Proceedings of the Korean Nuclear Society Autumn Meeting
Yongpyong, Korea, October, 2002

Characterization of U-10wt%Zr Alloy Powder and Dispersion Type (U-10wt%Zr)-Zr Fuels

Choon Ho Cho, Bong Sang Lee, Won Seok Park, Byoung Oon Lee

Korea Atomic Energy Research Institute
P.O. Box 105, Yuseong
Taejon, 305-600, Korea

Abstract

The characteristics of U-10wt%Zr alloy powder solidified rapidly by the centrifugal atomization process and dispersion-type (U-10wt%Zr)-xZr(x=50,55,60wt%) fuels have been examined. The results indicate that most of atomized U-10wt%Zr alloy powders have a smooth surface and frequently near-perfect spherical shape with few attached satellites. All phases of atomized powder are found to be α-U phases and δ-UZr_2 with fine and homogeneous structure, and as powder size decreases, these phases are much finer owing to high cooling rate. The atomized powder was cold pressed, and then hot extruded to rod at 1073K. During the extrusion, U-10wt%Zr particles are dispersed in Zr matrix by mechanical work, and they are broken and torn into harder Zr matrix.

I. INTRODUCTION

Renewed interest in dispersion metallic fuel for ADS(Accelerator Driven System) has arisen in the USA and Korea. Either TRU-Zr metal alloy or (TRU-10wt.%Zr)-Zr dispersion fuel is considered as a blanket fuel for HYPER(Hybrid Powder Extraction Reactor). In case of dispersion fuel, the particles of TRU-10wt.%Zr metal alloy are dispersed in Zr matrix. Blanket rod is made of sealed tubing containing actinide fuel slug in columns. The blanket-fuel cladding material is ferritic-martensitic steel HT9.

Two computer codes, MACSIS-H for the alloy type fuel and DIMAC for the dispersion type fuel, have been being developed for the fuel design. In order to increase the accuracy of the simulated results, material properties and fuel performance data are required. Although there are lots of experimental data on the metallic fuel of U-Pu-Zr and U-Zr, they are for the fuel types having Zr fraction less than 20wt%. Therefore, few data are available for the HYPER system fuel in which Zr fraction is higher than 30wt%. The basic material properties of Uranium were assumed to be very similar to those of TRU. A simulated fuel using Uranium instead of TRU was fabricated and tested to produce the required basic material data for the HYPER system fuel design.

In this work, as a basic study to fabricate dispersion-type (U-Zr)-Zr fuel, we investigated characteristics of rapidly solidified U-10wt%Zr powders obtained by rotating disk centrifugal atomization and (U-10wt%Zr)-Zr fuels.

2. Experimental procedure

A proportioned charge of depleted uranium lumps with purity 99.9% and zirconium buttons with purity 99.9% was induction-melted in a graphite crucible coated with a high-temperature-resistant ceramic. The molten metal was fed through an orifice onto a rotating graphite disk in an argon atmosphere. In order to obtain the desired size distribution and shape, the atomization parameters, such as feeding rate of melt, revolution speed of disk, etc., were adjusted[1,2]. The atomized powder was collected in a container at the bottom of the funnel shaped chamber.

Powder size distribution of the atomized powder was classified by sieve analysis. The density of powder according to particle size was measured by Archimedean immersion method. The morphology and microstructure of the powder according to atomized particle size were characterized with a SEM (scanning electron microscope). The alloy phases of as-atomized powder were analyzed by X-ray diffraction, using the Cu Kα wave length.

The atomized powder was cold pressed to about 80% of theoretical density, and then hot extruded to 8-mm-diameter rod at 1073K. The microstructure of (U-10wt%Zr)-xZr(x=50,55,60wt%) fuels were also investigated.

3. Result and discussion

The shape of the atomized U-Zr alloy particles as observed by scanning electron microscope is shown in figure 1. Most of the particles have a smooth surface (fig. 1(d)) and generally near-perfect spherical shape with few attached satellites. On the other hand the fine particles(below 45㎛) produced have a few flake-like morphologies. The action of surface tension force is thought to be the reason why atomized particles have a spherical shape[3,4]. These results correspond with the experimental results by Kato et al. who illustrated the effect of disk materials on the shape of atomized Ni-base superalloy powder[2]. Kato's results showed that atomized particles prepared by a graphite disk with higher thermal conductivity had near-perfect spherical shape, but those prepared by a carbon steel disk and an asbestos disk with lower thermal conductivity had an irregular shape. Because the heat of the melt on the rotating disk is easily removed through graphite with higher thermal conductivity, a frozen layer with a serrated shape is formed in graphite disk edge. Under these circumstances the droplets that are directly separated from frozen layer edge have the shape of a sphere before its material begins to solidify. The spherical particle then completely solidifies and its collision with an atomization chamber wall does not alter its shape. Hence, the particles would have a tendency to form spherical shape under the action of surface tension force, when the disintegrated droplets maintain a liquid state for the time required for the formation of spherical particles.

