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FOUL RELEASE SYSTEMS AND DRAG

Authors: **M. Candries[1] (University of Newcastle-upon-Tyne), C. D. Anderson[2] (International Coatings) and M. Atlar[1] (University of Newcastle-upon-Tyne)**

Company: **[1]Department of Marine Technology, Armstrong Building**
University of Newcastle-upon-Tyne, Queen Victoria Rd.
Newcastle-upon-Tyne NE1 7RU

[2]International Coatings Ltd, Stoneygate Lane,
Felling, Tyne & Wear
NE10 0JY

e:mail: maxim_candries@yahoo.com
http: **www.geocities.com/maxim_candries**
Telephone: **+ 44 (0) 191 222 89 77**

SUMMARY

Foul Release systems offer a low energy surface that prevents firm adhesion of fouling organisms on underwater hulls. Above a critical threshold speed, hydrodynamic forces wash off any attached organisms. Particularly for fast, high-activity vessels, Foul Release systems offer an environmentally attractive, long-term, cost effective alternative to toxic biocidal antifoulings.

Research carried out at the University of Newcastle-upon-Tyne in the UK has investigated whether the specific surface properties of Foul Release systems have a beneficial effect on drag. Flat plate towing tank experiments carried out in the Department of Marine Technology and in collaboration with CEHIPAR, Spain[*], have shown that the total resistance of Foul Release coatings is lower than that of biocidal SPC antifouling systems, when first applied.

To date, this laboratory-observed drag reduction has only been observed on ships in the first month or two of service life. After this, Foul Release coatings generally only show speed and fuel performance that is similar to, but not better than, that of tributyltin (TBT) SPC antifoulings. This is explained by the accumulation of slime fouling, which can remain attached on Foul Release coatings even at speeds in excess of 30 knots. Raft panel testing and full ship applications of Foul Release systems have shown that the slime does not lead to further fouling, and does not detract from the desirable environmental profile of such coatings.

Given their proven 5 year dock-to-dock capability, even in high fouling areas, Foul Release coatings are therefore ideal as alternatives for fast and active ships as the marine industry moves towards a ban on TBT antifoulings.

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[*] Canal de Experiencias Hidrodinamicas de El Pardo (El Pardo Model Basin), Madrid

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INTRODUCTION

The majority of antifoulings control fouling settlement through the release of biocides from the coating surface. Foul Release coatings work quite differently, and prevent the settlement of the fouling by providing a low-friction, ultra-smooth surface onto which organisms have great difficulty attaching. If vessels are stationary for extended periods, settlement can occur, but there is only weak bonding between the fouling and the Foul Release coating surface and so the organisms can be relatively easily removed, either by underwater cleaning or by the hydrodynamic forces against the surface when the vessel is travelling at speed.

Foul Release coatings were actually conceived almost simultaneously with tributyltin (TBT) self-polishing co-polymers (SPCs), in the early 1970's(1). However the efficacy and commercial benefits delivered by SPCs was such that development work on Foul Release technology was low key for many years except in a few Research laboratories(2). The commercial development of Foul Release systems started in earnest in the 1980's, as the demand for faster delivery times for passengers and cargoes increased, and as vessels with increased design speeds were developed. This work also coincided with the move to ban TBT antifoulings.

The first full Fast Ferry application of a Foul Release coating was on a 33 knot aluminium catamaran, in March 1996(3). Prior to this, the vessel concerned had been coated annually with a low copper TBT-free antifouling, suitable for use on aluminium. This product had required regular in-water scrubbing in the summer months when the fouling was most intense. After the application of the Foul Release coating the operating crew of the vessel noticed an immediate improvement in performance, with in an increase of 2-3 knots in all weather conditions compared to performance when the previous antifouling system was first applied(4). Each journey (of approx. 1 hour) was about five minutes shorter in 1996 than 1995, with an overall fuel consumption reduction of 12%, more than 20,000 litres/month. It was thought that these results were linked to the smoother surface of the Foul Release system and the University of Newcastle-upon-Tyne was contacted to carry out towing tests in order to verify the results and look for an explanation. The preliminary findings from this study are discussed here.

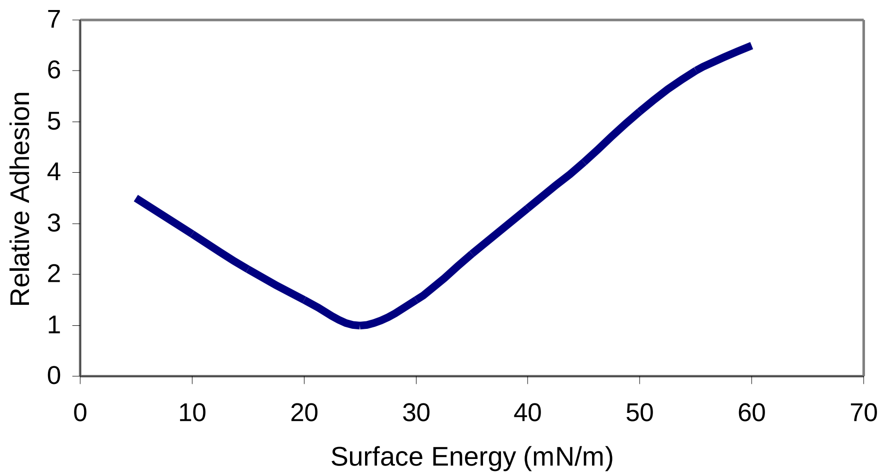
In addition to the surface characteristics, it has also been found that a significant factor affecting the performance of Foul Release coatings is the ubiquitous presence of slime fouling. All Foul Release coatings quite rapidly accumulate a thin adherent layer of slime once they are immersed, and this cannot be easily dislodged simply by the movement of water over the hull, even at speeds in excess of 30 knots. To study the effect of slime on drag is a significant challenge, and one that has not been extensively reported in the literature previously. A discussion on the effects of slime, and some observations of ship data, forms the final part of this paper.

