IS THE MUCH SOUGHT-AFTER, BETTER ALTERNATIVE UNDERWATER HULL COATING SYSTEM ALREADY HERE?

B. Van Rompay, Hydrex NV, Belgium

SUMMARY

An antifouling strategy has been in commercial use for a decade now whereby "surface treated composites" (STCs) are given an in-water treatment which consists of "conditioning" that improves the surface characteristics, and routine in-water cleaning that removes any marine fouling preferably at an early stage of development. The surface roughness of the coating is thereby reduced, which makes it more difficult for fouling organisms to attach. The in-water conditioning/ cleaning can be carried out rapidly and economically. The integrity of the coating is maintained and its frictional properties improve, unlike conventional antifouling and foul-release coatings which need frequent repair/replacement.

A large number of full-scale applications of STCs show excellent corrosion protection and resistance to fouling, a long service life due to high durability, and significant drag reduction when compared to conventional antifouling methods. Research projects have demonstrated conclusively that commercially available STCs are non-toxic in use and during cleaning. Further research projects have been designed to study whether the standard use of STCs prevents the spread of hull-borne, non-indigenous marine species (NIS) and significantly reduces fuel consumption and greenhouse gas emissions.

NOMENCLATURE

FRC	Foul-release Coating
IMO	International Maritime Organization
NIS	Non-indigenous Species
Ra	Centre-line average roughness height (m)
Rt	Highest peak to lowest valley height (m)
SPC	Self-polishing Copolymer
STC	Surface Treated Composite
TBT	Tributyl-tin
VOC	Volatile Organic Compounds
dft	dry film thickness (μm)

1. INTRODUCTION

At the turn of the century, the large majority of ship hull coatings applied worldwide were tributyl-tin (TBT) self-polishing co-polymers. By means of a steady release of TBT, ships could be kept relatively free of fouling for a period of up to five years, which coincided with the inter-docking survey period required by the Classification Societies. Due to the severe environmental effects of TBT, the International Maritime Organization (IMO) imposed a complete ban on the use of these chemicals, with profound consequences for the marine industry.

Since the disuse of TBT, the major challenge has been to find effective antifouling strategies in order to keep the economic penalties due to fouling and the number of dry-dockings to a minimum. Strategies which avoid the use of coatings, such as electro-chemical methods or techniques involving vibration have been considered, but it is clear that coatings will be the most viable antifouling strategy for years to come.

The majority of antifouling coatings applied today continue to attempt to control fouling settlement through the release of biocides from the coating surface, but their lifetime is restricted to three years, at best. These coatings tend not to be effective against slime which, all on its own, can incur a fuel penalty as high as 20%. Only "tin-free" SPCs that use the same chemical principle but, instead of TBT, gradually leach copper or copper oxides aim to keep a hull foul-free for five years by the incorporation of so-called "booster biocides" [1]. From an ecological point of view, however, the continuing leaching of heavy metals and other biocides into the aquatic environment, affecting non-target organisms, lowering water quality and contaminating sediments raises major concerns and remains unacceptable [2,3].

Low surface energy or foul-release coatings aim to prevent the settlement of fouling by providing a low-friction surface onto which organisms have difficulty attaching. If vessels are stationary settlement occurs, but initially there is only weak bonding between the fouling organisms and the coating surface. Hence, the organisms are in theory relatively easily removed, either by the hydrodynamic forces when the vessel is traveling at a sufficiently high speed or by underwater cleaning. The lifetime of foul release coatings is restricted as they are permeable, mechanically soft and easily damaged. Underwater cleaning needs to be carried out with soft brushes which may not remove all organisms that have settled, for example after longer stationary periods [4]. In addition, mechanical damage will result in local unprotected areas that will eventually require touch-ups in dry-dock. Repair of such areas is difficult due to the nature of the coating itself. Questions have arisen as to the toxicity of the substances used in foul-release coatings and research has shown that these substances can, for example, interfere with enzyme activity in fouling organisms and can be fatal to marine organisms [5,6,7].

