GUIDANCE NOTES ON

THE APPLICATION AND INSPECTION OF MARINE COATING SYSTEMS

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the State of New York 1862

Foreword *(1 January 2017)*

The steel structure of a vessel is prone to corrosion throughout its service life. Due allowance should be made at the new building stage and by periodic maintenance to provide effective corrosion protection that contributes to the continued structural integrity of the vessel.

Given the emphasis on protective coatings in the various mandated Rules and Regulations and the unprecedented acceleration of coating technology, personnel involved with coatings should have factual knowledge of coating systems and the applicable standards. It is the intent of these Guidance Notes to meet this need in a straight-forward and practical manner.

The Performance Standards for Protective Coatings (PSPC) from IMO are intended to standardize the requirements for protective coatings for ballast tanks, cargo oil tanks and void spaces for a target of 15 years of useful life. A good quality protective coating can delay the onset of corrosion of the structure. The mandated standards represent the latest in the line of many regulatory actions taken to enhance vessel longevity and thereby enhance safety.

There has been an increased industry focus placed on the consequences of corrosion and an increased demand for better coating performance as primary corrosion control. This has led to adoption of ballast tanks' PSPC for SOLAS Chapter II Part A-1 Regulation 3-2 on December 8, 2006, and adoption of PSPC for cargo oil tanks of all crude oil tankers per SOLAS Chapter II Part A-1 Regulation 3-11 on May 21, 2010. Those mandated PSPC standards specify requirements for coating application processes during various stages of new construction.

To help industry to understand the major elements of PSPC requirements, ABS has produced and maintained this publication since 2007. As a direct response to the needs of industry personnel involved with the PSPC implementation, a complete revision has addressed the fundamentals of coating technology as applied to ship structures for the regulatory requirements for coatings in ballast tanks, void spaces, cargo tanks, cargo holds and outer hull anti-fouling systems. Figure 1 gives a brief timeline of requirements or recommendations from IMO and IACS.

These Guidance Notes start with the basics of the chemistry, and mechanics of corrosion to understand protective coatings as a barrier to corrosion. The coating application process technology and coating inspection for surface preparation, environmental controls, film thickness measurements and the methods of coating application are included. Once a vessel is in-service, the coatings are subject to various conditions. To aid in the assessment of the coatings in service, coating assessment methods and typical failures are illustrated as guidance.

For ballast tank's PSPC of ABS classed vessels only, ABS provides the *Guide for the Class Notation Coating Performance Standard (CPS)* and a detailed procedure to obtain the ABS **CPS** notation. ABS also provides the optional notations Environmental Protection (**ENVIRO**) or Environmental Protection Plus (**ENVIRO+**) for vessels and antifouling systems are as part of the **ENVIRO** or **ENVIRO+** Notation requirement.
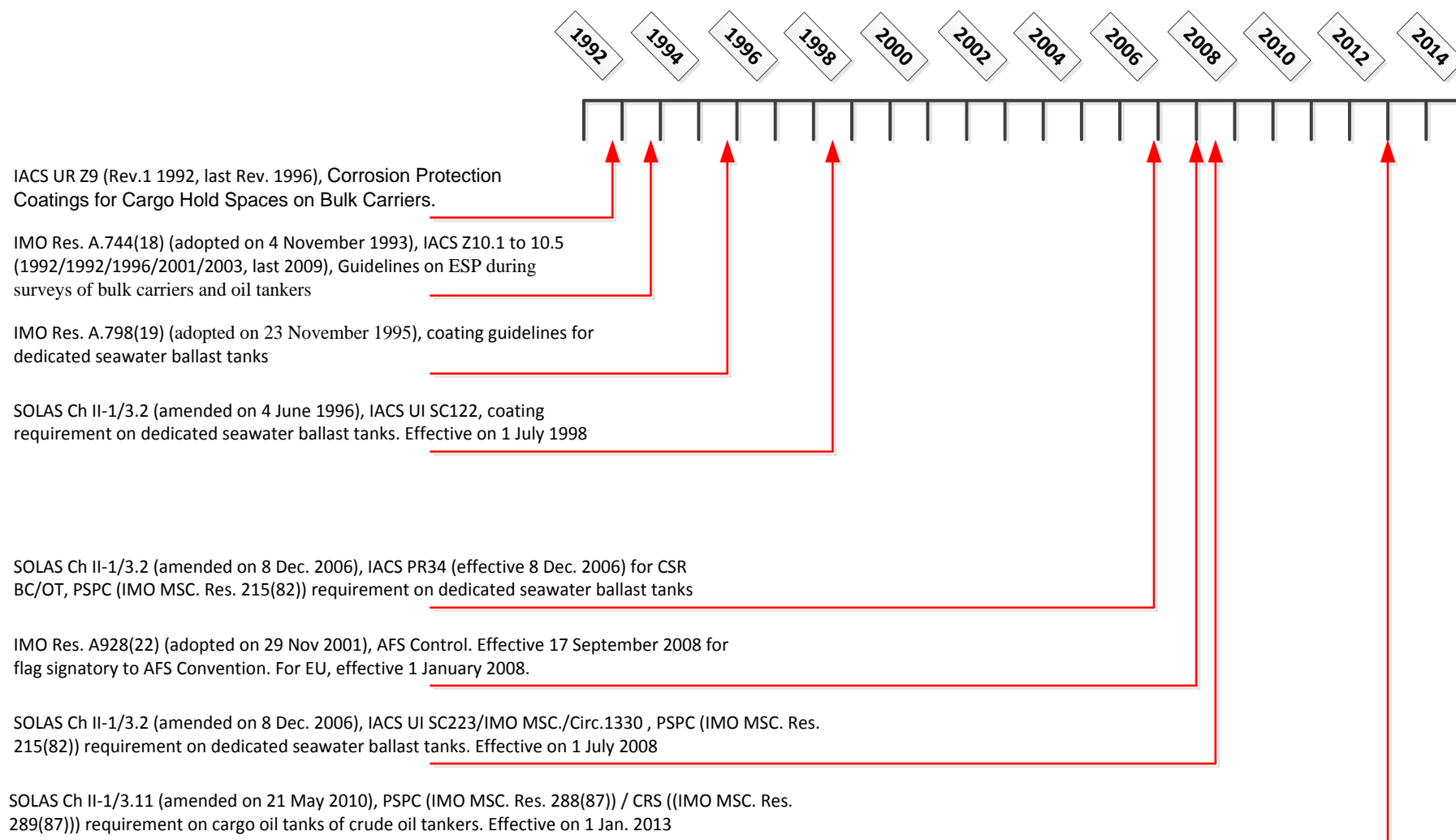
Please note that the adoption of ballast water exchange practices (as per IMO Resolution A.868(20)) may potentially have a negative effect on the longevity of the coatings. NACE has developed a test standard (NACE TM0112-2012) to determine the potential corrosion effects of Ballast Water Treatment Systems on Ballast Tanks.

These Guidance Notes become effective on the first day of the month of publication.

Users are advised to check periodically on the ABS website www.eagle.org to verify that this version of these Guidance Notes is the most current.

We welcome your feedback. Comments or suggestions can be sent electronically by email to rsd@eagle.org.

FIGURE 1
Timeline of Development

IACS UR Z9 (Rev.1 1992, last Rev. 1996), Corrosion Protection Coatings for Cargo Hold Spaces on Bulk Carriers.

IMO Res. A.744(18) (adopted on 4 November 1993), IACS Z10.1 to 10.5 (1992/1992/1996/2001/2003, last 2009), Guidelines on ESP during surveys of bulk carriers and oil tankers

IMO Res. A.798(19) (adopted on 23 November 1995), coating guidelines for dedicated seawater ballast tanks

SOLAS Ch II-1/3.2 (amended on 4 June 1996), IACS UI SC122, coating requirement on dedicated seawater ballast tanks. Effective on 1 July 1998

SOLAS Ch II-1/3.2 (amended on 8 Dec. 2006), IACS PR34 (effective 8 Dec. 2006) for CSR BC/OT, PSPC (IMO MSC. Res. 215(82)) requirement on dedicated seawater ballast tanks

IMO Res. A928(22) (adopted on 29 Nov 2001), AFS Control. Effective 17 September 2008 for flag signatory to AFS Convention. For EU, effective 1 January 2008.

SOLAS Ch II-1/3.2 (amended on 8 Dec. 2006), IACS UI SC223/IMO MSC./Circ.1330 , PSPC (IMO MSC. Res. 215(82)) requirement on dedicated seawater ballast tanks. Effective on 1 July 2008

SOLAS Ch II-1/3.11 (amended on 21 May 2010), PSPC (IMO MSC. Res. 288(87)) / CRS ((IMO MSC. Res. 289(87))) requirement on cargo oil tanks of crude oil tankers. Effective on 1 Jan. 2013

Note: See applicable regulations for details of the above dates

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CONTENTS

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S E C T I O N   **1**   **Corrosion**

1   General *(1 January 2017)*

The ability of coatings to resist corrosion over extended periods is an important contributor in safeguarding the capital investment in the structure of a vessel. Protective coatings are the primary barrier to the corrosive marine environment. Coatings can minimize the rate of corrosion, thereby potentially reducing designed corrosion margins included in a vessel's structural scantlings.

Understanding how coatings reduce corrosion rates, how they must be maintained and how coatings eventually break down are important elements of safe vessel operation. This Section deals with the basic theory of corrosion and sets out the various factors controlling breakdown rates.

Corrosion is defined as the deterioration of a material that results from a reaction with its environment. Corrosion of steel in ballast and cargo tanks is mainly an electrochemical process in which the steel reacts with its environment to form an oxide or other compound. The electrochemical process involves the transfer of irons and electrons across a surface and forms corrosion products. The oxides of metal such as iron oxides do not provide strength to structural components. In such a case, the metal or steel structural member is deteriorated.

In order for corrosion to occur, certain conditions and elements must exist. Those are collectively referred to as the corrosion cell, as depicted in Section 1, Figure 1. Four essential elements for corrosion are anode, cathode, metallic pathway and electrolyte.

i)   *Anode:*   The less noble part of the metal that corrodes. It is the negatively charged portion of the cell where metallic iron forms its ion and dissolves in the electrolyte. Generated electrons pass the anode and metallic conductor to the cathode. Oxidation occurs at the anode.

ii)   *Cathode:*   The more noble part of the metal where electrons are consumed. Reduction occurs at the cathode. Both oxidation and reduction always occur together.

iii)   *Metallic Path:*   A return path for connecting anode and cathode and allowing electrons generated at the anode to pass to the cathode.

iv)   *Electrolyte:*   Ion conductor which is pathway to transport the ions between the anode and cathode.

All the above components must be present and form a closed circuit for corrosion to occur. Removing one or more of these components prevents corrosion from occurring. This is the principle of corrosion controls. When an organic protective coating is applied on steel surface, which acts as a barrier and prohibits direct contact between the electrolyte and metal surface, one of these components from the corrosion cell is eliminated and corrosion on the steel surface is prevented.

FIGURE 1
Corrosion Cell *(1 January 2017)*
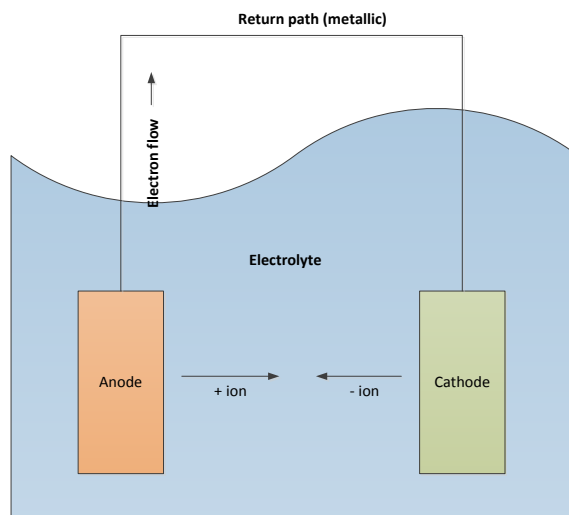
2   Uncoated Steel and the Corrosion Reaction *(1 January 2017)*

During the corrosion process, steel loses iron atoms into the environment in the form of ions. In return, some of the metal ions from the environment plate out and return to the metallic state. This is known as a reversible reaction. When the rates of the forward and reverse reactions are the same, then the process is in equilibrium and the steel takes up its equilibrium potential.

Metal atoms leave the metal and go into a solution as positively charged metal ions, leaving behind negatively-charged electrons. Consequently, the metal becomes more negatively charged. This makes it increasingly difficult or impossible for the remaining metal atoms to escape as positively charged ions as they are being held by the negative charge of the metal. For the process to continue, the excess of electrons in the metal must be consumed elsewhere in another reaction. The manner and speed with which these excess electrons can be removed is one of the factors that determine the rate of corrosion.

One important step in the corrosion of steel is the transformation of an iron atom to an iron ion by the loss of two electrons at anode sites. This is called the anodic reaction (oxidation reaction):

(1) Fe $=>$ Fe^{++} + $2e^-$

(IRON ATOM) $=>$ (IRON ION)   +   (2 ELECTRONS)
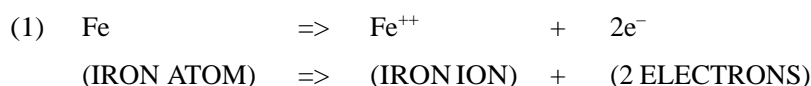
The free electrons created at the anode pass within the metal to another site on the metal surface, which is the cathode where the electrons are consumed by the cathodic reaction (reduction reaction) at cathode sites.

At the cathode, two following possible reactions occur in the electrolyte such as seawater. Electron consumption occurs at cathode site by reduction reaction through oxygen concentration cell or acid. Oxygen concentration cell reduction reaction can generate hydroxyl ions and acid concentration cell reduction reaction can generate hydrogen gas. See equations (2) and (3).

(2) O_2 + $2H_2O$ + $4e^-$ $=>$ $4OH^-$

(OXYGEN)   +   (WATER)   +   (4 ELECTRONS) $=>$ (HYDROXYL IONS)

(3) $2H^+$ + $2e^-$ $=>$ H_2

(Hydrogen ions)   +   (Free electrons) $=>$ (Hydrogen gas)
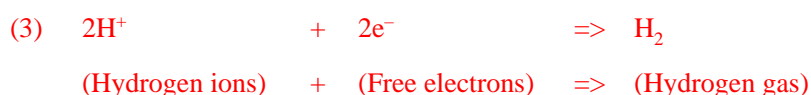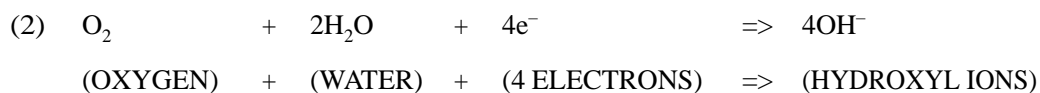
Freshwater or seawater contains dissolved atmospheric oxygen. The dissolved oxygen is electrochemically reduced to hydroxyl ions in the cathodic reaction. The formed hydroxyl ions react with the ferrous ions resulting in iron oxides (rust).

The heterogeneous character of the metal surface allows some areas for anodic sites and other areas for cathodic sites. The whole surface of the metal is therefore divided up into large numbers of anodic sites and cathodic sites. Section 1, Figure 2 shows anodic and cathodic sites and also shows the progress of corrosion where metal is lost from the anode, accompanied by a flow of electrons from the anode to the cathode within the metal. The electrons in turn react with both oxygen and water from the environment to form hydroxyl ions.

FIGURE 2
Anodic and Cathodic Areas Form on the
Uncoated Steel Surface *(1 January 2017)*
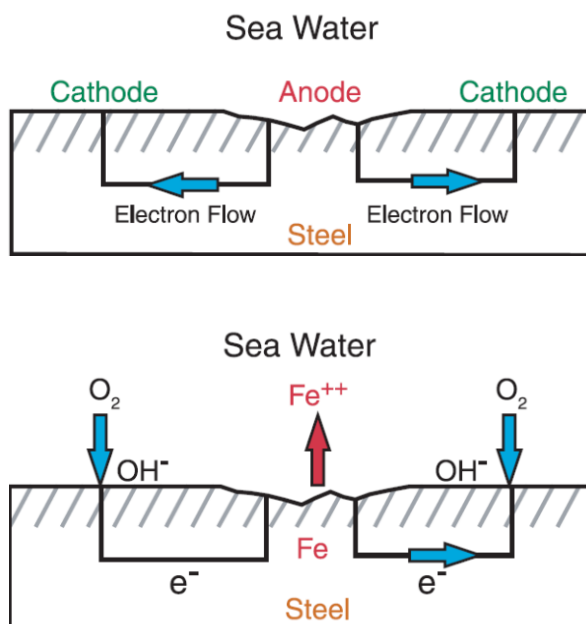
Both the iron ions and the hydroxyl ions diffuse in the solution and then react together to produce ferrous hydroxide as shown in reaction (4):

(4) Fe^{2+} + $2OH^-$ => $Fe(OH)_2$

(FERROUS IONS) + (HYDROXYL IONS) => (FERROUS HYDROXIDE)

Ferrous hydroxide in the presence of an abundant supply of oxygen is oxidized to form the familiar reddish brown rust.

(5) $2Fe(OH)_2$ + O_2 => $Fe_2O_3 2H_2O$

(FERROUS HYDROXIDE) + (OXYGEN) => (RUST)
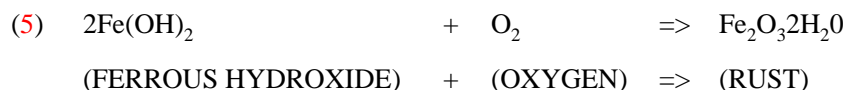
Reactions (1) through (5) are basic reactions which occur when iron or steel is in an electrolyte such as seawater or an acidic solution. However, in practical situations, the process is complex.

In given environments, certain metals, such as aluminum, copper and stainless steel, can form a thin and dense oxide film as a protective layer, which retards further corrosion. Such a protective layer acts as a natural barrier to corrosion. However, the oxide film formed on iron steel cannot act as a protective layer since it is porous and brittle and permeable to oxygen and electrolyte.

3   Factors Influencing Corrosion Rates

3.1   Oxygen *(1 January 2017)*

In most cases, the corrosion rates of metals are controlled by the availability of reactants at the metal surface and removal of the products. The diffusion rates of reactants can affect the availability of the reactants. Freshly exposed bare steel surfaces corrode at a greater rate than those covered with a compact layer of rust.

The corrosion rate is heavily controlled by the oxygen level in the water at the steel surface. In areas where oxygen is prevalent, corrosion occurs at faster rates. High flow areas, such as in the vicinity of bell mouths, tend to exhibit higher corrosion rates because of the increased oxygen levels, although erosion is also a factor. Areas covered by a thin, conducting moisture film, such as ballast tanks after the ballast water is removed and cargo tanks after sea water washing, corrode faster than areas under immersion. Tank's underdeck, where air has been trapped, appears to have a higher corrosion rate than other areas of the tank where they are submerged and have a lower availability of oxygen. Section 1, Figure 3 shows oxygen and ion diffusion pathways near anodes and cathodes.

FIGURE 3
Diffusion Pathways near Anodes and Cathodes
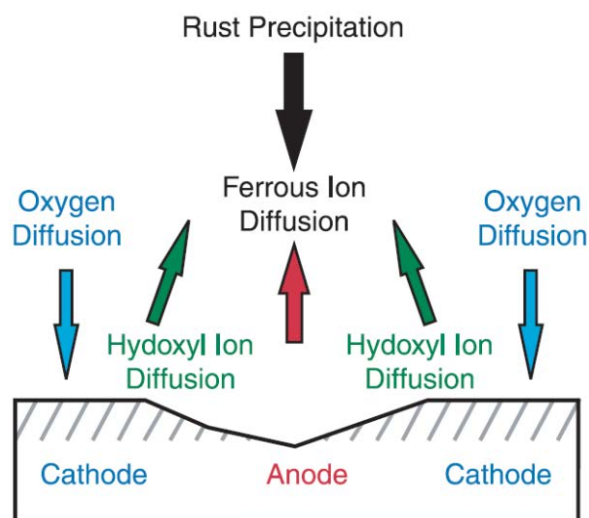
3.2   Temperature *(1 January 2017)*

As corrosion rates are determined by the diffusion rates of reactants and products, which are controlled by temperature. Corrosion rates are higher at higher temperatures than at lower temperatures. As a result, under-deck areas and regions adjacent to the engine room or to heated cargo tanks tend to corrode faster.

One of the features of the modern double hulled tankers is that when the cargo tanks are fully loaded, the empty ballast tanks act as a vacuum flask or thermos-bottle and retain the heat in the cargo for significantly longer periods than the single hull tankers. This increase in temperature of the cargo/ballast bulkhead combined with the cooler outer shell bulkhead (in the underwater regions) produces a complex set of corrosion conditions and results in an increase in the corrosion rate of the steel in both ballast tanks and cargo tanks.

3.3   Conductivity of Electrolytes *(1 January 2017)*

For corrosion to occur, there must be a conductive medium (electrolyte) between the two parts of the metal surfaces. Corrosion does not occur in pure distilled water with no dissolved substances and the rate of corrosion increases as the conductivity of electrolyte increases due to the presence of more ions dissolved in the solution.

The corrosion rate of steel reaches a maximum close to the normal ionic content of sea water. Fresh water corrodes steel to a lesser extent than brackish or estuarine water, with sea water usually being the most corrosive to steel.

3.4 Type of Ions

Some types of ions present in sea water or in cargoes are more corrosive than others. Chloride ions are usually the most destructive with sulfate and other sulfur-containing ions also presenting major problems.

Chloride ions have a destructive effect on the protective properties of any rusts produced by preventing the formation of the more protective, densely packed oxides. Sulfur-containing ions become involved in additional electron generating reactions within the rust itself which in turn forms a cyclic, self-regenerating process. This can produce intensive pitting on the inner bottoms of cargo tanks in oil and product carriers. The sulfur can originate from both the inert gas system and from cargoes containing sulfur, such as sour crude oil.

3.5 Acidity and Alkalinity (pH)

pH is a measure of the acidity or alkalinity on a scale of 1 to 14. pH 7 is neutral. In neutral sea water, the pH is around 7.5 which means that the hydrogen ions (acid) and hydroxyl ions (alkali) are almost in balance. Under such circumstances, the reaction that balances the iron dissolution is the reduction of dissolved oxygen to form hydroxyl ions. If, however, the environment becomes more acidic and the pH falls closer to 1, then there is a greater quantity of hydrogen ions than hydroxyl ions present in the solution. The excess hydrogen ions can become involved in the balancing (cathodic) reaction which results in the evolution of hydrogen gas. As both the hydrogen ions and the hydrogen gas can diffuse very rapidly, the steel can corrode faster. This is a common effect when carrying cargoes such as pet-coke, sulfur and sour crude oils.

Under alkaline conditions, where there is an excess of hydroxyl ions and the pH levels tend towards 14, steel cannot corrode and remains unaffected.

Many of the blisters which are found in ballast tanks, particularly in the double bottoms, are filled with a high pH fluid. When the blister caps are removed, the steel is bright underneath. However, it begins to corrode once the cap is removed, so once one or two of a group of blisters have been checked and the liquid found to be alkaline, the remainder of the blisters should be left intact.

3.6 Electrochemical Potential *(1 January 2017)*

Every metal takes up a specific electrochemical potential when immersed in a conducting liquid. This potential is called the half-cell potential as it can only be measured by comparing it to another known reference potential produced by a reference electrode, which is to be explained in the following Subsection 4/4. Common reference electrodes are the Saturated Calomel Electrode (SCE), silver/silver chloride and copper/copper sulfate reference electrodes.

The potential that a metal takes up in a solution can determine if and how fast it corrodes. The potential can be changed by connecting it to another dissimilar metal or by applying an external potential.

4 Types of Corrosion

4.1 Uniform Corrosion *(1 January 2017)*

The most common type of corrosion is uniform corrosion in nature. The loss of metal occurs at the anode sites and there is a continual change of the anode sites in the surface over time. With progressive metal loss, areas which were initially anodic cease to be active and new anodic sites take over. There is a continuous interchange between the anodic and cathodic areas, such that over a period of time the loss of metal over the entire surface is fairly uniform. This is the easiest form of corrosion to combat or allow for because structural lifetime can be predicted.

4.2   Pitting Corrosion *(1 January 2017)*

The characteristic of this type of corrosion is extremely localized and the penetration is deep in relation to the surrounding area. Pitting is one of the most dangerous forms of corrosion as it often occurs in places where it cannot be readily seen. Pitting corrosion can be intense on steel surfaces not continuously covered by mill-scale, which has been left outdoors, as shown in Section 1, Figure 4.

FIGURE 4
Pitting Corrosion on Uncoated Steel, Showing Layers of Iron Oxides
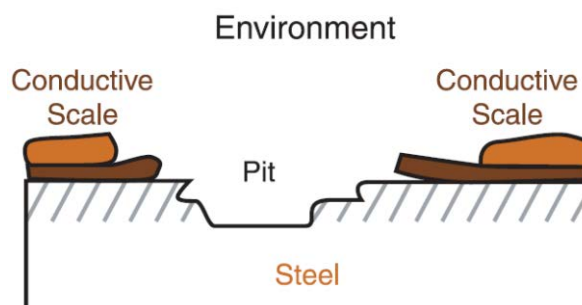
Pitting corrosion can occur whenever there are suitable localized conditions. Typically, pits form where there is a small anodic area which is supported by a large cathodic area, such as a situation of broken mill scales on steel surface. The discontinued mill scaled areas serve as small anodes and continued mill scales serve as large cathodic areas. This can also occur at isolated areas where the coating has been damaged.

Before segregated ballast tanks were introduced, cargo tanks with heating coils which were also used as ballast tanks tended to pit severely.

On uncoated stainless steel pipe work, for example, pitting can occur where the passive oxide layer becomes damaged and corrosion can initiate at individual sites. If the corrosion environment is not eliminated from the surface, corrosion continues and forms small pits. The rate of corrosion can accelerate as the pit develops.

Pits can grow in a variety of shapes, the common ones are V shaped, undercut pits, saucer pits as step sided, as shown in Section 1, Figure 5.

FIGURE 5
Different Pit Shapes
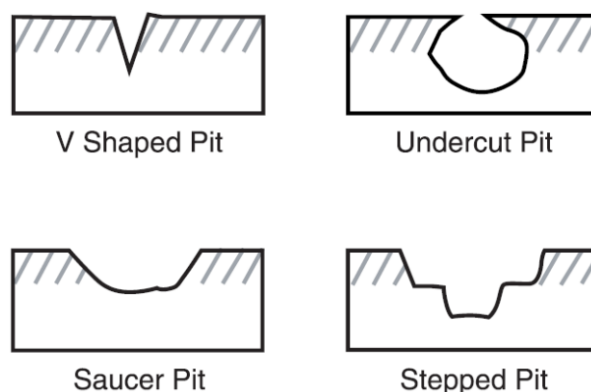
V shaped pits are a serious type of pitting as their rate of penetration through steel can be very high. Once this type of pit occurs, it becomes very difficult to clean the corrosion products from the base of the pit and the corrosion rate can increase rapidly.

Undercut pits are also a serious problem as the actual metal loss can be significantly greater than is initially apparent. If the pits are relatively shallow, then the overhang area can break under pressure and cause the pits to "open up". Over a large area such as inner bottom plating, the effect can be the equivalent of rapid general corrosion. If the pits do not become open, then the rate of corrosion can increase as the pits contain all the constituents necessary for corrosion and the anodic and cathodic areas can separate out within the pit. As with the V shaped pits, these are extremely difficult to clean thoroughly and corrosion rates can be high. See Section 1, Photograph 1 for examples of undercut pits.

Saucer shaped and stepped pits are the least detrimental, as the rate of metal penetration is relatively low over short time periods as compared with the other types and they are easier to clean and repair.

