Development of the Fabrication Technology for a HANARO Fuel Rod by the Indirect Extrusion Method

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Abstract

In order to get basic data for the developing of a new fabrication process for a HANARO fuel rod, extrusion characteristics by using the direct and in-direct extrusion methods were investigated with extrusion billets composed of a dummy fuel core and an aluminum can as functions of the temperature, conical angle of the die, green density of the fuel compaction, and the shape of the core compact. In the case of in-direct extrusion, the cross section at the middle of the fuel rod showed a closely octagonal shaped core with a constant cladding thickness. However, at both the front and rear end parts of extruded fuel rod, imbalances existed in the cladding thickness as well as a penetration of Al into the fuel core of extruded rod. It is of note from the result that the variables such as extrusion temperature, conical angle of the die, and green density of the fuel compact did not effect significantly the degree of imperfections in the extruded fuel rod, but the imperfections were improved greatly by changing the shape of the core compact in the extrusion billet. Direct extrusion appeared to have no advantage for improving the imperfections due to a severe fluctuation of the metal flow between the fuel core and cladding material.

1. Introduction

U_3Si-Al dispersion fuel with a rod type has been used in the HANARO reactor as a driver fuel. To date, KAERI has launched a localization program to provide driver fuels for HANARO since the centrifugal atomization technology was developed.[1-2] The fuel rod is composed of a fuel core, in which both end parts are plugged with aluminum, and surrounded by an aluminum cladding with eight fins. Therefore, the fabrication of the rod type HANARO driver fuel should include two stages of extrusion, i.e., core extrusion and cladding extrusion and is followed by electron beam(EB) welding at the end plug to seal the fuel core. Because various fabrication processes exist for the HANARO fuel rod, it is always possible that failure can appear during the fabrication as well as irradiation stages due to various defects in the fuel.

Indirect extrusion has been known to have an advantage related to a more uniform flow pattern of the complete billet cross section with no tendency to form an extrusion defect.[3] Although the indrect extrusion method has been known to be useful for a co-extruding billet containing two kinds of materials, this method has not been applied yet for the fabrication of a research reactor fuel rod. Therefore, if the indirect extrusion method by using a billet composed of a fuel core and an aluminum can is applied to fabricate a HANARO fuel rod, its simplified process can reduce the fabrication cost and occurrence of defects. In this study, the effect of the fabrication variables on the co-extrusion characteristics of a HANARO fuel rod by applying indirect as well as direct extrusions has been investigated to understand the basic nature prior to developing a new fabrication process.

2. Experimental

In order to investigate effectively the metal flow during the co-extrusion of a billet, zirconium powder was used as a simulated U_3Si fuel powder. Zirconium powder, with a size less than 125 microns, was mixed with aluminum 1060 powder to have a fuel volume fraction of 22.5 %, which is the fraction of U_3Si in the HANARO fuel rod. The mixture was blended for two hours with 75 rpm in V-type mixer to enhance the blending homogeneity. By varying the compacting pressure, the cylindrical fuel compacts with different green densities of 60 ~ 75 %TD were fabricated from the double-action press. The length of the compact was adjusted to have the same core volume as the HANARO fuel rod. The champer or taper machining of several compacts at both ends was added to investigate the effects of the metal flow during a co-extruding billet containing two kinds of materials. The compact was inserted into an aluminum can with a outer diameter of 38 mm, as shown in Fig. 1, and was sealed by electron beam welding. The co-extrusion of the billet was carried out by using the direct and in-direct extrusion methods with varying temperatures, conical angles of the die, green densities of the fuel compaction, and shapes of the core compact.

3. Results and Discussions

3-1 Indirect extrusion

The billet was co-extruded by the indirect extrusion method with varying temperatures of both the billet and the container, but mainly at 400 ^{o}C. All the extruded rods exhibited a fuel core length of 700~710 mm, that is slightly longer than the standard core length, i.e., 700 mm. Figure 2 shows the fuel cross sections obtained at the middle of the extruded fuel core. Irrespective of the co-extruding temperature, the fuel rod exhibits a closely octagonal shaped core due to the occurrence of a slight increase of the metal flow into the cladding fin. However, all the fuel rods were measured to have a constant cladding thickness of 0.71~0.77 mm. When considering the cladding thickness of the standard is 0.76±0.08 mm, the above result is quietly promising for applying the co-extrusion technique for the HANARO driver fuel.

