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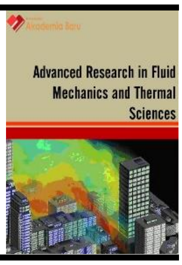

Investigate the Drag Resistance of Antifouling Self-Adhesive Film

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ABSTRACT

Fouling has always been a common issue for ships as fouling drastically increases the surface roughness and ship resistance. The microfiber self-adhesive antifouling film is claimed to be effective up to 5 years and is environmentally friendly. However, there is lack of information about the drag characteristics of the antifouling material. Thus, this project is conducted based on an experimental study to determine the drag characteristics of the surface installed with microfiber self-adhesive antifouling film. The rotor apparatus is used to study the coefficient of friction of the microfiber surface. From the experimental results, a flat plate simulation using ANSYS-Fluent is conducted to further estimate the coefficient of friction up to Reynolds number of 10^9 and to evaluate the total ship resistance for the Semi-SWATH (fast vessel) and KVLCC (slow trading ships). The results show that the percentage increase in total ship resistance for the KVLCC is about 80%, which is more than the Semi-SWATH of 30%, as frictional resistance has high significance for slow trading ships. The speed drop experienced by the ship model installed with the microfiber antifouling is 2 knots for the KVLCC and 1 knot for the Semi-SWATH if the power remained the same for both models.

Keywords:
Microfiber Antifouling; Frictional Resistance; Rotor Apparatus; Flat Plate Simulation

1. Introduction

Marine fouling is the build-up of microorganisms on the surface and especially serious in the marine environment. Fouling contributes to the increase in drag, speed reduction and higher fuel consumptions. Poor coatings and biofouling on the ship hull resulted with up to 6% to 80% increase in the ship resistance [1]. A model tested by Schultz *et al.,* [2] mentioned that accumulation of fouling increases the fuel consumption by 10.3% and raises the fuel cost by approximately $1.15M. Effects of fouling mainly causes the drastic increase of viscous drag friction due to the influence of the fouling

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size [3] and fouling surface coverage on the boundary layer of the hull surface [4]. Fouling rate depends on the abundancy of microorganisms in various sea and the rate of activity of the vessel [5]. The accumulation of fouling also causes reduced manoeuvrability, rise in emission of air pollutants due to the increase in fuel consumption, increase in regularity of dry docking and translocation of invasive species across different marine organisms [6]. Antifouling materials or methods are used to prevent and reduce the growth of marine fouling.

One of the early techniques use for antifouling is through the usage of toxic materials to inhibit growth of marine organisms, such as mercury, arsenic and tributyltin (TBT), where TBT has been proven to contaminate the marine ecosystem and bring accumulative effects that can bring harm to human health. Self-polishing copolymer (SPC), more commonly known as the copper paint has been used for a long time and contains copper compounds, but constantly release copper compounds to the ecosystem [6]. Hence, with the rise of cleaner and safer environment, more effective and non-releasing antifouling were produced, such as the High-density Silicone Antifouling, that utilizes the smooth surface of silicone to reduce adhesion of marine fouling [7] and the self-adhesive microfiber antifouling surface that uses constant moving synthetic fibers to prevent growth of microorganisms [8], which will be discussed in this paper.

Resistance is the force opposing the motion of the body when the body moves through a medium. For ships, drag can be divided into two main types, which is the form drag and the viscous drag. Hydrodynamic effects of the floating structure affect the dynamic performance of the structure [9-10]. As drag resistance or frictional resistance contributes to a high proportion of the total resistance of a ship, especially for slow trading vessels, there is a need to study the drag resistance of the antifouling self-adhesive film. Frictional resistance, also known as skin friction is affected by the surface roughness [11]. Drag reduction has been observed for super-hydrophobic surfaces that have the “lotus effect” such as self-cleaning properties and low wettability [12]. The micro-structured surfaces capable of retaining air play the role of reducing resistance with the formation of an apparent slip length [13]. The microfiber surface also has the properties similar to the super-hydrophobic surface and able to retain air when immersed in water. Flow across the microfiber surface are visualized using high-speed digital holographic microscopy and it shows that the impact of roughness is localized on the momentum while the pillar effect of the micropillars affect the pressure field throughout the depth [14]. The flow rate of particles across the microfiber surface depend on the dimensions of the microfiber. By utilizing innovative methods, the structural behavior will interactively change with the external loadings [15-16].