PHOTOGRAPH 1
Undercut Pits

(a) Surface View   (b) Cross Section View

4.3 Crevice Corrosion *(1 January 2017)*

Intense localized corrosion, ranging from small pits to extensive attack over the whole surface, can occur within narrow crevices formed by the geometry of a structure, for example: riveted plates or threaded joints. Crevice corrosion is characterized by a geometrical configuration in which the cathode reactant, oxygen, can readily gain access to the metal surface outside the crevice and have less access in way of the crevice. The metal within the crevice is therefore anodic to the surrounding steel and suffers preferential corrosion, see Section 1, Figure 6.

FIGURE 6
Crevice Corrosion
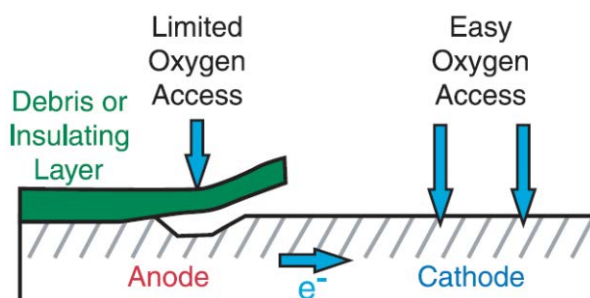
When mud, poorly adherent coating, sand and other debris cover a passive surface it undergoes a similar corrosion mechanism to that occurring in crevices. Wherever loose debris collects, there is a depletion of oxygen in a crevice. Consequently, the corrosion is localized there.

Crevice corrosion and subsequent pitting can also initiate where particles of material such as soot fall on an exposed metal surface. Crevices form where two surfaces are in close contact, for example, pipes and pipe support brackets in ballast and cargo tanks can suffer from crevice corrosion where the two items touch. Another example of crevice corrosion in shipyards is from steel storage. Open air storage of stacked steel plates can cause serious pitting around overlapped out areas between plates after certain periods of weathering.

Crevice corrosion can also form between a metal structure and a nonmetallic item, such as a gasket. An example of crevice corrosion forming pits is shown in Section 1, Photograph 2.

PHOTOGRAPH 2
Pits Forming as a Result of Crevice Corrosion
between the U Bolt Support and the Pipe

4.4 Galvanic Corrosion *(1 January 2017)*

Galvanic corrosion (also called "dissimilar metal corrosion") refers to corrosion damage induced when two dissimilar materials are coupled in a corrosive electrolyte. When a galvanic couple forms, one of the metals becomes the anode and corrodes while the other becomes the cathode and is protected. In order to have galvanic corrosion, the dissimilar metals must contact in an electrolyte. The corrosion rate (at anodic site) is controlled by the corrosion potential, which is a potential difference between the dissimilar metals. The well-known galvanic series lists the electrochemical potentials of certain metals in sea water. In the galvanic series shown in Section 1, Figure 7, the reference potential is a Standard Calomel Electrode (SCE). This is a common reference point in chloride containing environments such as those found in the marine industry. The figure gives the ranking of a number of common engineering materials in the Galvanic Series. The most positive (noble) material is protected against corrosion at the cost of the most negative (base) material.

FIGURE 7
The Galvanic Series of Metals with the Most Noble Metals at the Bottom

GALVANIC SERIES
CORROSION POTENTIALS IN FLOWING SEAWATER
(8 TO 13 FT./SEC) TEMP RANGE 50° - 80°F

VOLTS: SATURATED CALOMEL HALF-CELL REFERENCE ELECTRODE

Alloys are listed in the order of the potential they exhibit in flowing seawater. Certain alloys indicated by the symbol: ▬ in low-velocity or poorly aerated water, and at shielded areas, may become active and exhibit a potential near -0.5 volts.

When two different metals in the series are electrically in contact in an electrolyte (e.g., sea water), one of them becomes the anode and the other becomes the cathode. Anodes corrode in preference to cathodes.

For instance, when steel and copper are connected as in Section 1, Figure 8, steel is the less noble and therefore corrodes rapidly. Corrosion of the steel is accelerated through its contact with copper. The steel suffers galvanic corrosion while the copper is protected cathodically.

Stainless steel is also cathodic to mild steel. When the two are in direct contact, the mild steel corrodes sacrificially.

FIGURE 8
Flow of Electrons in the Iron/Copper Couple

Sea Water

Fe++   O₂

OH⁻

Fe
Steel   Copper

e⁻
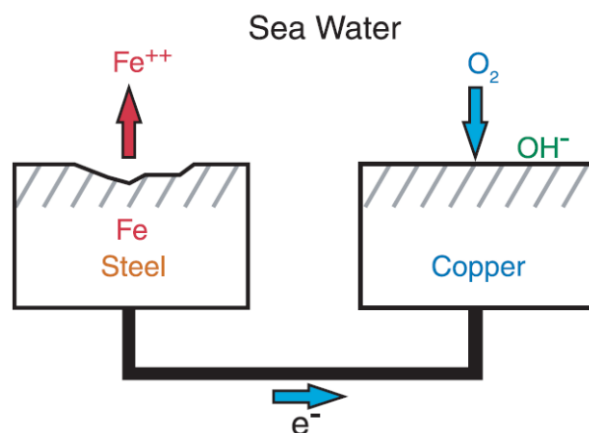
4.5   Deposition Corrosion *(1 January 2017)*

Deposition corrosion is a subtle form of galvanic corrosion that occurs when the ions of a more noble metal (cathodic metal) come into contact with a less noble metal (anodic metal). This results in a local galvanic couple being formed and the less noble metal corrodes.

A common example is that of copper ions from pipe work and heating coils being deposited on exposed steel tank tops and rapid pitting corrosion can develop. See Section 1, Photograph 3.

PHOTOGRAPH 3
Deposition Corrosion

Copper ions have deposited out on an aluminum structure and caused deposition corrosion to aluminum.

4.6 Impingement Corrosion *(1 January 2017)*

Impingement corrosion is a form of erosion-corrosion generally associated with the local impingement of a high-velocity of flowing fluid against a solid surface.

Impingement corrosion commonly occurs in the way of tank washing and cleaning processes. Areas that are closest to the jets can suffer from a loss of coating and pitting. The force of the jet, whether it is oil or water, is sufficient to remove the protective oxide layers from the metal surface and if the protective oxides cannot reform, localized corrosion (pitting) occurs. See Section 1, Photograph 4.

PHOTOGRAPH 4
Impingement Corrosion

Structures in the way of tank washing systems can lose their coating
and pitting corrosion can occur.

4.7 Microbiologically Influenced Corrosion (MIC)

This type of corrosion can very occasionally occur in ballast tanks and has sometimes been blamed for the excessive pitting found on the tank tops of VLCCs. All metals, even stainless steel, can incur corrosion from microbiologically influenced corrosion (MIC). It is very difficult to clearly differentiate MIC from other forms of corrosion and opinions differ widely as to its significance. Only when mats or webs of slimy material are present in clearly de-oxygenated environments (zero oxygen) can its presence be definitively confirmed.

The two most common types of bacteria that cause corrosion are acid producing bacteria (APB) and sulfate reducing bacteria (SRB). Both live in colonies attached to the surface of the steel where they assist each other in their growth. Corrosive bacteria, such as SRB which grow in oxygen free environments, rarely thrive over large areas in the conditions on board vessels. On ships, microbes can live in the water layer at the bottom of oil cargo tanks and in the sediment in ballast tanks, but stagnant conditions are usually required for MIC to become widespread. The exact reaction of microbes and steel is not clear, but they do produce acids, create corrosive cells and produce hydrogen sulfide.

The initial detection of sulfate reducing bacteria is first achieved visually by noting a black slime deposit on the surface of the steel. Additionally, the detection of hydrogen sulfide (as a rotten egg smell) could be noted. Corrosion attributed to MIC almost always manifests as highly localized pitting and the pits are generally filled with a black ferrous product. The walls of the pit can be terraced and the metal surface below the corrosion products is often bright and active. Further confirmation can be obtained by culturing samples.

However, similar corrosion effects can also be found where MIC is not a factor. In crude oil tanks, the corrosion and pitting are driven mainly by sulfur deposits from the cargo or produced by inert gas systems.

All permitted hard coatings used in cargo and ballast tanks are known to be resistant to bacteria with the possible exception of vinyls. The latter are only rarely used in these areas. Supplementing a coating protection system with sacrificial anodes can cause the pH within the tank to increase locally. Bacteria do not usually thrive in areas where the pH level is in the alkaline range of 10 to 14.

Note that although sacrificial anodes may be present, the local pH under a bio-film or rust scale may become or remain acidic if it is shielded from the effects of the sacrificial anode. The use of biocides for treating bacterially affected areas has been tested successfully in small, enclosed tanks, but these have short-term effects and are expensive. Biocides such as chlorine, hydrogen peroxide, iodine and quaternary amine have been used.

At the new construction phase, design features should be utilized to minimize or eliminate areas for the accumulation of mud and sediment. Also, proper drainage of all liquids to a common stripping area is desirable to eliminate the possibility of stagnant water accumulating.

SECTION 2 Protective Coatings

1 General *(1 January 2017)*

For the reasons described in the previous section, corrosion requires a corrosive environment. Coatings, as barriers between a steel surface and a corrosive environment, work first by excluding water, ions and oxygen from reaching the steel. The efficiency of the barrier determines the extent of corrosion and coating breakdown.

For a perfectly intact coating applied to a perfectly clean surface with good surface preparation, the expected lifetime (assuming that there is no mechanical damage to the coating and/or strain applied on the steel substrate due to structural behavior) would probably exceed that of the vessel. It is the deviations from perfection that compromise the coating lifetime.

2 Factors Affecting Coating Lifetime

2.1 Oxygen Permeability

Most coatings used in the marine industry are not good barriers to the diffusion of gases. Coatings allow more than sufficient oxygen through the bulk of the coating to sustain any corrosion reaction taking place at the interface with the metal.

2.2 Water Vapor Permeability

Water in its gaseous phase can generally penetrate coatings with much the same ease as oxygen. Water vapor then condenses at the metal interface back to liquid water where it can drive such phenomena as osmotic and cold wall blistering. The latter occurs when water vapor passes through the coating and then condenses on the underlying cold metal. Liquid water cannot return through the coating and so blisters are formed, usually containing neutral pH fluid.

Inward rates of water vapor diffusion are generally higher than outward diffusion rates. The corrosion process is therefore rarely limited by a lack of water availability.

2.3 Liquid Water Uptake

As well as water vapor, coatings also transmit liquid water, which is taken into the bulk of the coating and (depending on the type of coating) can cause it to swell, disbond from the metal or to leach soluble components over an extended time period. Cyclic effects can eventually compromise the barrier properties of the coating.

2.4 Ionic Permeability

It is usually the availability of aggressive ions such as chlorides or sulfates at the interface that determines the rate of the corrosion reaction. For cross-linked coatings such as epoxies and polyurethanes, the network structure prevents the transmission of these ions through the bulk of the coating. Ions can only reach the interface via pores and defects in the coating.

2.5 Coating Porosity *(1 January 2017)*

All coatings could contain pores and other similar defects. These are usually produced during coating application and are a result of air entrapment, solvent boiling, pigment segregation or other similar phenomena. The density and size of the defects can vary with coating thickness in the manner shown in Section 2, Figure 1.

FIGURE 1
Schematic Coating Porosity in Single Coatings of Different Thickness
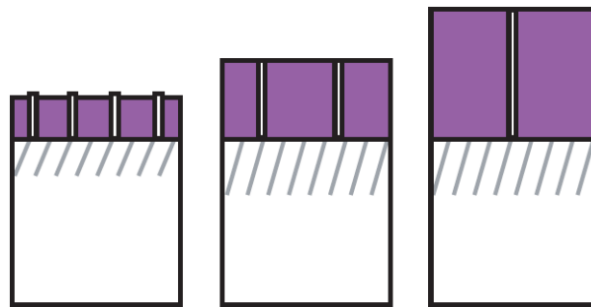
The thicker the coating, the lower the defect concentration and the less the likelihood of pores reaching from the surface to the steel. The chance of a pore penetrating through a single coat system is greater than through a double or multi-coat system of the same total thickness, as shown in Section 2, Figure 2. Pores can penetrate both layers as the pore in the lower layer can act as a nucleation site for the pore in the upper layer.

FIGURE 2
Schematic Coating Porosity in a Two Layer System
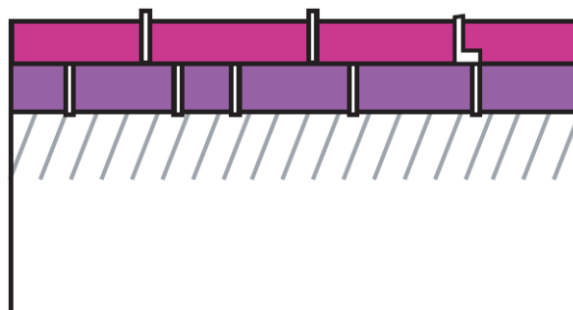
However, over thickness in a coating can lead to internal stresses being generated and cracking can occur. Therefore, a very thick coating is not necessarily better. The manufacturer's recommendation on dry film thicknesses (DFT) and numbers of coats should be achieved.

In order to achieve specified DFTs with good adhesion to substrate steel, stripe coatings are generally recommended for welds and edges before spray coating is applied. They become common practice for the new building process. They are also applied during maintenance and repair/refurbishment. Spray application processes and the inherent nature of paints in the liquid state cause the coating to pull back from sharp edges and this results in the formation of a thin film at edges, as shown in the first coat portion of Section 2, Figure 3(a). Due to the consequence from the sharp edges, sharp edge grinding (as shown in Section 2, Figure 3(b)) and irregular weld grinding are required from IMO PSPC. IMO PSPC sets out a minimum of 2 mm round edge after grinding and weld treatment to ISO 8501-3 (P2). In addition, IMO PSPC requires at least two stripe coatings, and a second stripe coat can be reduced for weld seams only if the total dry film thickness meets the requirement. The purpose of the stripe coat is to add an extra thickness (preferably about 30 µm) of coating around vulnerable areas such as cut edges, welds and drain holes. During routine maintenance on board the vessel, the application of stripe coats during repair work (particularly if the vessel was constructed without stripe coats) prolongs the life of the coating scheme.

FIGURE 3
Schematic Showing the Need for Stripe Coatings

(a)

(b)
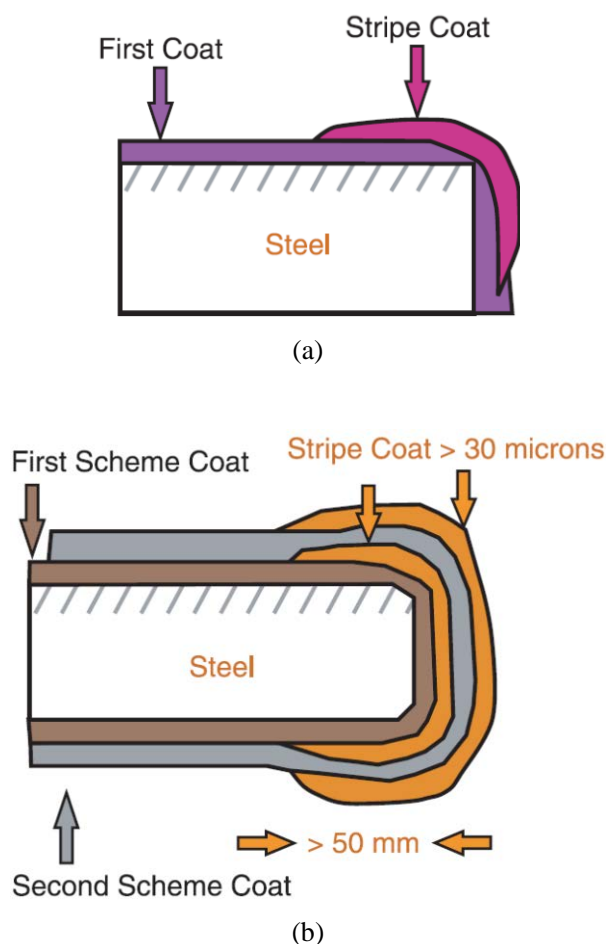
2.6 Surface Contamination *(1 January 2017)*

In practice, it is almost impossible to produce a perfectly clean surface in a shipyard or dry dock. Surfaces are contaminated to a certain extent with a mixture of ions, water, oils and greases, blasting dusts, soot and other deposits. When the coating is applied to the surface, service lifetime is expected to be limited. Ionic materials cause blistering and other disbonding phenomena while the other contaminants result in various degrees of lack of adhesion.

Coating manufacturers should provide the surface cleanliness requirements for each coating in their technical data sheets. In particular, the level of ionic contamination must be less than or equal to the test qualification of the coatings certification. Ionic contamination is usually measured in micrograms of ionic material per square centimeter or milligrams per square meter. It should be noted that there is a factor of ten to convert between these two measurement systems. In addition to the coating manufacturer's requirements, the IMO PSPC_SWBT and IMO PSPC-COT set out the minimum surface cleanliness standard.

2.7 Surface Profile *(1 January 2017)*

The roughness of the surface prior to coating also affects coating longevity. A good mechanical key is essential for adhesion. The term "mechanical key" describes the surface profile where the abrasive blast media has produced and allows the coating to flow in. The mechanical key helps to resist rust jacking (and calcareous deposit jacking).

3 Types of Coating Breakdown

(1 January 2017) Coating breakdown is covered here from a physical viewpoint; real life examples are shown and discussed later in Sections 10 and 11.

3.1 Blistering via Osmosis

Blistering is usually caused by the presence of ionic contamination or water soluble species at the interface between the coating and the steel. Water is drawn from the environment through the coating from an area of low ionic concentration to an area of high ionic concentration by osmosis. The coating domes upwards as a result of the pressure difference, as shown in Section 2, Figure 4.

FIGURE 4
Schematic Osmotic Blister Formation
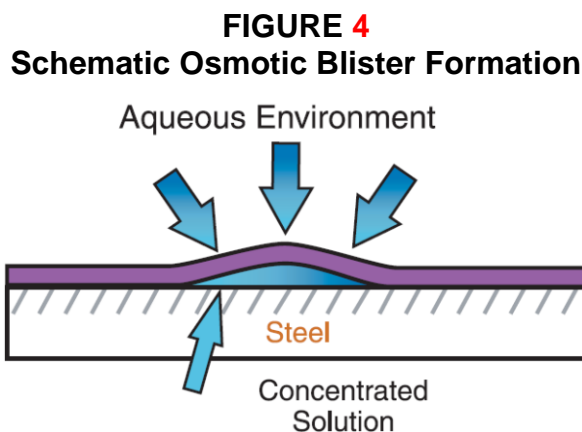
3.2 Blistering via Electro Osmosis

Osmotic blisters are usually small and relatively closely spaced. Larger blisters are the result of electro osmosis. When a normal blister grows so that it encompasses a pore in the coating, electro osmotic blistering can take place. The difference in potential between the anodic site and the local cathodic site that occurs beneath the blister drives ions into the blister. These then result in further growth of the blister via the mechanism shown in Section 2, Figure 5.

In Section 2, Figure 5 an actively corroding site or an external sacrificial anode would provide the same driving force for blistering. Osmosis and electro osmosis tend to occur early in the lifetime of a coating while it retains a degree of plasticity.

FIGURE 5
Schematic Electro Osmotic Blister Formation
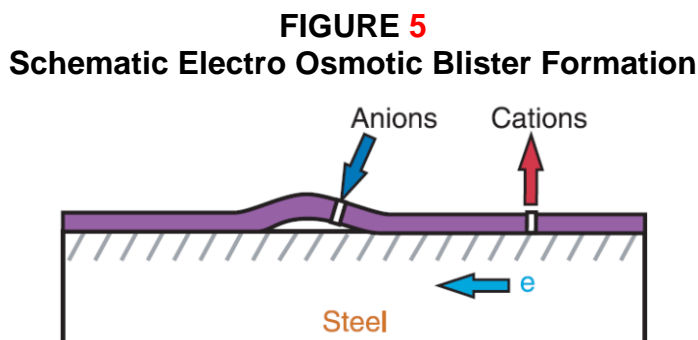
3.3 Rust Jacking

Rust jacking or rust leverage is the predominant mechanism of coating failure during the late stages of the service life of the coating. It occurs at defects in the coating, cut edges, welds and at sites of mechanical damage. It is a result of the change in volume that occurs between iron in the steel and iron in the corroded condition. Typically, there occurs a volume increase of between eight (8) and twelve (12) times when iron becomes rust. This volume change occurs beneath the coating and mechanically levers it from the surface in the manner shown in Section 2, Figure 6. Good mechanical strength in the coating and a good mechanical key to the substrate both help to resist this occurrence.

FIGURE 6
Rust Jacking
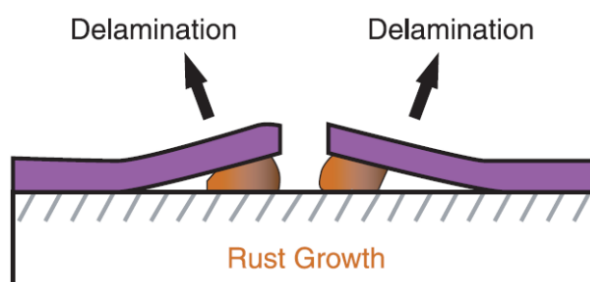
3.4 Calcareous Deposit Jacking

Calcareous deposit jacking is similar to rust jacking in that the coating is levered from the surface mechanically by a deposit growing beneath it. In this case, the white calcareous deposits grow at the interface of the steel and coating as a result of electrochemical polarization by the cathodic protection system. Hydroxyl ions are generated at the cathodic site beneath the coating. These ions change the pH of the environment, which in turn changes the solubility of components of the sea water and cause precipitation to take place in this area. Dissolved carbon dioxide can also diffuse into the gap under the coating and react with the hydroxyl ions, giving rise to chalky deposits in the manner shown in Section 2, Figure 7.

Calcareous deposit jacking and rust jacking usually occur together (sometimes in alternating layers) due to the cyclic conditions found in ballast tanks.

It should be noted that the calcareous deposits help to protect steel from further corrosion by the formation of a barrier layer on the steel. This is particularly of benefit in the ballast tanks of bulk carriers which suffer from impact damage from grabs, etc., on the opposite side of the plate in the cargo holds. The paint in the ballast tanks can crack or become detached and the calcareous deposits assist in the prevention of rapid corrosion at these areas until repairs to the coating can be carried out.

FIGURE 7
Calcareous Deposits
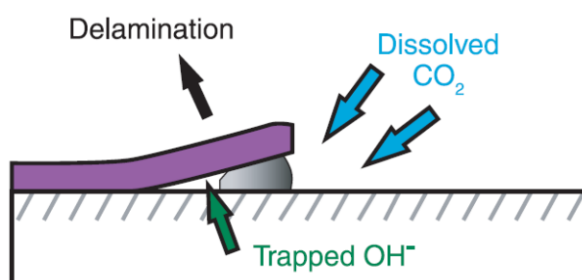
4   Protective Coatings *(1 January 2017)*

Protective coatings for corrosion prevention possess at least one of the following three main principles. They:

1)   Create a barrier that keeps out charged ions and retards the penetration of water and oxygen.

2)   Provide metallic contact between the steel and a less noble metal, such as zinc in the paint, which provides cathodic protection of the steel utilizing the galvanic effect.

3)   Cause water on its passage through the paint coating to take on special properties or compounds inhibiting its corrosive action.

4.1   Barrier Effect

The barrier effect may be obtained by applying a thick coating, typically 200 μm to 350 μm (8 mil to 14 mil). This barrier effect is the most commonly used type of anti-corrosion mechanism. Typical paints employing this mechanism include epoxies and polyurethanes.

By adding flake pigments, such as leafing aluminum, an improved barrier effect can be achieved. The flake pigments are oriented parallel to the steel surface, and water trying to pass through encounters a more complicated and longer passage around the pigment particles, as shown in Section 2, Figure 8.

For permanently immersed steel, the first and often the only choice in coating protection is to utilize the barrier effect. However, if a barrier coating is damaged, the damaged area is open for corrosion to begin. Corrosion can then proceed into the steel substrate and outwards under the intact coating, known as rust jacking or under film rusting. Where there is a risk of mechanical damage, additional protection such as cathodic protection is sometimes provided.

FIGURE 8
Complex Pathway Produced by Lamellar Pigments
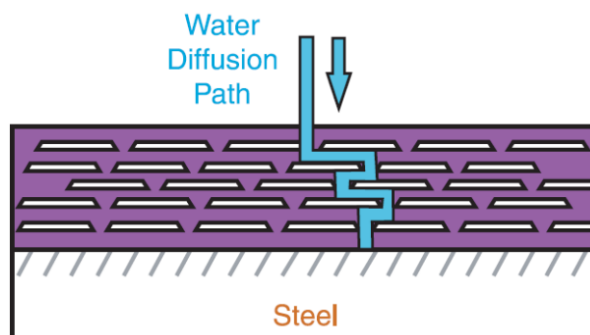
4.2   Galvanic Effect

Protection of steel through the galvanic effect (cathodic protection) can be achieved with paints containing large amounts of metallic zinc or aluminum. A condition for effective protection is that the paint is formulated to give metallic contact between the individual metal pigment particles, and between these particles, and the steel.

The very nature of these paints requires an absolutely clean steel surface and, especially for zinc silicates, a well-defined surface profile for a lasting coating system. When applied, zinc silicates are initially porous. Over time, the porosity is filled with corrosion products from the zinc and a barrier is formed. When damaged, the galvanic effect is re-established at the damaged area and the steel is protected effectively against rust creeping.

4.3 Inhibitor Effect

A corrosion-inhibiting effect is achieved by using primers containing inhibitors. These are soluble or basic pigments designed to suppress the corrosion process. Inhibitors work by reducing the rate of either the anodic or the cathodic process, or by depositing a high resistance film onto the corroding surface. The corrosion current flowing between the anodic area and the cathodic area is usually reduced by at least an order of magnitude. To prevent them from being washed out of the primer coats, top coats without inhibitors are applied to provide the barrier necessary for the inhibitive primer to last. However, due to the water solubility of the pigments used, inhibitive primers are not suited for prolonged immersion, as they suffer from blistering and subsequent early breakdown of the coating system can occur. When damaged, reasonable protection against rust creeping or under rusting is provided if the damaged area is not too large. When the inhibitor has been used up, corrosion occurs.

4.4 Surface Tolerant Coatings *(1 January 2017)*

After a vessel enters service, corrosion begins to occur under coatings in tanks and holds at areas of damage or at regions where good surface preparation was not initially carried out. Maintenance of the coating is essential if its target service life is to be achieved. Any damages to the paint or any areas of rust jacking must be repaired as quickly as possible. Under service conditions, it is not always possible to achieve a very high standard of surface preparation, although some vessels have small scale abrasive blasting equipment on board.

The application of a surface tolerant paint product can be practical during coating maintenance and repairs. However, it should be remembered that no paint performs adequately if it is applied onto heavily rusted or contaminated surfaces and that steel preparation should always be carried out to the proper or highest possible standards, to avoid the necessity to repair the same area many times.

Outer hulls of vessels suffer from mechanical damage from fendering, tugs, etc., and with time, this can result in pitted steel which is difficult to clean by spot abrasive blasting. The steel looks clean visually but ionic contaminants, such as salts, can be trapped under rust scales or in pits as shown in Section 2, Figure 9.

Washing the surface with fresh water can help to reduce the residual contamination. Paint manufacturers specify the minimum surface cleanliness level allowed for their products.

