Fabrication of nitride coated U-Mo powders for an advanced research reactor fuel

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1. Introduction

U-Mo/Al dispersion fuel is being developed as a high-uranium-density fuel for high performance research reactors due to its excellent stability during irradiation[1]. Interaction layer formation between the U-Mo particle and the Al matrix has been considered one of the most challenging issues in the development of U-Mo/Al dispersion fuel[2]. As the matrix Al is consumed by the interaction, thermal conductivities of U-Mo/Al dispersion fuel come to decrease, and a breakaway swelling of fuel elements may occurs due to the irradiation induced softening of the interaction layer[3,4]. Use of larger-than-usual size U-Mo powder(200~500 μm) can be an acceptable option to mitigate the interaction problem[5]. Irradiation test with the Al-Si(2~5wt%) matrix resulted in much reduced interaction layer growth. However, use of the Al-Si matrix has some drawbacks such that the concentration of Si in the interaction layers is not controllable.

Several studies to reduce the total amount of Si in Al are under progress. Si coatings on U-Mo particle surface can reduce Si because Si is concentrated only on the surface of U-Mo particles. Protective layer coating on U-Mo particle surface can be an alternative approach to solve the interaction problems. It was reported that ceramic coatings of oxide or ZrN on U-Mo power can reduced the interaction layer growth during the irradiation.

In this study, a simple gas phase reaction method was tested to form nitride layers on the surface of atomized U-Mo powder. We investigate nitride coated layer evolution on atomized U-Mo powder by annealing in N_2 gas. We further examine correlations between nitride layer growth and annealing parameters. Diffusion couple annealing test to investigate the effect of nitride layer on interaction between U-Mo and Al is also a part of the present work.

2. Experimental Procedures

Centrifugally atomized U-7wt%Mo powder with 150~210 μm in diameter was used for UN coatings. The vacuum rotator heat treating furnace was developed to coat nitride layer on surface of U-7wt%Mo powders as shown in Fig. 1. The several process parameters were shown in Table 1.

The green compacts for annealing test to examine the interaction layer growth between nitride coated U-Mo particles and Al matrix were prepared by pressing the U-Mo and Al powder mixture. For a comparison, green compacts of U-Mo/Al mixture were also prepared. The annealing tests were conducted in a muffle furnace at 580℃ for 5h.

Cross-sectional microstructures of the specimens were observed by using scanning electron microscopy (SEM). EDS and X-ray diffraction (XRD) technique were used to characterize the composition and crystal structure of the coated layer.

Fig. 1. Vacuum rotator heat treating furnace

Table 1. The process parameters of VRHF.

Parameters	N/U-Mo Reacted Condition
Back ground pressure	1×10^{-6} Torr
Working pressure	5×10-2 Torr
N_2-gas flow	10 sccm
Number of Revolution	30 rpm
Temperature	1000 ℃
Holding Time	3 hours

3. Results and discussion

Nitride layer coating on U-Mo powder in N_2 gas atmosphere was conducted at 1000 ℃ for 3 hour by using VRHF. Morphological changes and chemical

composition of coated particles were observed by SEM and EDS. Fig. 2 and table 1 show the cross-sections of as-atomized and coated U-Mo powders and coated layer composition. Since centrifugally atomized powders were passivated under Ar gas and then stored under an air, the oxide layer was formed on the as-atpmized powder surface. Meanwhile, N-containing layers were formed in the sample annealed at $1000^{o}C$ as shown in Table 1.
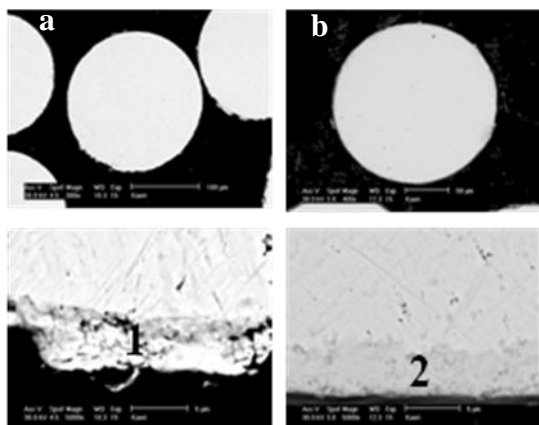

Fig. 2. A scanning electron micrograph of (a) an as-atomized U-7wt%Mo powder and (b) a UN coated U-7wt%Mo powder .

Table 1. Surface layer compositions measured by EDS for samples shown in Fig. 2.

Element	① As-atomized (at%)	② Nitride coated (at%)
O	49.6	8.5
N	-	71.8
Mo	6.4	0.2
U	44.0	19.4

Phase evolution of U-7wt% Mo powders before and after the annealing was examined by using room temperature X-ray diffraction. Fig. 3(a) shows a XRD pattern for as-atomized U-7wt%Mo powders. Main phase of as-atomized powder was γ-UMo. Diffraction peaks from UO_2-like oxide phase also observed. After an nitride coating annealing, phase change was observed in a XRD pattern as shown in Fig. 3(b). Diffraction peaks from a uranium mononitride-like phase, as denoted by diamonds, were appeared in this pattern.
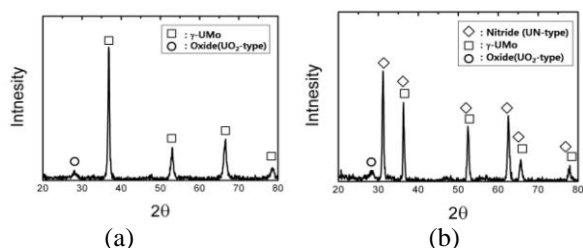

Fig. 3. XRD patterns for (a) as-atomized U-7wt%Mo powder and (b) nitride coated U-7wt%Mo powders.

Fig. 4 shows the results of annealing tests of U-Mo/Al dispersion fuel compacts. Annealing test results showed that there is no reaction between nitride coated U-Mo particle and Al matrix. Whereas, in un-coated U-Mo dispersed sample, interaction layer was grown up to ~10μm.
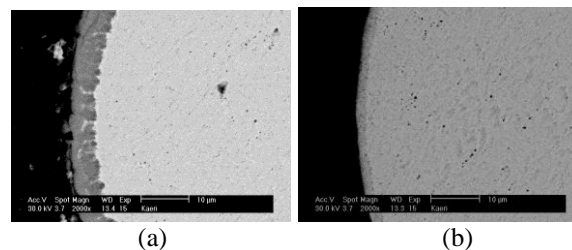

Fig. 4. Cross-sectional microstructures of U-Mo/Al dispersion fuel compacts after annealing at 580 ℃ for 5 hours.
(a)as-atomized U-Mo/Al (b) nitride coated U-Mo/Al

4. Conclusions

Nitride coated U-Mo powders were fabricated by using a VRHF. Annealing test result showed that nitride layer was very effective in suppressing the interaction layer formation and growth between U-Mo and Al.

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