

Ship Painting: Current Practice and Systems in Europe

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The underwater hull and boottop are among the most critical areas of a ship for painting. (Photos courtesy of Camrex Chugoku Ltd.)

As long as ships sail the seas, they will need protection from the corrosive environment in which they operate.

This article presents an overview of current practice in the selection and use of marine coatings. It looks at recent developments in coating systems for ships and describes the most critical parts of a ship for coating protection, including the underwater/boottop areas, ballast tanks, and cargo tanks. Particular attention is given to the role of anti-corrosive and antifouling systems for the underwater hull and boottop areas and recent developments in antifouling protection. Also included are other areas of a ship such as the topside and superstructure and the decks.

At the outset is a summary of current shipbuilding practices, including the role of shop primers and methods of painting a ship during assembly.

COMMON METHOD OF SHIPBUILDING

Current shipbuilding practice is to clean the steel in a centrifugal blasting machine and then immediately apply a weldable shop primer. This process is normally automated.

After mechanical treatments, such as rolling flat, cutting to size, bending, stretching, and drilling, the shop-coated plates and profiles are welded into block sections, which are transported to the slipway for assembly.

Unlike earlier days, many yards now build ships completely under cover. Consequently, the yards are less dependent on the climate, which is a considerable advantage for preventing premature corrosion during construction. It also means secondary surface preparation (i.e., cleaning of corroded areas, welds, or damaged and burned areas) is limited, and since power tool cleaning can be used for this purpose instead of total blasting, the result is less dust emission and considerable savings of costs.

Shop Primers

The main function of a prefabrication, preconstruction, or shop primer is to protect steel against corrosion and pollution during the building stage. It usually functions as a base for the final coating system. However, it sometimes is removed by blasting first, such as when the steel has corroded during construction or when the shop primer is too weathered to form a solid base for the coating systems. In cargo tanks for aggressive chemicals, a shop primer must be removed to ensure full chemical resistance of the final coating system.



An aesthetic topcoat usually is applied to the topside and superstructure for good appearance.

Shop primers should meet the following requirements:¹

- provide adequate corrosion protection during shipbuilding;
- be sprayable in a continuous thin film of uniform thickness;
- have a very short dry-to-handle time for transportation of steel parts by conveyor rollers, magnetic cranes, or vacuum hoists without damage to the primer;
- be fully compatible with advanced welding/cutting processes (there should be no need to remove the shop primer first, and it should not affect the speed of these processes);

- have little or no effect on the homogeneity and strength of welds;
- not emit noxious or toxic fumes during welding and flame cutting (a safety certificate is required);
- be able to withstand rough mechanical handling of the steel, including bending;
- be suitable as the base for the final coating systems;
- be highly resistant to water and compatible with cathodic protection systems (resistant to alkaline conditions);
- have no adverse effects on the environment during application and use; and
- be approved by classification societies.

The dry film thickness (DFT) of shop primers is a compromise between various requirements (i.e., weldability, limit of welding fumes, weld quality, and drying time), which all require less thickness, and corrosion protection, which requires more thickness. The prescribed DFT for most shop primers is

15-25 μm .

For shipbuilding, the most common types of shop primer now are based on unsaponifiable binders, such as two-component epoxy resins and partially hydrolysed ethyl silicates. Reinforced wash primers based on polyvinyl butyral/phenolic resins are no longer used because they contain chromate, which produces hazardous fumes during welding or cutting, and because they are not fully compatible with cathodic protection systems.

Epoxy shop primers are pigmented mainly with iron oxide and

active corrosion-inhibiting pigments, such as zinc and calcium phosphates. Zinc (potassium) chromate, which has better anticorrosive properties, is generally no longer used in Europe and other parts of the world because of the release of dangerous fumes during welding and because it could form blisters in underwater systems.

Ethyl silicate shop primers are pigmented with zinc dust, which is added to the binder solution shortly before application. Most of these products are not zinc-rich but have a reduced zinc content. This is necessary for satisfactory performance in automatic, semiautomatic, and robotic welding processes. Moreover, primers with a reduced zinc content produce less hazardous fumes during welding and also less zinc salts during weathering, which means less risk of osmotic blistering. Consequently, they provide better recoatability.

