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Research Article

Experimental Study of Impact of Foul Release with Low Surface Energy on Ship Resistance

Abstract

A comparison between coating frictional resistances of several ship hulls has been conducted by experimental studies (Foul Release and conventional paint) in the unfouled conditions in Hydrodynamic open water tests in a lake using a ship model test.

Models are completely similar, in order to eliminate other factors of resistance such as wave-making resistance and viscous pressure resistance. Foul Release systems based on silicon offer a low surface energy and smooth surface that prevents adhesion of fouling organisms on underwater hulls. Wall roughness measurement was carried out by roughness analyzer and there is not much difference between Foul Release and conventional paint roughness. The results indicate that model with low surface energy has lower resistance compared to model with higher energy surface.

Introduction

The most widely applied marine antifouling's is Tributyl-Tin Self-Polishing Co-Polymers (TBT-SPC), which can keep a surface of ship free of fouling for 5 years by means of a steady release of the TBT toxin. Due to environmental side-effects related to TBT, the International Maritime Organization (IMO) decided in October 2001 to phase out the use of TBT-SPCs until 2008. There are currently two alternatives on the market that can also offer 5 years of satisfactory antifouling performance. The first alternative, Tin-free SPC, uses the same chemical principle, but instead of TBT, gradually leaches copper-based toxins which are complemented by so-called "booster biocides". The second type, Foul Release coatings, works by an entirely different principle. Instead of killing marine organisms that have attached to the hull, they try to prevent the stick of the fouling by providing a low surface energy onto which organisms have great difficulty attaching. If vessels are stationary for short times, 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, by the hydrodynamic forces against the surface when the vessel is travelling fast enough. The Foul Release coatings described in this paper are silicone elastomers based. Experimental studies on the attachment of fouling organisms to different types of materials have shown that silicones are least prone to foul [1,2]. Eventually, all surfaces will foul, but experiments have also shown that the strength of attachment of the organisms on silicones is lower than other materials. Kovach and Swain towed a plate, which was coated with a Foul Release system and covered by fouling, at different speeds and showed that the organisms started to release at speeds above 12 knots [3]. These antifoulings are therefore particularly suited for ships which spend a short time in port and travel at sufficiently high speeds.

The hull condition has important effect on the operation of marine vehicles. Highlighting the impact of Skin friction on some displacement ships, it has the share of about 90% of the total drag even in absence of hull fouling [4]. Hence, understanding and predicting of frictional drag must be the seat of focus in this research. To find out the influence of surface roughness on the frictional drag of marine paints, some investigations was conducted by Musker [5], Townsin et al. [6], Granville [7], Medhurst [8], Grigson [9] and Schultz [10]. Most of these studies were concentrated on analyzing the change in roughness and drag of the self-polishing copolymer (SPC) TBT systems, probably because of persistent fouling control against minimal fouling settlement in the TBT systems. A substantial part of research has been dedicated to studying the effects of fouling on drag specially the calcareous macro fouling (barnacles, oysters, etc.) and is reviewed in Marine Fouling and its prevention [11]. Focusing on the effect of plant fouling and biofilms, as well, date back to McEntee [12]. Moreover, further studies to acquire higher quantify of slime films effect on drag were carried out by Picologlou et al. [13]. To detect the effect of fouling on the drag of copper-based coatings full-scale ship tests were performed by Haslbeck and Bohlander [14]. Schultz and Swain [15] and Schultz [16] studied the details of turbulent boundary layers developing over biofilms and filamentous algae, respectively, using laser Doppler velocimetry. As a consequent, all of these studies showed that relatively thin fouling layers can significantly enhance the drag.

In some primary data from Candries et al. it can be seen that despite having a lower mean roughness in the unfouled condition, fouling-release systems may have slightly less frictional resistance than traditional Antifuling coatings [17].

There are little data to investigate effect of energy surface on ship resistance. The objective of present experimental investigation is to study effect of energy surface on ship resistance. The details of method and results of model test have been explained in the next sections.

