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Manufacturing of FeCrAl/Zr Dual Layer tube for its application to LWR Fuel cladding

Dong Jun Park [*], Do Wan Lim, Yang Il Jung, Hyun Gil Kim, and Jeong Yong Park
LWR fuel Technology Division, Korea Atomic Energy Research Institute, 989-111 Daedeok-daero,
Yuseong-gu, Daejeon 305-353, Korea
[*]Corresponding author: pdj@kaeri.re.kr

1. Introduction

The integrity of the fuel cladding should be maintained not only during normal operation but also in a postulated design-based accident. In terms of this, a loss-of-coolant accident (LOCA) is treated as one of the most important design-basis accidents in a LWR. Therefore, it is necessary to understand clearly the mechanical behavior of candidate materials under LOCA condition for their application to the fuel cladding material in LWRs. Many advanced materials such as MAX phases [1], Mo [2], SiC [3], and Fe-based alloys [4] are being considered a possible candidate to substitute the Zr-based alloy cladding has been used in light water reactors. Among the proposed candidate materials, Fe-based alloy is one of the most promising candidates owing to its excellent formability, very good high strength, and corrosion resistance at high temperature. However, neutron cross section of FeCrAl alloy is much higher than that of existing Zr-based alloys.

In this study, FeCrAl/Zr dual layer tube was manufactured by using a hot isostatic pressing (HIP) method. The thickness of outer FeCrAl layer was varied from 50 to 250 μm but all the FeCrAl/Zr dual layer tube samples maintained its total thickness of 570 μm. For a detailed microstructural characterization of FeCrAl/Zr dual layer, polarized optical microscopy and scanning electron microscopy (SEM) study carried out and its mechanical property was measured by ring compression test.

2. Methods and Results

In this section some of the techniques and experimental apparatus used to manufacture the FeCrAl/Zr dual layer tube are described. The highlight data will then be shown with a detailed explanation.

2.1 HIP process

To fabricate dual layer at optimum condition, we are carrying out HIP process with various conditions and mechanical property of HIPed sample was analyzed. Four different HIP temperatures were used, including 700, 750, 850, 950, and 1050℃. A HIP pressure was 100 MPa and all the samples were hipped for 3 hrs. It showed that optimum HIP temperature and pressure for welding FeCrAl and Zr-based alloy were 750℃ and 100 MPa, respectively.

Several short ring specimens having a 8 mm length were cut from the FeCrAl/Zr dual layer tube for the testing of its ductility. Slow ring-compression tests were performed at 135°C at a compression rate of 0.033 mm/s.

2.2 FeCrAl/Zr dual layer tubes

FeCrAl/Zr dual layer tube consists of outer FeCrAl layer and inner Zr layer. To compare its mechanical property with that of Zr-based cladding, FeCrAl/Zr dual layer tube samples having a same dimension as current fuel cladding were fabricated with different outer layer thickness. Fig. 1 The Cross sectional optical micrographs for as-fabricated dual layer tubes are shown in Fig. 2 at low magnification. The thickness of outer FeCrAl layers were 74, 100, 160, 214, and 260 μm, respectively. All the samples showed seamless interface between both layers.

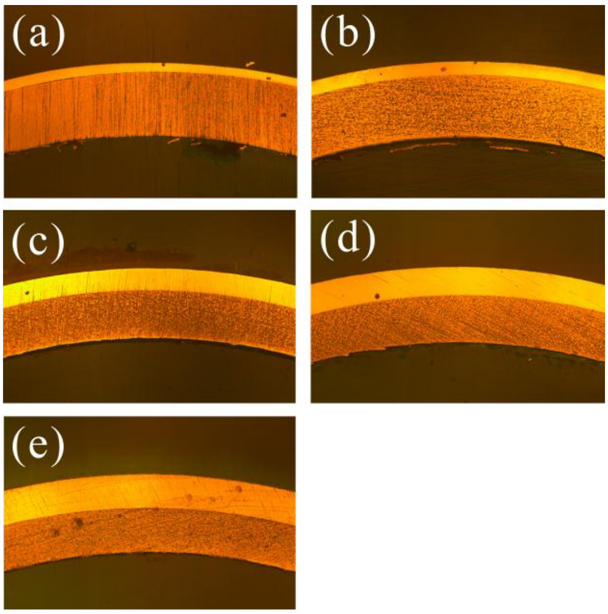

Fig. 1. Low magnification of inner- and outer layers for FeCrAl/Zr dual layer cladding with different thickness of outer FeCrAl layer: (a) 74 μm, (b) 100 μm, (c) 160 μm, (d) 214 μm, and (e) 260 μm.

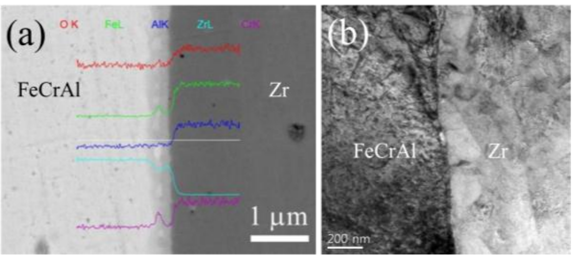

Fig. 2. (a) Element distribution of interface in FeCrAl/Zr dual layer tube sample and (b) TEM image obtained from same region.

The Fe, Cr, Al, and Zr element distribution of interface in the middle of tube is shown in Fig. 2(a). Interlayer between both layers was observed and distribution of each element varies gradually. Transmission electron microscopy image was obtained from interface and it also showed seamless interface.

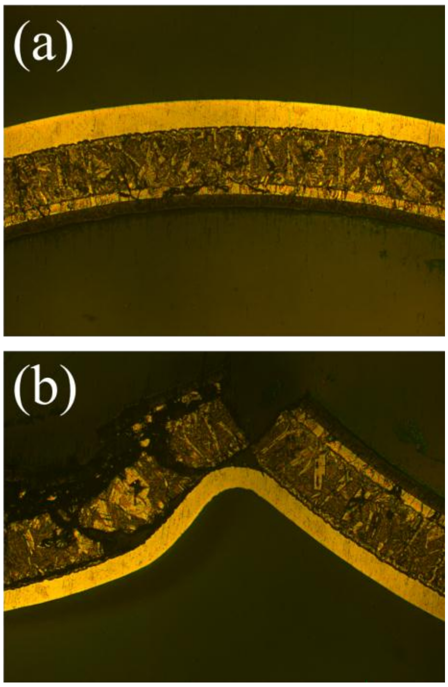

Fig. 3. (a) Cross-sectional micrograph of FeCrAl/Zr dual layer tube sample oxidized at 1200 for 500 s and (b) same sample after ring compression test.

Simulated LOCA test was carried out at 1200℃ using FeCrAl/Zr dual layer tube sample and its cross-sectional optical micrographs were shown in Fig. 3(a). Although thick oxide layer was formed on the surface of Zr layer side, no oxide layer was observed on the surface of FeCrAl layer. Outer FeCrAl layer maintained its integrity after ring compression test despite fully cracked inner Zr layer, as shown in Fig. 3(b).

3. Conclusions

FeCrAl/Zr dual layer tube sample was successfully manufactured with good adhesion between both layers. Inter layer showing gradual element variation was observed at interface. Result obtained from simulated LOCA test indicates that FeCrAl/Zr dual layer tube may maintain its integrity during LOCA and its accident tolerance had greatly improved compared to that of Zr-based alloy

ACKNOWLEGEMENT

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