Experimental Study of Effect of Graphene Nanosheets on the Critical Heat Flux

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1. Introduction

Graphene is two-dimensional carbon allotrope having atomic monolayer, and has received worldwide attention as a new material for its extraordinary properties, such as electronic, thermal, and mechanical. However, there have been still many problems to understand the characteristics of graphene, and to use it directly on the real application–Park et al. [1] firstly conducted the CHF characteristics of graphene nanosheets on the heater using graphene/graphene-oxide water-based nanofluids. They reported that graphene/graphene-oxide showed remarkable CHF enhancement on the wire heater in pool boiling experiment, even though graphene has very different characteristics compared with established nano particles, such as TiO_2 and Al_2O_3. In this study, we conducted the pool boiling CHF experiments on the wire heater using the graphene nanofluids. As the further research, we investigated the effect of graphene nanosheets' coating on the wire heater.

2. Experiment

2.1 Preparation of graphene nanofluids

In this study, graphene nanofluid is prepared with chemical method as called Modified Hummer's Method: oxidation and reduction process of graphene. Chemical oxidation of graphite and ultrasonication process makes hydrophilic graphene oxide nanofluid [2, 3], and the graphene oxide nanofluid is converted back to CCG (chemically converted graphene) nanofluid by reduction process [4]. The CCG nanofluid was diluted with DI water to make 0.001 volume % for pool boiling experiment in this study.

2.2 Pool boiling CHF experiment

Main test pool was 250 x 140 x 250 mm^3 rectangular Pyrex glass vessel, and the vessel was on a hot plate to heat up the working fluid to saturation-state under atmospheric pressure. A reflux condenser and a vessel cover were installed on the top of the vessel, in order to prevent loss of the working fluid from the test vessel. The wire heater was a commercial NiCr wire with the diameter of 0.2 mm and with the length of 112 mm, and horizontally suspended in the working fluid by two electrode rods mounted on the cover.

Heat flux data was calculated by measuring voltage and current applied to the NiCr wire, the heating surface. A reference resistance with the 1 ohm was employed to measure the current, and temperature of the resistance was controlled by constant temperature bath.

The degassing process of working fluids was performed at the saturation-state during 1 hour before the CHF experiments. The heat flux was increased with constant increasing rate, about 1100 W/m^2 per sec using the DC power supply. When CHF occurred, the wire heater was broken and the experiment was closed.

3. Result and discussion

The CHF results of DI water case in pool boiling experiments are shown in Fig. 1. The experiment was conducted several times in order to confirm reliability of the experimental facility, and this data is used as a standard parameter to compare CHF enhancement results of graphene nanofluid cases. The average CHF value of DI water was 983 kW/m^2 with the errors of 14.85 kW/m^2. Meanwhile, the average CHF value of graphene nanofluids is 1071 kW/m^2 with the errors of 33.54 kW/m^2. The CHF enhancement ratio (percentage) was just 8.9 % compared with DI water case, as shown in Fig. 1. This result indicated that there are some differences with the previous research of Park *et al*, [1].

It is well known that the nano-particle coated layer is related with exposure time at high heat flux in pool boiling experiment using nanofluid. Such tendency was also found in CHF experiments with graphene-coated wires prepared with different exposure time from 10min to 60min at 900 kW/m^2. However, the CHF result case, as shown in Fig. 1 the different exposure time case,

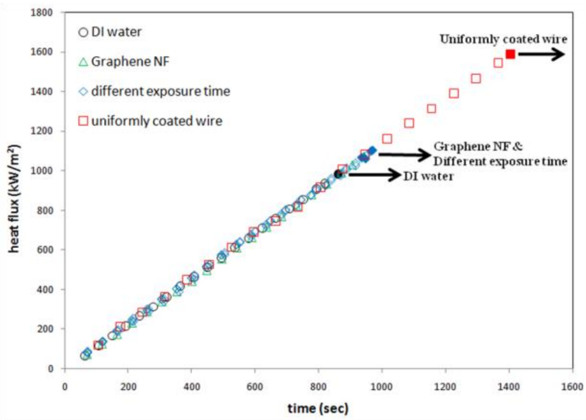

Fig. 1. CHF of DI water, graphene nanofluid, one side coated wire, and uniformly coated wire

