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Kaoruko Onishi, Kunimasa Matsuda, Kazuyoshi Miyagawa. Influence of Hydrophilic and Hydrophobic Coating on Hydrofoil Performance. International Symposium on Transport Phenomena and Dynamics of Rotating Machinery (ISROMAC 2017), Dec 2017, Maui, United States. hal-02349523

HAL Id: hal-02349523
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Influence of Hydrophilic and Hydrophobic Coating on Hydrofoil Performance

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ISROMAC 2017

International Symposium on Transport Phenomena and Dynamics of Rotating Machinery

Hawaii, Maui

December 16-21 2017

Abstract

Tidal power turbines take advantage of tidal energy to generate renewable hydropower. Since the tidal turbines are fixed in the ocean, it is common to paint the blade and the structure of tidal energy generator with antifouling coating to prevent marine organisms from attaching to them. Therefore, it is important to predict the influence of the coatings on the tidal turbine's performance. In this paper, hydrophilic and hydrophobic coatings which are known to be useful in antifouling were studied from the perspective of flow field and cavitation. Cavitation was visualized with a high-speed video camera and the cavitation characteristics of blades painted with hydrophilic or hydrophobic coatings were compared. With this visualization, it was possible to observe that the hydrophilic foil and hydrophobic foil had distinctive characteristics in cavitation inception and growth. Moreover, the reliability of both coatings was evaluated in order to discuss whether these coatings were useful for long. Immersion tests were carried out to evaluate the deterioration of the coatings in pure water. In addition, magnetostriction vibratory tests were carried out to evaluate the resistance to cavitation erosion of both coatings. From these investigations, a chemical transformation of the hydrophilic coating was observed. Moreover, both coatings were easily removed when they were exposed to strong cavitation impacts.

Keywords

Hydrophilic — Hydrophobic — Cavitation

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INTRODUCTION

Nowadays, renewable energy has attracted a lot of attention due to its environmental friendliness and global warming prevention capability. [1] Tidal power generation is one of the hydropower generation methods which relies on energy from tidal current. [2] Since the tidal turbine is fixed in the ocean environment, marine organisms can easily attach to its blades and structure. When the marine organisms stick to the blades, the turbine performs differently from what is designed. In order to prevent marine organisms from attaching to the blades or the structure, it is known to be effective to paint the turbine with antifouling coating. [3] Katsuyama et al carried out model turbine tests to evaluate the effectiveness of antifouling coatings. They compared how the marine organisms attached to the model turbines which were fixed in the ocean for more than 6 months. The turbine with antifouling paint had less marine organisms attached at the surface, compared to the turbine without antifouling paint. From this experiment, it turned out that antifouling paint was useful in reducing marine organisms which adhered to the turbine. Therefore, it is important to predict the influence of the coatings on the fluid performance if the coating is to be widely used. In this paper, hydrophilic and hydrophobic coatings which are reported to be useful in antifouling were studied from the perspective of flow field and cavitation. [4] According to Watanabe et al, highly-hydrophobic coatings contribute to reducing friction in laminar flows. [6][7] Williams and Arndt conducted experiments aimed at exploring the possibility of using hydrophobic surfaces to minimize unwanted vibration due to cavitation. They compared different surface properties by using different material and surface quality. Although they found that surface characteristics have a significant effect on cavitation unsteadiness, they were unable to clarify the relation between cavitation characteristics and contact angle measurement. The purpose of this paper is to clarify the influence and mechanism of cavitation which occurs on the surface of hydrophilic and hydrophobic coatings, which show distinct contact angles. Moreover, we will discuss which of the hydrophilic or hydrophobic coating has greater influence on cavitation occurrence.

