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Critical Heat Flux Measurement of SiC- and Cr-coated Plates, Bare Stainless Steel Plate and Zircaloy-4 Plate Under Atmospheric and Pool Boiling Conditions

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1. Introduction

Usually metal undergoes rapid oxidation under high temperature steam conditions. Since Zircaloy used in present LWR is a metal, it shows exactly the same trend. In LWR, in consideration of the neutron economy, Zircaloy-2 or -4 materials are dominantly used as a cladding material because of their highly low neutron absorption cross sections. In addition, other structures are also composed of the Zircaloy mateiral in BWR type. When metal undergoes rapid oxidation, hydrogen is produced as a byproduct. This hydrogen has high potential of explosion if not filtered out or eliminated properly. As seen in Fukushima accident in Japan, hydrogen explosion problem can lead to disastrous results which can allow the leakage of radioactive materials directly into the atmosphere.

Critical heat flux (CHF) is affected by many factors such as surface wettability and thickness. Surface wettability can be altered using different materials or changing surface morphology [1-6]. In addition, according to previous studies, thickness of the heated material has an effect on the CHF results [7, 8]. However, according to the studies, there is some saturated thickness over which CHF is almost constant. Before such thickness, CHF usually increases with increasing thickness since heat can be dissipated through direction horizontal to the heated surface.

This study measures the CHF of the SiC- and Cr-coated surfaces, bare stainless steel surface and Zircaloy-4 surface with some analysis. If surface changes from present Zircaloy surface into to other materials, CHF will also be changed according to previous studies. Thus, the purpose of the measurement is to assess the applicability of the representative materials known to resistant to high temperature corrosion [9-11].

2. Experimental Apparatus

Measurements were carried out under atmospheric and pool boiling conditions using DI water. Working fluid was contained inside the polycarbonate container. The condenser transformed the vapor into the liquid and kept the system under atmospheric condition. Pre-heaters were situated below the test sections to keep the system saturated. 3 K-tpye thermocouples (TCs) were situated on the downward face of the heater. Silicon rubber was located below the downward face, and the bakelite situated below it which rolled to insulate the downward face. The bulk temperature of the working fluid was measured with inserted K-type TC. Heat was supplied using a DC rectifier with a maximum capacity of 45 kW (15V, 3000A). The schematic description of the system is described in Fig. 1.

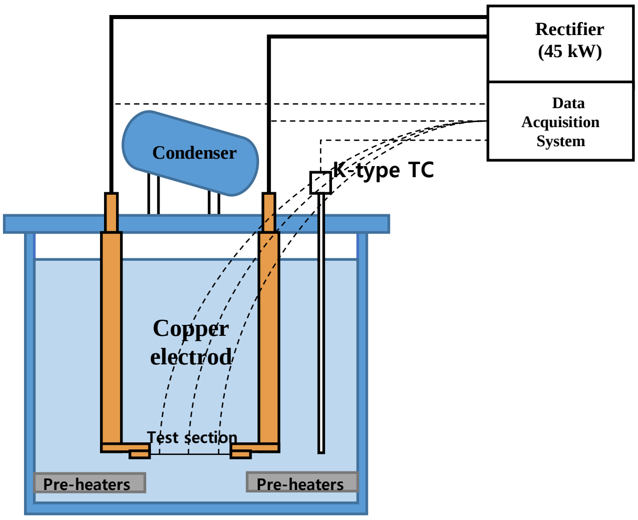

Fig. 1. Schematic description of the pool boiling apparatus

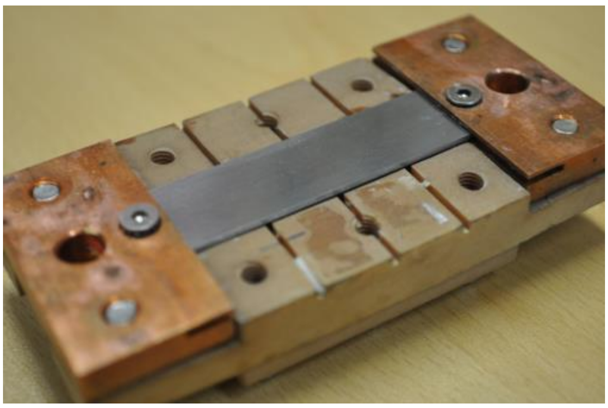

Fig. 2. Picture of the heater

2.1 SiC-coated surfaces

The SiC coatings have been achieved through the PVD-sputtering on the stainless steel plate for 1 hour

