Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 18-19, 2017

Study of droplet movement on surface modified Titanium and Aluminum plates with S.A.M coating method

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1. Introduction

Inside the condenser of power plant, the steam used in the turbine condenses and heat transfer occurs. Improving the condenser's condensation heat transfer efficiency will result in higher energy efficiency, smaller size of the condenser, and positive financial effects. The super-hydrophobic condenser tubes by surface modification can result in droplet condensation and it will improve condensation heat transfer efficiency. Most of Korea's power plant use seawater for cooling water in the condenser. So using Titanium (Ti) tube, which is corrosion resistant matter, as heat pipe and surface modifying the tube will improve the condensation heat transfer efficiency.

Lee et al. [1] executed experiments to evaluate the performance of super-hydrophobic Ti condenser tubes, for which Self Assembled Monolayer (S.A.M) coating method was applied. Not as expected, the experimental results showed that overall heat transfer coefficient of the surface modified Ti tube with dropwise condensation was 26 % lower than the bare Ti tube with film condensation. They observed that the condensate droplets by steam condensation on S.A.M coated Ti tube were not dripping easily from its surface. This phenomenon caused higher thermal resistance by reducing an effective heat transfer area by condensation. This is similar to the result of Jo et al. [2] condensation process, which showed the micro nano-structured hydrophilic surface losing its character.

Based on these results, an experimental study was conducted to confirm the droplet behavior on the surface modified plates depending on the characteristics of material and the condensation environment. The same experiment was also conducted on Aluminum materials. In other words, we would like to compare the droplet behaviors according to the material on the S.A.M coated Ti and Al plates. Also, we would like to confirm the characteristics of droplet behavior by changing the surface temperature of plate and the droplet temperature, too.

2. Experimental Setup

2.1 Surface Modification

Titanium tubes were sonicated in acetone for 1 minute at room temperature before acid etching. Cleaned titanium tubes were than etched in 70% concentration of sulfuric acid solution for 24 hours at room temperature.

The etched titanium tubes were dipped in oxygenated water for 48 hours at room temperature for oxidation.

To obtain hydrophobic characteristic on the surface, S.A.M coating method was used. The titanium tubes were dipped in a mixture of n-hexane and heptadecafluoro-1,1,2,2,-tetrahydrodecyl trichlosilane (HDFS), volumetric ratio 1000:1, for 10 min. HDFS S.A.M coating has a role of dramatically lowering the surface energy, preserving the surface structure. The pictures and SEM images of fabricated Al and Ti are shown in Fig. 2. As nano-flakes made of $Al(OH)_3$ are uniformly formed on the etched surface, hierarchical micro/nano structure is observed on the Al surface. Through the etching and oxidization of Ti, evenly formed micro and nano size structure were observed on the whole Ti surface. While both the original Al and Ti has gray color, the fabricated Al and Ti has dark gray and brown respectively.

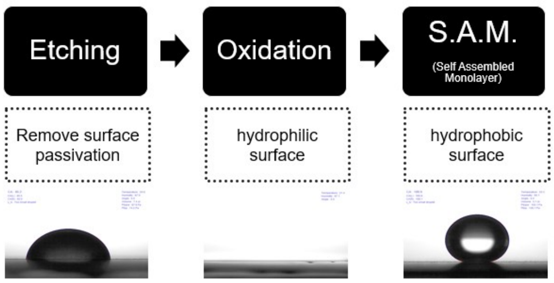


Fig. 1. Overall process of surface modification of Ti and Al tubes.

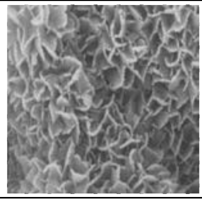
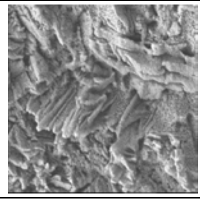
	Aluminum	Titanium
Plate		
SEM picture		

Fig. 2. S.A.M coated Al plate and Ti plate with SEM pictures.

2.2 Experimental facility

A photograph of experimental facility is shown in Fig. 3. A hot plate is fixed to a structure with an inclination of 70°. In order to measure the plate surface temperature, a thermocouple is installed on the hot plate. The surface temperature is adjusted with a built-in heater in the hot plate. In this study, the temperature range of 30 to 100 °C is selected considering the surface temperature of real condenser tubes of power plant using cold water as secondary coolant.

A pipette which can drip droplets from 2 to 20 μg is used. Its accuracy is between 0.8 to 3 %. Using this pipette, a fixed amount of droplet with 10 μg could be dripped or attached on the surface of the test plate constantly.

Demineralized water is used for droplet behavior experiments in the temperature range of 30 to 100 °C, which is controlled by another hot plate. This range is selected to consider the saturated steam temperature inside the condenser chamber in real power plant. As shown in Fig. 3, place a thermocouple in the beaker and adjust the temperature of water which use the droplet by using another hot plate

The temperature range is from 30 to 100 °C. Heat loss occurs when droplets are transferred from the beaker to the plate. It is difficult to accurately evaluate heat loss. However, quantitative assessment of heat loss is omitted as all droplets are adhering to plate under almost the same conditions as quickly moving a short distance.

