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THE REPLICATION OF MICRO-RIBLETS ON SHIP HULLS FOR DRAG REDUCTION APPLICATIONS

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ABSTRACT

Desired higher ship speeds can be achieved using many performance enhancement techniques. One of the techniques is drag reduction of ships' hulls by imbuing their surfaces with hydrophobic properties This paper presents an alternative method of fabricating micro-riblets using laminate transfer molding to modify painting morphology for micro-riblets' replication on ships' hulls. A performance test of these micro-riblets is also performed. The results show that micro-riblets can be replicated from the pattern to the ships' hulls. The geometries of micro-riblets are verified, which shows good agreement with the pattern. The performance of the fabricated micro-riblets was verified to decrease drag on the ship. As a result, ships' speeds increased under similar propulsion power. The significant effect of micro-riblets is obtained with these higher speeds.

Keywords: Drag reduction; High speed boat; Laminate transfer molding; Micro-replication; Micro-riblets

1. INTRODUCTION

Desired higher ship speeds can be achieved through many performance enhancement techniques. One of the techniques is reducing drag on ships' hulls by imbuing their their surfaces with hydrophobic properties. Zhao and colleagues have observed hydrophobic characteristics of shark-skin models for riblets, which can be used to achieve drag reduction. The results indicated that the proposed shark skin model is able to reduce contact angles suitable as micro-riblets (Wang et al., 2014)

The implementation of micro-riblets has been used widely in various applications, such as turbine blades, aircraft, and antifouling devices. Besides increasing speeds, drag reduction also reduces fuel consumption in the aviation and shipping industries (Chamorro et al., 2013; Stenzel et al., 2011; Abbas et al., 2013).

In nature, micro-riblets are avalaible on shark skin, and they make sharks able to move efficiently in the water. Many researchers have sought to replicate shark skin using warious techniques. Liu and colleagues (Liu & Li, 2012) sucessfuly replicated shark skin using PDMS. Zhao and colleagues (Zhao et al., 2012) introduced a vacuum casting replication of micro-riblets on shark skin for drag-reducing applications. The pitch distance for shark skin is 100 µm, and the riblets' height is up to 50 µm, as shown in Figure 1 (Liu & Li, 2012; Zhao et al., 2012).

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Currently, riblets are fabricated by using a rolling technique (Stille et al., 2014), and direct replication is done using photolithography. The technique was applied to shark skin and ahs model ship model, only on a specimen (Chen et al., 2014). This paper presents an alternative with a simple method for fabricating micro-riblets using laminate transfer molding to modify painting morphology to acommodate micro-riblets' replication on a ship's hull. A performance test of the micro-riblets is also performed.

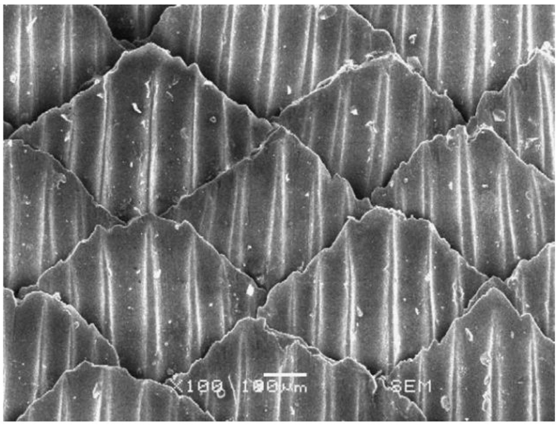

Figure 1 Scanning electron microscope of shark skin (Zhao et al., 2012)

2. EXPERIMENTAL METHOD

The ship model used in this work was a high-speed 2-meter long boat model, as shown in Figure 1. The paint material for the micro riblets was a commercial clear coat material designed for painting. The material used for the mold in this work was silicon rubber RTV 683 with a hardener. The riblet mold was fabricated using pattern materials made of nylon wire with diameters of 120, 250, and 500 µm. Application to the ship model was carried out via a laminate transfer molding process, as shown in Figure 2.

