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EXPERIMENTAL INVESTIGATION OF THE DRAG CHARACTERISTICS OF DIFFERENT SHIP HULL COATING WITH USING ROTOR APPARATUS

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ABSTRACT

This paper describes the experimental work on the drag characteristic of a tin-free Self Polishing Co-Polymer (SPC) with a Foul Release (FR) coating at the Marine Technology Centre, UTM. In this experiment a rotor apparatus has been used to measure drag of a coated aluminum cylinder. Various types of coating were investigated and the differential length technique was also applied to avoid the end effects during rotation. The measurements have been carried out using different cylinders, coated with both paint types and smooth surface. The experimental results shown that the frictional drag for the Foul Release test cylinders was lower than the tin-free SPC cylinders. According to the experiment, it has been found that the drag of an underwater hull coating was not depending only on the type of coatings which has been used on the hull surface but also that have been correlated with the speed of ship's hull moving through the water.

Keywords: Hull roughness, drag resistance, foul release coating, tin-free SPC coating, rotor apparatus.

1.0 INTRODUCTION

One of the factors affecting a ship's performance and fuel consumption is the roughness of the underwater hull. The condition and type of paint system can have a major influence on hull roughness and ship performance. Surface roughness of underwater hull should be kept as low as possible during the building and throughout the ship life cycle because increased in hull roughness will increase the total ship resistance which will affect the engine power, fuel

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consumption and bunkering cost. Hull roughness is divided into two types, firstly is physical hull roughness and secondly is biological hull roughness (bio fouling).

Physical hull roughness occurs due to the mechanical damages, welds, corrosion, coating condition whereas biological roughness occurs due to the accumulation of plants or animal growth on hull. Source of hull roughness can be categorized in to two main areas known as initial roughness and present roughness (roughness increase during service). Initial roughness is due to several items such as steel quality, construction method, coating system, coating application, weld condition, presence of lamination and weld spatter whereas the present roughness (roughness increase during service) is due to the mechanical damages, corrosion, fouling, over coated fouling remnants, coating defects (flaking and blistering), uneven areas (build-up of old coating) and coating detachment (build-up of sandwich coating) [1].

The regular survey will be conducted to determine the volume of hull roughness in order to perform the suitable maintenance to reduce the hull roughness which will adversely affect the ship performance. One of the methods which are used to reduce the present roughness is repainting a vessel after a year service period. There are several techniques which are used to measure the skin friction drag. The most common measurement techniques are the measurement on a rough plate in a towing tank or in a wind tunnel and also torque measurement on rotating cylinder.

This paper has been used the rotating cylinder (rotor apparatus) technique to determine the roughness function of different hull coatings. This method has been widely used as a simple comparator to measure the difference between smooth and rough surfaces [2]. The rotor apparatus has several advantages compared to the rough plate method, such as easy to operate, lower cost, compact and also there is no problem with the development of boundary layer along the length of the test section [3]. In this experimental work, the cylinders were coated with Foul Release and SPC coatings that has been used to determine the roughness function of each surface. The aim of this work is to ascertain reduction in drag by using different types of paint and compare them in the case of drag/resistance characteristics.

2.0 ROTOR APPARATUS

Rotating cylinder or Rotor apparatus has been used for many years as simple comparators to measure the difference between the resistance of smooth and rough surfaces. The advantages of Rotor apparatus are low operating cost, compact, easy to operate and maintain. In the other hand there is not exist any problem regarding to the development of the boundary layer along the length of a test section which occur with friction planes. However, the equivalent problem with the rotor is the end effects which occur at the top and bottom where the flow regime makes the transition from “cylinder” to “disc” flow [4,5,6,7,8].

The 3-dimensional nature of the flow has been the major objection to the use of rotors, but it has shown that if the speed of rotation is kept sufficiently high to avoid unstable modes of flow, the logarithmic law of the wall is closely obeyed in the inner part of the boundary layer. Measuring the velocity profile in the boundary layer allows the direct determination of the roughness function but is difficult due to the movement of the wall [9, 10, 11, 12]. By taking advantage of the existing apparatus and the knowledge accumulated from the experiments carried out in the 1980s with other coatings, it was thought to be appropriate to test Tin-free SPCs and Foul Release systems by using the same device and experimental procedure [13,14].