Fig. 2 shows the size distribution of atomized U-10wt%Zr alloy powder in terms of number fractions. Size distribution could be influenced by diameters of the rotating disk, revolution rates, and pouring rates of molten alloy during the centrifugal atomization process. It appears that the particle size distribution displays a bimodal distribution with the main and secondary particles. The secondary particles constitute a small portion of all atomized particles relative to the main particles. Champagne et al assumed that the bimodal particle size distribution was originated from the direct drop formation mode, which occurred at a relatively small rate of melt feed in the rotating electrode process of iron, steel, copper, aluminum and zinc [5].

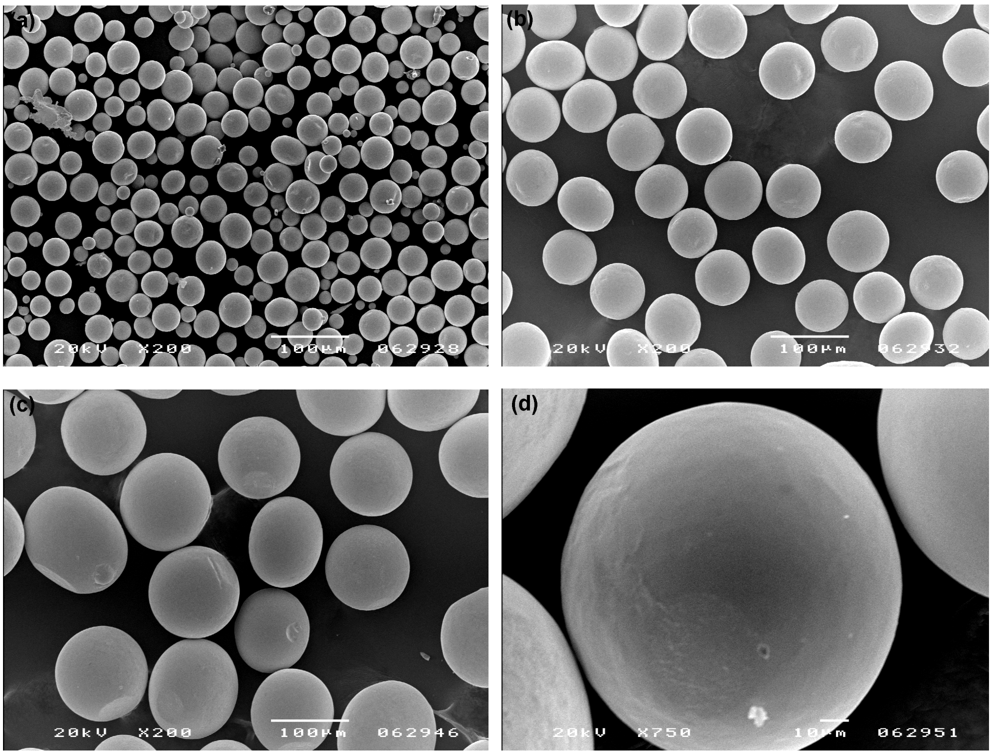


Fig. 1. Photographs showing the shape of atomized U-Mo alloy powder : (a) -325 Mesh, (b) 230-270 Mesh, (c) 140-170 Mesh, (d) the surface of atomized alloy powder.

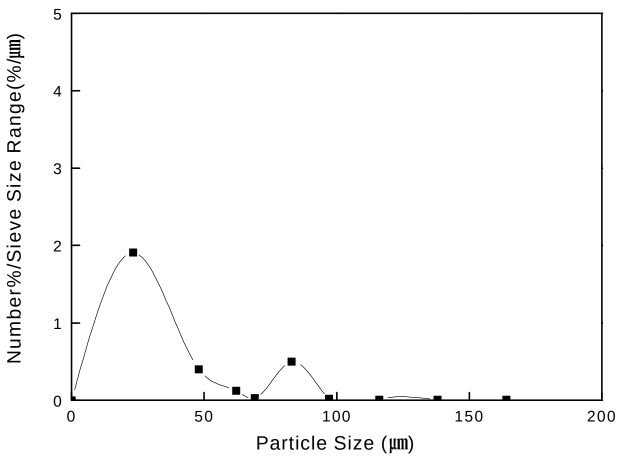


Fig. 2. The size distribution of atomized U-10wt%Zr alloy powder.