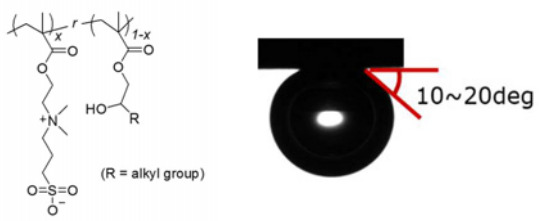
In order to accomplish this, experimental investigations of single blades were performed using a cavitation tunnel. Cavitation was visualized with a high-speed video camera and pressure fluctuation measurements which accompanied the cloud cavitation collapse was synchronized to it. The pressure was measured at the downstream of the foil. These recordings enabled the comparison of cavitation inception and growth. Furthermore, in order to discuss whether these coatings can be used practically, experiments were conducted to evaluate the reliability of both coatings. Immersion tests were carried out to measure how the coatings deteriorate in the pure water. In addition, magnetostriction vibratory test were carried out to investigate the deterioration of the coatings under cavitation condition.

1. Test Apparatus and Method

1.1 Characteristics of the Hydrophilic and Hydrophobic Coatings

The features of hydrophilic and hydrophobic coatings used in this research are shown in Fig.1. The coatings are heated to be cured, which enables the coatings to adhere to the base material. The hydrophilic coating is a networked polymer with surface segregated amphoteric ions. The hydrophobic coating is a fluorine polymer which is widely used as an antifouling coating.

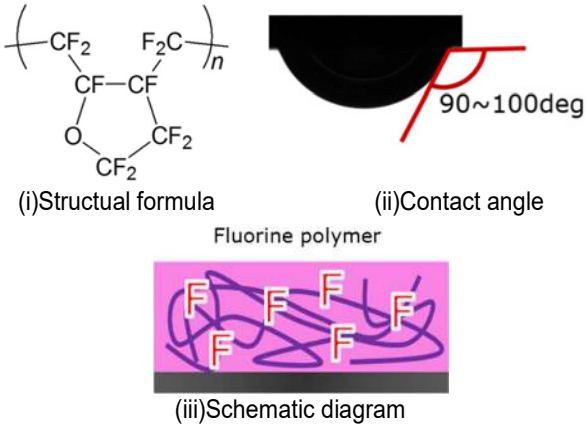
The wettability of the coatings was evaluated using the contact angle, it can be measured by sticking bubbles to the material surface. In this research, a contact angle goniometer was used, and air bubbles were put on the surface of the coating while sunk in pure water. The contact angles of the air bubbles were about 15deg for the hydrophilic coating, and about 100deg for the hydrophobic coating. The thickness of the coatings is about 3 ~ 4 μm.



(i)Structual formula (ii)Contact angle

(iii)Schematic diagram

(a) Hydrophilic coating



(i)Structual formula (ii)Contact angle

(iii)Schematic diagram

(b) Hydrophobic coating

Fig. 1. Characteristics of the coatings

1.2 Cavitation Tunnel

The experimental investigation was conducted using a closed loop water circuit tunnel described in Fig. 2 which contained the cavitation tunnel test section described in Fig. 3. The loop also contains two pumps and tanks upstream and downstream of the test section. The flow rate can be changed with two pumps, and the system pressure can be changed with a vacuum pump which is connected to downstream the tank. The test section has a 100mm ×100mm cross section, and is made of acrylic in order to visualize the cavitation using a high-speed video camera. A single blade which has the symmetrical NACA16-021 cross section shown in Fig. 4 is put into the test section. Its maximum chord length is 40 mm and its span length is 60mm. Its blade thickness distribution has an elliptical shape as shown in Figure 4.

The inlet pressure P_{in}(measuring point P1 in Fig. 3) was used to calculate the cavitation number and pressure fluctuations were measured using pressure transducers on the wall. The attack angle can also be changed with a turn table at the bottom of the foil. The cavitation number used here is defined as

$$\sigma = \frac{P_{in} - P_v}{\rho u^2/2}$$

where P_v is the vapor pressure, ρ is the density of water and u is mean velocity.