FOUL RELEASE SURFACE CHARACTERISTICS

The Foul Release systems that are in use today are mostly silicone materials based on polydimethylsiloxane (PDMS). PDMS is a non-polar polymer with an extremely flexible (low T_g) backbone, which allows the polymer chain to readily adapt to the lowest surface energy configuration. The surface energy is the excess energy of the molecules on the surface compared with the molecules in the thermodynamically-homogeneous interior. The size of the surface energy represents the capability of the surface to interact spontaneously with other materials(5), (6). Surface energy and the critical surface tension are determined by comprehensive contact angle analyses. The surface tension of a variety of diagnostic liquids is related to the cosines of the angles the liquid droplets make with the coated surface(7). The free surface energy of PDMS in air is 23mN/m, which is a direct result of the low intermolecular forces between the methyl groups(5).

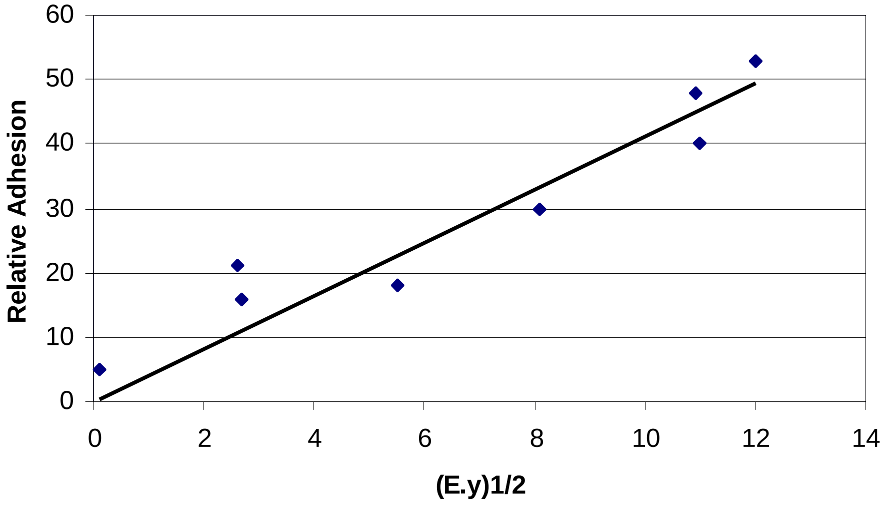
Experiments carried out in the early 1970s examined the adhesion of barnacles and other marine organisms on substrata with different surface energy. It was initially thought that there would be a direct correlation between the surface energy and the adhesion of fouling, and this was indeed found to be the case at higher surface energy values. However at lower values it was found that the adhesion started increasing again, as the surface energy decreased, with the minimum being around 25 mN/m, as shown in Figure 1:

Figure 1: The relationship between surface energy and adhesion(5)



To explain this minimum adhesion, it has been found that two other additional factors are important for Foul Release: the Elastic Modulus (E) and the Thickness(8). A good correlation has been found for the relative adhesion of barnacles and the square root of the product of the surface energy (γ_c) and Elastic Modulus (E), for a range of materials, as shown in Figure 2:

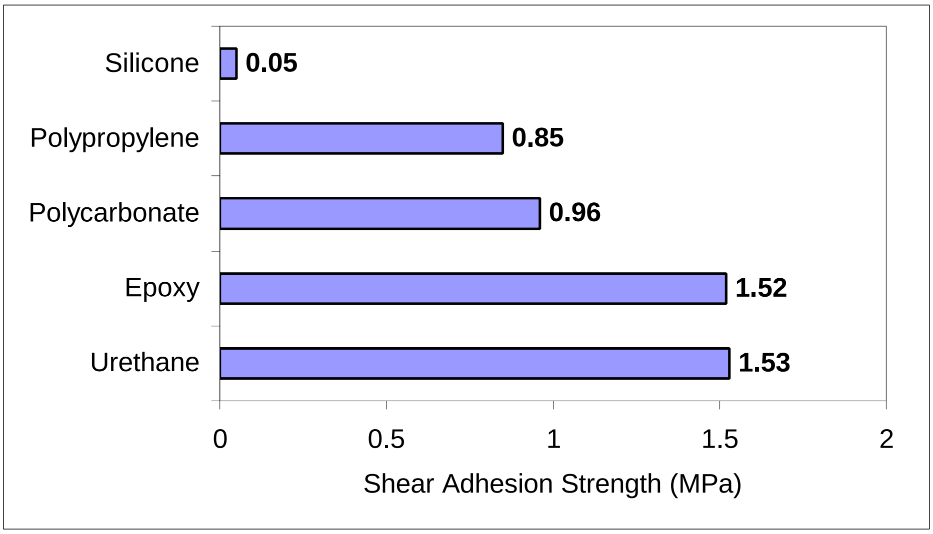
Figure 2: The relationship between $(E.\ \gamma_{\chi})^{\frac{1}{2}}$ and adhesion



A similar relationship has been shown to exist between barnacle adhesion and thickness of Foul Release coatings, with thicker films producing less adhesion(8). It is not so much the thickness itself but the elastomeric nature of thicker films that is important, and this has been demonstrated empirically in field trials. If the film is too thin, barnacles can “cut through” the Foul Release coating to the underlying non-elastomeric substrate, and attach securely.

