THE EXPERIMENTAL WORKS OF SHIP'S HULL COATING USING SUPERHYDROPHOBIC TO REDUCE FRICTIONAL RESISTANCE

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ABSTRACT

Frictional is a major contribution in ship's resistance. Reducing frictional resistance can be done by smoothing hull surfaces. This paper is study the use of *superhydrophobic* as a coating material to reduce frictional resistance. *Superhydrophobic* has physical characteristic to resist water so the ship's hull seem cannot wet. This phenomenon called as hydrophobic effects. The effects will be tested by experimental works in the ship's model resistance tests which are towed in ITS Hydrodynamic Laboratory. The experiment results average 10% to 22% reducing total ship's resistances.

Keywords: Hydrophobic, Superhydrophobic, coating, frictional resistance, ship's hull, towing tank, Experimental work, hydrodynamic laboratory

INTRODUCTION

Typical model of a modern ship may be shown by innovation related to save energy concept. One of the method is optimize hull by apply coating material that acts to reduce frictional resistance. Frictional has dominant effects on resistance which is contribute more than 30% of the total resistances (*Harvald,1983*). This paper study about the application of hydrophobic and superhydrophobic material when they coated over ship's hull below waterlines. *Hydrophobic* term is a physical property of molecule to resist water. The phenomenon can be seen when a grain of water drop on the surface of lotus leaf. The water cannot wet the leaf but perform a water bubble. This is usually called as *hydrophobic Effect*.

Figure 1. Hydrophobic effect on the lotus leaf surface

Superhydrophobic materials developed based on the above phenomenon. The capability of superhydrophobic to reject mostly all type of fluids therefore, such material by using nanotechnology exclusively, may be applied for coating many engineering objects, includes ship's hull. Superhydrophobic when used as a coating material can produces an air layer on the surfaces so that the objects can resist to the water.

Superhydrophobic layer can be applied to any surface composition even at its complicated geometry. Measuring the level of wetness commonly use contact angle as a reference. Hydrophobic condition can be achieved when the contact angle between water and surface more than 90^0. Moreover, superhydrophobic is a condition when the contact angle between water and surface is more than 150^0. (*Gusnedi,2014*).

Hydrophobic characteristic influenced by the viscosity of the fluid. Viscosity of the fluids is built by existence of the friction forces among molecules occurs cohesively by coherent forces among molecules. *Bhusan (2009)* had research to study the behavior of hydrophobic to materials that characterized by micro and nano approach and he has a conclusion that hydrophobilistic over a surface may possibly studied by analyzed the roughness and contact angle. At the surface of hydrophobic nano the increasing roughness will cause more contact angle, in the other hand, at the surface of hydrophilic nano the increasing roughness will cause lesser contact angle (*Gusnedi,2014*).

Frictional Resistance

Theoretically, ship move in water surface with certain speed will face with resistance that the direction opposite of the ship's heading. The resistance force must be overcome by suitable thrust force which is produced by main engine drive propulsion system. Ship's resistance has three main components. Wave making resistance, frictional resistance, and appendages resistance (*equation 1*). As the main objective of this study, frictional resistance will be in focus for discussion. Water particles at boundary layer of the main hull skin accelerate because of the speed when the ship moving. It would result drags cause by friction of the water. The boundary layer will thicker when the ship's hull not streamline. For example, due to the existence of fouling (*Harvald,1983*).

Total Resistance = Wave making resistance + frictional resistance + appendages resistance (1)

Modern ship design software may easy to predict mathematically the value of ship's resistance even for partial analysis such as frictional resistance. But physical scaled model towed in a hydrodynamic lab. also a good option to get more precise results.

$$\lambda_L = \frac{L_S}{L_M} \quad \text{: Dimensional scale}$$
$$\lambda_P = \frac{P_S}{P_M} \quad \text{: Specific density scale} \qquad (2)$$
$$\lambda_V = \frac{V_S}{V_M} \quad \text{: Velocity scale}$$