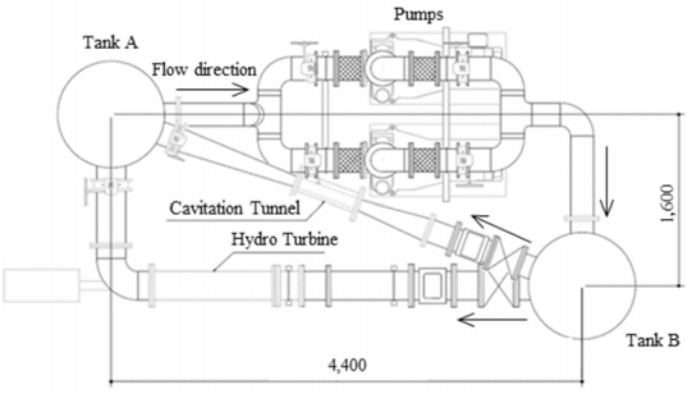


Fig. 2. Test loop

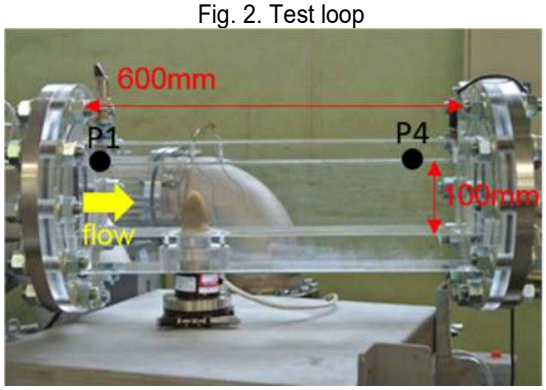


Fig. 3. Hydrofoil/Cavitation tunnel test section

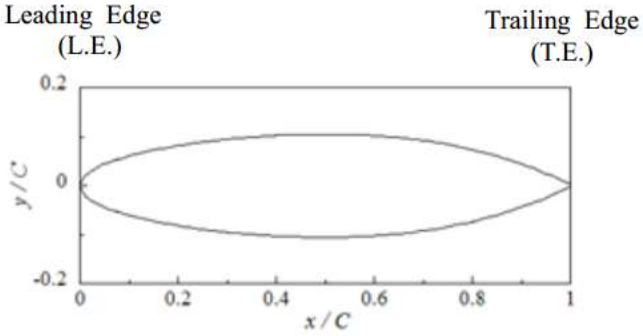


Fig. 4. Test hydrofoil

1.3 Immersion Test Apparatus

Fig. 5 shows the immersion test facility. It consists of heater and thermostatic tank which is filled with water. The pieces were put in the bottles and immersed into the pure water. The test pieces are aluminum (A7075). The time duration of the test varied between 1 hour and 432 hours. Since the velocity of chemical reactions increases at higher temperature, the water temperature was set to 20 ℃, 50℃,70℃ in order to accelerate the tests.

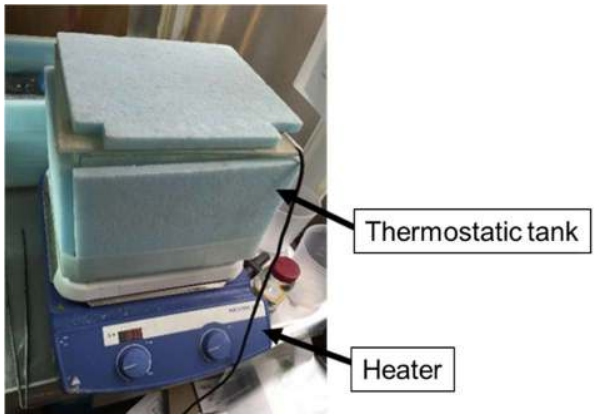
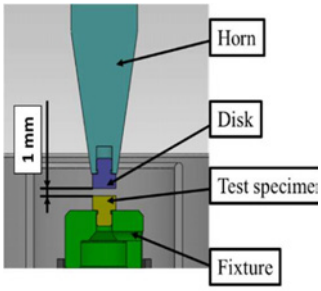


Fig. 5. Immersion test apparatus

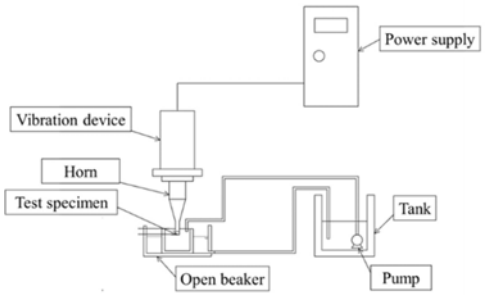
1.4 Magnetostriction Vibratory Apparatus