The rotor apparatus is a simple apparatus capable of measuring and comparing the frictional resistance of different surfaces. Although issues arise in the apparatus such as the end effects and doubt in the applicability of the logarithmic law on the 3D flow of the cylindrical block, previous studies have provided the method and prove to solve these issues such as the use of long and short rotor to remove the end effects. Resistance of the ship can be calculated based on the ITTC equations, which is the ITTC-1957 Model Ship Correlation Line and ITTC-1978 equation. Two case studies, which is the model resistance for the Semi-SWATH [17] and the model resistance test for the KVLCC [18] is selected for this research. For the conversion of model resistance to ship resistance, ITTC method is used.

Flat plate simulations have good agreement with towing test results of ship models with rough surfaces [19]. A simple 2D model can be used for the flat plate simulation using CFD to numerically calculate the frictional resistance of a surface with certain roughness by neglecting wave generation and end effects [20]. Previous researches showed that the CFD results for flat plate agree with experimental results of a rotating disc given that fine meshing is used [21]. The k-ω model turbulence model was selected as it suitable for near wall modelling and applicable throughout the boundary layer. It is also capable of providing accurate results with fine meshing of the flat plate. In addition, the comparison of different turbulent model shows that the simulation result from SST k-ω model is good agree with experimental data [22].

It is important to identify the frictional resistance of the antifouling surface to predict its effect on the ship resistance. The microfiber antifouling self-adhesive film is a new material that has not been tested on its' drag characteristics. As the surface of the microfiber is relatively soft, it is difficult to measure the surface roughness of the microfiber directly using a profilometer, leading to the need of this experimental study. The objectives of the research are to compare the drag characteristics of the microfiber material to a smooth surface and to estimate the ship resistance of the ship hull installed with the microfiber material. This paper presents the outcome from the study conducted which includes an experimental study using the rotor apparatus to determine the frictional resistance for the microfiber material and to conduct a flat plate simulation using ANSYS-Fluent to predict the ship resistance of the ship hull. Besides, this paper also presented the data for the drag characteristics of the microfiber surface, the estimation of speed drop and resistance performance for the ship hull if it is installed with microfiber anti-fouling material. The comparison presents the effect of microfiber anti-fouling material would influence the ship resistance. And then, this provide an information to industry for estimate the resistance and powering of ship if this new microfiber anti-fouling material is installed onto ship hull.

2. Methodology

The rotor apparatus experiment is conducted to obtain the coefficient of frictional resistance for the microfiber surface while the flat plate simulation is used to predict the coefficient of friction for higher Reynolds number and predict the total ship resistance of ship installed with the microfiber surface.

2.1 Rotor Apparatus Experiment

Figure 1 displays the experimental setup for the rotor apparatus. From the experiment, the speed of rotation and torque to rotate the rotor are recorded. The coefficient of friction for the surface can be calculated using the velocity loss theory. Two rotors with a diameter of 90mm are used for each surface measured to eliminate the end effects. A long rotor with the height of 80mm and a short rotor of 40 mm height are used. The diameter of the water tank is 1000mm and can hold a maximum capacity of 0.098m^3. An AC servo motor (095U2E3300VACAA100190 by Emerson Industrial Automation) of power 2.54kW is used to rotate the rotors with varying speed ranging from 0 rpm up to 1100 rpm. Futek TRS300 torque meter is used to measure the torque while a digital tachometer (RS Pro 163 -5348 Single Memory Optical Tachometer) is used to determine the rotation speed with a resolution of ±0.1 rpm. A digital thermometer with accuracy of ± 0.1ºC is used to measure the temperature of the working fluid (fresh water). The density and kinematic viscosity of the working fluid is determined from the measured temperature using tabulated values from Venard & Street (1975) [22].