This would provide an opportunity to confirm whether the rotor tests would support the findings from towing tank and water tunnel experiments. In addition, it would be possible to compare with the roughness characteristics of the earlier coated surfaces and tested on the same apparatus [15].

3.0 THEORY OF ROTOR EXPERIMENT

The velocity loss or roughness function ΔU^+ of a rough surface indicates how much its frictional resistance differs from a smooth surface and can be written as:

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

whereby the friction velocity $U\tau$ is defined as:

$$u_\tau = \sqrt{\frac{\tau_w}{\rho}} = \sqrt{\frac{c_f}{2}}\, u_e \tag{2}$$

with τ_w is the wall shear stress, ρ the density of the fluid, c_f the local frictional resistance coefficient and U_e the free stream velocity. In rotor experiments the free stream velocity U_e is equal to:

$$u_e = \frac{2\Pi r_1 n}{60} \tag{3}$$

with r_1 the radius of the cylinder and n the number of revolutions per minute.

The friction velocity of each test cylinder is determined by the measured difference in torque, ΔT, between the long and short rotor experiment. If *F* is the frictional force on the test cylinder, ΔT can be expressed as:

$$\Delta T = F \times r_1 \tag{4}$$

The wall shear stress τw is then equal to:

$$\tau_w = \frac{F}{S} = \frac{F}{2\Pi r_1 L} = \frac{\Delta T}{2\Pi {r_1}^2 L} \tag{5}$$

where *S* is the surface area of the cylinder and L the length of the cylinder. Thus:

$$u_\tau = \sqrt{\frac{\Delta T}{2\Pi \rho {r_1}^2 L}} \tag{6}$$

Substitution yields:

$$C_f = \frac{900\Delta T}{\rho \Pi^3 {r_1}^4 n^2 L} \tag{7}$$

4.0 ROTOR APPARATUS DESIGN

The Rotor apparatus has been designed and fabricated at the Marine Technology Centre (MTC) of Universiti Teknologi Malaysia based on the concept developed at the University of Newcastle Upon Tyne, using differential length technique to eliminate the end effects which occurs at the top and the bottom of the rotor as shown in Figure 1.

