Coating of Ships: The Design Challenge

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SUMMARY

In July 2007, IMO adopted amendments to SOLAS by resolution MSC216(82) which mandated compliance with the new IMO "Performance Standard for Protective Coatings for dedicated seawater ballast tanks in all types of ships and double-side skin spaces of bulk carriers", (IMO PSPC; Resolution MSC 215(82)). Compliance with the IMO PSPC is required by the IACS Common Structural Rules for Bulk Carriers and for Oil Tankers, which were implemented in December 2006.

This paper reviews work that is being undertaken to improve the safety of ships by looking at new ways in which structural design can be improved to gain the optimum benefit of modern coating materials, surface preparation and application technology.

1. INTRODUCTION

From the beginning of 1990 to mid-May 1997, a total of 99 bulk carriers sank with the loss of 654 lives [1]. As a consequence the International Maritime Organisation (IMO) adopted a series of measures to improve bulk carrier safety, culminating in November 1997, when an IMO conference adopted important new regulations designed to prevent bulk carrier losses [2]. These entered into force on 1 July 1999. Many of those vessels that were lost during this time suffered from severe structural failure, in some cases ships had simply broken apart without warning [1].

Following investigations the International Association of Classification Societies (IACS) introduced a new enhanced survey regime for Bulk Carriers which covered hull design changes, coating type, more intensive inspection standards and shorter survey intervals. As a result of these actions the number of ship losses reduced dramatically, with the loss of only two ships during 2000 [1]. This action by IACS was successful in achieving the principal goal of minimising losses; another important consequence was that it opened a wider debate on how to raise the global standards of protection of the steel work within Water Ballast Tanks (WBTs). It was corrosion in these areas that was deemed to be a primary contributor to the structural failure of these ships.

The lack of mandatory provisions relating to coatings for cargo holds and WBTs was further highlighted by the European Maritime Safety Agency [3]. They reaffirmed the relationship between the breakdown of a protective coating and the subsequent rapid corrosion of unprotected steel that will occur. Additionally, the subsequent repair of the failed coating was found not be to the same standard as that achieved during the new-build process. In that study a comparison was made between the condition of the WBT coatings of two vessel of the same age and it was concluded that the significance of using the correct application procedures was of the upmost importance to ensure coating reliability.

Having established the fundamental importance of coatings and current deficiencies, this paper provides background and insight to the current regulations and guidelines with respect to coating in WBTs. The history of the coating process in the shipbuilding industry is also considered and the problems the industry currently faces are highlighted. This paper then describes the aims of a new research project that proposes that ships should be designed for coatings just as they are for structural integrity and ease of production.

2. PERFORMANCE STANDARD FOR PROTECTIVE COATINGS (PSPC)

The IMO Maritime Safety Committee (MSC) identified that coating performance was of global concern for the safety and integrity of ships. Following a long period of technical discussion, the IMO Performance Standard for Protective Coatings (PSPC) for WBTs was approved in December 2006 and adopted in July 2007. The overarching aim of the PSPC is to improve the standards of WBT coatings and application in new builds, and in the process, achieve a 15 year target life for those coatings.

By the inclusion of the IMO PSPC into the International Convention for the Safety Of Life At Sea (SOLAS), the importance of WBT coating has been raised to a similar level of importance as ships lifeboats. The SOLAS Convention in its successive forms is generally regarded as the most important of all international treaties concerning the safety of merchant ships. It was first adopted in 1914 in response to the loss of the RMS Titanic. This was followed by the second Convention in 1929, the third in 1948, and the fourth in 1960 [4].

The implication for 'new-builds' is that a vessels WBT coating must be applied in accordance with the IMO PSPC regulations. As a ship cannot sail without meeting SOLAS requirements, it is now mandatory that a vessel's WBT coatings are deemed to comply with SOLAS before it can put to sea; this has obvious implication for the availability of the ship. In the case of Bulk carriers the IMO PSPC has been incorporated into the IACS Common Structural Rules (CSR).

The IMO PSPC sets out quite a specific framework with regard to the selection of coatings for ballast tanks and their application. In broad terms the PSPC defines:

- Basic coating requirements;
- Type approval testing for coatings;
- The need for a tri-partite agreement between owners, builders and coating producers;
- Surface preparation procedures;
- Application procedures;
- Data collection and reporting in a coating technical file (CTF);
- Inspection needs and procedures.

In order to provide an introduction and insight to the PSPC regulations, a summary of these key requirements and considerations governing the selection and application of coatings is now provided.