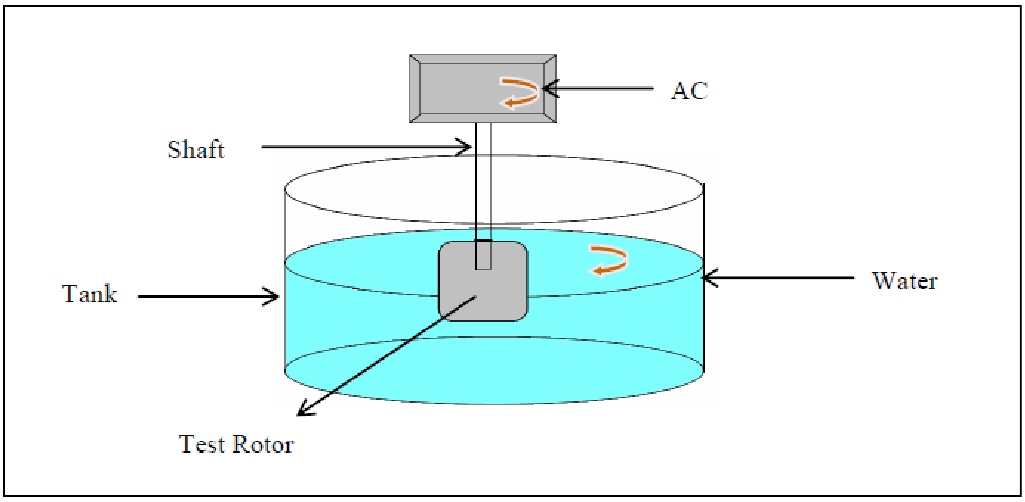

Fig. 1. Experimental setup for rotor apparatus

The loss in velocity or the roughness function ΔU^{+} is the difference between the frictional resistance of a rough surface and smooth surface, as shown in Eq. (1).

$$\Delta U^{+} = \frac{\Delta U}{U_{\tau}} = \left(\sqrt{\frac{2}{c_f}}\right)_{smooth} - \left(\sqrt{\frac{2}{c_f}}\right)_{rough} \tag{1}$$

From the substitution for the equation for shear velocity and free stream velocity, the Eq. (2) is formed, whereby used for the calculation for the coefficient of friction for the surface.

$$c_f = \frac{900\Delta T}{\rho\pi^3 {r_1}^4 n^2 L} \tag{2}$$

2.1.1 Procedure of rotor apparatus

In the Eq. (2), the frictional drag coefficient can be calculated if the different of torque between long rotor and short rotor for the speed are known. Before the experiment start to collect the data, the long rotor which attached to the servomotor through shaft is rotated by servomotor at slow speed for a few minutes. This step is proposed to warm up the servomotor so that the rotational speed can be more stable. All the apparatus is checked again for any problems or disturbance. Data is set to be taken for every 0.01 s for duration of roughly 30 s. After that, the servomotor is adjusted to the speed of 100 rpm. The speed obtained by the tachometer is compared with the speed display. If the speed tallies, then the data is started to record using DAQ system.

In this research, the speed of servomotor is increased from 100 rpm to 800 rpm with the increment of 100 rpm for each step. After the torque requires rotating the rotor at all particular speeds are measured, the experiment is repeated with short rotor. The torque requires rotating the short rotor at the similar rotation speed for long rotor are measured by torque meter.

2.2 Flat Plate Simulation

Flat plate simulation is used to estimate the surface roughness height for the microfiber antifouling. The k-omega turbulence model is used for the simulation and Figure 2 displays an example of the meshing for the flat plate. A 2D plate is drawn in the X-Y plane with the dimensions of 1 meter and the domain size of 0.5 meter. An iterative process is used and curve fitting is done to obtain an equation for the estimation of surface roughness height. Then the equation is used to further estimate the coefficient of friction of the microfiber up to Reynolds number of 10^9. Numerical simulation tool is used in this research to predict the coefficient of friction at higher Reynolds number. This is because the speed rotation of the experiment tool is only able to achieve Reynolds number up to 10^5. Moreover, the Reynolds number of ships are usually in the range of 10^9. Therefore, the estimated coefficient of friction from the experiment is insufficient for predicting ship resistance and exhibits the need for further simulation to predict the coefficient of friction.

