PRESERVATION OF SHIPS' STRUCTURE

WHAT IS THE FUTURE?

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Synopsis

The three major factors governing success or failure of protective systems applied to ships' structure are the quality of the surface preparation, the choice of a suitable painting scheme for the environment and intelligent painting procedures. The progress and pattern of current ships' painting and preservation to meet these conditions are discussed and the importance of designing ships' structure, equipment and fittings to resist corrosion is emphasized.

A review of the paint systems applied to ship's bottoms, weatherwork, decks, interior spaces and tanks, traces the development from simple oil paints and tar to synthetic-based paints, catalyst-cured coatings, specially formulated outer bottom compositions and sprayed metal coatings.

The adoption of the surface preparation of steel plates by shot-blasting methods in conjunction with new preservation materials and the concept of ensuring adequate total dry film thickness of surface coatings are shown to have effected improved performance. At the same time there is scope for the utilization of new alloys, fibre reinforced plastic resin, plastic coatings and improved methods of fabrication and fitting.

The increased use of epoxy paints, sometimes in conjunction with metal spraying, shows good preservation potential but personnel concerned with their application are warned that because of the new characteristics of these latest processes, use of the old methods of cleaning and applying could be detrimental.

The expanded employment of epoxy type paints is advocated, as is the increased use of equipment such as the catalyst spray gun, airless spray techniques and flame spraying processes and it is noted that further developments in preservation techniques carried out under water are proceeding.

The hazards associated with the use of flammable materials are pointed out and the need is stressed for an efficient painting plan with proper controls and integrated into the planned refit of a ship.

The immediate future of ships' preservation is closely allied to how far sprayed metallic coatings or plastics will replace the present coating systems and doubts are expressed whether the present fairly sophisticated paints can be further improved to be successfully and economically applied under the present conditions and with the type of labour available.

There is some evidence that a revolutionary change to materials of the fibre reinforced plastic type for ships' construction is imminent and the opportunity now presents itself for naval technologists to point the way to outside industry.

Introduction

The utilization of paint for ships' decoration and preservation can be traced far back into history. Since the days of the Phoenician traders, seafarers have coated their wooden ships with pitch, wax, arsenic, sulphur, seal fat, animal hair and other unusual coatings in attempts to discourage the ravages of teredo and the undesirable attachment of marine growth. A recent report in the Press (*Daily Telegraph*, March, 1970) revealed that sponge divers had discovered the wreck of 'The Kyrenia Ship' lost on a trip from Rhodes to Kyrenia in Cyprus in the year 320 B.C. Scientists are laboriously reconstructing the ship itself and it has been established that the vessel, as big as the caiques which still sail the same seas, was sheathed in lead to protect it from marine life.

Later on in history we read that Blue Town, in the immediate vicinity of the Royal Dockyard at Sheerness, derived its name from the colour of the paint then applied to the wooden vessels and hulks berthed at this location. In 1720 the *Royal William* was built for the Admiralty completely from charred wood in an attempt to foil fouling.

The problem of fouling on ships has always been present. Teredo, the destructive ship worm, bored its way into the timber of wooden craft. Copper sheathing over the wood hull was effective against teredo, but dry rot caused further trouble. It was noticed that the copper sheath not only prevented the teredo from boring into the hull, but also reduced fouling by other organisms, this fact indicating the possibility of using copper compounds for antifouling purposes.

In 1860, the first practical antifouling paint appeared, in which the toxic ingredient was copper sulphate. From 1880 onwards the introduction of wrought iron and steel brought the new problem of corrosion to be countered in addition to fouling. The problem of corrosion was later accentuated by the use of electricity in ships, the change from coal to oil-fired boilers and the constant demand for higher speeds and longer periods between dockings.

The use of aluminium, copper and their alloys gave rise to the problem of electrochemical action which manifests itself as corrosion when dissimilar metals are in contact in the presence of moisture.

There has been some progress in the research on marine finishes since the close of the last century and there was fresh impetus during the last war. The

Marine Corrosion Sub-Committee of the Iron and Steel Institute published many reports on the subject. Latterly, Ministry of Defence, Ship Department, have produced many detailed preservation and painting specifications covering the coating systems and processes necessary to meet the Service requirements for preservation of the various components and divers areas of H.M. ships. Structural research for the Navy has been carried out mainly at the Naval Construction Research Establishment to formulate codes for new materials such as fibre reinforced plastics.

There has been rapid development in techniques and materials over the last decade. In view of these developments and at this point in time the following questions can be asked. How far and how soon will sprayed metallic coatings and plastics replace the present paints? Can the present specified paints and processes be further effectively improved to be satisfactorily applied in ships with the type of labour available and under the conditions and environment met at the ship? Will ships be constructed of non-corrosive materials and if so how will the standard of appearance normally accepted by the Royal Navy be maintained?

These questions can best be answered by reviewing the path to the present position, at the same time indicating the problems that require to be resolved, and then attempting to assess the likely direction future developments may take.