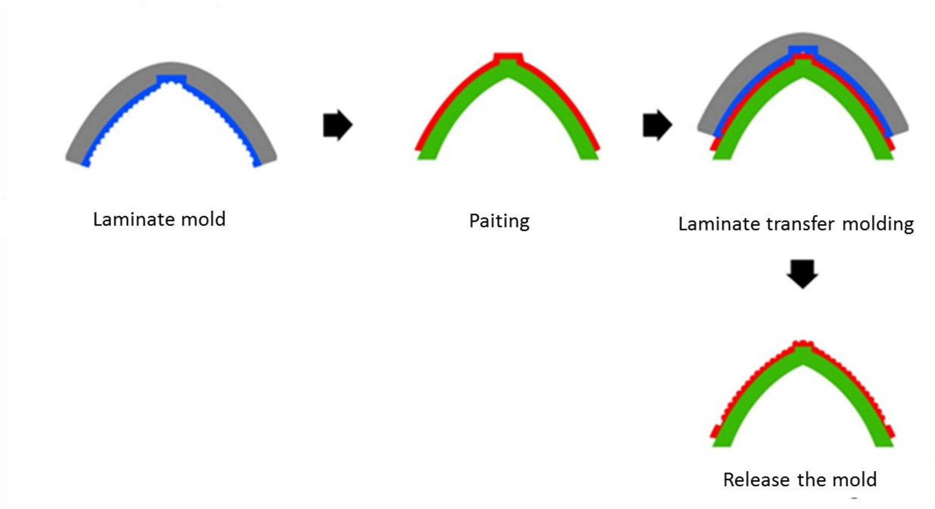

Figure 2 Procedure of laminate transfer molding

The procedure for laminating the transfer molding process began with pattern making, arranging a series of nylon wires on the glass surface. A mixture of silicon rubber and hardener was poured on top of the nylon pattern, and the silicon rubber was allowed to cure before being released from the pattern. A series of nylon wires formed a cavity of the micro-riblets' structure on the silicon rubber. A painting process was applied to the cavity of the micro-riblets' structure on the silicon rubber. Then, a painted area was attached to the ship's hull. Commercial painting materials were used. After the paint material had cured, silicon rubber was released, resulting in a micro-riblets structure on the ship's hull. The micro-riblets structure covered 50 % of the ship's hull area, on the front side, as shown in Figure 3. The speed test of modified ship's hull painting was conducted by pulling, using an electric motor as shown in Figure 4. The test was carried out under various motor powers.