Both biocidal antifouling and foul-release coatings are subject to long term paint degradation where each cycle of patch-up and partial repair/replacement in drydock leaves the hull rougher than before. This accumulates over the years and by the time the hull has been in service for 10-15 years without full removal and replacement of the entire coating system down to bare steel, the fuel penalty from the paint coating alone can be as high as 25-40%, even without considering the additional effects of fouling. [8]

The general idea behind the types of coatings described above is to provide an antifouling system whereby the condition of the ship hull is only attended to in dry-dock every three or five years where re-coating will take place, either over large patches that suffered damage or as a complete replacement coating. The majority of these coatings are designed to have effective antifouling properties in that they "actively" respond to fouling, either by the gradual release of toxins or by the use of hydrodynamic mechanisms. Experience has shown, however, that the five-year period is unrealistic and even a three-year period is optimistic for a hull to remain free of fouling using these coatings. It has become a practice to begin in-water cleaning on such hulls before the dry-docking interval has expired. This then poses new problems of damage to the coating and hazard to the environment.

These factors lead to a general dissatisfaction within the shipping industry with the antifouling and foul-release coatings in general use on ships since the banning of TBT.

Research into better hull coating systems has intensified since the banning of TBT, including a number of attempts to develop coatings which are non-toxic to the marine environment.

2. A DIFFERENT APPROACH: SURFACE TREATED COMPOSITES

2.1 SURFACE TREATED COMPOSITE DESCRIBED

An entirely different approach was introduced commercially in 2002 and has been in successful use since. Not just a coating, an STC is a system of hull protection and fouling control comprising two main elements:

- a hard, inert, long-lasting, tough, glass-reinforced coating designed to last the life of the hull without need for replacement and with only minor touch-ups required during routine dry-docking
- routine underwater conditioning/cleaning whereby the smoothness of the coating is improved over time and the hull is kept clean of any fouling beyond the light slime that will attach between cleanings.

2.2 THE COATING

One STC that is commercially available is formulated as a vinyl ester with a high concentration of embedded glass flakes, a microscopic view of which is shown in Figure 1. This coating has a very low amount of volatile organic compounds (VOC) and is typically applied in two coats of 500µm dft. each. The high film thickness and the presence of glass flakes which act as an impermeable barrier explain why this coating has excellent anti-corrosive properties and has been approved as a superior grade ballast tank coating [9] and recognized as an abrasion resistant ice-class coating which permits reduction of ice belt steel plating thickness by up to 1mm when standardly used [10]. It is extremely durable, making it excellently suited to regular in-water surface treatment and cleaning, as shown in Figure 2. Tests have shown that a very large number of repeated underwater cleanings (500) on the same surface improve its surface smoothness and have no deteriorating effects.

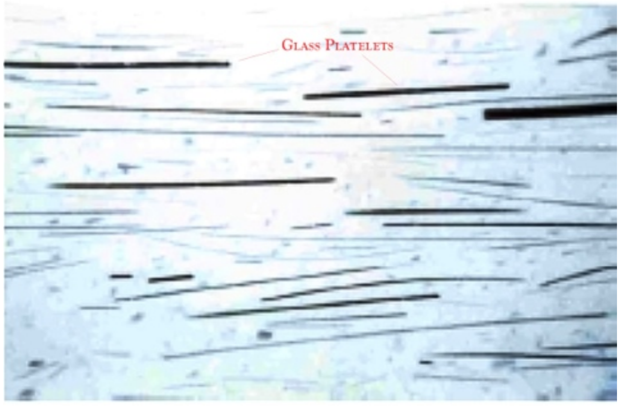

Figure 1: Microscopic cross-section view of a commercially available STC formulated as a vinyl ester with embedded glass flakes.

2.3 THE CONDITIONING/CLEANING

STCs are so named because of the in-water treatment used throughout their life which consists both of a "conditioning" aspect that improves the surface characteristics of the coating and a cleaning aspect that removes any marine fouling at an early stage of development. The overall effect of this treatment is to keep hull friction at a minimum throughout the service life of the coating and to improve the hydrodynamic properties of the surface over time.

By means of a special patented technique [11] the conditioning and cleaning operations of an STC can be carried out simultaneously, which greatly reduces the required amount of time and saves on costs.