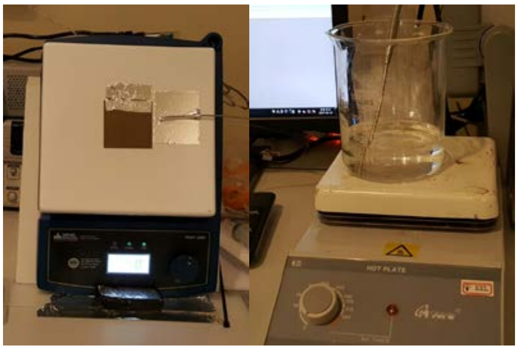


Fig. 3. Experimental facility of droplet movement.

2.3 Test procedure

Step 1. Install the equipment and the test plate as shown in the Fig. 3.

Step 2. Fix the plate surface temperature using the inclined hot plate and the demineralized water temperature using another hot plate.

Step 3. Drip or attach a droplet on the plate using the pipette. Repeat this step at least 5 times to judge the droplet movement confidently.

Step 4. Recode the droplet movement, the surface temperature, and the droplet temperature in a sheet of test matrix shown in Table I. The droplet movement is decided as O when the droplet is attached on the test plate as shown in Fig. 4. On the contrary, it is decided as X if the dripped droplet is disappeared from the surface due to the characteristics of super-hydrophobic.

Step 5. Repeat above steps by changing droplet temperature from 30 to 100 °C with intervals of 5 °C at a fixed surface temperature. For reference, the test plate is divided into 15 sections, and each case is tested on a new section to neglect the effects of the previous tests.

Step 6. Raise the surface temperature with 5 °C intervals from 30 to 100 °C, and repeat above all steps.

Table I. Test matrix of experiment.

Surface temp. / Droplet temp.	30	···	100
30	more than 5 times		
···			
100			

Fig. 4. Attached droplets on the S.A.M coated Al plate.

3. Results and Discussion

Fig. 5 shows the experimental results of droplet movement on the S.A.M coated Ti plate. As the surface temperature raises in the range of 30 to 45 °C, the stuck droplet section increases. When the surface temperature is over 50 °C, all droplet drips abruptly from the surface. In addition, a tendency of droplet to adhere widely to the plate is appeared as the temperature of the droplet is getting higher.

Fig. 6 shows the experimental results of droplet movement on surface modified Al plate with S.A.M coating method. As the surface temperature increases, the droplets could be difficult to adhere on the surface. Above 50 °C of the surface temperature, all droplet is fell from the surface easily except of a few case with 100 °C droplet temperature. From the comparison of Fig. 5 and 6, we can see that the surface modified Al plate has wide sections in which the droplets are not attached than the surface modified Ti plate.

An experimental study of condensation heat transfer for the S.A.M coated Al tube should be conducted considering the droplet behavior tendency studied in this paper. We could use this study to avoid the droplet attached conditions to get higher condensation heat transfer coefficients.

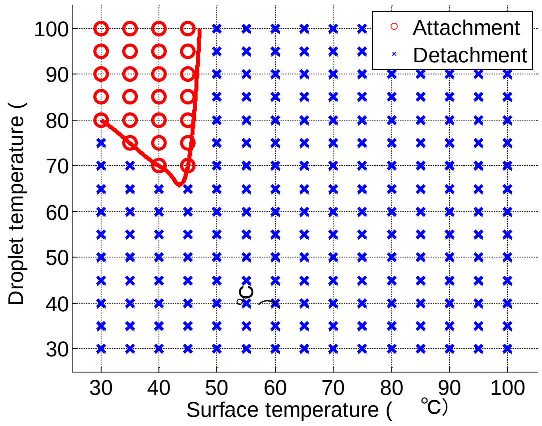


Fig. 5. The results of droplet movement on S.A.M coated Ti plate.

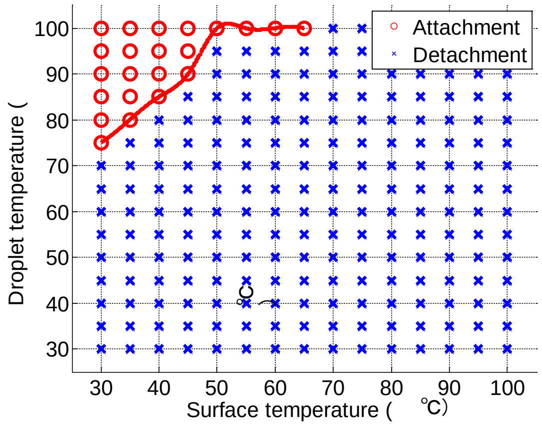


Fig. 6. The results of droplet movement on S.A.M coated Al plate.

3. Conclusion

In previous study by Lee et al.[1], overall heat transfer coefficients decreased due to water droplets adhering to the super-hydrophobic surface of the S.A.M coated Ti tube. In order to analyze the cause of these results, an experimental study for the droplet movement was conducted by changing the plate material, the surface temperature, and the droplet temperature. As a result, it was confirmed that there was a condition that the droplet was fell or adhered. Furthermore, we would see the difference in droplet movement according to the properties of the material by comparing experimental results of droplet movement on Ti plate and Al plate. Not attached sections for the surface modified Al plate was wider than those of the surface modified Ti plate.

We can expect that this study will be used to analyze the cause of the deterioration of condensation heat transfer performance on some dropwise condensation conditions.

REFERENCES

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