Types of Paint and Conditions of Service

The conditions of service of marine paints and the surfaces to which they are applied vary enormously. Widely different types of paint are used on the various areas of a naval vessel and no single finish can be satisfactory under all conditions. In general ships' paints must be a compromise between the ideal paint which gives very excellent durability and the practical paint which can be applied under very exacting conditions and will give a very useful degree of service.

The conditions to which the painted surfaces are subjected can include constant sea-water immersion, changes of temperature from tropical heat to arctic cold and wear caused by high speeds and high seas. In addition, many surfaces have to withstand mechanical bombardment as in the case of flight decks of aircraft carriers. Due consideration must also be given to the effects of chemical warfare and radiation fall-out. The post-war frigates have been designed to operate at sustained speeds in adverse weather.

Factors for Successful Painting

However good the paint system, it will fail to protect for any length of time if the surface on which it is superimposed has been poorly prepared.

Three factors are essential for the applied paint system to give a successful performance, namely, correct surface preparation, the choice of the most suitable paint system and good painting procedures.

Good paint procedure involves the application of the paint system at the appropriate time under good conditions and at adequate film thickness. The quality of the materials and proper supervision of the standard of workmanship also plays an important part.

Importance of Design

Designers should plan a ship to resist corrosion. Provision of good means of access for maintenance personnel is essential, avoiding complexity and small enclosures.

Simplicity in design of structure should be the keynote. Curves are more easily maintained than sharp angles and water lodgements should not occur. Contact of dissimilar metals should be avoided and special high duty paints should be specified for protection against corrosive fluids and for application in less accessible compartments.

In machinery space bilges, sullage and drain tanks should be provided in order to avoid the use of bilges as an open drainage system. Metal sprayed coatings should be specified, where advantageous, in situations of great complexity. The possibility of dealing with rusting offered by a change of materials should be exploited. An example of this, presently used, is the glass reinforced plastic casing for submarines.

Development in Ships Paints

The development of paint for naval vessels can be broadly classified as follows:—

(*i*) Up to 1880: Wooden ships. Simple oil paints for decoration above water — tar and copper sheathing below water.

(*ii*) 1880 to 1939: Iron and steel ships. Red lead, white lead, zinc oxide, etc., in linseed oil. Proprietary anti-corrosive and antifouling paints applied to outer bottoms. This was the era when most paints were mixed to patternized formulae within paint mixing shops at each Royal Dockyard.

(*iii*) 1939 to 1958: Titanium dioxide, etc., in oil modified synthetic resins (alkyds, phenolics, etc.) Admar and Pocoptic underwater.

(*iv*) 1958 to date: Abrasive blasting adopted as necessary surface preparation of steel plates in conjunction with shop primers. Improved modified alkyd resin paints for general protection. Increasing use of sprayed metal coatings in association with new high duty paint systems (e.g., catalyst-cured epoxies). Plasticized coatings for ships fittings. Main underwater protection ACC 655, coal tar epoxy and aluminium bitumen. Antifouling paints CDL formulation 161P and CDL formulation 317/62 (non-mercurous version of 94 MM as used on submarines). Increasing use of cathodic protection systems with resultant choice of more compatible paint systems (e.g., coal tar epoxy). Paint mixing within Royal Dockyards ceased and paints supplied under contract to Ministry of Defence (Navy) specification. Changes in application techniques with emphasis of an adequate film thickness of protective coatings. Increasing use of equipment such as the airless spray machines.

Surface Preparation and Film Thickness

The choice of method for preparing a steel structure for painting is influenced by many factors including its importance, the environment, the surface condition, the type of paint system to be applied, the ease of accessibility for future maintenance and the true cost of the surface preparation. A broad distinction can be drawn between relatively inefficient methods such as hand cleaning, power tool cleaning and flame cleaning that leaves surfaces carrying millscale and/or rust and superior methods such as blast cleaning and pickling that yield clean surfaces free from millscale and rust.

Surfaces that are grossly soiled with oil, grease and other materials should first be cleaned with white spirit, naphtha, steam or other means.

The runs of welds and the adjacent steel surfaces need special attention, because welding slag and spatter impair paint adhesion, and if they are alkaline may destroy the paint itself by saponifying the binder. These areas should be washed down with clean fresh water and thoroughly cleaned by hand or blast cleaning, and the prefabrication primer made good or the priming coat of the final paint scheme applied.

Shot-blasting methods have now been introduced into all dockyards, automated shot-blasting plants for steel plating before being worked at the ship and vacuum type shot-blasting equipment for work at the ship. The previous method of pickling plates either in dilute sulphuric or hydrochloric acid solution has been superseded.

The desire to take advantage of the improved modern coating materials has hastened the progress of shot-blasting procedures.

As a rule, the efficiency of a protective coating system increases with its thickness. Protective paints should never be chosen solely on the basis of their spreading power and it is most desirable to control and check the thickness of paint applied.