Fig. 3 shows the particle density versus particle size. The average densities of U-10wt.%Zr alloy powder are about 15.48g/cm^3. The density of atomized U-Zr powder decreases slightly as the particle size increases. This is due to the increased frequency of internal pores, shown in fig. 4. Scanning electron microscopy reveals that a few of the centrifugal atomization particles contain large spherical pores in their centers, created during the liquid drop formation. The volume fraction of internal

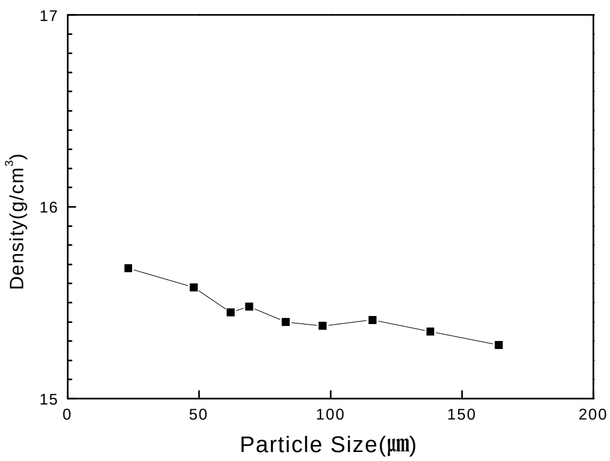


Fig. 3. Variation of density according to particle size in the atomized U-Zr alloy powder.

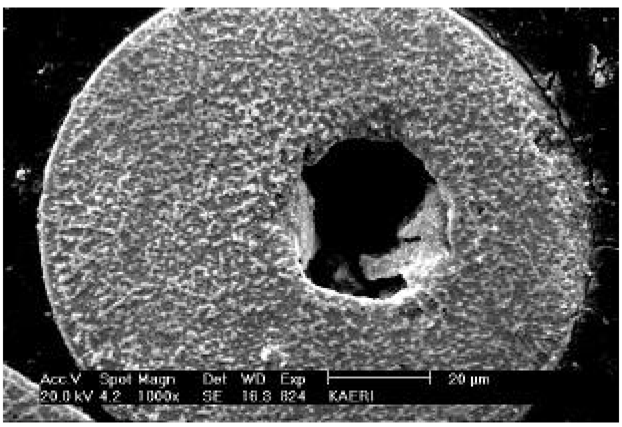


Fig. 4. Photograph showing the pore of atomized U-Zr alloy powder.

pores is thought to increase with powder size, because the larger droplets have a greater tendency to trap cooling gas while separating from the disk[6].

The cross-sectional micrographs of atomized U-10wt.%Zr alloy particles, with the EDX analysis results, are illustrated in fig. 5. It is seen that the microstructure of atomized particles is polycrystalline, with many non-dendritic grains. The grain size becomes smaller as the particle size becomes finer. This suggests a more-rapid cooling of finer powder owing to the increase of the specific surface area. Because the cooling rate in finer drop is higher, the time available for solidification is decreased and the tendency to form finer microcrystallines is enhanced. The X-ray diffraction patterns of atomized U-10wt.%Zr alloy powder are shown in fig. 6. The result indicates that atomized alloy powders consist of α-U phases and δ-UZr_2.