An ASTM standard (D 5618-94) has been developed to evaluate the dynamic foul release properties of coatings by measuring the adhesion of barnacles in shear. Barnacles are macrofouling organisms that will eventually attach firmly to a submerged surface and thus allow quantification of adhesion on surfaces. The barnacle shear adhesion strength for a Foul Release silicone surface is an order of magnitude lower than that found on other surfaces, as shown in Figure 3:

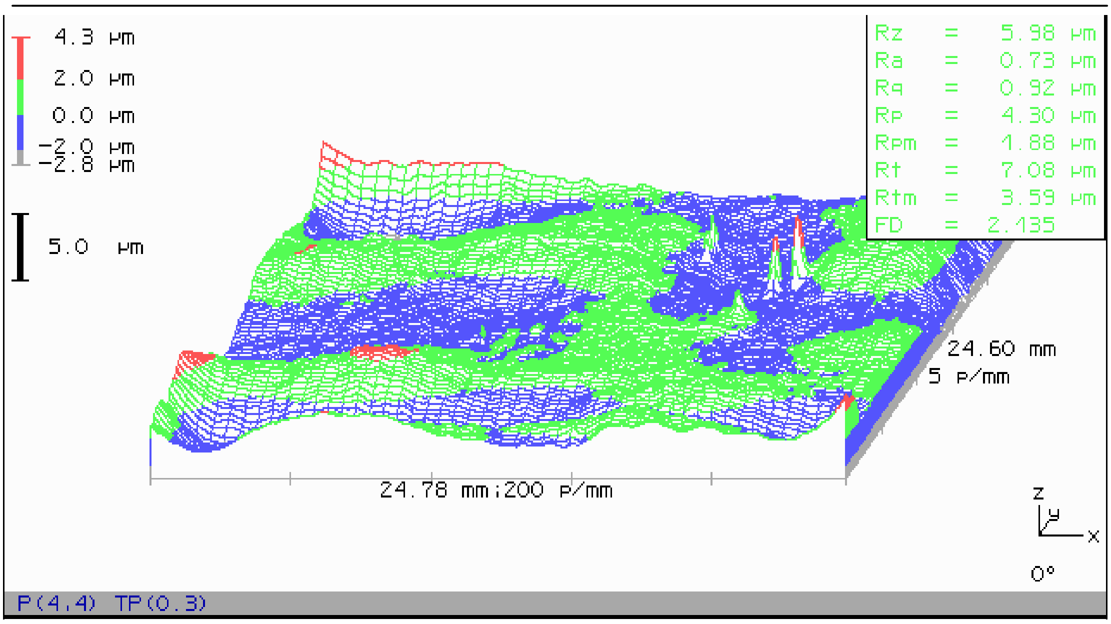
Figure 3: Barnacle Adhesion strength in shear(11)



The speed at which the barnacles can release from Foul Release surfaces has been measured at the Florida Institute of Technology by towing experiments(9, 10), and these trials have shown that the silicone in Figure 3 above would self-clean at about 10 knots. Other fouling species with a low surface profile (such as Bryozoa) can attach more firmly, and it is generally recognised that, with current Foul Release technology, speeds in excess of 15 knots are required to prevent most fouling types settling. If Foul Release were not to occur, fouling organisms would quickly protrude the near-wall viscous sub-layer and increase the drag and roughness of the surface(11-13).

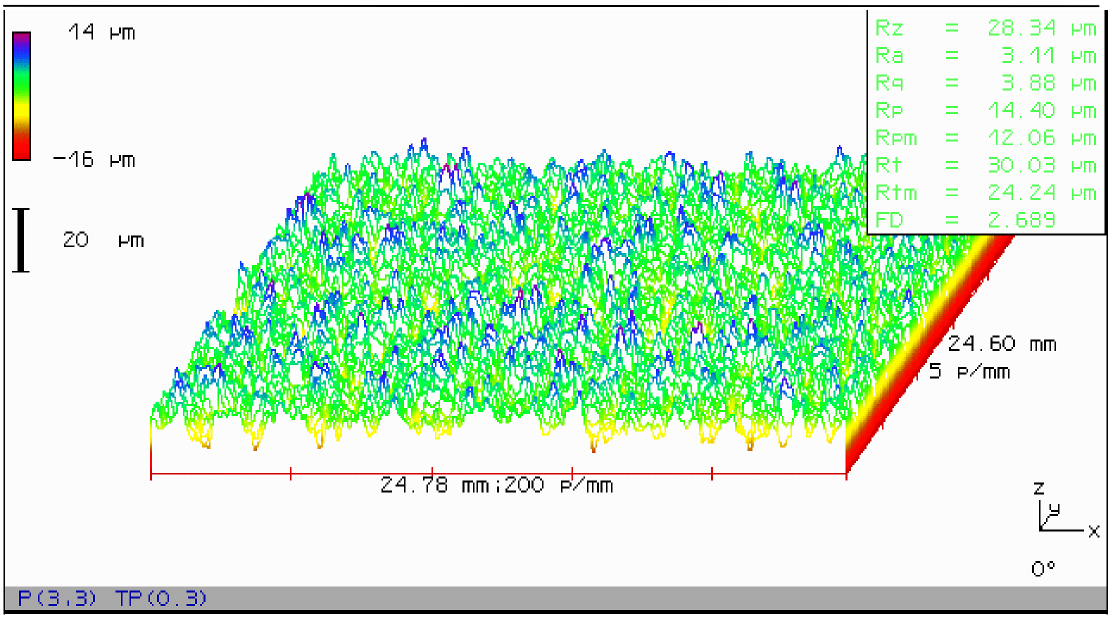
In addition to the Surface Energy, Elastic Modulus and Thickness, smoothness is a very important factor for an effective Foul Release coating. The surface area available for adsorption and attachment increases with decreasing smoothness (or increasing roughness), and the valleys of rough surfaces have a greater surface area for adhesion, and are penetrated by marine adhesives so making it easier for fouling to more readily attach. Moreover, the fouling also finds shelter from shear and abrasion in the crevices and thus roughness also poses a threat to the hydrodynamical removal of the organisms.

