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Drag resistance measurements for newly applied antifouling coatings and welding seams on ship hull surface

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Abstract

Drag resistances of newly applied antifouling coatings and welding seams on ship hull surface have been investigated using a pilot-scale rotary setup. Both conventional biocide-based antifouling (AF) coatings and silicone-based fouling release (FR) coatings have been studied and compared in their newly applied conditions. The effects of water absorption of newly applied antifouling coatings on frictional resistance were measured. A flexible rotor with artificial welding seams on its periphery has been designed and constructed to estimate the influence of welding seams on drag resistance. Both the density of welding seams (number per 5 m ship side) and the height of welding seams had a significant effect on drag resistance.

Introduction

Biofouling on ship hull surfaces, defined as the undesirable accumulation of marine species, such as bacteria, algae, slime, seaweed, barnacles and tubeworms, decreases the speed and/or increases fuel consumption. This leads to increased emissions of harmful gases (CO_2, SO_2, and NO_x), higher frequency of dry dockings, as well as translocation of invasive species [1]. Consequently, the increased surface roughness from biofouling increases drag resistance. A part of the added drag resistance is due to residual resistance from wave and eddy formation. Nevertheless, the major part is due to frictional resistance which accounts for 60-90% of the total drag resistance [2]. For this reason, predicting frictional resistance has been an active research area for decades.

To limit biofouling, the ship hull surfaces are normally protected by antifouling coatings. The conventional biocide-based antifouling (AF) coatings release biocides, which are toxic to marine organisms during the immersion period. Alternatively, silicone-based fouling release (FR) coatings, which possess low-energy and smooth surfaces, minimize the adhesion between marine organisms and coating surface so that the marine organisms can be removed by hydrodynamic force (i.e. when the ship sails). However, the surface roughness condition varies among different antifouling coatings, where rough coating surfaces will increase the risk of biofouling and frictional resistance when the surface is still free of biofouling. Therefore, the initial surface roughness condition of antifouling coatings is of significant importance to the frictional resistance and the performance of large marine vessels.

Ship owners have observed some performance differences between the two types of coatings up to some weeks sailing period when the ship hull surfaces are still free of biofouling. So, there may be an economic benefit to harvest for large ships. The present work has focused mainly on estimating frictional resistance and comparing different newly applied antifouling coatings. Hence, the biofouling process associated with drag will not be covered in this work.

A water absorption effect of antifouling coatings in their initial immersion period may change the surface conditions of antifouling coatings and thereby influence the frictional resistance. Therefore, it is of interest to investigate the effect of water absorption of antifouling coatings on frictional resistance in the initial immersion period.

In addition, large surface irregularities (e.g. welding seams) on the ship hull surfaces cause drag resistance during sailing. Therefore, the effects of welding seams on drag resistance were also studied in this work. Only welding seams perpendicular to the water surface were considered. The quality of welding seams varies from different ship yards. Normally, the welding seam height differs from 3 to 9 mm depending on the quality standard of the ship yard. The welding width is typically around 13-15 mm. Furthermore, the density of welding seams on the ship surfaces may also have an influence on drag resistance. Therefore, the effects of welding seam height and welding seam density on drag resistance are another important part of this work.

Experimental

The drag resistance was predicted using a pilot-scale rotary setup as shown in figure 1 (left). A rotor with antifouling coatings on its periphery rotates at various speeds inside a tank containing 600 liter of artificial seawater. A torque sensor records the torque values which can be used to estimate drag resistance. A detailed description of the setup can be found in [2–4]. A flexible rotor has been designed to simulate welding seams on ship hull surfaces as shown in figure 1 (right) based on assumptions that the welding seams on the rotor do not affect each other and that the cylindrical geometry does not affect drag resistance (relative to flat plate geometry). The rotor has a smooth surface and no coating was applied. The density of the welding seams was controlled by the number of welding seams on the rotor periphery surface. For reasons of balance, the number of welding seams on the rotor can be 2, 4, 6 and 8 corresponding to 10, 20, 30 and 40 welding seams per 5 m ship side respectively, which are much higher densities compared to that on full-scale ships (assumed to be one welding seam per 5 m ship side) (the unit for density was chosen for convenience of comparison at different scales). The density is limited by the relative short circumference of the rotor and minimum 2 welding seams should be present. The welding width was generalized to 15 mm and the welding heights were 3, 5 and 9 mm. The rotor with welding height of 0 mm was also tested and used as reference.