Figure 1: Rotor Apparatus at the Marine Technology Centre, UTM

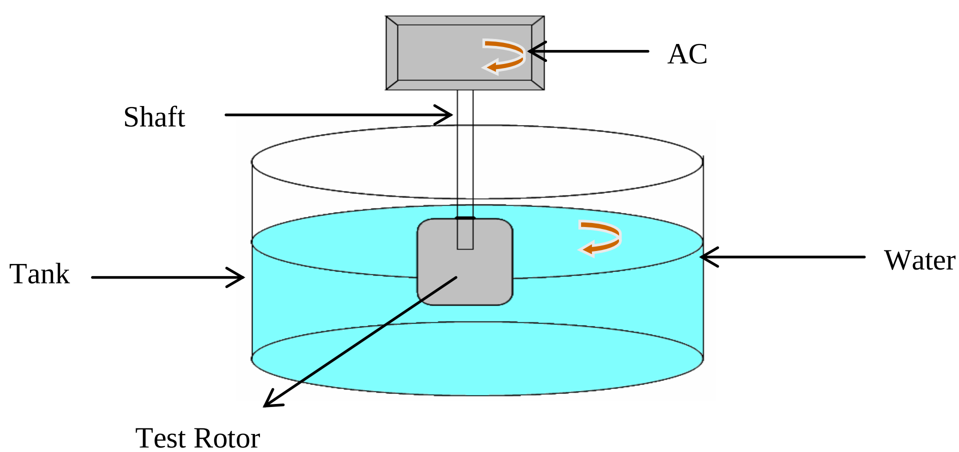

Figure 2: Rotor Apparatus diagram

Figure 2 shows the essential elements of rotor apparatus, it comprises of:
-Motor: the prime mover for the rotary motion.
-Shaft: The shaft is used to transfer the rotation movement from the AC motor to the rotor. The shaft length is 570 mm and the diameters for the shaft are varied along the shaft. The material used was stainless steel provided by Universiti Technologi Malaysia's central store.
-Rotor: The rotor is made up of a concentric aluminum cylinder attached to the shaft which is driven by three phase AC induction motor. The actual Rotor element consists of two aluminium cylinders. One is for the long rotor element and the other is the short rotor element. Each rotor was painted with different hull coating schemes provided by International Paint Sdn. Bhd with one set of rotor as the smooth reference. Both rotors have same diameters of 90mm but with different length. Long rotor: 80mm length and short rotor: 40mm length as shown in Figure 3.
-AC motor: Three phase AC motor (flange-mounted type) with variable frequency drive speed control which is horizontally mounted on the supporting structure have been used to drive the Rotor. The AC motor specifications are: 4 poles, 318 - 415V, 1.56 - 1.70A, 1410 rpm, star/delta connection.
-Water Tank: The outer stationary cylinder (tank) which houses the rotor has an inside diameter of 1000mm. The cylinder water tank can hold the maximum of $0.098 m^3$ of water.
-Water: Fresh water is used as the working fluid.

Figure 3: The actual rotor element with the coating scheme

5.0 COATING SCHEMES

The specification of each coating schemes which have been applied on the specimens (Rotor) are as follow:

1) Specimen A
   Tin Free SPC-Airless Spray Application

- 1*150 microns Intertuf 262 Red (KHA303/KHA062)
- 1*100 microns Intergard 263 Gray (FAJ034/FAA262)
- 1*100 microns Intersmooth 360 Red (BEA369)
- 1*100 microns Intersmooth 360 Red (BEA369)

2) Specimen B
Foul Release System (Intersleek)-Airless Spray Application

- 1*125 microns Intershield 300 Aluminium (ENA301/ENA303)
- 1*125 microns Intershield 300 Bronze (ENA300/ENA303)
- 1*100 microns Intersleek 737 Tie Coat Pink (BXA736/BXA738/BXA739)
- 1*150 microns Intersleek 757 Finish Gray (BXA757/BXA758/BXA759)

One set of rotor (long and short) is set as the smooth surface with no coatings application on it Figure 4.

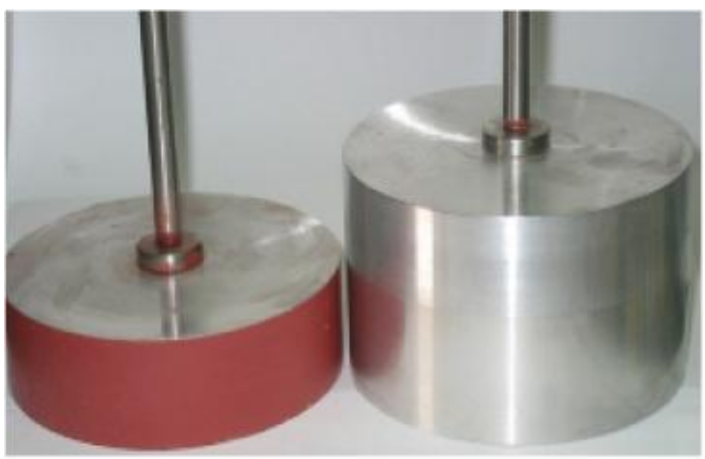

Figure 4: From left-short rotor painted with the first layer of Intertuf 262 Red and long rotor as smooth reference

6.0 TEST RESULTS

The Rotor torque is measured by a 'friction belt' using a linear force gauge (spring type) strain gauge, attached to friction belt wrapped around the driving shaft. Force exerted during rotation is then multiplied by the radius of the rotor to obtain the torque reading. A digital tachometer with a resolution of ±0.1rpm is used to measure the rotation of the shaft. The temperature of the water was measured with a digital thermometer with an accuracy of

±0.1°C which is inserted through the top opening of the tank. The kinematic viscosity ν and the density ρ were determined from the temperature measurements using the tabulated values given by van Manen and van Oossanen (1988).