Figures 3-5 exhibit the X-ray and metallography images of both end parts of the extruded fuel rods from the cylindrical core billets, respectively. In the front part of the fuel core(see detail Fig. 5(a)), a slight protrusion of the fuel core existed into the cladding side, having a snake-head-like shape, which was observed mostly at the position of about 50 mm after the core front. This result promoted an imbalance in the cladding thickness, in which the cladding thickness appeared to be about 0.3~0.5 mm. Moreover, a penetration of the aluminum into the fuel core occurred at the rear part of the extruded rod with having a thin wall layer thickness.(Fig. 5(c)) The length of the cladding imperfections at the rear part was mostly measured to be about 140 mm, irrespective of extrusion temperature.

As shown in Fig. 3, it appears that the changes of the variables such as the green density of the core compact as well as the angle of the extrusion die not effect significantly the degree of imperfection in the extruded fuel rod. However, when the compact has a lower green density, the extruded fuel rod has a tendency to have a thicker cladding. The extruded fuel rod by using 180° die exhibited a little enhanced protrusion of fuel core into the cladding side due to the occurrence of an abrupt size reduction of the billet at an extrusion die.

It is of significant that the occurrence of a cladding imperfection at both end parts of core in the extruded fuel rod should result mainly from the difference of the deformation flow stresses depending on the billet location, i.e., from the center to the periphery. Because tensile stress is a major controlling factor at the billet center while shear stress becomes a major factor at the periphery region of the billet where the friction occurs with the container wall, it can be assumed that the periphery of the fuel compact in the billet was co-extruded under a mixed flow stress.

Therefore, a billet with a champer-machined, or taper-machined, fuel compact was co-extruded in order to minimize the cladding imperfections at both ends of the extruded fuel core. By adjusting the appropriate degree of machining on both the front and rear edges of the fuel compact, as shown in Fig. 6, a fuel rod with almost an uniform cladding thickness could be extruded, in which the protrusion of the fuel core at the front part disappeared easily and a significantly restrained aluminum penetration existed at the rear part of the extruded fuel core. It is thought that the improvement of the cladding imperfections by applying a shape change to the billet resulted from controlling the size ratio between the fuel core and cladding materials in the billet.

3-2. Direct extrusion

In order to understand the difference of the extrusion characteristics between the direct and in-direct extrusion methods, an experiment was carried out by applying direct extrusion at various temperatures, 400, 370 and 340^{o}C, to fabricate the fuel rod from the canned billet. Irrespective of the extrusion temperature, the length of fuel rods after direct extrusion was measured to be in the ranges from 880 mm to 910 mm, which are quite longer than that of the standard fuel rod. It should be noted that severe size imperfections existed, both in the reduction of the cladding thickness and the penetration of aluminum into the fuel core from the back side of the extruded rod, where the length was longer than 300 mm, at both the front and rear parts of the fuel core compared to the imperfections by indirect extrusion. Figure 7 shows the typical cross sections of the fuel rod fabricated by direct extrusion. The aluminum cladding exhibited a wide range of thicknesses, from 0.17 mm to 1.19 mm, along the whole length of the fuel core. It is thought that heat is produced during direct extrusion due to the friction between the container and the billet surface, and consequently a temperature increase occurs at the billet surface. This reduces the strength of the aluminum and enhances a non-uniform metal flow between the fuel core and the cladding material. Therefore direct extrusion appeared to have no advantage for improving the imperfections.

4. Conclusion

In order to get basic data for the developing of a new fabrication process of the HANARO fuel rod, extrusion characteristics by using the direct and in-direct extrusion methods were investigated with extrusion billets composed of a dummy fuel core and an aluminum can as functions of the temperature, conical angle of the die, green density of the fuel compaction, and shape of the core compact. In the case of in-direct extrusion, the cross section at the middle of the fuel rod showed a closely octagonal shaped core with a constant cladding thickness. However, at both the front and rear end parts of the extruded fuel rod, imbalances existed in the cladding thickness as well as a penetration of Al into the fuel core of the extruded rod. It is of note from the results that the variables such as the extrusion temperature, conical angle of the die, and the green density of the fuel compact did not effect greatly the degree of the imperfections in the extruded fuel rod, but the imperfections were improved greatly by changing the shape of the core compact in the extrusion billet. Direct extrusion appeared to have no advantage for improving the imperfections due to a severe fluctuation of the metal flow between fuel core and cladding material.