Surface analysis

A large number of Foul Release coatings that are in use today

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are based on silicone, with an extremely flexible backbone, which allows the polymer chain to readily adapt to the lowest surface energy configuration. The size of the free surface energy represents the capability of the surface to interact with other materials. Figure 1 shows relationship between relative adhesion and free surface energy. It was found experimentally that the relative adhesion of fouling organisms on a material is directly proportional to √ where by E is the elastic modulus of the material, and **y** is surface energy, direct relationship between relative adhesions and √ has been established, as shown in Figure 2 [19]. Surface energy of silicone materials is at least an order of magnitude smaller than for other materials. Moreover, if organisms eventually do attach to the surface with foul release coating, it has been shown that they attach less strongly than on other materials (provided the coating is applied thickly enough), which explains why fouling organisms can release from the surface under the influence of hydrodynamic forces. An effective Foul Release coating relies on the smoothness of its surface. Surface free energy and the surface area available for adsorption and attachment of fouling organisms increase with roughness. The valleys of rough surfaces are penetrated by marine adhesives, therefore fouling will 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 hydrodynamic removal of the organisms. Because of the fact that fouling organisms attach less quickly and less strongly on Foul Release surfaces it could be expected that the material is in some ways smoother than most surfaces. In turn this could explain why Foul Release surfaces exhibit less drag than other surfaces.

Although the no-slip boundary condition is the standard for any interface between a fluid and a solid, but this condition there was not always hold. The existence of a slip velocity can have a dramatic effect on the shear stress at the wall. Flow with a thin shear region near the wall, even a small slip velocity on solid surface will drastically reduce the velocity gradient at the wall and, therefore, the skin friction drag. Slip velocities may result from a variety of factors that affect interactions between the fluid and the solid surfaces. For example, slip has been observed for the flow of water over hydrophobic surfaces. Hydrophobic surface is made with low surface energy such as foul release coating based on silicon. Figure 3 shows slip velocity and slip length.

Experimental facilities and method

The open water test was in a lake with geometry of 1.2 km length, 100 m width and depth of 2.5m, the model has been towed by a catamaran. The catamaran has a velocity range of 0–18 knots. In Figure 4 the catamaran with its Equipment is shown. In current research a variety of model velocity has been used. To measure and control the velocity of catamaran an encoder on the board has been used. Fresh water was chosen as working fluid in the experiments. A thermocouple with digital readout was used to monitor the temperature of water with the accuracy of 0.05°C during the experiments. The water temperature was about 17°C.

Two sets of model test is performed, in first set, two models of container ship with bow are tested and in second set two models of conventional ship without bow are tested. In the first set, two models were constructed in GRP with lightweight closed-cell polyurethane foam, putting a lot of attention to minimizing the weight, size of models are shown in Table 1. All surfaces to be coated should be clean. On model A1 (gray model) Intershield 300, Intersleek 737 and Intersleek 757 applied respectively (surface energy=30 (mN/m)). On model A2 (yellow model) conventional paint was applied (surface energy=44 (mN/m)). Figure 5 shows both models.

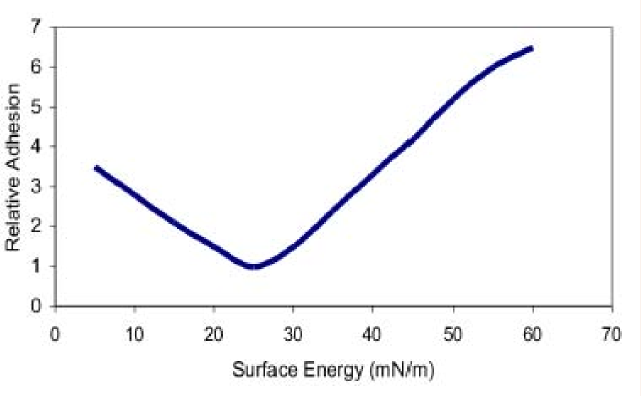

Figure 1: The relationship between surface energy and adhesion [19].