Figure 4: Laser profileogram of a sample aluminium plate coated with a Foul Release scheme



Figures 4 and 5 compare the surface profiles of two sample plates, one coated with a Foul Release system, and the other with an SPC antifouling scheme. The wet film thickness of both systems was 350 µm, each carefully applied in 3 coats, and it is clear that the texture of the two surfaces is completely different. The Foul Release system in Figure 4 displays a much smoother micro-surface, with an "open" texture, whereas the SPC antifouling micro-surface in Figure 5 exhibits much steeper and closely packed roughness peaks and valleys, which can be described as a "closed" texture.

Figure 5: Laser profileogram of a sample aluminium plate coated with an SPC antifouling scheme

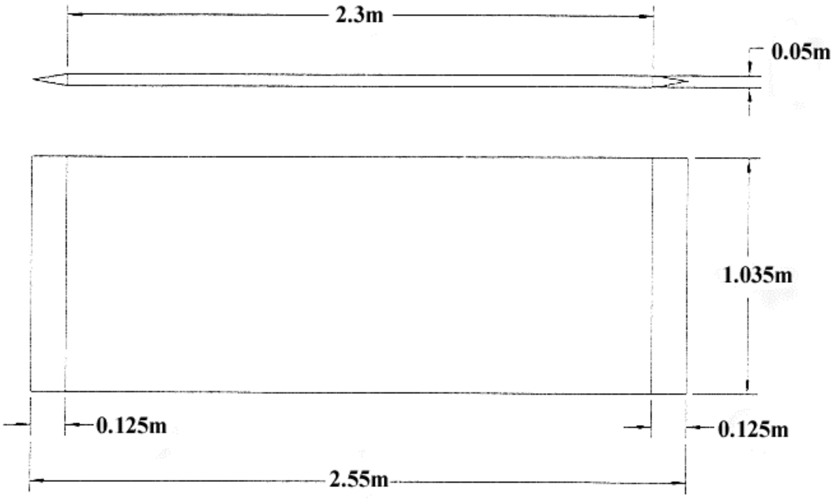


This observation of the differences in the micro-surface texture between Foul Release and SPC coatings resulted in the programme of work to compare the drag of the different surfaces, carried out in the Department of Marine Technology, University of Newcastle-upon-Tyne, UK.

THE DRAG OF FOUL RELEASE SYSTEMS

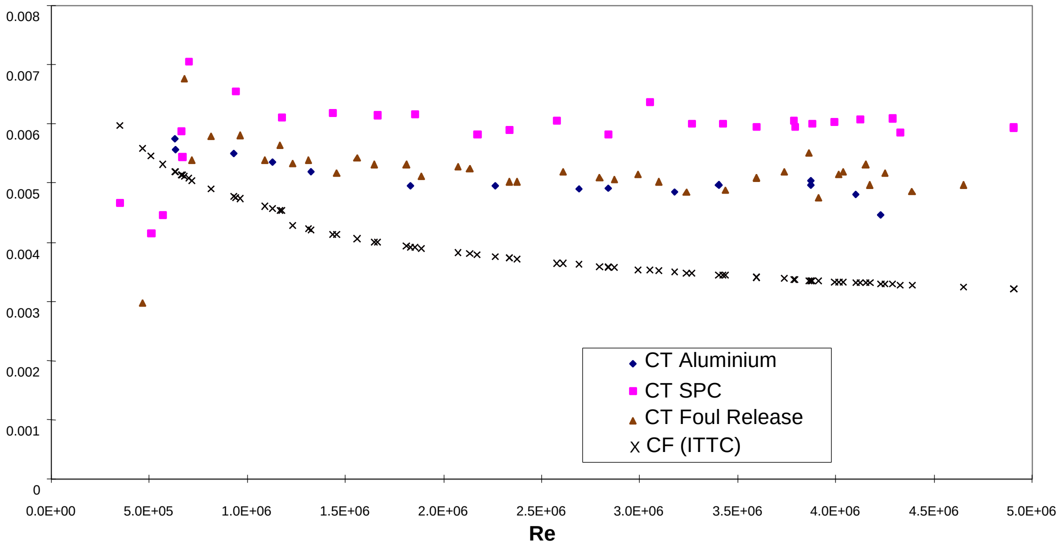
Two sets of flat plate towing experiments were carried out. The first set of experiments involved a 2.55m long plate that was towed in the 40m long, 3.75m wide, 1.2m deep tank of the University of Newcastle-upon-Tyne(14). The aluminium plate, as shown in Figure 6, was towed over a speed range up to 2m/s.