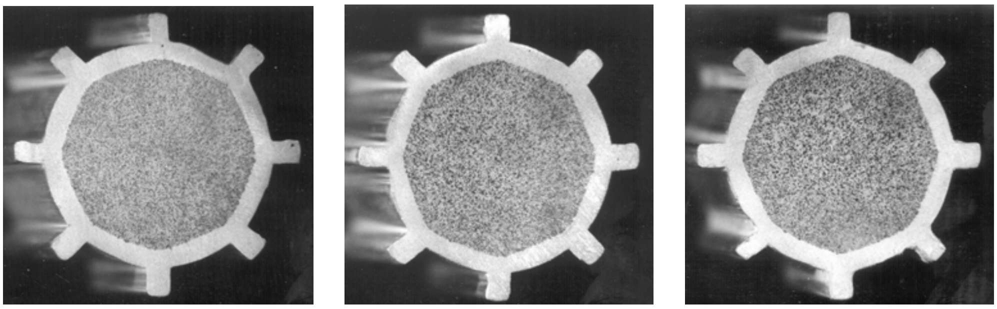
5. References

1. J.M. Park, K.H. Kim, D.B. Lee, E.S. Lee, J.S. Lee, C.K. Kim, Proceedings of Korean Nucl. Society Spring Meeting, Pohang, 1999.
2. C.K. Kim, K.H. Kim, J.M. Park, E.S. Lee, W.H. Sohn, S.H. Hong, Metals and Materials, 15(1999)149-156.
3. Extrusion, K. Laue, H. Stenger, American Society for Metals, 2nd Ed.,(1981)

(a) Cylindrical

(b) Champer

Fig. 1. Extrusion billet containing a fuel compact and an aluminum can.



(a) (b) (c)

Fig. 2. Cross sections observed at the middle section of indirectly co-extruded fuel rod;

(a) container T : 300 °C , billet temperature 400 °C
(b) container T : 400 °C , billet temperature 400 °C
(c) container T : 350 °C , billet temperature 450 °C

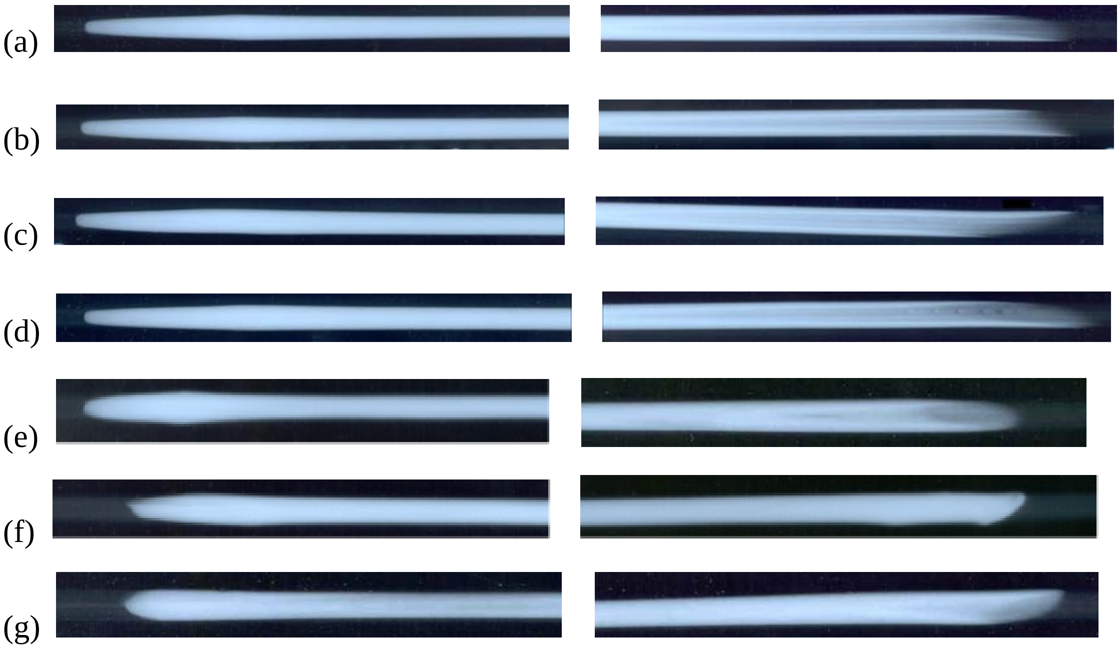
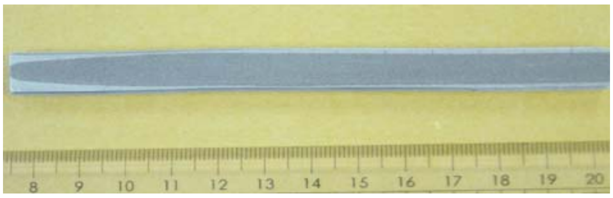
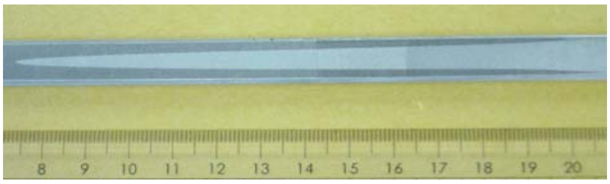


Fig. 3. X-ray photographs of indirectly co-extruded fuel rods.

