Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 29-30, 2014

Rapid Cooling Heat Transfer of Rod-shaped Test Specimen for Nuclear Reactor Application

Chi Young Lee [a*], Chang Hwan Shin [a], Dong Seok Oh [a], Tae Hyun Chun [a], Wang Kee In [a], Yang Hyun Koo [a]
[a] *KAERI (Korea Atomic Energy Research Institute), 111, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon 305-353, Republic of Korea*
[*] *Corresponding author: chiyounglee@kaeri.re.kr*

1. Introduction

Under a loss of coolant accident in pressured water nuclear reactor core, the reflood phase is associated with the emergency cooling, and in such a case, the fuel rods are quenched when water is being refilled in a reactor vessel [1]. In the nuclear reactor core, zircaloy and SS (Stainless Steel) are widely and popularly used. Hence, the performance comparison of rapid cooling heat transfer between both materials can be meaningful.

After the Fukushima accident, the hydrogen generation is considered to be one of critical issues for nuclear reactor safety. Hydrogen is generated by the corrosion reaction of zirconium alloys in nuclear reactor components. The corrosion reaction can become active with increasing the environmental temperature. Therefore, a decrease in high-temperature oxidation rate of nuclear fuel cladding should be achieved to decrease the amount of hydrogen generation under the accident condition [2]. Recently, the researches on ATFC (Accident Tolerant Fuel Cladding) developments have been highlighted, and the chromium-coated (Cr-coated) zircaloy cladding may be considered to be one of candidates for ATFC [2]. Thus, the investigation on the behavior of Cr-coated surface during quenching should be performed.

In this paper, transient boiling heat transfer behavior of rod-shaped zircaloy and SS test specimens is studied. In addition, commercially Cr-coated SS test specimen is prepared using the plating method, and preliminarily tested for ATFC application.

2. Test set-up and procedure

The experimental set-up for quenching test consists of furnace, test assembly with test section and its moving device, quenchant pool, and data acquisition system. A furnace can radiantly heat up the test specimen up to ~1000 °C. Four K-type sheathed thermocouples are installed, and one of them is used to set and control the furnace temperature. The test specimen is the vertical cylinder shape having a hemispherical shaped bottom to minimize the vapor film collapse and help the stable vapor film be formed. To measure the center temperature of test specimen, a K-type ungrounded sheathed thermocouple (Watlow) of 0.5 mm in diameter and 1500 mm in length is tightly inserted to the hole of about 30 mm in depth precisely drilled at the center of test specimen. The test specimens with thermocouple is connected to a SS tube of 3.175 mm (1/8 inch) in diameter and 50 mm in length, which is connected to a rigid SS tube of 12.7 mm (1/2 inch) in diameter and 700 mm in length using the compression fitting. Then, this assembly is fixed to the moving holder. Moving holder is operated vertically up and down using the airslide. As the quenchant, pure water is used. To measure the quenchant pool temperature, a T-type sheathed thermocouple is installed. The temperatures of the furnace, quenchant pool, and the center of test specimen are monitored and stored using the data acquisition system (Data Translation, DT9828).

Quenching tests are performed as the following procedures: The quenchant pool and the furnace are heated up to the saturation and targeted temperatures, respectively. At the steady state of quenchant pool and furnace, the test specimen is put into the furnace. When the center of test specimen reached a desired temperature, it is forcibly and rapidly immersed into the water pool using the airslide. The temperature-time variation of test specimen is recorded into the data acquisition system with the sampling rate of 20 Hz. The tests are repeatedly performed 4-5 times at different initial rod center temperature conditions (e.g., 400-600 °C).

3. Result and discussion

In Fig. 1, the exemplified quenching curves of zircaloy test specimens with different sizes are compared under the saturated water condition. The initial rod center temperature was ~500 °C. The dimensions of large and small test specimens were 14 mm in diameter and 65 mm in height, and 10 mm in diameter and 60 mm in height, respectively. Small-sized test specimen appeared the shorter quenching time than large-sized one, which was due to its small volume-to-surface area ratio.

In Fig. 2, the exemplified quenching curves of zircaloy and SS test specimens are shown to examine the material property effect. The initial rod center temperature was ~500 °C, and the quenchant was under the saturated water condition. The test specimen size was 10 mm in diameter and 60 mm in height. Zircaloy test specimen exhibited the shorter quenching duration, which might be due to its smaller heat capacity.