The cylinders used in the experiments were made of aluminium and were 80 mm and 40 mm for long and short rotor respectively, and 90 mm in diameter. One set of cylinders (long and short rotor) were used as smooth reference surfaces and three sets of cylinders were coated with a tin-free SPC scheme and a Foul Release scheme applied by spraying. In order to eliminate the end effects of the rotor, an experimental procedure is adopted whereby two lengths of rotor are tested. Firstly, a short rotor test is conducted. Secondly, long rotor test is conducted whereby the short rotor is being replaced by the long rotor. These test cylinders for each type of coatings are changed for each surface under investigation. The measured difference in torque between the short and long rotor test gives the torque for each test cylinder. Torque, speed and temperature measurements are taken at different speeds and time is given for the apparatus to reach a steady state for each speed. The braking action is applied slowly until the shaft stops rotating. Readings are recorded by the amount of force exerted multiplied by the rotor's radius.

The results have been obtained from both Foul Release Schemes (Airless Spray) and Tin Free SPC Schemes (Airless Spray) test in order to compare with the result which has been obtained from Smooth Reference test. Tables 1, 2 and 3 are representing the data which have been obtained during the experimental test related to Smooth Reference test, Foul Release Schemes (Airless Spray) and Tin Free SPC Schemes (Airless Spray) test respectively.

Table 1: Results for Smooth Reference

N (rpm)	**T_{s-av} (N.m)**	**T_{l-av} (N.m)**	**ΔT (N.m)**	**U_1 (m/s)**	**Uτ (m/s)**	**$U_1/U\tau$**	**Re = rU_1/ν (×10^4)**	**rUτ /ν (×10^4)**	**$C_f = 2(U\tau/U_1)^2$**
294.9	0.0025	0.0030	0.0004	1.39	0.029	47.74	5.486	0.105	0.00088
443.7	0.0036	0.0040	0.0005	2.09	0.031	67.99	8.254	0.111	0.00043
593.2	0.0035	0.0040	0.0006	2.80	0.033	84.83	11.036	0.119	0.00028
742.0	0.0051	0.0057	0.0006	3.50	0.036	98.05	13.804	0.128	0.00021
891.2	0.0061	0.0070	0.0008	4.20	0.040	105.18	16.580	0.144	0.00018
1040.3	0.0067	0.0076	0.0009	4.90	0.041	118.86	19.354	0.148	0.00014
1190.0	0.0067	0.0075	0.0008	5.61	0.041	138.45	22.139	0.146	0.00010

Table 2: Results for Foul Release Schemes (Airless Spray)

N (rpm)	**$T_{s\text{-}av}$ (N.m)**	**$T_{l\text{-}av}$ (N.m)**	**ΔT (N.m)**	**U_1 (m/s)**	**Uτ (m/s)**	**U_1/Uτ**	**Re = rU_1/ν (×10^4)**	**rUτ /ν (×10^4)**	**C_f = $2(U\tau/U_1)^2$**
293.8	0.0014	0.0021	0.0007	1.38	0.037	37.36	5.466	0.133	0.00143
443.1	0.0021	0.0027	0.0006	2.09	0.034	60.53	8.243	0.124	0.00055
592.4	0.0027	0.0036	0.0010	2.79	0.044	63.68	11.021	0.158	0.00049
741.3	0.0033	0.0044	0.0011	3.49	0.047	74.53	13.790	0.169	0.00036
890.7	0.0034	0.0047	0.0012	4.20	0.049	86.04	16.570	0.176	0.00027
1039.9	0.0043	0.0058	0.0015	4.90	0.055	89.17	19.346	0.198	0.00025
1188.5	0.0048	0.0064	0.0015	5.60	0.055	101.91	22.111	0.198	0.00019

Table 3: Results for Tin Free SPC Schemes (Airless Spray)

