaces by Abridged Goniophotometry
 ASTM G14 Standard Test Method for Impact Resistance of Pipeline Coatings (Falling Weight Test)
 BS3900 Methods of test for paints
 BS 5493 Code of practice for protective coating of iron and steel structures against corrosion
 BS 6374 Lining of equipment with polymeric materials for the process industries.
 DIN 50900 Corrosion of metals – Terms

DIN 50927 Planning and application of the electrochemical corrosion protection. (internal protection)

DIN 50929 Probability of corrosion of metallic materials when subject to corrosion from the outside

DIN 50930 Corrosion of metallic materials under corrosion load by water inside of tubes, tanks and apparatus

DIN 51755 Testing of Mineral Oils and Other Combustible Liquids; Determination of Flash Point by the Closed Tester according to Abel-Pensky

DIN 53177 Binders for paints and varnishes – Measurement of the dynamic viscosity of liquid resins; Resin solutions and oils by the capillary viscosimeter of isocelses type according to Ubbelohde

DIN 81249 Corrosion of metals in seawater and sea atmosphere

EN 1395 Thermal spraying – Acceptance inspection of thermal spraying equipment

EN 4618 Paints and varnishes – Terms and definitions

EN 12473 General principles of cathodic protection in seawater

EN 12474 Cathodic protection for submarine pipe- lines

EN 12495 Cathodic protection for fixed steel off- shore structures

EN 13173 Cathodic protection for steel offshore floating structures

EN 13174 Cathodic protection for harbour installations

EN 13507 Thermal spraying – Pre-treatment of surfaces of metallic parts and components for thermal spraying

EN 13509 Cathodic protection measurement techniques

EN 14879 Organic coating systems and linings for protection of industrial apparatus and plants against corrosion caused by aggressive media

ISO 1461 Hot dip galvanized coatings on fabricated iron and steel articles – Specifications and test methods

ISO 1517 Surfaces for sports areas – Determination of resistance to impact

ISO 1520 Paints and varnishes – Cupping test

ISO 2409 Paints and varnishes – Cross-cut test

ISO 2808 Paints and varnishes – Determination of film thickness

ISO 2813 Paints and varnishes – Determination of gloss value at 20 degrees, 60 degrees and 85 degrees

ISO 3233 Paints and varnishes – Determination of the percentage volume of non-volatile matter

ISO 4624 Paints and varnishes – Pull-off test for adhesion

ISO 8501-1 Preparation of steel substrates before application of paints and related products – Visual assessment of surface cleanliness Part 1 Rust grades and preparation grades of uncoated steel substrate and of steel substrates after overall removal of previous coatings

ISO 8501-3 Preparation of steel substrates before application of paints and related products- visual assessment of surface cleanliness- Preparation grades of welds, cut edges and other areas with surface imperfections

ISO 8501-6 Preparation grades of welds, cut edges and other areas with surface imperfections

ISO 8502-3 Preparation of steel substrates before application of paint and related products – Tests for the assessment of surface cleanliness – Part 3: Assessment of dust on steel surfaces prepared for painting (pressure-sensitive tape method)

ISO 8502-6 Preparation of steel substrates before application of paints and related products – Tests for the assessment of surface cleanliness – Part 6: Extraction of soluble contaminants for analysis – The Bresle method

ISO 8502-9 Preparation of steel substrates before application of paints and related products – Tests for the assessment of surface cleanliness – Part 9: Field method for the conductometric determination of water-soluble salts

ISO 8503-2 Preparation of steel substrate before application of paints and related products- Surface roughness and characteristics of blast-cleaned steel substrate- Part 2: Method for grading of surface profile of abrasive blast-cleaned steel- Comparator procedure

ISO 11124 Preparation of steel substrates before application of paints and related products – Specifications for metallic blast- cleaning abrasives

ISO 11126 Preparation of steel substrates before application of paints and related products – Specifications for non-metallic blast-cleaning abrasives

ISO 12944 Paints and varnishes-Corrosion protection of steel structures by protective paint systems