Fig. 6 shows external view of the apparatus a schematic diagram of it. The facility and method is based on the ASTM G 32-98 standard. The disk which is made of stainless (SUS304) was set at the tip of the vibratory horn, and test pieces were fixed facing this disk. The horn vibrates inside the open double-sided beaker which is filled with water. The water was circulated to control the temperature to 25~30℃. The amplitude of the vibratory horn was 4.8μm, and the vibratory frequency was 19.5kHz. The clearance between disk and test piece was set to 1mm. The test pieces were removed, and wettability of the coating was evaluated.

(i)External view



(ii)Test section



(i) Schematic diagram

Fig. 6. Magnetostriction vibratory apparatus

2. Results and Discussion

2.1 Influence of Hydrophilic and Hydrophobic Coating on Cavitation

2.1.1 Cavitation Inception

Fig. 7 shows cavitation maps comparing incipient cavitation number of the foil with different coatings. The measurements were done with a mean velocity of u=3m/s (Re=1.1 × 10^5), 5m/s (Re=2.0 × 10^5) and attack angle of α=10deg, 14deg, 20deg. Cavitation conditions were classified into Tip Vortex Cavitation (T.V.C), Sheet Cavitation (S.C.) and Cloud Cavitation (C.C). Sheet cavitation occurs at the surface of the hydrofoil and it leaves from the surface to the wake region, at which it usually transformed into cloud cavitation. Cloud cavitation was not observed at the test condition: u=3m/s, α=10deg due to requirements of the test apparatus. At every attack angle, first, Tip Vortex Cavitation (T.V.C) occurs, Sheet Cavitation (S.C) and then Cloud Cavitation (C.C.) occurs in sequence. As the attack angle and Re number increases, the incipient cavitation number of each cavitation form increases. At α=10deg and α=14deg, the hydrofoil painted with hydrophobic coating (H-PHO.) has a higher incipient cavitation number. The second highest is associated with the non-coating hydrofoil (N-C.), third is the hydrophilic coating (H-PHI.). However, the incipient number of each hydrofoil was almost the same when α=20deg. In addition, when α=10deg, the difference in incipient cavitation number is smaller compared to α=14deg. Similar results have been made by Arndt et al. [6]

2.1.2 Cavitation Growth

Table1 shows comparison of cavitation growth for each hydrofoil. The snapshots of cavitation were taken using a high-speed video camera. As the attack angle increases, the cavity get larger. Comparing cavitation growth on the hydrofoils with different coating, larger cavity occurs on the surface of the hydrophobic foil for the same cavitation number. When α=10deg, tip vortex cavitation and some small sheet cavitation were observed in the hydrophilic foil. On the other hand, tip vortex cavitation and larger sheet cavitation were observed in non-coating foil and hydrophilic foil. When α=20deg, Cloud cavitation was observed for all the foils, but the difference in the cavity size between hydrophilic and hydrophobic is smaller.

Figure 8 shows the time histories of the pressure, in which

fluctuations can be observed. The pressure fluctuations of each hydrofoil differ when α=10deg, σ=0.67. The hydrophobic foil has the largest amplitude and the hydrophilic foil has the smallest. On the other hand, the amplitude of each foil is almost the same when α=20deg, σ=0.70 and σ=2.26. When α=10deg σ=2.20, the amplitude is also larger with hydrophobic foil compared to hydrophilic foil, but the difference is smaller than the result from σ=0.67.

The hydrophilic and hydrophobic foils have distinctive characteristics for cavitation inception and cavitation growth. The difference in incipient cavitation number is apparent when the attack angle and mean velocity is small. The difference in cavitation growth and pressure fluctuation is apparent when the cavitation number and the attack angle are small. On the other hand, when the attack angle is large: α=20deg, the condition at which the flow separates at the leading edge, this difference disappears.