The introduction of improved preparation techniques and the different types of paint make it most important to specify the overall thickness of paint coatings required instead of the number of coats, as hitherto.

Improved Constructional Methods

Having reviewed the problems and position to date concerning ship preservation particularly in respect of design, surface preparation, painting procedures and noting the transition to the new high duty paints and specially formulated outer bottom compositions, we have now reached a point where an assessment can be given of the future of the currently approved ship preservation systems. At the same time it is possible to suggest improvements in the protection of surfaces against corrosion and fouling under marine conditions.

The improvement of methods of protection, particularly against corrosion, does not depend entirely on the development of new types of surface coatings. There is considerable scope for the use of new alloys, glass reinforced plastic resin and other plastic coatings, and for improved methods of fabrication. For example where welding is used for fabrication, problems can be avoided by the control of such factors as choice of materials and welding procedures and attention to welding design.

A major difficulty is caused by localized electro-chemical erosion at small anodic points, usually gaps in the protective system at which the composition or physical characteristics of the metal surface vary sufficiently to give rise to potential differences. Any improvement in constructional techniques which reduce the defects in the protective system or increase the homogeneity of the metal will aid the protection of the hull.

The problem of stray electric currents at the fitting out berths,which accelerate corrosion at gaps in the paint film, should be closely watched.

Effort should be made to minimize the damage caused during the launch of a vessel. Launching cradles, drag chains and similar gear can often be prevented from damaging the hull by careful adjustments in the launching technique.

Electrolytic corrosion caused by the bronze propeller of a vessel is an instance of corrosion involving two dissimilar metals in an electrolyte (sea water). The effects of using the same metal in varying conditions of stress or strain (applied or internal) can be contributory to corrosion.

Internal stresses caused by irregularities in the crystalline structure of the metal can themselves induce corrosion. Lamination of hull plating can also present a corrosion problem.

Closely allied to the problem caused by internal stresses in metal are the problems that might result from faulty design. Corrosion fatigue due to external stresses in the construction of the hull and crevice corrosion due to different aeration at inaccessible points or crevices between plates are important factors in marine corrosion.

Fresh thinking is required concerning the corrosion problem caused by the welding of innumerable lugs and brackets to plating for the fixing of pipes, carrier plating, trunking and fittings. A suggestion some time ago was that a basic assembly bar would be welded to the back of each stiffener bar. Attachment of fittings and equipment would then be by special fasteners.

A more logical approach to structural design must be made, bearing in mind the complexity of modern warships, space availability, high ambient temperatures and humidity and other considerations. One main aim during design should be to avoid water traps where stagnant water pools would collect. Where crevices cannot be avoided they should be sealed by welding or filled, e.g., with mastic. If lap joints have to be used they should be sealed by welding or filling. The design should allow for circulation of air to reduce condensation.

Another main aim of the designer should be to make the painters' task as simple as possible, both initially and when repainting is required. Sharp edges and other features that prevent the application of an adequately thick, uniform film are undesirable. The design should permit easy access to all parts for painting and if necessary special fittings should be provided to facilitate maintenance painting. Seams, and similar situations which are difficult to penetrate or seal with paint, should be avoided.

Scantlings in most modern warships are very light and the 'ribbed' distortion caused by welding causes a problem of appearance of vertical surfaces (gloss paints accentuate the defect) and of rust streaking from decks where distortion aggravates the drainage problem. Any improvement in welding techniques in solving this problem would be a major step forward in the fight against rust staining and corrosion.

Protective Metal Coatings

A special case of dissimilar metals in contact occurs when a metal is used as a protective coating on another metal. With a properly prepared coating the exposed surface consists of one metal only and the conditions for electro-chemical action do not arise. However, should the base metals be exposed because the outer metal is discontinuous, electro-chemical corrosion can take place. If the outer metal is anodic to the base metal, as in the case of a zinc coating on steel, corrosion will result in the dissolution of the zinc coating and the steel base will be protected by the sacrificial action of the zinc. Under static conditions in home waters a zinc coating weighing 3 oz per sq ft of surface (5 mls. thick) should protect mild steel for five years.

Suitably chosen metal coatings are an excellent basis for paints. Deposition of the metal is performed at the ship by the flame spraying method. Metal coatings minimize discolouration of the paint film by rust staining and increase durability by eliminating disruptive effects of corrosion products. They are also less susceptible to damage by impact or abrasion than paint films.

There is some evidence that aluminimum sprayed metal coatings are to be preferred on structure exposed to marine conditions.

Much greater use is being made of combined protection schemes consisting of metal coatings with high duty coatings superimposed. It is now accepted practice to use these combined schemes on extensive areas of H.M. ships, e.g., in machinery space bilges and on weatherdecks.

The use of chlorinated rubber paint system over zinc sprayed surfaces has been specified for some time in the machinery space bilges of H.M. ships.

The indications are that use of metal coatings in association with high duty compositions will be extended.