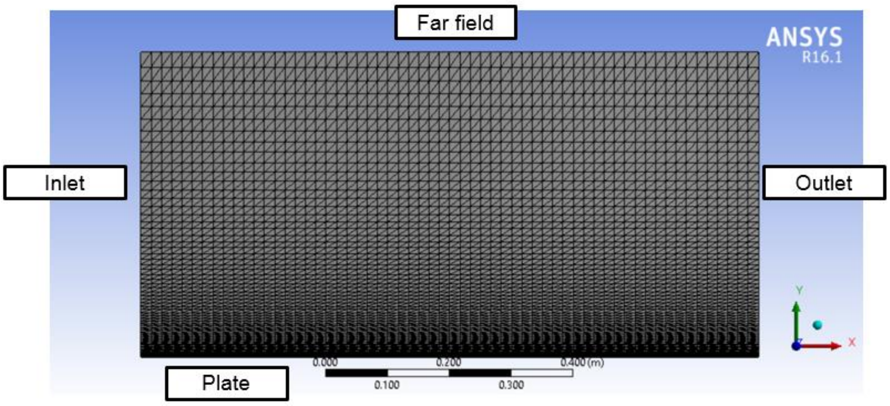

Fig. 2. Meshing of flat plate (3721 nodes and 7200 elements)

The flat plate simulation is also used to predict the frictional resistance for the ship hull, where a convergence study is used to determine the number of divisions required for the flat plate with the size as long as the ship waterline length. The model resistance test data is converted to ship resistance by using the ITTC method. After the simulation results for the local coefficient of friction is obtained, the coefficient of friction is replaced and the total ship resistance for the ship hull installed with the microfiber antifouling is estimated. Eq. (3) is used for the conversion of resistance to its non-dimensional terms and vice versa.

$$C = \frac{R}{\frac{1}{2}\rho S V^2} \quad (3)$$

The relationship of total resistance to frictional resistance and residual resistance is shown in Eq. (4) while the Eq. (5) is used for the determination of coefficient of frictional resistance using ITTC-1957 and Eq. (6) is the standard frictional drag coefficient equation used for the determination of coefficient of frictional resistance by using the drag force from simulation.

$$C_T = C_R + (1+k)C_F \quad (4)$$

$$C_F = \frac{0.075}{(\log_{10} Re - 2)^2} \quad (5)$$

$$C_{Fl} = \frac{F_D}{\frac{1}{2}\rho A V^2} \quad (6)$$

3. Results and Discussion

Figure 3 displays the experimental results for the rotor apparatus compare to the coefficient of frictional resistance using the ITTC method. The result of smooth rotor experimental results and rotor with antifouling surface experimental result are also presented in this figure. The C_f calculated via ITTC method is lower compared to the experimental results because it is an empirical formula that does not consider the effects of surface roughness.

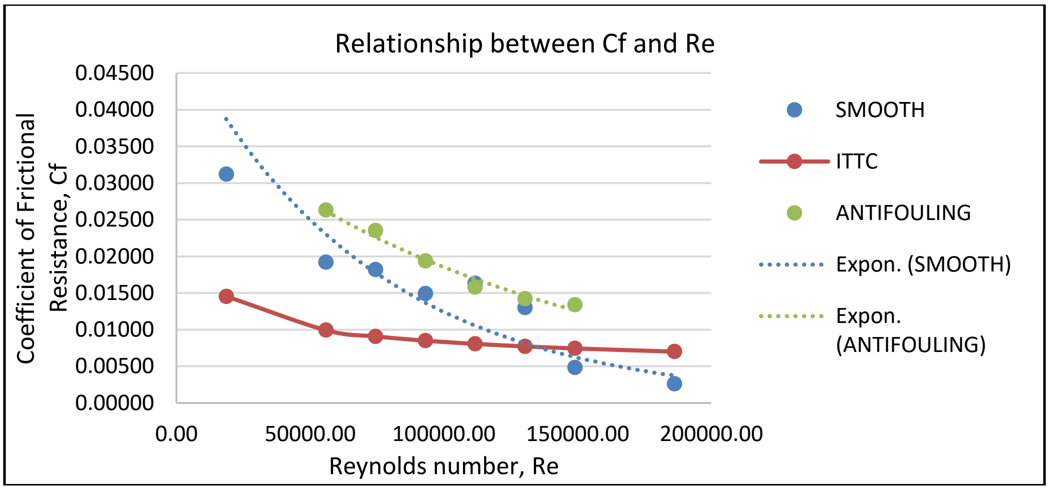

Fig. 3. Experimental results for rotor apparatus

From the experimental results, the surface roughness for the microfiber antifouling estimated using the Flat Plate Simulation by ANSYS-Fluent. This is because the microfiber is not a solid surface making it difficult to measure the surface roughness directly. Figure 4 displays the relationship of C_f to Reynolds number for the simulation results using constant roughness height and varying roughness height. Eq. (7) is the equation for surface roughness obtained via curve fitting method.