Based on the equation 1, then can be developed for:

$$\lambda_S = \lambda_L^2 \quad \text{: Surface scale}$$
$$\lambda_V = \lambda_L^3 \quad \text{: Volume scale}$$
$$\lambda_M = \lambda_P \lambda_L^3 \quad \text{: Mass scale} \qquad (3)$$

$\lambda_t = \frac{v_L}{v_V}$: Time scale

$\lambda_t = \frac{\lambda_V^2}{v_L}$: Acceleration scale

Dynamic similarity between scaled model and full scaled ship represented by certain ratio which is developed depend on the dimension of the towing tank (*Harvald,1983*).

$$
\begin{aligned}
&C_V = f(R_n), && C_W = f(F_n) \\
&R_{nS} = R_{nM}, && F_{nS} = F_{nM} \\
&\frac{L_S V_S}{v_S} = \frac{L_M V_M}{v_M}, && \frac{V_S}{\sqrt{gL_S}} = \frac{V_M}{\sqrt{gL_M}} \\
&V_M = V_S \frac{v_M}{v_S} \frac{L_S}{L_M}, && V_M = V_S \sqrt{\frac{L_M}{L_S}} \qquad (4)
\end{aligned}
$$

Both geometric and dynamic similarity not directly can be achieved in the same time when scaled model tested in the towing tank because of making similar Reynold Number (R_n) and Froude Number (F_n) physically impossible. It is need special correction factor.

EXPERIMENTAL SET UP

Design of Experiment

This research is an experimental works that had been carried out in Campus ITS Hydrodynamic Laboratory as shown in Figure 2. A crew-boat with length of 40.5 meters and draught about 1.8 meters will be used for study.

Table 1: Dimensional data of the Crew Boat and its scaled model

KAPAL		MODEL KAPAL
40.5 m	Length Overall	1.000 m
37.9 m	Length Part Perpendicular	0.9358 m
7.5 m	Breadth	0.1852 m
3.65 m	Height	0.0901 m
1.8 m	Draught	0.0444 m
276.38 m^2	Water Surface Area	0.1685 m^2
224.5 ton	DISPLACEMENT	3.3795 kg

The scaled model determined, and the result is 1 : 40.5. The test had been carried out in these conditions:

Gravitational Force $g = 9.81$ m/det^2.
Density sea water (28ºC) $\rho = 1022.25$ kg/m^3
Viscosity Kinematic sea water (28ºC) $\upsilon = 0.8847.10^{-6}$ m^2/det
Density and Viscosity kinematic fresh water on tank calculated based on the water temperature when the experimental Works was done (27 ºC)
ρ airtawar (27 ºC) = 996.45 Kg/m^3 υ air tawar (27 ºC) = $0.85409.10^{-6}$ m^2/det

Experiment 1: Model Without coating

Firstly, the model's hull wash with water and evaluate the initial effects between the hull and water. The visual observation reported that the water flow normally in the hull surfaces. Then the scaled model installed in the carriage ready for towing test. This test called as baseline condition without any hyperphobic coating material.

Experiment 2: Model coated with hydrophobic material

All surfaces of the scaled model coated with hydrophobic material. The material sprayed at distance of 8 to 10 cm with inclination of 45^0. The coated model left for natural dry at about 24 hours. After dry, the coated model tested the effect of the coating hyperphobic by washing it with water. The visual observation reported that the hull's surface still dry and some water bubbles sticks in the hull. This effect proves that hyperphobic affects the scaled model. Then, model ready for the next towing tests.

Figure 2. Resistance test at ITS Hydrodynamic Laboratory

Experiment 3: Model coated with superhydrophobic

After take data from the experimental 2 then the scaled model dry-up for a while and continue with lay up using superhydrophobic material. This coating material have two different layers. First layer acts as an adhesive material so the upper layer can stick strongly above the hull's surface. Coating process for first layer after finish then dry up at about 24 hours. Then, the upper layer laid up respectively and dry up also for about 24 hours. Finally, the coated scaled model observed visually to evaluate the effect of the superhydrophobic to the surfaces. Visually, it seen that water cannot wet the surfaces and performs water bubbles in some location. Model ready for the next experiments.