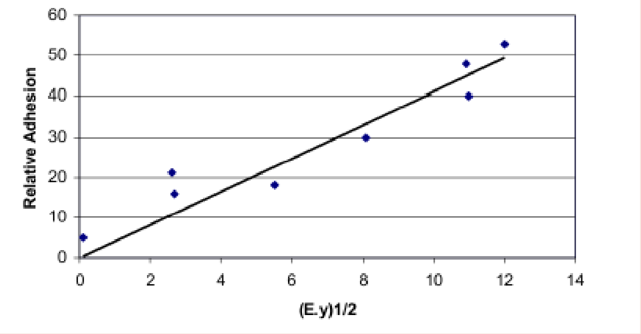

Figure 2: Relative Adhesion as a function of (E.y)1/2 [19].

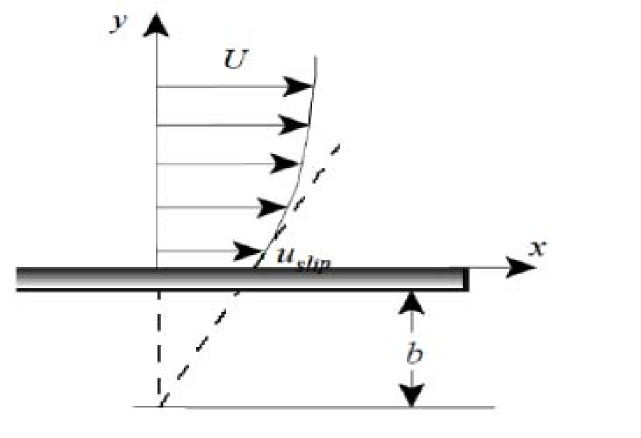

Figure 3: Diagram showing the slip velocity and slip length.

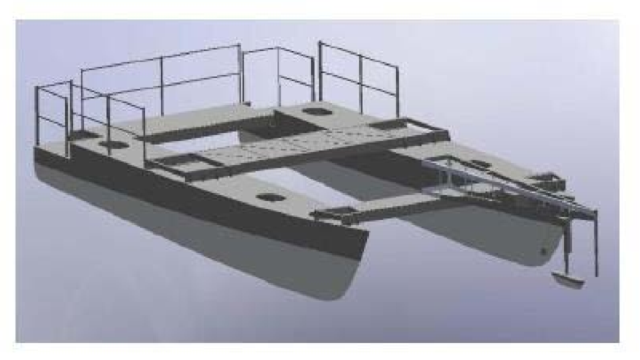

Figure 4: Schematic of model carriage.

Table 1: Characteristic of 1. 2 m ship model.

Description	Dimensions
Length over all	1.2 m
Length of waterline	1.16 m
Draft	0.07 m
Maximum velocity	2.7 kn
Weight	8.23 kg
Longitudinal center of gravity	0.45 m

Figure 5: 1.2 m ship model.

In second set of model test, models were constructed in the same process as the first set, size of models are shown in Table 2. All surfaces to be coated, as mentioned for the first set, should be clean. Three difference layers of paint were applied on the model surface. On model B1 Intershield 300, Intersleek 737 and Intersleek 757 applied respectively (surface energy=30 (mN/m)). On model B2 Intershield 300, Intersleek 737 and Intersleek 757 Additive SA-162 applied respectively (surface energy=26 (mN/m)). Figure 6 shows both models.

