The coating condition of water ballast tanks in existing ships has become part of the classification scope of work since the Unified Requirement titled “Hull Classification Surveys” introduced in 1990 by the International Association of Classification Societies.

(Photos courtesy of Jotun Paints)
corrosion prevention of water ballast tanks apply to tank and bulk carriers built on or after 1 July 1998. They can be summarised as follows: Coating specifications are to be submitted to a classification society for evaluation and approval, and, if anodes are installed, their specifications, calculations, and drawings also are to be submitted for information. (Anodes are treated differently than coatings because they are not required.) The classification society—in this case, DNV—then approves the coating specification if it is in line with the SOLAS Amendment and the IACS Unified Interpretation.

This article examines some of the factors behind these developments, including motives for classification societies to increase their focus on protective coatings. It also looks at methods used to maintain the structural integrity of ships despite corrosion and the regulatory framework developed by classification societies for protecting ballast tanks. Finally, it covers the new DNV Rules for Ships regarding corrosion protection of sea water ballast tanks.

**Motives for Increased Focus on Coatings**

In the late 1960s and early 1970s, shipbuilding saw several major developments that profoundly changed ship design and building practices and that strongly influenced everyday operation and maintenance practices. One of these developments was an increase in ship sizes along with a corresponding increase in strength requirements. Another development involved the various steps taken to prevent accidental pollution from tankers.

**Increased Ship Sizes and Structural Optimisation**

A number of new yards were established in Europe and East Asia with large dry docks and improved production facilities to meet demands from the shipping community for bigger ships. In the mid-1960s, the maximum size of tankers was about 100,000 dwt. Ten years later, tankers exceeding 500,000 dwt had been built. In order to meet the strength requirements of these larger ships, the scantlings of ship structures had to be increased.

With the introduction of computers in the late 1960s, calculation methods for structural optimisation were developed based on a more theoretical, model-based approach than the semi-empirical rule formulae used earlier. Optimisation often focused on minimising the steel weight of the ship. Therefore, use of high-tensile-strength steel became standard practice. In extreme cases, high-tensile steel accounted for 80–90% of the ship’s steel weight.

Improvements in production facilities and controls at steel mills resulted in steel being delivered at the minimum specified thickness without the traditional variations in thickness.

The combination of optimised scantlings (i.e., having minimum weight and maximum strength) and high-tensile steel has caused large deflections or movements of the steel plates in the newbuilding structures. As the deflections increase and the structure becomes more highly strained, the protective coatings tend to crack, resulting in exposure of the steel to corrosive attack. As rust and scale flake off and the steel plates get thinner, the stress level increases. And so the process accelerates, possibly resulting in holes and cracks in the ship hull, thereby jeopardising its integrity and its ability to contain polluting cargoes.

Today, DNV’s Rules include requirements to direct strength calculations, using finite element methods, of girder structures and separate fatigue requirements for critical details.

**Pollution Prevention and Corrosion**

Public concern about accidental pollution from tankers as a result of collision or grounding resulted in limitations in IMO’s Marine Pollution Act of 1973 (Marpol 1973) on oil tank capacities depending on their location (i.e., centre or side tanks). Segregated ballast tanks (i.e., tanks for carrying ballast water only) became mandatory in 1978 as a defence against oil spills and to reduce the risk of discharging oily ballast water into the sea. Previously, the
Table 1: Contents of Coating Specification: Selection, Application, and Maintenance

| Selection | 1) Coating type, material, and manufacturer’s data sheets concerning items 2–5 below  
2) Definition of coating system, including number of coats and minimum/maximum variation in dry film thickness  

| Application | 3) Surface preparation, including preparation of edges and welds, and surface cleanliness standard (e.g., blast cleaning to Sa 2½)  
4) Coating manufacturer’s safety data sheets  
5) Maximum allowable air humidity in relation to air and steel temperatures during surface preparation and coating application  
6) Yard’s control and inspection procedures (see Guidance Notes below), including acceptance criteria and tests/checks (e.g., surface cleanliness, film thickness, air humidity, temperature controls) and handling of deviations from specified quality  
7) Details of anodes, if used  
8) Evidence of yard’s experience in coating application (*)  

| Maintenance | 9) Coating manufacturer’s recommended procedure and preferably alternative procedures for future maintenance of coating on the ship in operation  

*) Minimum evidence is a reference list stating some or all ships coated by the yard. Other relevant evidence may be technical reports on the performance of coatings applied by the yard or a quality system certificate for the yard’s coating application division or subcontractor. It is essential that the evidence is acceptable to the owner.