Reducing the zinc content also reduces the corrosion-inhibiting properties, but they generally are sufficient to protect steel during building, especially because many ships are built under cover. However, the best option would be to develop a zinc-rich shop primer with good automatic welding properties or to develop a suitable automatic welding method for such primers.

Since epoxy shop primers have an organic binder, they generate large amounts of fumes during welding and flame-cutting, which can burn a large area of primer in the process. In addition, large heat-affected zones adjacent to the burnt areas and on the back of the steel are an unreliable base for a paint system. Therefore, these areas must be thoroughly pretreated again (secondary surface preparation) by



blasting or power tool cleaning.

Zinc silicate shop primers, which are totally inorganic after curing and very heat-resistant, show less damage around welds and cuttings. Therefore, they need less secondary surface preparation, which limits costs. These facts, coupled with their better resistance to cathodic protection, explain the popularity of zinc silicate shop primers.

In an effort to decrease the usually high levels of volatile organic compounds (VOCs) found in shop primers, water-borne products based on alkali silicate or epoxy resin emulsion have been developed, but they have not yet found wide acceptance.

Assembly and Painting

After assembly of the sections of

a ship, they are painted in one of two ways:

- as soon as possible after assembly, partially or completely (the “block painting” or “paint-then-weld” method), in which each block is painted prior to welding of the blocks to form the ship structure, or
- after a long period, e.g., after erection on the slipway (the “building in the shop coat” or “weld-then-paint” method), in which the shop-coated blocks are welded into the ship structure and painted later.

The main advantages of block painting are that premature corrosion and weathering of the shop-primed surfaces are avoided and that the final coating systems can be applied under cover. In theory, block painting allows shipbuilders

to take control of their environment and to handle advanced solvent-free and water-borne systems, even in winter. In practice, however, if building halls are not climate-controlled, delays may be expected after a change in the weather when no coating work can be done for several days because of condensation.

The main disadvantage of block painting is a risk of mechanical damage and burns during transport of the sections to the slipway and during fitting-out. However, this damage can be minimised by adequate planning during the construction phase. Subsequent pretreatment and painting of the section welds is unavoidable, of course, and these areas must be left unpainted during block painting.

Premature damage of the final paint systems plays no role when building in the shop coat. The main disadvantage of building in the shop coat is that shop-coated steel is subject to weathering and corrosion during construction of the ship. Another disadvantage is that final painting must be done in a late stage of the building procedure. This may be more difficult from an accessibility viewpoint, or it may be undesirable with respect to other activities or the spreading of paint dust. However, building ships in the shop coat completely under cover minimises corrosion considerably.

COATING SYSTEMS

The most important recent developments in coating systems for ships have resulted from increasing regulations on the use of hazardous raw materials and the prevention of environmental pollution. Seeking better performance and economic advantages have also played impor-

Keywords

- Epoxy mastic: a surface-tolerant modified high-solids epoxy coating suitable for application over aged coatings
- High-build coating: a coating that can be applied in thick layers without sagging on vertical surfaces
- High-solid(s) coating: a coating with a reduced level of solvents classified as volatile organic compounds (VOCs), which contribute to air pollution
- Interval-free epoxy coating: a modified epoxy coating that does not have a limited overcoating time
- Modified epoxy coating: a coating based on an epoxy resin that is modified with another binder (e.g., a coal tar or hydrocarbon resin) to make a less expensive coating or to improve properties like water impermeability or recoatability
- Reinforced coating: a coating that has special materials added, such as hard fillers or glass flake, to improve abrasion resistance, mechanical strength, flexibility, impermeability, or other properties
- Solvent-free coating: one that in principle contains no VOCs but in practice often has a very low level of VOCs, perhaps 1–2% by volume
- Solventless coating: one that has a low level of VOCs (e.g., not more than 5% by volume)
- Surface-tolerant epoxy coating: an epoxy coating that can be applied successfully to substrates that are not optimally pretreated and are perhaps damp or slightly corroded



tant roles.