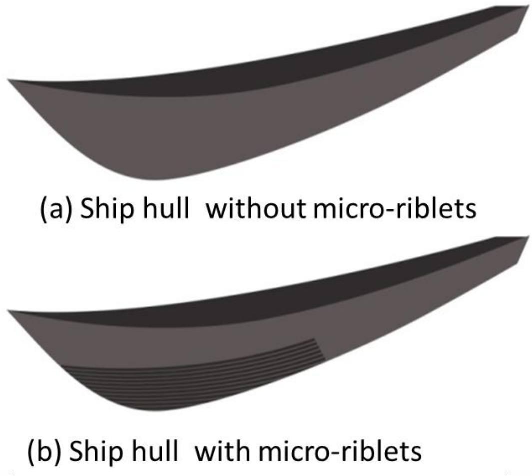

Figure 3 Position of micro-riblets' application on the ship's hull

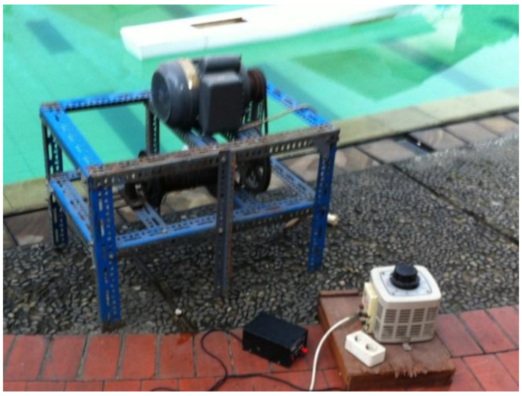

Figure 4 Motor used to pull the ship model

3. RESULTS AND DISCUSSION

Micro-riblets were successfully fabricated using a laminate transfer molding process with a nylon wire pattern. Figure 5 shows the experimental results of various riblets' sizes: 120, 250, and 500 µm. When comparing riblets on shark skin with 100 µm of riblet pitch, the riblet dimension is almost the same size at 120 µm. Silicone molds can be produced with good accuracy to replicate the wire pattern. However, further replications using a painting technique showed low accuracy, especially with bigger riblet sizes. This may lead to the increasing aspect ratio of the wall structure of the silicon mold. Several gas traps were also produced during the replication, since the process was not conducted under vacuum conditions.

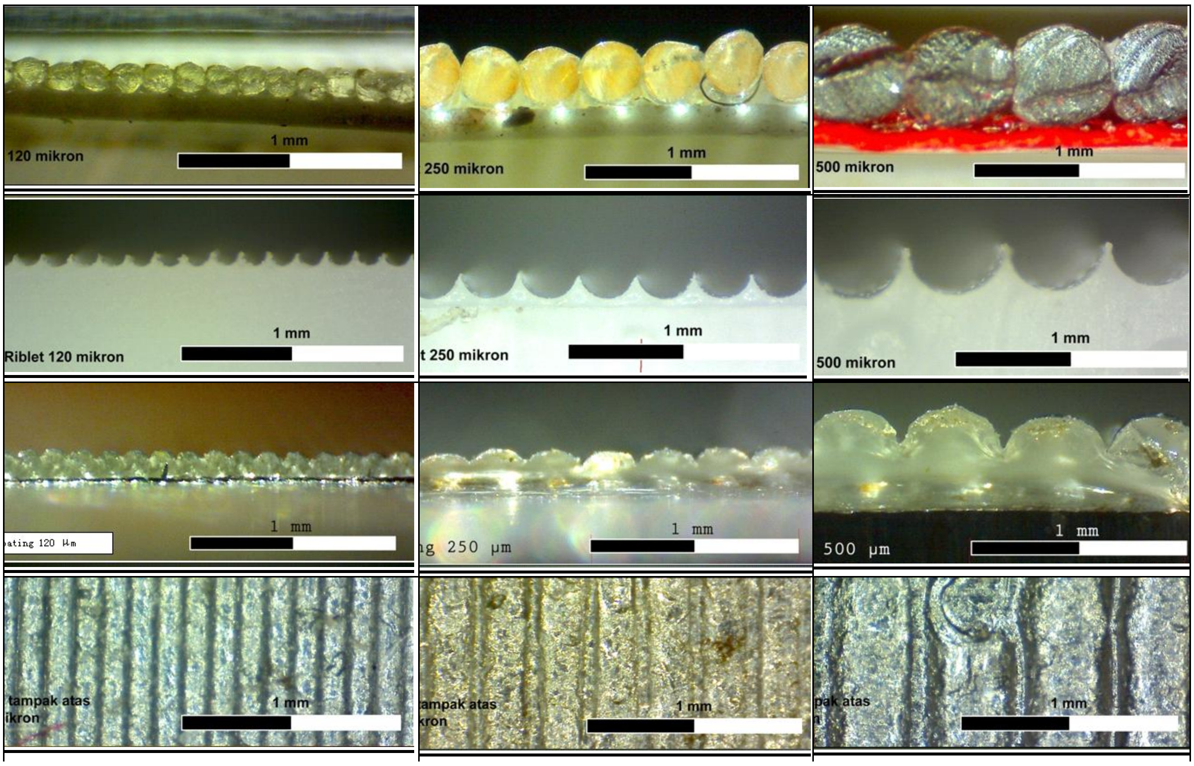

Figure 5 Cross-section area of laminate transfer molding stage

3.1. Micro-riblet Analysis

One important parameter for the design of round riblets is the riblets' height and pitch. The height of micro-riblets decreases, compare to the pattern, especially for larger sized patterns. This occurred due to the ratio of the thin and tall mold structure, as shown in Figure 6. Laminate transfer mold using 500 microns of nylon wire as the pattern yielded the thinnesy and highest fin, which might buckle during transfer molding. Another reason for this occurrence could be the total surface area is larger with a smaller pattern size. Decreasing the riblets' height by 1 to 24 % under the given range of patterns is recommended.