Wall roughness

Experiments indicate that the mean velocity distribution near rough walls, when plotted in the usual semi-logarithmic scale, has the same slope $(\frac{1}{k})$ but a various intercept (additive constant B in the log-law). Thus, the law-of-the-wall for mean velocity modified for roughness has the form [20]:

$$\frac{u_p u^*}{\frac{\tau w}{\rho}} = \frac{1}{k} In(E\frac{\rho u_p u}{\mu}) - \Delta B \tag{1}$$

$$u^* = C_\mu^{1/4} K^{1/2} \tag{2}$$

$$\Delta B = \frac{1}{k} In f_r \tag{3}$$

$$k_S^+ = \rho k_S u^* / \mu \tag{4}$$

Where f_r is a roughness function that quantities the shift of the intercept due to roughness effect. ΔB depends, in general, on the type (uniform sand, rivets, threads, ribs, mesh-wire, etc.) and size of the roughness. There is no universal roughness function valid for all types of roughness. For a sand-grain roughness and similar types of uniform roughness elements, however, ΔB has been found to be well correlated with the non-dimensional roughness height (k_S^+), where k_s is the physical roughness height and μ^* Analysis of experimental data shows that the roughness function is not a single function of k_S^+ but takes different forms depending on the k_S^+ value. It has been observed that there are three distinct regimes:

1) Hydro dynamically smooth $^+ \leq 2.25$
2) Transitional $2.25 < + \leq 90$
3) Fully rough $+ > 90$

According to the data, roughness effects are negligible in the hydro dynamically smooth regime, but become increasingly important in the transitional regime, and take full effect in the fully rough regime [18]. Wall roughness measurement was carried out by roughness analyzer. Figure 7 shows the roughness analyzer. This instrument measures arithmetic average height (Ra), maximum height of the

Table 2: Characteristic of 1.89 m ship model.

Description	Dimensions
Length over all	1.89 m
Length of waterline	1.77 m
Draft	0.07 m
Maximum velocity	7 kn
Weight	10.77 kg
Longitudinal center of gravity	0.73 m

Figure 6: 1.89 m ship model.

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profile (Rt) and largest peak to valley height (Ry). Arithmetic average height (Ra) is the most universally used roughness parameter for general quality control. It is defined as the average absolute deviation of the roughness irregularities from the mean line over one sampling length. Maximum height of the profile (Rt) is defined as the vertical distance between the highest peak and the lowest valley along the assessment length of profile. Largest peak to valley height (Ry) is defined as the largest value of the maximum peak to valley height along the assessment length. The roughness parameters are shown in Table 3. k_S^+ for all surfaces is about 6.2.

Resistance calculation

When a fluid flows around the outside of body, a kind of energy transfers between the body and fluid that tends to drag it in direction of the flow. This drag is divided into two forms of skin friction drag and form drag. Skin Friction or viscous drag is caused by the interaction between fluid particles and surface of the body in the fluid. Boundaries between the surfaces of the body and the layer of fluid particles in contact with the surface, cause these particles to be held in place on the surface. In this condition, there is a linear decreasing in fluid particles velocity from the moving body to the stationary bulk fluid till the fluid particles velocity reaches to the bulk fluid velocity. Decreasing in velocity has happened because of the forces between layers of fluid particles (intermolecular bonds) that pull each successive fluid layer and accelerate it. As flow velocities increase, there is no distinct direction for particles motion. Fluid particles exhibit velocity components in any directions and move in swirling motions such that the point velocities in the fluid flow are totally different but the average velocity is maintained in the direction of flow. In the turbulent flow and in the vicinity of the body there is a very thin layer of fluid where turbulent fluctuations are damped (viscous sub layer) and velocity varies linearly in it. Outside of this region, the layers of the turbulent boundary layer are more chaotic and disorganized. At the surface in the viscous sub layer, some stream wise vortices are created that outward ejection of these vortices causes the disorganized motion of layers in turbulent flow. As these vortices rotate and flow along the surface, they can independently translate back and forth across the surface in the cross flow direction. When the vortices in the flow collide with the surface and vortices in the vicinity of surface, an interaction between them causes the immediately ejection from the surface into the outer boundary layer. In this condition vortices that are ejected tangle with other vortices and twist such that transient velocity vectors in the cross stream direction can become as large as those in the average flow direction. The translate laminar flow to the turbulent flow, ejection of vortices out of the laminar sub layer and disorganized flow in the outer layers of the turbulent boundary layer flow are all forms of momentum transfer and are large factors in fluid drag. Coatings with lower surface energy could increase speed of fluid in nearest layer to the body, subsequently, could diminish both velocity gradient and ejection of vortices which impact directly on turbulence intensity in outer layer and wall friction.

