Correlation between billet microstructure & anisotropy 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 [1, 2]. The annular metallic fuel design has been considered as a solution to relieve the fuel-cladding mechanical interaction (FCMI) caused by significant swelling of metallic fuels at high burnup, and it has been reported that the combination of annular fuel and lower plenum configuration is favorable to increase the average fuel burnup beyond 20%FIMA (Fissions per initial Metal Atom) without affecting fuel performance [3]. The one of most attractive advantage of extrusion method is save the process waste by omitting the sodium process. However, the extrusion 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, correlation between billet microstructure & anisotropy of annular fuel was studied by using Cu as a surrogate of U. The controlling of microstructure on billet 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 specimens for the production of the simulated annular fuels were determined. In the case of the fuel design, the annular shape having a diameter of 5 mm and a smear density of 75% was selected as a 10 mm in diameter.

2.2 Controlling 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 1 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.

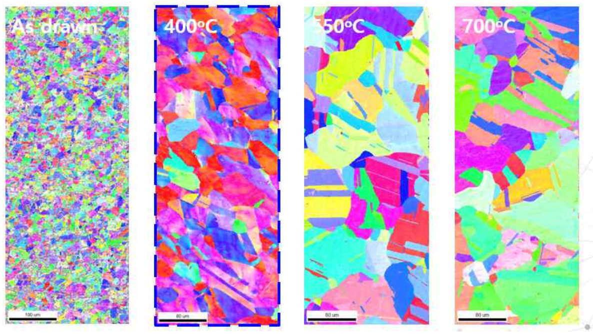


Fig. 1. Texture analysis of heat treated billet (L direction)

2.3 Select the conditions for extrusion

Based on the results of the billet heat treatment, heat treatment conditions suitable for the process parameters for the initial grain size were selected as 400°C, 550°C, and 700°C. By controlling the initial grain size in the range of 100um to 150um, the effect of the initial grain size on the anisotropy of the extruded annular metal fuel was evaluated to secure process parameters for the appropriate grain size. Other variables that can be considered in the extrusion process include extrusion speed, extrusion temperature, and extrusion ratio. In the case of double extrusion speed and temperature, it is reported that the change in grain size is not significantly affected. It was selected as a variable and evaluated. To control the extrusion ratio, Cu billets with an outer diameter of 20, 30, 40, 50 mm and an inner diameter of 5 mm were prepared to evaluate process parameters for the extrusion ratio.

Table. Process condition for annular extrusion.

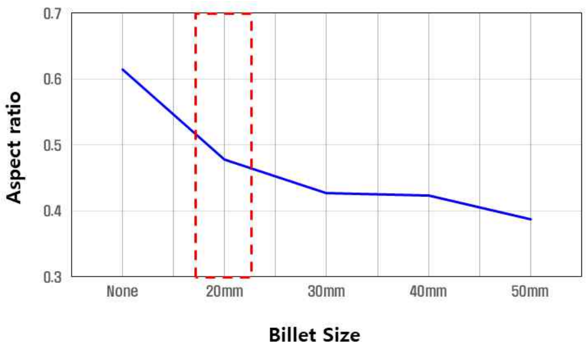
Size/ Temp.	400°C	550°C	700°C	As drawn
50mm	O	O	O	O
40mm	O	O	O	O
30mm	O	O	O	O
20mm	O	O	O	O

2.4 Microstructure analysis of annular fuel

As a result of analyzing the microstructure of the fuel core after extrusion, it was concluded that the value in the range of anisotropy of 0.6 to 0.65 occupies a high rate of 15 to 20% compared to other values. The misorientation value of 105° was a major axis orientation corresponding to an inherent property of copper with FCC crystal structure that related with deformation of slip plane in the (111) direction which occurred by extrusion deformation. This phenomenon is a general characteristic of materials having an FCC crystal structure that appears during extrusion deformation, and is a characteristic that does not appear in U having an orthogonal crystal structure. Therefore, in this study, the intrinsic properties of copper were excluded, and the extrusion process was compared by focusing only on the change in anisotropy caused by plastic deformation.

2.5 Effects of microstructure on anisotropy

From the previous analysis results, the effect of copper's inherent (111) surface was excluded, and the anisotropy change of the extruded fuel core was analyzed according to the billet diameter. Figure 2-8 shows the change in the average anisotropy according to the billet diameter, and it can be seen that the anisotropy gradually decreases as the extrusion ratio increases. Thus the anisotropy is maintained at 0.42 in the billet size of 30 to 40 mm, while the anisotropy decreases further as the billet diameter increases. Since anisotropy in metal nuclear fuel is a major cause that uniform combustion does not occur during combustion, it is determined that the higher the anisotropy after extrusion, the better the properties. Therefore, in this study, the billet condition of 20mm diameter with the lowest extrusion ratio was judged to be the most advantageous for the characteristics of the extruded annular fuel.



3. Conclusions

KAERI is developing the extrusion type annular metallic fuel manufacturing technology as a part of the development of the original technology for the production of innovative metal fuel. In this study, the correlation between billet microstructure & anisotropy of annular fuel were investigated. In order to control the microstructure, an extrusion test were performed using the billet heat-treated at a temperature of 400 °C, 550 °C, and 700 °C for 1 hour. hot extruded tissues tended to have a general orientation in the extrusion direction, which tended to relax as the initial grain size became smaller. Based on the microstructural analysis, the billet condition of 20mm diameter shows the most advantageous for the characteristics of the extruded annular fuel. Further study will be discussed in the future.

Acknowledgement

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