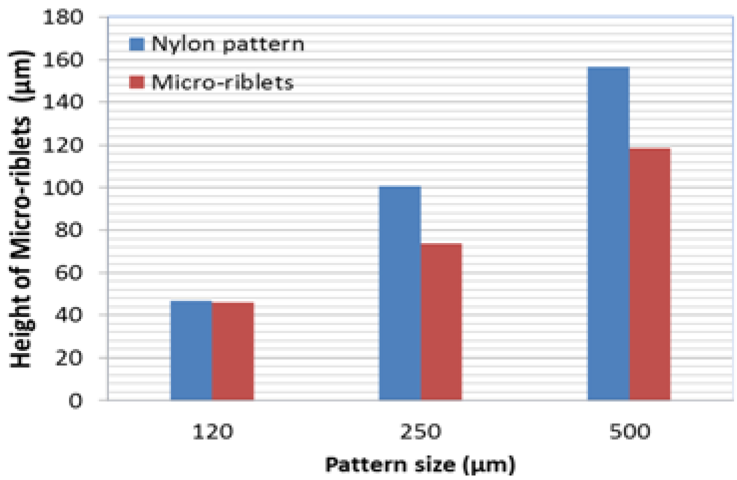

Figure 6 Average micro-riblets' heights

Laminate transfer molding using a flexible molding material has a tendency toward riblet distortion; therefore, monitoring the distance between each riblet is necessary. The results show that the pitch distance of riblets for a given pattern size is almost homogenous and similar to the pattern. The consistency of pitch occurs under given pattern sizes, as shown in Figure 7. These show that the use of a flexible mold does not significantly affect micro-riblets' arrangement. Accuracy of the replication is rated up to 96%.

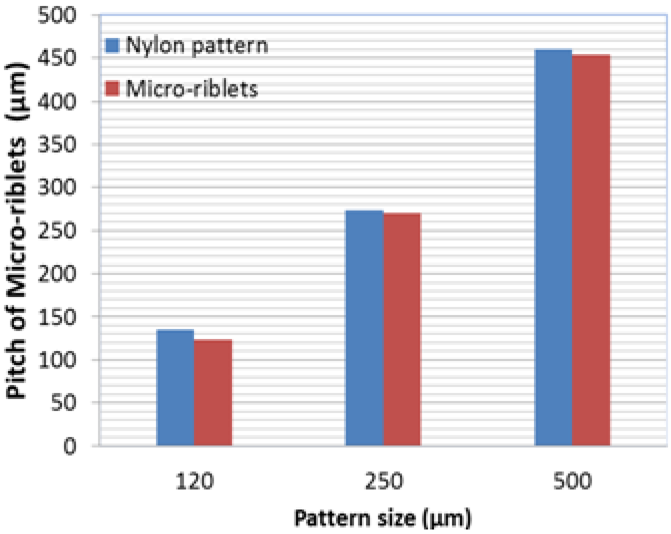

Figure 7 Average pitch of micro-riblets

3.2. Performance Test Of Micro-riblets

Verification of 500 µm micro-riblet performance on the high-speed boat model was conducted. Under similar propulsion force, the boat model with mico-riblets performed faster than the model without riblets. This effect increases with increasing propulsion power, as shown in Figure 8. As showm in the figure, the use of micro-riblets increases the speed of the model by up to 40%. This value might be increased by decreasing riblet sizes closer to shark skin dimensions.

Speed tests show that the ship with LTM-µR is up to 40% faster than one with a conventional surface paint texture. The effect of LTM-µR is more significant with higher propulsion power, as indicated by applying more power to the motor. The tests also verified that micro-riblets are suitable for high-speed ships or boats.