Models were built and tested according to size and speed of real ships based on Froude number. Figure 8 shows a model of container ship at the time of testing. The results are shown in Tables 4,5 and Figures 9-12. Wall roughness for all models is similar. It can be seen that models experienced hump in Froude number A1 =A2=0/15 and 0/33, B1 = B2=0/6, similar to displacement and semi displacement ships. Resistance of model A1 (surface energy=30 (mN/m))is lower than A2 (surface energy=44 (mN/m)) due to coating with lower surface energy, it could increase speed of fluid in layer near to surface and diminish velocity gradient and ejection of vortices to outer layer. In the second study, surface energy of two types of coating were very similar about 26 versus 30 (mN/m) for model B2 and B1 respectively,

Figure 7: The hull roughness analyzer.

Table 3: Roughness statistics for all test surfaces.

Model	Ra (μm)	Rt (μm)	Ry (μm)
Model **A$_1$**	3.43	18.75	11.03
Model **A$_2$**	3.98	21.62	12.76
Model **B$_1$**	3.12	20.45	11.76
Model **B$_2$**	3.68	19.43	10.79

Figure 8: Model of container ship at time of testing.

Table 4: Resistance result of models 1.2m.

Velocity (kn)	Froude NO.	Resistance of model A$_1$ (N)	Resistance of model A$_2$ (N)
0.5	0.074963	0.5	0.6
1	0.149926	0.8	1
1.25	0.187407	0.7	0.9
1.5	0.224888	0.8	1.05
1.75	0.26237	1.2	1.45
2	0.299851	1.6	1.9
2.2	0.329836	1.85	2.1
2.4	0.359821	1.75	2

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Table 5: Resistance result of models 1.98m.

Velocity (kn)	Froude NO.	Resistance of model B_1 (N)	Resistance of model B_2 (N)
2.65	0.33	3.85	3.54
3.47	0.44	5.55	5.2
3.86	0.49	6.7	6.25
4.31	0.53	7.5	7.2
4.79	0.59	8.15	7.9
4.99	0.63	8.27	8.1
5.39	0.66	8.35	8.2
5.7	0.70	9.1	8.7
6.3	0.78	10.3	9.6
7	0.86	11.4	11.05

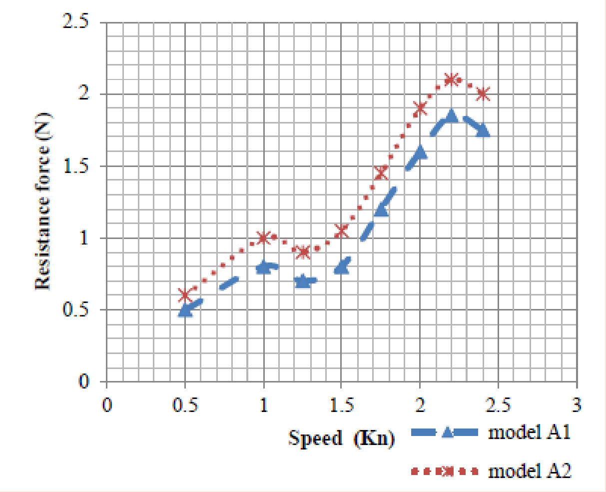

Figure 9: Resistance force versus speed for 1.2 m model.