The process specification for the preservation of weatherdecks (DG Ships 68 November, 1967) amplifies the full preparation treatment and subsequent preservation coatings of steel and aluminium alloy weatherdecks. For steel weatherdecks a sprayed metal coating is deposited after abrasive blasting. Where it is intended to apply an epoxy finishing paint the specification for the full metal coating consists of a zinc coating evenly applied by spray to give a deposit thickness of between 0·001 and 0·002 in. Before the surface becomes contaminated, and certainly within 2 hours, this should be followed by a coat of aluminium evenly applied by spray to give an overall metal sprayed coating of between 0·005 and 0·006 in. total thickness.

It is safer to apply a pretreatment primer over the metal coating rather than superimpose the paint system direct in order to eliminate the risk of any harmful reaction between the paint and the coating metal

It is just as important to maintain paint in good condition on a steel structure that has received a metal coating as on one that has not, because, by retaining moisture, a broken down paint film stimulates corrosion of the metal coating beneath it.

It is therefore important that the metal sprayed/paint coatings should be protected from indiscriminate damage. During building and when installing machinery the preservation surfaces should be adequately protected at all times by the use of polythene sheeting, hardboard or similar material. Proper painting control and procedures should be exercised.

A problem arises when it becomes necessary to remove paint from metal coated surfaces. The use of chipping hammers and other mechanical implements likely to damage the surface of the metals is precluded and paint remover is the only answer. This can be a costly and time consuming operation.

The selected areas which are metal coated are required to be identified in the Ship's Book but it is also recommended that a special note be inserted in the D.171 Survey of Compartments. It is apparent that unless the dockyard and ships staff are educated in the matter and exercise a modicum of care, misguided treatment of these special areas will occur as the employment of this particular preservation system is extended. Documentation within the appropriate Dockyard Trade Office, similar to that normally carried out for recording areas of a vessel that have been shot-blasted should be implemented.

Epoxy Paints

Development in the use of epoxy resins in surface coating application goes back to 1947. Large scale quantities became available for the first time in 1949 in the USA and in 1953 in Europe. Epoxy paints include the solvent free types, cold cured solvent type and coal tar epoxy. The use of epoxy paints has considerably increased over recent years. For naval vessels this type of coating has been specified for surface applications on many areas.

Shop primers of the epoxy type are specified on shot-blasted surfaces and the type are applied as Tanclene to Diesel-oil (water compensated) tanks and aluminium alloy weatherdecks. Similarly, epoxy type Epinamel is used in aviation fuel tanks and red lead epoxy primer is specified for helicopter landing decks and flight decks.

The solvent free type coating (Araldite) has good resistance to cavitation erosion and is specified for application to combat the corrosion problem on main inlets and discharges, rudders, hydroplanes, stabilizer fins and stems of vessels. It is also used in the vicinity of anodes fitted to the outer bottom of nuclear submarines and on boot-top areas. No primer or corrosion inhibitor is applied, and protection is effected by ensuring adhesion of a relatively thick film almost completely impermeable to water.

Coal tar epoxy coatings are applied to the outer bottom of cathodically protected ships. Epoxy coal tar coatings are a blend of coal tar and epoxy resins, with the complementary curing agent. It was considered that by blending with coal tar the good water-resisting properties would be improved. Coal tar when used in a protective coating suffers from bleeding on recoating with other paints, thermoplasticity and poor solvent resistance. By interlocking the coal tar within the epoxy system, these detracting properties of the coal tar are reduced to a minimum. Such dilution of the epoxy coating with a cheaper compound has the additional advantage of reducing cost.

Exterior Weathering of Epoxy Coatings

Amine-cured, polyamide cured and epoxy esters on exposure to natural weathering will gradually lose their gloss and commence chalking markedly sooner than a good alkyd enamel paint. The chalking is entirely a surface effect. Furthermore, the lower decorative value due to loss of gloss is relatively immaterial where epoxy coatings give long lasting protection against the corrosion environment, in which a better gloss retentive conventional paint would break down. In some instances, such as whites, the self-cleaning characteristic due to chalking is an advantage. Although epoxy enamel commences chalking sooner than an alkyd enamel, once chalking of the latter commences it proceeds at a markedly faster rate, particularly when exposed to marine environment. The chalking rate of epoxies is in fact very slow, with a sound adherent protective coating under the film of superficial chalking. Gradual weathering is, of course, far preferable to weathering by chalking or cracking of the film.

From the foregoing it is evident that epoxy coatings could be further exploited for the external painting and certain interior painting of naval vessels.

The advantage of using epoxies for internal tank lining, whereby the structure is protected and contamination of the liquid stored is prevented, seems obvious. The present laborious method of coating fresh water storage tanks with hot bituminous 'enamel' gives good performance but with the contraction of the experienced labour force available, the tendency towards an increased accident rate coupled with increased overall cost appears to call for re-examination for a more easily applied composition such as a high build epoxy coating.

