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Analysis of Nitride or Silicide Layers on Single or Duplex Coated U-Mo Powder

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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 owing to its excellent stability during irradiation [1]. Gamma phase U-Mo alloys are one of the promising candidates to be used as advanced high uranium density fuel for high power research reactors owing to their stable irradiation behavior.

However, a severe pore formation at around the interaction layers between the U-Mo and Al matrix degrades the irradiation performance of U-Mo fuel. The interaction layer formation between the U-Mo particle and Al matrix has been considered one of the most challenging issues in the development of U-Mo/Al dispersion fuel [2]. The use of larger-than-usual size U-Mo powder (200~500 ㎛) can be an acceptable option to mitigate the interaction problem [3].

One of the remedies to the interaction problem is the small amount of Si addition to the Al matrix. Recent irradiation tests have shown that the use of Al-(2-5wt%)Si matrices retard the growth of interaction layers effectively during irradiation. Because the interaction formation also degrades the thermal properties of the dispersion fuel, it is necessary to minimize the interaction layer growth. Recently, KAERI proposed silicide[4] or nitride-coated U-Mo fuel for a minimization of the interaction layer growth.

In this study, nitride and silicide duplex coating, as well as a single coating was performed. In addition, to observe the formation of the coating layers, SEM, EDX, and XRD analyses were performed.

2. Experimental procedures

Centrifugally atomized U-7wt%Mo particles 90-150㎛ in diameter were used for nitride or silicide coating. A vacuum rotator heat treatment furnace was developed by nitride coating on the surface of the U-Mo particles. The operation conditions are listed in Table 1.

Pure Si powder (99%, -325 mesh) was used for silicide coating on U-Mo particles by vacuum annealing. U-Mo particles and pure Si powder were mixed in a ball mill with a rotation speed of 30 rpm for 8 hours. The mixed powder was annealed at 1000℃ for 1 hour under a vacuum of about 7×10^{-5} torr.

U-Mo/Al dispersion rods were extruded after mixing Al powder and coated U-Mo particles. To form the interaction layers, annealing was performed with 580℃ for 1hour in a vacuum furnace.

Nitride or silicide coated powders have been coated again with another coating method to form duplex coating layers.

The surface and cross-sectional microstructure of the coated particles were observed using SEM and characterized by EDX and XRD.

Table 1. The operation conditions of nitride coating.

Parameters		Conditions
Back ground pressure		1×10^{-6} torr
Working pressure		6×10^{-3} torr
N_2-gas flow		80 sccm
Number of Revolution		30 rpm
Temperature		1000 ℃
Holding Time	U-7Mo	6 hours

3. Results and discussion

The surface of atomized U-7wt%Mo powder was very smooth and round, as shown in Fig. 1.

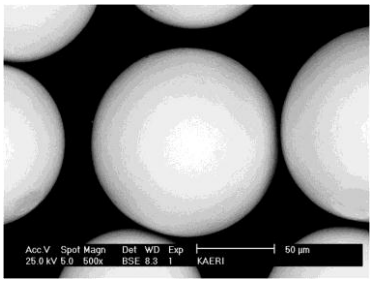

Fig. 1. SEM image of the surface of atomized U-7wt%Mo particles

Fig. 2 shows the surface of the nitride or silicide single and duplex coated U-7wt%Mo particles. The surface of the nitride coated particle was very smooth, as shown in Fig. 2(a). However, the surface of a silicide coated particle was very rough and Si powder attached to the surface of the coating layer, as shown in Fig. 2(b). Fig. 2(c) shows the surface of the duplex coated U-7wt%Mo particle. The duplex coating was performed by silicide coating on the nitride coating layers. Si powder attached to the surface of the duplex coated particle. Fig. 2(d) shows the surface of the duplex coated particle. It was performed by nitride coating on the silicide coating layers. The particles were aggregated and deformed.

