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Feasibility Study for Manufacturing High-density LEU U_3Si_2 Plate-type Fuel

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1. Introduction

As a part of a Reduced Enrichment for Research and Test Reactors (RERTR) Project, a lot of efforts for the conversion of high enriched uranium (HEU) fuel to low enriched uranium (LEU) fuel in research reactors have been made for last decades. Until now, HEU fuel has been converted to LEU fuel with a uranium density of 4.8 gU/cc using uranium silicide alloys such as U_3Si and U_3Si_2 in more than 90% of the research reactors[1-2]. However, the development of U-Mo LEU fuel for high flux research reactors (HFRR) using HEU fuel has been still in progress and some problems to be solved have been remained for using it in HFRR. Currently, high-density U_3Si_2 LEU fuel is being investigated for its use in HFRR as a backup solution of U-Mo LEU fuel. In this study, feasibility of high-density U_3Si_2 LEU fuel manufactured by KAERI is presented

2. Fabrications and Results

In this section, fabrication and inspection results of high-density U_3Si_2 LEU fuel are described.

2.1 Atomized U_3Si_2 powder

U_3Si_2 powder as a raw material of high-density U_3Si_2 fuel was produced by centrifugal atomization with depleted U-Si alloys. The basic principle of atomization is that molten uranium alloys formed by induction heating in a vacuum is poured onto a rotating disk, and then the melt is spread outward by centrifugal force to form fine spherical droplets, which rapidly solidify[3]. The morphology of atomized powder was observed by scanning electron microscopy and the phase was identified by X-ray diffraction. Spherical powder with an average size of about 70 um was obtained, as shown in Figure 1. An X-ray diffraction pattern of the powder shows that the phase of the powder is primarily U_3Si_2, in addition to uranium oxides on its surface. (Figure 2)

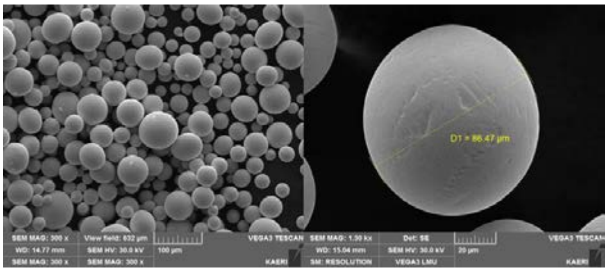

Fig. 1. SEM images of atomized U_3Si_2 powder

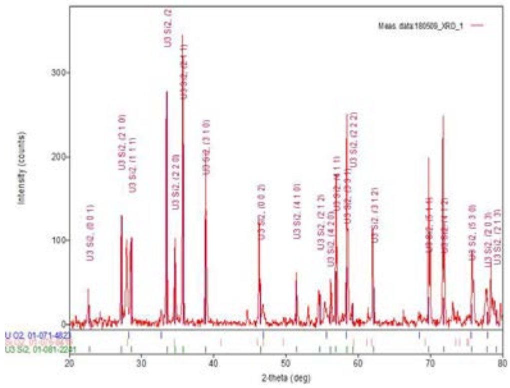

Fig. 2. XRD pattern of atomized U_3Si_2 powder

2.2 Fabrication of high-density U_3Si_2 plate

Atomized U_3Si_2 powders were blended with aluminum powders and pressed into green compacts with uranium density of 5.3 gU/cm^3. The loading of U_3Si_2 powder and aluminum powder is 98.444 g and 24.390 g, respectively. The green compact was sandwiched between two 6061 aluminum alloy cover plates and the assembly was TIG-welded. The assembly, with a total thickness of 10.7 mm, was hot rolled at 500^{o}C and cold rolled into plate with a final thickness of 1.27 mm. (Figure 3) Blister test was performed at 500^{o}C for 1h after hot rolling process. As a result of blister test, there were no blisters on fabricated plate.

Fig. 3. Photo of fabricated high-density U_3Si_2 full-size plate

2.3 Inspection of high-density U_3Si_2 plate

Core location and dimension of fabricated plate was checked by using X-ray linear scanner (HAWKEYE 1600 model) and that corresponded well with the drawing and specification as shown in Figure 4. Voltage and ampere for inspection were 120 kV and 4 mA, respectively. Core length and width of fabricated plate were 601.20 mm and 62.50 mm, respectively.

Fig. 4. Core location & dimension check by X-ray

Stray particles on fabricated plate were inspected by using X-ray CT (TVX-IMT225CT model). Voltage and ampere for inspection were 200 kV and 150 uA, respectively. As a result, there were no stray particles on fabricated plate as shown in Figure 5.