N (rpm)	**$T_{s\text{-}av}$ (N.m)**	**$T_{l\text{-}av}$ (N.m)**	**ΔT (N.m)**	**U_1 (m/s)**	**Uτ (m/s)**	**U_1/Uτ**	**Re = rU_1/ν (×10^4)**	**rUτ /ν (×10^4)**	**C_f =$2(U\tau/U_1)^2$**
293.5	0.0007	0.0018	0.0011	1.38	0.046	30.15	5.460491	0.165	0.00220
443.1	0.0012	0.0023	0.0011	2.09	0.047	44.55	8.242479	0.169	0.00101
592.0	0.0017	0.0031	0.0014	2.79	0.052	53.24	11.01284	0.189	0.00071
741.4	0.0022	0.0033	0.0011	3.49	0.046	76.15	13.79273	0.165	0.00034
891.0	0.0028	0.0039	0.0011	4.20	0.047	89.59	16.57612	0.169	0.00025
1040.0	0.0034	0.0045	0.0011	4.90	0.046	106.82	19.34811	0.165	0.00018
1189.5	0.0038	0.0049	0.0011	5.61	0.047	119.60	22.1294	0.169	0.00014

7.0 DISCUSSION

In Figure 1, velocity distribution ($U_1/U\tau$) versus Reynolds number (Re) is plotted using the data presented in tables above. For all specimens, with increasing Reynolds number the velocity distribution is increased. Also, the curves for all coated cylinders are placed below the curve for smooth reference cylinder. This means that coating has increased the surface roughness, however, the extent of this depends on the nature of the coating. Also Figure 1 shows that as the roughness (characterized by rUτ/ν) increases, the added drag (ΔU/Uτ) increases accordingly. As the rotational speed increase, the velocity distribution also increases according to the log law. But as the rotational speed reaches about 740 RPM (which corresponds to Reynolds number 13.8 x 10^4), the trend lines for TBT free SPC coatings and Foul Release starts to intersect. Thereafter, the velocity distributions for TBT free SPC coating began to exceed Foul Release coating. This was because by increasing the velocity, the effects of coating type on the frictional drag become less important. This is because in high speeds, wave making resistance has more effect on total resistance than skin frictional drag.

In Figure 2, frictional resistance coefficients of various coatings are plotted against Reynolds number. According to the graph the SPC coating (sprayed) has the highest frictional resistance coefficient, C_f, and the Foul Release coating (sprayed) is placed in between smooth reference and SPC coating. Also Figure 2 shows that as Reynolds number increase, there is a point where the frictional resistance coefficient for SPC coatings intersects with the Foul Release's and becomes lower than Foul Release frictional resistance coefficient. This may be attributed to the *'self-polishing'* characteristics of the coating itself, compared to the *'low surface energy'* characteristics of the Foul Release coating. The results presented with the discussion above can be used to determine the correlation between roughness function and Reynolds number, and extrapolate it to suit the conditions of the real ship.

