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XRD and Neutron Diffraction Analyses of Heat Treated U-Mo/Al Dispersion Fuel

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1. Introduction

High density U-Mo alloys are regarded as promising candidates for advanced research reactor fuel because they have shown stable irradiation performance when compared to other uranium alloys and compounds [1]. However, interaction layer formation between the U-Mo alloys and Al matrix degrades the irradiation performance of U-Mo dispersion fuel. Therefore, addition of Ti in U-Mo alloys, addition of Si in Al matrix and silicide or nitride coating on the surface of U-Mo particles have been proposed in order to inhibit the interaction layer growth [2-4]. In order to analyze the mechanisms of interaction layer growth inhibition by adding Ti in U-Mo alloys or Si in Al matrix, accurate phase characterization of the interaction layers is required. While previous studies using X-ray diffraction have been reported, laboratory x-ray diffraction method has limitations such as low resolution and small measurement volume. Neutron diffraction method can be a more accurate analysis when compared with X-ray diffraction method due to the large penetration depth of neutron.

In this study, X-ray diffraction and neutron diffraction experiments have been performed by using the laboratory X-ray diffractometer and high resolution powder diffractometer (HRPD) of the HANARO research reactor in KAERI.

2. Experimental procedures

U-7wt%Mo and U-7wt%Mo-1wt%Ti alloy powders were used in this experiment. Powders were fabricated by using a centrifugal atomization method. Superheated molten U-Mo was fed through a small nozzle onto a rapidly rotating graphite disk and liquid alloy droplets were then spread from the disk by a centrifugal force and cooled in an argon atmosphere [5]. The produced U-Mo alloy powder was extruded into rods after mixing with Al or Al-(2~8wt%)Si. The dispersion rod samples were annealed at 580℃ for 1 hour in a high temperature vacuum furnace in order to form interaction layers.

The microstructures of extruded and annealed rods were observed by scanning electron microscopy (SEM). X-ray and neutron diffraction experiments were performed to characterize the interaction layers by using laboratory XRD and HRPD. The diffraction patterns were analyzed by the Rietveld refinement using the FullProf suite program [6]. The list of experimented specimens were shown as Table.1

Table. 1. List of experimented specimens

Alloys	Matrix
U-7wt%Mo	Al
	Al-2wt%Si
	Al-5wt%Si
	Al-8wt%Si
U-7wt%Mo-1wt%Ti	Al
	Al-2wt%Si
	Al-5wt%Si
	Al-8wt%Si

3. Results and discussion

The differences of interaction layers between U-Mo alloys and Al matrix were compared as in Fig. 1. It was observed that the interaction layers were increased with increasing until the 5wt%Si in the Al matrix(a-c). However, for the specimen with 8wt% of Si content in the Al matrix, evenly formed thin interaction layers were observed around the U-Mo alloy particles. The interaction layers concentrated on particular particles were not observed.

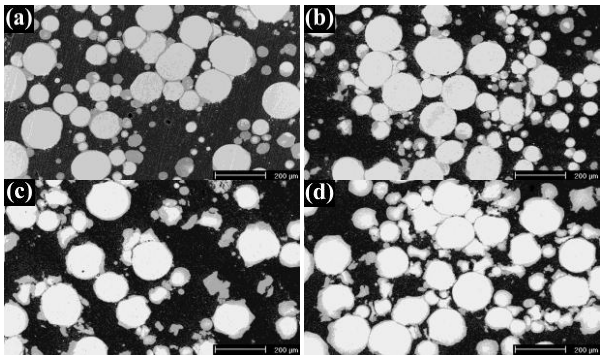

Fig. 1. Cross-section SEM images of annealed U-Mo/Al-Si extruded rods ; (a)U-7wt%Mo/Al, (b) U-7wt%Mo/Al-2wt%Si, (c) U-7wt%Mo/Al-5wt%Si, (d) U-7wt%Mo/Al-8wt%Si.

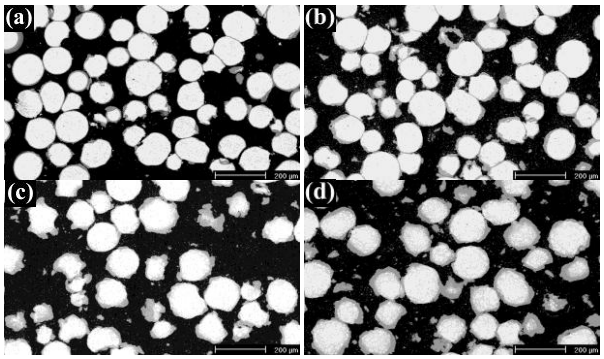

Fig. 2. Cross-section SEM images of annealed U-Mo-Ti/Al-Si extruded rods; (a)U-7wt%Mo-1wt%Ti/Al, (b) U-7wt%Mo-1wt%Ti/Al-2wt%Si, (c) U-7wt%Mo-1wt%Ti/Al-5wt%Si, (d) U-7wt%Mo-1wt%Ti/Al-8wt%Si.