2.2 Reliability of Hydrophilic and Hydrophobic Coating

2.2.1. Deterioration in the Pure Water

Fig. 9 shows the results of immersion test. The X-axis represents time and the Y-axis represents the contact angle. When the water condition was 50 ℃ and 70 ℃, both hydrophilic and hydrophobic coatings were present on the surface of the material even after 430 hours. On the other hand, when the water was 20 ℃, the contact angle of hydrophilic coating got smaller as the time passed. It can be said that hydrophilic function changed to hydrophobic coating over time at 20℃. This phenomenon is not widely known or studied, since the hydrophobic coating is not supposed to exposed to water for such a long time. We can only guess that the chemical transformation occurred at the coating surface.

2.2.2 Cavitation Erosion

Table 2 shows pictures of air bubbles stuck to the surface of the coatings and their contact angles. Before carrying out the test, hydrophilic piece showed 12.3 deg and hydrophobic as 108.5 deg. However, as the pieces were exposed to cavitation, the contact angle changed and after 210 seconds, the angles of both hydrophilic and hydrophobic were almost same as uncoated pieces. Both coatings lost their function due to the strong cavitation impacts force which was caused by the collapse of cavitation bubbles.

The cavitation intensity was measured using a piezoelectric sensor. The measurement was done for 20 times and each was 0.4 μsecond long. Fig. 10 shows the cavitation impacts distribution at this condition. From this result, cavitation impact Ic was calculated to 2069N2-counts using the following definition.

$$\mathrm{Ic} = \mathrm{F}^2 * \mathrm{counts}$$

Fig. 11 shows the mass loss of the aluminum test piece under same vibratory test condition. From this result, the mass loss of aluminum test piece was 1.33mg after 5.5 hours of cavitation exposure. From this result, the cavitation impacts of the test condition were a lot stronger than that of cavitating turbines or pumps, in which cavitation erosion is not critical for the short time like 5 hours.