Many countries now regulate coating materials that adversely affect human health or pollute the environment, and more legislation can be expected in the future. For shipbuilding, this can mean (depending on the country) avoiding open blasting and open paint spraying, adhering to drydock discharge guidelines, and restricting or prohibiting the use of coatings containing hazardous materials, such as VOCs, anticorrosive pigments containing lead or chromate, asbestos, organotin-containing biocides, coal tar, and hardeners based on aromatic amines and isocyanates.

Developments in coatings for shipbuilding have focused on the reduction of VOC content. Best results have been obtained with two-component epoxies and polyurethanes. In addition, waterborne coatings for steel have been developed, and much work has been done in developing antifouling coatings that have minimal adverse effects on the environment. Very high-solids epoxy siloxane hybrid coatings introduced recently² are said to offer excellent anticorrosive properties and extended gloss and colour retention. According to the supplier, use of such a product in a marine coating system could result in a reduced number of anticorrosive layers of paint, and it could be suitable to replace isocyanate-curing polyurethane topcoats where they are restricted or banned.

CRITICAL AREAS FOR PAINTING

The most critical parts of a ship from the viewpoint of painting are the underwater/boottop areas, bal-

last tanks, and cargo tanks. Considerable financial losses can result from premature damage to the coating systems of these parts. Following is a summary of the most common coating systems for these and other parts of a ship.

Underwater Hull and Boottop

Coating systems for the underwater parts of a ship should be corrosion-inhibiting, antifouling, abrasion-resistant, smooth, and compatible with cathodic protection.

To minimise bunker (fuel) costs, the underwater hull should remain smooth during service. Consequently, a coating system should be applied as evenly as possible, and it should provide long-term protection against corrosion and fouling. Increased hull friction due to fouling can result in up to 40% more fuel consumption compared to a clean hull and greater air pollution because of the extra fuel burned to maintain a ship's speed.

Systems for the underwater hull/boottop areas consist of an anticorrosive paint and an antifouling paint on top of it. Sometimes a sealer or tie coat is applied between these two paints, especially when tar-containing anticorrosives are used. The sealer prevents the tar from bleeding into the antifouling, thereby improving its effectiveness and adhesion.

ANTICORROSIVE SYSTEMS

In modern high-performance coating systems, the anticorrosive system usually consists of at least two layers of chemically curing two-component epoxy or coal tar epoxy. Polyurethane/coal tar combinations, which cure at lower temperatures than epoxy/coal tar, can

also be used. However, polyurethane products are becoming less popular because of the toxicity of the isocyanates they contain.

Most anticorrosive coatings are high-solids and sometimes high-build materials. Use of epoxy mastics is increasing. Apart from good surface tolerance, they generally have long maximum overcoat times and good recoatability. Total DFT of underwater hull and boottop systems ranges from 250-400 μm .


Anticorrosive properties are obtained by barrier protection, which means that the water vapour transmission of the system should be very low.

Vinyl and chlorinated rubber paints, which can be applied and dried at lower temperatures than two-component paints, are not used very often anymore because of their high VOC levels.

Minimum curing temperatures of two-component epoxy products are 5-10 C. (Special "winter qualities" can cure at temperatures down to -10 C, but they have long curing times and usually somewhat higher VOC content.)

In The Netherlands, a ban on coal tar began in June 1997 because of its hazardous polycyclic aromatic hydrocarbons. A provisional exception was made for ship painting, and so two-component coal tar epoxy paints are still allowed for seagoing vessels. Other countries, such as Germany, also regulate the use of tar. It seems realistic to expect other countries to follow.

Increasing use of glass flake in coatings for underwater hulls and especially for boottop areas is evident. Glass flake improves a coating's mechanical strength and water vapour impermeability. Mechanical



strength is especially important for the boottop, which requires coatings to be very resistant to impact and scratching. The use of glass flake in epoxy and polyester coatings is very popular.