Figure 6: Dimensions of the plate used in the Newcastle towing experiments Newcastle towing Tank



The total drag was measured with 2 suitably designed load cells, which were fitted to the plane and then to the two towing pins at the fore and aft of the plane. The measurements were taken with the three different surfaces, which were the aluminium reference surface, the 3-coat SPC antifouling scheme and the 3-coat Foul Release system. Figure 7 shows the total resistance coefficients for the three surfaces as well as the ITTC-57 friction line plotted against the Reynolds number, and shows the significant difference between the two coatings.

Figure 7: Total Resistance coefficients against Reynolds number (Re) of the three tested surfaces



Because of the limited speed range and run-length in the first set of experiments, the maximum Reynolds number was restricted to 5E6 and the time-span over which measurements were taken was only 3 seconds for the highest speeds.

The second set of experiments was carried out over a much larger speed range, up to 8m/s, with a 6.3m long plate, in the 320m long El Pardo Calm Water Tank, shown in Figure 8(15). The aluminium plate, as shown in Figure 9, was modelled on the NSRDC friction plane model 4125, which has been used for similar experiments at the David Taylor Model Basin(16).

Figure 8: Dimensions of the CEHIPAR Calm Water Tank

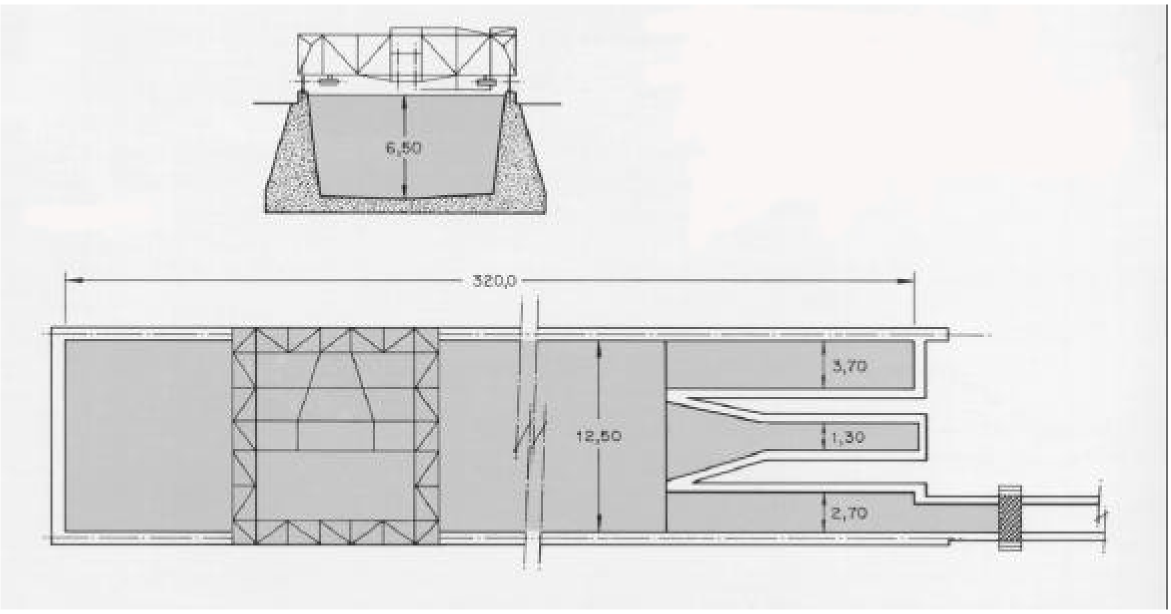
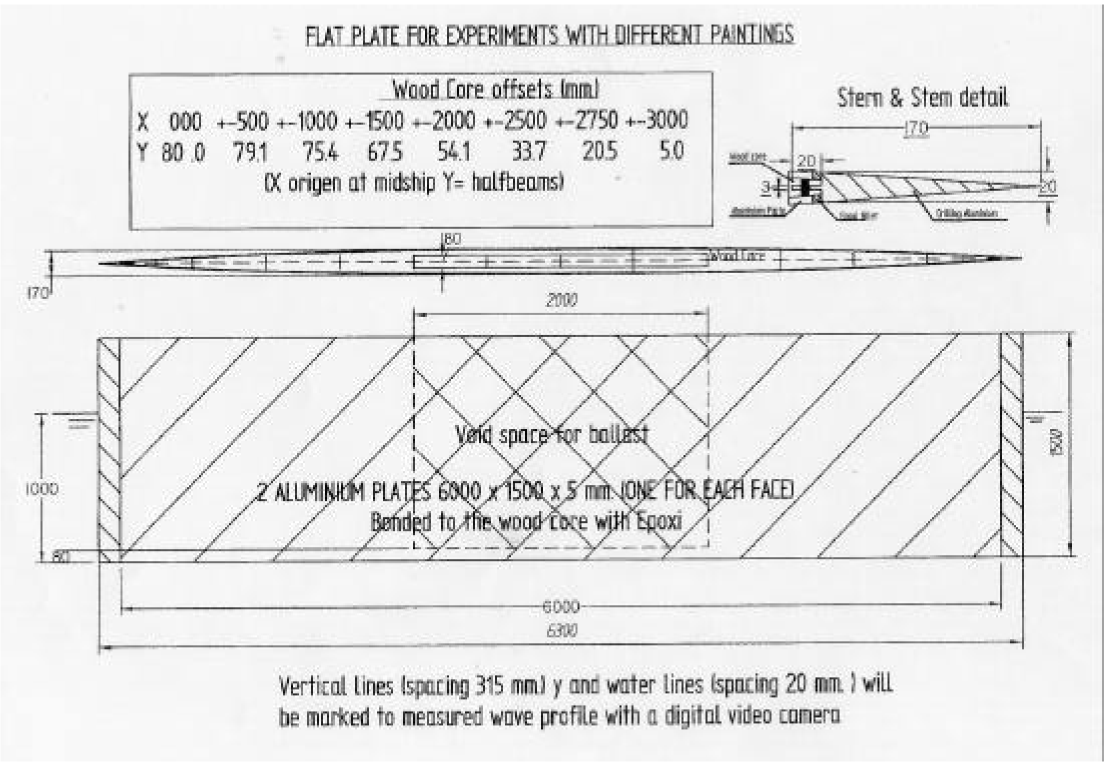