FIGURE 9
Residual Contamination in Pits
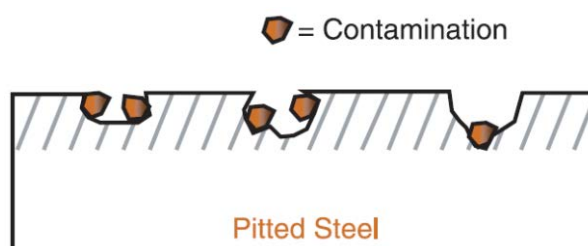
5 Coating Compatibility *(1 January 2017)*

The compatibility between different types of coatings varies considerably. Coatings such as epoxies have very specific over-coating time intervals (sometimes called the over-coating window) and these times must be strictly followed if the individual layers are to adhere to each other.

Incompatibility between coating types, such as epoxy anti-corrosive coatings with some types of anti-fouling paints, can be overcome by the use of a tie coat, which has good adhesion to both paint types and is therefore applied onto the anti-corrosive layer before the anti-fouling layer is applied.

If paints from different manufacturers are used, advice should be sought from the manufacturer of each of the different paints. Coating compatibility is important in new building PSPC projects and its approval is specifically addressed in the PSPC standards.

Coating compatibility is also important when maintenance and repair work is carried out so that the repair coat adheres to the original paint or inter-coat adhesion failure occurs.

SECTION 3 Coating Types and Their Uses

1 General *(1 January 2017)*

This Section covers the major types of coatings that are currently available for use on vessels and includes general information on the composition of coatings. It is intended to give basic information on coatings and is not a comprehensive guide to coating selection. The coating manufacturer is to be consulted if information on a specific product or coatings suitable for particular areas on the vessel is required.

Coatings for ships are often divided into two broad categories:

i) Products for application at new building and;

ii) Products suited for maintenance and repair, which would include both major refurbishments, either at sea or in port, and On Board Maintenance (OBM). The types of coating used for OBM are often single pack products as this avoids the difficulties of measuring and mixing small quantities of two-pack products, although small quantities of two-pack products are sometimes available from paint manufacturers.

In general, paints are either targeted for specific vessel areas and for specific functions for best performance, or universal coatings are available for all areas with a compromise in performance. In all cases, a balance between cost, performance and difficulty of maintenance has to be achieved. For example, anti-corrosive coatings used on the outside of the accommodation area have different performance requirements from anti-corrosion paints used in sea water ballast tanks as the corrosion stress placed on the latter is far greater. Ballast tanks are also much more difficult to maintain due to access difficulties. Therefore, to maintain the steel in good condition cost-effectively, the use of a highly effective (and often more expensive) coating is preferred.

In contrast, the holds of bulk carriers suffer from abrasion damage due to cargo impact and grab damage, which often leads to erosion and corrosion. Cargo holds used as ballast tanks during heavy weather can be particularly susceptible to corrosion at damage sites, and a different coating is sometimes used for this cargo hold. This also applies to cargo tanks for oil carriers with a class notation for "Clean Products", where any cargo tank may be used for heavy weather ballast.

2 Paint Composition *(1 January 2017)*

Paint can be defined as a liquid-applied coating which subsequently dries or hardens to form a continuous, adherent film.

Paints basically consist of three major components and many types of additives included in minor quantities. The major components are:

- Binder (also called vehicle, medium, resin, film or polymer)
- Pigment and extender
- Solvent

Of these, only the first two form the final dry paint film. Solvent is only necessary to aid paint application and the initial film formation, but inevitably, some solvent is always retained in practice depending upon the level of ventilation and dry time.

3 Binders *(1 January 2017)*

Binders are the film-forming components of paint which determine the principal characteristics of the coating, both physical and chemical. Paints are generally named after their binder component (e.g. epoxy paints, chlorinated rubber paints, alkyd paints, etc.). The binder forms a continuous film which is responsible for adhesion to the surface and which will contribute to the overall resistance to the environment.

Binders used in the manufacture of paints fall into two classes, thermoset and thermoplastic. A thermoset coating when dry will be chemically different from the paint in the can. Thermoset coatings are not dissolved by solvents once cured. With a thermoplastic coating, the dry film and the wet paint differ only in solvent content and chemically, these remain essentially the same. If the solvent originally used is applied to a thermoplastic coating, it will soften and can be redissolved in that solvent.

4 Cross-linked (Thermoset) Coatings

(1 January 2017) These paints are usually supplied in two separate packs which are mixed together immediately before application. In solvent-based paints, drying is considered a two-stage process. Both stages actually occur together but at different rates.

Stage One: Solvent is lost from the film by evaporation and the film becomes dry to touch.

Stage Two: The film progressively becomes more chemically complex by one of the following four methods:

  1) Reaction with atmospheric oxygen, known as oxidation.

  2) Reaction with an added chemical curing agent.

  3) Reaction with water (moisture in the atmosphere).

  4) Artificial heating.

This transformation in the paint is known as drying or curing. The films formed by the above methods are chemically different from the original binders and will not redissolve in their original solvent.

4.1 Epoxy Resins *(1 January 2017)*

These resins are particularly important and their development for use as binders was one of the most significant advances in paint technology. The rate of cross-linking or curing is dependent on temperature. The curing rate of standard epoxies is considerably reduced below 5°C (41°F). Full cure is essential to obtain optimal film properties. Epoxies will cure or set with special curing agents at temperatures down to –5°C (23°F). It is essential that the coating manufacturer's recommendations on application temperatures are strictly followed.

The choice of curing agent is very important as with the base, this determines the properties of the film. There is a wide choice of both resins and curing agents which allows for formulation of products to suit most applications.

Epoxies are used in both underwater and above water situations and show good resistance to many marine environments, but they have a tendency to chalk in sunlight. This occurs when the binder is degraded by ultraviolet light to produce a loose and friable surface, with the pigment particles remaining on the surface.

4.2 Polyurethane Resins

These are polymers formed by reaction between hydroxyl compounds and compounds containing isocyanates.

In two-pack systems, a special polyether or polyester resin with free hydroxyl groups is reacted with a high molecular weight isocyanate curing agent. A possible problem with these materials is their water sensitivity on storage and on application. Transport and storage should be in strict compliance with the manufacturers' recommendations. Due to their poor curing properties at low temperatures, manufacturers' recommendations must be followed during application.

Polyurethane resins have excellent chemical and solvent resistance and are superior to standard epoxies in acid resistance. Epoxies are more resistant to alkaline than polyurethanes. Polyurethane finish coats are very hard and have extremely good gloss, gloss retention, and can be formulated to be non-yellowing. However, they can in some instances be difficult to overcoat after ageing and require very clean surfaces for optimum adhesion. Because of the isocyanate curing agent, there is also a potential health hazard when sprayed, which can be overcome with the appropriate protective equipment.

4.3   Alkyd Resins *(1 January 2017)*

Alkyd resins are formed by the reaction between a special organic acid (e.g., phthalic acid), a special alcohol (e.g., glycerol or pentaerythritol) and a vegetable oil or its fatty acids. The final properties of the alkyd depend on the percentage of oil (termed "oil length") and also on the alcohol and organic acid used.

Alkyds are not resistant to acids or alkalis and many of the modifications are aimed at improving this weakness. However, none provide complete resistance. Alkyd resins can be further modified with different resins for specific purposes.

4.4   Inorganic Resins *(1 January 2017)*

These types comprise the silicates which are almost always used in conjunction with zinc dust pigments. There are water-based inorganic silicates based on lithium, potassium, or sodium silicate and solvent based inorganic silicates normally based on ethyl silicate. Coatings based on these resins are very hard, corrosion resistant and temperature resistant. They require a good standard of surface preparation and are often repaired using organic coatings.

The zinc in the inorganic resins can dissolve under acid or alkali conditions, but the coatings perform well around neutral pH and are often used as tank coatings.

5   Thermoplastic Coatings

These types of paint binders are simple solutions of various resins or polymers dissolved in suitable solvent(s) and are usually supplied as one pack products, making them especially suitable for maintenance work. Drying is simply effected by the loss of the solvent by evaporation. This is termed physical drying as no chemical change takes place. The resulting film is therefore always readily soluble in the original solvent and can also be softened by heat. Since these coatings, by definition, require the presence of significant amounts of solvent, they are disappearing from markets where volatile organic content is regulated, particularly the USA and the EU. Generic types of binders in this category include:

5.1   Chlorinated Rubber Resins

Chlorinated rubber resins have good acid and water resistance on well-prepared surfaces. Their temperature sensitivity can lead to various film defects when used in very hot climates. In addition, white and pale colors have a pronounced tendency to yellow when exposed to bright sunlight. Chlorinated rubber paints will dry at low temperatures and give good inter-coat adhesion in both freshly applied and aged systems, making them suitable for maintenance purposes.

5.2   Vinyl Resins

Vinyl resins are based on film forming polymers consisting of varying ratios of polyvinyl chloride, polyvinyl acetate and polyvinyl alcohol. Plasticizer types used are tricresyl phosphate or dioctyl phthalate.

Higher volume solid materials can be produced by blending the vinyl resin with other materials such as acrylic resins. Generally, the film properties and weathering characteristics also show good low temperature drying and inter-coat adhesion characteristics. Coal tar can be added to increase water resistance.

6 Pigments and Extenders

Pigments and extenders are used in paints in the form of fine powders. These are dispersed into the binder. The particle sizes are of about 5-10 microns for finishing paints and about 50 microns for primers.

These materials can be divided into the following types:

Type	Purpose
Anti-corrosive pigments	To prevent corrosion of metals by chemical and electrochemical means, in above water areas.
Barrier pigments	To increase impermeability of the paint film.
Coloring pigments	To give permanent color.
Extending pigments	To help give film properties required.

6.1 Anti-corrosive Pigments *(1 January 2017)*

6.1.1 Zinc

Metallic zinc is widely used in primers for protecting steel from corrosion. Initial protection is by galvanic action. However, as the coating is exposed to the atmosphere, a progressive buildup of zinc corrosion product occurs to fill up pores in the coating, producing an impermeable barrier with little or no galvanic protection. To give both good galvanic and barrier protection, high levels of zinc, such as about 85 percent of zinc in the dry film by weight, are necessary.

Resins which may be considered are epoxies and silicates. Obviously, for the zinc to function correctly, it has to be in intimate contact with the steel substrate and good surface cleanliness prior to application is therefore essential.

6.1.2 Aluminum Pigments

Metallic aluminum flake is commonly used as an anti-corrosive pigment by producing a circuitous pathway for water and ions around the lamellar flakes, as well as reacting to form aluminum oxides, which fill up pores in the coating. Where the aluminum is in contact with steel, a limited cathodic protection mechanism will also be provided, although when used on oil and chemical tankers where flammable gases build up, the aluminum content in the dry film should not exceed 10 percent by weight to avoid possible spark hazards.

6.1.3 Zinc Phosphate

Zinc phosphate $(Zn_3(PO_4)_2)$ pigments are also widely used in corrosion-inhibiting coatings for steel surface corrosion protection. Zinc phosphate hydrolyzes in water to produce zinc ions (Zn^{2+}) and phosphate ions (PO_4^{3-}). The phosphate ions act as anodic corrosion inhibitors by phosphating the steel and rendering it passive. The zinc ions act as cathodic corrosion inhibitors. Zinc phosphate can be incorporated into almost any binder and paint with any color of paint.

Please note that IMO performance standards of protective coatings require shop primers containing inhibitor free.

6.2 Barrier Pigments

The most common types of these pigments are aluminum (leafing aluminum) and Micaceous Iron Oxide (MIO). Both have particle shapes which are termed lamellar (plate-like). These materials can be used in combination, the aluminum lightening the almost black shade of MIO.

MIO-pigmented films have durability, but to achieve this, high levels of MIO are necessary in the order of 80 percent of the total pigment. Aluminum has been used for many years as the principal pigment in paints for use underwater. The lamellar shape helps to make the film more water impermeable. Glass flake is also used as a barrier pigment.

6.3 Coloring Pigments *(1 January 2017)*

These pigments provide both color and opacity and can be divided into either inorganic or organic types. The most common coloring pigment is titanium dioxide, which is white. In paint, all pigments are normally dispersed to a very fine particle size in order to give maximum color and opacity (hiding power). Traditionally, bright colors were obtained using lead and chrome pigments. However, due to health and safety concerns, these are less common. Organic pigments are now used instead, but the opacity is not as high with these products.

Where the IMO PSPC is applicable, a multi-coat system with contrasting color is recommended. The top coat shall be a lighter color to facilitate in-service inspection.

6.4 Extender Pigments

As the name suggests, they basically adjust or "extend" the pigmentation of the paint until the required pigment volume concentration (PVC) is achieved. Extender pigments are inorganic powders with various particle shapes and sizes. Although making little or no contribution to the color opacity of the paint, they can have significant influence on physical properties. These include flow, degree of gloss, anti-settling properties, spray-ability, water and chemical resistance, mechanical strength, hardness and firm build (volume solids, hold up thixotropy). Mixtures of extenders are often used to obtain the desired properties. They are relatively inexpensive when compared to resins, anticorrosive pigments and coloring pigments.

7 Solvents *(1 January 2017)*

Solvents are used in paints principally to facilitate application. Their function is to dissolve the binder and reduce the viscosity of the paint to a level suitable for the various methods of application, such as brush, roller, conventional spray, airless spray, etc. Solvents also can help with coating wetting on the surface to be coated. After application, the solvent evaporates and plays no further part in the final paint film. Liquids used as solvents in paints can be described in one of three ways:

7.1 True Solvent

True solvent is used to dissolve the binder and is completely compatible with the binder.

7.2 Latent Solvent

Latent solvent is not a true solvent. It is designed to mix with a true solvent. The mixture has stronger dissolving properties than the true solvent alone.

7.3 Diluent Solvent

Diluent solvent is not a true solvent. It is normally used as a blend with true solvent/latent solvent mixes to reduce the cost. Binders will only tolerate a limited quantity of diluent.

There are numerous solvents used in the paint industry and this is partly due to the number of different properties which have to be considered when selecting a solvent or solvent mixture. In addition to commercial factors such as price and availability, properties include toxicity, volatility, flammability, odor, compatibility and suitability.

In some countries, certain types of solvents are not allowed. This is especially true in the USA, where the Hazardous Air Pollutant Substances Act, (HAPS) dictates a timeline for removing many solvents and extenders from coatings. Application properties, dry times and overcoat windows will most likely be affected as this Act is implemented.

8 Anti-corrosion Paints

(1 January 2017) With few exceptions (such as anti-fouling paints, cosmetic effects, fire retardants, etc.), the majority of coatings applied to a vessel are used for anti-corrosion protection. There are many types of anti-corrosion coatings, but epoxy paints generally cover the greatest area on a vessel, particularly when they are used in sea water ballast tanks.

8.1   Pure Epoxy *(1 January 2017)*

Pure epoxy coatings are generally regarded as paints which contain only epoxy polymers, the cross linking agent, pigments, extenders and solvents. The coatings contain high levels of epoxy binder and are therefore expected to provide the maximum possible performance from a coating in terms of anti-corrosion protection, long life and low maintenance.

In addition, some products also claim abrasion-resistance properties. Pigments such as aluminum can be added to pure epoxy coatings to provide additional anti-corrosion performance.

Epoxy Phenolic coatings can be used in cargo tanks where a high cargo resistance is required, such as on oil-product and chemical carriers. Special care needs to be taken with the surface preparation, high temperature, and curing during construction of tanks. Coating manufacturers can provide advice on the specific requirements for each tank.

8.2   Modified Epoxy

Modified epoxy is also known as epoxy mastic, tar-free epoxy and bleached tar epoxy. This group covers a wide range of products and anti-corrosion performance capabilities. In service, modified epoxies can be effective. However, as there are many possible modified epoxy formulations, it is not possible to make generalizations on their anti-corrosion performance.

Modified epoxies can contain non-epoxy materials which are capable of cross-linking into the final film. They may also contain non-reactive materials, either solid or liquid, which do not take part in film formation, but remain like pigments or extenders in the final coating. If these materials are water (or cargo) soluble, they can leach out over an extended time period leaving a porous or brittle film with reduced anti-corrosive properties.

8.3   Coal Tar Epoxy *(1 January 2017)*

Coal tar is a naturally occurring product. Coal tars are available in a wide range of types from liquid to solid. The inclusion of coal tars in a coating results in a very dark brown or black color to the coating, which can be slightly lightened by the addition of aluminum flake pigment for lighter colored paints. However, it is unlikely that coal tar epoxies can be sufficiently light in color to be used in compliance with the IMO PSPC for the top coat. A light colored, non-tar based epoxy top coat can be used over a tar based first coat. However, tar "bleed through" may discolor the top coat.

Certain constituents of the coating can leach out over long periods of time, leaving a more brittle and less protective coating. Coal tar epoxies have a long track record in service and generally have performed well. Since the 1990s, they have been phased out in ballast tanks due to health and safety issues for the coating applicators and the recommendation for light color coatings to aid visual inspections.

8.4   High Solid Content Epoxy *(1 January 2017)*

High solid content epoxy coatings usually have solid content 70-100% by volume. They have low solvent content and therefore they have less solvent retaining, so better coating flexibility and less potential for cracking. Those high solid content coatings can provide high DFT buildup and good "edge-retentive" – save stripe coatings or less sharp edge grinding.

The viscosity required to spray the paint is obtained from the selection of low molecular weight raw materials or by heating and the use of plural component systems. Typical applications include ballast and cargo tanks. They are sometimes used where volatile organic components (VOC) removal is difficult due to poor ventilation. It should be noted that the VOC for solvent-free systems is not necessarily zero.

Typical applications for solvent-free coatings include the inside of pipe work, some tanks and other areas where adequate ventilation cannot be provided or for areas where stringent VOC controls are in force.

9   Impact and Abrasion-resistant Coatings

This type of coating is generally applied to the areas of ships which are most susceptible to damage, such as boot-tops and decks, and are sometimes used for the holds of bulk carriers. The regions around suction pipe ends and bell mouths are occasionally coated with abrasion-resistant coatings as these areas can be subjected to damage from the high flow rates of the cargo or ballast water and may suffer from erosion due to the presence of sand or small particles of debris in ballast water.

Coatings which are described as abrasion- or damage-resistant exhibit an increased resistance to cargo damage, but will not be able to withstand the severe impact of grabs and hold cleaning equipment which results in deformation of the steel itself.

10   Shop Primers *(1 January 2017)*

Shop primers, also referred to as pre-construction primers, are anti-corrosive coatings designed for application in automated plants to plates or profiles prior to steel plate cutting, assembly, or construction, at the new building of vessels.

Shop primers must:

• Provide protection against corrosion during the construction period

• Be spray applicable in a variety of automatic installations

• Permit a very short time between application and being dry to handle

• Not significantly influence the speed of welding or cutting

• Not produce noxious or toxic fumes during the welding or cutting process

• Not influence the strength of the welds or induce weld porosity

• Be able to withstand comparatively rough handling during vessel construction

• Form a suitable base for the widest possible range of coating systems

• Be capable of remaining on the steel and be over-coated or they may be partially removed prior to coating

Shop primers possess properties not normally found in paints designed for other marine purposes. They are applied at low film thicknesses, (typically 15 µm to 20 µm) so as to cause minimal interference to the speed of cutting or welding. The most common type of shop primer is zinc silicate.

Inherent in the formulation of shop primers are fast drying and retarded flow properties. A side effect of this is low cohesive strength. Shop primers that are applied with excessive dry film thickness (DFT) have a pronounced tendency to crack and split when over-coated.

To achieve the desired protection and avoid immediate or subsequent cracking, the dry film thickness of the primer must be closely monitored and the manufacturer's specification followed closely. Shop priming usually occurs in automated paint facilities. Regular checks on the efficiency of the abrasive cleaning and shop primer application lines should be carried out.

The weathering characteristics of zinc silicate shop primers depend upon the type of binder, the level of zinc in the primer and the local weather conditions. Longer lifetimes are achieved with higher levels of zinc, but the zinc salts caused by atmospheric corrosion must be removed from the surface before subsequent coatings are applied. Iron oxide epoxy shop primers are also used successfully in some parts of the world but generally do not have a long weathering period. The weathering time will depend upon the local climate.

Where a temporary protection to blast cleaned steel is applied by hand spray, as in a maintenance situation, a suitable anticorrosive holding primer with a reasonably long re-coating interval is often applied at relatively low film thickness. Anti-corrosive primers used for this purpose are referred to as holding primers. They are generally epoxy-based materials capable of accepting other generic top coats.

Both IMO PSPCs for ballast tanks and cargo oil tanks require that shop primer must be inhibitor free and zinc rich zinc silicate based or equivalent. Compatibility with the main coating system shall be confirmed by the coating manufacturer.

SECTION 4 **Surface Preparation** *(1 January 2017)*

1 General

Good surface preparation may be considered to be the most important part of the entire coating process in that the greatest percentage of coating failures can be traced directly to poor surface preparation. All paint systems fail prematurely unless the surface has been properly prepared to receive the coating. No paint system gives optimum performance over a poorly prepared surface. Surface preparation is to a coating system what a foundation is to a building. If a coating system has a poor surface preparation, it fails sooner than expected or it can fail catastrophically within the first year of application.

Surface preparation creates a foundation in two important ways:

i) A mechanical way, by providing an anchor (roughness) for the coating; and

ii) A chemical way, by allowing intimate contact (cleanliness) of coating material molecules with the steel (or other material) surface.

Steel, when it is abrasive blasted, has a rough surface with a series of tiny peaks and valleys called surface profile (see Section 4, Figure 1). Coatings anchor themselves to the valleys of the profile, and the peaks are like teeth. This is why surface profile created by blasting is sometimes called an "anchor pattern" or "mechanical tooth".

FIGURE 1
Surface Profile *(1 January 2017)*
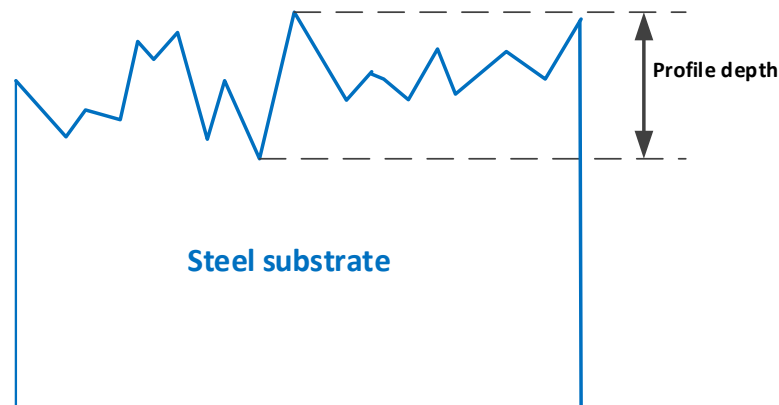
A clean substrate steel surface is to provide intimate contact between coating material and the substrate. The adhesion can be developed before curing or drying. This chemical bonding (secondary bonding such as hydrogen bonding, dispersion bonding or dipole bonding) is a major contribution to the adhesion between the coating and the substrate.

2   Surface Cleanliness

The extent to which a surface is made clean before the coating is applied is a balance between the expected performance of the coating, the time available for the job, the relative cost of the various surface preparation methods available, accessibility to the area to be prepared and the condition of the steel prior to surface preparation. In many instances, coatings cannot be applied under ideal conditions, especially under repair and maintenance conditions.

The quality of surface cleanliness to be achieved is very different for new steel plates and corroded steel plates. Any substance which prevents a coating from adhering directly to the steel can be considered a contaminant. Major contaminants at the new building stage include:

- Moisture, water, ice

- Oil, grease

- Soluble salts and other ionic species from the nearby sea, industrial areas, and workers, such as chlorides and sulfates

- Rust, millscale

- White rust (zinc salts from weathered zinc silicate shop primers)

- Dust/dirt, abrasive

- Weld spatter, weld flux, weld fume

- Cutting fume

- Burn through from welding on the reverse side of the steel

Non-visible contaminants are chemical contaminants. The most dangerous forms of chemical contaminants are soluble salts such as chlorides and sulfates. When such contaminants are painted over, they have the power to draw the moisture through the coating to cause blistering, detachment, and accelerated corrosion of the underlying steel.

Soluble contaminants remaining on a surface should be quantified using commercially available tests to ISO 8502-6 for overall soluble salts and further surface preparation work should be carried out, if necessary, until the specified cleanliness standards are achieved. Coating manufacturers' representatives and relevant shipyard personnel can perform these tests when necessary. An example of soluble contamination measurement is shown in Section 4, Photograph 1. SSPC Technology Guide 15 describes the most commonly used field methods for the extraction and analysis of soluble salts on steel and other nonporous substrates.

PHOTOGRAPH 1
Salt Contamination Testing

In maintenance and repair situations, the presence of pitting, corrosion products, cathodic protection products, aged coatings and trapped cargoes, etc., must also be considered, particularly if only localized surface preparation of the most severely affected areas is being carried out prior to re-coating. This is particularly important for outer hull refurbishment, water ballast tank and cargo tank coating repairs. See Section 4, Photograph 2.

PHOTOGRAPH 2
Outer Hull Showing Application of Primer after Localized Spot Blasting

3 Surface Cleaning

There are many methods currently available for the cleaning and preparation of steel surfaces prior to painting. The choice of preparation method depends upon the areas of the vessel to be prepared and the equipment available. For example, in a dry dock, the outer hull may be prepared by abrasive or water blasting before paint is applied.

On board maintenance may involve abrasive or water blasting, power and/or hand tool preparation depending upon the size and location of the area to be prepared and painted.

At new building, building blocks may be prepared for coating by thorough abrasive blasting to a pre-agreed standard, such as ISO Sa 2.5, by sweep blasting, or by power tools as specified.

One of the major causes of coating blistering is the presence of retained soluble salts on steel surfaces before painting. For some types of paint, such as chemical, cargo and ballast tank coatings, the level of soluble salts is crucial to the long-term performance of the coating.

While most of the salts can be removed from flat surfaces by water washing, it is difficult to remove the salts which are trapped in cracks, in the coating, under old paint and rust and in pits. Such residual salts cause blistering or detachment of the new coating, if not removed. In such cases, high pressure water washing should be used to remove the majority of these trapped salts. Some commercial products (such as Chlor*rid) are available which can be added to the water wash to reduce the presence of salts. It is recommended that verification of their efficacy be obtained or prior to use acceptance be obtained from the coating manufacturer for purposes of compatibility and longevity.

Paint manufacturers specify the maximum level of soluble salts which may be allowed on the surface before coating application for specified coating and its service environment. IM PSPC (Section 8) dictates the importance of residual salts on coating performance by specifying a limit of 50 mg/m^2 (7.11 × 10^{-8} psi) of water soluble salt equivalent to sodium chloride.

Techniques and standards available from NACE, SSPC and ISO for surface cleaning are listed in the following table:

Techniques	NACE and SSPC Standards		ISO 8501-1
Solvent cleaning	SSPC-SP 1		
Hand tool cleaning	SSPC-SP 2	SSPC-VIS 3	St2, St3
Power tool cleaning	SSPC-SP 3, SSPC-SP 11, SSPC-SP 15	Guide and Reference Photographs for Steel Surfaces Prepared by Power and Hand Toll Cleaning	
Flame cleaning	SSPC-SP 4		
Acid pickling	SSPC-SP 8		
Blast cleaning by using shot and/or grit	SSPC-SP 5/NACE No. 1: White Metal Blast Cleaning	SSPC-VIS 1 Guide and Reference Photographs for Steel Surfaces Prepared by Dry Abrasive Blast Cleaning	Sa 3
	SSPC-SP 10/NACE No. 2: near-White Metal Blast Cleaning		Sa 2 ½
	SSPC-SP 6/NACE No. 3: Commercial Blast Cleaning		Sa 2
	SSPC-SP 14/NACE No. 8: Industrial blast clean		
	SSPC-SP 7/NACE No. 4: Brush-off Blast Cleaning		Sa 1
Waterjetting or water washing	SSPC-SP 12/NACE No. 5	SSPC-VIS 4/NACE VIS 7 Guide and Reference Photographs for Steel Surfaces Prepared by Waterjetting	
	SSPC-SP WJ-1/NACE WJ-1 – Clean To Bare Substrate		
	SSPC-SP WJ-2/NACE WJ-2 – Very Thorough Cleaning		
	SSPC-SP WJ-3/NACE WJ-3 – Thorough Cleaning		
	SSPC-SP WJ-4/NACE WJ-4 – Light Cleaning		
Wet abrasive blasting	SSPC-TR 2/NACE 6G198: Wet Abrasive Blast Cleaning	SSPC-VIS 5/NACE VIS 9 (wet abrasive blast cleaning)	

Notes:

    ISO   =   International Organization for Standardization

    SSPC   =   Steel Structures Painting Council (now the Society for Protective Coatings).