Conditioning/cleaning of the main hull of a large cruise ship is shown in Figure 2.

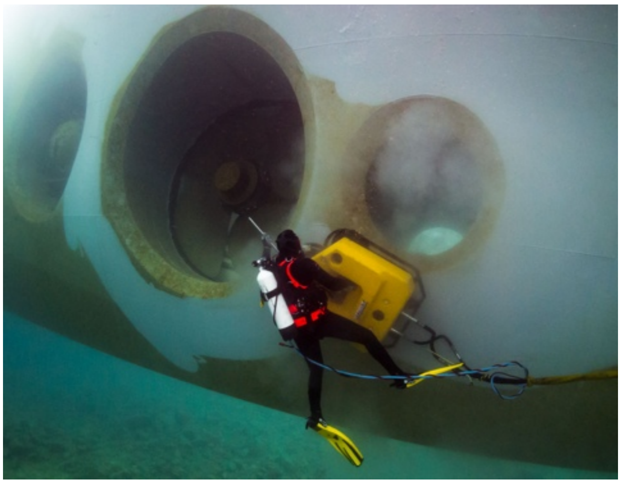

Figure 2: Conditioning/cleaning of the main hull of a large cruise ship.

The effect over time of the in-water surface treatment on the coating may be illustrated by Figure 3, in which sketches of typical cross-sections are shown for different stages in the lifecycle of the coating.

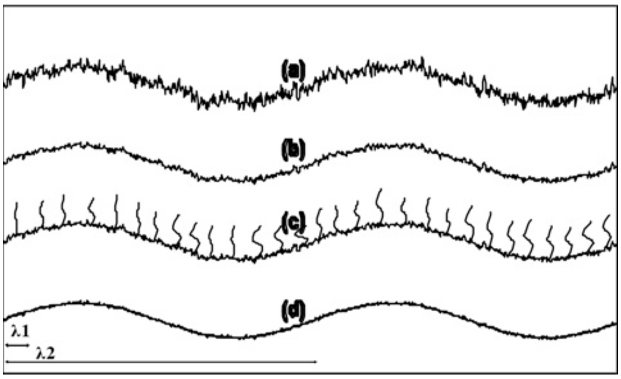

Figure 3: Sketch of a typical cross-section of an STC at different stages: (a) freshly applied (b) after conditioning (c) gradual exposure to attachment of fouling organisms (d) after cleaning/conditioning.

Stage (a) shows a typical roughness profile when the coating is freshly applied. The coating typically exhibits a waviness on which micro-roughness is superimposed. As soon as possible after initial application, the coating undergoes an in-water conditioning whereby the surface becomes smoother in that the micro-roughness is drastically reduced, as shown in stage (b). Stage (c) illustrates that in service, fouling organisms will gradually try to attach. Subsequently, in stage (d) the STC has undergone a cleaning and conditioning whereby all fouling organisms have been removed and the surface roughness has been further reduced.

2.4 WHAT MAKES THE STC UNIQUE

An STC is unique in that it is designed to last the full service life of the ship without need for major repair or replacement, and in that conditioning of the surface is part of the system.

Underwater cleaning of ship hulls coated with antifoulings or foul-release coatings is carried out to remove fouling but it is well known that the cleaning operation will damage the coating and reduce its efficiency. In addition, spores of algae, protozoa or other marine fouling organisms may take shelter in the crevices of the rough surface [12] and as a consequence ship hulls have been found to still have added resistance due to fouling roughness after underwater cleaning operations [13]. Furthermore it has been found that removal of fouling from a vessel without the reapplication of antifouling paint increases the susceptibility of the surface to new fouling [14]. This exacerbates biosecurity risks of NIS [15].

There is a long term hull coating degradation phenomenon associated with antifouling and foul-release coating systems due to the soft nature of these coatings, the fact that the systems are made up of numerous heterogeneous layers and in the case of antifouling coatings due to the fact that they are designed to wear out through ablation or self-polishing. When the underlying anticorrosive scheme is spot repaired and the antifouling or foul-release top coat is reapplied, the hull surface remains rougher than before the repair. With multiplied spot repairs and recoatings over time, the hull roughness can become very pronounced and can account for an additional fuel penalty of 25-40% [8].