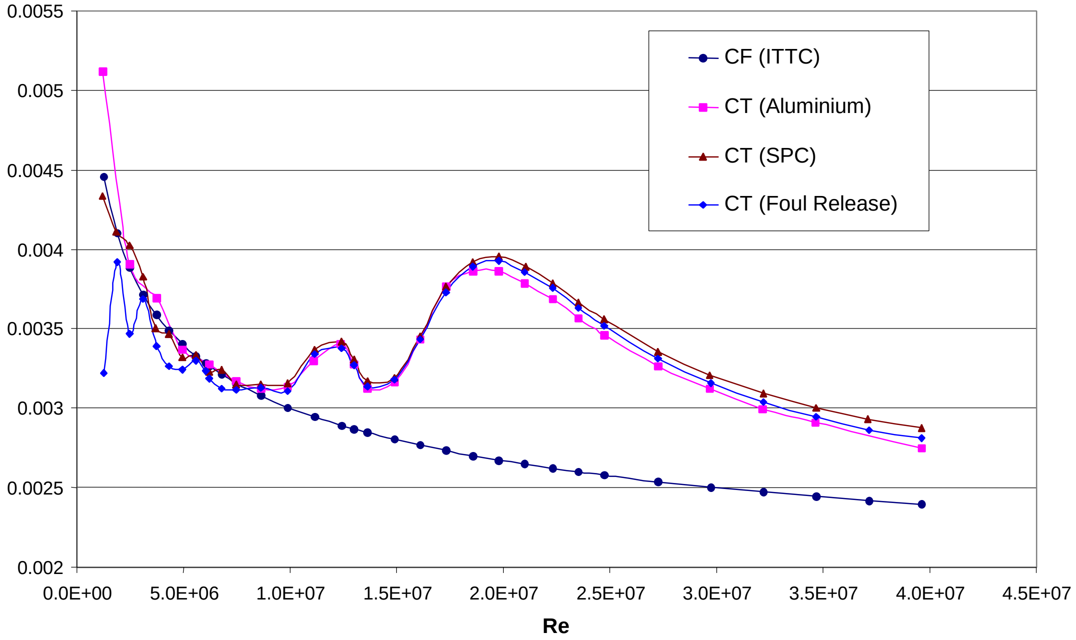
Figure 9: Particulars of the plate used in the CEHIPAR towing experiments.



Vertical lines (spacing 315 mm) y and water lines (spacing 20 mm.) will be marked to measured wave profile with a digital video camera

The total resistance of the plane was measured with the dedicated dynamometer of the carriage for the same three different surfaces: the aluminium reference surface, that coated with a 3-coat SPC antifouling scheme and the surface coated with a 3-coat Foul Release system. Figure 10 shows the total resistance coefficients for the three surfaces plotted against the Reynolds number. Above a Reynolds number Re = 2.0E7, the Foul Release surface exhibits a drag which is on average 1.56% higher than the aluminium surface, and the SPC surface exhibits a drag which is on average 2.91% higher than the aluminium reference. In other words, the total drag coefficient of the Foul Release surface was on average 1.41% lower than the SPC surface.

Figure 10: Total resistance coefficients against Reynolds number in the CEHIPAR Calm Water Tank$^{(15)}$



Compared to Figure 7, the differences in drag are much smaller in Figure 10, and the scatter of Figure 7 is absent. The latter is explained by the fact that during the CEHIPAR experiments, Bessel-function filters were applied immediately during measurement to filter out the vibrations caused by the passing of the carriage over the railway and its undesirable effects on the measured drag values. The reduced difference between the SPC and the Foul Release surfaces can be partly attributed to the difference in roughness of the two surfaces, as discussed in the next section.

Further tests are underway to measure the boundary layer characteristics of the above coating systems, using laser doppler velocimetry (LDV) equipment in the Cavitation Tunnel at the University of Newcastle-upon-Tyne. These tests will provide further insight into the drag characteristics of Foul Release systems.

THE ROUGHNESS OF FOUL RELEASE SYSTEMS

Throughout both sets of flat plane experiments, the roughness of the different surfaces was measured with a BMT (previously known as BSRA) Hull Roughness Analyser, which is the standard equipment for this purpose in marine technology. The ball stylus of the hand-held equipment measures the highest peak to lowest valley perpendicular to the mean line over a 50mm interval, R_{t50}. When the head has traversed the surface over about 0.5m, fifteen readings of R_{t50} and an average, the mean hull roughness (MHR) are printed out. For the small and large plate experiments reported here, in general 10 and 20 values for MHR respectively were averaged to obtain the overall average hull roughness (AHR). It was observed from the beginning that the Foul Release surface required special treatment in that the coated surface had to be wetted slightly in order to get meaningful readings(17). If the surface is dry, the stylus hopped over the rubber-like material whereas if the surface is too wet, the gauge skidded sideways very easily; both practices giving erroneous readings. Table 1 presents the average roughness in microns for the three surfaces for both sets of experiments.