    NACE   =   National Association of Corrosion Engineers

Each of these techniques must be controlled by specification. Related standards are available to help define the process.

It should be noted that the majority of the standards, such as ISO, NACE/SSPC for steel preparation, are based on a visual assessment of the surface condition only. Visual standards are not indicative of the extent of cleanliness of a substrate with regard to ionic contamination, nor are they an indication of the surface profile. Both of these should be checked separately to confirm that they match the specified requirements.

The visual surface cleanliness conditions are all assessed relative to the original condition of the substrate prior to cleaning. Steel is usually categorized into four grades: A, B, C and D grade, where A grade is new steel from steel mills, which is in the least corroded condition. D grade steel is corroded steel, which can be very difficult to clean satisfactorily.

The following table gives ISO 8501-1 cleanliness grades as an example:

ISO Sa 3	Blast cleaning to visually clean steel	When viewed without magnification, the surface shall be free from visible oil, grease and dirt and shall be free from mill-scale, rust, paint coatings and foreign matter. It shall have a uniform metallic color.
ISO Sa 2.5	Very thorough blast cleaning	When viewed without magnification, the surface shall be free from visible oil, grease and dirt and shall be free from mill-scale, rust, paint coatings and foreign matter. Any remaining traces of contamination shall show only as slight stains in the form of spots or stripes.
ISO Sa 2	Thorough blast cleaning	When viewed without magnification, the surface shall be free from visible oil, grease and dirt and from most of the mill-scale, rust, paint coatings and foreign matter. Any residual contamination shall be firmly adhering.
ISO Sa 1	Light blast cleaning	When viewed without magnification, the surface shall be free from visible oil, grease and dirt and from poorly adhering mill-scale, rust, paint coatings and foreign matter.

3.1 Solvent Cleaning

This is a process of using solvents or other cleaning compounds, to remove oil, grease and other similar contaminants, as shown in Section 4, Photograph 3. Any visible oil and grease on the surface to be coated must be removed before subsequent abrasive cleaning, such as blasting and tooling, since the subsequent abrasive cleaning may simply spread some of the contaminants over the surface rather than remove them.

PHOTOGRAPH 3
Oil and Grease Stains during Block Assembly
Show as Dark Stains on the Shop Primer

Although widely used, solvents are not necessarily the preferred substance recommended by paint companies for large areas of contaminants, as they may become an impediment rather than an aid if not properly removed. A proprietary, water soluble oil and grease remover followed by copious fresh water washing is the preferred method of achieving this standard. Care must be taken that the cleaner does not leave any ionic residues on the surface, particularly if the fresh water washing is limited to the use of buckets of water and cloth.

If solvent cleaning is chosen, then safety is very important. Adequate ventilation and minimizing the potential fire hazard are paramount. Clean-up rags should be changed often to prevent smearing, and two or three solvent applications may be necessary. Brush application should be avoided or the oil could simply spread over a larger area, as shown in Section 4, Photograph 4.

PHOTOGRAPH 4
Poor Removal of Oil Contamination using Solvent and a Brush

The dark area at the top of the photograph shows the extent of oil contamination after cleaning.

3.2   Abrasive Dry Blasting

This is the most commonly used method of preparing a surface for the application of paint, as shown in Section 4, Photograph 5. Abrasive blasting removes old paint, rust, mill scale, fouling, etc., and provides a good mechanical key (blast profile) for the new coating. The surface should be degreased if necessary before abrasive blasting. Weld spatters and deposits should also be removed before blasting. After abrasive blasting is completed, the surface must be cleaned to remove loose debris and dust before painting commences.

Dry abrasive blasting has an increasing concern for compliance with state and local regulations for health and environment.

PHOTOGRAPH 5
Abrasive Blasting

3.2.1   Spot Blasting

Spot blasting is an abrasive, localized preparation process commonly used on the outside of ships' hulls during repair and maintenance work, when patches of localized corrosion have occurred. Care must be taken to avoid the following problems:

- Undercutting and loosening of paint edges around the cleaned spot. Paint edges must be feathered as shown in Section 4, Figure 2, which is required by IMO PSPC.

- Stray abrasive particles (ricochet damage) damage surrounding paint in confined spaces and this must be treated and repaired as necessary.

- Blasting should be discontinued when moving from one spot to the next rather than trailing blast media over the surface. Any damage caused in this way should be repaired.

FIGURE 2
Schematic of Feathered Edges
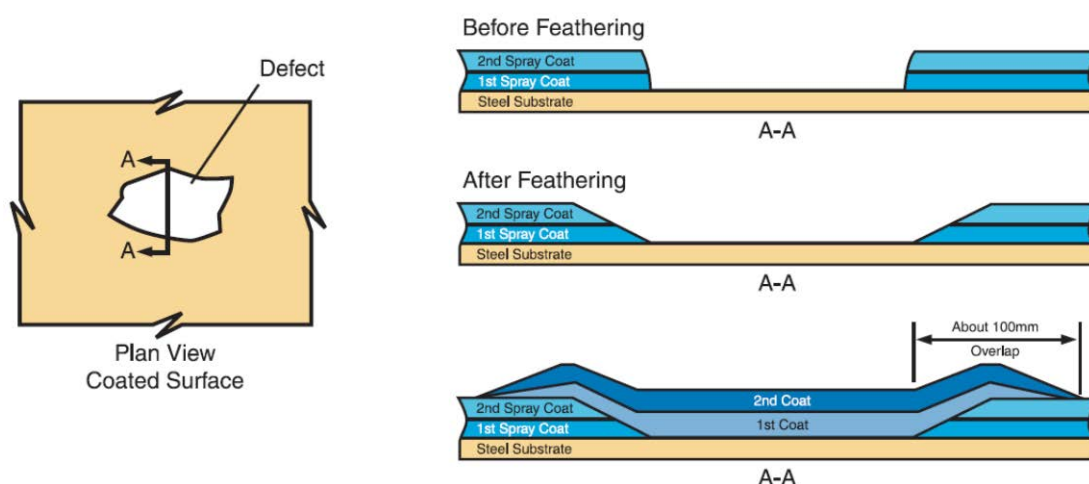
3.2.2   Sweep Blasting

A jet of abrasive is swept across the surface of the steel rather than being focused on one area for any period of time. Its effectiveness depends upon the type and particle size of the abrasive used, the condition of the surface and the skill of the operator. Three major types of sweep blast are in common use:

- Light sweeping is used to remove surface contamination, flash rust, or loose coatings. It is also used for etching of existing coatings to improve adhesion. Fine abrasive [0.2-0.5 mm (8 mil-14 mil)] is commonly used for light sweep blasting.

- Heavy or hard sweeping is used to remove old coating, rust, etc., for revealing the original shop primer or bare steel.

- Sweeping shop primers at new building is used to partially remove the shop primer to an agreed standard immediately prior to over-coating.

3.2.3   Blast Profile

It is important that the correct blast profile is achieved before the substrate is coated. Paint manufacturers should specify the blast profile for each coating in terms of the anchor pattern required for that paint. In general, thicker coatings require a profile with a greater peak to trough measurement than a thin coating.

However, when the profile is too rough, the coating may not cover the peaks of the profile with the right dry film thickness, and the result is pinpoint rusting. This could lead to premature coating breakdown.

Abrasive blasting may result in an insufficient surface profile and may simply redistribute contamination over the steel surface, trapping contaminants under the surface as shown in Section 4, Figure 3 below.

FIGURE 3
Contamination Trapped in the Blast Profile is Over-coated

Trapped Contamination

If the blast profile is too shallow or the surface is insufficiently blasted to produce a uniform profile, the adhesion of the coating to the metal substrate is insufficient and could result in early failure.

There are several methods for assessing the blast profile characteristics, such as replica/Testex tapes, surface comparators, surface profile gauges, etc.

If the blasting media is contaminated, the quantity of soluble salts remaining on the steel surface after blasting can be higher than before blasting. The quantity of soluble salts in blasting media can be checked by aqueous extraction techniques.

3.2.4   Abrasive Blasting Media

There are many types of abrasive blasting media available and each has its own characteristics in terms of the shape and hardness, recycling properties, etc. Shot produces a shallow and round profile, while abrasive grits result in a rougher and more irregular profile. The choice of blasting media depends upon substrate material, initial surface condition and the desired results. The blast profile should be specified.

Special blast media (e.g., garnet, etc.) are also available. Garnet can be used where disposal of used blast media is difficult (for example during on board maintenance), as it can be recycled several times without loss of blast quality and does not decompose into rust (compared with iron grit) if it becomes damp, thus aiding its removal from the interior spaces of tanks.

Galvanized steel and aluminum (for example) should never be blasted with iron or copper-based media.

Abrasive blasting material shall be managed to agreed standard, such as ASTM D4940, SSPC-AB 1, SSPC-AB 2, SSPC-AB 3, SSPC-AB 4 or ISO 11127-1 to 7. If the abrasive, recycled or non-recycled, is contaminated, the contamination can transfer to the steel surface being blasted. The most important items to be checked for abrasive contamination are moisture, oil, grease and soluble salts.

It is very important to confirm that the substrate surface is free of potential contaminants before blasting the surface. Oil, grease, soluble salts and dirt/dust should be removed from the surface by methods such as power washing, steam cleaning, solvent wipe, etc., prior to abrasive blasting for reducing the contamination levels of the abrasive.

3.2.5 Abrasive Blasting Advantages and Disadvantages

Advantages:

- Most effective method for removal of mill scale, rust and old coatings

- Gives a good profile to steel

Disadvantages:

- Environmentally unfriendly – noisy, dirty and creates large quantities of dust.

- Embedded grit can cause poor adhesion of coating in service.

The most recently developed new technology, such as Spongejet abrasive blasting (see Section 8, Photograph 17), can reduce most dust, rebound and waste compared with conventional abrasive blasting. Again, the selection of blasting technology should consider area to be treated, cost, regulatory restriction, surface quality to be achieved for best compliance with the agreed specification.

3.3 Hydro Blasting/Waterjetting

While dry abrasive blasting is the most commonly used method for surface preparation, government and local regulations increasingly restrict the use of dry blasting in open air and require the development of more environmentally-sensitive and user-friendly methods of surface preparation. The use of hydro blasting (also known as hydro jetting, waterjetting) is increasing. ASTM F20-16-00 (2006), SSPC-SP12 and NACE No.5 all include information on water jetting.

It should be noted that water-blasted surfaces are visually very different from those produced by abrasive cleaning or power tools, and surfaces often appear dull or mottled after the initial cleaning is completed.

One drawback of water blasting is the formation of flash rust (also called flash back or gingering) after blasting. Heavy rust formed in a short time period is indicative of residual salt on the steel and re-blasting is necessary before painting.

Waterjetting does not produce a profile on the steel surface as compared with abrasive blasting. It does however remove rust and loose paint, as well as soluble salts, dirt and oils, from the steel to expose the original abrasive blast surface profile plus the profile produced by corrosion and mechanical damage. The use of ultra-high pressure water blasting can also remove adherent paint from steel.

The terms water washing (usually used to remove salts, slimes and light fouling from vessels in dry dock), waterjetting (used to remove paint and loose rust), and water blasting (using an abrasive added to the water stream) can easily become confused. To clarify the situation, the following pressure guidelines, based on SSPC-SP 12/NACE No. 5, are given:

- Low pressure water washing/cleaning (LP WC): pressures less than 5,000 psi (34 MPa, 344 bar)

- High pressure water washing/cleaning (HP WC): pressures between 5,000 and 10,000 psi (34-68 MPa, 344-689 bar)

- High pressure waterjetting (UH WJ): pressures between 10,000 and 30,000 psi (68-206 MPa, 689-2068 bar)

- Ultra high pressure waterjetting (UH WJ): pressures above 30,000 psi (206 MPa, 2068 bar). Most machines operate in the 30,000-36,000 psi (206-248 MPa, 2068-2482 bar) range

Inhibitors can sometimes be added to the water to help prevent flash rusting prior to coating being applied. They are often ionic in nature. Their use should be permitted by the coating manufacturer or otherwise must be completely removed by further washing before the paint is applied. It is also important that the water being used is sufficiently pure so that it does not contaminate the surface being cleaned.

The use of slurry blasting, where an abrasive is included in the water stream, is also popular in some locations. This has the advantage of producing a profile on the steel as well as washing away soluble salts. However, its blast generally requires a subsequent rinse step to remove any residual abrasive left on the treated surface.

Waterjetting has advantages and disadvantages of water:

Advantages:

- Removes soluble salts from the steel surface

- Water as a cleaning material is generally inexpensive and available in large quantities. (The Middle East is an exception)

- Lack of contamination of surrounding areas because there are no abrasive particles

- Lack of dust

Disadvantages:

- No surface profile is produced. It relies on the original profile, if present.

- Flash rusting may be a problem in humid environments.

- Visibility during hydro blasting is very poor unless good ventilation is provided, particularly in confined spaces.

- The areas behind angles require particular attention as they are difficult to clean effectively by water blasting.

3.4   Power Tool Cleaning

Power tool cleaning is a method of preparing steel surfaces by the use of power-assisted hand tools.

Power tool cleaning removes all loose mill scale, loose rust, loose paint, and other loose detrimental foreign matter. It is not intended that adherent mill scale, rust, and paint be removed by this process.

Power tools use electrical or pneumatic equipment to provide faster cleaning. They include sanders, wire brushes or wheels, chipping hammers, scalers, rotating flaps (rotopeen), needle guns, hammer assemblies, and right angle or disk grinders.

The power tool cleaning standards require that visible deposits of oil, grease or other materials that may interfere with coating adhesion shall be removed before power tool cleaning.

After power tool cleaning and prior to painting, re-clean the surface by removing dirt, dust or similar contaminants from the surface. Acceptable methods include brushing, blow off with clean, dry air, or vacuum cleaning.

A pictorial series of standards published by Japan Ship Technology Research Association, the "Standard for the Preparation of Steel Substrates for PSPC (SPSS for PSPC 2008" shows welds and burn through damages both before and after different types and grades of cleaning. The effectiveness of cleaning using power tools rather than abrasive or waterjetting methods depends on the effort and endurance of the operator.

Power tools are limited to be only used for weld, edge treatments, and spot coating repairs. Abrasive blasting is more effective for big damaged areas.

Section 4, Photographs 6 and 7 show some commonly used power tools.

PHOTOGRAPH 6
Sander Paper Grinder *(1 January 2017)*

PHOTOGRAPH 7
Abrasive Grinder *(1 January 2017)*

3.5 Hand Tool Cleaning

Hand tool cleaning is a method of preparing steel surfaces by the use of non-power hand tools.

This method is the slowest and usually the least satisfactory method of surface preparation. It is frequently used in confined areas where power tool access is not possible. Scrapers, chipping hammers or chisels can be used to remove loose, non-adherent paint, rust or scale, but it is a laborious method and very difficult to achieve a good standard of surface preparation. Wire brushing can make the surface worse by polishing rather than cleaning the rusted surface. Soluble salts, dirt and other contaminants are frequently trapped and over-coated, leading to early paint breakdown.

3.6 Pickling

In new building shipyards, an acid pickling process can be used for the preparation of small items before coating. The items, such as pipes, are alkali cleaned followed by a wash and then an acid pickling bath to remove rust. Thorough washing must take place to remove all the acid, particularly if the item is to be painted, as shown in Section 4, Photograph 8.

PHOTOGRAPH 8
Pipes Undergoing Pickling

4   Preparation of Non-ferrous Metals

4.1   Galvanized steel with Zinc

The surface must be dry, clean and free from oil and grease before painting. Degreasing requires some effort to obtain a clean surface, as the zinc corrosion products can trap grease and other contaminants. Any white zinc corrosion products should be removed by high pressure fresh water washing or fresh water washing with scrubbing.

Sweep blasting or abrading are suitable preparation methods, but fresh water washing should be used additionally to remove soluble salts. An etch primer can also be used after cleaning to provide a key for further coatings. Paint companies should be consulted on suitable preparation methods, primers and coatings for galvanized steels and should advise on individual cases.

4.2   Aluminum

The grade of aluminum used in the marine environments is usually in the 5000 and 6000 series. These aluminum series are very corrosion-resistant to seawater. For some reasons, such as galvanic corrosion or pitting, aluminum is to be coated.

The surface should be clean, dry and free from oil and grease. Corrosion salts should be removed by light abrasion and water washing. Clean surfaces should be abraded or very lightly blasted using a low pressure and a non-metallic abrasive (e.g., garnet).

Alternatively, a proprietary etch primer should be used to provide a key for subsequent paint coats. Paint companies should be consulted regarding suitable primers and coatings.

4.3   Stainless Steel

Stainless steels are used because of their corrosion resistance in a wide variety of service environments, usually without additional coatings. In certain circumstances, however, stainless steel components or structures may require a coating.

Rough and clean surfaces prior to coating is essential. The surface shall be free of oil, grease and dust. Roughness can be achieved by abrasive blasting, light hand abrasion or chemical etching.

Abrasive blasting can be accomplished by using clean, fine, hard non-metallic abrasive particles (e.g. alumina or silicon carbide). The abrasive medium must be iron-free to avoid contamination, which can result in rust staining on the surface prior to coating.

To avoid distortion to light sections, light hand abrasion is an alternative method to blasting. Chemical etching treatments can also be considered. Certain paint manufacturers have special primers designed for such applications and it is recommended that details of the surface to be coated are specified when seeking advice on an appropriate coating system.

5   Steel Work before Surface Preparation

Experience has shown that edges and welds are generally the first areas to have corrosion and coating breakdown, particularly in ballast and cargo tanks. This is due to a number of interrelated processes including surface preparation, coating application, deflection, and shear and buckling stresses on the edges and welds and so on. The quality of the surface preparation plays an important role in determining the service lifetime of the coating.

5.1   Weld Preparation

The process of welding generally produces some type of slag on the weld itself, together with spatter (small droplets of the parent or weld material) and fume (smoke), as shown in Section 4, Photograph 9. Submerged Arc Welding (SAW) does not generally produce welding fume as the arc is covered by a slag blanket. Slag needs to be removed completely since residual slag on a surface can result in early failure of the paint in service.

PHOTOGRAPH 9
Weld Fume (Brown Stains) and Spatter

Removal of the weld spatter is essential as this material causes an irregular surface and results in poor coverage by the paint. Spatters must be removed by chipping or other mechanical means.

Weld fume must also be removed. If weld fume is over-coated, the paint may blister and/or peel from the steel in service. Blisters can also form where the shop primer is damaged due to the welding of stiffeners on the other side of the plate. This is often referred to as "burn through" and Section 4, Photograph 10 is typical of the results in service when the burn through is not adequately cleaned or removed prior to coating application.

PHOTOGRAPH 10
Blistering where a Stiffener was Welded on the Other Side of the Plate

Special effort is needed for the cleaning and weld treatment, particularly when the weld forms part of a complex structure such as the bulbous bow on a forepeak ballast tank. See Section 4, Photograph 11.

PHOTOGRAPH 11
Complex Structure, with Lower Welds Only Accessible Through the Hole

Welds must be efficiently prepared according to standard, such as ISO standard 8501-3 (grade P2) for IMO PSPC, for good coating adhesion.

FIGURE 4
Schematic Fillet Weld Showing Typical Defects
that Form Voids under the Coating

Fillet Weld
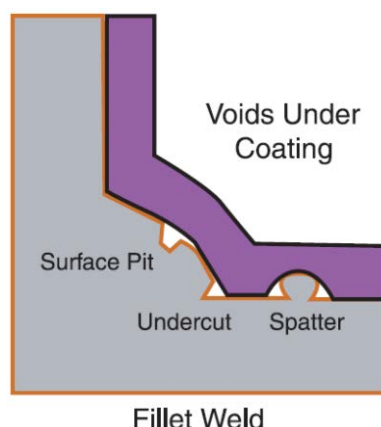
5.2   Edge Preparation

After application as the coating is still liquid, there is a tendency for liquid coatings to pull back from sharp edges leaving a very thin layer of paint which can quickly break down in service. Grinding the edges of cut outs, drainage holes, etc., as shown in Section 4, Figure 5, greatly helps liquid coatings stay with increased dry film thickness. Roughness from grinding to the edges can also improve the adhesion and coverage of the coating around the edge. IMO PSPC for both ballast tanks and crude oil tanks require at least three passes of the grinding disc or equivalent over the cut edges for giving at least 2 mm (0.08 in.) radius of round edges. Even one pass of grinding as required from IMO PSPC for void spaces, could give a better surface for painting than no preparation.

In addition, during coating applications, stripe coating to the edges is also beneficial in providing long-term protection. IMO PSPC for both ballast tanks and crude oil tanks require a minimum of two stripe coating to edges and welds unless for weld seams only, the second stripe coating can be skipped for avoiding over thickness of dry film.

FIGURE 5
Types of Edge Profile
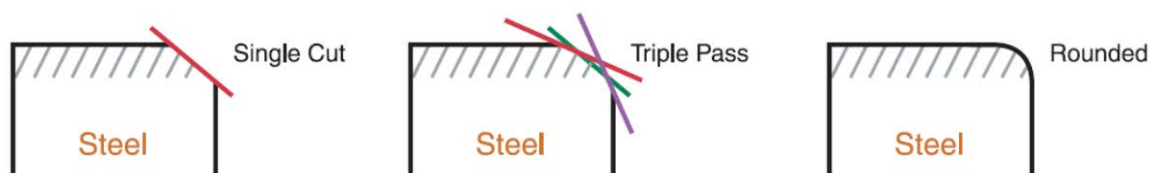
SECTION 5 Coating Application *(1 January 2017)*

1 General

The protective coating acts as a barrier to its corrosive environment, so that the substrate steel surface is protected. The objective in applying coatings is to provide an appropriate thickness of coating to the substrate steel surface with agreed surface profile and cleanliness under certain conditions. The variables which govern the coating quality during new construction and subsequent performance are:

* Surface preparation

* Coating application

2 Surface Preparation

As detailed in the previous section, it is essential to confirm that an appropriate surface preparation is achieved for the desired service life.

3 Coating Application Methods

The normal methods of application of coatings are by:

* Stripe coating by brush or roller

* Spray coating by conventional air spray or airless spray

* Plural airless spray

3.1 Brush Application

Brush application is a relatively slow method and is generally used for building up the dry film thickness in small complicated or complex areas or where spray application is restricted. Brushes are also used for applying the first coat where good penetration or good wetting to applied surfaces, such as welds, is needed. Brushes are also a commonly used method for "touch-up" of coatings during service. Section 5, Photograph 1 shows touch-up work to a stringer in a ballast tank.

PHOTOGRAPH 1
Brush Applied Touch-up Paint on a Forepeak Stringer

The choice of brush, brush size, length and type of bristle and brush shape are important, and the type of paint being applied will also influence the selection of the brush. Special brushes are available with offset heads and long handles to facilitate painting the "backs" of structures and inaccessible areas.

It is generally not possible to achieve the required film thickness in the same number of coats as with spray coating application, and multi-coat applications are necessary to give the specified film build.

At new building, the use of brushes for the application of stripe coats to welds and cut edges is required for IMO PSPC. See Section 5, Photograph 2.

PHOTOGRAPH 2
Stripe Coating on Welded Details

3.2   Roller Application

Roller application is faster than brushes on large, flat surfaces, such as walkways and deck areas, but it is not as appropriate for complex shapes. It is hard to control film thickness and high film build is only generally attained by applying multiple coats. The correct choice of roller pile is dependent on the type of coating and the roughness and irregularity of surface being coated and is essential for a good finish. Rollers can be used for applying stripe coats under certain circumstances to areas such as rat holes, scallops, cut outs, etc.

3.3   Conventional Air Spray

This is a method commonly used for applying zinc silicates to large surfaces. The equipment is relatively simple and inexpensive and is usually confined to fairly low-viscosity paints. Paint under pressure and air are fed separately to the spray gun and mixed at the nozzle, where the paint is atomized and air is mixed with these droplets forming a fine mist of paint which is carried by the air pressure to the work surface. It is essential to use the correct combination of air volume, air pressure and fluid flow to provide good atomization and a paint film which is free from defects. Poor control gives rise to overspray and rebound from the work surface in addition to defects in the paint.

3.4   Conventional Airless Spray

This is by far the most important and efficient method for the application of heavy duty marine coatings, which allows the rapid application of large volumes of paint as well as the application of high build coatings without thinning. Compared to conventional spray methods, overspray and bounce back are reduced. Section 5, Photograph 3 shows application of paint onto the topsides of a vessel in dry dock.

PHOTOGRAPH 3
Airless Spray Application of Paint to Vessel Topsides

As the name implies, airless spray is a technique of spray application which does not rely on the mixing of the paints with air to provide atomization. Instead, atomization is achieved by forcing the paint through a specially designed and precisely constructed nozzle or "tip" by hydraulic pressure. The choice of tip determines the film thickness applied per pass of the spray gun and should be selected in accordance with the coating manufacturers' guidelines. The speed of each pass and the volume solids of the paint are also influential in determining film thickness.

Airless spray equipment normally operates at fluid line pressures up to 352 kg/cm^2 (5,000 psi) and care should be taken to follow the equipment manufacturers' operating instructions and safety guidelines.

Hand guns are used in areas where there is direct access to the surface, for example, in tanks, while pole guns, such as the one in the photograph, are used for large surface areas.

3.5   Plural Component Airless Spray

To spray solvent free or high solid coatings, it is often necessary to heat the components to reduce their viscosity to an acceptable level for spraying. As these paints can cure very rapidly once mixed, the components are often heated separately and fed to a mixing head which is a short distance from the spray tip. Some solvent free coatings do not require pre-heating but rely on a higher pressure system to apply the paint.

4   Film Thickness

An adequate film thickness is necessary for a coating system to perform effective corrosion protection. Under thickness, of course, results in premature failure. However, over thickness can also cause problems, such as solvent entrapment, brittleness, cracking (including mud-cracking) and subsequent loss of adhesion. Recommendation on final dry film thickness (DFT), together with maximum coating thickness allowed, should be provided in the coating technical data sheets.

Conventional liquid applied coatings contain solvent. The solvent does not contribute to final DFT. The final DFT can be calculated from the wet film thickness (WFT) of the coating with a given value of a solid content percentage from the coating technical data sheets. The basic formula using solids by volume is:

$$WFT = \frac{DFT}{\% \text{ solids by Volume}}$$

Practically, the actual DFT applied to the substrate surface is not uniform. To determine whether a coating thickness variation is acceptable, there is guidance from the agreed-upon specification, such as the 80-20 or 90-10 rules. For example, the 90-10 rule means no measurement can be below 90% of the DFT specified and not more than 10% of the measurements can be less than the DFT specified. The DFT measurement locations are also to be agreed.

The gauge for measurements of the dry film thickness shall be calibrated to a standard such as SSPC PA-2. The DFT measurements are influenced by the profile and cleanliness of the substrate. Thin films [of less than 25 μm (1 mil)] cannot be measured accurately over blasted surfaces by using commercially available paint thickness gauges. Measurements of DFT at edges and corners are also not accurate due to uneven surfaces and edge effect of the thickness gauges. Paint companies can advise on suitable methods for these circumstances.