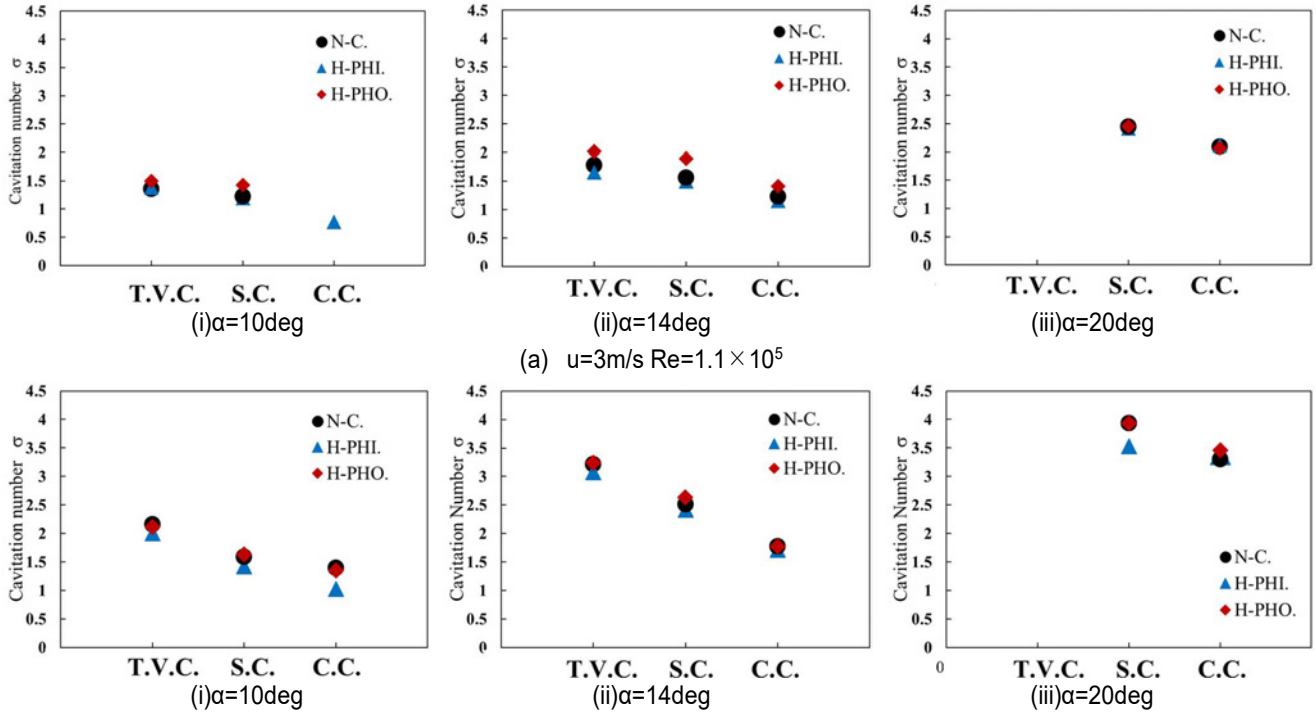
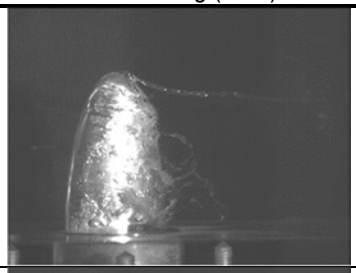
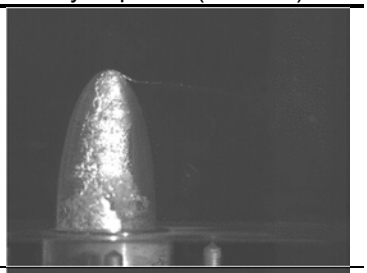
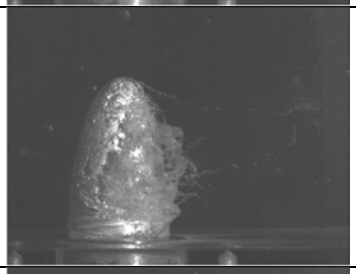
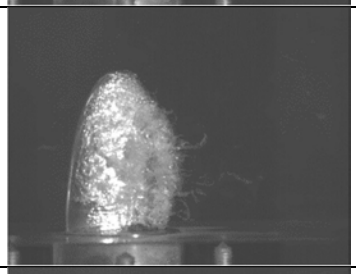
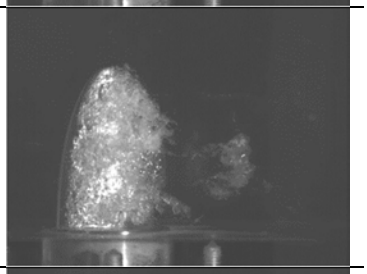
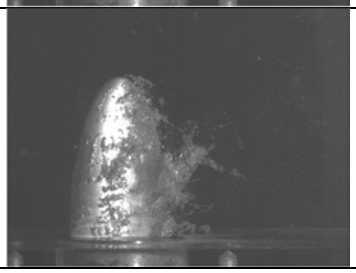
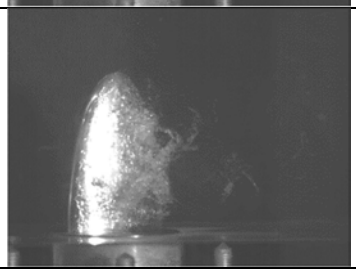
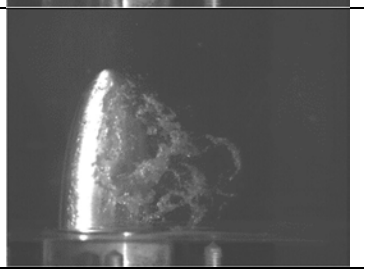
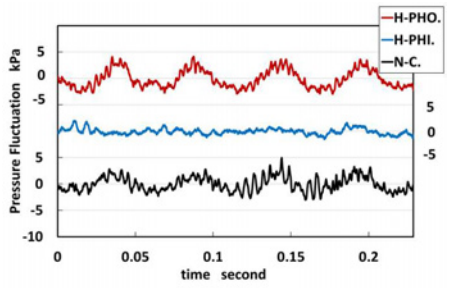