ANTIFOULING SYSTEMS

The antifouling part of an underwater coating system consists of two or three layers of paint containing toxic materials (biocides) to prevent fouling of the hull by grass (seaweed, algae) and shells (barnacles, tubeworms, polyzoans, mussels, etc.).

Copper and Tributyltin Toxins

The main toxins used are copper compounds (mainly cuprous oxide, cuprous thiocyanate, or metallic copper), organometallic compounds such as tributyltin oxide, and other biocides that are used mainly as herbicides in combination with the other toxic materials.

Copper and tributyltin (TBT) compounds offer a broad range of protection against fouling organisms.³ However, microalgae and amphora are tolerant to copper, and brown weed, seagrass, and certain diatoms are tolerant to TBT. Most herbicides are highly bioaccumulating and strongly absorbed by sediments.

TBT is highly toxic to marine organisms such as oysters, mussels, and crustaceans. For human beings, it is a skin irritant, and it may also be a sensitizer. As a result, TBT antifoulings are hazardous to workers because of the possible inhalation of spray mist or blasting dust. Copper, on the other hand, is less toxic to humans and much safer than TBT for non-target species.

Self-Polishing Antifoulings

So-called contact-matrix antifoulings have nearly disappeared from the market in recent years. They offer limited service life (1-2 years) and form an empty matrix on their surface that consists of the leached-out, insoluble part of the binder. This matrix provides a certain roughness to the hull, and forms a poor base for subsequent paint layers.

These products have been gradually replaced by more expensive self-polishing antifoulings, which are high-build coatings based on organometallic copolymers, often tributyltin acrylate. The organotin is chemically bound to the acrylic backbone of the copolymer and released in contact with seawater by a combination of hydrolysis and ion exchange. The remaining backbone is then dissolved and washed away by the movement of the ship. The erosion occurs at the rate of about 0.2-0.3 $\mu\text{m}/\text{day}$.¹ This gradual erosion or self-polishing of the antifouling protects against fouling growth and keeps the underwater hull smooth. Because no leached-out matrix remains, fresh toxic material is continuously available.

An advantage of tin-containing self-polishing antifoulings is their five-year service life, which is the maximum time between dry-dockings permitted by classification societies. For this service life, at least two coats of paint with a DFT of 150 μm each should be applied. Cuprous oxide often is added to the TBT copolymer for maximum effectiveness against barnacles.

To limit costs and the amount of TBT released into the environment, an optimum level of biocide and polishing rate are determined for

each vessel type^{4,5} based on its typical trading pattern, speed, and length of stationary periods. High activity or high-speed ships need a slower polishing product than low-speed ships or those that are stationary for long periods.

Increasing environmental concern over use of tin has resulted in legislative restrictions in many countries.^{6,8} In light of the positive biological effects of existing restrictions on marine life in coastal waters, further legislation may be expected. In fact, there may be a worldwide ban on use of TBT antifoulings within 5-10 years.


Consequently, TBT-free antifouling paints and biocide-free products known as non-stick, low surface energy, or foul release coatings^{3,4,5,6} have been developed.

TBT-free Antifoulings

TBT-free erodible/ablative antifoulings, also known as controlled depletion polymer antifoulings,⁵ are based on a seawater-soluble binder (e.g., rosin) combined with insoluble polymers that control the dissolution of the soluble binder. In seawater, the biocide dissolves with the soluble binder, and the ingredients controlling dissolution are washed away.⁷ The main biocide is cuprous oxide, which often is combined with one or more "boosting biocides" for better efficiency.

TBT-free products do not erode as ideally as TBT self-polishing antifoulings. They produce an empty matrix, which affects their long-term performance. The matrix should be removed before applying subsequent paint layers. Also, high copper contents are essential.⁸

Recently developed TBT-free self-



polishing antifouling contain hydrolysing polymers. In addition, they are rosin-free, which means they have better stability to ultraviolet light. This property is especially important for boottops. These products generally are based on copper acrylates combined with boosting biocides. Zinc acrylates also are used. The polymers react with seawater, similar to TBT self-polishing copolymers, and the paint polishes away with a controlled release of biocide.^{4,5,6}

Because of their relatively fast polishing rates, the maximum in-service period of TBT-free systems is about three years, although one supplier says it produces a self-polishing tin-free product as good as TBT self-polishing types.⁵

Overall, however, it generally is agreed that for large, fast vessels, which are particularly sensitive to increases in fuel consumption, TBT self-polishing systems are still indispensable because of the savings in fuel, the reductions in maintenance, and the extended dry-docking intervals that they offer.