Table I: Average hull roughness (in microns) of the three tested surfaces in both sets of experiments

Average Hull Roughness	*Newcastle Experiments (2.55m long plate)*	*CEHIPAR Experiments (6.3m long plate)*
Aluminium	17	18
SPC	75	39
Foul-Release	48	62

The roughness of the aluminium reference surface was virtually identical for both sets of experiments, but in contrast to the first experiments, the roughness of the Foul Release surface was higher than the roughness of the SPC surface in the second set of experiments. This oddity is explained by the poor surface condition prior to application of the Foul Release surface. The previous SPC coating had been stripped off with the intention of leaving the primer on, but there were large patches where the aluminium was exposed. Thus, instead of applying the Foul Release system on a smooth aluminium surface as in the first set of experiments, the Foul Release Tiecoat and Finish were applied on an uneven primer surface with an average roughness of 37 microns. In contrast the SPC surface was much smoother for the second set of experiments due to a better application than in the first set.

Both sets of flat plane towing tank experiments showed that a Foul Release surface exhibits lower drag than an SPC surface. What is extraordinary is that the Foul Release surface exhibited lower drag in the second set of experiments when measurements had shown that its R_{t50} roughness compared to the SPC surface was actually higher, due to poor surface preparation. R_{t50} is the roughness parameter normally used to correlate the roughness of newly painted surfaces with their drag(18). However, as explained above, laser profilometry has shown that the surface texture of Foul Release coatings is fundamentally different from traditional antifoulings and thus it is possible that R_{t50} may not be a suitable parameter to adequately describe the roughness of Foul Release surfaces.

THE EFFECT OF SLIME ON PERFORMANCE OF FOUL RELEASE COATINGS

Slime accumulates on underwater hulls as a result of the build up of algae, diatoms and bacteria, as well as sediment from the sea bed. Certain SPC antifoulings can reduce slime settlement but this is not possible with Foul Release coatings which do not use biocides to control fouling. The slime has a very low surface profile, and grows within the viscous sublayer near the hull, and can remain intact even at speeds in excess of 30 knots. Being made up of varied biological components, slime films are hard to quantify and therefore do not lend themselves to easy laboratory study.

A study on the effects of slime on drag has been carried out(19) and contains a useful literature review on the subject. In general, most authors agree that slime films increase drag, although on very rough surfaces it is suggested that slime films may actually smoothen the surface and so give a reduction in drag. The size of the increase in drag caused by slime (“microfouling”) is an order of magnitude lower than that of weed and barnacles (“macrofouling”), with weed fouling equating to an increases in roughness of at least 500 µm.

Attempts have made been to replicate slime films in the laboratory by use of nylon tufts(20), and this study showed an increase in the shear stress coefficient of 18%. This is similar to a study on fibre floc surfaces, which showed that they have a higher total coefficient of friction than that of a badly cleaned or medium density covered barnacle surface(21). In other experiments(22), slime films were replicated by the use of agar-gel of different concentrations. Towing tests carried out with a flat plate subsequently showed that the frictional resistance increased and these results show good agreement with experiments carried out with discs on which slime films were grown in laboratory from batch cultures(23).

On ships, the following observations concerning slime fouling on Foul Release systems have been made:

- The thickness of the slime fouling is inversely proportional to the vessel speed.
- Slime build-up is usually thicker on the area below the bilge keel than above it.
- Even with the slime, the speed and fuel consumption of a vessel with a Foul Release system are similar to that with a TBT SPC scheme.
- The slime is readily removed in dry-dock or by in-water cleaning.
- Fish “grazing” marks are often evident in the slime

The fact that full ship applications have confirmed that Foul Release coatings give similar speed and fuel consumption data to SPC antifoulings can be explained as follows: initially (based on the laboratory drag tests described earlier) the Foul Release coating has less drag than the SPC system, but after a few weeks the slime builds up and this increases the drag to the level of the SPC system.

At present, there appears to be no easy way to prevent this accumulation of slime fouling (apart from the addition of biocides). But in contrast to biocidal antifoulings, the slime on Foul Release coatings does not provide a base on which further larger forms of fouling (“macrofouling”) can settle. Weed fouling is almost never seen on Foul Release coatings, even after prolonged immersion, and shell (barnacle) fouling only occurs in static situations.

Overall, leading Foul Release product performance has been proven to be equivalent to TBT SPC antifoulings, even in high fouling environments, for in-service periods of up to 60 months. So despite the slime, well formulated and proven Foul Release systems must be considered as being close to the ideal as alternatives to TBT SPC products for ships that are fast (> 15 knots) and active.

CONCLUSION

Two sets of towing tank experiments using a Flat Plane have shown that a PDMS Foul Release system has less drag than a typical SPC antifouling, when initially applied. In the first experiment this reduction in drag could be correlated with the surface roughness, Rt_{50}, as measured using the BMT Hull Roughness Analyser, but in the second the roughness of the Foul Release system was higher than that of the SPC antifouling. This indicates that some other parameter is associated with the drag of Foul Release coatings. A surface profile scan comparing a Foul Release surface to an SPC antifouling surface shows that the texture of the two surfaces is quite different.