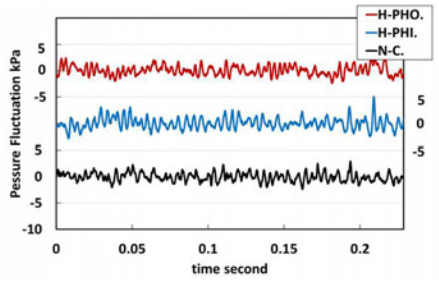
Fig. 7. Incipient cavitation number

Table. 1 Cavity shapes of each hydrofoil (σ = 1.1 Re=2.0×10^5)

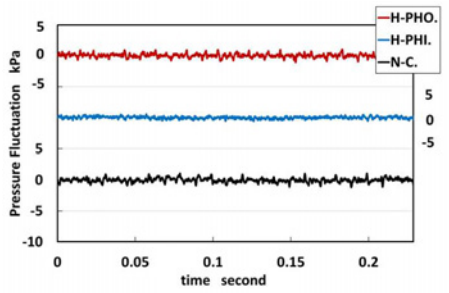
	Hydrophilic (H-PHI.)	Non-coating (N-C.)	Hydrophobic(H-PHO.)
α=10deg			
α=14deg			
α=20deg			



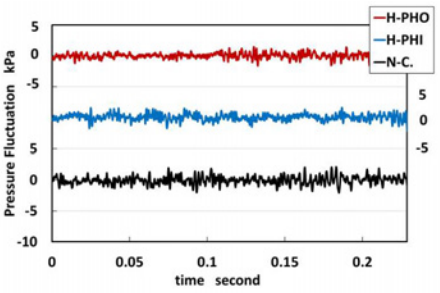
(i) α=10deg σ=0.67



(ii) α=20deg σ=0.70

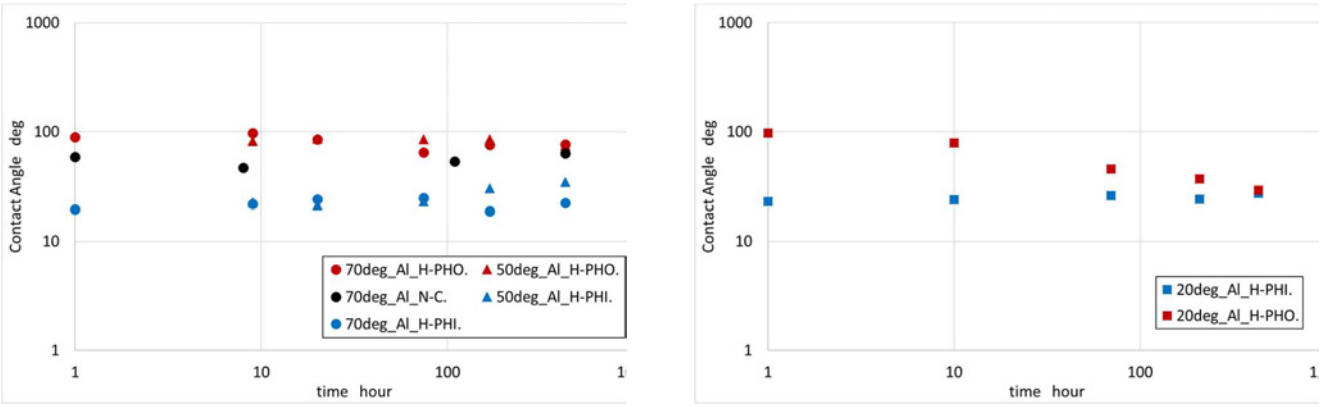


(iii) α=10deg σ=2.20



(iv) α=20deg σ=2.26

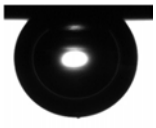
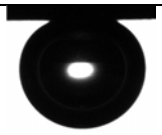
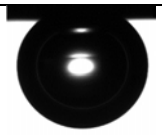
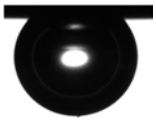
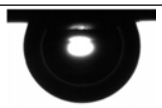
Fig. 8. Pressure fluctuation (Re=2.0×10^5)