Curing Reaction of Epoxy Paints

The minimum practical temperature for the curing action between the epoxy resin component and amine or polyamide activator (or curing agent) is 10 degrees C. This implies also reasonable maintenance of temperature during application, evaporation of the solvents and subsequent chemical reaction that continues in the film between the epoxy and amine groups — that is the so-called cure.

Efforts should be more vigorously exerted to create the proper environment for the application of epoxy paints. Indeed, the whole question of temperature limitations for the painting throughout of ships needs to be reviewed.

The use of suitable portable space heaters (such as the Khamsin or Bacho type) supplying properly arranged warm ducted air and, if necessary, backed up by suitable black heaters will go a long way to rectifying the difficulties that surround the successful application of ships paints during cold weather conditions. For external painting heating should be in conjunction with polythene tenting or something similar.

Catalyst Spray Gun Equipment

The use of solvent free epoxies reduces labour costs involved in multi-coat application, avoids solvent hazards, simplifies ventilation problems in confined spaces, eliminates the risk of contamination between coats and economizes on staging where this is required.

The early solvent free coatings were rather thick, difficult to apply and of short pot life. Solvent free coatings are now available which are rather more easy to apply by brush and can even be sprayed.

Catalyst spray gun equipment is now available and the extended use of this equipment is advocated. Catalyst spraying is the process of spraying simultaneously a protective coating and a catalyst additive, where the two materials cannot be premixed because of incompatibility or where the materials have insufficient pot life to permit of application by conventional spraying equipment. A twin-headed spray gun is used so that the two materials are mixed in the spray pattern after they have left the gun and before they reach the surface. The gun has its head fitted with a standard atomizing and fluid nozzle but has another nozzle at the side of the head which feeds a controlled amount of catalyst into the atomized paint when the trigger is depressed.

Two pressure feed tanks are used, one for the basic material and the other for the catalyst. The pressures are regulated separately, and because the proportion of catalyst to material is critical the catalyst tank has two regulators to compensate for any fluctuation in the main air line pressure. In addition, there is a flow meter in the catalyst line so that once the correct rate of flow has been established it can be verified visually when required. The air cleaning and regulating gear used with the equipment is the standard pattern. The pressure feed tanks are similar to standard tanks except that corrosion resistant metals and coatings are used for those parts which come in contact with the fluids.

Water-Displacing Epoxy Coatings

One of the principal problems when using epoxy resins has been the creation of a sound bond on wet or damp surfaces.

Reformulation of the basic epoxy resins by a Swiss company now enables them to be applied under saturated conditions, and even under water, when the displacement property of the material produces an extremely strong bond. A range of wet adhesion coatings have been successfully applied in the recent past in some European countries.

A British organization has now developed a technique which enables the epoxides to be sprayed under water. The system utilizes the Volspray airless spray system giving a nozzle pressure of 4 000 lb/sq inch. Water is displaced ahead of the spray gun by a high volume compressed air flow producing an air envelope. A similar system is used for shot-blasting under water so that submerged steel work can be shot-blasted prior to spray application of the epoxide. The successful application of epoxide, especially those in the wet adhesion range is dependent upon skilled preparation and application.

Airless Spraying

Airless spraying consists of subjecting the fluid paint to an extremely high pressure and then forcing it through a tiny aperture with the result that the release of the paint causes it to explode into a cloud of very fine particles. Atomization of the paint is therefore due to pressurizing of the fluid and not to any action of the compressed air.

The airless method of spray painting is a rapidly developing new technique which provides for spraying a very wide spray pattern for fast coverage of large areas. Nearly all materials, light or heavy, can be sprayed in their original unthinned state, which saves the cost of thinners and mixing time. Paint can thus be applied with a high solid content to produce a heavy film or thick coating where required.

Airless spray is becoming increasingly important and is widely used, for example, in automatic plant for the application of prefabrication primers to steel plates and sections following the shot-blasting operation.

When used manually the operators have to move extremely quickly. There being little or no air in the stream there is negligible rebound of paint and comparatively little overspray.

Airless spray methods have been used to a degree for the coating of outer bottoms of naval vessels but their use could be further exploited. For outer bottoms the question of adequate and proper staging or portable platforms needs to be resolved in order to take every advantage of the speed of this method. Wider use of the equipment on other extensive areas of ships is advocated in order to make full use of this quick and labour-saving method.

One form of airless spraying which has been developed for the retail market is aerosol spraying. This system of spraying has obvious limitations but there is scope for its employment for shipwork in the application of paint removers and touch-up purposes particularly.

Coatings for Outer Bottoms

Marine fouling of a ship's outer bottom leads to loss of speed and increased fuel consumption. In war-time this could be the cause of losing a major naval battle. Fouling can contribute to hull corrosion by accelerating the breakdown of the protective coatings, can block inlets and discharges and impair the performance of sonic detection equipment by fouling the sound transmitting and receiving surfaces.

The cost for frequent recoating of outer bottoms of H.M. ships is substantial and there is much financial benefit to be derived from the elimination of intermediate dockings between refits.