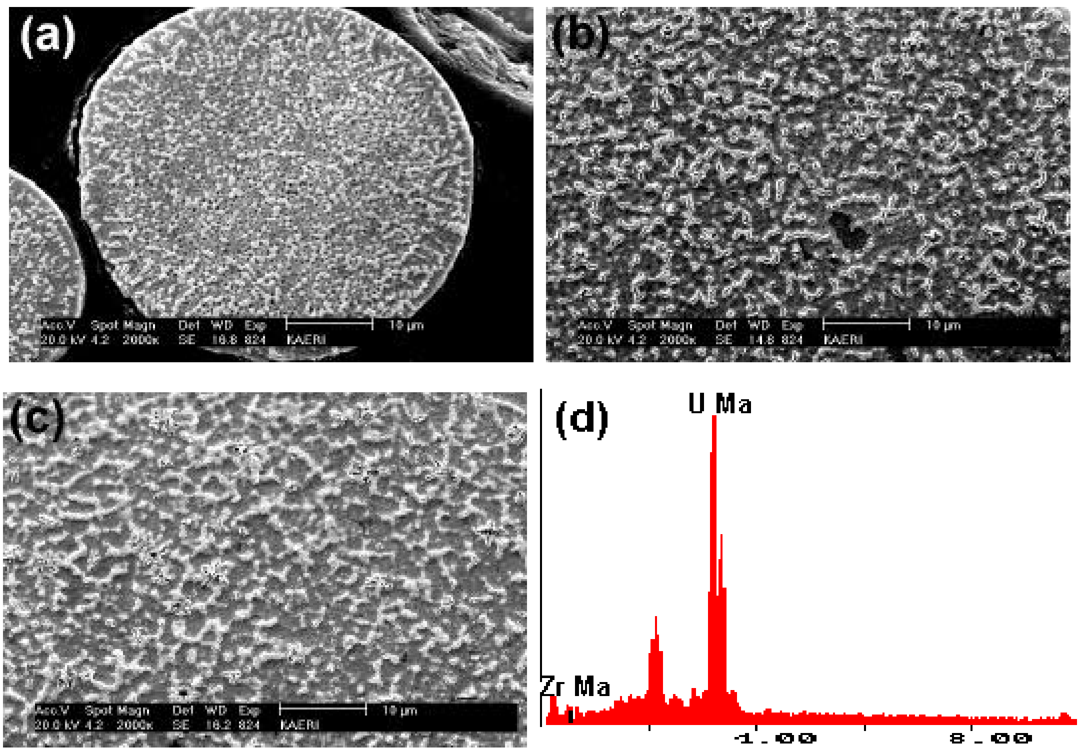


Fig. 5. Photographs of atomized U-10wt.%Zr powder(a,b,c) and energy dispersive spectra from its matrix(d). (a) -325 Mesh, (b) 230-270 Mesh, (c)

140 - 170 Mesh.

Fig. 7 shows scanning electron micrographs of the (U - 10wt%Zr) - xZr(x=50,55,60wt%) fuels extruded at 1073K, with an extrusion ratio of 16:1. During the extrusion, U - 10wt%Zr powders are dispersed in Zr matrix by mechanical work, and they are broken and torn into harder Zr matrix. Fig. 7(d) shows that dispersion - type (U - 10wt%Zr) - Zr fuels consist of Zr matrix of black regions and α - U phases and δ - UZr_2 of white region.

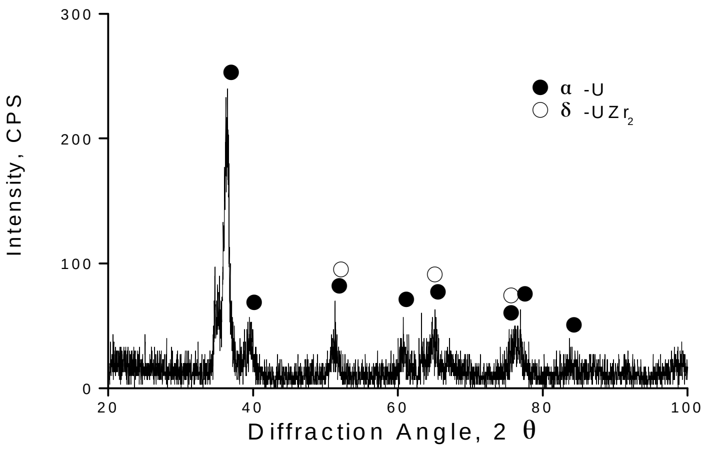
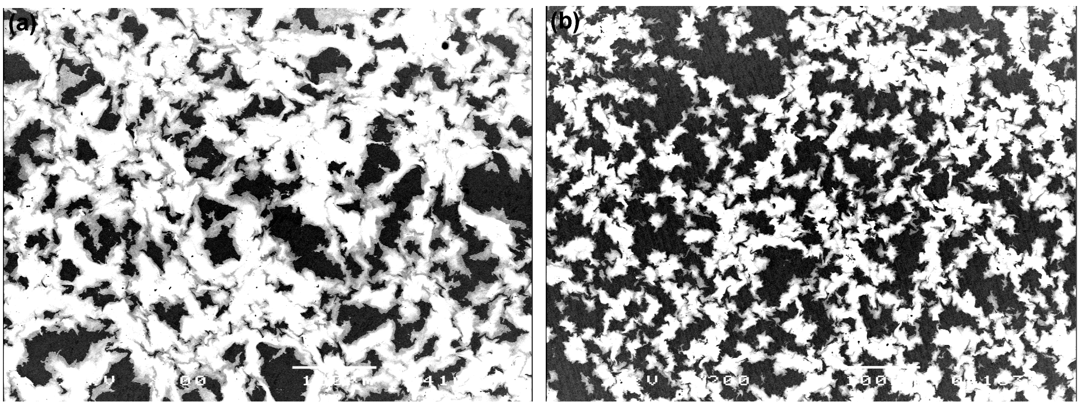


Fig. 6. X - ray diffraction patterns of atomized U - Zr powders.



, 6 (1985)
719.

[3] L. K. Druzhinin, B. V. Safronov, Metal Powder Report, 38 (1983) 447.

[4] B. Champagne and R. Angers, Powder Metallurgy International, 16 (1984) 125.

[5] B. Champagne and R. Angers, Modern Developments in Powder Metallurgy, 12 (1980) 83.
[6] W. J. Boettinger, S. R. Coriell, and R. F. Sekera, Mat. Sci. & Eng., 65 (1984) 27.