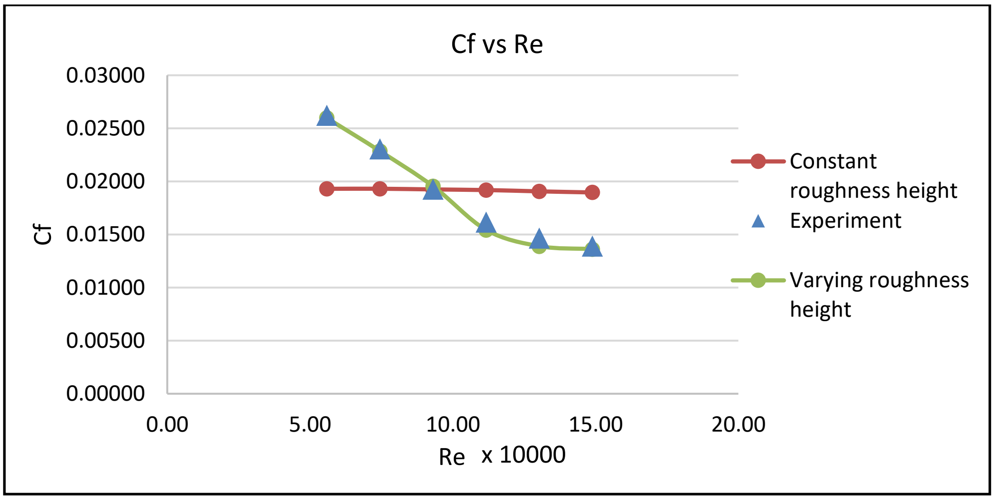

Fig. 4. Comparison for simulation results using constant roughness height and varying roughness height

$$Roughness\ height = \frac{0.003}{(\log_{10} Re - 4.5)^2} \quad (7)$$

From observation, as the speed of rotation increases, the surface roughness height decreases while Figure 4 also shows that the surface roughness for the microfiber antifouling is not a constant value. Simulation using constant roughness height does not show a similar trend to the experimental results, while the simulation using the estimation of roughness height by using the Eq. (7) exhibits similar trend to the experimental results. Figure 5 displays the estimation of friction coefficient, C_f by simulation and it shows similar trend to the ITTC results.

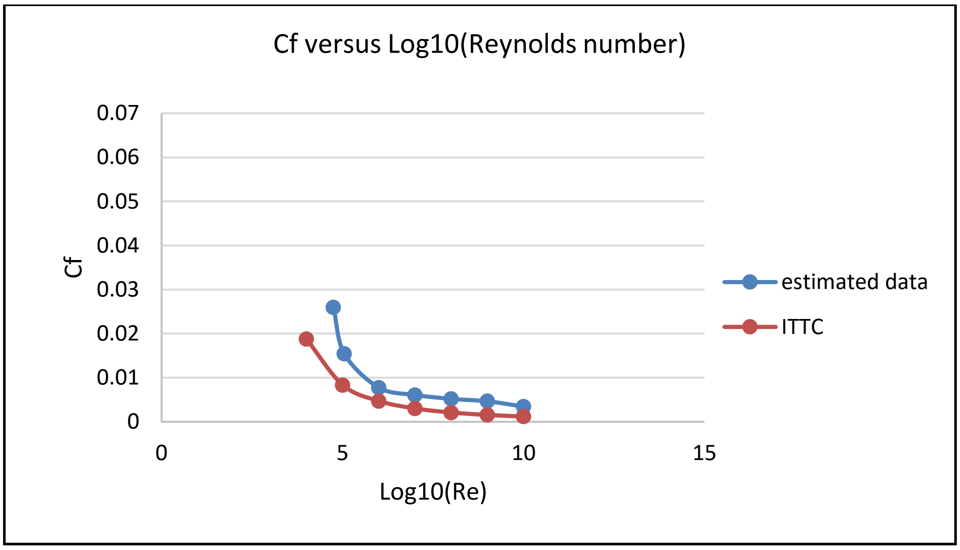

Fig. 5. Estimation for C_f for higher Reynolds number

Figure 6 displays the relationship of total ship resistance to Reynolds number for the Semi-SWATH while Figure 7 shows the power to ship relationship. The simulation results for the total ship resistance installed with microfiber antifouling is 30% higher compared to the experimental results and the speed drop experiences is 1 knot.