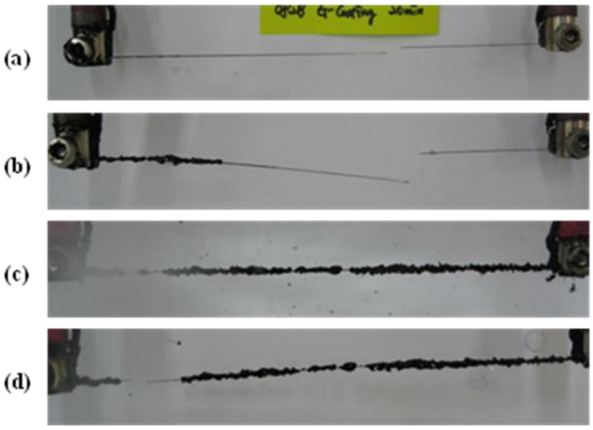

Fig. 1. Coated wire a) one side coated wire 10min, b) one side coated wire 60min, c) uniformly coated wire, and d) broken uniformly coated wire (left is anode, and right is cathode)

because graphene tended to be attracted only to anode side of wire in figure 2a and 2b. Caused by this non-uniformly coated graphene layer, the local dry out always occurred at cathode side, uncoated wire.

The non-uniformly coated phenomenon, which is affected by the electric polarity, is more obvious in SEM image analysis. Figure 3 is SEM image of anode and cathode side of wires prepared with different exposure time: 10min, 20min, 30min, and 60min. As the time increased, the growth of graphene nanosheets' structures was found only in anode side. It means that the characteristics of graphene nanosheets coating is affected by the electric polarity, not by the fowling as well known in many previous studies in nanofluids. This can be explained by negative charged characteristic of CCG (chemically converted graphene) used in this study. In the chemical process for CCG, the carboxyl groups were remained on the edge of the nanosheets and activated to ensure the stability of dispersion with repulsion force to each other [4].

Uniformly coated wire was prepared by changing electric polarities in preparing process for graphene-coated wire, as shown in figure 2c. The pool boiling experiment with the wire showed over 60% enhancement of CHF compared with DI water case in Fig. 1, and local dry out occurred with losing graphene-coated layer by vigorous boiling in anode side, as shown in figure 2d. This is almost same result with the previous research of Park *et al*, [1].

4. Conclusions

The characteristics of graphene nanofluids in CHF pool boiling experiment were investigated in this study. As increasing the exposure time, graphene nanofluid showed the growth of graphene-coated layer, but the surface was non-uniformly coated due to the negative zero potential characteristic of CCG nanosheets so that it showed the slight CHF enhancement compared with DI water case. Based on such phenomenon, uniformly coated wire was obtained with changing electric

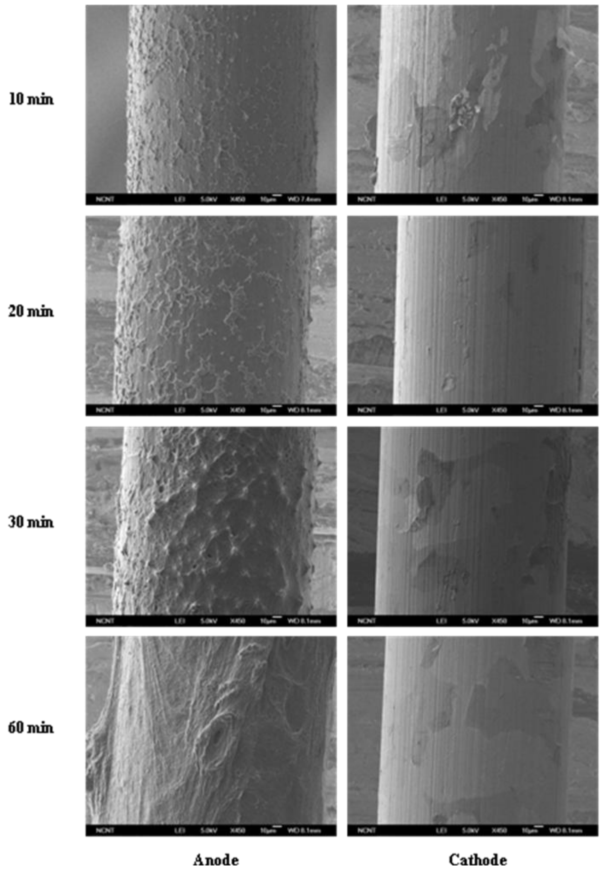

Fig. 2. SEM image of anode and cathode of wires after pool boiling experiment for one side coating with different coating time: 10min, 20min, 30min, 60min

polarities method in preparing wire process, and this showed over 60% enhancement of CHF.

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