Guidance Notes

The items listed below should be described in the control and inspection procedures (and thus included in the coating specification) for newbuildings:

a) organisation of operators, inspectors, facilities, equipment, and procedures  
b) working conditions (e.g., access, staging, illumination)  
c) conditioning of steel temperatures and relative humidity  
d) methods of conditioning of steel temperatures and relative humidity (e.g., indoor facilities for blast cleaning and coating, heating/drying equipment, etc.)  
e) storing of coating materials and abrasives  
f) preparation of sharp edges  
g) blast cleaning and any other surface preparation  
h) cleaning, including removal of abrasives after blast cleaning  
i) cleanliness with respect to chloride content on surfaces to be coated, oil, weld smoke, dirt, etc.  
j) shielding of painted surfaces from blasting operations  
k) blast cleaning equipment and type of abrasive  
l) coating application equipment and methods  
m) curing times for individual coats in relation to temperatures  
n) dry film thickness of individual coats  
o) total dry film thickness  
p) coating repairs in case of damage and handling of coated surfaces  
q) installation of anodes, if specified

Supplementary Description of Items in Table 1

Item 1): The coating type and material will typically be epoxy, light-coloured epoxy, tar epoxy, or a similar coating delivered by a selected coating manufacturer. The manufacturer should have brochures or data sheets describing the coating type in detail, including recommendations for steel surface preparation and coating application, equipment to be used, temperatures and air humidity conditions, film thickness, curing conditions, ventilation, etc.

Item 2): The build-up of the system by primer, intermediate coat (if any), and topcoat should be described along with the dry film thickness of each layer and the total thickness.

Item 4): Allowable air humidity in relation to steel temperature should be explicitly stated, and it should be in compliance with the coating manufacturer’s recommendations.

Item 6): The newbuilding yard should have a coating inspection procedure and a team of inspectors dedicated to steel surface preparation and coating application activities. These inspectors should be part of the yard’s quality control organisation. Tests and checks (e.g., regarding chamfering or rounding of edges, blast-cleaning quality, temperature and air humidity, coating film thickness, etc.), including acceptance criteria and how deviations from specified quality will be handled, should be described.

Item 7): Anodes are not a mandatory requirement in ballast tanks for ships with only main class 1A1 Tanker for Oil ESP and Bulk Carrier ESP. However, if anodes are installed, the anode type and manufacturer, and calculations of anode mass, number, and useful life are to be described in an anode specification.

Item 8): IMO guidelines state that “the shipyard and/or its subcontractor should provide clear evidence of their experience in coating application.” The DNV minimum requirement for such evidence is a reference list stating some or all ships coated by the yard or subcontractor. It is considered to be essential that the evidence is acceptable to the ship owner.

Item 9): SOLAS and IMO also include maintenance of corrosion prevention systems as an item to be considered. Since this is something that will be carried out by the ship’s future owner(s), it is difficult to define relevant requirements. The coating manufacturer should have the best knowledge of how to carry out future maintenance of the coating, so a minimum requirement is that this be indicated either in the coating specification or in the manufacturer’s data sheets. However, periodic surveys, including the enhanced survey program (ESP), will provide an impetus for the

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future owner(s) to care for maintenance of the corrosion prevention system.

The Guidance Notes (a–q) at the bottom of Table 1 are items that should be included in a shipyard’s inspection procedure for coatings-related operations, according to the IMO Guidelines.5

The guidelines state: “Inspections relevant to surface preparation and coating application should be agreed upon between the shipowner and shipyard under the manufacturer’s advice. Clear evidence of all the above-mentioned inspections should be reported in an agreed format.”

The following information on these guidance notes is intended to form a checklist that should be reflected in the coating specification, at least briefly.

**Note a):** The yard’s organisation, facilities, equipment, personnel, and procedures for coatings-related work, including inspections, tests or checks, and reporting routines should be described, defining the scope of the quality control activity.

**Notes b)–d):** Details of working conditions, such as access and staging, methods of conditioning, as well as acceptable limits for steel temperature vs relative air humidity, should be described (e.g., the relative humidity should be <85 % or the steel temperature >3 degrees C above the dew point during blast cleaning and coating application).

**Note f):** The preparation of sharp edges for coating should be defined.

**Note g):** Acceptable surface preparation quality should be defined (e.g., Sa 2½ or similar).

**Note h):** The methods of removal of abrasives and cleaning up after surface preparation should be described.

**Note i):** Any washing with respect to removal of salts or degreasing operations on surfaces to be coated should be described.

**Note j):** Precautions should be taken to avoid damage with grit or other abrasives on already-coated surfaces.

**Notes n) and o):** Dry film thickness of individual coats and the finished coating film as well as acceptable methods and frequency of measurements should be defined.

**Note p):** The applied coating is sometimes damaged during shipbuilding (e.g., by welding or traffic), so methods of repair should be described.

**Note q):** If anodes are installed, the type of anode, its location and welding should be in accordance with the anode specification and drawings. These items should be included in the inspection procedure. Coating repair, if relevant, also should be included. Anodes should not be painted.

same tanks were used to alternately carry ballast water and oil cargo.