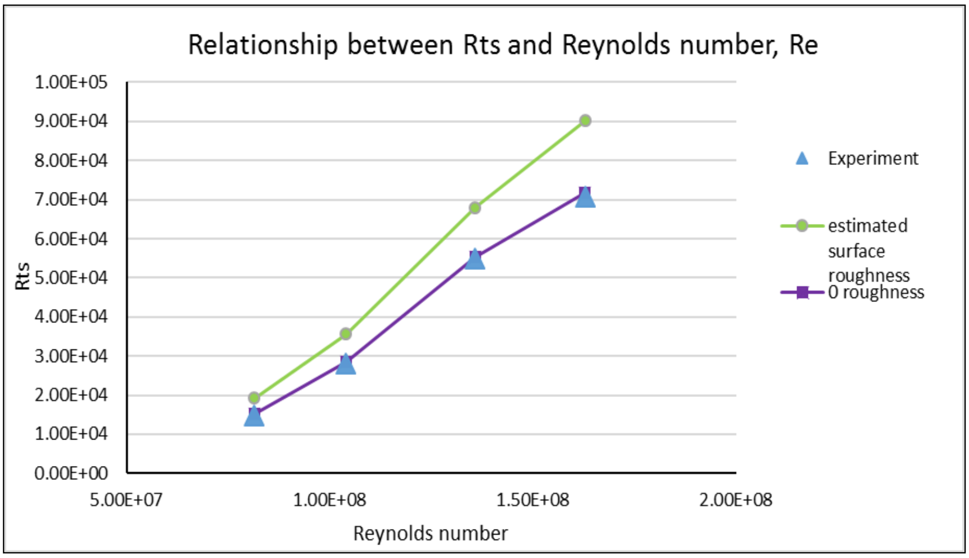

Fig. 6. Total ship resistance for Semi-SWATH

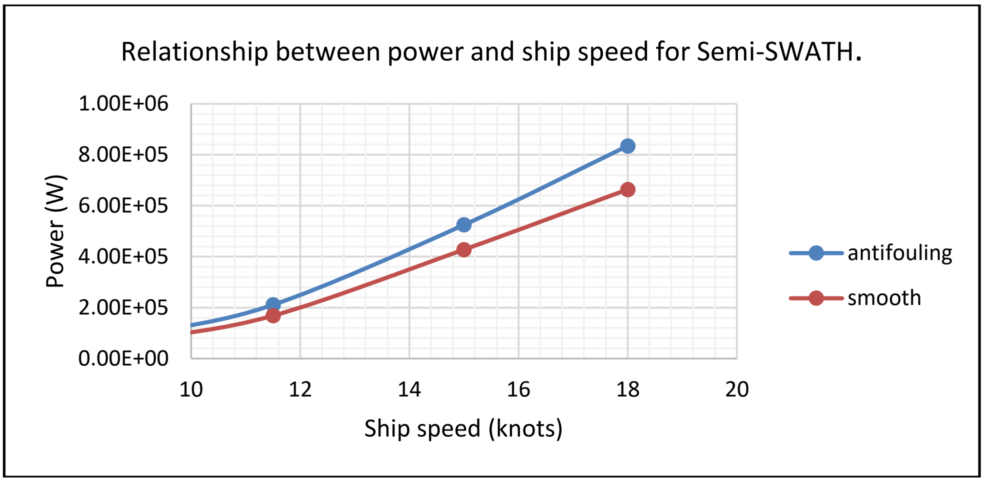

Fig. 7. Relationship between power and ship speed for Semi-SWATH

Figure 8 displays the total ship resistance for the KVLCC while Figure 9 exhibits the relationship of power to ship speed for the KVLCC. The percentage increase in total ship resistance is 90% compared to the experimental results for the bare hull while the speed drop for the ship hull installed with antifouling is 2 knots.