Biocide-free Antifouling

Non-stick, low surface energy, or fouling release coatings are biocide-free. The most promising types are silicone elastomers based on polydimethylsiloxane. Coatings based on fluorinated epoxy and polyurethane materials are found to be less effective.

Non-stick coatings provide a smooth, non-polar, low-energy surface to which the fouling species cannot easily stick or from which it is easily removed by water movement when the ship is sailing or by mechanical cleaning.^{3,4,5,6}

Disadvantages include the risk of

silicone contamination (leading to cratering/pinholes in nearby drying paint layers that may be accidentally contaminated by overspray of the non-stick coating), poor resistance to mechanical damage, poor adhesion to conventional coatings, and high cost. Practical use of self-cleaning, non-stick antifouling up to now has been limited to very fast vessels such as some naval ships and ferries.

With respect to the further development of environmentally compatible antifouling, research is underway to produce coatings based on natural compounds with antifouling properties developed from marine organisms.

Ballast Tanks

Coating systems for ballast tanks should be resistant to (polluted) seawater, corrosion inhibiting, free from pores, and resistant to the side effects of cathodic protection.

According to the classification societies, the life-determining factor for a ship is the condition of its ballast tanks. Serious corrosion damage in them is a main reason for taking a ship out of service, and a ship's second-hand price is largely determined by the condition of its ballast tanks.

The inner water ballast tank area of a ship is extremely large. For a single-hull very large crude carrier (VLCC), the water ballast tank area might be 140,000-160,000 m²; for a modern double-hull design, it could be 240,000-280,000 m² or even larger.^{9,10}

Double-hull design prevents oil leakage into the sea in case of damage to a ship's hull. Because of the difficulty of recoating complex steelwork in modern double-hull


ships and the deletion by classification societies of the allowance for reduced scantlings for new vessels, optimum long-life protection is vital.

Regulations from the U.S. government, the classification societies, and the International Maritime Organisation since 1990 have had a clear and positive effect on the structural protection of ships.^{9,10,11,12} They deal with the duty to coat ballast tanks (with light-coloured, hard coatings combined with cathodic protection), the minimum width of double hulls, the height of double-bottom tanks, the deletion of the allowance for reduced scantlings when tanks are coated with an approved system, and a harmonised system of survey and certification from the classification societies.

An additional international regulation likely to come into force in 1999 would require steelwork in ballast tanks to be designed to minimise awkward-to-coat surfaces, to give easy access for personnel and equipment, and to facilitate cleaning and drying the tanks.¹²

In ballast tanks, pitting corrosion can occur easily because of coating irregularities, mechanical damage, and poorly coated areas. Pitting corrosion is often promoted by the presence of a more noble material than steel and by one or more stainless steel bulkheads from adjacent cargo tanks. To prevent pitting corrosion, sacrificial anodes are sometimes installed in addition to the coating system.

Ballast tank coatings may be applied over the shop primer, which should be cleaned thoroughly first, although it is far better to



remove the shop primer by blasting, especially when the primed surfaces are in a poor condition.

To avoid osmotic blistering, the soluble salt (Cl^-) content on the surface should be very low. A maximum concentration of 20 mg/m^2 before coating application is generally acceptable.

Ballast tank coatings should provide very good edge coverage. This reduces the need to round the edges inside the tanks. However, the stripe coating of sharp edges and irregular or rough welds is good standard painting practice before spray application of each coat.

Most ballast tank coating systems provide barrier protection against corrosion. Consequently, they should have very low water vapour permeability. Some products are reinforced with micaceous iron oxide or similar pigments to reduce moisture and oxygen penetration.