The PSPC states that when selecting a coating system, the parties involved must consider the service conditions and planned maintenance routines, relevant to different vessel types. Aspects that need consideration include location of the space relative to heated surfaces such as fuel oil or cargo tanks. In addition to the ballasting cycles, the inclusion of supplementary cathodic protection systems must also be borne in mind when selecting a coating system as well as the impact of Ballast Water Management Systems.

To gain type approval a coating must pass the test procedures as defined in Annex 1 of the PSPC. Epoxy based systems that were tested prior to the entry into force of the regulation can be approved if there is evidence of field exposure showing that the coatings have remained in 'GOOD' condition for not less than 5 years.

The PSPC also sets out the standards for both primary and secondary surface preparation. Primary surface preparation is based on the Swedish standard 'Sa 2 ½' [5]. This standard requires a very thorough blast cleaned surface that when viewed without magnification is to be free of oil, grease, dirt and poorly adhered mill scale, rust, paint coating or any other foreign matter. This standard of blasting should provide surface profiles of between 30-75 µm.

Secondary surface preparation should also be to a 'Sa 2 ½' standard on areas of damaged shop primer and in way of weld seams. Shop primer that has not passed pre-compatibility testing requires 'Sa 2' surface preparation [5], with removal of at least 70% of any such primer. Surface blasting cannot be carried out when the relative humidity is greater than 85% or the surface temperature of the substrate is less than 3˚C above the dew point. The water soluble salt limit, equivalent to NaCl, is set at $50mg/m^2$ and the shop primer should be a zinc based product containing inhibitor free zinc silicate or equivalent. The compatibility of the shop primer with the main coating system is to be confirmed by the coating manufacturer.

The job specification defines that there are to be a minimum of two stripe coats on edges and welded seams plus a multi coat system for the rest of the structure. It does note that the second stripe coat may be reduced in way of welded seams to prevent unnecessary over-thickness. The total nominal dry film thickness (NDFT) is set as 320µm and the layers are to be appropriately cured before application of the next coat. The measured dry film thickness should meet the '90-10' rule, namely 90% of measurements are to be greater or equal to 320 µm within the remaining 10% greater than 288 µm.

To comply with the regulations the shipbuilder must prepare and deliver a Coating Technical File (CTF) with respect to the whole WBT coating process. The coating manufactures are required to provide technical assistance and documentation of the satisfactory performance of their products, and offer adequate technical support. The CFT document is required for each new ship to act as an 'as-built record'. The inspection records are also to be included within this document and are used to manage the ongoing maintenance of the WBT coatings. A set of guidelines have recently been published by the IMO [6] to aid the relevant parties with the maintenance and repairing process of protective coatings. The areas and extent of the survey process of a vessels WBTs is further defined. The guidelines also give further definition on the three terms used to define the quality of a coating, namely 'GOOD', 'FAIR' and 'POOR'.

They also draw a distinction between coating maintenance, which can be undertaken by ships staff and repair which would be carried out during a scheduled repair period.

Thus the PSPC is very clear as to how the steel substrate is to be prepared, cleaned, painted and inspected. In order to comply with the regulations there is a great demand placed on information recording as part of the inspection process. Coupled with this a suitable information management system is required in order to compile the CTF.

3. APPRECIATION OF THE COATING PROCESS

If the breakdown of all new build costs is considered, it is apparent from Figure 1 that the paint acquisition cost typically represents a very small amount of the total new build price of a vessel. This has led to the perception of coatings and their application as being a 'low value' process. As a consequence of this very little development has taken place in the last 40 years to improve practices and the technology even though coating chemistry technologies themselves have advanced significantly over this period. It is the steelwork activities that have continued to drive forward shipyard technological advances. This is further compounded by the lack of development in the management systems used within the coating process as a whole. Thus the coating process has become unstable and unpredictable without suitable controls [7].