Figure 1: A pilot-scale rotary setup for drag resistance measurements (left) and the flexible rotor with six artificial welding seams on the periphery (right)

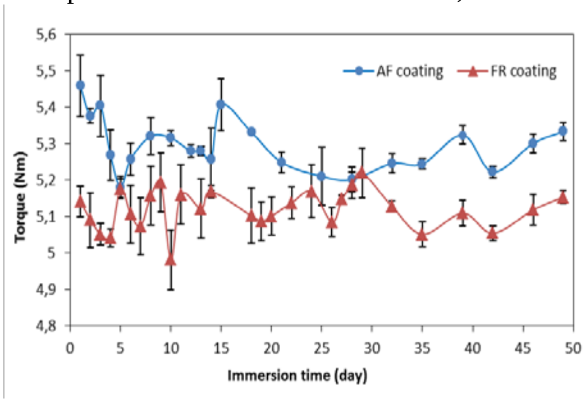
Two representative antifouling coating formulas, listed in table 1, were chosen to compare two antifouling coating technologies (AF and FR coating) and to investigate the effects of water absorption on frictional resistance. A rotation speed of 400±1 RPM was chosen to maintain stability of measurements with the rotary setup. To correlate the data of immersion tests from the rotary setup with water uptake, standard water absorption tests (WAT) were conducted. The same AF and FR coatings were applied to small panels and statically immersed in 23 °C artificial seawater for 28 days and the weights of the panels were recorded regularly.

Table 1: Two representative antifouling coatings used for immersion tests

Antifouling coating samples	**Speed (RPM)**	**Temperature (°C)**	**Immersion time (day)**
AF (antifouling) coating	400±1	20±2	49
FR (fouling release) coating	400±1	20±2	49

Results

The torque values of AF and FR coatings, obtained during immersion, are shown in figure 2 (left) and water absorption results from standard WAT, are illustrated in figure 2 (right).



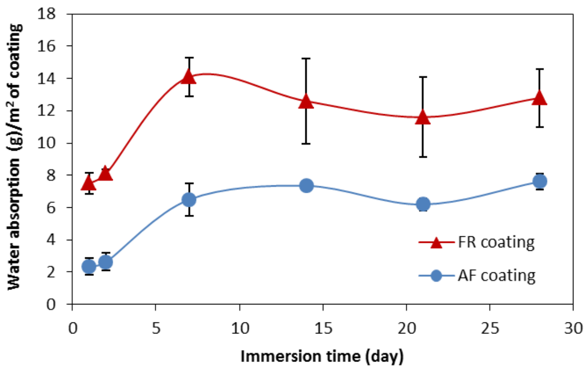
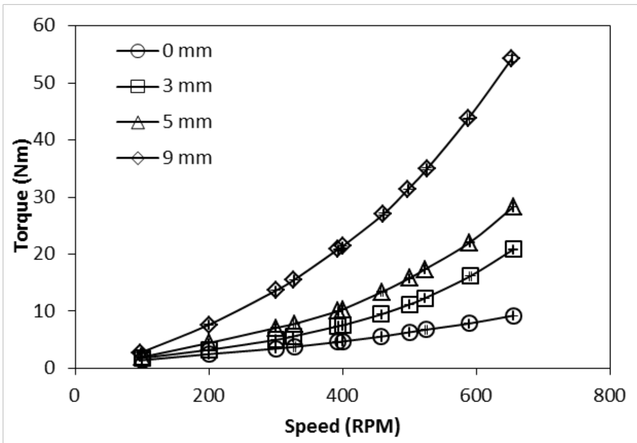
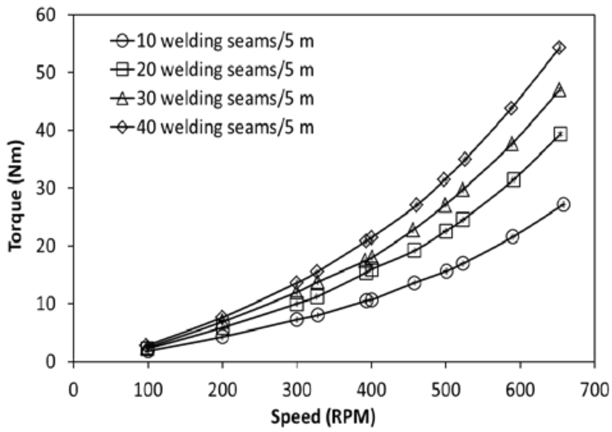
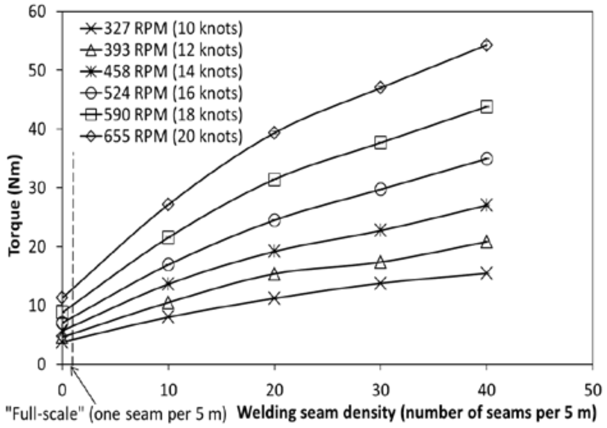


Figure 2: The average torque values of daily measurements for AF coating and FR coating during the entire immersion period at a temperature of 20±2 °C and a speed of 400±1 RPM (left). Water absorption of AF and FR coating from standard WAT as a function of immersion time (right). Error bars for daily measurements based on three replicates are also shown in the plots.