The water vapour transmission rate of coatings is given by their μ -value (the ratio of water vapour transport through a layer of air to that through a coating at the same thickness). For a good water ballast tank coating system, the μ -value \times the DFT (μm) should be at least 25 m.¹³ Therefore, an epoxy coal tar coating with a μ -value of 100,000 requires a DFT of $250 \mu\text{m}$. Since tar-free coatings generally have lower μ -values, they should be applied at higher DFTs. For optimal corrosion protection, a ballast tank coating also should offer long-lasting adhesion under wet conditions.

Conventional coating systems for ballast tanks, such as bituminous coatings and solvent-free bituminous compositions that should be heated before application, are seldom used anymore.

Modern systems for ballast tanks usually consist of at least two coats of high-solids coal tar epoxy, straight epoxy, or modified epoxy with a total DFT of at least $250 \mu\text{m}$. Because of the decreasing popularity of coal tar, modified epoxy often is used, preferably in light colours to enhance the ease of inspection.

Solvent-free epoxies are also used in ballast tanks. They are applied in one or two layers with a minimum DFT of $300\text{--}350 \mu\text{m}$. (A one-layer coating should be used in conjunction with cathodic protection.) Besides being environmentally friendly, they present no risk of explosion or fire. A disadvantage of solvent-free epoxies is their very short pot life.

Other systems sometimes specified for ballast tanks include high-solids vinyl tar, water-borne asphaltic emulsion, and acrylic-reinforced cementitious coatings. For high-temperature bulkheads or places sensitive to mechanical damage, water-borne or solvent-borne zinc silicate coatings also are prescribed sometimes. For maintenance purposes, epoxy mastics suitable for hydrojetted or mechanically pretreated surfaces are used more and more.

Soft coatings based on petroleum derivatives containing sulphonates or wool grease containing penetrating additives also are used sometimes. Both types contain water repellents.¹⁴ They can be applied to marginally prepared surfaces, but they should be reapplied frequently. Special attention should be paid to the risk of water pollution in harbours when soft coatings are used in ballast tanks. Soft coatings remain soft after application and wear away under low mechanical

impact. Marine coating regulations favour hard coatings, which offer properties opposite those of soft coatings, particularly in light colours as an aid for inspection.

Det Norske Veritas guidelines¹¹ for ballast tank coatings include three categories: epoxy-based (light-coloured); epoxy coal tar (no longer recommended due to their dark colour); and other recognised coating systems. The guidelines also include three specification levels requiring increasing degrees of surface preparation:

- Specification I: 5 ± 3 years useful life and 1 coat of $200 \mu\text{m}$ DFT;
- Specification II: 10 ± 3 years useful life and $2 \times 200 \mu\text{m}$ DFT; and
- Specification III: 15 ± 3 years useful life and $2 \times 200 \mu\text{m}$ or $3 \times 130 \mu\text{m}$ DFT.

Cargo Tanks

Coating systems for cargo tank interiors should resist the following: cargo to be transported and substances the cargo might release; tank cleaning procedures; and cross-contamination between different cargoes and also ballast water. These coatings also should be corrosion-inhibiting, free from pores, and easy to clean. Finally, they must not contaminate or affect the colour or taste of the cargo, particularly cargoes intended for human consumption and pure chemical cargoes (which require coatings systems approved by the appropriate regulatory agency).

CLEANING/COMPATIBILITY

It is often necessary to clean or ventilate cargo tanks when changing cargoes in order to prevent undesired interactions between

cargo residues and the next cargo. Such interactions can form substances that may attack the coating system, promote steel corrosion, and contaminate or discolour the next cargo.