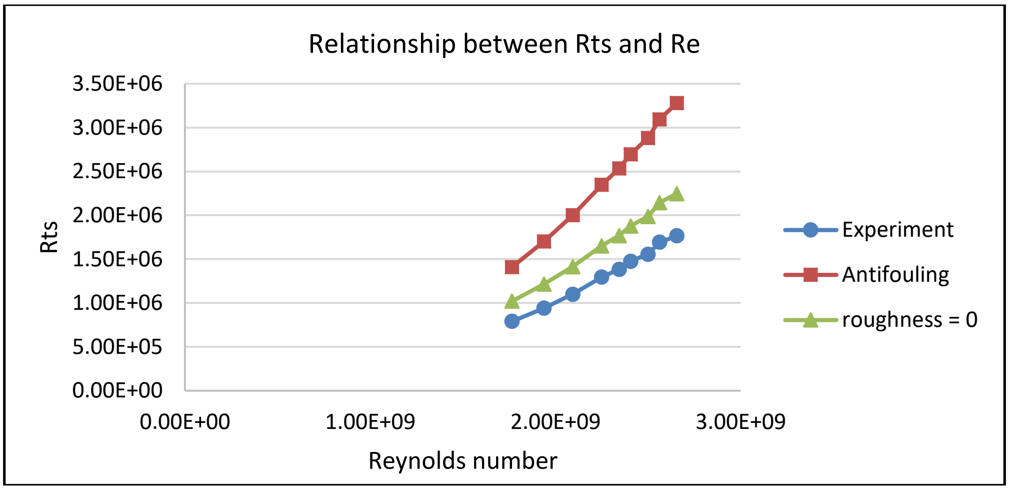

Fig. 8. Total ship resistance for KVLCC

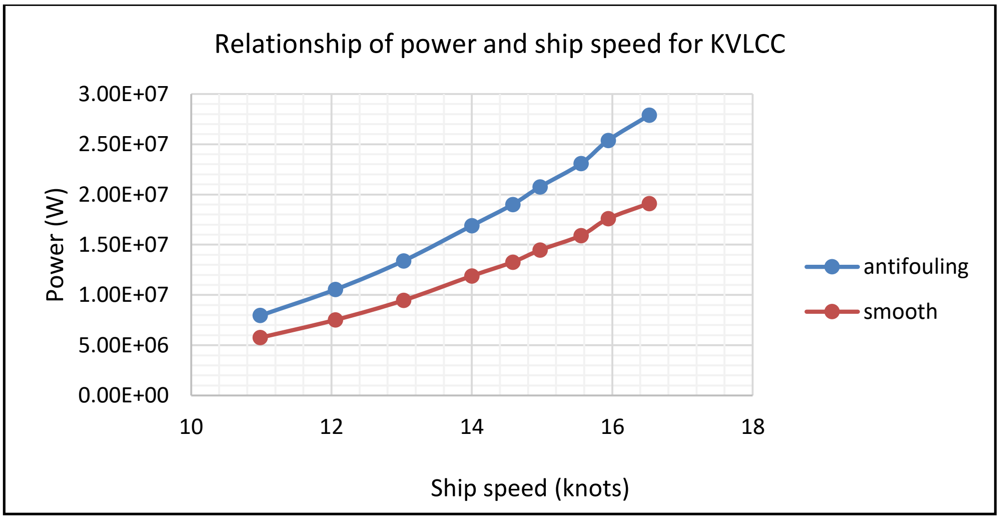

Fig. 9. Relationship of power to ship speed for KVLCC

4. Conclusion

This research compares the drag characteristics of the surface installed with antifouling self-adhesive film (microfiber surface) to smooth surface. The ship resistance for the ship hull installed with antifouling self-adhesive film was also estimated. From the rotor experiment, the results obtained are consistent with the research conducted from previous studies. The average difference in coefficient of frictional resistance between the rotor installed with microfiber antifouling and the smooth rotor is about 30 percent. For the KVLCC, increase of frictional resistance due to the surface roughness of the hull results an increase in total ship resistance of 80%, while for the Semi-SWATH, the increase in frictional resistance only causes 30% increases of total ship resistance. By consider the increase of frictional resistance due to fouling, this antifouling material can be considered as the antifouling material to avoid fouling growth on hull surface, especially for fast vessels. This is because drastically the ship hull will fully be covered with fouling and the surface roughness height in this condition is around 130µm. In this fouling condition, the frictional resistance is about 178% higher as compare to frictional resistance of clean hull. Based on what claim by microfiber anti-fouling material producer, the microfiber antifouling material able to maintain it antifouling effects up to 5 years. Future studies should also consider a ship resistance experiment with the antifouling material attached to a ship model. Therefore, the effect of the antifouling self-adhesive film contribute to ship resistance can be calculated more accurately.

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