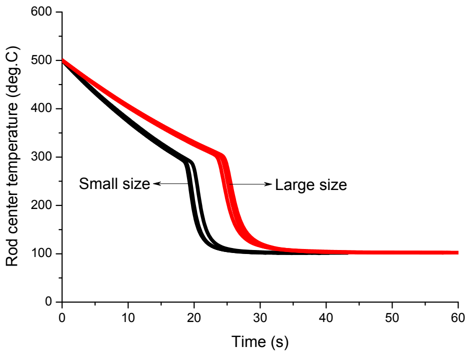

Fig. 1 Effect of test specimen size on quenching curve.

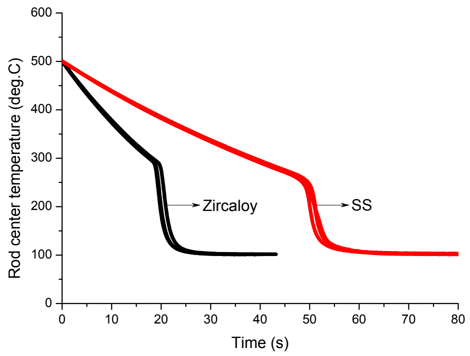

Fig. 2 Effect of test material on quenching curve.

For ATFC application, the chromium was commercially coated on SS test specimen using the plating technique, and it was preliminarily tested. In Fig. 3, the photographs and microscopic images of commercially Cr-coated SS specimen before and after quenching tests are shown. Before quenching tests, the test specimen had the shiny and gray surface. In microscopic image, the commercially Cr-coated surface was likely to be smooth without any special features. On the other hand, after repeated quenching tests, the surface was changed to be yellow. In addition, surprisingly, the cracks seemed to be propagated on the surface. To apply the Cr-coated surface to ATFC, the innovative coating techniques for Cr-coated zircaloy surface should be developed and optimized.

4. Conclusions

In this paper, transient boiling heat transfer behavior was examined using rod-shaped test specimen. For reduction in quenching time, the test specimen with small size and small heat capacity was needed. In the Cr-coated SS test specimen prepared by commercial plating method, the cracked morphology was likely to be observed on the surface after repeated quenching tests. Therefore, the optimized coating technology for ATFC application should be proposed and developed.

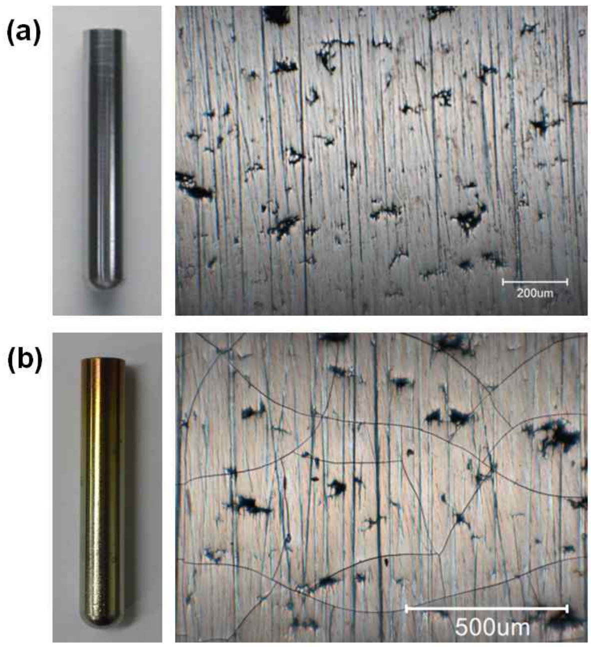

Fig. 3 Surface images of commercially Cr-coated SS test specimen: (a) before and (b) after repeated quenching tests.

Acknowledgements

This work was supported by the National Research Foundation of Korea (NRF) funded by the Korea government (MSIP) (NRF-2012M2A8A5025824).

References

[1] H.G. Kim, I.H. Kim, Y.I. Jung, D.J. Park, J.Y. Park, Y.H. Koo, Surface Coating Technology on Zirconium-Based Alloy to Decrease High-Temperature Oxidation Rate, Transactions of the Korean Nuclear Society Spring Meeting (2013).

[2] S.W. Lee, S.Y. Chun, C.H. Song, I.C. Bang, Effect of nanofluids on reflood heat transfer in a long vertical tube. International Journal of Heat and Mass Transfer 55 (2012) 4766-4771.