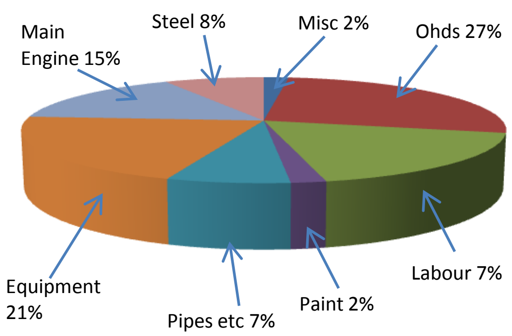

Figure 1: Typical New Build Cost Breakdown [13]

A number of papers have examined the production cycle within various shipyards [7-12] and identified how the lack of pre-production planning and integration of the coating process has led to the creation of a bottleneck in the painting of finished steelwork blocks. The scheduling of painting activities are often determined by the planning of the steelwork department to maximise steel throughput, rather than prioritising the coating activities themselves. Similarly the coating process is often used as a buffer to compensate for steelwork and other production delays [8]. If the new PSPC requirements are to be met then there needs to be a greater emphasis on the coating process as a value adding activity and it must be afforded equal importance to other production activities. Only then can the problems associated with the reliability of coating application can themselves be addressed.

If the coating process is classed as all those activities involved in the application of the coating to the steel substrate, it can be broken down into distinct activity groups; surface preparation, paint application, ventilation and inspection. The requirements for all of these activities are very similar in terms of access and ventilation. To consider their implication on the reliability of the overall coating process, it is useful to consider the implications of progressing from a simple flat panel through to a complete WBT.

The simplest case is that of flat panel of moderate size, placed at a comfortable working height in a temperate well lit and ventilated environment, it is likely that an averagely skilled worker would achieve a high quality of coating finish. As a result of this the probability of an in-service coating failure during the predicted life of the coating is much reduced.

At the next level of complexity, the ships outer hull plating is made up of many such 'flat' panels however they are not situated at comfortable working heights in controllable environments and in many cases require staging for access. This increases the complexity of the coating process and may lead to a reduction in the quality of the surface finish. However as the topsides finish forms part of the corporate identity of the owner/operator and the below water portion of the hull has a significant influence on the ships performance in terms of speed loss and increased fuel consumption, a disproportionate amount of time and effort must be invested to ensure a high quality of finish to the outside of the hull.

The cargo tanks or holds of vessels, especially in the chemical trade, are where the payload is carried and as such are the revenue generating portions of the vessel and are therefore afforded a significant amount of maintenance and repair. The difficulty in coating these areas is more an issue of access rather than structural complexity.

The areas of the vessel with the greatest complexity and with restricted access tend to be, the fore and aft peak areas, the double bottom structure and any double hull structure. It is in these areas in which ballast water is often carried but which were prior to the PSPC often overlooked in terms of maintenance despite the corrosive nature of the environment in such tanks.

It is not possible to consider a typical WBT, as one does not exist upon which to base any investigations. For example the WBT capacity on board an oil tanker is driven by the need to achieve a suitable draft for propeller immersion and need minimum draft dictated by MARPOL on the ballast voyage. The maximum tank size on board a tanker is driven by the MARPOL regulations for the maximum size of a cargo oil tank [15]. This subdivision of the ship's hull both longitudinally and transversely will define the maximum individual size of its WBTs. In contrast an offshore supply vessel has a very low total ballast capacity, it being principally used for trimming and heeling the vessel. This capacity is broken up in to a number of small WBTs. This then introduces the problems of access in ballast tanks as due to their range of sizes some require multiple staging to gain access to the entire tank whilst others are very small and confined. Therefore there is no such thing as a 'typical' WBT.

Additionally there is the geometric complexity created by the primary and secondary longitudinal and transverse stiffening. The result of this is a large amount of 'shadowing' of the surface to be coated within a given space. To carry out coating processes efficiently the operator must have access to all surfaces. Another consequence of the complexity of water ballast tanks is the amount of weld and edge length; it is often almost impossible to gain visual access to many surfaces let alone shot blast or paint them. A further consideration is that the edges require rounding to allow better edge retention of the paint; a radius of a minimum of 2mm, or three passes of a hand held grinder are defined in the PSPC. The effect of all of these factors is that even very skilled operatives struggle to deliver a consistently high quality of finish, thus the probability of an in-service failure is considerably increased.

The majority of coating failures are generally attributed to the process stage as indicated in Figure 2, namely surface preparation and paint application. The chart shows the typical number of failures against the cause of failure as observed by Safinah; it does not take into account the cost or value of the failure. This would suggest that the current designs are adequate, and as such effort should be focused on improving the process. This is how the PSPC seeks to achieve the 15 year target life. The question which should be asked are;

- Why did the process fail to provide the quality of finish required?
- Is it that the operators could not gain the required access to the surfaces?
- Did the area contain an excessive amount of edges and welds?

