Effects of initial billet microstructure on the properties of annular fuel fabricated by hot extrusion method

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1. Introduction

The motivation for innovative fuel development is the development of the advanced ultra-high burnup sodium-cooled fast reactor metallic fuel concepts. The fabrication experiment seeks to investigate advanced fuel designs with the following features: decreased fuel smeared density (SD), venting of the fission gas to the sodium coolant, reduce the FCCI (Fuel Cladding Chemical Interaction), and an advanced fabrication method that includes consideration of annular fuel and extrusion method. The one of most attractive advantage of extrusion method is save the process waste by omitting the sodium process. From the previous study, annular fuel shows the possibility of the reduction of swelling effect and then prevention of the FCMI (Fuel Cladding Mechanical Interaction) [1]. However, the fabrication technology of the annular fuel has not been developed yet. Therefore, KAERI has started to study the annular fuel fabrication method by using hot extrusion method. In this study, the effects of initial microstructure on the microstructure of annular fuel was studied by using Cu billet. The controlling of microstructure on billet was performed by changing heat treatment conditions. After the heat treatment the Cu annular fuel has been fabricated and its texture were examined by us EBSD (Electron Back Scatter Diffraction).

2. Methods and Results

2.1 Design of billet & annular fuel

The size of the billet and the fuel core specimens for the production of the annular simulated fuel shims were determined. In the case of the fuel padding, the annular shape having a diameter of 5 mm and a smear density of 75% was selected as a ring 10 mm in diameter. In the case of a billet, a diameter of 40 mm was selected by extrusion. The inside of the billet was designed to be easily manufactured into an annular shape by extruding holes of the same size as the annular fuel slug.

2.2 Design and manufacture of extrusion mold

A mold for extruding annular metal fuel shims was designed using Deform 3D analysis program. In this study, Cu which is similar to the dissolution condition of uranium was selected as the material for making the simulated annular fuel, Deform 3D was used to select the jig design suitable for extruding Cu and stress and temperature conditions. Figure 1 is an analysis of the stresses at each part generated during extrusion using Deform 3D. As a result of the analysis, it was confirmed that a stress of about 900 MPa was generated at the center portion, and a stress of about 1800 MPa was expected to occur when the actual extrusion was performed.

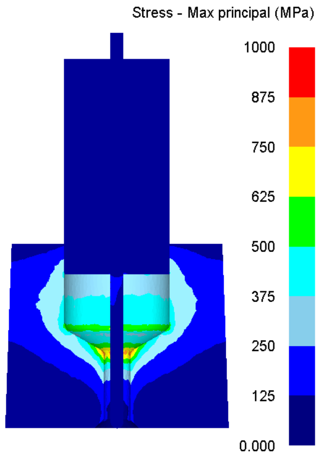

Fig. 1. Stress analysis of the extrusion mold.

Figure 2 shows the result of analyzing the temperature at each part during actual extrusion. The extrusion conditions were selected based on the extrusion of the annular simulated fuel core with Cu at a maximum temperature of 726 ℃.

2.3 Preliminary fabrication of annular fuel

Based on the analysis results, the jig design was designed, and the mold was manufactured based on the design. In the simulated fuel core extrusion, a press machine capable of extruding a maximum of 200 tons was used, and the extrusion was performed by inserting the billet before extrusion into a mold set at 450℃ after heating at 600℃. As a result of the extrusion, it was possible to successfully fabricate the annular fuel.

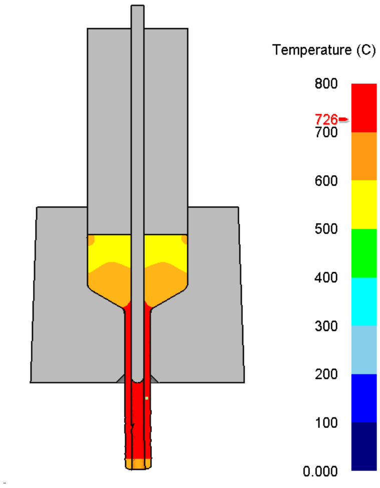

Fig. 2. Temperature analysis result of extrusion mold.

2.4 Control the billet microstructure

In order to confirm the effect of the initial microstructure of the billet on the extrusion result, the microstructure change according to the heat treatment temperature of the billet was observed. Figure 3 shows the results of the EBSD analysis of the billet microstructure at different temperatures. The billet structure before heat treatment showed a typical process ability, and the grain size gradually increased as the heat treatment temperature was increased to 400ºC, 550ºC, and 700ºC for an hour. In the previous study, it was confirmed that the change of grain size had a great influence on the grain distribution after extrusion. In this study, the initial microstructure of the billet was extruded by performing a hot extrusion test on the billet subjected to such heat treatment conditions. The impact on the organization was examined.

2.5 Microstructure analysis of extruded fuel

After the initial microstructure of the billet was adjusted by heat treatment, hot extrusion tests were performed on each of the microstructures before and after extrusion. Similar to previous studies, hot extruded tissues tended to have a general orientation in the extrusion direction, which tended to relax as the initial grain size became smaller. Therefore, it is judged that the smaller the grain size is, the more advantageous the control of the microstructure of the annular extrusion method will be studied based on the additional process conditions.

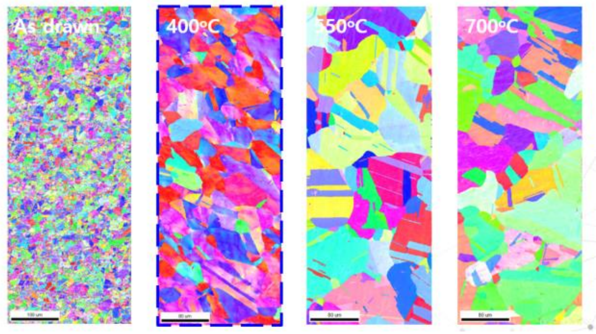

Fig. 3. Texture analysis of heat treated billet (L direction)

3. Conclusions

KAERI is developing the extrusion type metal fuel manufacturing technology as a part of the development of the original technology for the production of innovative metal fuel. In this study, the effect of the initial microstructure of the annular extruded fuel core on the final fuel core was investigated. In order to control the initial microstructure of the billet, an extrusion test was performed using the billet heat-treated at a temperature of 400 ºC, 550 ºC, and 700 ºC for 1 hour. Since the anisotropy of the microstructure was confirmed that the tendency is relaxed. Further research on this will be performed by adjusting the size of billets in the future.

Acknowledgement

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