Quenching experiment with modified surface using Anodic Oxidation

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1. Introduction

When LOCA [Loss Of Coolant Accident], ECCS [Emergency Core Cooling System] should be activated against the core melt-down. Improvement of cooling performance can afford to guarantee the safety of NPPs (Nuclear Power Plants) at Severe-Accident situation. Recently, repetitive quenching in nano- fluid which is containing nano- sized particles resulted in significantly enhancement of cooling performance. [1] That's because surface of test section during rapidly quenching modified due to deposition of nano- particles. Since then, many of researchers have paid attention to surface modification by quenching. [2]

So, in this paper a novel approach attempted. By using modified zirconium-702 surface from Anodic Oxidation, quenching experiment was conducted to evaluate a cooling performance of test section.

2. Experimental apparatus & result

When a solid overheated very high temperature plunges into the liquid bath, layer of vapor wraps around it. It is generally refereed as regime of film boiling heat transfer. Above all, so called MHF (Minimum Heat Flux) point which is end of the film boiling is the critical value to evaluate the cooling performance. A higher MHF point is desirable for rapid cooling overheated components in thermal-hydraulic system, such as NPPs.

2.1 Experimental apparatus & test section

Figure 1 shows schematic of Quenching experiment in this paper. Apparatus consists of mainly 4 parts; 1) Quenching Pool maintained nearly saturated temperature of D.I water (~97℃) by immersion heater (450W), 2) Radiation Furnace(1.2 kW) heating up the test section to about 850℃ asymptotically, 3) Rod-less Cylinder rapidly delivering a test section by compressed air from Radiation Furnace to Quenching Pool. 4) Reflux Condenser keeping water level of Quenching Pool. Elsewhere, DAS (Data Acquisition System) is selected NI 9213 (50Hz) and all of temperature are controlled by P.I.D. system.

Test section is cylindrical geometry which can be replicated as real nuclear fuel-cladding. Figure 2 (left) shows the composition into the test section. Diameter and length of test section is 10mm and 60mm, respectively. Precision of hole manufacturing machine (NSD-700 EDM) is used to install the thermocouple into the test section. A thermocouple sheathed by inconel (0.5, K-type) is retrofitted into the center of the test section and it is fastened by friction fitting and stake fitting at each position. To decrease the contact-resistance, thermo grease (Arctic cooling, MX-4) daubed at junction of thermocouple. 1/16-inch reinforced tube protects the thermocouple against damage of thermal condition and its length was considered to minimize heat-loss and vibration of test section, empirically.

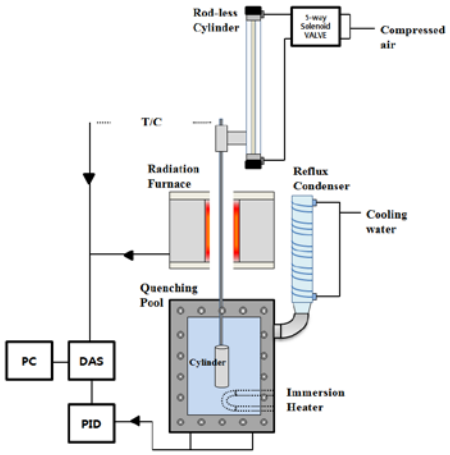

Figure1. Schematic of Quenching experimental

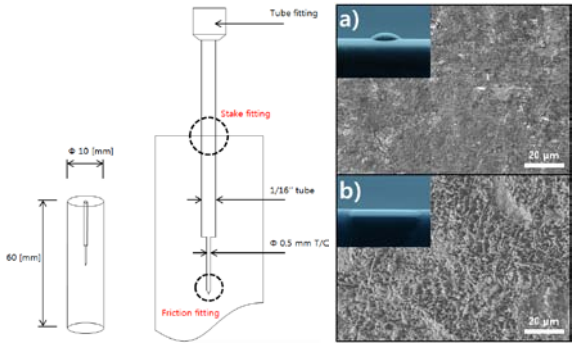

Figure2. Schematic of test-section & surface characteristics (a: bare, b: modified)