For example, when residues of a vinyl acetate monomer cargo are still present in the lining of a tank filled with a water-containing cargo, these residues will hydrolyse and form acetic acid. This reaction will cause corrosion and may attack the coating. Likewise, cargo containing ethylene dichloride can form hydrochloric acid upon contact with water or water-containing cargo. To avoid such interactions, all esters and chlorinated hydrocarbons must be transported in dry cargo tanks.¹⁵

Methanol cargoes can be especially problematic. Besides having a softening effect on organic coatings, methanol residues in a coating can promote water vapour permeability, causing osmosis and corrosion of the steel substrate. In addition, methanol can extract residual solvent and low molecular weight materials from the coating. This induces stresses in the coating that can lead to cracking. Only highly crosslinked coatings are resistant to methanol. Most coatings suppliers do not allow transportation of water-containing cargoes after transportation of methanol.

Commodity lists from coating manufacturers commonly indicate which cargoes may be transported in tanks coated with their systems and under what conditions (e.g., cargo temperatures, transport times,

and types of subsequent cargoes). Guidelines for tank cleaning procedures when changing cargo should be followed carefully to ensure that cargo residues are sufficiently removed before loading a new cargo or ballasting.¹⁶

Organic tank lining systems can absorb materials from cargoes, and the amounts after different time periods are not well defined. Variable and unpredictable absorp-



Ballast tank protection is critical to a ship's service life. This coating is being applied to the fore peak tank.

tion/desorption characteristics are found not only among different coating types but also within the same generic type of coating from different manufacturers. In addition, different rates of absorption/desorption are found among different cargoes.¹⁷ This can make it difficult to select the correct cargo tank coating system.

VARIOUS APPLICATIONS

Crude oil tanks of VLCCs often are left uncoated (apart from shop priming), or only the bottom area (on which acidic water settles) and the deckhead area (on which water condenses) are coated. A cathodic protection system also is often installed.

However, crude oil tanks of smaller tankers are usually completely coated with a system consisting of two coats of polyamine- or polyamide-cured coal tar/epoxy with a total DFT of at least 250 μm . Modern systems are based on high-solids products. Also, one-coat systems of solvent-free epoxy (after stripe coating) are possible. The DFT should be at least 300 μm .

For clean petroleum products (e.g., white oils, aliphatic hydrocarbons, etc.), systems for crude oil tanks are used except for products containing coal tar.

For more aggressive products (e.g., chemicals, vegetable and animal oils, and aromatic hydrocarbons), the system often consists of two coats of (high-build) polyamine (adduct)-cured epoxy with a DFT of at least 250 μm . Polyurethane and isocyanate-curing epoxy systems are available but not

commonly used now because of the trend toward isocyanate-free coatings. Shop primer usually is removed from these tanks by blasting to at least Sa 2½ for good adhesion and to avoid undesired interaction of the cargo with the shop primer.

When the highest chemical resistance is required (e.g., for cargoes with high acid values), three-layer systems based on phenolic epoxy are used with a total DFT of 300 μm .

One-layer zinc silicate systems (either solvent-borne, moisture-curing zinc-rich ethyl silicate or water-borne, self-curing zinc-rich alkali silicate) with a DFT of 75-100 μm are used for tanks carrying very

aggressive solvents such as esters and ketones. There are pH restrictions for zinc silicate coatings, because acidic or alkaline cargoes will affect the tank linings.

For the highest chemical resistance, environmentally friendly cargo tank coatings with reduced VOC levels have been unavailable until now. One of the latest developments, based on cyclosilicone epoxy resins, is said to offer significant advantages in terms of cargo range, cargo handling, and tank-cleaning operations, especially for light chemical tankers.¹⁵ Since 1993, it has been applied to about 30 tankers, mainly for the methanol trade. For full chemical resistance, heat curing at 80 C with hot air or steam is necessary.

COATING OTHER SHIP PARTS

For other parts of a ship, the same anticorrosive coatings described for the outer hull are applied, perhaps with some reduction in film thickness. For convenience and efficiency, it is advantageous to keep the number of specified products as low as possible.

Topside and Superstructure

For the topside and superstructure, an aesthetic topcoat of aliphatic polyurethane or aliphatic polyurethane/acrylic may be used. Isocyanate-free alternatives include epoxy/acrylic or other modified epoxy coatings, although they generally have reduced gloss and colour retention compared to polyurethanes. Polysiloxane epoxy hybrid coatings also can be used as aesthetic topcoats.