In order to provide further insight into the drag characteristics of Foul Release systems, boundary layer measurements using LDV techniques are being carried out in the Cavitation Tunnel at the University of Newcastle-upon-Tyne, UK.

Data from full ship applications of Foul Release coatings in service shows that the ubiquitous presence of slime fouling appears to off-set the initial reduced drag. However this is not a large effect, and even with this slime present, Foul Release coatings give equivalent speed and fuel performance to TBT SPC antifoulings.

Leading Foul Release coatings also have the proven 60-month capability of TBT SPC antifoulings, in strong fouling areas, and so with their highly attractive environmental profile, these products are close to the ideal as fouling control systems for fast and active ships in the 21st century.

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REFERENCES

1. A. Milne, *British Patent* 1,470,465
2. R.F. Brady et al, *Journal of Coatings Technology*, 59 (755), 113 ff, December 1987, (1987).
3. J. Millett and C.D. Anderson, ‘Fighting fast ferry fouling’, *Fast ’97, Conference papers, Vol. 1*, Baird Publications, Australia (1997).
4. Personal Communication from Fred Neville, Ship Manager, Condor Marine Services Ltd., Hamworthy, Poole, Dorset, England BH15 4AJ
5. R.F. Brady, ‘In search of non-stick coatings’, *Chemistry & Industry*, www.mond.org/9706/970615.html (1997).
6. H.L. Vincent and G.G. Bausch, ‘Silicon fouling release coatings’, *Naval Research Reviews*, Vol. 49, Office of Naval Research (1997).
7. R.E. Baier, A.E. Meyer and R.L. Forsberg, ‘Certification of properties of nontoxic fouling-release coatings exposed to abrasion and long-term immersion’, *Naval Research Reviews*, Vol. 49, Office of Naval Research, pp. 60-65 (1997).
8. R.F Brady and I.L Singer, ‘Mechanical factors favouring release from fouling release coatings’, *Biofouling,* 15 (1-3), pp. 73-81 (2000).
9. B.S. Kovach and G.W. Swain, ‘A boat mounted foil to measure the drag properties of antifouling coatings applied to static immersion panels’, *Proc. Int. Symp. Seawater Drag Reduction*, July 22-24, Newport, Rhode Island (1998).
10. G.W. Swain, ‘Redefining antifouling coatings’, *PCE July 1999,* pp18ff. (1999).
11. J.C. Lewthwaite, A.F. Molland and K.W. Thomas, ‘An investigation into the variation of ship skin frictional resistance with fouling’, *Trans. R.I.N.A*., Vol. 127, pp. 269-284, London (1984).
12. M.P. Schultz and G.W. Swain, ‘The effect of biofilms on turbulent boundary layers’, *Journal of Fluids Engineering,* Vol. 121, pp. 44-51 (1999).
13. G.W. Swain, ‘Biofouling control: a critical component of drag reduction’, *Proc. Int. Symp. Seawater Drag Reduction*, July 22-24, Newport, Rhode Island (1998).
14. M. Candries, M. Atlar, G.H.G. Mitchell, and D. Lamb, ‘Flat plane towing experiments with two coatings’, *Report No. MT-1998-034*, Department of Marine Technology, University of Newcastle-upon-Tyne (1998).
15. M Candries and M. Atlar, “Influence of Two Different Antifoulings on the Resistance of Roughness of a Flat Plate”, *Report No. MT-2000-102,* Department of Marine Technology, University of Newcastle-upon-Tyne, 2000.
16. E.E. West, ‘The effect of surface preparation and repainting procedures on the frictional resistance of old ship bottom plates as predicted from NSRDC friction plane model 4125’, *Report 4084*, Naval Ship Research and Development Center, Bethesda, Maryland (1973).

17. C.D Anderson, R.L. Townsin, and M. Candries, 'Idiosyncracies of low surface energy (foul-release) antifoulings: drag, roughness and maintenance'. Presented by C.D. Anderson at the *10th International Congress on Marine Corrosion and Fouling*, Melbourne, Australia (1999).
18. R.L. Townsin and S.K. Dey, 'The correlation of roughness drag with surface characteristics', *Marine Roughness and Drag Workshop*, Paper 8, R.I.N.A, London (1990).
19. M.P. Schultz and G.W. Swain, "The influence of Biofilms on Skin Friction", *Biofouling*, 2000, Vol 15(1-3) pp 129-139.
20. A.K. Lewkowitcz and P.K. Das, 'Turbulent boundary layers on rough surfaces with and without a pliable overlayer: a simulation of marine fouling', *Proceedings of the A.S.M.E./A.S.C.E.Bioengineering Fluid Engineering and Applied Mechanics Conference,* pp. 174-186 (1981).
21. M. Leer-Andersen, 'Two studies of ship flows: Skin Friction measurements on Fouled and Structured surfaces', *Report submitted for fulfilment of the degree of Licentiate of Engineerring,* Chalmers University of technology, Gothenburg, Oct 1999, p61.
22. A.F. El-Labbad, 'Techno-economic analysis of the problems of the bottom maintenance of ships', *MPhil Thesis*, Department of Marine technology, University of Newcastle-upon-Tyne, (1987).
23. G.I. Loeb, D. Laster and T. Gracik, 'The influence of microbial fouling films on hydrodynamic drag of rotating discs'. In J.D. Gostlow and R.C. Tipper (Eds.): *Marine Biodeterioration: An Interdisciplinary Study*, Naval Institute Press, Maryland USA (1984).