(a) container T : 300 °C , billet temperature 400 °C, 120° die, 67%TD compact
(b) container T : 350 °C , billet temperature 400 °C, 120° die, 67%TD compact
(c) container T : 400 °C , billet temperature 400 °C, 120° die, 67%TD compact
(d) container T : 350 °C , billet temperature 350 °C, 120° die, 67%TD compact
(e) container T : 400 °C , billet temperature 400 °C, 180° die, 67%TD compact
(f) container T : 400 °C , billet temperature 400 °C, 120° die, 74%TD compact
(g) container T : 400 °C , billet temperature 400 °C, 120° die, 63%TD compact

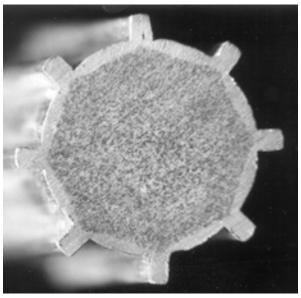


(a) front

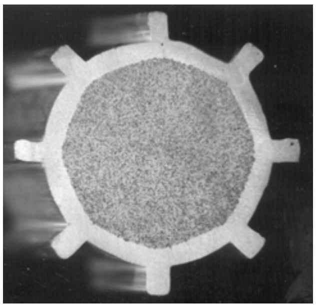


(b) rear

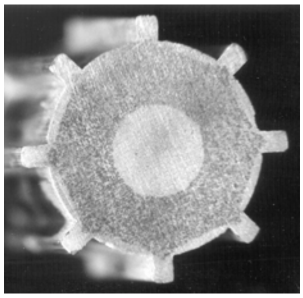
Fig. 4. Fuel cross section from the cylindrical billet along the longitudinal direction.



(a) front

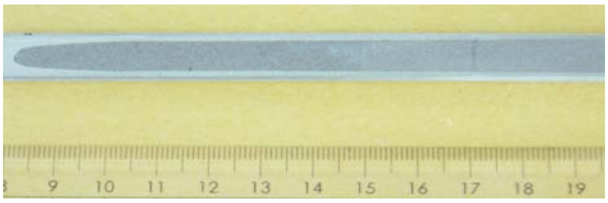


(b) middle

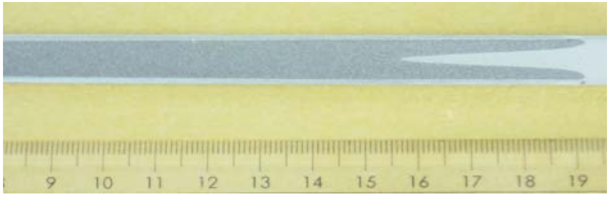


(c) rear

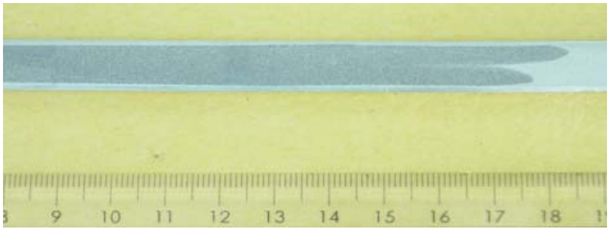
Fig. 5. Cross sections of the indirectly co-extruded fuel rod from a cylindrical billet; (container T : 300 ^{o}C , billet temperature 400 ^{o}C)



(a) front

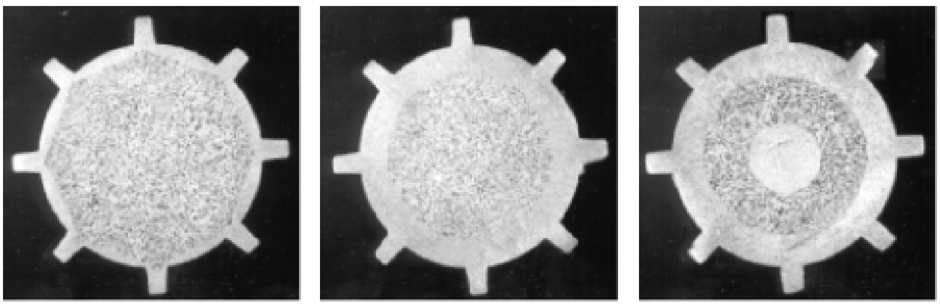


(b) rear



(c) rear

Fig. 6. Fuel cross section from the champer(and taper) billets along the longitudinal direction.



(a) (b) (c)

Fig. 7. Fuel cross sections of the directly co-extruded fuel rod observed at different lengths from the fuel core front; (a) 150 mm, (b) 350 mm, and (c) 650 mm.