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Inspection of Pool Boiling with Superhydrophilic and Superhydrophobic Coating

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1. Introduction

In conventional nuclear power plants, increasing critical heat flux (CHF) margin by converting existing parts is economically meaningful since it means overall energy production increase without building additional power plants. There were researches to enhance margin from the very beginning of the commercialization of nuclear power plants and many efforts have led to current model of plants, optimized for both safety and production efficiency. Examples are mixing vane which is actually applied to plants nowadays, using nanofluids to enhance heat transfer coefficient (HTC), trying porous surfaces and so on. Takata et al. [1] studied effects of surface wettability by using hydrophobic coating and observed enhanced nucleate boiling at coated surface regions. Betz et al. [2] experimented superhydrophilic (SHPi), superhydrophobic (SHPo), and superbiphilic surfaces. Results indicate heat transfer coefficient enhancement due to increase of nucleation sites by hydrophobic regions and constrained diameter of growing bubbles by hydrophilic regions. Although it would be rough to apply their concept to real reactor coolant surface wall, understanding the possibility of enhanced boiling is meaningful. In this paper, SHPi and SHPo coatings were applied to wire at traditional pool boiling experiment by Nukiyama [3]. By observing altered CHF margin and nucleate boiling, the effects of each coating and their tendencies are discussed.

2. Method and Results

In this experiment, wire is Nichrome, other conditions are same with Nukiyama [3].

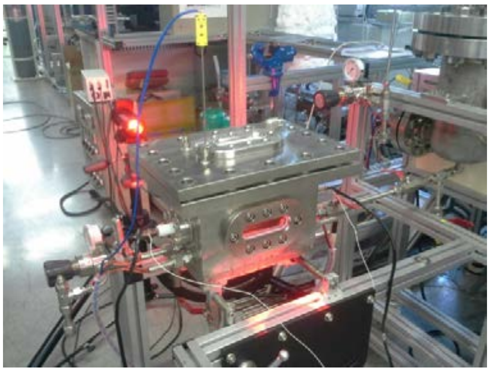

Fig. 1. Boiling vessel

2.1 Bare

Nichrome wires, immersed in water, were heated electrically. Wire's diameter is 0.0005m, valid length is 0.12m. The current in the wire and voltage across the end of the wire enable the power, and therefore the heat flux, to be calculated. Also, from the resistance of the wire the temperature of the wire can be found [4].

Absolute CHF value of bare wire could be questionable, because conventional data indicates around 1.0 MW/m^2. The absolute value of heat flux is inversely proportional to the circuit's internal resistance. The bare graphs are consistent with each other and data is similar. Hence it is reasonable to guess that internal resistance is underestimated. All data used internal resistance as 0.001 Ω.

CHF of bare 1 is 1.712 MW/m^2 at 436 K and bare 2 is 1.721 MW/m^2 at 429 K.

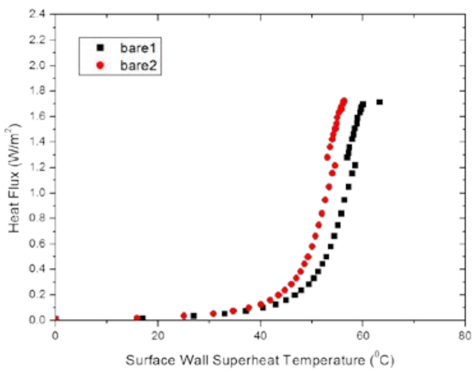

Fig. 2. Boiling curve of bare wire 1,2

2.2 Superhyrophilic

Al_2O_3 solution was used for SHPi coating. Volume percentage of the solution is 0.01%, 0.397 g of Al_2O_3 is mixed with water. After the solution was well mixed, coating was processed for 40 minutes by electric heating as shown in Fig. 4.

CHF of SHPi 1 is 2.193 MW/m^2 at 488 K and SHPi2 is 1.998 MW/m^2 at 418 K.

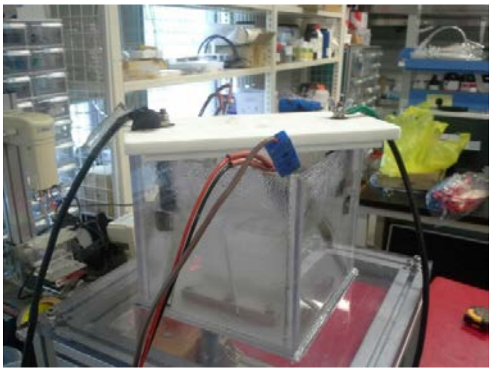

Fig. 3. Coating Al_2O_3 solution by electric heating

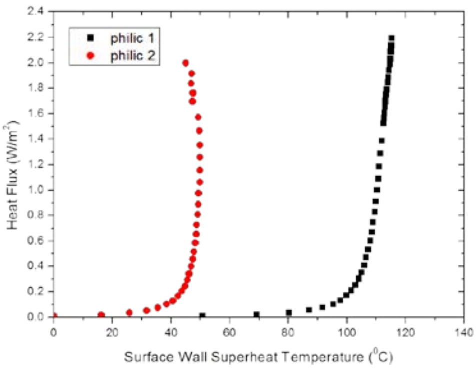

Fig. 4. Boiling curve of SHPi wire 1,2

2.3 Superhydrophobic

Coating of SHPo wire was done by spraying two kinds of sprays. Spraying and drying was repeated.

CHF of SHPo 1 is 1.056 MW/m^2 at 499K and SHPo 2 is 1.132 MW/m^2 at 498 K. SHPo wires showed partial CHF and this is discussed later.