5   Coating Application Conditions

There are a number of factors which must be considered when marine coatings are applied. The major ones include:

- Condition of the substrate

- Temperature

- Relative humidity

- Weather conditions

- Condensation

- Ventilation

- Ultraviolet light (UV)

5.1   Condition of the Substrate

The surface to be coated must be clean and free from dirt, dust, abrasive blast medium (if used), oil, grease and soluble salt contamination.

5.2   Temperature

The temperature of both the air and the substrate must be considered. Exposure to direct sunlight can increase the surface temperature of steel significantly in excess of the air temperature.

Paint application must not occur when the temperatures are either higher or lower than those specified on the coating manufacturer's data sheets. In general, coatings are not applied at ambient temperatures below 5°C (41°F).

Below 5°C (41°F), curing of coatings such as epoxies slows dramatically and can stop altogether for certain paints. Some epoxy coatings are available in both winter and summer temperature versions to allow for seasonal temperature variations. It is important that the change-over to the winter grade occurs ahead of seasonal temperature drops, and also it is important to be aware that winter type coatings have a reputation of coating brittleness because the winter type coatings are designed for fast curing and solvent can be trapped within the coatings, causing brittleness. Winter and summer versions of coatings are considered different unless they are proved the same from the test of infrared (IR) identification and Specific Gravity (SG).

Above 40°C, rapid loss of solvent can cause sprayed paint to dry before it reaches the substrate. This is known as dry spray. As the paint does not flow to form a coalesced film, this significantly reduces the performance of the coating. Paint manufacturers' guidelines should be carefully followed if paint is to be applied at temperatures above 40°C (104°F).

5.3   Relative Humidity and Condensation

Some coating systems can tolerate high humidity, but condensation must not form on the surface being painted. Coating application shall not take place when the steel temperature is less than 3°C (6°F) above the dew point.

Temperatures tend to fall during the night and then rise again during the day. The lag in air movement can allow condensation to form if the steel temperature is below the dew point of the atmosphere.

Some coatings, such as epoxies, are particularly sensitive to water during curing. If the outer surface is exposed to moisture before the paint has cured sufficiently, components in the coating react with the water to produce a condition known as amine bloom or amine sweating. This layer prevents successful adhesion of the next paint layer, causing it to peel off. An example of this is shown in Section 5, Photograph 4.

PHOTOGRAPH 4
Amine Bloom
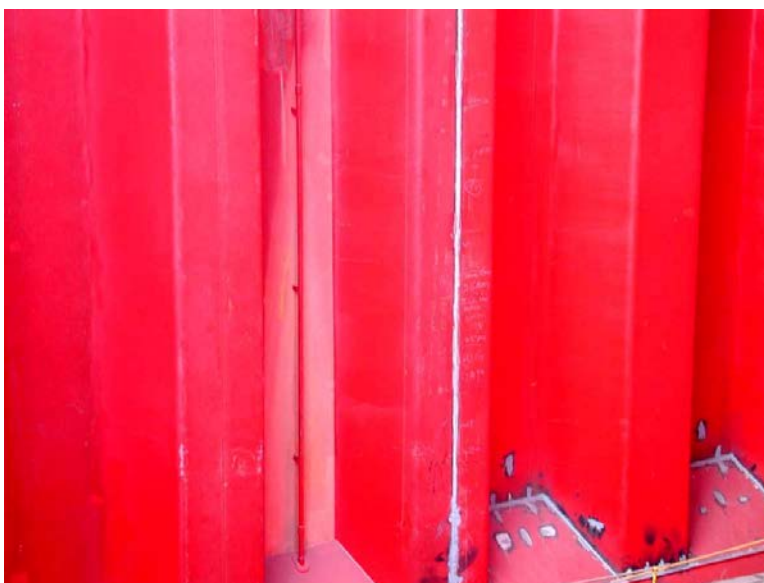
The vertical pink areas have been affected by amine bloom. When
the block was left outside for the coating to cure, water collected on
the exposed areas and adversely affected the paint.

5.4   Weather Conditions

Paint should not be applied during fog or mist or when rain or snow is either falling or imminent. Generally under these conditions, it is difficult to maintain the steel temperature above the dew point.

When paint is being applied outdoors, particular care should be taken under windy conditions. Winds can cause many problems such as uneven coverage of paint, dust inclusion in paint, dry spray, and also over spray on surrounding structures/subjects.

5.5   Ventilation

Ventilation is required for reasons of health and safety, In addition, the quality of coating systems for solvent-containing coatings is greatly affected by the amount and type of residual solvent in the coatings when the coating dries or cures.

Ventilation must be maintained throughout the application process and for a period after application is completed, while the paint cures or dries. Product data sheets indicate any special ventilation requirement for the coating.

5.6   Ultraviolet light (UV)

In some geographic locations, high levels of UV light are present. Certain coatings (such as epoxies) are sensitive to UV light, which breaks bonds in the surface layers of the coating. Under service conditions, this effect is known as chalking.

At new building, the action of UV light on epoxy coatings can cause problems when applying additional coats of paint or when painting around erection seams, etc. Care must be taken to confirm that the surfaces are suitably prepared to remove any affected paint before application of the subsequent layer.

SECTION 6 **Cathodic Protection** *(1 January 2017)*

1 General

Steel structures in marine environments can be protected efficiently using protective coatings. However, the coatings, even new coatings, are not perfect and will inevitably be damaged or deteriorated during operation. To preserve the structural strength against corrosion timely maintenance and repairs of the protective coating systems is essential and cathodic protection (CP) is common practice to protect immersed parts of the surfaces as a supplemental method to the coating corrosion protection.

As introduced in Section 1 for corrosion basics, the dissolution of steel is an anodic process which takes place when metallic iron loses two electrons and becomes an iron ion in solution. If the potential of a corroding object is lowered (i.e., it is made more electronegative) to the reversible potential of the anodic reaction, the metal dissolution will slow down and eventually stop.

The accepted criterion for protection of steel in aerated seawater is a protection potential more negative than –0.800 V measured with respect to Ag/AgCl/seawater reference electrode (SSC). When the steel in seawater is polarized to –0.800 V (SSC) the corrosion rate will be suppressed to an acceptably low level. These criteria have been developed through laboratory experiments and field experience.

In the case of steel with active sulfate-reducing bacteria (generally in anaerobic conditions) the potential for protection should be –0.900 V (SSC) instead of –0.800 V for mild steel.

With increasing negative potentials there may be a blistering of some coatings, an adverse effect on fatigue properties and a risk of hydrogen embrittlement of susceptible steels. For mild steel a negative limit of –1.10 V (SSC) is generally accepted as the negative limit. In the case of high strength steels [yield strengths > 700 N/mm^2 (101.5 ksi)], it has been the practice to use potentials in the range –0.80 V to –0.95 V (SSC) for many applications.

2 Cathodic Protection Systems

The reversible potential can either be provided by sacrificial (galvanic) anode cathodic protection system or impressed current cathodic protection system. A combination of both systems may be used (hybrid).

2.1 Sacrificial Anodes

Cathodic protection using sacrificial anodes is illustrated in Section 6, Figure 1 below. Ship hull metal surfaces are cathodically protected by connecting the ship hull to sacrificial anodes in order make ship hull metal surface's potential less than –0.800 V (SSC).

FIGURE 1
Sacrificial Cathodic Protection Schematic
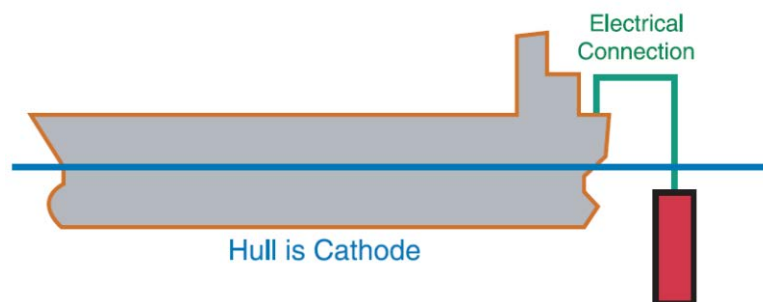
Common material choices for sacrificial anodes are zinc, aluminum and their alloys. Both zinc and aluminum produce potentials more negative than –1.000 V (SSC). Aluminum has to be alloyed with a metal such as cadmium, indium, mercury, or tin to keep the anode active. Other metals such as manganese, silicon or titanium are alloyed to balance activation and self-corrosion of aluminum anode. Magnesium anodes cannot be used in ballast tanks because they generate hydrogen in use and can have deleterious effects on some ballast tank coatings. Aluminum anodes have limited use in tankers as they can produce a spark hazard if they fall or are dropped from significant heights.

Zinc is one of the oldest galvanic anode materials, first used around 1824 by Sir Humphrey Davy.

Early failures of zinc anodes were due to passivation of the zinc from iron impurity. The protection current available from the zinc and aluminum anodes are different. Zinc requires 10.7 kg (23.6 lbs) of material to produce one Ampere-year of current, while 2.9 kg (6.4 lbs) of aluminum is necessary.

Sacrificial systems in ballast/cargo holds and ballast tanks are not capable of working during the period when the tanks are empty. This may constitute 60% of the vessel usage pattern.

Unfortunately, steel corrodes most rapidly when it is damp with a conducting film over the surface rather than fully immersed and the sacrificial anode system cannot act directly at this time. The CP system does have an indirect effect during this period before the tank dries, as the retained hydroxyl ions work to keep the steel surface passive and the calcareous deposits act as a barrier to oxygen.

In very general terms, an exposed steel surface may require 110 mA/m^2 (10.22 mA/ft^2) for protection, while a steel surface which is coated with a good quality of coating system will drain in the order of about 5 mA/m^2 (0.46 mA/ft^2). Consequently, the current requirement for a tank will increase with time as the extent of coating breakdown (and thus exposed metal area) increases.

The efficiency of a cathodic protection system can be assessed by examination of both the condition of the sacrificial anodes and the nature of the calcareous deposit produced. Section 6, Photograph 1 below shows an anode functioning normally. The surface is covered with a compact layer of coherent white deposit.

PHOTOGRAPH 1
Normally Working Anode

Section 6, Photograph 2 below shows an overworked zinc anode. The deposit is very loose and is easily removed from the surface of the anode.

PHOTOGRAPH 2
Overworked Zinc Anode

Section 6, Photograph 3 below shows an overworked aluminum anode. The gelatinous deposits dripping from the anode are indicative of high current drain.

PHOTOGRAPH 3
Overworked Aluminum Anode

Section 6, Photograph 4 below shows that the areas in which coating has failed are protected with calcareous deposits forming throughout the tank. These deposits form as a result of hydroxyl ions being generated at the cathodic sites. The hydroxides then react with both carbon dioxide from the air (which is dissolved in the water) and carbonates and bicarbonates present in the sea water to form the complex deposit known as a calcareous film.

PHOTOGRAPH 4
Heavy Calcareous Deposits

The location of sacrificial anodes is also important as they must be placed clear of any overhanging stiffeners whenever possible to aid the ionic flow around the anodes and prevent incorrect current flow. Incorrectly positioned anodes can result in severe blistering of the coating in their immediate vicinity, and can prevent the current from being directed to areas where it is required for protection. Section 6, Photograph 5 below is an example of this effect.

PHOTOGRAPH 5
Poorly Sited Anode

The anode is enclosed and can only protect a small area.

3   Impressed Current Cathodic Protection

For the exterior hulls of marine ships it is efficient to use Impressed Current Cathodic Protection (ICCP) systems to prevent metal loss, as shown in Section 6, Figure 2. In the ICCP system, an auxiliary anode made from a non-consumable (inert) material, such as platinized titanium or mixed metal oxides, is used instead of the zinc or aluminum anodes used in the sacrificial system.

A reference electrode is also required to monitor the polarization voltage on the hull. It allows feedback control in the voltage rectifier that is used to produce the current for the ICCP systems, as shown in Section 6, Figure 2 and Section 6, Photograph 6.

FIGURE 2
Schematic Diagram of an Impressed Current System
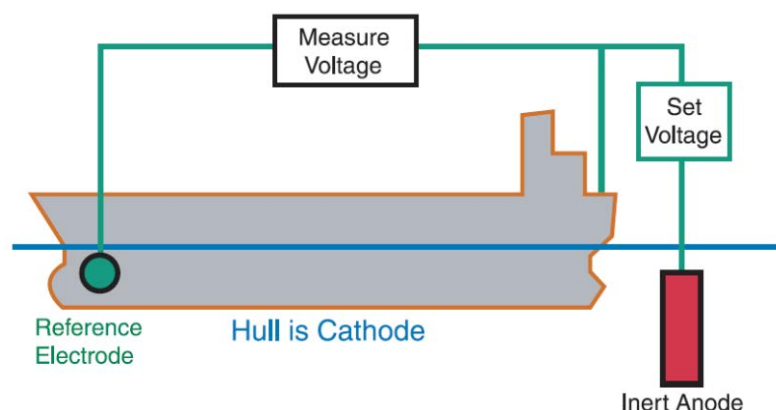
PHOTOGRAPH 6
An Example of a Zinc Reference Electrode on a Ship

Areas immediately around the impressed current anodes are required to be coated with thick dielectric materials to prevent hull coating damage from the ICCP systems, as shown in Section 6, Photograph 7. It is very important that the active anodes and reference electrodes are not painted over as this will prevent the ICCP system from operating.

The electrodes in such an impressed current system are capable of drawing very high currents locally and thus producing copious quantities of oxygen, hydrogen and chlorine if the system malfunctions. This is totally unacceptable in holds and tanks and consequently impressed current systems are not used in these spaces.

PHOTOGRAPH 7
An Example of an ICCP Anode on a Ship

4   US EPA VGP Requirement on Cathodic Protection Systems

Cathodic protection systems must be maintained to prevent the corrosion of the ship's hull, sea chest, rudder, and other exposed areas of the vessel. Sacrificial anodes must not be used more than necessary to adequately prevent corrosion of the vessel's hull during the design life or between docking. Vessel operators must appropriately clean and/or replace these anodes during periods of maintenance (such as drydocking), so that release of these metals to waters is minimized.

Vessel operators should note that magnesium is less toxic than aluminum and aluminum is less toxic than zinc. If vessel operators use sacrificial anodes, they are to select less toxic metals as far as technologically feasible and economically practicable and achievable. For vessels that spend the majority of their time in freshwater, if aluminum or zinc is selected, the vessel owner/operator must document in their recordkeeping documentation the reasoning why the use of magnesium is not appropriate. Likewise, for vessels that spend the majority of their time in saltwater, if vessel zinc is selected, the vessel owner/operator must document the reasoning why aluminum is not selected. The documentation requirement is applicable after the vessel's first drydocking after December 19, 2013.

Particularly for new vessels the US EPA recommends the use of Impressed Current Cathodic Protection (ICCP) systems in place of or to reduce the use of sacrificial anodes when technologically feasible (e.g., adequate power sources, appropriate for vessel hull size and design), safe, and adequate to protect against corrosion. If ICCP systems are used, the cathodic protection potential must be maintained to the specific protection level neither under protected nor over protected. The dielectric shields around ICCP anodes are to be maintained to prevent flaking.

SECTION 7 Anti-fouling

1 General *(1 January 2017)*

Ship hulls are to be coated for corrosion protection. The underwater hulls are also protected by supplemental ICCP systems as introduced in the previous Section. In order to prevent the underwater hull from fouling attachments for reducing hull roughness or resistance to sailing movement, which results in reduced speed and/or increased fuel consumption and consequently a higher operational cost, the underwater hull is over-coated with the antifouling system. However, the anti-fouling systems are controlled by the IMO International Convention on the Control of Harmful Anti-fouling Systems on Ships (AFS Convention), which was adopted on 5 October 2001 and entered into force on 17 September, 2008.

Implementing practices to control and manage biofouling can greatly assist in reducing the risk of the transfer of invasive aquatic species. Guidelines for the Control and Management of Ships' Biofouling to Minimize the Transfer of Invasive Aquatic Species from IMO Resolution MEPC.207(62) was adopted on 15 July 2011 to provide a globally consistent approach to the management of biofouling from ship hulls. Such management practices can also improve a ship's hydrodynamic performance and can be effective tools in enhancing energy efficiency and reducing air emissions from ships. This concept has been recognized by the IMO Resolution MEPC.213(63), adopted on 2 March 2012, "Guidance for the development of a ship energy efficiency management plan (SEEMP)".

2 Fouling *(1 January 2017)*

The most significant cause of hull roughness is fouling. Micro-fouling organisms are the first to settle. They form the primary bio-film or slime layer (micro-fouling). The most significant micro-fouling organisms are bacteria (animal) and unicellular algae. See Section 7, Photograph 1.

PHOTOGRAPH 1
Light Plant Fouling
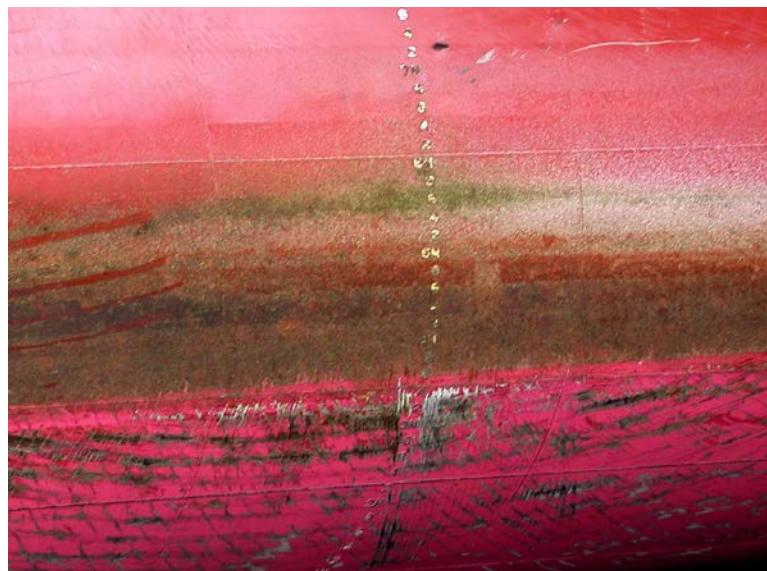
Macro-organisms such as the green algae enteromorpha and ectocarpus are sometimes known as "grass" fouling because of the similarity in appearance. Since all algae need some light intensity, they are usually found only on the side shell of vessels. When divers are used to remove algae growth by scrubbing, embedded roots may remain on the surface. Because of the simplicity of the plant, rapid growth occurs and further cleaning becomes necessary. It is likely that scrubbing of the vessel hull further roughens the surface and that attracts more algae colonization.

Soft-bodied animals such as hydroids and tunicates may also be present. Of the larger fouling species, hard-bodied animals such as barnacles, mussels, tubeworms, and bryozoans are the most common. See Section 7, Photograph 2 for early stages of barnacle fouling on an area where the anti-fouling paint had been damaged.

PHOTOGRAPH 2
Early Stages of Barnacle Fouling on an Area Where
the Anti-fouling Paint had been Damaged

The adult forms of fouling species such as mussels and barnacles are not floating around in the water ready to be attached to the hull structure; rather it is the larvae or sea spores which float around in the top 30 m or so of the sea water. Once attached to a structure, they have the ability to withstand extreme temperatures and salinity. Although the seaweed spores and certain barnacle larvae are capable of attaching in water flows up to 10 knots and other barnacle larvae of attaching at up to 5 knots, it is still assumed that the bulk of settlements to vessel's hull occurs while the vessel is stationary in a moored position or under very slow sailing conditions, such as movement between berths in a port. See Section 7, Photograph 3 for mussel fouling in a sea chest.

PHOTOGRAPH 3
Mussel Fouling in a Sea Chest

3   Anti-fouling System (AFS)

3.1   General

The anti-fouling paints used today are based on physically drying binders. The majority of paints prevent fouling by releasing bioactive materials that interfere with the biological processes of the fouling organisms. Bioactive materials used today are mainly cuprous oxides or organic biocides. The ability to register new biocides is based on the environmental profile of the new product. It is very difficult and expensive to register new biocides. Anti-fouling paints are subject to the most extensive regulations of any paint. In some countries, they have to be registered and approved for use by the relevant regulatory bodies of that country.

New advances in anti-fouling technology have resulted in improved biocide release systems and in foul release coatings which do not use biocides to control the fouling but prevent the fouling organisms adhering effectively to the paint surface.

3.2   AFS 2001 Convention *(1 January 2017)*

The AFS Convention entered into force on 17 September, 2008 after being ratified by 25 States that represented 25% of the world's merchant shipping gross tonnage.

IMO Resolution A928 (22), effective from 1 January 2003, prohibits the application or re-application of organotin compounds TBT (tri-butyl tin) which act as biocides in anti-fouling systems.

ABS can provide assistance to vessel's owners and AFS coating manufacturers regarding with AFS Convention compliance requirement. For ABS-classed vessels, the following documentation may be issued for compliance:

- A statutory Statement of Compliance (SOC) on behalf of the vessel's flag Administration when authorized; or

- Statement of Voluntary Compliance (SOVC) at the request of the ship owner, if no authorization has been received from the flag Administration.

In order to comply with the above, the following is required to be submitted for review prior to commencing an AFS Survey:

From the AFS Manufacturer:

- Type of anti-fouling system

- Name of anti-fouling system manufacturer

- Name and color of anti-fouling system

- Active ingredient(s) and their Chemical Abstract Service Registry Number (CAS number)

- Copy of the purchase order or contract linking the identified AFS with the ship to which it is (or has been) applied

Where organotin-free compounds are used, suitable wording describing such compounds are to be indicated in the documentation. Typical examples include: organotin-free self-polishing type, organotin-free ablative type, organotin-free conventional, biocide-free silicon type paint. If the AFS contains no active ingredients, the words "biocide-free" should be indicated. Supporting documentation (e.g., Material Safety Data Sheet or similar document) should also be submitted with the product information.

A documentation check should be carried out whenever the anti-fouling system is initially applied for new construction or is subsequently changed, replaced or repaired.

From the AFS Application Facility:

A statement indicating that the noncompliant paint has been either removed and replaced or sealed with the AFS identified by the information provided by the AFS manufacturer; and a purchase order for the AFS that is to be or has been applied which provides a link to the information requested from the AFS manufacturer.

ABS performs a review of the documentation required to be submitted. The documentation review is to confirm that:

- Declaration indicates all of the information required from AFS Manufacturer per above;

- Product identification on the AFS containers corresponds to the declaration of AFS provided by the facility; and

- An identification system exists that establishes a traceable link between the supporting documentation and the AFS container based on a random check of the containers.

A survey (documentation check) should be carried out whenever an anti-fouling system is initially applied for new construction or is subsequently changed, replaced or repaired. Resolution MEPC.102 (48) recommends that a repair which affects approximately 25% or more of the AFS (generally measured by repair area vs. the AFS covered area) should require a survey to be carried out.

3.3 Self-polishing Anti-fouling Coatings

In contact with seawater, the binder dissolves at an even and predictable rate. As the anti-fouling paint is removed by a polishing action or the friction effect of the water, the bioactive material is released at an even rate and this enables coatings to remain fouling free even when the vessel is not moving. The polishing nature of the coating results in a smooth finish to the hull, as the polishing rate is highest at the roughest points.

3.4 Insoluble Matrix (Controlled Depletion) Coatings

This is an old anti-fouling technology and is based on the use of rosin which is slightly soluble in sea water, but it is also brittle and slowly releases biocides. Rosin-based paints need other film forming resins to provide their mechanical strength and the load of bioactive material must be high enough for the particles of this material to be in contact with each other.

3.5 Foul Release Coatings

This type of paint is a relatively new addition to the category of anti-fouling paint. The mechanism for effective anti-fouling in this coating type is based on the low free surface energy of the coating surface. Fouling organisms find the surface unattractive. Biocides are not used, and therefore these coatings are not affected by legislation commonly affecting other biocide containing antifouling paints.

3.6   Coating Compatibility

Many of the coatings used on vessels today are compatible with each other, providing that the over-coating times and conditions recommended by the paint manufacturers are followed. This is particularly true for epoxy coatings, where the time intervals between coats are critical for the performance of the paint.

Some paints are specifically designed as repair or maintenance products which are suitable for application to vessels in service using rollers or brushes. The types of coating onto which they can be applied and the surface preparation required is specified by the coating manufacturer.

SECTION 8 **IMO Performance Standards for Protective Coatings** *(1 January 2017)*

1 SOLAS Requirements on Corrosion Prevention of Ships

1.1 Introduction

International Maritime Organization (IMO) mandated two Performance Standards for Protective Coatings (PSPC), from SOLAS regulations SOLAS II-1/A-1/3-2 and 3-11. SOLAS II-1/A-1/3-2 has the PSPC requirement for Dedicated Seawater Ballast Tanks in all types of ships and double-side skin spaces of bulk carriers. SOLAS II-1/A-1/3-11 regulates the PSPC requirement for Cargo Oil Tanks of Crude Oil Tankers. Both PSPCs are minimum requirements for the goal of providing a target useful coating life of 15 years, which is considered to be the time period, from initial application, over which the coating system is intended to remain in "GOOD" condition.

The ability of the coating system to reach its target useful life depends on the type of coating system, steel preparation, coating application and inspection, operating environment, maintenance and repair. All of these aspects contribute to the good performance of the coating system.

1.2 Performance Standard for Protective Coatings for Dedicated Seawater Ballast Tanks in all Types of Ships and Double-side Skin Spaces of Bulk Carriers

SOLAS II-1/A-1/3-2, amended by IMO Resolution MSC.216(82), requires all dedicated seawater ballast tanks in all types of ships and double-side skin spaces of bulk carriers comply with 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 (IMO PSPC-SWBT).

The IMO PSPC-SWBT applies to all ships 500 gross tonnage and over for which:

- The building contract is placed on or after 1 July 2008; or

- In the absence of a building contract, the keels of which are laid or which are at a similar stage of construction on or after 1 January 2009; or

Regardless of the applicability of the above two criteria, the delivery of which is on or after 1 July 2012 for:

- All dedicated seawater ballast tanks arranged in ships; and

- Double-side skin spaces arranged in bulk carriers of 150 meters (492 feet) in length and upwards.

Section 8, Figure 1 shows an example from a crude oil tanker for IMO PSPC-SWBT spaces.

IMO MODU Code 2009 recommends complying with the IMO PSPC-SWBT when flag Administrations have made the Code mandatory through their national law or regulation. The Code applies to such MODUs the keels of which are laid on/after 1 January 2012, unless instructed otherwise by the flag Administration. The Code's IMO PSPC-SWBT requirement is applicable to all dedicated seawater ballasts of MODU. Pre-load tanks on self-elevating units are to be considered dedicated seawater ballast tanks. Mat tanks and spud cans on such units are not to be considered dedicated seawater ballast tanks.

In application of IMO PSPC-SWBT, IACS UI SC223 is to be uniformly implemented by IACS Classification Societies. In addition, IACS provided further unified interpretations in SC226.2 and SC227 regarding dedicated seawater ballast tanks and single hull tanker conversions:

    i)   As interpreted by IACS UI SC227, the following tanks are not considered to be dedicated seawater ballast tanks and are therefore exempt from the application and requirement of the IMO PSPC:

- Ballast tank identified as "Spaces included in Net Tonnage" in the 1969 ITC Certificate; and

- Seawater ballast tanks in passenger vessels also designated for the carriage of grey water.

- Seawater ballast tanks in livestock carriers also designated for the carriage of the livestock dung.

    ii)   As interpreted by IACS UI SC226.2 for the application of SOLAS regulations to conversions of a Single Hull Tanker to a Double Hull Tanker or a Bulk Carrier/Ore Carrier, the following cases need to be considered for the IMO PSPC requirement:

- *For conversion of a Single-Hull Tanker to a Double-Hull Tanker.* SOLAS II-1/A-1/3-2 (MSC.216(82)) only applies to dedicated water ballast tanks if constructed with all structural members being entirely new. If converting existing spaces into water ballast tanks with part of the existing structural members remaining in place, SOLAS II-1/3-2 (amended by MSC.216(82)) need not be applied.