The U.S. Oil Pollution Act of 1990 requires all new tankers operating in U.S. waters to be built with double hulls to reduce the risk of oil spills in the event of a hull rupture. Transport of oil is not allowed between the double hulls.

The former practice of alternately carrying crude oil and ballast water in the same tanks created a particularly corrosive environment in those tanks. In addition, corrosion tended to be severe in the ullage space above the deck for two reasons: the possibility of high temperatures there and the fact that the area was frequently washed by ballast water. Severe corrosion would occur especially on horizontal surfaces such as bulkhead longitudinals and deck girder face plates where water was trapped.

Since the introduction of segregated ballast tanks, corrosion in cargo tanks is mostly observed in the bottom plating and other horizontal surfaces due to sulphuric water precipitated from crude oil. Pitting and grooving corrosion may be extensive. Occasionally, pits may penetrate the bottom plating and result in oil polluting the sea. Segregated ballast tanks may be subject to severe corrosive attack, and they may require extensive steel renewals. The large ballast tank surfaces in double-hull ships are likely to increase the maintenance problems. Corrosion and cracking may result in oil leaks from adjacent cargo tanks, causing pollution when the ballast water is pumped into the sea.

Microbial corrosion seems to be an increasingly severe problem in cargo tanks and ballast tanks, especially in double-hull vessels, due to prolonged periods of elevated oil cargo temperature. New regulations concerning ballasting routines may have a negative effect in this respect. For example, limitations on release of ballast tank water could increase microbial activity.

**Corrosion: Protection and Maintenance**

While corrosion in ships is inevitable, there are various ways of countering it: by allowing for extra steel thickness, by adding new steel to replace what is lost to corrosion, and—perhaps most effectively—by properly selecting, applying, and maintaining protective coatings.

**Corrosion Additions**

Classification society requirements for additional thickness of steel scantlings to allow for corrosion are based on documented corrosion experience of ships built earlier. However, the calculations for these “corrosion additions” are based on the assumption that the ships have been properly maintained. Studies show that corrosion rates observed on ageing ships vary greatly, and occasionally very high rates have been observed.

**Steel Renewals**

Sometimes, the problem of steel thickness lost to corrosion is addressed by adding new steel. However, a key problem with steel renewals is that the new steel is welded against a corroded structure. Welds between the new steel and the old, corroded steel may contain flaws; cracks may be generated in the heat-affected zone of
the old plating during cutting and welding; and the coating of the old plating may be damaged and not repaired. Consequently, corrosion of the old plating may be intensified, and the stress levels and stress concentrations in the whole structure of the ship may become affected by the thickness differences in old and new plates. In extreme cases, incidents are known where parts of a ship’s side have been lost into the sea as a result of this stress.

Factors in Coating Protection

A significant contributing factor to coating degradation is increasing brittleness and loss of flexibility with time, causing cracking and disbonding at structural “hot spots,” typically in deckhead structures. The coating may be flexible enough when newly applied and a few years afterwards. Then, due to cyclic temperature variations, the more volatile, low molecular weight coating constituents are lost by evaporation or washed away by ballast water. Oxidation and other chemical changes of the coating constituents further contribute to the gradual loss of flexibility.

The tendency to lose flexibility depends on the type and quality of a coating’s ingredients—its binder (typically an epoxy resin and curing agent), extenders, flexibilisers, pigments, etc.

The shipping industry and coating manufacturers need to investigate how coating flexibility changes with time due to ageing processes. The behaviour of coatings under simulated ballast tank conditions is of primary interest. Coating manufacturers have not published much data on this subject so far.

For a durable, high-quality coating, the following factors are important:
• easy access for surface preparation, coating application, inspection and maintenance;
• good drainage and avoidance of pockets and areas where water and dirt can accumulate;
• selection of profiles; and
• avoidance of sharp edges and intricate cut-outs.

Predicting corrosion rates in ballast tanks is difficult, the authors say. Some areas are more prone to corrosion than others.

Coatings applied by a ship’s crew or in repair yards will often have shorter useful lives than coatings applied at the newbuilding stage. This is because the surface preparation and strict control of temperature and humidity conditions necessary for good results often are not obtained. However, semi-hard or other coating types have been especially developed for ships in operation, and they are intended for application on non-blast-cleaned surfaces.

Market demands for more information about coating technology in general, specifications of coating systems, especially specifications concerning surface preparation and follow-up of surface preparation and coating application-related operations resulted in the development of the DNV Guidelines for Corrosion Protection of Ships.4

The guidelines were first issued in 1992 as an advisory document for voluntary use. They were amended in 1994 and 1996. They define three target durability levels for coatings: approximately 5, 10, and 15 years, with emphasis on the coating of water ballast tanks and cargo tanks. More or less parallel with the development of the IACS unified requirements,1-3 similar although less specific advisory documents on corrosion protection were issued by most classification societies.