ISO 14918 Thermal spraying – Approval testing of thermal sprayers

ISO 14919 Thermal spraying – Wires, rods and cords for flame and arc spraying

ISO 19840 Paints and varnishes – Corrosion protection of steel structures by protective paint systems – Measurement of, and acceptance criteria for, the thickness of dry films on rough surfaces

ISO 20340 Paints and varnishes – Performance requirements for protective paint systems for offshore and related structures

ISO 29601 Paints and varnishes – Corrosion protection by protective paint systems – Assessment of porosity in a dry film

NACE SP0274-2011 High-Voltage Electrical Inspection of Pipeline Coatings

NORSOK Standard M-501 – Surface preparation and protective coatings

NORSOK Standard M-503 – Cathodic protection

SIS184160 T1 Paints and varnishes – Determination of thickness of a dry film on a metal substrate – Magnetic flux and eddy current methods

SIS 184207 Paint and varnishes – Surface-drying test – Ballotini method

SSPC-PA 2 Paint application specification No. 2 (2004) Measurement of dry coating thickness with magnetic gages

STG 2215 Corrosion protection for ships and off- shore structures, Part 1 "...newbuildings"

STG 2216 STG-Data sheet for coating materials

STG 2220 Testing and assessment of the suitability of coatings for immersed service for ships and offshore structures with cathodic protection systems

STG 2221 Corrosion protection for ships and off- shore structures, Part 1 "...maintenance"

STG 2222 Preparation grades for high-pressure water cleaning

VG 81255 Cathodic protection, materials for galvanic anodes

VG 81256 Cathodic protection of ships, external protection by galvanic anodes

VG 81258 Cathodic protection of ships, internal protection by galvanic anodes

VG 81259 Cathodic protection of ships, external protection by impressed current

3 DNV GL documents

DNV GL rules for classification: Ships [DNVGL-RU-SHIP Pt.6 Ch.1 Sec.9](#) *Performance standards for protective coatings- COAT-PSPC*

DNV-RP-B401 – *Cathodic Protection Design*

[DNVGL-RP-B101](#) *Corrosion protection of floating production and storage units*

Class programmes related to content of these guidelines;

- [DNVGL-CP-0106](#) *Fastening devices for sacrificial anodes - Metallic materials*
- [DNVGL-CP-0107](#) *Sacrificial anode materials - Metallic materials*
- [DNVGL-CP-0108](#) *Protective coating systems for seawater ballast tanks and double-side skin spaces - Non-metallic materials*
- [DNVGL-CP-0109](#) *Shop primers for corrosion protection of steel plates and sections*
- [DNVGL-CP-0110](#) *Anti-fouling systems*
- [DNVGL-CP-0139](#) *Protective coating systems for cargo oil tanks - Non-metallic materials*
- [DNVGL-CP-0484 App.B](#)

4 Other literature

- /1/ L. L. Shreir, *Corrosion*, Newnes-Butterworths, 1979.
- /2/ NTNF-prosjekt *Extended Lifetime for Ships*, DNV Report No. 89-0205 dated 5.5.91, NTNF MV.24918.
- /3/ R. Sundby, *Synpunkter på korrosjonsskydd i havsvattenkylda varmegämslar*, Stal-Laval Turbin AB, 1973. (in Swedish)
- /4/ NACE *Corrosion Engineers Reference Book*, NACE 1979, after F.L. LaQue, *Marine Corrosion Causes and Prevention*.
- /5/ ASTM D610 – 85, *Evaluating Degree of Rusting on Painted Steel Surfaces*. ASTM Annual Book of Standards, Vol. 06.01.
- /6/ Camrex Limited, *Manual of Tank Coating – Procedures & Standards*. Camrex Limited, Washington, UK.
- /7/ Y. Akita, *Ships damages and the counterplans to protect ships*. Nippon Kaiji Kyokai. Paper presented in London, June 1980.

CHANGES - HISTORIC

There are currently no historical changes for this document.

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Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification, technical assurance, software and independent expert advisory services to the maritime, oil & gas and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our experts are dedicated to helping our customers make the world safer, smarter and greener.