- *For conversion of a Single-Hull Tanker to a Bulk Carrier/Ore Carrier.* SOLAS II-1/A-1/3-2 (MSC.216(82)) only applies to dedicated water ballast tanks and double-side skin spaces of bulk carriers if constructed with all structural members being entirely new. If converting existing spaces into dedicated water ballast tanks or double-side skin spaces of Bulk Carrier with part of the existing structural members remaining in place, SOLAS II-1/3-2 (amended MSC.216(82)) need not be applied.

For compliance with IMO PSPC-SWBT, ABS provides the **CPS** Notation requirement for ABS-classed Common Structural Rules (CSR) vessels contracted for construction between the builder and the owner on or after 8 December 2006. The ABS **CPS** Notation is optional for all other ABS-classed vessels contracted for construction between the builder and the owner on or after 8 December 2006 and subject to the owner's request.

When IACS harmonized Common Structural Rules (CSR-H) become effective in June 2015, IMO PSPC-SWBT is not to be a Class requirement for CSR-H vessels. It is to be part of the statutory requirements of a vessel. ABS is not to provide **CPS** Notation for CSR-H vessels. However, it is optional to other ABS-classed vessels.

1.3 Performance Standard for Protective Coatings for Cargo Oil Tanks of Crude Oil Tankers (IMO PSPC-COT)

New regulation SOLAS II-1/A-1/3-11, amended by IMO Resolution MSC.291(87), requires IMO Resolution MSC.288(87) - Performance Standard for Protective Coatings for Cargo Oil Tanks of Crude Oil Tankers (IMO PSPC-COT).

This SOLAS requirement is only applicable to crude oil tankers, as defined in regulation 1 of Annex I to the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto, of 5,000 tonnes deadweight and above.

"Crude Oil Tanker" means an oil tanker engaged in the trade of carrying crude oil, as listed in sections 1.11.1 and 1.11.4 of the Supplement to the International Oil Pollution Prevention Certificate (Form B). The requirement is not applicable to combination carriers or chemical tankers which are also certified to carry oil.

The effective dates of SOLAS regulation II-1/A-1/3-11 are that:

- The building contract is placed on or after 1 January 2013; or

- In the absence of a building contract, the keels of which are laid or which are at a similar stage of construction on or after 1 July 2013; or

- Regardless of the applicability of the above two criteria, the delivery of which is on or after 1 January 2016.

Section 8, Figure 1 shows an example from a crude oil tanker for IMO PSPC-COT spaces.

In application of IMO PSPC-COT, IACS UI SC259 is to be uniformly implemented by IACS Classification Societies on ships contracted for construction on or after 1 January 2014.

In accordance with SOLAS II-1/A-1/3-11 amended by IMO Resolution MSC.291(87), the crude oil tanks can be protected by alternative means of corrosion protection or utilization of corrosion resistance material to maintain required structural integrity for 25 years in accordance with the Performance standard for alternative means of corrosion protection for cargo oil tanks of crude oil tankers, adopted by the MSC resolution MSC.289(87) interpreted by IACS UI SC258.

FIGURE 1
Illustration of IMO PSPC Spaces of Oil Tanker *(1 January 2017)*

Crude Oil Tanks:
New SOLAS II-1/A-1/3-11 amended by MSC.291(87) adopted by MSC.288(87) and MSC.289(87) – effective 1 Jan 2013

Seawater Ballast Tanks:
SOLAS II-1/A-1/3-2 amended by MSC.216(82) adopted by MSC.215(82) – effective 1 July 2008
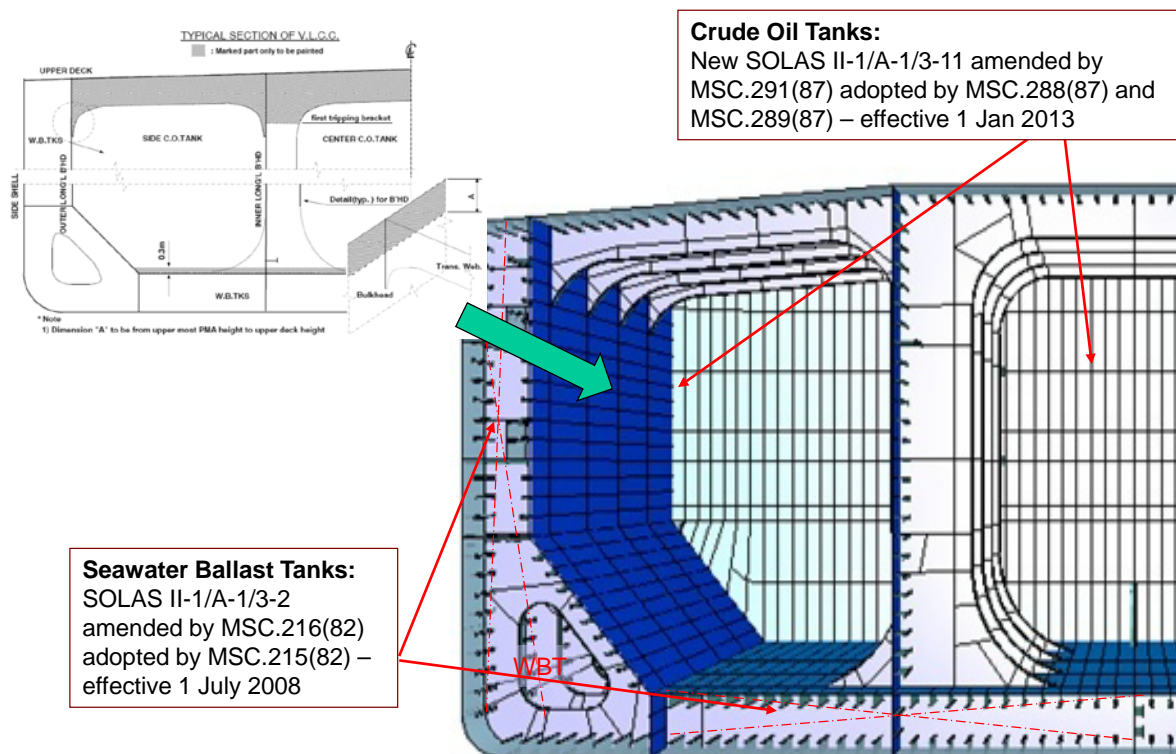
2   IMO Performance Standard for Protective Coatings (PSPC) for Void Spaces

2.1   Introduction

IMO set out recommendation on Performance Standard for Protective Coating for void spaces located within the cargo block area and forward, applying only to Oil Tankers and Bulk Carriers through IMO MSC.244(83) - Performance Standard for Protective Coatings for Void Spaces on Bulk Carriers and Oil Tankers (IMO PSPC-Void).

The IMO PSPC-VOID provides technical requirements for protective coatings for void spaces constructed of steel in bulk carriers and oil tankers.

2.2   Void Spaces for IMO PSPC-VOID

Void space is an enclosed space below the bulkhead deck within and forward of the cargo area of oil tankers or the cargo length area of bulk carriers.

Protective coatings for the following void spaces should comply with the requirements in the IMO PSPC-VOID Standard:

i)   *Bulk Carriers:*

  a)   Double bottom pipe passages/pipe tunnels;

  b)   Small void spaces located behind gusset or shedder plates at the bottom of corrugation bulkheads with the exception of totally enclosed spaces;

  c)   Other small void spaces in cargo spaces, with the exception of totally enclosed spaces;

  d)   Lower transverse stool of transverse bulkheads, with the exception of totally enclosed spaces; and

  e)   Upper transverse stool of transverse bulkheads, with the exception of totally enclosed spaces; and

ii)   *Oil Tankers:*

  a)   Forward cofferdam/cofferdam separating cargo from forepeak;

  b)   Cofferdam in cargo area/cofferdam separating incompatible cargoes;

  c)   Aft cofferdam;

  d)   Duct keel/pipe tunnels;

  e)   Lower bulkhead stools; and

  f)   Upper bulkhead stools.

However, the following spaces are not applicable for IMO PSPC-VOID:

  a)   A dedicated seawater ballast tank which shall comply with the IMO resolution MSC.215(82) (IMO PSPC-SWBT);

  b)   A space for the carriage of cargo;

  c)   A space for the storage of any substance (e.g., oil fuel, fresh water, provisions);

  d)   A space for the installation of any machinery (e.g., cargo pump, ballast pump, bow thruster);

  e)   Any space in normal use by personnel; and

  f)   A double-side skin space of bulk carriers of 150 m in length and upwards which shall comply with the IMO resolution MSC.215(82) (IMO PSPC-SWBT).

2.3   Void Space Recommended for IMO PSPC-SWBT

The following void spaces are recommended to comply with the IMO resolution MSC.215(82) (IMO PSPC-SWBT) - Performance standard for dedicated seawater ballast tanks in all types of ships and double-side skin spaces of bulk carriers:

• *Bulk Carriers.* Double-side skin spaces in ships of less than 150 m (492 ft) in length; and upper and lower side void spaces and double bottom void spaces in cargo area; and

• *Oil Tankers.* Double-side skin (DSS) voids including sides, bottoms/double hull void spaces protecting cargo oil tanks.

2.4   Void Spaces with no IMO PSPC-VOID Requirement

No coating requirements of the IMO PSPC-VOID are needed for the following void spaces in bulk carriers and oil tankers:

i)   Totally enclosed spaces located behind gusset or shedder plates at the bottom of corrugation bulkheads and other small totally enclosed spaces in cargo tanks

ii)   Lower transverse stool of transverse bulkheads that are totally enclosed spaces

iii)   Upper transverse stool of transverse bulkheads that are totally enclosed spaces

iv)   Transducer voids

v)   Any void spaces not specifically mentioned in 8/2.2 and 8/2.3 above

3   Inspection Agreement

IMO PSPCs require that the inspection of surface preparation and coating processes agreement (tripartite inspection agreement) is to be agreed to by the shipyard, shipowner and coating manufacturer and be presented by the shipyard to the Administration for review prior to commencement of any coating work on any stage of a new building and, as a minimum, shall comply with the IMO PSPC.

To facilitate the review, the following shall be available:

*   Areas (spaces) to be coated

*   Selection of coating system

*   Type Approval of the coating system, Technical Data Sheets and the Material Safety Data Sheets

*   Qualifications and appointment of certified and qualified coating inspector(s) who are responsible for verifying that the coating is applied in accordance with the PSPC and specification agreed. Where more than one coating inspector is used, their responsibility for areas (i.e., multiple construction sites) shall be identified

*   Inspection specification for surface preparation, coating process and coating system repair with detailed procedures and inspection criteria during ship construction

*   Procedures for in-service maintenance and repair of coating system in accordance with the Guidelines from IMO MSC.1/Circ. 1330 for the PSPC-SWBT and IMO MSC.1/Circ. 1399 for the PSPC-COT

*   Inspection forms and nonconfirmity form at each construction stage

The agreed-to tripartite agreement is the part of coating technical file (CTF) (Subsection 8/4 below).

3.1   Areas to be Coated

The shipyard is to prepare and submit a list of all spaces including block identifications to be coated for compliance of IMO PSPC, together with a general arrangement drawing of the ship or structure.

3.2   Selection of Coating System and Coating System Type Approval

In accordance with IMO PSPC, the selection of coatings is to take into account the expected service conditions and intended maintenance program that should provide a target useful coating life of 15 years in "GOOD" condition. The selected coatings are to be listed and cross-referenced to the spaces to be coated as per 8/3.1 above.

The selected coating system shall be Type Approved by a pre-qualification test in accordance with the test procedure provided by the IMO PSPC or equivalent.

The coating manufacturer is to provide copies of the Technical Data Sheets, Materials Safety Data Sheets and the Type Approval Certificate for each coating system to be used, to the shipyard for inclusion into the CTF.

The coating technical data sheet typically consists of the following data:

- *Product Description.* The product name, type and identification mark and/or number which should also be shown on tight cans containing the agreed-to paint

- *Recommended Use.* Indicates for which area of the vessel the coating is recommended to be used

- *Film Thickness.* Minimum and maximum DFTs

- *Physical Properties.* Materials, components, composition and colors of the coating system

- *Surface Preparation.* Recommendations for the condition of the surface to be coated; including the steel profile, (roughness) as well as the edge roundness, degree of removal of rust and the extent of cleanliness from contaminants

- *Conditions During Application.* Limitations concerning the environment (temperature, humidity, etc.) during the application and curing of the coating system

- *Application Methods.* Application method, tools and/or machines

- *Application Data.* Coating application should be stated, indicating clearly the number and sequence of coats and stripe coats to be applied, plus where and how each of these coats and stripe coats are to be applied

- Drying time

- Storage

- Handling

- Packing Size

- Health and Safety (details are noted in the MSDS)

3.3   Coating Inspector

For compliance with the IMO PSPC, the inspection items shall be carried out by qualified coating inspectors certified to NACE Coating Inspector Level 2, FROSIO Inspector Level III or equivalent.

Qualification requirements for assistant inspectors are clarified in IACS UI SC223 or SC259.

In addition to verification of the coating inspector's qualification and certification, ABS is also to monitor the coating inspection by confirming, on a sampling basis, that the inspectors are using the correct equipment, techniques, and reporting methods as described in the agreed-upon inspection procedures. Destructive testing is to be avoided.

Following are examples of coating inspection tools commonly used by the inspector:

3.3.1   Dry Film Thickness Gauge/Wet Film Thickness Gauge

The final dry film thickness (DFT) needs to be measured, see Section 8, Photograph 1, and recorded to prove that the coating has been applied to the thickness specified by the agreed specification.

Measurement of wet film thickness (WFT), see Section 8, Photograph 2, is usually done by the applicators/shipyard as part of their quality control procedures to confirm that the final required DFT levels are achieved for each coat. The WFT does not need to be recorded as part of the CTF.

PHOTOGRAPH 1
Dry Film Thickness Gauge *(1 January 2017)*

(Elcometer 456 Coating Thickness Gauge)

PHOTOGRAPH 2
Wet Film Thickness Gauge *(1 January 2017)*

(Elcometer Coating Thickness Gauge)

3.3.2   Surface Roughness Measurement

The inspection of surface profiles is required to be carried out at the primary and secondary surface preparations by using a visual comparator, as shown in Section 8, Photograph 3 for ISO 8503-1/2 comparator and Section 8, Photograph 4 for Keane-Tator Surface Profile Comparator, as agreed by involved parties. A semi- quantitative roughness measure method, such as the Testex tape replica as shown in Section 8, Photograph 5, is preferred for keeping as a permanent record.

PHOTOGRAPH 3
ISO 8503-1/2 Surface Roughness Comparators *(1 January 2017)*

PHOTOGRAPH 4
Keane-Tator Surface Profile Comparator *(1 January 2017)*

Magnifier
with Special Magnetic Disc
Holder

PHOTOGRAPH 5
Testex Press-O-Film Replica Tape *(1 January 2017)*

3.3.3   Dust Level Test

ISO 8502-3 method provides a permanent record of the dust present on a surface by using an adhesive tape (certified to IEC 454-2). A report is to be made on the dust levels prior to coating application to confirm compliance with IMO PSPC (ISO 8502-3 dust quantity rating 1 for dust size class "3", "4" or "5"). Section 8, Photograph 6 shows a test kit from Elcometer.

PHOTOGRAPH 6
Elcometer 142 Dust Tape Test Kit *(1 January 2017)*

3.3.4   Environment Condition Tests

Measurement of relative humidity and surface temperature is to be carried out at different stages (before and during blasting and coating applications) to confirm that the maximum relative humidity is 85% and the surface temperature of the substrate is at least 3°C (5.4°F) above the dew point. Conventionally, these measurements are carried out using a surface temperature gauge and a wet and dry bulb psychrometer of the type shown in Section 8, Photograph 7. However, a single digital gauge to measure and record all relevant climatic parameters is available in market to determine whether the conditions are suitable for painting or blasting. See Section 8, Photograph 8, "Elcometer 319 Meter".

PHOTOGRAPH 7
Elcometer 116 Whirling and Sling Psychrometer *(1 January 2017)*

PHOTOGRAPH 8
Elcometer 319 Dewpoint Meter *(1 January 2017)*

3.3.5   Oil, Grease, and other Visible Surface Contaminants

The surface should be free, and kept free, of contaminants such as oil, grease, dust, flame burns and chalk marks. Refer to Section 4 for removing surface contaminants. The visual inspection for oil contamination can be aided through use of a fluorescent light.

3.3.6   Soluble Salt Test

Soluble salts are to be measured in accordance with ISO 8502-9 (Bresle Patch method) to confirm ionic contaminants have been removed. The maximum permitted level is 50 mg/m^2 (7.11×10^{-8} psi) for primary surface preparation and secondary surface preparation before coating application. Various ISO 8502-9 compliance Bresle test kits can be available in market (see Section 8, Photograph 9). ISO 8502-9 or equivalent method shall be validated according to NACE SP0508.

PHOTOGRAPH 9
ISO 8502-9 Compliance Bresle Test Kits *(1 January 2017)*

3.4   Primary Surface Preparation

Primary surface preparation relates to the preparation of the steel plate at the start of the shipbuilding process and usually occurs as part of an automated system that removes mill scale and applies a layer of shop primer to the steel.

Steel from the stockyard is usually flame-heated to remove water and burn off oil and organic residues. The steel then passes through an abrasive blasting process (see Section 8, Figure 2) that is designed to remove the mill scale, rust and any other contaminants from the surface. The basic elements of an automated blast system are:

• The centrifugal throwing wheel which throws the abrasive in a controlled pattern; and

• The recycling system which separates and returns good abrasive to a storage hopper for reuse.

A surface profile should be introduced onto the steel plates and stiffener sections after blasting as specified in the inspection agreement.

IMO PSPC specifies a blasting standard of Sa $2^1/_2$ (ISO 8501-1) with profiles between 30-75 μm (1.2-3 mil) (ISO 8503-1/2). After removal of any blasting dust, the steel surfaces (both sides of steel plate) should be examined to see that it meets the agreed standard before the application of shop primer.

Both blasting and coating application are to be carried out with a maximum relative humidity of 85% and with a surface temperature of the steel more than 3°C (5.4°F) above the dew point. The total water soluble salt limit should be less than or equal to 50 mg/m^2 (7.11×10^{-8} psi) of sodium chloride which can be verified using a Bresle Patch (ISO 8502-9) before coating application.

In an automated process, the compliance with the standard may be demonstrated through a quality control system. It is the responsibility of the coating inspector to confirm that the quality control procedures provide compliance with the IMO PSPC. The quality control procedures include (IACS UI SC223/SC259):

• Procedures for management of the blasting grit including measurement of salt and contamination

• Procedures for recording steel surface temperature, relative humidity and dewpoint

• Procedures for controlling or monitoring surface cleanliness, surface profile, oil, grease, dust and other contamination

• Procedures for recording/measuring soluble salts

• Procedures for verifying thickness and curing of the shop primer conforms to the values specified in the Technical Specification. See Section 8, Photographs 11 and 12 for coating application of shop primer

The QC inspection form(s) shall include above noted inspection data

FIGURE 2
Typical Automated Shop Primer Line *(1 January 2017)*

1. Cross transfer conveyor
2. Inlet roller conveyor
3. Pre-heater
4. Roller conveyor shot blast machine
5. Blast machine filter
6. Paint spray chamber
7. Paint supply system
8. Filter from VOC system
9. VOC treatment system
10. Drying chamber
11. Slat conveyor
12. Outlet roller table
13. Cross transfer conveyor
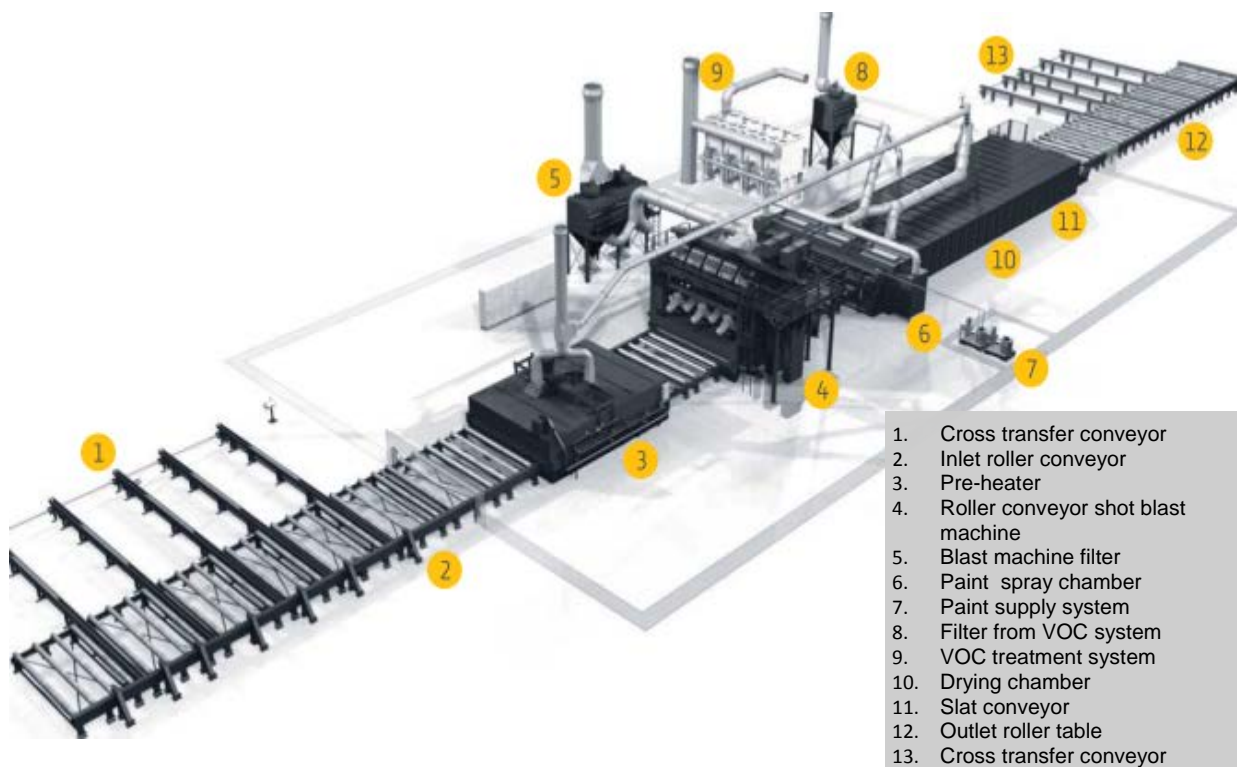
PHOTOGRAPH 10
Steel Plate after Blasting on the Shop Primer Line

PHOTOGRAPH 11
Shop Primer Application *(1 January 2017)*

PHOTOGRAPH 12
Steel Plate Coated with Shop Primer *(1 January 2017)*

3.5 Secondary Surface Preparation

The IMO PSPC specifies two different surface treatments, one for the block stage and one for the erection stage.

3.5.1 At Block Stage

Secondary surface preparation at the block stage is carried out after steel work is completed and the block's steel work has been accepted by the yard quality control, owner's inspector and class Surveyor. The surface preparation may occur indoors and under controlled conditions such as in the blast cell.

The steel surface shall be prepared so that the selected coating can achieve an even distribution at the required NDFT by removing weld beads, weld spatter and any other surface contaminant (ISO 8501-3 (P2), see Section 8, Figure 3). Edge preparation is generally achieved by three pass grinding or by any other method proven to provide at least a 2 mm (0.08 in.) rounded radius, see Section 8, Photographs 13 and 14. Confirm that any surface grinding is completed before blasting. If the grinding is done following the blasting, the required surface profile will be damaged and the coating will fail prematurely.

Abrasive blasting to Sa 2$^1/_2$ (ISO 8501-1) with a profile of 30-75 μm (1.2-3 mil) (ISO 8503-1/2) is required on the welds, grinded edges and damaged shop primer. Undamaged shop primer is to be treated with sweep blasting, high pressure water washing or equivalent method to remove dust (such as white zinc salts) and other contaminants provided the shop primer has passed the pre-qualification test noted in the IMO PSPC. If the shop primer has not passed the pre-qualification test, the shop primer is to be removed by abrasive blasting to Sa 2(ISO 8501-1), at least 70% of each unit area of the shop primer removed. If the block is to be blasted to Sa 2$^1/_2$ (ISO 8501-1), no requirement on the shop primer is needed.

Before coating application, thorough removal of dust residues from abrasive blasting is required to ISO 8502-3 dust quantity rating "1" for dust size class "3","4" or "5" or non-visible without magnification for both IMO PSPC-SWBT and IMO PSPC-COT.

The soluble salt level is to be measured using the Bresle test method (ISO 8502-9) and limited to 50 mg/m^2 (7.11 × 10^{-8} psi) of sodium chloride equivalent before coating application. All visible surface contaminants are to be removed.
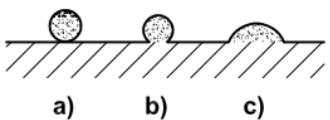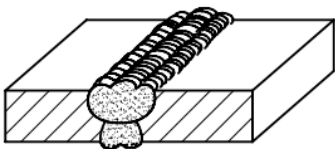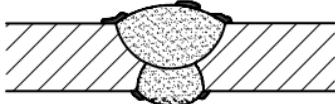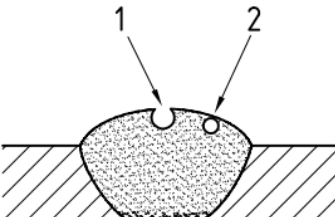
As with the primary surface preparation, both blasting and coating application are to be carried out in an environment with a relative humidity of 85% or less and with a surface temperature of the steel not less than 3°C (5.4°F) above the dew point.

Inspection form(s) shall include above noted inspection data.

<div align="center">

FIGURE 3
ISO 8501-3 Weld Preparation Standard *(1 January 2017)*

(P2 column is to be followed as a minimum)

Table 1 — Imperfections and preparation grades

</div>

Type of imperfection		Preparation grades		
Description	**Illustration**	**P1**	**P2**	**P3**
1 Welds				
1.1 Welding spatter	a) b) c)	Surface shall be free of all loose welding spatter [see a)]	Surface shall be free of all loose and lightly adhering welding spatter [see a) and b)] Welding spatter shown in c) may remain	Surface shall be free of all welding spatter
1.2 Weld ripple/profile		No preparation	Surface shall be dressed (e.g. by grinding) to remove irregular and sharp-edged profiles	Surface shall be fully dressed, i.e. smooth
1.3 Welding slag		Surface shall be free from welding slag	Surface shall be free from welding slag	Surface shall be free from welding slag
1.4 Undercut		No preparation	Surface shall be free from sharp or deep undercuts	Surface shall be free from undercuts
1.5 Weld porosity	1 2 Key 1 visible 2 invisible (might open after abrasive blast cleaning)	No preparation	Surface pores shall be sufficiently open to allow penetration of paint, or dressed out	Surface shall be free from visible pores
1.6 End craters		No preparation	End craters shall be free from sharp edges	Surface shall be free from visible end craters

PHOTOGRAPH 13
Edge Preparation *(1 January 2017)*

PHOTOGRAPH 14
Edge Preparation *(1 January 2017)*

3.5.2   At Erection Stage

Preparation of the steel for painting at the erection stage is more difficult as the environmental conditions cannot be controlled. The erection joints and damaged coatings to a certain level can be treated by the use of power tooling St 3 (ISO 8501-1) rather than by abrasive blasting.

Care should be taken when using power tooling not to over-polish the surface of the substrate. A certain roughness [such as 25 μm (1 mil)] is needed after power tooling for achieving a good adhesion of the coating to the substrate.