If ships are to be fitted with cathodic protection, the outer bottom paints must withstand the alkaline conditions existing at a cathodically protected surface. For this reason we have seen the introduction of coal tar epoxy for use as an anti-corrosive coating.

Additionally there has been greater emphasis placed on adequate thickness of coating. For instance, the recommended minimum dry film thickness of coal tar epoxy is 0·009 in. measured over the peaks of the shot-blasted steel substrate.

For ships not cathodically protected A.C.C. 655 is applied to the outer bottom to a minimum dry film thickness of 0·006 in.

A.C.C. 655 and coal tar epoxy have proved to provide a good anti-corrosive surface for the application of antifouling paints. Admar protective is a maintenance anti-corrosive applied over leached antifouling coatings.

A good antifouling paint must be compatible with the anti-corrosive used. It must be capable of brush or spray application and it must resist mechanical abrasion and erosive action under conditions of high speed and rough weather. The toxin should be of suitable toxicity to marine organisms and should be released at a controlled rate to give the maximum active antifouling life.

Although the use of antifouling paint is the accepted method for H.M. ships some alternatives have been proposed. Two such methods are the ultrasonic anti-fouling system based on high frequency vibration and the 'Toxion' antifouling process based on a toxic dispersion system.

Formulation 161P antifouling with cuprous oxide as the toxin is generally used on the outer bottom of H.M. surface vessels in conjunction with the anti-corrosive mentioned. For extended periods between dockings an additional coat of antifouling is applied, periods of more than twelve months normally qualifying for the extra coat.

Black antifouling to formulation CDL/94/MM, containing mercurous chloride is specified for the outer bottom of nuclear submarines. The introduction of anti-fouling paints containing mercury introduces a serious hazard for painters and those who are concerned with removing paint or cutting plates which have been so painted. The material involves similar hazards to lead based paints and the precautions given in the Lead Paint Regulations are required to be observed. Arisings are required to be dumped at sea and care will need to be exercised to safeguard against a possible pollution problem.

Interior Paints

For spaces in H.M. ships such as messes and cabins the requirement is for a durable decorative finish. In addition, there is a requirement that the coating must be fire retardant.

Special fire resisting paints have been developed to counter the danger of the propogation of fire by means of the paint film on the far side of an overheated bulkhead.

Previously, interior spaces were painted with oil paints containing a fairly high percentage of linseed oil. This gives very pleasing smooth glossy finishes but such coatings constitute a grave fire risk. Much investigation has gone into producing a durable paint with good fire resistance. The result of this work was the production of a paint based on an alkyd resin medium and pigmented with titanium oxide and antimony oxide. Anatase titanium oxide is used in place of the rutile form because it gives a purer white.

Weatherwork Paint System

For the past two or three years trials have been carried out on certain frigates to assess the practicability of achieving a superior, high class weatherwork finish.

The hull and superstructure have been cleaned back to bare metal and coated with a full system of three coats of primer, one undercoat and one or two top coats. Fairing of hull imperfections has also been carried out using rivet filler.

Where correct painting procedure has been followed the life of the paint system will usually be determined by the local breakdown at rust raisers rather than a general overall failure.

The vulnerable areas which promote early breakdown of the paint scheme include nuts, bolts, sharp edges of brackets and those situations difficult of access.

All corrosion products and weld splatter should be carefully removed and an additional coat of the appropriate priming paint applied. Potential rust raisers should be faired with hard stopping or rivet filler, the stopping being applied over the priming paint.

The first phase of these trials has shown that repainting overall of the hull can be reduced from about every 2½ months to about every 9 months, and appearance can be maintained to an acceptable standard by regular washing of paintwork.

The non-setting red lead at present used in dockyards has long drying characteristics which renders it unsuitable when time is at a premium. Red lead graphite partially meets the requirements but there is need for the introduction of an exceedingly quick drying material or the use of a high build material.

Undercoat to DG Ships/5956 (formerly DNC/M/78) and top coat to DG Ships/5957 (formerly DNC/M/80) are currently specified for weatherwork painting and they show improved colour stability on the previous linseed oil modified paints. They are based on an alkyd media, a high linoleic acid content being specified, tobacco seed and soya bean being the only two oils allowed.

It is to be noted that the present structural paint film breakdown occurs on the hulls near the waterline. If extended intervals between painting are to be met, there is still a need for further investigation into alternative coatings (e.g. epoxies).

For maintenance and overall paintings by ships staff a single coat weatherwork paint remains a firm requirement.

In the case of submarines an elecrochemical corrosion problem arises because of the different materials used in the superstructure. Experimental work has shown that a system based on a pretreatment primer DEF 1408 followed by coating with a black oleo-resinous paint DGS 5952A is most suitable for general use in H.M. submarines. Maintenance is by cleaning down and the application of a further coat of black. The same oleo-resinous paint can be applied direct to GRP after lightly rubbing down with grade 'O' glass paper to remove traces of mould release agents and provide a better key for painting.