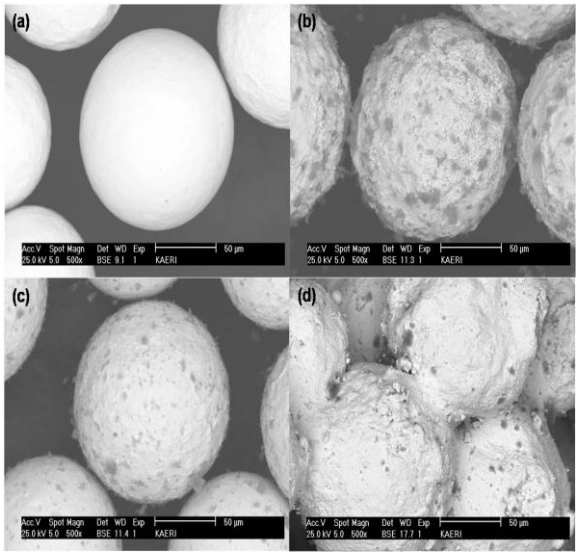

Fig. 2. SEM images of the surface of the coated U-7wt%Mo particles (a) nitride coated, (b) silicide coated, (c) silicide coated after nitride coating, and (d) nitride coated after silicide coating

Silicide coating layers were formed on the surface of U-7wt%Mo particles with a thickness of about 7-8 ㎛, as shown in Fig. 3(a). After annealing at 580℃ for 1h, interaction layers were formed as shown in Fig. 3(b).

While silicide coating layers formed on U-7wt%Mo particles were able to inhibit the formation of interaction layers, interaction layers formed on the uncoated surfaces of the particles.

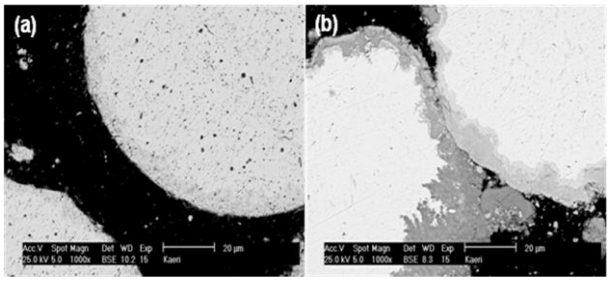

Fig. 3. SEM images of silicide coated U-7wt%Mo particles (a) as extruded, and (b) as annealed (580℃/1h)

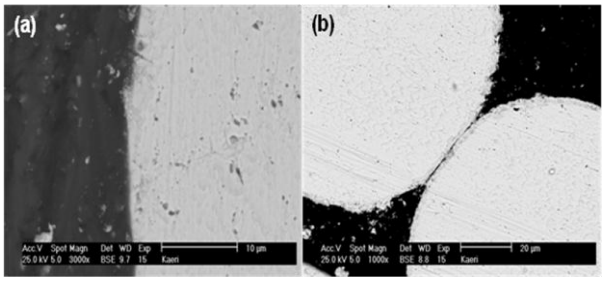

Fig. 4. SEM images of nitride coated U-7wt%Mo particles (a) as extruded, and (b) as annealed (580℃/1h)

Nitride coating layers were formed on the surface of U-7wt%Mo particles to a thickness of about 1-2 ㎛, as shown in Fig. 4. Although thinner than the thickness of the silicide coating layer, but annealing test result, the interaction layer formation was almost completely suppressed.

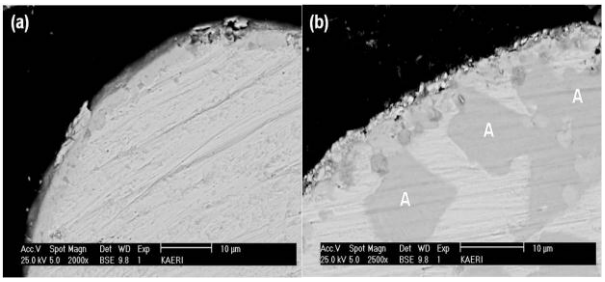

Fig. 5. SEM images of the cross-sectional microstructure of duplex coated U-7wt%Mo particles (a) silicide coated after nitride coating, and (b) nitride coated after silicide coating

Fig. 5 shows cross-sectional microstructures of the duplex coated particles. However, a duplex coating layer was not formed. Nitride coating layer inhibits the formation of the silicide coating layer. In addition, the silicide coating layer penetrates into the inner side of the particle during nitride coating.

4. Conclusions

1. The silicide coating layer was formed on the surface of U-7wt%Mo particles with a thickness of about 7-8 ㎛ and the nitride coating layer has a thickness of about 1-2 ㎛
2. The results of the annealing tests showed that nitride coating was more effective than silicide coating in suppressing the formation of interaction layers.
3. Nitride coating layer inhibits the formation of the silicide coating layer and the silicide coating layer interpenetrates the inner side of the particle for nitride coating.

ACKNOWLEDGMENTS

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