RESULTS AND DISCUSSION

The experimental results shown in table 2 and Figure 3. Relation between test conditions 1, 2, and 3 shows that there is decreasing resistance. This results prove the previous hypothesis that the both hydrophobic and superhydrophobic coatings can reduce ship's resistance. Laying up the surface with those materials that capable of refuse water to stick the surfaces and slip over then the friction between them consequently could be reduced. Finally, the frictional resistance decreased and influence also to the decreasing of the total resistance. It is one of the good challenge to lowering more fuel consumption when others method to maintain the cleanliness and smoothness hull's surfaces already known and always done.

Table 2: Summary of the experimental results of the Crew Boat and its scaled model

SCALED MODEL

Run Ke:	V(m/s)	**Rt** (kg) 1	**Rt** (kg) 2	**Rt** (kg) 3
1	1.2933	0.0765	0.0647	0.0556
2	1.4549	0.1118	0.0882	0.0778
3	1.6166	0.1412	0.1294	0.1000
4	1.7783	0.1647	0.1412	0.1222
5	1.9399	0.1765	0.1647	0.1389
FULL SCALE (KAPAL)				
Run Ke:	**V** (knot)	**Rt** (KN) 1	**Rt** (KN) 2	**Rt** (KN) 3
1	16	30.069	26.021	22.86
2	18	45.079	38.35	34.37
3	20	59.704	57.361	45.68
4	22	73.962	64.44	56.77
5	24	76.108	71.596	61.72

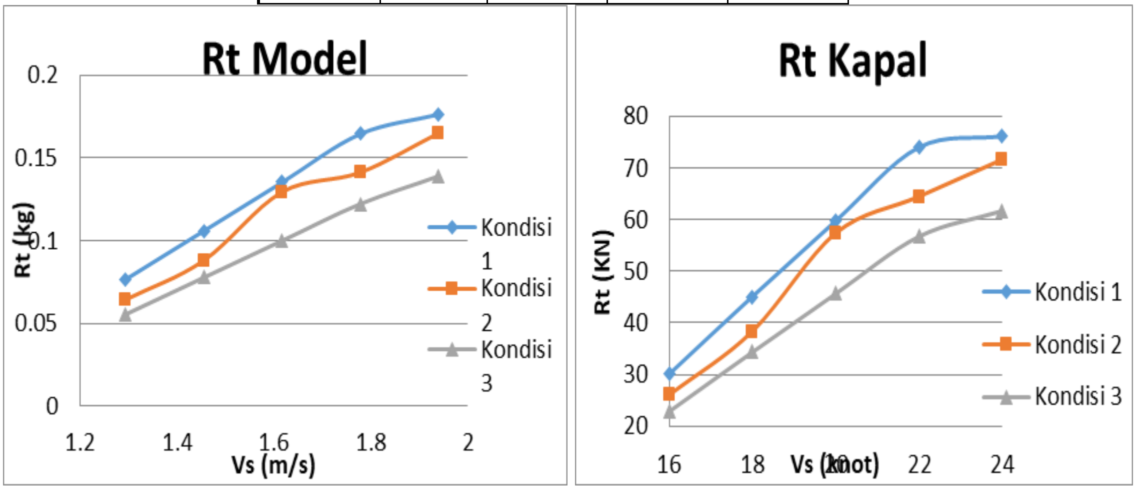

Figure 3. Experimental results

Relation between scaled model with C_f model

Theoretically, the relation between speed and frictional coefficient can be shown as following equation. Friction coefficient inversely proportional with the ship speed. The bigger increasing speed then C_f will be smaller.

$$C_f = \frac{0.075}{(Log\, R_n - 2)^2} \tag{5}$$

While Reynold Number R_n expressed as:

$$Rn = \frac{VL}{\upsilon} \tag{6}$$

Where: C_f = Frictional coefficient
R_n = Reynold number
V = Model speed
L = Length model
υ = Viscosity kinematic of water

Table 3 shows the experimental results of the Frictional Coefficient C_f when the model speed varied at three test conditions. Increasing the model speed cause decreasing frictional coefficient. It can be easily explained that higher speed make higher slip happened between hull surface and water so the friction tends to decrease. Frictional Coefficient C_f3 which is resulted from experiment-3 using superhydrophobic has lower value than the results C_f2 from experiment-2 that use hydrophobic coating. Surely, the value of C_f2 lower than C_f1. The experimental results for the three condition tests also represented to the Figure 4.