(400 nm) and 3 hours (1 μm) with 100 W power. Two kinds of thickness of the coating were prepared to measure the CHF and to assess the thickness effect.

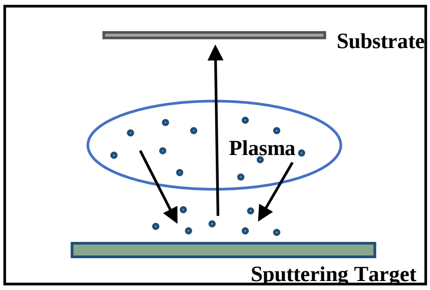

Fig. 3. PVD-sputtering process

2.2 Cr-coated surfaces

Cr coating was achieved by electroplating for about 1 μm and 10 μm, respectively. Electroplating is for the metallic coating that is layered on conducting materials. Substrate to be coated is the cathode, and the target material to be used as a coating material is the anode in electrolyte with dissolved metal cations. Dissolved metal cations form coating on the surface of the substrate with supplied electrons, and the target material dissolves, accordingly.

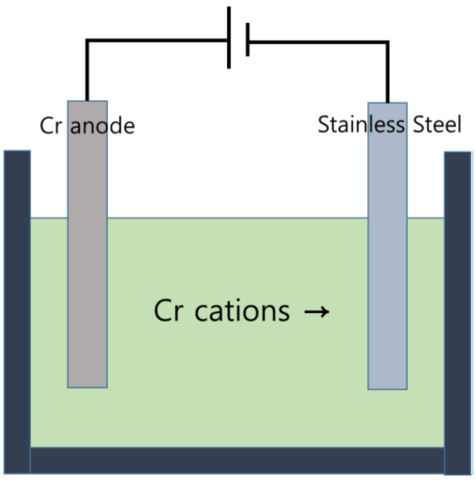

Fig. 4. Electroplating process

3. Results

The experiments were carried out more than 3 times for each surfaces. SiC-coated surfaces have shown enhanced CHF results compared with other surfaces regardless of the thickness. Furthermore, there was a thickness effect that 1 μm thickness specimen has shown better result than the 400 nm thickness. Cr-coated surfaces showed lower CHF values compared with other surfaces, and there was no thickness effect in our experimental range.

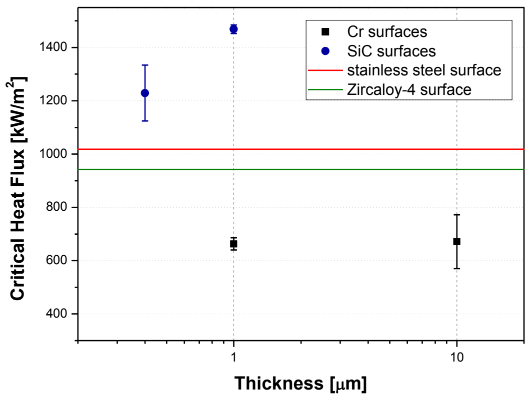

Fig. 5. CHF results of the surfaces

There was almost no difference in roughness among SiC- and Cr-coated surfaces and bare stainless steel plate according to the AFM results. Therefore, the CHF results was solely because of the material properties and thickness.