0 mm
3 mm
5 mm
9 mm
Torque (Nm)
Speed (RPM)


10 welding seams/5 m
20 welding seams/5 m
30 welding seams/5 m
40 welding seams/5 m
Torque (Nm)
Speed (RPM)



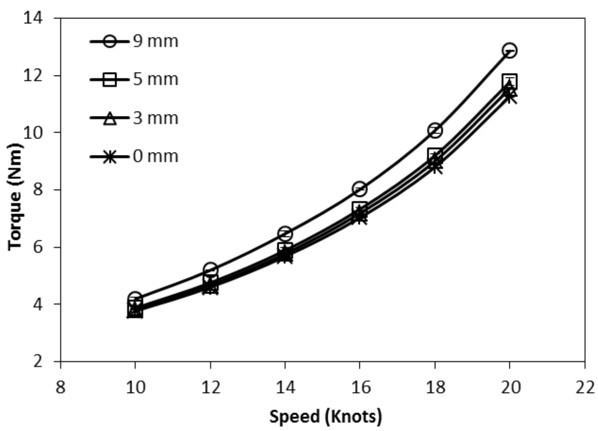


Figure 3: Torque values of different welding seam heights (0, 3, 5, 9 mm) with 8 welding seams on the rotor surface (top left) and torque values of different welding seam densities (10, 20, 30, 40 welding seams per 5 m) with a welding seam height of 9 mm (top right) as a function of speed. Torque values at different speeds with a welding seam height of 9 mm as a function of welding seam density (bottom left). Interpolated torque values of different welding seam heights at"full-scale" welding seam density (one welding seam per 5 m ship

side) as a function of speed (bottom right). Error bars for each measurement based on three replicates are shown in the plots. Most of them are too small to be seen.

In figure 3, the torque values of different welding seam heights (top left) and different welding seam densities (top right) at different speeds are seen. The plot of torque values at different speeds as a function of welding seam density with same welding seam height of 9 mm is also shown in figure 3 (bottom left). In addition, the interpolated torque values of different welding heights as a function of speed at "full-scale" welding seam density (one welding seam per 5 m ship side) is illustrated in figure 3 (bottom right).

Discussion

Based on a comparison of the torque values between AF and FR coating from figure 2 (left), it can be seen that the FR coating caused less torque than the AF coating. Small fluctuations in temperature (±2 °C) did not affect the torque measurements. As shown in figure 2 (right), for both coatings, water absorption mainly occurred in the first week and then reached steady states. In addition, the torque values of the FR coating did not change much with the immersion time, which indicates that the water absorption effect on frictional resistance is not significant for the FR coating. However, for the AF coating, there was a small torque drop during the initial immersion days before the steady state, which might be attributed to water absorption according to figure 2 (right). Small fluctuations observed in figure 2 (left) are probably due to experimental uncertainties from the torque sensor and the unstable flow conditions inside the tank.

The effect of welding seam height on torque has been demonstrated in figure 3 (top left). The torque increased largely with welding height, especially when the welding height is increased from 5 to 9 mm. Besides, the torque differences among different welding heights are not very large at low speeds (below 200 RPM). The differences are enlarged when the speed is increased. Based on the experimental results (not fully shown here), the effect of welding seam density on torque is similar for different welding seam heights. Therefore, as an example, welding seam height of 9 mm with different welding seam densities was shown in figure 3 (top right). It can be clearly seen that the torque increases with welding seam density. However, the increase in torque is much larger from 10 to 20 welding seams per 5 m ship side than from 20 to 30 welding seams per 5 m ship side. The increase in torque became smaller when the welding seam density was increased linearly. This can also be observed in figure 3 (bottom left). Torque increased significantly from 0 to 20 welding seams per 5 m ship side and then continued to increase linearly with welding seam density. As mentioned before, welding seam density on "full-scale" ships was typically assumed to be one welding seam per 5 m ship side as indicated by the dashed line in figure 3 (bottom left). The effect of welding seam height on drag resistance is much higher when welding height is above 5 mm at full-scale welding seam density as shown in figure 3 (bottom right), which is consistant with the results shown in figure 3 (top left). Therefore, controlling the welding seam height below 3 mm could contribute significantly to economic benifits when ships are constructed in shipyards.

Conclusions

Based on the above results and discussion, the following conclusions can be drawn:

- The FR coating causes less frictional resistance than the AF coating.
- The water absorption effect on frictional resistance is significant for the AF coating.
- Welding seam height has a significant effect on drag resistance, especially at high speeds.
- The effect of welding seam density on drag resistance is significant especially when welding seam densities are in the low range
- It is possible to obtain drag data at full-scale welding seam density using the designed rotor.

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