Table 3. Relation between model speed and C_f model at the tests condition 1,2, and 3

SCALED MODEL				
No :	**V** (m/s)	**C_f** 1	**C_f** 2	**C_f** 3
1	1.2933	0.004352	0.003681	0.00316
2	1.4549	0.004247	0.003537	0.00311
3	1.6166	0.004156	0.003974	0.00307
4	1.7783	0.004076	0.003494	0.00302
5	1.9399	0.004005	0.003737	0.00315

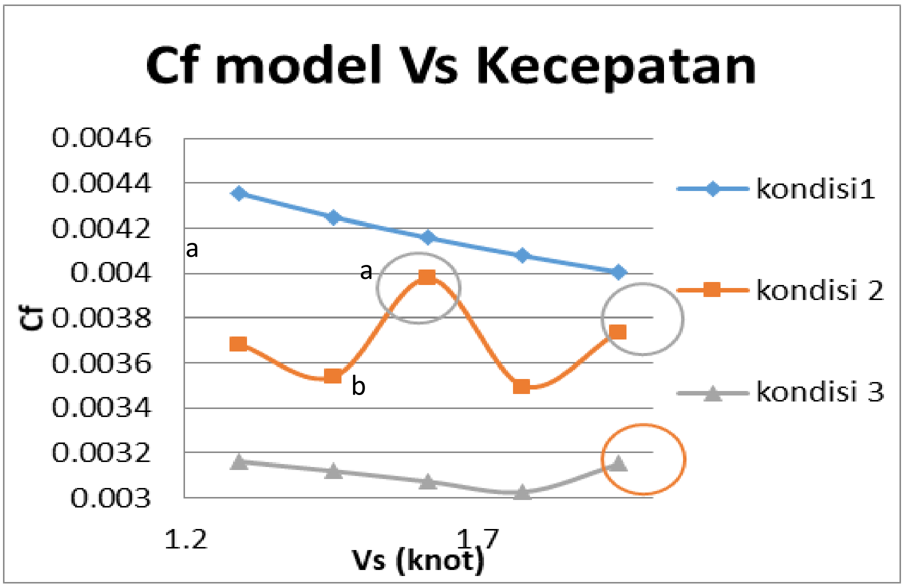

Figure 4. Relation between model speed and C*f* model at condition 1,2, and 3

Figure 4 shows anomaly data at the second experiment where the speed between 1.6 m/s and 1.9 m/s occurred high jump data significantly. We suspect it may be caused by less smoothness of the painting and coating works or worstly it may be caused by erosion of the coated surfaces due to low durability of the hydrophobic layer. Erosion make the surface become rough.

At the third experiment especially when the model run at 1.9 m/s there is also jump data of the frictional coefficient significantly. It may be also caused by erosion due to weakness of durability and the existence of surface roughness when the model run at high speed.

For C_f calculation at model 2 and 3 carried out by multiply the percentage reduction of the model R_t at condition 2 and 3 and initial condition of C_f. Then validate it by using empirical formula:

$$\Delta C_f = [105(\frac{ks}{L})^{1/3} - 0.64]/1000 \qquad (7)$$

Where : Δ C_f = divergency of the frictional coefficient

k_s = material roughness (coating paint $100\sim150 * 10^{-6}$)
L = Length of model

CONCLUSION

Based on the experimental results, data analyzing, and discussion above therefore can be concluded that the ship's resistance will be decreased when it's hull coated by using hydrophobic and superhydrophobic materials. Under the experimental-2 run at 16 ~ 24 knots which is coated by hydrophobic material the experimental results show that resistance may reduce up to 10.22%. Using superhydrophobic at the experimental-3, run at the same speed, the resistance reduces up to 22.66%.

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