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An Experimental Study on Pool Boiling CHF with Hierarchical Porous Surface Fabricated by PMMA Coating and Electron Irradiation

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1. Introduction

Critical heat flux, CHF is a significant safety criteria for engineering devices which have high heat flux surfaces like nuclear reactors or steam generators, because boiling heat transfer coefficient between a heated surface and fluid is dramatically dropped at CHF point. Many studies have been performed for enhancing CHF, finding CHF models, and predicting CHF for pool boiling and flow boiling.

CHF enhancement is one of the most important issue in experimental thermal-hydraulic field because it is strongly coupled with safety and economic problems.

There have been many researches for enhancing CHF, such as modification of surface, imposing additional physical transition to thermal-hydraulic system, or change of fluid properties.

The usual way to enhance CHF is by controlling heated surface conditions. Attaching promoters, porous coatings, and artificial roughness such as micro and macro-roughness, finning vibroroling, and tunnel-and pore forming are examples.

In this paper, a new technique for providing hierarchical porous surface was applied. This technique can provide augmented and durable porous structure on heating surface relatively easily than other usual surface treatment technique. Also surface characteristics such as roughness can be modified by just changing sphere size, so effect of surface characteristics can be measured.

CHF experiment was performed with treated surface made by new technique in water pool boiling condition. Enhancement of CHF was measured, and effect of surface characteristic to CHF was discussed simply.

2. Fabrication of Surface Structure

In this section, techniques used to providing hierarchical porous structure on heating surface are described.

2.1 Material Preparation

PMMA spheres (Soken) and silicone grease (Dow Corning high vacuum grease) were used as precursor materials. PMMA spheres were solved in ethanol with 60wt% and then PMMA-ethanol colloidal solution was made. The 50mm*50mm*0.4mm(thickness) SUS304 substrate was prepared to build porous structure on it.

2.2 Multilayer Formation on Substrate Surface

PMMA-ethanol colloidal solution was spin coated onto SUS304 substrate at 700 rpm for 1min. Then silicone sphere multilayer was set on the substrate.

A silicone grease solution (10 wt%) was prepared using hexane as a solvent. This silicone grease solution was poured and spin coated onto the substrate on which multilayer of PMMA spheres was formed for 1 min at 2500 rpm. Then silicone grease soaked in to multilayer of silicon sphere and layer stuck each other.

2.3 Electron Beam Irradiation

The prepared substrate was irradiated with an electron beam generated from a thermionic electron gun. The irradiation process was carried out at ambient temperature under a pressure of less than $2*10^5$Torr.

The electron beam irradiated the substrate by 20 keV constantly for 785 minutes. The diameter of electron beam diameter was ~7 cm. The total electron fluence was $1.5*10^{18}cm^{-2}$.

The substrate was cooled with water during irradiation to prevent melting of the PMMA spheres by heat from the electron beam.

3. CHF Experiments

3.1 Experimental Apparatus and Procedures

After electron irradiating, the substrate was sliced into 5 sections uniformly. As a result, each sliced section had 10mm(width) * 50mm(length) * 0.4mm(thickness) dimension. The sliced sections were manufactured as test section which is suitable for CHF experiment. Three thermocouples were attached to back side of section and then insulated by epoxy. The side heat and tail of section was welded by copper electrode.

The pool boiling CHF experiments were conducted in polycarbonate pool which is transparent through every direction. The test pool consists of drain valve, 1kw pre heater, condenser, and copper electrodes which is hanged at top part of the pool.

The heating process is direct Joule heating from 30kw DC rectifier which has specification of 10V*3000A. The test section was fastened to copper electrode which is hanged on top part of the pool and then electric power was provided. The signals of thermo couples, electric voltage and current were acquired by data acquisition system, Agilent 34972A.

All tests were conducted under atmospheric pressure and saturated condition. Test fluid, water was preheated up to saturation temperature all the time by pre-heater which is established at test pool before starting heating experiment. The heat flux at surface was calculated as

$$q = \frac{VI}{A}$$

where V and I are the measured voltage and current, and A is area of heating surface.

The input power was increased by control input voltage from rectifier. The heat flux was increased by about 20kw/m2 from start of experiment to near boiling crisis. Near CHF condition, increment rate of heat flux was reduced, less then 5kw/m2. Then, CHF was detected from sudden increase of surface temperature.

3.2 Preliminary Test

First, CHF experiment with plain surface was conducted for earning reference data and investigating rationality of test apparatus.

The Zuber`s hydrodynamic instability model was used to compare the value of basic CHF value.

$$q'_{CHF} = 0.131 h_{fg}\, \rho_g^{0.5} \left(\sigma g(\rho_l - \rho_g)\right)^{0.25}$$

The CHF data of plain surface was well corresponded with Zuber`s model in the error range of 7%.

3.3 Experimental Results and Discussion

The experimental results with hierarchical porous structure surface and discussion will be reported at the conference.

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