It is essential that good coating performance in service can be achieved by

- Reducing power tooling through reducing erection joint areas and coating damages and/or

- Using advanced surface preparation technology such as bristle blaster, portable abrasive blaster or Sponge-Jet System, see Section 8, Photographs 15 to 17.

IMO PSPC requires the erection joints to be treated to St 3 (which is a very thorough cleaning with power tools) or Sa 2.5 where practicable.

For coating damage repair in the erection joint stage, please note that requirements from IMO PSPC-SWBT and IMO PSPC-COT are different:

i) For sea water ballast tanks, coating damages up to 2% of the total area and contiguous damages up to 25 m² (270 ft²) may be treated to minimum St 3. Contiguous damages over 25 m² (270 ft²) or over 2% of the total area of the tank shall be treated to Sa 2.5.

ii) For cargo oil tanks:

- Inner bottom's coating damages up to 20% of the area to be coated to be treated to minimum St 3. Contiguous damages over 25 m² (270 ft²) or over 20% of the area to be coated shall be treated to Sa 2$\frac{1}{2}$.

- Under deck's coating damages up to 3% of area to be coated to be treated to minimum St 3. Contiguous damages over 25 m² (270 ft²) or over 3% of the area to be coated shall be treated to Sa 2$\frac{1}{2}$.

In case of full or partial blasting, surface roughness 30-75 μm (1.2-3 mil) is needed, otherwise as recommended by the coating manufacturer.

Dust, soluble salts and other surface contaminants shall be removed to the same level as the block stage before the coating is applied.

Inspection form(s) shall include above noted inspection data.

PHOTOGRAPH 15
Bristle Blasting *(1 January 2017)*
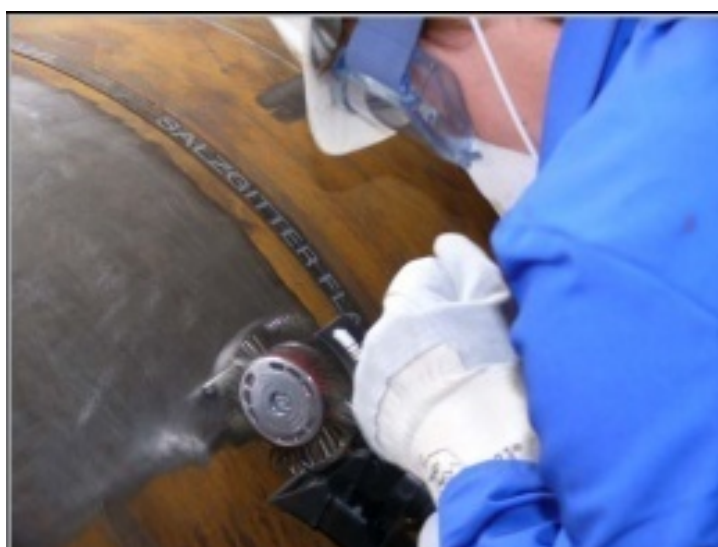
PHOTOGRAPH 16
Vacuum Blasting *(1 January 2017)*

PHOTOGRAPH 17
SpongeJet *(1 January 2017)*

3.6   Coating Application

Coating application at the block stage is usually carried out indoors and under controlled environmental conditions. This may occur in the same location as abrasive blasting or in another, nearby building.

It is important that the correct conditions of temperature, relative humidity, etc., are maintained as specified by the coating manufacturer's technical data sheets and agreed specification, whichever is more stringent, and documented in the CTF. Poor application or curing conditions can cause defects in the paint and, therefore, early failure in service.

The coating system shall be a minimum of two stripe coats and two spray coats. Stripe coats are used for complex shapes and areas which cannot be adequately coated by spray application. See Section 8, Photograph 18. Stripe coats shall be applied by brush or roller. Rollers may be used for scallops, ratholes, etc., but not for edges and welds. Stripe coats should be applied as a coherent film showing good film formation and no visible defects. The sequence of application methods is not specified. It is recommended that a stripe coating is applied to the weld and edges first for so as to provide good wetting, and thus good adhesion to the steel substrate. However, in shipyard practice, a spray coat is applied to the block first in order to protect it against corrosion of treated surface. In certain circumstances, the second stripe coat may be omitted for welded seams only where the NDFT can be met. Any reduction in scope of the second stripe coat is to be fully detailed in the CTF.

Spray coats are to be applied, shown in Section 8, Photograph 19, in accordance with the coating manufacturer's instructions from the technical data sheets, such as nozzle size, pressure ratio, thinner, mixing ratio, induction time if any, pot life and re-coat time windows. The dry times and walk-on times given by the coating manufacturer are to be observed. IMO PSPC requires that, in addition to the requirement from the coating manufacturer, the coating is not be applied when the relative humidity is above 85% or the surface temperature is less than 3°C (5.4°F) above the dew point.

Surface preparation also applies to the preparation of surfaces between coats of paint, and it is equally important that contaminants are removed from painted surfaces before the next layer is applied; otherwise inter-coat failures could occur during service. Inclusions, such as blast grit, embedded in the coating are to be removed.

For an epoxy-based coating system, NDFT 320 μm with 90/10 rule shall be met for IMO PSPC-SWBT and IMO PSPC-COT. For other systems, the NDFT is to the coating manufacturer's recommendation. Maximum total DFT shall be specified in the manufacturer's technical datasheets. Unless otherwise specified by the manufacturer, maximum DFT is to be 3 times of the NDFT, which is 960 μm (38 mil).

With the NDFT 320 μm (12.6 mil), the 90/10 Rule specifies the following criteria:

i)   90% of all DFT readings must be 320 μm (12.6 mil) or higher

ii)   10% of remaining DFT readings must be 90% of the NDFT, which is 288 μm (11.3 mil), or higher

iii)   No reading below 90% of the NDFT, which is 288 μm (11.3 mil), is allowed

Care shall be taken to avoid increasing the DFT in an exaggerated way. Wet film thickness shall be regularly checked during application for the desired DFT.

For coating repairs and erection joint coating, the coating in overlap shall be feathered.

The coating inspectors shall carry out inspections and document that the coating application is within the standard. The documents are to be included in the CTF.

Inspection form(s), when completed, shall include above noted inspection data.

It is imperative that upon completion of the coating application that the tanks are be protected from further damage. This includes damage from additional hot work falling on the coatings, scratching the coating surface from trapped grit on work shoes, mechanical damage from staging removal, grease, etc. All damaged coatings are to be repaired in accordance with the TPA prior to the vessel entering service.

Confirm that the curing temperature and time, recoat interval time, thinner used, etc., from coatings manufacturer's Technical Data Sheets are to be strictly followed.

PHOTOGRAPH 18
Stripe Coating Application *(1 January 2017)*

PHOTOGRAPH 19
Spray Coating Application *(1 January 2017)*

Spray gun should be perpendicular to the surface to be applied.

4   Coating Technical File (CTF)

The shipyard is responsible for compiling the Coating Technical File (CTF) either in paper or electronic format, or a combination of the two.

The CTF shall include the specification of the coating system applied, job specifications, record of the shipyard's and shipowner's coating work, inspection and any deviations/corrective actions. The CTF shall also include a service maintenance schedule and activities of in-service maintenance, repair and partial re-coating in accordance with the Guidelines IMO MSC./Circ. 1330 and/or IMO MSC./Circ. 1399. For full re-coating, the documentation requirement is the same as for new construction.

The CTF, upon the completion of the PSPC coating, is to be reviewed by ABS, acting on behalf of the Flag Administration, including at least the following items in addition to the items in the tripartite agreement listed in section 8/3:

    i)   Shipyard work records of coating application are to be maintained and include the following items.

- A list of ballast tanks and voids where the agreed coating system is to be applied. This should include the corresponding area to be coated in m^2.

- The applied coating system for each area, number of spray coatings, stripe coatings and sequence.

- The time required for the application of each coat plus the time between coats and stripe coats for a multi-coated system as stipulated in the IMO PSPC. If the wet film thickness (WFT) is also required/agreed to be measured, then this should also be stipulated.

- The ambient temperature during the coating application and curing process shall be continuously monitored and recorded.

- The method of surface preparation of the steel substrate and/or primer prior to the application of any coating system is to be stipulated.

- The method of surface preparation regarding repairs of the coating system including the removal of any contaminants, holidays and inclusions between coats and stripe coats is to be clearly specified. The dry-to-recoat times and walk-on times are also to be specified.

    ii)   The shipyard's verification report is a summary report stating the results of the coating inspection and is to include the following data:

- Name of part or structure

- Inspection completion date

- Inspection results and remarks

- Coating inspector's signature

- Shipyard representative's signature

    iii)   The CTF is to include specific requirements that the inspector is required to address on a daily basis during any coating process agreed to between the parties. The qualified coating inspector is to maintain a daily log which would typically include:

- Date

- Vessel identification

- Name of structure or block

- Environmental information

- Steel condition

- Surface preparation conditions

- Coating type and identification numbers

- Coating application (number of coats, stripe coating)

- Dry-film thickness measurement

- Nonconformity and rectification

5   Verification Requirements

In addition to the tripartite agreement review prior to commencement of any PSPC coating work on any stage of a new building, the following items, as a minimum, are to be verified during the PSPC coating work:

- Confirm that the Technical Data Sheet and Type Approval Certificate comply with this Standard;

- Confirm that the coating identification on representative containers is consistent with the coating identified in the Technical Data Sheet and Type Approval Certificate;

- Confirm the qualification and certification of the inspector;

- Confirm that the inspector's reports of surface preparation and the coating's application indicate compliance with the manufacturer's Technical Data Sheet and the agreed specification; and

- Monitor implementation of the coating inspection requirements. Monitoring implementation of the coating inspection requirements entails confirming, on a sampling basis, that the inspectors are using the correct equipment, techniques and reporting methods as described in the inspection procedures reviewed by the Administration or the Class Society.

Any deviation found is to be raised initially with the coating inspector, who is responsible for identifying and implementing the corrective actions. In the event that corrective actions are not satisfactorily resolved or not closed out, then ABS is to inform the shipyard.

In the event that corrective actions are not acceptable to the Administration or in the event that corrective actions are not closed out, then the shipyard is to be informed. A Passenger Ship Safety Certificate or Cargo Ship Safety Certificate or Cargo Ship Safety Construction Certificate, as appropriate, is not to be issued until all required corrective actions have been closed to the satisfaction of the Administration.

ABS, acting on behalf of the flag Administration, verifies the CTF contents for compliance with the IMO PSPC and for the issuance of the related certificate. Section 8, Figure 4 summarizes the PSPC process.

FIGURE 4
Coating Process Flow *(1 January 2017)*

Before IMO PSPC Project Starts

Tripartite agreement upon inspection of surface preparation and coating processes between the shipowner, the shipyard and the coating producer

Areas to be coated: a list of tanks/spaces and construction blocks

Coating system: selection and type approval

Coating Inspector(s): certification, qualification and appointment

Surface preparation and coating processes and procedures at all construction stages

Procedures for in-service maintenance and repair of coating systems

Organize by the shipyard and Agreed by the three parties.
- Organize by the three parties.
- Submit for ABS Review

Inspection During IMO PSPC Project

Primary surface preparation & shop priming

Secondary surface preparation – welds, edges, and damaged shop primer

Coating application of blocks

Secondary surface preparation – erection joints, coating damages

Erection join coating application and coating damage repair

Coating inspection and documentation by coating inspector(s)
- Coating inspection and documentation by coating inspector(s)
- Shipyard work records and verification reports
- monitored and verified by ABS

End of New Construction PSPC

CTF documentation assembly & submission by the shipyard for ABS review

In-Service after Construction

CTF is to be kept on board and maintained throughout the life of the ship

In-service maintenance, repair and partial/full re-coating activities shall be recorded in the CTF

6 In-service Maintenance and Repairs

In-service maintenance, repair and partial re-coating activities shall be recorded in the Coating Technical File in accordance with the relevant sections of the Guidelines for coating maintenance and repair from IMO MSC.1/Circ.1330 and IMO MSC.1/Circ.1399.

Definitions of coating maintenance and repair:

i) *Maintenance* means minor coating restoration work regularly performed by a ship's crew using normal shipboard means and tools to maintain "GOOD" or "FAIR" coating conditions. Maintenance delays or slows down the coating deterioration and affects short-term steel protection.

ii) *Repair* means coating restoration work of a longer term nature, usually performed during ship's drydocking or scheduled repair period (ship idle) to restore the "FAIR" or "POOR" coating condition to "GOOD" condition. This usually requires specialized preparation, manpower and equipment such as blasting equipment, operators and dehumidifiers together with good surface preparation procedures.

6.1 Survey Recommendations

The coating system in ballast tanks and cargo tanks is to be examined in connection with intermediate surveys and renewal surveys in accordance with the class survey requirements.

The coating system in ballast tanks is to be examined in connection with intermediate surveys and renewal surveys for all steel ships above 500 gross tonnage exceeding five years of age.

The coating system in cargo tanks is to be examined in connection with intermediate surveys (exceeding ten years of age) and renewal surveys for all crude oil tankers of 5,000 tonnes deadweight or above. The coating system in cargo tanks is to also be examined when it is damaged by incidents during service of the ship.

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

6.2 In-service Condition Monitoring by the Crew

It is recommended that all ballast tanks, especially in ships over six years of age, are inspected at least annually by the crew. For cargo oil tanks, in cases where tank entry is made and coating condition monitoring is carried out, a report should be provided as CTF records are maintained on board for use by the owner. The report of the coating condition is to identify how urgent the repairs are and identify the most cost effective solution.

6.3 Recommended Maintenance

Coating maintenance for ballast tanks and cargo oil tanks is to be done in accordance with Section 5 of IMO MSC.1/Circ.1330 and IMO MSC.1/Circ.1399.

6.4 Recommended Repair

Coating repair for ballast tanks and cargo oil tanks are to be done in accordance with Section 6 of IMO MSC.1/Circ.1330 and IMO MSC.1/Circ.1399.

Coating repair is to be inspected by qualified inspectors certified to NACE Coating Inspector Level 2, FROSIO Inspector Level III or equivalent as verified by the Administration.

6.5 Coating Technical File (CTF)

Maintenance and repair is to be carried out in accordance with the procedures and recommendations provided in the Coating Technical File (CTF).

The minimum items listed in Section 7 of IMO MSC.1/Circ.1330 and IMO MSC.1/Circ.1399 are to be recorded in the CTF for both maintenance and repair.

SECTION 9 **Coating Requirements for Cargo Spaces of Bulk Carriers** *(1 January 2017)*

ABS Rules 5-3-5/1.3 "Protection of cargo hold spaces" and IACS UR Z9 include requirements for the protection of cargo hold spaces for the areas shown in Section 9, Figures 1 and 2 and described below.

The current revision of IACS UR Z9 is applicable to new vessels for which the request for class is received on or after 1 July 1998. A copy of the latest revision of IACS UR Z9 may be obtained from the IACS website: http://www.iacs.org.uk/

It is the responsibility of the shipbuilder and of the owner to choose coatings suitable for the intended cargoes, in particular for the compatibility with the cargo. The technical agreement between the ship owner, the coating manufacturer and the shipbuilder may include selection of coatings and details of the coating procedure for the cargo holds.

At the time of new construction, all internal and external surfaces of hatch coamings and hatch covers, and all internal surfaces (side and transverse bulkheads) of cargo holds, excluding the flat tank top areas and the hopper tanks sloping plating approximately 300 mm below the side shell frame and brackets, are to have an efficient protective coating (epoxy coating or equivalent) applied in accordance with the manufacturer's recommendation.

For existing bulk carriers, where Owners may elect to coat or recoat cargo holds as noted above, consideration may be given to the extent of the close-up and thickness measurement surveys. Prior to the coating of cargo holds of existing vessels, scantlings are to be ascertained in the presence of a Surveyor.

FIGURE 1
Extent of Internal Cargo Space Areas
in a Single Side Skin Bulk Carrier *(1 January 2017)*

Hatch Covers are to be coated
externally and internally as
see IACS Z9 & ABS Rules 5-3-5/1.3

Topside tank

Hopper tank

300mm
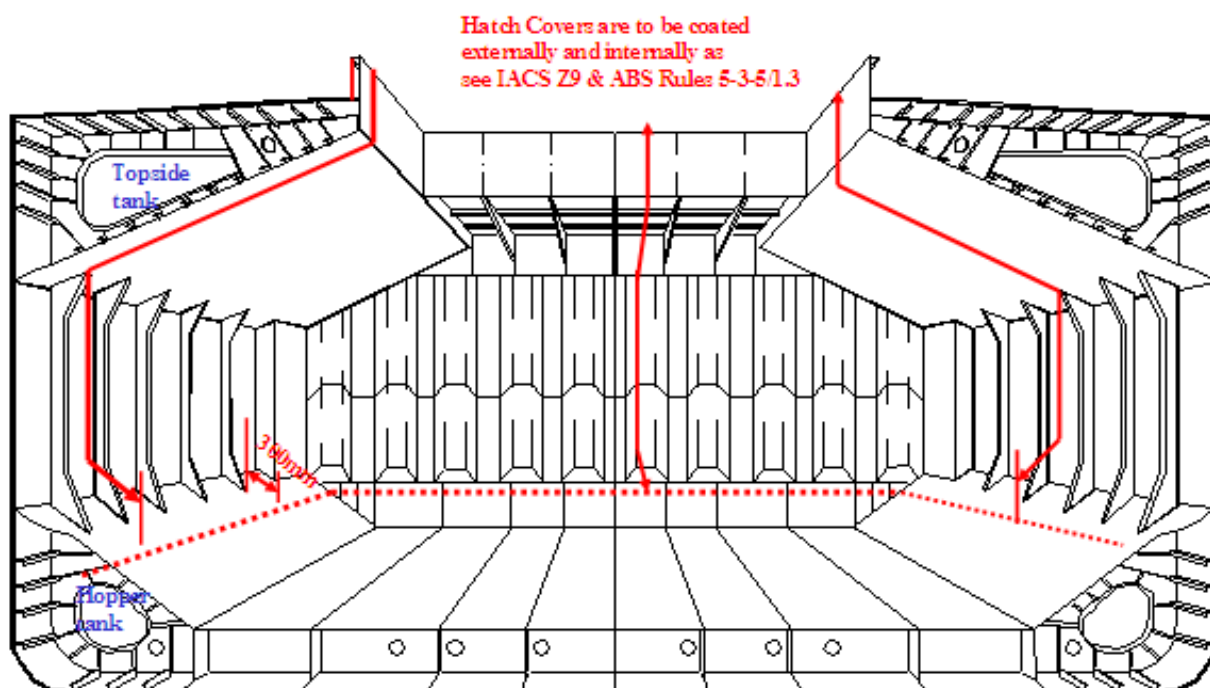
FIGURE 2
Extent of Internal Cargo Space Areas and Hatch Cover *(1 January 2017)*

300 mm

300 mm

Single Hull

Double Hull
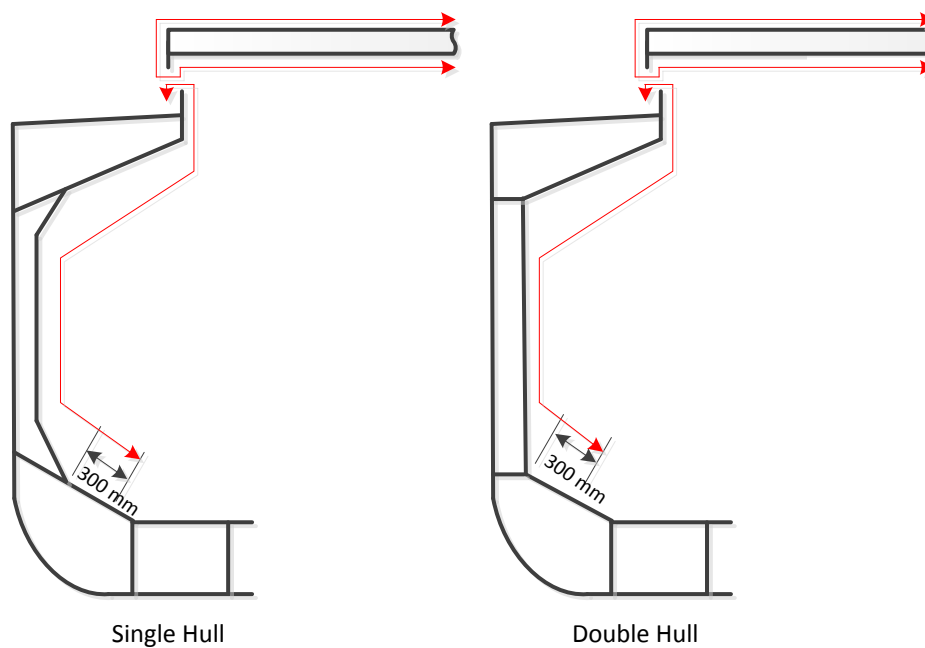
SECTION 10 Coating Failures *(1 January 2017)*

1 General

Coatings do not last forever. They age, weaken and deteriorate and eventually their useful life ends. Coating failures may occur for a number of reasons. They can generally be caused from coating manufacturer-related, owner/specifier-related, coating applicator-related or environmental service-related reasons. The most common cause for premature coating failure is poor surface preparation and/or insufficient care during the mixing, application and curing processes of paints. Poor application technique can typically cause problems such as improper thickness, pinholes, sags, mud-cracking, and holidays. Inadequate surface preparation results in poor adhesions to the substrate. This includes blistering, peeling and inter-coat delamination. In addition, structures are not designed with the coating process in mind. Poor design or fabrication of the structures such as skip welds, sharp edges and crevices lead to early coating failures.

2 Coating Defects During Application

2.1 Sags

Also known as overloading, curtains, gun spits, runs, sagging, or drips, sags generally occur on vertical surfaces when paint is applied too thickly in localized areas in excess of the WFT. See Section 10, Photograph 1. They can also be caused when too much thinner has been added to the paint, if the gun is held too close to the surface, or if the gun is held in one position for too long a time. In extreme circumstances, it could be due to incorrect formulation. If it is not a formulation problem, the problem can be resolved by brushing out while the paint is still wet. When the paint has dried, the defective areas can be abraded and cleaned and an overall coat or spot repair can be applied, as necessary.

PHOTOGRAPH 1
Sags *(1 January 2017)*

2.2   Cissing or Fisheye

They are small holes in the coating that are caused by entrapped air bubbles leaving the paint or improper wetting of the substrate by the paint. This is also caused by surface contamination such as moisture, oil or grease. See Section 10, Photograph 2.

This can be prevented by confirming that the surface is clean and free from oil, grease and foreign contaminants prior to application of the coating. This kind of defect can be resolved by removing the coating completely to achieve a clean surface and reapplying the coating system to the coating manufacturer's recommendation.

PHOTOGRAPH 2
Fisheyes *(1 January 2017)*
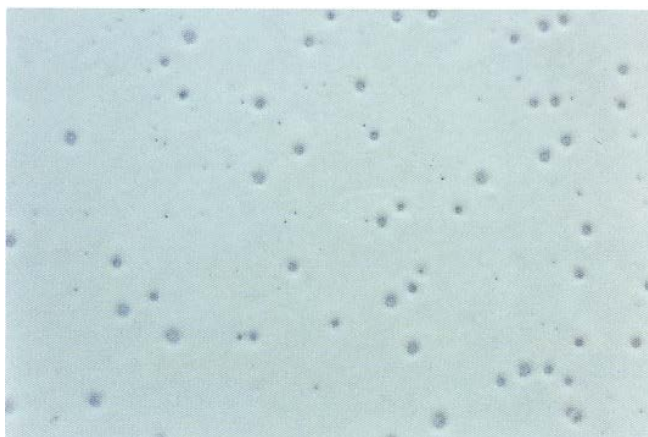
From Fitz's Atlas of Coating Defects

2.3   Orange Peel

Typically, the surface is uniformly pock-marked and looks like an orange peel. See Section 10, Photograph 3. This is usually caused by poor application techniques, by incorrect solvent blend or too high thixothopy. This defect can be avoided by using correct application techniques with suitably formulated products. Once it occurs and requires repair, the entire affected area is to be cleaned and recoated.

PHOTOGRAPH 3
Orange Peel *(1 January 2017)*
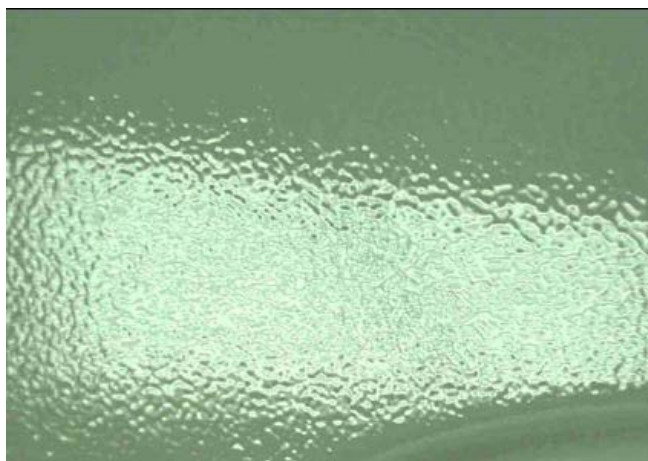
2.4   Cracking or Mud Cracking

Mud cracking usually occurs on horizontal surfaces when paint has been applied too thickly or from over-application of heavily pigmented primers such as inorganic zinc silicates or water-based coating. See Section 10, Photograph 4. The cracking is generally a stress-related failure from lack of flexibility of the coating (internal stress build-up in the coating as it dries and cures, thereby causing cracking). In order to prevent such a defect, use recommended application techniques with suitable formulated products. To repair such a defect, all cracked paint is to be removed to clean the substrate and reapply the coating system with the correct application technique.

PHOTOGRAPH 4
Cracking *(1 January 2017)*

2.5   Holiday

A holiday is any discontinuity, bare or thin spot in a painted area. See Section 10, Photograph 5. Corrosion sites usually initiate in these areas. Holidays need to be repaired by abrasion cleaning to bare substrate and reapplying the coating system.

PHOTOGRAPH 5
Small Holes or Holidays *(1 January 2017)*
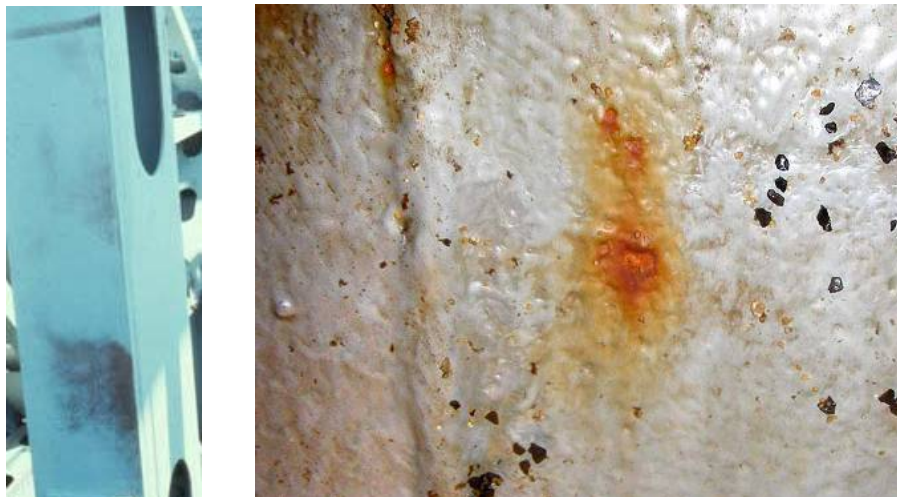
Small holes or holidays in the coating allow rapid corrosion to initiate in service.

2.6   Over Thickness

The total coating dry film thickness applied is greater than the maximum thickness specified by the coating manufacturer for that product. If the coating is too thick, it can fail by peeling away from the substrate or cracking as shown in Section 10, Photograph 6.