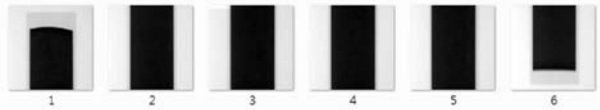

Fig. 5. Stray particle inspection by X-ray from head to tail

Uranium distribution on fabricated plate was inspected by X-ray linear scanner (HAWKEYE 1600 model). Voltage and ampere for inspection were 120 kV and 4 mA, respectively. The gray level measured in the area 1, 2, and 3 of 5.3 gU/cm^3 fuel plate corresponded with specification as show in Figure 6. From the result, we found that uranium was well distributed throughout the whole plate.

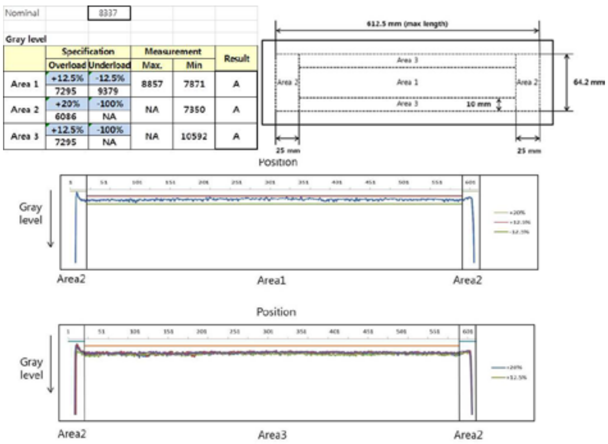

Fig. 6. Homogeneity inspection by X-ray

Bonding of fabricated plate was inspected by using ultrasonic test (SAM-ATHLON model). The resolution of ultrasonic C-scan was over 0.2. As you can see in Figure 7, any de-bonding in the plate was not detected.

Fig. 7. Bonding inspection by ultrasonic test

Cladding and fuel core thickness were checked by using destructive test. The head, tail and center parts of fabricated plate were cut and polished into final specimens for SEM observation. In the tail dog-bone area of 5.3 gU/cm^3 fuel plate, the measured minimum cladding thickness was 278.52 um. In the center area, the average cladding thickness was within 324.72 um ~ 362.65 um and in the head dog bone area, the measured minimum cladding thickness was 218.32 um, as shown in Figure 8. From these results, we can notice that high-density U_3Si_2 fuel plate fabricated by KAERI has sufficient margin for the minimum cladding thickness in a dog-bone area which is over 200 um.

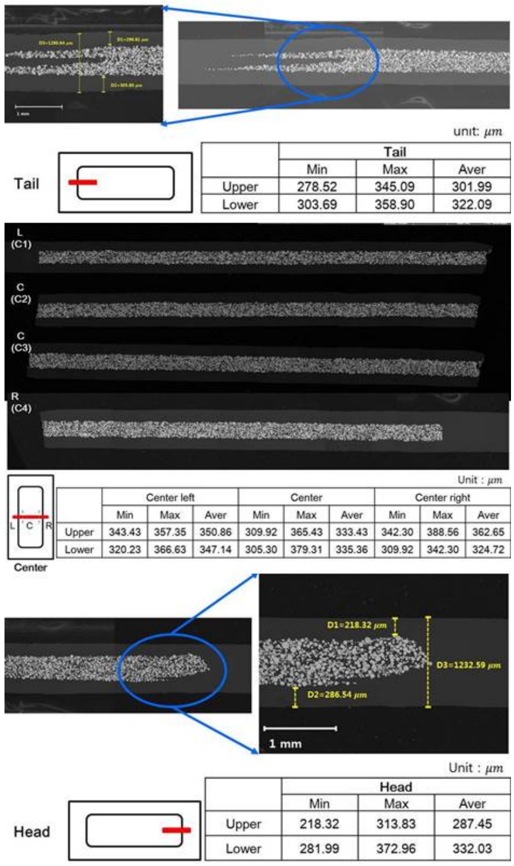

Fig. 8. Cladding thickness measurement of fabricated plate

3. Conclusions

KAERI successfully manufactured high-density (5.3 gU/cm^3) U_3Si_2 LEU fuel with atomized powder. From the results of fabrication and inspection, KAERI's high-density U_3Si_2 fuel corresponds well with commonly used specifications of 4.8 gU/cm^3 U_3Si_2 LEU fuel. According to this feasibility study on high-density U_3Si_2 LEU fuel, qualification test of KAERI's high-density U_3Si_2 fuel will be conducted at HFRR and the result will be discussed in the near future.

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