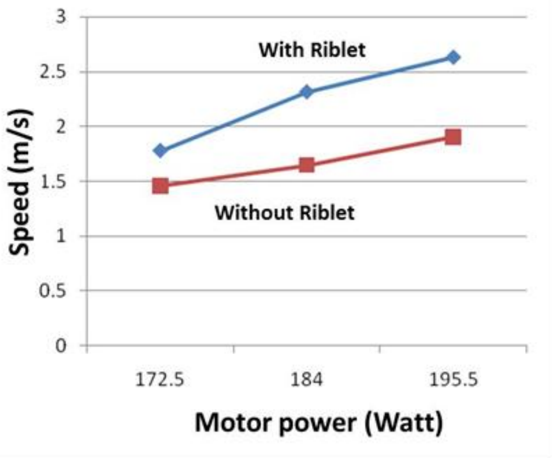

Figure 8 Effect of using a 500 µm micro-riblet on the speed of the boat model

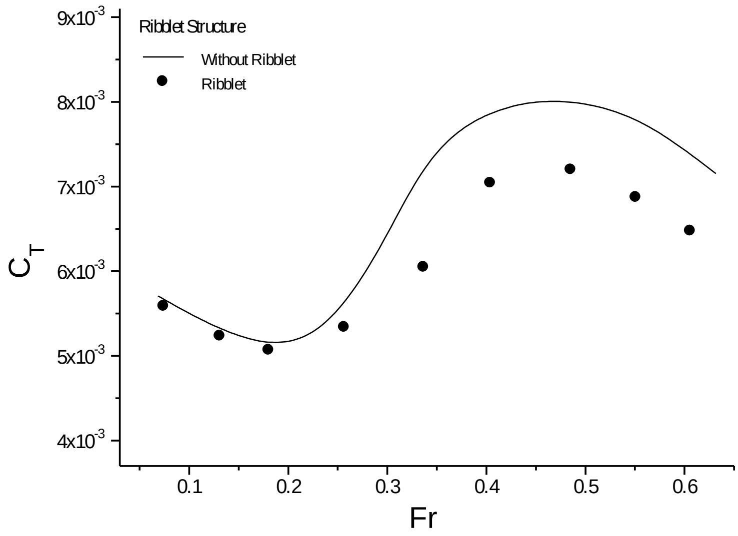

Figure 9 Total resistance coefficient (C_T) and Froude numbers (Fr) for the ship model

Figure 9 shows the relationship between the total resistance coefficient (C_T) and the Froude number (Fr) for the ship model with riblets, compared to the ship model without riblets. The results show that the total value of the resistance coefficient of the ship model with and without riblets has the same trend. The value of the total resistance coefficient (C_T) for the ship model with riblets is greater thanthe monohull model with the same displacement at Fr < 0.2. Meanwhile, at Fr > 0.2, for all ship model with riblet sticking, there is a positive effect, as indicated by the value of the total drag coefficient, which is lower than the ship without riblets.

In the turbulent-flow regime, fluid resistance typically increases dramatically with an increase in surface area, owing to the shear stresses at the surface acting across the new, larger surface area. However, as vortices form above the riblets' surface, they remain above the riblets, interacting with the tips only and rarely causing any high-velocity flow in the valleys of the riblets. Since the higher velocity vortices interact only with a small surface area at the riblets' tips, only this localized area experiences high-shear stresses. The low-velocity fluid flow in the valleys of the riblets produces very low-shear stresses across the majority of the surface of the riblets. Based on Figure 9, the obtained drag reduction ratio for riblets is 10% at Fr = 0.45.

4. CONCLUSION

This paper presents a fabrication plan for micro-riblets using laminate transfer molding and silicon rubber as old material. The results show that micro-riblets can be replicated from the pattern to a ship's hull. The performance of the micro-riblets was verified: they can increase a ship's speed under similar propulsion power. The significant effect of micro riblets is greater with speed.

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