Table I: AFM Results

		Roughness[nm]	Average[nm]
SiC	400 nm	22.714	21.496
	400 nm	19.508	
	1 μm	22.267	
Cr	1 μm	28.141	24.593
	1 μm	27.071	
	10 μm	24.185	
	10 μm	18.975	
Bare Stainless Steel		22.765	25.438
		26.741	
		26.809	

The affinity of the surfaces with DI water could be explained through the contact angle measurements before the experiment and bubble generation picture during the experiment under same heat flux condition.

Comparable to our CHF results, SiC-coated surfaces have shown most hydrophilic conditions. Cr-surfaces showed relatively hydrophobic conditions. The results of the contact angle measurement corresponded well with the bubble sizes. During the experiment, the size of the bubbles generated from the Cr-coated surfaces were relatively larger than that generated from the bare stainless steel plate. Larger bubble tends to merge each other more easily and inhibit water supply into the heated surface. Therefore, there's more chance of CHF occurrence.

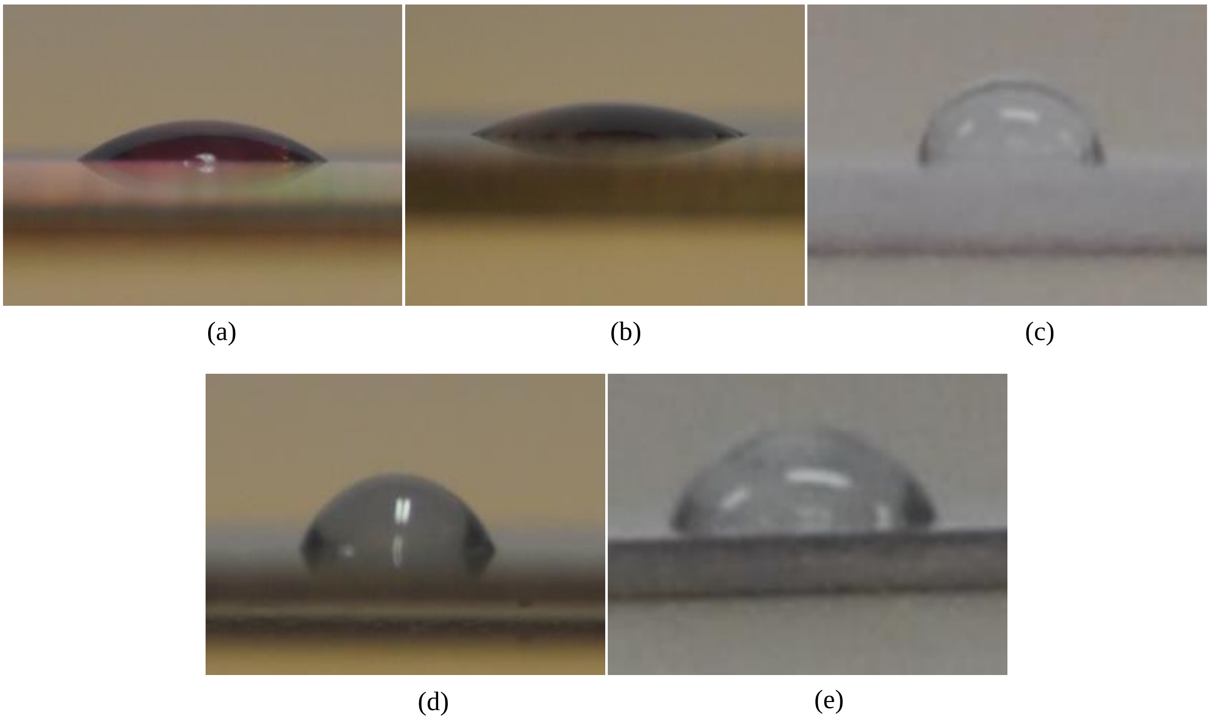

Fig. 6. Contact angle measurements before the experiments. (a) 400 nm SiC-coated, (b) 1 μm SiC-coated, (c) Cr-coated, (d) bare SS and (e) Zircaloy-4 surfaces.

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