The conditioning of an STC, however, results in a smooth surface to which fouling organisms have difficulty re-attaching. In effect, for the commercial STC example given above, the conditioning results in a surface layer of aligned glass flakes which are suspended in a matrix that has been leveled. This explains why the micro-roughness is drastically reduced. Since the number of crevices around the impermeable glass flakes is drastically reduced, good antifouling properties are obtained for a coating which was originally developed as an anti-corrosive barrier coating.

Figure 4 shows this phenomenon diagrammatically.

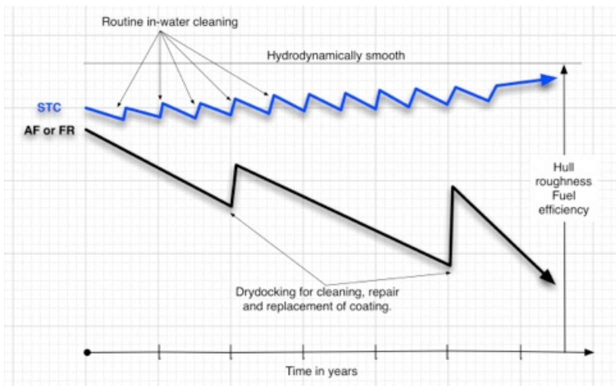

Figure 4. Comparison of hull roughness over time between coating types due to long term paint degradation.

3. SURFACE TREATED COMPOSITES AND SHIP HULL PERFORMANCE

A large number of full-scale applications of the commercially available STC described above have led to the observation of excellent resistance to fouling, a very long service life due to high durability and significant drag reduction when compared to more conventional antifouling methods. One cruise line cited fuel efficiency improvements of 10% compared to an earlier SPC coating in use on the ships of the fleet [16].

Indicative towing tests have confirmed that the resistance of a plate coated with an STC exhibits significantly less drag than a plate coated with a conventional paint system. A conditioned STC exhibits less drag than when the STC is freshly applied and not yet conditioned [17].

The observed drag reduction is at least partly due to the smooth surface characteristics that are achieved through conditioning.

Recent tests conducted in Hamburg compared performance of one of the most advanced SPCs, one of the most advanced FR coatings and an STC. The conditioned STC proved to offer the least resistance of the three and therefore to be the fastest hull coating of those tested.

Traditionally, only an amplitude parameter is used to characterize the average hull roughness to correlate with added resistance [18]. This parameter, Rt(50), represents the highest peak to lowest valley perpendicular to the mean line over a 50mm cut-off length. However, it is known that for certain types of coatings, additional parameters are required to correlate roughness with drag [19].

Measurements have indeed shown that Rt(50) is substantially higher for an STC than for a conventional antifouling coating. This is because the waviness, which may be defined as that component of surface texture upon which roughness is superimposed [20], is not completely filtered out over a 50mm cut-off length for an STC profile. When measured over a smaller cut-off length such as 0.8mm or 2.5mm, Rt and particularly Ra (= average peak to valley height) correspond much better with values of conventional coatings. This may be appreciated when one would consider the amplitude parameters over a cut-off length $\lambda 1$ instead of $\lambda 2$ as indicated in Figure 3.

It is clear that the micro-roughness of the surface, i.e. the roughness characteristics when considered over a short cut-off length $\lambda 1$, is reduced by the conditioning operation, as may be observed when stage (b) of Figure 3 is compared with stage (a). Moreover, it has been observed that each subsequent conditioning results in a further reduction of the micro-roughness, as may be seen when stage (d) of Figure 3 is compared with stage (b).

It may be emphasized that the roughness of conventional coatings increases each time after underwater cleaning operations, which stands in sharp contrast to the situation shown in Figure 3 for an STC where stage (d) is as smooth as or smoother than stage (b) by benefit of conditioning.

In addition, the durability of an STC gives a significant advantage because it avoids the build-up of roughness that occurs with recoating. A survey done by Townsin *et al.* found that for a variety of reasons 68% of the hulls increased in roughness during dry-docking [21].