To address these questions, it is proposed that the design of the structure has a detrimental effect on the physical activities of coating process, ultimately resulting in premature coating failures. If the actual structures that are to be prepared and coated are examined, credit should be given to applicators and paint chemists that there are not more coating failures in service.

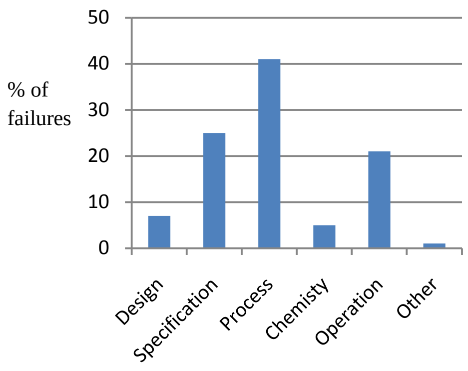

Figure 2: Major Causes of Coating Failures [13]

4. DESIGN FOR COATING

If the design of WBT structures could be simplified, while still meeting structural and other operational requirements, it may be possible to provide significant benefits, such as; reduction in the cost of coating ships, improved through life performance and possible routes to automation of the coating process. Typically the coating process requires between 12-25% of the total man hours for the construction of the complete vessel, depending on vessel and yard type [9]. Coating rework can account for as much as 30% of the total coating man hours, it can be seen that if the rework and thus the overall coating work content can be reduced, then the first cost of a vessel can be significantly lowered [10]. In addition to this if the structural design is simpler then the number of coating failures should also reduce thus giving through life benefits to the shipowners.

The structural design of ships has conventionally sought to seek an appropriate balance of requirements with respect to strength, weight, operation, ease of construction and cost whilst still complying with Classification Society rules concerned with the safety of the vessel. Naval Architects have long been accustomed to designing vessels to meet these requirements. However the concept of design to improve the performance of coatings is a novel approach, in fact there is often a tendency to create corrosion problems as a by-product of designing to meet other requirements, for example:

- Complex geometries that are difficult to prepare and coat adequately;
- Tight spaces that are difficult to access, ventilate and de-humidify;
- Tight spaces that cannot easily be coated using an airless spray gun and so require build up coats to be applied by brush and roller;
- Spaces that are subsequently difficult to repair and maintain;
- Flat surfaces with no camber or rise of floor to assist with drainage;
- Use of dissimilar metals;
- Poor placement of outfit items resulting in corrosion traps;
- Poor drainage plans and design detail.

In merchant vessel structural design there is an emphasis on seeking designs with reduced complexity and inherent work content to facilitate ease of production and further exploit the increased utilisation of automation techniques and advanced modular outfitting. These first cost related objectives have been conventionally balanced against structural weight to identify 'optimal' weight-cost solutions. The issues of ease of coating and in service performance of coatings have not normally been considered as part of this trade-off but there is now a need to re-evaluate design methodology. The PSPC has lead to a greater need to focus on identifying suitable coating products and consideration of whether current structural designs are actually capable of being coated efficiently and reliably. The PSPC highlights this issue in section 3.3.2, states that:

"the coating performance can be improved by adopting measures at the ship design stage such as reducing scallops, using rolled profiles, avoiding complex geometric configurations and ensuring that the structural configuration permits easy access for tools and to facilitate cleaning, drainage and drying of the spaces to be coated".

Thus for the first time the new regulations establish a formal link between the design and corrosion of ballast tanks on board ships.

If the influence on corrosion prevention through the different stages of a vessel life is examined, from the design stage through to decommissioning; it is then possible to postulate that it is the design of the vessel that has the greatest influence on preventing or at least minimising corrosion through life. As an example the decision to build the vessel from mild steel and place it in a highly corrosive environment has a huge affect on the vessel throughout its entire life cycle. Quantifying the influence of corrosion prevention at this moment in time is not possible, predominately due to the general lack of in-service coating performance information available in the public domain. The curves within Figure 3 represent different levels of influence of corrosion prevention and how they all diminish through the vessels life time. It is not possible to suggest an exact form of the relationship; however the figure does provide insight as to could be conceived as good and poor practice, and the shaded area represents the sought improvement. It also demonstrates how good design will assist in minimising the amount of corrosion that a vessels structure is subjected too through life.