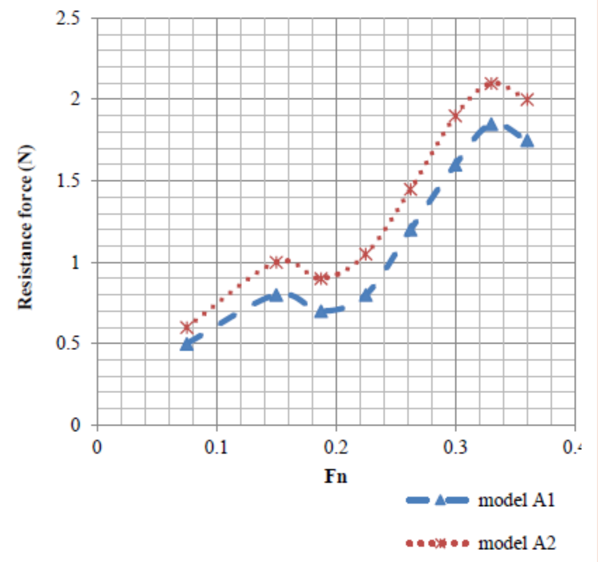

Figure 10: Resistance force versus Froude number for 1.2 m model.

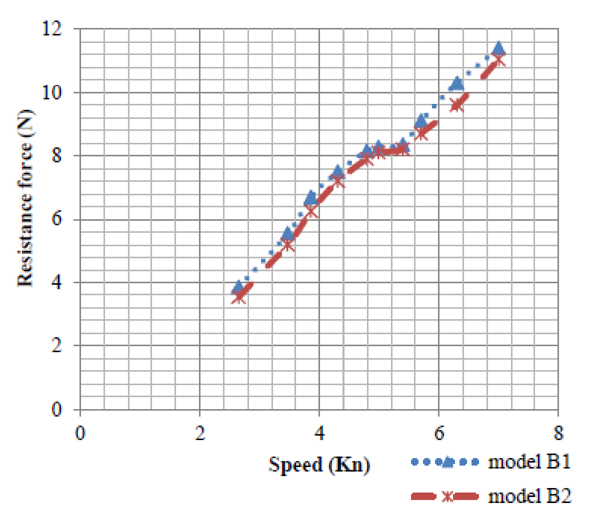

Figure 11: Resistance force versus speed for 1.89 m model.

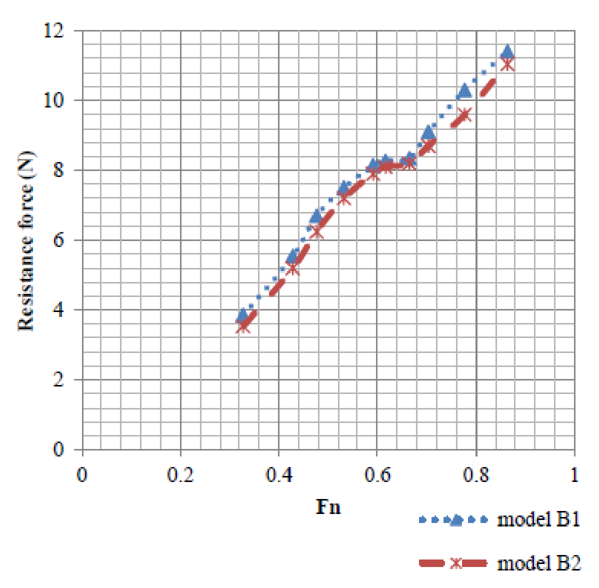

Figure 12: Resistance force versus Froude number for 1.89 m model.

as shown model with lower surface energy could decrease velocity gradient and handle lower amount of ejection, however the resistance difference is not striking.

Conclusions

In order to compare the frictional resistance of any types of coatings (Foul Release and conventional paint) in the unfouled conditions, hydrodynamic open water tests were performed. The models are similar, in order to eliminate other factors of resistance such as wave-making resistance and viscous pressure resistance. Foul Release systems based on silicon offer a low surface energy and smooth surface that prevents adhesion of fouling organisms on

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underwater hulls. Wall roughness measurement was carried out by roughness analyzer and there were not much differences between Foul Release and conventional paint roughness. The results indicate that model with low surface energy has lower resistance in comparison to model with higher energy surface. So the paint of Inter sleek 757 with Additive SA-162, has better performance to decrease hydrodynamic resistance.

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