(i) Water temperature 50℃, 70℃ (ii) Water temperature 20℃

Fig. 9. Immersing test result

Table 2. Contact angle of air bubble

Test time [s]	0	30	210
Non-coating			
Contact angle [deg]	50.1	54.5	54.3
Hydrophilic			
Contact angle [deg]	12.3	31.6	43.5
Hydrophobic			
Contact angle [deg]	108.5	101.8	59.1

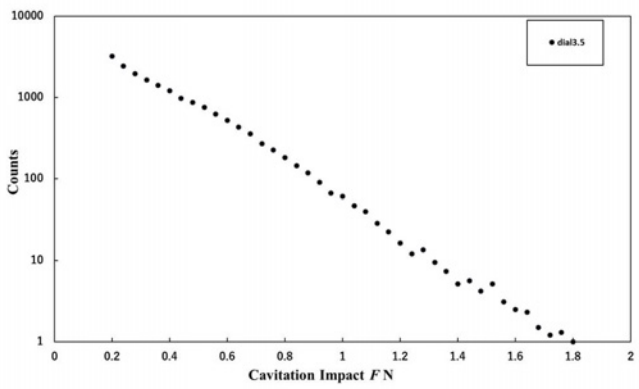


Fig. 10. Cavitation impact distribution

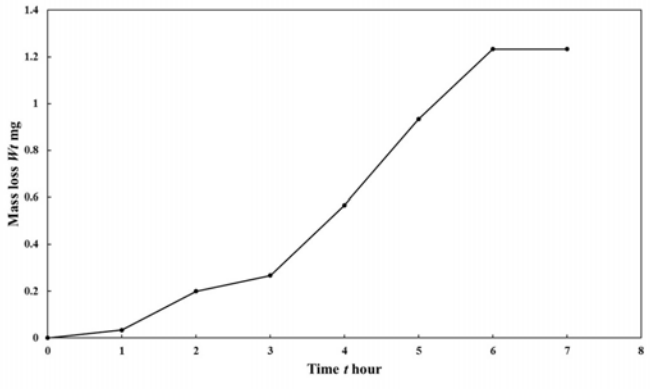


Fig. 11. Mass loss of Aluminum

3. Conclusion

・Incipient cavitation number is lower for the hydrophilic coating rather than for the hydrophobic coating especially when the angle of attack is small.

・The hydrophilic coating is useful to reduce growing of cavitation especially when the angle of attack is small.

・Both hydrophilic and hydrophobic coatings did not deteriorate over time (maximum 430 hours) at hot temperature. When immersed in water at 70℃. However, hydrophobic coating transformed to function as a hydrophilic coating at 20 degrees Celsius.

・Both hydrophilic and hydrophobic coatings lost their function only after 210 seconds of cavitation exposure. They were not strong enough against strong cavitation impact.

ACKNOWLEDGEMENTS

This work was done as part of the project financially supported by the NEDO (New Energy and Industrial Technology Development Organization). We would like to thank the organizers of this work.

REFFERENCES

[1] Elghali et al, " Marine Tidal Current Electric Power Generation Technology: State of the Art and Current Status", IEEE, 2007.

[2] Fitirdge et al, "The impact and control of biofouling in marine aquaculture: a review", *Biofouling*, 2012, Vol. 28, No.7, p649-669.

[3] Katsuyama et al, "Biofouling of model turbines for tidal current power generation and the effect of anti-fouling paint", Sessile Organisms, 2014, 31-1, pp.1-5.

[4] Watanabe et al, "Drag Reduction in Flow through Square and Rectangular Ducts with highly Water-Repellent Walls", 7th International Symposium on Cavitation, 2009.

[5] S.Fialová et al, "A Study of The Impact of Surface Hydrophobia on Hydraulic Loses and Velocity Profiles",19th International Seminar on Hydropower Plants, 2016.

[6] Arndt et al, "Effects of Surface Characteristics on Hydrofoil Cavitation", WIMRC FORUM 2008.

[7] Megan Williams *et al*, "Effects of Surface Characteristics on Hydrofoil Cavitation", 7th International Symposium on Cavitation, 2009.