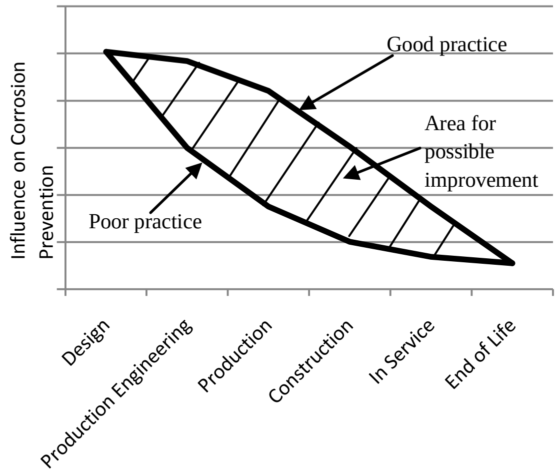

Figure 3: Influence on Corrosion Prevention through a Vessels Life

It is also known that as the vessel ages the average cost of maintaining the coatings will increase as can be proposed in Figure 4. This is a result of the increased amount of on-board maintenance work as well as the increased costs of repair work. There will be a diverse range of cost attributable to ship type.

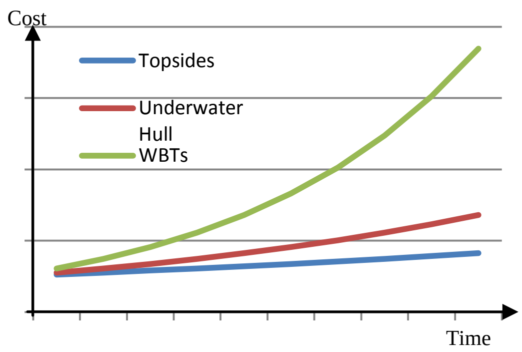

Figure 4: Representative Cost of Maintaining Coatings through a Vessels Life

If Figures 3 and 4 are considered in combination with each other, it is possible to conclude that the design stage has perhaps the greatest influence on a vessel in terms of cost and corrosion throughout its working life. Figure 5 demonstrates this and shows how the in-service performance of a coating system is not only dependent on the processes involved in preparing and painting a surface and the paint applied to it, but is also a function of the design of the structure itself.

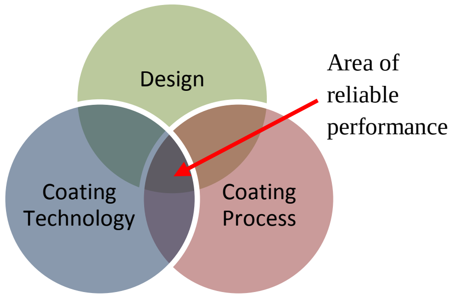

Figure 5: The Three Main Elements of a Reliable Coating system.

The PSPC seeks to reduce the failure rate of WBT coatings by imposing greater controls on the processes and the products applied to steel substrates. However the importance of good efficient design cannot be overstated. The current work being carried out seeks to increase the 'area of reliable performance' by improving design, which in turn may offer opportunities to improve processes and technology.

5. CURRENT GUIDELINES ON DESIGN

There are number of International Standards Organisation (ISO) standards that do not cover design but are related to the process of the preparation of steel substrates namely ISO 8501, 8502, 8503 and 8504.

The ISO 12944 standard deals with 'Paints and varnishes – Corrosion protection of steel structure by protective paint systems'; it is made up of eight sections, of most interest in this context are:

- Part 3 – Design considerations;
- Part 4 – Types of surface preparation;
- Part 5 – Protective paint systems.

ISO 12944-3 notes how the design of a structure should be carried out in such a way as to facilitate surface preparation, painting inspection and maintenance. It also considers how the shape of a structure can influence its susceptibility to corrode, and recommends that the complexity of a structure should be kept to minimum. The standard also shows examples of good working practice in terms of rounding edges, spacing between stiffeners and use of corrosion resistant materials or the use of a corrosion allowance. A set of minimum required distances are presented which will allow adequate accessibility for the tools required for corrosion protection work.

ISO 12944-4 gives guidance on the range of surface preparation methods that are available to ensure that a surface is provided that permits satisfactory adhesion of the paint to the steel substrate. It notes that ISO 8503 specifies the requirements of surface profile required.

ISO 12944-5 defines the terms used within the paint industry and the different types of paint that are available. The standard sets out the classification of environments and provides guidance for the selection of different types of protective paint systems.

These standards are further supported by publications such as the UK based Marine Painting Forum MPF [14]. The information contained within the guide is primarily aimed at naval vessels and the prevention of corrosion to secondary steel items such as bulwarks and stanchions. It does however make note of how a great deal of the in-service ship husbandry can be reduced at the design and build stage, by closer attention to detailed design.