"Anodic Oxidation" or "Anodization" is well known as methodology of surface treatment. Essence of Anodic Oxidation naturally was formation of oxide layer for uniform thickness, but recently occurrence of some micro/nano- scale structures under certain well

constructed condition has been reported. In this paper Anodic Oxidation of zirconium-702 adopted based on reference [3]. Figure 2 (right) indicates the contact angle and SEM image of bare(a) and modified surface(b), respectively. Modified surface with Anodic Oxidation has generally two types of characteristic. First of all, there is some unique morphology of micro/nano-structure. Second is that it has spreading feature which is completely wetting. Contact angle of modified surface has 0° contrast to bare case which is about 41°. Since the morphology of micro/nano- scale, the spreading is characterized by capillary wicking. [4]

2.2 Experimental result and Discussion

In nearly saturated pool temperature condition, quenching experiment was conducted. All of test section was polished as 2000-grit sand-paper to assure the identical roughness and cleaned by Aceton-Ethanol-D.I water, sequentially.

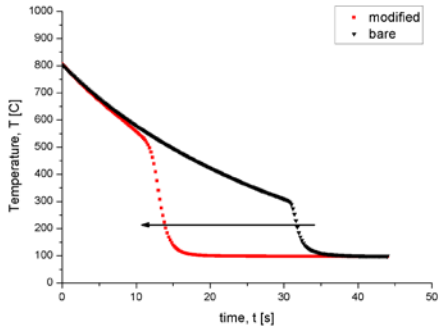

Figure4. t-T graph from quenching experiment

Figure 4 is Temperature versus time graph from quenching experiment. K-type thermocouple inserted into the center of the test section acquires the history of temperature during rapidly cooling. Intriguingly, MHF point enhanced on modified surface, 532℃, compare with bare surface, 307℃. It means overall cooling time which is dominated of MHF point was also shortened compared with bare case, from 30.0s to 19.6s.

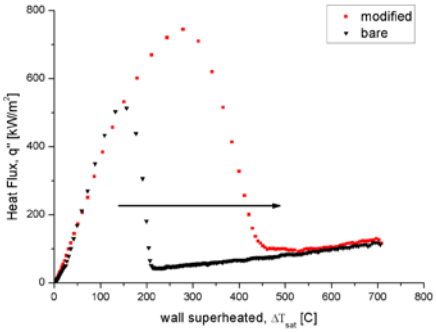

Figure5. Boiling curve from quenching experiment

Biot number of experiment is about 0.03 therefore, it is possible to analysis by LPM (Lumped Parameter Method) in regime of the film boiling heat transfer. Figure 5 is boiling curve obtained from LPM by quenching. It is shown the enhancement of MHF on modified surface (136 kW/m^2) compared with bare case (51 kW/m^2). Additionally, CHF which is the peak point of boiling curve also enhanced compared with bare case. But, because of large heat transfer coefficient of nucleate boiling regime ($h_{nucleate}$ ~ 20 kW/m^{2}K) there is no longer able to adopt the LPM for evaluating CHF in this paper.

Classically, definition of MHF point is only function of its own inherency such as system's condition or property. [5,6] But, experimental result in this paper is quite different due to the effect of modified surface. Also, through the visualization of experiment, it was ascertainable that there is no stable film boiling regime contrast to bare case. Spreading effect on modified surface brought about a result that perturbs of interface at liquid-vapor. These result finally caused the enhancement of MHF point which means the contact of liquid and solid in advanced of predicted value, classically.

3. Conclusions

Enhancement of MHF point was shown from quenching experiment on modified zirconium-702 surface by Anodic Oxidation. Overall Cooling performance of the modified surface enhanced significantly, compared with bare case. For a deep understanding of physics, further research which can interpret the reason of the enhancement of MHF point will be planned.

ACKNOWLEDGMENTS

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