Regular cleaning and conditioning is integral to an STC's ship hull performance capabilities, resulting in substantial fuel savings when taken over the lifecycle of the coating. The combination of an absence of hull coating degradation and an absence of biofouling give the STC very significant performance advantages, especially when the entire lifecycle of the hull is considered.

The resulting fuel savings overshadow the costs of underwater maintenance.

4. ECONOMICAL AND ENVIRONMENTAL BENEFITS OF AN STC

The economical benefits are best studied in terms of the lifecycle of a ship, comparing the costs and savings associated with different coating types. One such study was conducted in 2006 [22]. The conclusions of the study are expressed in the chart in Figure 5. The numbers, and therefore the variation in costs between the different coatings, would be considerably emphasized if one substitutes today's fuel prices which are significantly higher than those at the time the study was conducted.

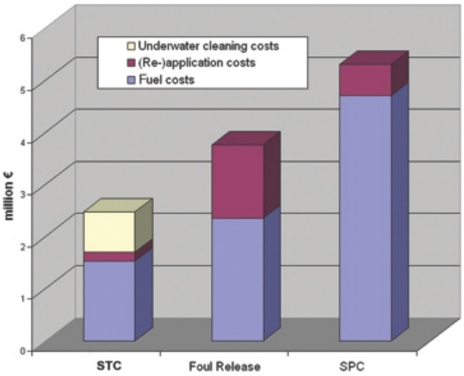

Figure 5. Lifecycle costs of different paint types compared.

In addition to fuel savings, other advantageous factors which need to be considered in the lifecycle analysis of an STC, are the cost of repeated repainting in dry-dock required by AF and FR coatings, much less time to be spent in dry-docks and the elimination of the costs and environmental damages, such as the release of VOC and toxic materials, associated with traditional recoating.

In addition to the reduced greenhouse gas emissions and the very low amount of volatile organic compounds (VOC), non-toxic STCs offer additional environmental benefits in that no toxic substances are released into the environment. Tests have been undertaken to fully validate the non-toxicity of an STC in general use and as a result of underwater cleaning/conditioning. The preliminary results have shown that only non-toxic fine particulate matter is released in quantities that are smaller than the daily release of fine particulate matter of a biological waste processing plant [23]. This indicates that conditioning is an entirely environmentally safe operation.

Complete and easy removal of fouling organisms is a topic of a planned research project. It is well known that ship hull fouling is a vector in the transport of NIS. However, it has been demonstrated that frequent cleaning/conditioning of a ship hull coated with an STC, including the nooks and crannies where unwanted passenger organisms are apt to attach themselves, eliminates the risk of transporting NIS, especially when effective underwater cleaning/conditioning equipment is used. Several systems have been developed, evaluated and used to this end, ranging from large, multi-brush heavy equipment to smaller brush units and underwater high pressure systems.

5. CONCLUSIONS

Surface treated composites (STCs) are formulated for regular in-water conditioning/cleaning throughout the lifetime of the coating without the need for reapplication.

Regular underwater maintenance of ship hulls is often considered as a final remedy for a failed antifouling system. In the case of STCs, however, cleaning and conditioning are an integral part of the hull coating system and can be carried out rapidly at limited cost resulting in improved, rather than repaired or repainted, surface conditions which offer the prospect of significant drag reduction. Moreover, the release of toxic compounds into the aquatic environment is entirely avoided. This system has the added advantage of offering the potential of entirely eliminating the threat of hull-borne invasive aquatic species.

STCs offer a viable antifouling strategy that is entirely non-toxic. A number of applications have led to substantial fuel savings and reduced greenhouse gas emissions. On-going research is being carried out to further quantify the economical and environmental benefits of applying STC.

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9. AUTHORS BIOGRAPHY

Boud Van Rompay is the founder and CEO of Hydrex, an international company delivering underwater technology including a patented non-toxic ship hull coating and fouling control system. He holds a long list of patents for underwater technology developments designed to assist the shipping industry with due regard for protection of the marine environment.