The guidelines observe that careful consideration must be given to provide maximum access to any compartment that requires painting. So that coating work may be carried out throughout the ships life. What is clear however is that together with the ISO Standards other than detail design guidance for issues such as edge preparation and the use of scallops, no consideration is given to global design of a structure to aid the actual physical tasks required in the coating process.

6. DISPRO PROJECT AIMS

The Design to Improve Structural PROtection (DISPRO) project brings together key partners to address the problems of design. The aims of the project can be summarised as the reduction of the complexity of ballast tank design to provide the following coating related benefits: reduced man-hours; improved productivity in shipyards; reduced repair hours; improved turnaround in dry-dock; increased coating life, and hence reduce the operational cost to the owner.

In order to gain a level of control of the coating process a complexity index of a given structure must first be established. This index may be based upon a combination of the weld and edge length, the surface area per cubic meter, and measure of the amount of shadowing within a given space. The index if used during the initial design stage it would give a designer an indication of the level of intricacy of a given structure. A threshold value will be proposed, such that above which it becomes increasingly difficult for an operator to deliver a good standard of coating.

The project will review existing designs for Water Ballast Tanks and quantify their complexity and explore what can be achieved by altering the approach to structural design. The current designs will then be 'simplified' and 'rationalised' whilst still satisfying the structural, operational and production requirements of the vessel. Once a number of design options have been identified, they will be reviewed by the project partners, to ensure that they would satisfy any other vessels operational and safety criteria. They could then form the basis for the development of coating friendly design guidelines.

If consideration is given to the coating process during design, it may then be possible to reduce the overall work content by reducing the amount of rework in the coating process. If this is supported by improvements in the management systems, it should then be possible develop a sustainable and predictable process with reduced requirements on resources and time.

All parties involved in the coating process seek to reduce costs. If it were possible to attach cost saving in terms of the factors previously outlined by this new approach becomes far easier to demonstrate the added value of considering the coating process during design process. Ideally this would include not just the first costs but also provide an estimate of through life costs too.

7. CONCLUSIONS

This paper has discussed how the introduction of the PSPC has increased the importance of the coating process with regard to WBTs. An overview of the requirements of the PSPC has been given in terms of surface preparation, coating systems and application procedures.

The development of coating activities within shipyards has been examined, detailing how very little investment in this area has lead to many of the problems seen today. The problems associated with coating WBTs have been analysed, from which it is possible to attribute many of the coating failures to the processes of surface preparation and application of the paint, but this paper proposes that it is the design which is the real cost driver.

The paper has reviewed current standards, guidelines and best practices, including the current ISO standards and concluded that they only offer limited advice on design detail.

The aims of the on-going project have been presented, introducing the work being done to attach an objective measure to the complexity of a given Ballast space. Whilst trying to determine a threshold value above which the achievable standard of finish will drastically reduce.

The aim of this project is to improve the safety of ships by looking at new ways in which structural design can be improved to gain the optimum benefit of modern coating materials, and coating processes.

8. ACKNOWLEDGEMENTS

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The project will be carried out in collaboration with Newcastle University School of Marine Science and Technology, American Bureau of Shipping (ABS), a world leading classification society, IHC Merwede Offshore & Marine, an innovative and specialist shipbuilder in the Netherlands, Jotun Paints of Norway, one of the marine paint majors and Muehlhan International of Germany, one of the world's best known marine painting contractors.

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11. AUTHORS' BIOGRAPHIES

Darren R Broderick is currently under taking a KTP project involving, Newcastle University and Safinah Ltd. The project aims to improve the design of water ballast spaces with a view to coating them. Previous to this he undertook a project on the application of longitudinal framing to short sea vessels as part of the CREATE3S project. He completed his under graduate degree at Newcastle University, after having completed a cadetship and four subsequent years of deep sea service, reaching the rank of second engineer, with P&O Nedlloyd (formally P&O Containers). He is a graduate member of RINA.

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Rauof M Kattan is the managing director of Safinah ltd a unique consultancy in the marine, protective and offshore industries. Dr Kattan has extensive expertise in shipping, shipbuilding and naval architecture, with specialist knowledge of coatings.

He has worked with all the world's leading coatings companies and headed the product development teams of a multinational company. He has a broad experience in the problems associated with the use of marine coatings and has worked in both industry and academia. He is a Chartered Engineer and corporate Fellow of RINA.