PHOTOGRAPH 6
Over Thickness

Over thick coating detaches easily. Poor preparation between coats of paints causes early failure.

2.7   Under Thickness

The total coating dry film thickness applied is less than the minimum specified by the coating manufacturer and/or the 90/10 rule for that coating. Too thin coating thickness causes premature failure, see Section 10, Photograph 7.

PHOTOGRAPH 7
Under Thickness

Where the coating is too thin, early failure occurs in service.

2.8   Overspray and Dry spray

Overspray or dry spray is described as small particles of paint adhering to a previously painted dry surface, generally adjacent to the area being sprayed. See Section 10, Photograph 8. This could be caused by wet paint particles falling outside the spray pattern as misapplication to an adjacent surface or spray application under windy condition.

Dry spray is described as a rough surface with paint particles poorly adhered to the surface, which is caused by incorrect spray application (i.e., spray gun distance or by using fast dry coating applied at high temperature).

Overspray or dry spray particles are typically small and poorly adherent to the surface. Those overspray or dry spray particles need to be removed if the affected area is to be top-coated.

PHOTOGRAPH 8
Dry spray or Overspray *(1 January 2017)*

From Fitz's Atlas of Coating Defects

2.9   Grit Inclusions

Grit can be trapped under the paint, through the paint or on top of the paint. If the steel surface is not properly cleaned after abrasive blasting or if blasting dust and grit is deposited onto a layer of paint prior to application of the next coat, grit becomes trapped. Steel grits corrode when water penetrates through the paint and the coating is locally forced away from the steel when the grit is under the coating. If grit is trapped between coating layers, then the outer layer of paint is damaged. See Section 10, Photograph 9.

Grit trapped in the outer layer of paint also corrodes and this causes stresses in the coating that weaken its integrity and shorten its service life.

PHOTOGRAPH 9
Trapped Grit *(1 January 2017)*

Trapped Grit at the welds and in the coating has caused rust staining.
Grit that penetrates through the coating allows corrosion of the substrate to initiate.

2.10   Human Error

Human error covers instances of the wrong type of paint applied, poorly mixed/wrong mixing ratio or exceeding pot life. The application of coating under unsuitable environmental conditions, such as too low/too high temperature or high humidity, can also be categorized as human error.

2.10.1   Poor Penetration

Coatings should completely cover the item to be coated. Poor application practices can cause incomplete coverage. It is difficult to obtain a good and even coverage of paint on edges and welds and it is also difficult to ascertain that the correct thickness of paint has been applied. For a complicated structure, spray technique should be combined with roller and brush techniques for good coverage and better paint penetration on welds, edges and other difficult to reach areas.

2.10.2   Footprints

When the specified "walk on time" for curing on the technical datasheets has not been met, walking on the coatings to check DFT's can leave footprints. The paint at the footprint areas is below the specified thickness and can have embedded contamination.

2.10.3   Winter/Summer Grades

For a specific coating, paint manufacturers may supply a "winter grade" and "summer grade" paint for winter and summer season coating application. It is essential that the change over from summer to winter grades takes place before the minimum temperatures occur. Compatibility between winter and summer grades should be confirmed from the paint manufacturer before the coating project starts. Special attention is to be paid to winter coating applications when ambient temperature is below freezing. Heating and ventilation needs to be facilitated and maintained at all times during curing and drying. Interrupted curing is not to be resumed when temperature is not continuously maintained.

2.10.4   Poor Mixing

Poor mixing of paint, either by insufficient stirring or mixing the wrong ratios of a two component system, can result in uneven or incomplete curing of the coating. This seriously affects the service lifetime of the coating.

2.10.5   Pot Life Exceeded

The pot life of a coating is specified in the coating technical data sheets by the paint manufacturer and depends on the type of paint and the ambient conditions. Paint that has exceeded its pot life may appear to be applicable, but should be discarded as it does not produce a satisfactory coating performance in service. Adding thinner to extend pot life is not allowed since adding more than the allowed amount of thinner is prohibited in the data sheets.

2.10.6   Induction Period not Allowed

Some coatings require an induction (waiting) period after mixing and before application of the coating. This is specified on the paint manufacturer's data sheets. The induction time is needed; otherwise, the coating may not adhere to the substrate and may not cure appropriately.

2.10.7   Shelf Life Exceeded

All coatings should be labeled with a "use by" date on the container. Out of date paints are not to be applied as the film forming and curing properties are affected.

2.10.8   Storage Temperature Too High or Too Low

Paint manufacturers' data sheets specify storage conditions for the paints. Storage outside the given temperature range can seriously affect the shelf life and so the application, curing and coating performance.

2.10.9   Dust

Dust may be brought in during the coating application. The sprayer should be aware of dust introduced during the coating application.

3   In-service Coating Failures

3.1   Through Film Breakdown

Through film breakdown most commonly occurs in the ullage space underneath sun-heated decks at the top of ballast tanks. A typical example is shown in Section 10, Photograph 10. The coating breakdown shown is in the later stages of development, where the rust spots have grown due to the warm and humid conditions found in these areas.

**PHOTOGRAPH 10
Through Film Breakdown**

Through film breakdown also typically occurs first on the upper surfaces of longitudinal stiffeners (Section 10, Photograph 11) and on stringer decks (Section 10, Photograph 12), where residual water remains after the tank is first emptied.

Water and condensation drain down vertical and sloping surfaces and collect on suitable horizontal surfaces. Water may be trapped on horizontal stiffeners due to the design of the stiffener, end plates, bulkheads, etc. It is also trapped by mud and debris on the stiffener.

Stringers and tank bottoms also collect pools of water due to the vessel trim, poor drainage at cut outs and rat holes, at the intersection of web frames and horizontal structure and where buckling of the plates has occurred. Residual mud, cargo and other debris also trap and hold water against the paint and any exposed metal surfaces.

PHOTOGRAPH 11
Corrosion Spots on Longitudinal Stiffener

PHOTOGRAPH 12
Corrosion Spots on Stringer Deck

3.2   Blistering

Blisters often take the form of clusters of liquid-filled or dry, hemispherical bubbles at the paint/metal interface. Although blisters can form between layers of paint, these are less common.

Typical blister rashes are shown in Section 10, Photographs 13 and 14. In order to give a sense of scale, a small notebook has been included in the Photographs 14.

PHOTOGRAPH 13
Blister Rash

PHOTOGRAPH 14
Blister Rash

Blistering is one of the most common forms of adhesion-related coating failure, particularly when the coating is immersed in water, seawater or other liquid. It can also occur in areas of high humidity when there is continuing or intermittent condensation on the surface.

Blisters either originate from soluble salts contamination on the substrate prior to coating or are due to soluble material leaching out from the coating itself and migrating to the interface with the substrate. Water always migrates through the film driven by osmosis, and when the osmotic pressure within the blister balances the coating adhesion and internal cohesion, the blister ceases to grow. Where the pressure is greater than the tensile strength, the blister breaks. This is often the case for a brittle coating with little flexibility. After the blister breaks, the substrate steel frequently begins rusting.

Blisters are also associated with areas of corrosion. In this instance, their growth is electrochemically driven and complex rules govern their eventual size.

Typically, blisters do not show corroded steel underneath (due to the highly alkaline blister fluid) and such cathodic blisters are of concern only in areas where they can be broken mechanically (e.g., by the action of water or foot traffic). It is recommended that blisters containing high pH fluid should NOT be broken unless a complete repair of coating of an area is undertaken. If the blisters become deflated or leak fluid, then the coating should be repaired as soon as possible.

3.3 Too Thin Coating

The most common cause of coating failure is poor surface preparation. However, when the coating is also poorly applied or too thin, then failures of the type shown in Section 10, Photograph 15 tend to occur. In practice, a combination of blistering and corrosion may be observed at the failed area.

PHOTOGRAPH 15
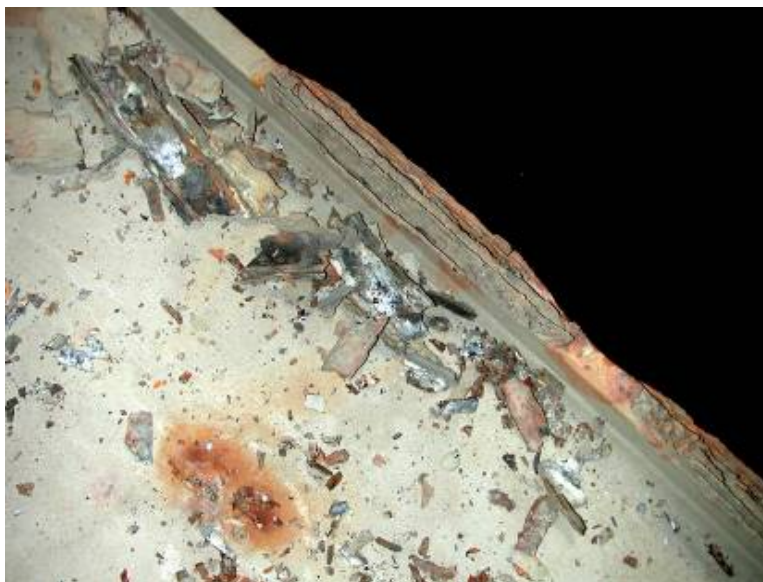**Example of Poor Surface Preparation Prior to Coating**

3.4 Edge Breakdown

One of the areas to exhibit early coating breakdown is the edge of stiffeners (Section 10, Photograph 16) and around cut outs (Section 10, Photograph 17).

PHOTOGRAPH 16
Coating Breakdown on Stiffener Edge

PHOTOGRAPH 17
Coating Breakdown around Cut Out

Special care should be taken with the coating process in these areas. To increase coating service life, sharp edges shall be ground and rounded, and stripe coats of paint shall be applied for building up DFT, which is especially true for conventional solvent-containing coating.

3.5   Weld Corrosion

Welds are susceptible to enhanced localized coating breakdown in the same manner as edges because of their irregularity of surface profile. Typically, for manual welding, welds are to be grinded smooth. All weld spatters and contaminants from welding are to be removed. During block building stage, all welds are normally also blasted for cleaning. However, during erection stage and repairs, the welds are usually grinded for cleaning. It is important that all surface contaminants such as oil and grease are removed before grinding or blasting.

Two types of weld corrosion commonly occur. The first type of weld corrosion failure is illustrated in Section 10, Photograph 18 where corrosion initiates on either side of the weld. Coating breakdown is associated with poor surface preparation after welding.

PHOTOGRAPH 18
Corrosion around Weld

The second type of weld coating failure occurs much closer to the weld and is again associated with stress cracking from thick coatings and/or substrate structure members, see the "stress-related coating failures" section below. An example is shown in Section 10, Photograph 19.

PHOTOGRAPH 19
Corrosion at Welds

3.6   Calcareous Deposit-Induced Coating Failures

The presence of sacrificial anodes in ballast tanks induces the formation of hydroxyl ions at the coating/metal interface, which has the result of inhibiting or preventing corrosion from occurring beneath the coating. A side effect is the formation of a white, chalky material (called calcareous deposit) that can lift the coating.

The calcareous deposit originates partially from the reaction of carbon dioxide with the hydroxyl ions and partly as the result of semi-soluble carbonates being deposited from the sea water.

When the cathodic protection system is working properly, the volume of the deposits is just sufficient to fill any cracks in the damaged area, as shown in Section 10, Photograph 20.

PHOTOGRAPH 20
Well-performing Cathodic Protection System
with Tight Calcareous Deposits

When the anodes are overworked, then the voluminous deposits forming beneath the coating can lever it off the steel, as shown in Section 10, Photograph 21.

PHOTOGRAPH 21
Voluminous Calcareous Deposits

3.7   Reverse Impact Damage

Reverse impact damage occurs on the inside of ballast tanks due to a sharp, high intensity impact from the outside of the tank. It is extremely common in bulk carriers, particularly on the hopper sides due to the action of grabs. The underside of the double bottom also receives many reverse impacts from grabs and bulldozers.

A typical example is shown in Section 10, Photograph 22, which illustrates the shatter patterns that result from the coating failing in a brittle manner.

PHOTOGRAPH 22
Reverse Impact from Grab Causing Brittle Coating to Shatter

Reverse impact damage is also common in the shell plating in way of and above the water line on the vessel. It is especially common around tug contact areas, where the vessel changes shape forward and also in way of the forepeak tank as a result of collisions with floating objects or piers and mooring facilities (Section 10, Photograph 23). These types of reverse impact damages are usually slower than grab damage and result in distortion of the coating, which in turn leads to through film corrosion at the damaged site.

PHOTOGRAPH 23
Reverse Impact from External Collision

3.8   Mud Cracking

Cracks in a typical pattern extend down from the surface of the coating and can reach the coating/metal interface. Mud cracking is generally a result of either a very high build-up of coating (high DFT) or can be due to excessive thinning in conjunction with thick films. Often the interface with the steel is weakened and corrosion quickly initiates in the cracks. Very thick paint that cracks can often detach from the steel, due to internal stresses in the coating, leaving exposed metal. Mud cracking of coatings typically takes the form shown in Section 10, Photographs 24 and 25.

PHOTOGRAPH 24
Typical Mud Cracking in a Thick Coating

PHOTOGRAPH 25
Typical Mud Cracking in a Thick Coating

3.9 Stress-related Coating Failures

Corrosion can initiate at heavily stressed areas within tanks. Stress-related coating failures can be recognized by their location or by the presence of a repetition of the same failure in the same place along the length of a structure, as shown in Section 10, Photograph 26.

PHOTOGRAPH 26
Stress-induced Coating Failures

Abrasive Blasting:	Cleaning and roughening of a surface produced by the high-velocity impact of an abrasive that is propelled by the discharge of pressurized fluid from a blast nozzle or by a mechanical device such as a centrifugal blasting wheel.
Adhesion:	The state in which two surfaces are held together by chemical interfacial forces, mechanical interlocking forces, or both.
Aging:	(1) The process of exposing materials to an environment for an interval of time. (2) change in metallurgical properties that generally occur slowly at room temperature (natural aging) and more rapidly at higher temperature (artificial aging). Ageing Degeneration occurs in a coating during the passage of time and/or heating.
Air Drying:	Process by which an applied wet coat converts to a dry coating film by evaporation of solvent or reaction with oxygen as a result of simple exposure to air without intentional addition of heat or a curing agent.
Airless Spraying:	Process of spraying coating liquids using hydraulic pressure, not air pressure, to atomize. In this method, the paint is put under great pressure [up to 360 kg/cm^2 (5000 psi)] by a compressed air driven pump and is atomized by being forced through a small nozzle. Airless spray is a very fast and efficient method of application.
Alkyd:	Type of resin formed by the reaction of polyhydric alcohols and polybasic acids, part of which is derived from saturated or unsaturated oils or fats.
Anode:	The electrode of an electrochemical cell at which oxidation occurs. (Electrons flow away from the anode in the external circuit. It is usually the electrode where corrosion occurs and metal ions enter solution). It is usually a piece of less noble metal fixed to steel to provide cathodic protection.
Antifouling Coating:	A coating used for underwater hulls for preventing fouling. It contains biocides which are released and prevent the adhesion and growth of organisms on the hull. See also "foul release coatings".
Barrier Coating:	A coating that has a high resistance to permeation of liquids and/or gases.
Barrier Pigment:	A pigment that impedes permeation through an organic coating solely by its physical presence [contrast with corrosion-inhibitive pigment and sacrificial pigment].
Binder:	The component in paint or varnish which binds the constituents to the surface. Paints are usually named after the binder type.
Bleached Tar Epoxy:	See "modified epoxy".
Blister:	A dome-shaped projection on the surface of a coating resulting from the local loss of adhesion and lifting of the film from an underlying coat or from the base substrate.
Blushing or Blooming:	Whitening and loss of gloss of a coating, usually organic, caused by moisture.
Calcareous Coating:	A layer consisting of calcium carbonate and other salts deposited on the surface. When the surface is cathodically polarized as in cathodic protection, this layer is the result of the increased pH adjacent to the protected surface.

Calcareous Deposit:	See calcareous coating.
Cathode:	The electrode of an electrochemical cell at which reduction is the principal reaction. (Electrons flow toward the cathode in the external circuit.)
Cathodic Disbondment:	The destruction of adhesion between a coating and the coated surface caused by products of a cathodic reaction.
Cathodic Protection:	A technique, by attaching a sacrificial anode or by the use of impressed current, to reduce the corrosion rate of a metal surface by making that surface the cathode of an electrochemical cell.
Chalking:	The development of loose, removable powder (pigment) at the surface of an organic coating, usually caused by weathering.
Coal Tar Epoxy:	A combination of epoxy resins, tar and a curing agent, which produces a very water-resistant film.
Coat:	One layer of a coating system applied to a surface in a single continuous application to form a uniform film when dry.
Coating:	1) A liquid, liquefiable, or mastic composition that, after application to a surface, is converted into a solid protective, decorative, or functional adherent film. (2) [in a more general sense] A thin layer of solid material on a surface that provides improved protective, decorative, or functional properties.
Coating System:	The complete number and types of coats applied to a substrate in a predetermined order. (When used in a broader sense, surface preparation, pretreatments, dry film thickness, and manner of application are included.)
Corrosion:	The deterioration of a material, usually a metal, that results from a chemical or electrochemical reaction with its environment.
CPS:	ABS notation given to a vessel when it complies with the ABS *Guide for the Class Notation Coating Performance Standard (CPS)*.
CSR:	IACS Common Structural Rules, see ABS *Rules for Building and Classing Steel Vessels*, Part 5A (General Hull Requirements) and Part 5B (Ship Types).
CTF:	Coating Technical File is a document that contains all information of coating project during new construction and coating maintenance and repairs after construction.
Curing:	Chemical process of developing the intended properties of a coating or other material (e.g., resin) over a period of time.
Curing Agent:	A chemical substance used for curing a coating or other material (e.g., resin). (Also referred to as "hardener".)
Dew Point:	The temperature at which air is saturated with moisture.
DFT:	The Dry Film Thickness after the paint or coating has cured.
Dielectric Shield:	An electrically nonconductive material, such as a coating, sheet, or pipe, that is placed between an anode and an adjacent cathode, usually on the cathode, to improve current distribution in a cathodic protection system.
Dissimilar Metals:	Different metals that could form an anode-cathode relationship in an electrolyte when connected by an electron-conducting (usually metallic) path.
Dry Film Thickness:	The thickness of a dried film, coating, or membrane.
Dry Spray:	A rough, powdery noncoherent film produced when atomized coating particles partially dry before reaching the surface.
Dry to Handle:	Stage of drying or curing of an applied coating at which time the coated object can be carefully handled without damage.

Drying Time:	Minimum time required for an applied coating to reach the desired stage of drying or curing.
Dust:	Loose particle matter on a surface prepared for painting which may arise from blast-cleaning or other surface preparation processes, or resulting from the action of the environment.
Edge Grinding:	The treatment of edges before secondary surface preparation.
Electrochemical Cell:	An electrochemical system consisting of an anode and a cathode in metallic contact and immersed in an electrolyte. (The anode and cathode may be different metals or dissimilar areas on the same metal surface.)
Electrode:	A material that conducts electrons, is used to establish contact with an electrolyte, and through which current is transferred to or from an electrolyte.
Electro osmosis:	The migration of water through a semipermeable membrane as a result of a potential difference caused by the flow of electric charge through the membrane.
Epoxy:	Type of resin formed by the reaction of aliphatic or aromatic polyols (such as bisphenol) with epichlorohydrin and characterized by the presence of reactive oxirane end groups
Epoxy Mastic:	Originally a high build epoxy containing a high level of thixotropes. Also see "modified epoxy".
Erosion-Corrosion:	A conjoint action involving erosion and corrosion in the presence of a moving corrosive fluid or a material moving through the fluid, leading to accelerated loss of material.
Feathering:	Reducing the thickness of the edges of an undamaged coating film, such as adjacent to a damaged coating or rusted area, by abrasion or sanding to produce a smoothly tapered transitional area prior to recoating.
Fouling:	An accumulation of deposits. (This includes accumulation and growth of marine organisms on a submerged surface and the accumulation of deposits on heat exchanger tubing.)
Foul Release Coatings:	Antifouling paints which do not contain biocides and which have a low free energy surface unattractive to fouling organisms.
Galvanic Corrosion:	Accelerated corrosion of a metal because of an electrical contact with a more noble metal or nonmetallic conductor in a corrosive electrolyte.
Galvanic Series:	A list of metals and alloys arranged according to their corrosion potentials in a given environment.
General Corrosion:	Corrosion that is distributed more-or-less uniformly over the surface of a material.
"GOOD" Condition:	The coating condition with minor spot rusting as defined in IMO Resolution A.744(18) and IMO MSC.1/Circ.1330.
Hard Coating:	A coating which chemically converts during its curing process, normally used for new construction, or non-convertible air drying coating which may be used for maintenance purposes. Hard coatings can be either inorganic or organic.
Holiday:	A discontinuity in a protective coating that exposes unprotected surface to the environment.
Impressed Current:	An electric current supplied by a device employing a power source that is external to the electrode system. (An example is direct current for cathodic protection.)
Impressed Current Anode:	An electrode, suitable for use as an anode when connected to a source of impressed current. (It is often composed of a substantially inert material that conducts by oxidation of the electrolyte and, for this reason, is not corroded appreciably.)
Induction Time:	The period of time which must elapse between mixing the paint and its application, for some two-pack materials.
Inorganic Zinc-rich Coating:	Coating containing a metallic zinc pigment (typically 75 mass percent zinc or more in the dry film) in an inorganic vehicle.

Mix Ratio:	For a two-pack system, the mix ratio is the relative quantity of each pack.
Modified Epoxy:	Also called epoxy mastic, tar free or bleached tar epoxy. An epoxy paint containing non-epoxy polymers which can be cross-linked into the film. Nonreactive polymers, either solid or liquid, may also be included to provide specific properties in the final film.
NDFT:	The Nominal Dry Film Thickness specified in the specification for required DFT of the paint or coating after it has cured.
90/10 Rule:	90% of all thickness measurements shall be greater than or equal to NDFT and none of the remaining 10% measurements shall be below $0.9 \times$ NDFT.
Organic Zinc-rich Coating:	Coating containing a metallic zinc pigment (typically 75 mass percent zinc or more in the dry film) in an organic vehicle.
Organotin Compounds:	These are chemical compounds based on tin with hydrocarbon constituents. Triorganotins are very toxic. Depending on the organic groups, they can be powerful bactericides and fungicides. Tributyltins were used in marine anti-fouling paint, however, now they cannot be applied to larger vessels.
Oxidation:	(1) Loss of electrons by a constituent of a chemical reaction. (2) Corrosion of a material that is exposed to an oxidizing gas at elevated temperatures.
Paint:	A pigmented liquid or resin applied to a substrate as a thin layer that is converted to a solid film after application. (It is commonly used for decoration or protection.)
Pickling:	(1) Treating a metal or alloy in a chemical bath to remove scale and oxides (e.g., rust) from the surface. (2) Complete removal of rust and mill scale by acid pickling, duplex pickling, or electrolytic pickling. (See SSPC-SP 8.)
Pigments:	Insoluble powders dispersed in resins which give the paint its color, finish, and protective properties.
Pinhole:	A minute hole through a coat or coats that exposes an underlying coat or the substrate.
Polarization:	The change from the corrosion potential as a result of current flow across the electrode/electrolyte interface.
Polyester:	Type of resin formed by the condensation of polybasic and monobasic acids with polyhydric alcohols.
Polymer:	A high molecular weight material created from lower molecular weight constituents by chemical reaction. Polymers with resinous characteristics are frequently used in paints.
Polyurethane:	A polymer formed by reaction of an isocyanate with a polyol (hydroxyl-containing material). When it is used as a coating binder, it generally produces a tough, durable, glossy protective coating with good chemical and ultraviolet light resistance.
Pot Life:	The maximum elapsed time during which a coating can be effectively applied after all components of the coating have been thoroughly mixed.
Power Tool Cleaning:	Removal of loose rust, loose mill scale, and loose coating by power tool chipping, descaling, sanding, wire brushing, and grinding. (See SSPC-SP 3.)
Prime Coat:	See "primer".
Primer:	A coating material intended to be applied as the first coat on an uncoated surface. The coating is specifically formulated to adhere to and protect the surface as well as to produce a suitable surface for subsequent coats. (Also referred to as "prime coat".)
Primer Coat:	The first coat of the coating system applied on the bare steel substrate. Also see shop primer coating. Shop primer coat is the first coat of the coating system applied in the shipyard or steel mill shop before steel cutting.
Protective Coating:	A coating applied to a surface to protect the substrate from corrosion.

PSPC:	Performance Standard for Protective Coatings
Pure Epoxy:	A paint where the binder is based on epoxy polymers only.
Relative Humidity:	The ratio, expressed as a percentage, of the amount of water vapor present in a given volume of air at a given temperature to the amount required to saturate the air at that temperature.
Resin:	A material used as a binder constituent which forms a non-crystalline film when dried.
Sacrificial Anode:	See "galvanic anode".
Sacrificial Pigment:	A pigment that provides cathodic protection to the substrate by galvanic action [contrast with corrosion-inhibitive pigment and barrier pigment].
Sag:	Non-uniform downward flow of a wet-applied coating under the force of gravity that results in an uneven coating having a thick lower edge.
Semi-hard Coating:	A coating which dries in such a way that it stays flexible, but still hard enough to touch and walk upon. These coatings do not appreciably erode with the usual ballast water movement. Since 1st July 1998, semi-hard coatings have not been applied to ballast tanks of new vessels.
Shelf Life:	The maximum length of time packaged materials (e.g., coating materials) can be stored, at specified conditions, and remain in usable condition.
Shop Primer:	A rust inhibiting primer designed to protect steel from general weathering immediately after plate fabrication. At new building yards, the shop primer is applied to steel plates and profiles after blasting and before construction, often in automated plants. Shop primers can be welded and are used to protect the surface from corrosion during construction and until the final paint system is applied.
Solvent Cleaning:	Removal of oil, grease, dirt, soil, salts, and contaminants using organic solvents or other cleaners such as vapor, alkali, emulsion, or steam. (See SSPC-SP 1.)
Stripe Coating:	Painting method, usually by brushes or rollers, used before or after a general spray coating. This method applies on positions (weld, back, edge, corner, etc.) where it is not easy to achieve the required DFT with the spray application. This method is used to also provide paint adhesion and proper DFT in critical areas.
Surface Tolerant:	Coatings which are able to withstand a higher level of surface contamination. Manufacturers' data sheets specify the type and maximum quantity of contamination.
Sweep Blast:	See "brush-off blast".
Tar Epoxy:	See "coal tar epoxy".
Target Useful Life:	The target value, in years, of the durability for which the coating system is designed.
Technical Data Sheet:	The paint manufacturers' Product Data Sheet which contains detailed technical information relevant to the coating and its application.
Thermoplastic Paint:	Paints which dry by evaporation of solvent only. The binder is un-reactive.
Thermoset Coating:	A coating with a thermoset binder or resin. Contrast with thermoplastic, thermoset coating undergoes a chemical cross-linking reaction leading to a relatively infusible state.
Two-pack Paints:	Used to describe paints which are supplied in two separate containers and which have to be mixed together before use.
Waterjetting:	Use of standard jetting water discharged from a nozzle at pressures of 70 MPa (10,000 psig) or greater to prepare a surface for coating or inspection.
Zinc Phosphate:	A pigment with corrosion preventing properties.

Zinc Silicate Paints:	Zinc-filled paints based on an inorganic binder. Zinc silicates are commonly used as shop primers.
Zinc-rich Paints:	Zinc-filled paints based on a large proportion of metallic zinc in powder form. They usually contain (for example) more than 85% zinc in the dry film and provide very hard films which are resistant to solvents.