Hull Structural Integrity

Most ship losses are caused by a series of events that include operational factors and human error. Groundings and collisions are the most common reasons for serious hull damage. Hull failures as the initiating event account for about 15–17% of serious casualties, according to DNV statistics for the world fleet from 1978–95. Failures caused by corrosion are included in this figure. For bulk carriers, corrosion of cargo hold structures has contributed to the loss of a number of ships and lives during the last decade.

The relative amount of hull damage, including corrosion, cracks, and fractures, on DNV-classified ships from 1985–94 is presented for different ship types in Figure 1. The relative hull damage rate is defined as the damage rate for the actual ship type divided by the damage rate for all ships, multiplied by 100. It is observed that bulk carriers, chemi-
Quality Coating is Cost Effective - LCC Analyses

In recent years, calculation procedures have been developed to estimate life cycle costs (LCC). Although the methods still need validation by accumulated experience, they indicate the cost effects of different corrosion protection systems applied on a ship newbuilding, maintenance strategies adopted by the shipowner, future steel renewals, and off-hire costs.

Recent LCC analyses by DNV confirm the following assumptions.
- Application of high-quality coating in sea water ballast tanks at the newbuilding stage is more cost effective than upgrading with steel renewals later, because of the expense of dry-docking and the loss of revenue while the ship is out of service.
- Application of increased corrosion margin is not cost effective compared with improving the coating quality.

Regulatory Framework

The condition of coatings in water ballast tanks of existing ships has become part of the classification scope of work due to the IACS Unified Requirement (UR) titled “Hull Classification Surveys” that was introduced in 1990.

Based on this UR, the ballast tank coating condition is to be evaluated by a surveyor and categorised as good, fair, or poor. These coating conditions are assigned based on visual inspection and estimated percentages of areas with coating breakdown and rust.

If a ballast tank is found with a coating in poor condition, without a coating, or with only a soft coating, it is subject to an annual survey. The potential cost of annual surveys is a considerable impetus for owners to keep a ballast tank coating in good or fair condition, and it should be considered in LCC analyses.

Following are other recent regulatory developments on this topic.

In the aftermath of several severe accidents involving oil tankers and bulk carriers, IACS introduced two other unified requirements—“Corrosion Protection Coating for Salt Water Ballast Spaces” (which applies to newbuildings) in 1990 and “Corrosion Protection Coating of Cargo Hold Spaces on Bulk Carriers” in 1992. IMO’s “Guidelines for the Selection, Application and Maintenance of Corrosion Prevention Systems of Dedicated Seawater Ballast Tanks” were issued in 1994 and adopted in 1995 as Resolution A.798.

SOLAS Amendment Ch. II-1,
Regulation 3-2, “Corrosion Prevention of Seawater Ballast Tanks,” which, as noted, applies to oil tankers and bulk carriers built on or after 1 July 1998, states: “All dedicated sea water ballast tanks shall have an efficient corrosion prevention system, such as hard protective coating or equivalent. The coatings should preferably be of a light colour. The scheme for the selection, application, and maintenance of the system shall be approved by the administration based on the guidelines adopted by the organisation (i.e., the above-mentioned IMO Guidelines). Where appropriate, sacrificial anodes shall also be used.”

Finally, IACS Unified Interpretation SC 122, “Corrosion Prevention in Seawater Ballast Tanks,” which was issued in early 1998, sets a framework and boundary conditions for the involvement of classification societies in corrosion protection of sea water ballast tanks.

**Conclusion**

Adequate surface protection is fundamental in coatings work. The surface finish or coating should have a pleasant appearance and be able to protect the structure against deterioration from its more or less corrosive surroundings and to some degree from mechanical loads and impacts.

The psychologically positive effect of an aesthetically successful coating should not be underestimated, even in ships’ ballast tanks. This is clearly demonstrated by the lengthy discussions about the IMO/SOLAS recommendation of using light-coloured coating, which basically was introduced to facilitate inspections.

The “market” concerned with protective coatings for ships includes not only shipowners and shipyards but also maritime authorities, ship brokers, the coating industry, the ships’ crew, and really the general public.

In simple terms, shipyards have a fundamental interest in building ships quickly and effectively. The market generally wants ships to be in good shape, nice looking, safe, and economical in operation.

Surface protection, including steel preparation and application of coating materials, adds considerable cost to a ship, so an optimal coating quality at an acceptable cost must be sought.

Increased classification society involvement will imply more focus on coating and coating-related work in shipyards. This may lead to improved general knowledge of coating technology; improved status for the personnel involved in this often dirty, heavy and sometimes dangerous work; and, finally, improved quality and increased coating life.

**References**