Fig.2 shows the differences of interaction layers between U-7wt%Mo-1wt%Ti alloys and Al matrix as the weight fraction of Si in the Al matrix changes. More evenly formed interaction layers were observed when 1wt% of Ti was added in U-7wt%Mo as shown in Fig. 2 (a). However, it was observed that the interaction layers were increased with increasing weight fraction of Si in the Al matrix (b-d).

XRD patterns of interaction layers were shown as Fig. 3. It was observed that the compounds of interaction layers were composed UAl_3 and UAl_4. But extra compounds could not be found when 1wt% of Ti was added in U-7wt%Mo or with Si content in the Al matrix.

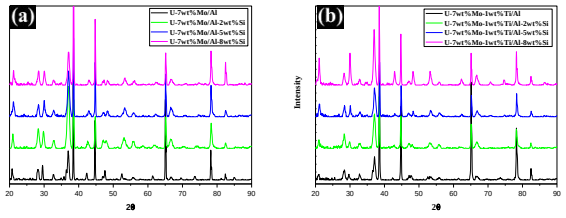

Fig. 3. XRD patterns analysis of U-7wt%Mo/Al, U-7wt%Mo/Al-(2~8wt%)Si(a) and U-7wt%Mo-1wt%Ti/Al, U-7wt%Mo-1wt%Ti /Al-(2~8wt%)Si (b).

Neutron diffraction patterns of interaction layers were analyzed by the FullProf suite program as shown Fig. 4 and Fig. 5. The refined results showed that the interaction layers were composed of UAl_3, UAl_4, UMo_2Al_{20}, U_6MoAl_{43}. Also, U_3MoSi_2, U_3Si_5 compounds were observed in the specimens with Si in the Al matrix. Extra compounds were not found in the specimens with the addition of Ti in U-Mo alloys. However, decrease in the peak intensities of the interaction layers was observed. It is shown that weight fraction of interaction layers was decreased when 1wt% of Ti was added in U-7wt%Mo.

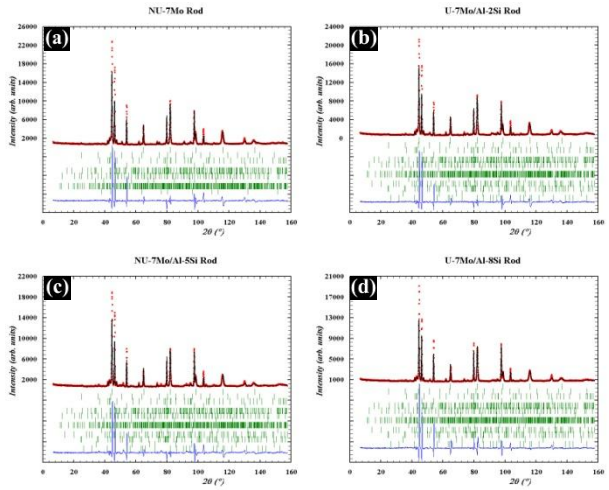

Fig. 4. Neutron diffraction patterns analysis of (a) U-7wt%Mo/Al, (b-d) U-7wt%Mo/Al-(2~8wt%)Si by using the FullProf suite program.

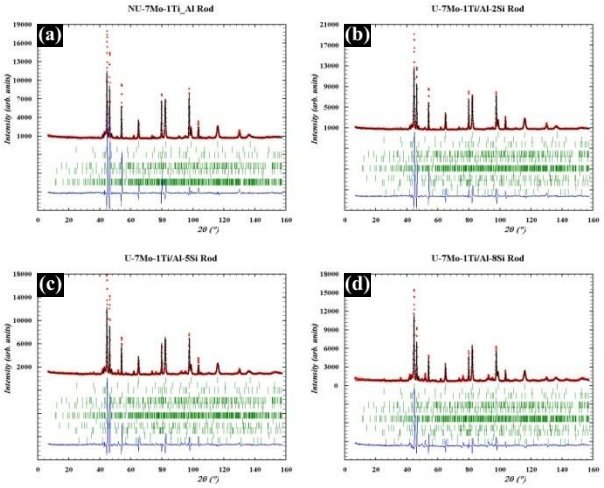

Fig. 5. Neutron diffraction patterns analysis of (a) U-7wt%Mo-1wt%Ti/Al, (b-d) U-7wt%Mo-1wt%Ti/Al-(2~8wt%) Si by using the FullProf suite program..

4. Conclusions

1. Neutron diffraction experiment was able to identify more compounds accurately than laboratory XRD analysis.
2. XRD patterns analysis identified UAl_3 and UAl_4 compounds in the interaction layers.
3. The refined results of neutron diffraction patterns using the Fullprof suite program showed that interaction layers were composed of UAl_3, UAl_4, UMo_2Al_{20} and U_6MoAl_{43}. U_3MoSi_2 and U_3Si_5 compounds were identified in the specimens with Si in the Al matrix.
4. The weight fraction of interaction layers were decreased when 1wt% of Ti was added in U-7wt%Mo.

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