Weatherwork should not be painted in bad weather and special tenting and covers should be rigged and if necessary safe heating applied to dry the painted surfaces.

If the standards of surface preparation and necessary application conditions are to be achieved, in order that the paint technologists' successful work is to be justified, painting must take place under enclosed and controlled ambient conditions.

Slips and docks should be utilized with this in mind, the problem of the continued use of cranes being recognized.

The painting on the ship's side is best performed in dock having regard to the need for staging and tenting required. It is an unfortunate aspect of a ship's long refit that the long docking period is some considerable time before completion date, resulting in consequential damage to the newly painted surfaces by welding and other refit work before completion.

Petroleum Solvents

The development of refining and fractionating techniques in the petroleum industry has made possible the production of a wide spectrum of solvents of different boiling ranges, volatility, and solvents extending from essentially pure isoparaffins to pure aromatics.

The most important feature of isoparaffins is their low odour, and they form the basis of special grades of solvent used in interior paints.

Aromatics are found in petroleum solvents mainly in the form of alkyl benzenes. Aromatics form the major constituents of the various grades of high solvency distillates used in paints. Their odour is sharp and penetrating and they are often responsible for the lachrymatory effect often encountered during the evaporation of solvents from paint films. Alkyl benzenes are powerful narcotics, but not acute or chronic poisons.

Low flash point paints applied in ships form a serious fire and explosive risk. When high duty paints are applied to the internal surfaces of fuel tanks, for instance, there is the great risk from the presence of the paint and the release of residual solvent vapour into the air space.

This type of work involving flammable solvents requires to be properly planned and scheduled with the necessary attendant ventilation and fire precautions which are clearly laid down in the standing instructions.

Plastics for Boat Construction

The trend towards greater use of reinforced plastic resins, principally polyester, for boat construction continues. Exhibits at the 1970 International Boat Show reflected the growing switch from traditional materials to glass fibre in boat construction, 70 per cent being of this material.

After sailing single-handed non-stop round the world Robin Knox-Johnston's next venture was the two-handed Round Britain Sailing Race which took place in July, 1970. The boat he chose, in association with Lieutenant Leslie Williams, was the 71 ft *Ocean* 71, the world's largest glass fibre sailing yacht. In the near future glass reinforced plastics will replace other materials for hulls up to about 130 ft in length because such hulls are claimed to be more durable and easier to repair. With the cost of steel now substantially increasing, the cost of hulls from fibre glass compares very favourably.

So far as the Navy is concerned large scale sections of vessels have been constructed of plastic material and subjected to rigorous static and explosive tests.

34 ft GRP fast motor launches based on a Keith Newton hull design are progressively being introduced for duties with the Port Auxiliary Service and in large ships for transport.

The only painting generally required is coating the bottom with anti-fouling paint. Inorganic pigments of most polyester resins keep above-water sections of the boat looking trim.

Today many U.S. Navy and Coastguard boats made of plastics are fabricated from polyester resins which are inherently fire-resistant and self-extinguishing.

Another development is the hydroskimmer which cruises over the water on a cushion of air, and is made of fire resistant polyester resins reinforced with fibre glass. Hydroskimmers would have a variety of military applications such as in anti-submarine warfare and for amphibious assaults, logistics and utility operations.

The combination of wrappings of glass cloth with epoxide resins has been extended for use on warships for the protection of ship's propeller shafts and rudders from electrolytic corrosion and cavitation erosion.

Reinforced plastics can be made transluscent and are transparent to radio waves. Asdic domes are manufactured in resin/glass laminates.

Use has been made of Acrylic filament wound piping of large diameter for the de-ballasting system in Assault Ships.

Plastic Coatings

Since the early 1940's plastic protective coatings have been available for the application to iron and steel and these coatings offer means of coating surfaces with a uniform dry powder coating of predetermined thickness without requiring a fluid medium such as a solvent. Usually a subsequent stoving process is required in order to fuse the powder into a hard, uniform and continuous film. The principle methods of applying plastic coatings are by dip-coating, flame spraying and electrostatic spraying. The plastic powders that are used with these methods include nylon, cellulose acetate butyrate, polythene and epoxy resin.

These coatings have been effectively used for ship's fittings such as cable trays, guard rail stanchions, door clips and torpedo trolley straps. Their use will undoubtedly extend and plasticizing of huck bolts to GRP submarine casing has solved a painting and corrosion problem.

Plastic Coatings Ltd. have PVC coated come 20 000 lead bars of various sizes, specially designed for use as ballast in the nuclear submarine *Dreadnought*. The bars will lay adjacent to the submarine's hull and it was necessary to give a protective anti-corrosive coating which would act as an insulation and thus prevent electrolytic decomposition of the submarine metal surfaces. Besides insulating the bars this tough, highly adhesive, resilient coating ensures that they will resist knocks and damage when they are placed in position. They were coated in a trough of paste based on Geon 121 PVC resin.