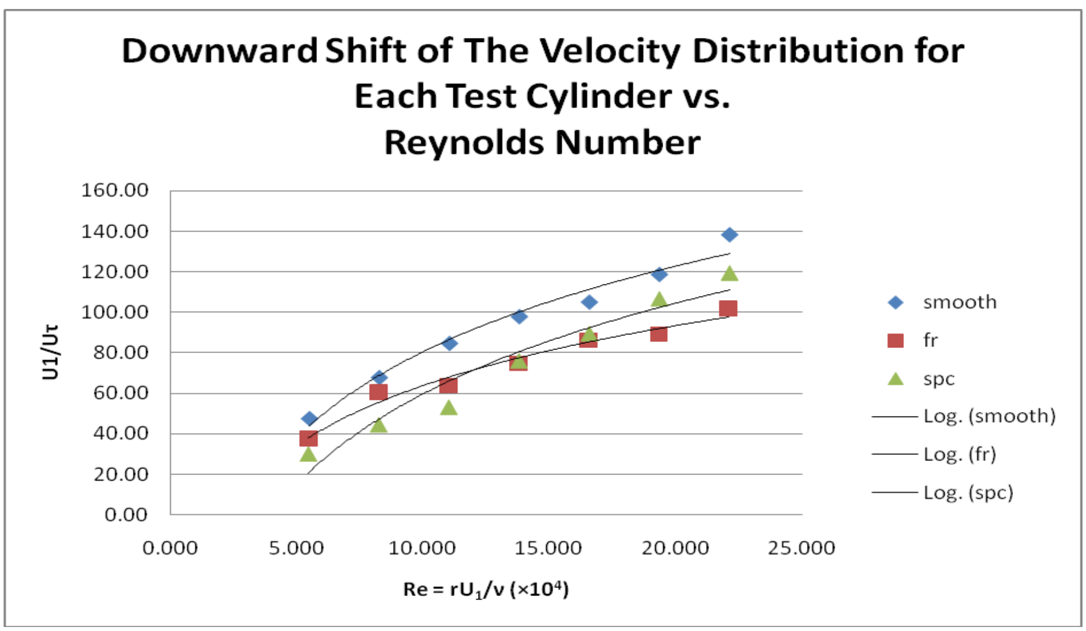

Figure 1: Downward Shift of the Velocity Distribution for Each Test Cylinder vs. Reynolds Number.

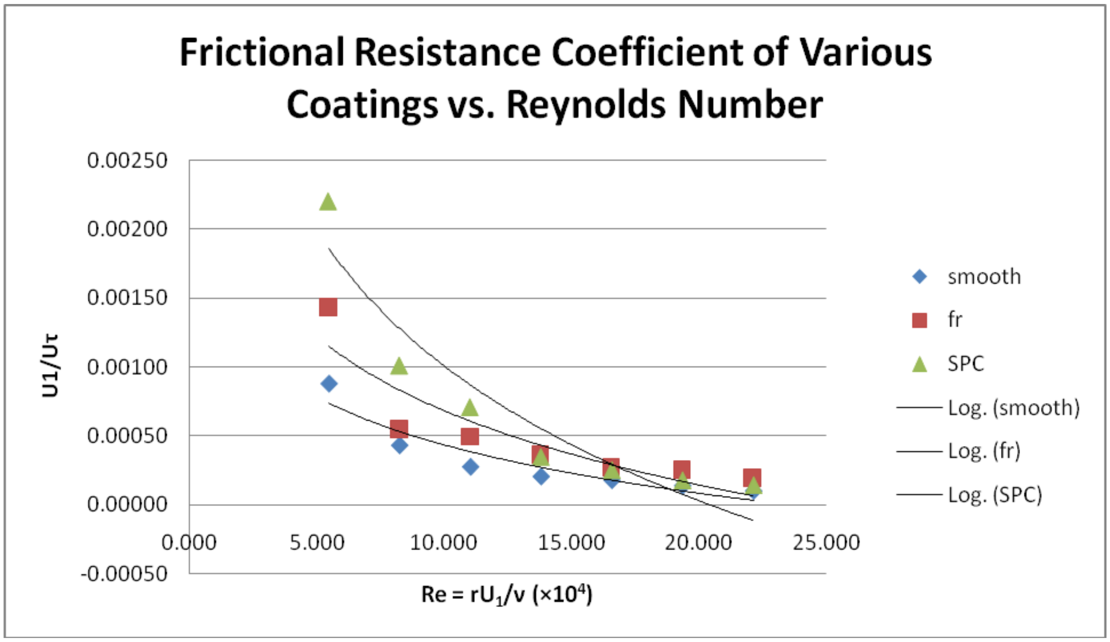

Figure 2: Frictional Resistance Coefficient of Various Coatings vs. Reynolds Number.

8.0 CONCLUSION

In this paper the drag characteristics of test specimen coated with a Tin-Free Self Polishing Co-Polymer (SPC) and Foul Release (FR) has been compared by using rotor apparatus designed and fabricated at the Marine Technology Centre (MTC) of Universiti Teknologi Malaysia. The experimental results show the frictional resistance for a Foul Release test cylinder was lower than a Tin-Free Self Polishing Co-Polymer (SPC) cylinder.

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