A special antirust-stain finish may

be applied to the topside and superstructures. This finish contains an active pigment that chemically combines with rust to produce a colourless, water-soluble material. As a result, rust stains are not visible.

Although not often mentioned in painting specifications, water-borne coatings based on alkali zinc silicate, styrene acrylate dispersion, or epoxy or alkyd emulsion are suit-



A light-coloured coating, such as on this fresh water tank, is an aid to effective inspection.

able for the topside and superstructure. However, their use generally is limited to the mid- and topcoat layers. Suitable products include acrylic dispersions and epoxy acrylic or (silicone) alkyd emulsions. However, their gloss levels are usually lower than those of solvent-borne paints.

Water-borne systems can be successfully applied, especially for ships built completely under cover. However, this requires at least moderate temperature and humidity levels and strict planning. Also, painters experienced in applying water-borne paints are needed.

Decks

Paint systems for decks should be very resistant to corrosion and the influences of weather. They should be non-slip (even when the decks

are wet) and resistant to impact, scratching, and abrasion, as well as resistant to (sea) water, fuel oils, lubricating greases, cleaning agents, and cargo spills.

To minimise damage that may occur to a deck coating before delivery, the best procedure may be to apply a recoatable epoxy holding primer during construction and the final coating system as soon as possible before delivery.

The most common deck coating systems are two-component epoxies, polyurethanes, and zinc silicates with a DFT of 250-300 µm for epoxy/polyurethane systems and 75-100 µm for zinc silicates.

Epoxy/polyurethane systems often consist of a primer, a thick midcoat, and an easily recoatable topcoat, preferably all high-solid products. The topcoat can be made anti-skid by adding an aggregate such as non-sparking silica, pumice powder, or aluminium oxide.

For zinc silicate, the deck surfaces should be blast cleaned to Sa 2½ (or sweep blasted when an intact silicate shop primer is present) directly before coating application. Due to their limited resistance to acids and alkalis, zinc silicates should not be used on the decks of chemical tankers.

Special, heavy-duty systems based on thick, solvent-free elastomeric coatings applied by trowel or roller over a thin primer to a DFT of 1-3 mm also are available. In addition, water-borne systems consisting of an alkali zinc silicate primer and an epoxy emulsion mid- and topcoat can be considered for decks.

SUMMARY

As a result of regulatory pressures, developments in coating systems for ships in recent years have emphasised reduced VOC levels. Traditional high-VOC coatings such as those based on vinyl resins and chlorinated rubber have gradually been replaced by chemical-curing, two-component coating systems.

However, use of low-VOC coatings gives rise to specific problems, such as a reduction in substrate wetting, which can reduce adhesion, corrosion resistance, chemical resistance, and mechanical properties. Other difficulties include shorter pot life times, longer drying times, more difficult film thickness control, and sometimes the need for special application equipment. These disadvantages play a smaller role with paints containing some solvent rather than no solvent at all, which explains the popularity of high-solids products.

Further development is needed, however, for solvent-free epoxy underwater hull coatings and high-solids/solvent-free cargo tank coatings with high chemical resistance.

Water-borne coatings have played a limited role in marine applications, probably because of their sensitivity to humidity and low temperatures during application and curing. Also, apart from alkali zinc silicate, most water-borne coatings remain more or less water sensitive even after full curing, which makes them less suitable for immersion service.

Much work has been done in Europe and countries throughout the world to substitute hazardous coating materials such as coal tar, aromatic amine and isocyanate hardeners, certain plasticizers, lead

and chrome-containing pigments, and asbestos. This work will go on.

At the same time, new materials such as epoxy siloxane hybrid coatings have begun to find their way into the marine painting field. Also, high-performance, surface-tolerant mastics have been developed that perform well on less than ideally prepared substrates. Further developments are expected in this area as well as in the improved performance of tin-free antifouling and other ways to combat fouling, such as the use of low surface energy or anti-stick coatings.

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