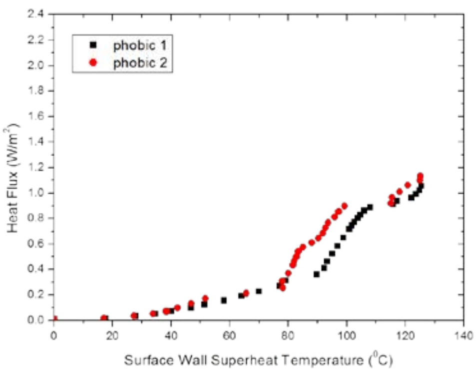

Fig. 5. Boiling curve of SHPo wire 1,2

2.4 Contact Angle

In order to verify the effectiveness of SHPi and SHPo coatings, contact angles are measured at copper surfaces treated with same condition as wires. Fig. 6 shows that coating methods were valid since SHPi has smaller angle compared to bare while SHPo was hard even to contact the bubble on the surface. Bubble's volume is uniform with 10 μL.

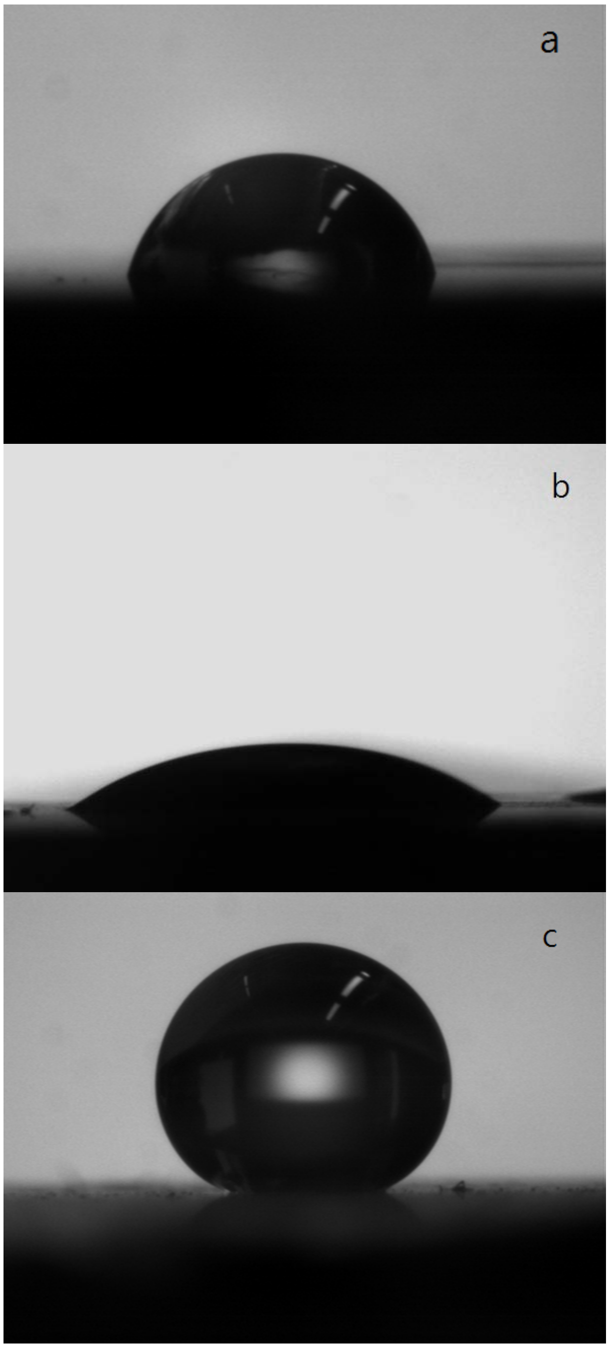

Fig. 6. Contact angle of (a) bare, (b) SHPi and (c) SHPo coating surfaces

3. Discussion

Presented in Fig. 2, bare Nichrome wire's CHF occurs around 1.7MW/m^2 and two types of coating showed clear difference in CHF data. In SHPi coating, the tendency of liking water delays the transition from nucleate boiling to film boiling. Thus it was expected that CHF margin will increase. 'Philic 1' in Fig. 4 shows clear enhancement since CHF occurs at 115 K, roughly 50 K higher than bare wires. However 'philic 2' shows slight decrease in margin. There could be two possible interpretations: either something unexpected accelerated film boiling or the coating was fragile so it had little effect. Since margin damage by hydrophilic traits is unheard of, the latter explanation is more convincible.

In SHPo coating, the nucleate boiling starts early because the nature of repelling water induces drawing of bubbles instead. This was expected to make extra nucleation sites and enhance nucleate boiling. However Fig. 5 shows drastic decrease in heat flux and unusual non-continous stair shaped graph compared to other wires. Although CHF was measured when the whole wire is burnt out, SHPo wires showed partial CHF and this began around 47 K. The CHF parts gradually increased and this is the reason why the graph is stair shaped, the cut-off regions represent additional CHF regions. Overall, SHPo coating damaged heat transportation. It is guessed that small air bubbles were created by hydrophobic wire before the boiling, when water is poured in the boiling vessel. Even before the heating, there were visible air bubbles attached on the wire. Although they were removed before the main experiment begun, nothing could be done to micro scale bubbles. It is reasonable to think that those unwanted bubbles formed micro scale film, resulting faster CHF and damaged HTC irrelevant to hydrophobic trait of the wire. For more accurate data, external bubbles should be removed from the wire especially in the case of hydrophobic wire.

4. Conclusion

SHPi, SHPo and bare wire's pool boiling was investigated and their boiling graphs were discussed. SHPi shows enhancement in CHF while SHPo's case is more complicated since there were variables like partial CHF or micro scale bubbles. Additional experiment could be comparing HTC, checking whether hydrophobic wire's nucleate boiling enhancement can exceed the decreased CHF margin. More sophisticated method to remove unwanted bubbles should be considered such as using degassed water.

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