Plastic Coating of Steel Strip

The advance of plastics in the structural field has laid emphasis on those materials which can co-function or actively combine with traditional materials construction. Considerable progress has been in the coating of steel strip, notably with PVC, to give materials which combine the strength and manipulative properties of steel with the corrosion resistance of plastics. In this connection, plastics bring more than corrosion resistance, they bring their other asset, colour potential.

Painting Procedures

In almost every instance ship construction and refitting takes place under outdoor conditions, exposed to the vagaries of the climate. When a schedule is being worked, painting must continue under all conditions. When painting in bad weather is unavoidable, the provision of temporaty shelters or covers and, if necessary, appropriate local heating should be resorted to.

The relationship between the temperature of the surfaces being painted, of the surrounding air, and of the paint itself are of importance. Condensation can also be caused by the rapid evaporation of solvents from some paints, particularly when spray painting.

When carrying out such work as shot-blasting and coating of flight and helicopter decks, and painting weatherwork to a high standard, tenting with polythene sheeting has been effective.

Large translucent enclosures comprising a weatherproof cover supported by inflated tubular structure members are also available for protection and possible utilization as workshops and storage spaces at ships' refitting berths. The stanchion members are flexible and when inflated with compressed air they become load bearing beams which assume a semi-circular shape with each end anchored to the ground.

The importance of cleanliness and tidiness combined with proper planning of painting procedures for ships under refit cannot be overstressed.

Take, for instance, the vexed problem of painting bilges. Cleaning and painting operations should be carefully scheduled in conjunction with other work, especially in machinery spaces, to ensure maximum efficiency and economy of effort.

Ideally for a satisfactory finish the final painting of machinery and bilges should be performed after all tests have been completed with cool machinery and dry bilges, but this would inevitably involve a loss of operational availability. In the event, cleaning and painting is carried out under steamy conditions and with accumulations of oil, water and lagging debris on the surface to be coated.

Any special effort to suppress pipe leakages, stop filling of the bilges with oil and water and to improve the standard of general cleanliness during the painting period would lead to a more satisfactory and durable finish.

Conclusions

The problems of corrosion associated with the design and fitting out of a ship have been pointed out. The advent of the preparation of steel surfaces by shot-blasting and shop priming, the promising performance of the specially formulated outer bottom compositions, the successful application of high duty compositions sometimes in conjunction with metal sprayed coatings, represents a major advancement in combating the preservation problem.

The process specifications emanating from Ministry of Defence, Ship Department, which covers the whole range of painting processes for ships' preservation, go a long way to ensure satisfactory, durable decoration and preservation lasting between refits.

There are, however, many other facets to be recognized and this would seem to be the right point in time for the naval architect, the paint manufacturer and paint chemist together with those responsible for seeing that protective coatings are properly applied, to take a hard collective look at the problem. The technologists in the Ministry of Defence(Navy) will no doubt be taking note of developments in industry and measuring the correct time for any change in Service materials. Matters should not be left just to evolve as this could mean losing out in these days of rapid technological change.

It is good to rapidly develop new, successful materials and techniques but the technological advantage will not be sustained if the dockyards are not geared to meet the required situation. Quality control and properly planned procedures are a pre-requisite to successful preservation using the modern sophisticated materials.

The dockyards are faced with a diminishing labour force both in numbers and quality. The new high performance coatings introduce problems of fire and health hazards. The exact role and quality of a dockyard painter requires new definition. Too often skilled painting procedures are performed by virtually unskilled, transient labour. Too often the conditions met at ship nullify the advantages of the new painting processes.

We have seen the introduction of fibre glass boats, GRP structures, plastic powder coatings and plastic piping. Plastic is also currently used for floor coverings, insulation and linings. Wooden vessels, such as coastal minesweepers are GRP sheathed or treated with the cascover coating process.

Outside industry is now aiming at pushing into the new growth area of composite materials. Glass fibre will provide the main support for the new products, challenging steel and other traditional materials but currently handicapped by a lack of volume that keeps cost high. But glass fibre is only one of the range of materials in the composites running. Other light elements, nitrogen, oxygen, silicon, boron, light metals and the heavily-publicized carbon fibre material, are competing.

The commercial reasons for the use of plastic materials are gaining strength and the evaluation of the commercial possibilities is always helped by naval application and experimental work.

Larger ships will inevitably be constructed with materials of this type. We appear to be nearing a similar revolution to that which occurred when ships changed from wood to iron.

New problems for preservation and decoration will arise. The use of scaling hammers and paint removers, so long the tools of the old type skilled labourer painter, will no longer be able to be employed on plastic surfaces.

Although self-pigmented plastics theoretically require no painting it may be necessary to make good damaged areas for the sake of the high standard of appearance usually associated with the Royal Navy. New application techniques and new materials will evolve.

Steel has been the material from which ships have been built but it may not be too far in the future before warships will be constructed of non-corrosive materials which will only require protection against fouling.

Given the funds and facilities for the necessary research, military ships of fibre reinforced plastic will most assuredly show the way to commercial fibre reinforced plastic ships.

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