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Microstructure and Thermal Stability on Dispersion Type (U-10wt%Zr)-xZr(x=50,55,60wt%) Fuels

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Abstract

The characteristics of dispersion type (U-10wt%Zr)-Zr fuels have been examined. In dispersion type fuels, most of the atomized U-10wt%Zr alloy powders have a smooth surface and frequently near-perfect spherical shape with a few attached satellites. All phases of U-10wt%Zr powder are found to be α-U phases and δ-UZr_2 with fine and homogeneous structure. During extrusion, the dispersed U-10wt.%Zr particles were broken due to the harder Zr matrix. After heat treatment at 903K, (U-10wt%Zr)-xZr(x=50,55,60wt%) fuels have a good thermal stability with little change in the volume and density owing to a good phase stability of Zr matrix.

Ⅰ. INTRODUCTION

Either dispersion type (TRU-10wt.%Zr)-Zr fuel or alloy type TRU-Zr is considered as a blanket fuel for HYPER(Hybrid Power Extraction Reactor). In case of dispersion type fuel, the particles of TRU-10wt.%Zr alloy are dispersed in a Zr matrix. Blanket rod is made of sealed tubing containing fertile material in columns.

Computer code 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. But 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 (U-Zr)-Zr 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 paper, as a study on dispersion type (U-10wt%Zr)-Zr fuels, we fabricated dispersion type (U-10wt%Zr)-xZr(x=50,55,60wt%) fuels. Afterward, the characteristics of fuels were investigated.

2. Experimental procedure

A proportioned charge of depleted uranium lumps and zirconium sponges were induction-melted in a graphite crucible. The molten metal was fed through an orifice onto a rotating graphite disk in an argon atmosphere. The atomized U-10wt%Zr powder was collected in a container at the bottom of the funnel shaped chamber.

The morphology and microstructure of the powder according to atomized particle size was characterized with an 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 U-10wt%Zr powder and zirconium powder were mixed, cold pressed to about 80% of theoretical density, and then hot extruded to a cylinderical rod at 1123K. The hot extruded (U-10wt%Zr)-xZr(x=50,55,60 wt%) samples were annealed for 300, 600, 900, 1200 and 1500hrs at 903K. The microstructures, volume changes and density of fuels before and after annealing, were investigated.

3. Result and discussion

The shape of the atomized U-10wt%Zr alloy particles as observed by scanning electron microscope is shown in Fig. 1. Most of the particles have a smooth surface (Fig. 1(d)) and generally near-perfect spherical shape with a 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[1,2]. 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[3]. 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 on the edge of the graphite disk. Under these circumstances the droplets that are directly separated from the 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.

It is seen that Zr powders were fabricated by hydride-dehydride method in Fig. 2. The mean size of Zr powders is 57㎛, and the powders below 125㎛ were used during extrusion.

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 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[4].

The cross-sectional micrographs of atomized U-10wt.%Zr alloy particles 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 microcrystalline 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. 7 shows scanning electron micrographs of the (U-10wt%Zr)-xZr(x=50,55,60wt%) fuels extruded at 1123K, with an extrusion ratio of 16:1. During extrusion, the dispersed U-10wt.%Zr particles were broken due to the harder a Zr matrix. Fig. 8 shows that dispersion-type (U-10wt%Zr)-Zr fuels consist of a Zr matrix in black regions and α-U phases and δ-UZr_2 in white regions.

Fig. 9 shows the dependence of the swelling behavior on time and temperature of the three (U-10wt%Zr)-xZr(x=50,55,60wt%) samples. Specimens of 25 mm length were cut, vacuum-sealed in quartz tubes and annealed in a box furnace at 903K for up to 1500hrs. The volume of the dispersion samples has little change with respect to time. These results show that a Zr matrix containing the relatively low thermal expansion has a good thermal stability. Density variation with heat-treatment time also shows little change(Fig. 10).

4. Conclusion

1. U-10wt%Zr powders 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 the high cooling rate.
2. In dispersion type (U-10wt%Zr)-Zr fuels, U-10wt%Zr powders are dispersed in a Zr matrix by mechanical work during the extrusion, and they are broken and torn into a harder Zr matrix.
3. The volume and the density of the dispersion samples have little change with respect to time at 903K.

Reference

[1] T. Kato, K. Kusaka, A. Horata and J. Ichikawa, Tetsuto-to-Hagane, 6 (1985) 719.

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

[3] T. Kato, K. Kusaka, Materials Transactions, JIM. 31 (1990) 362.

[4] J. E. Flinn and G. R. Smolik, J. Mater. Sci. & Eng., A124 (1990) 39.

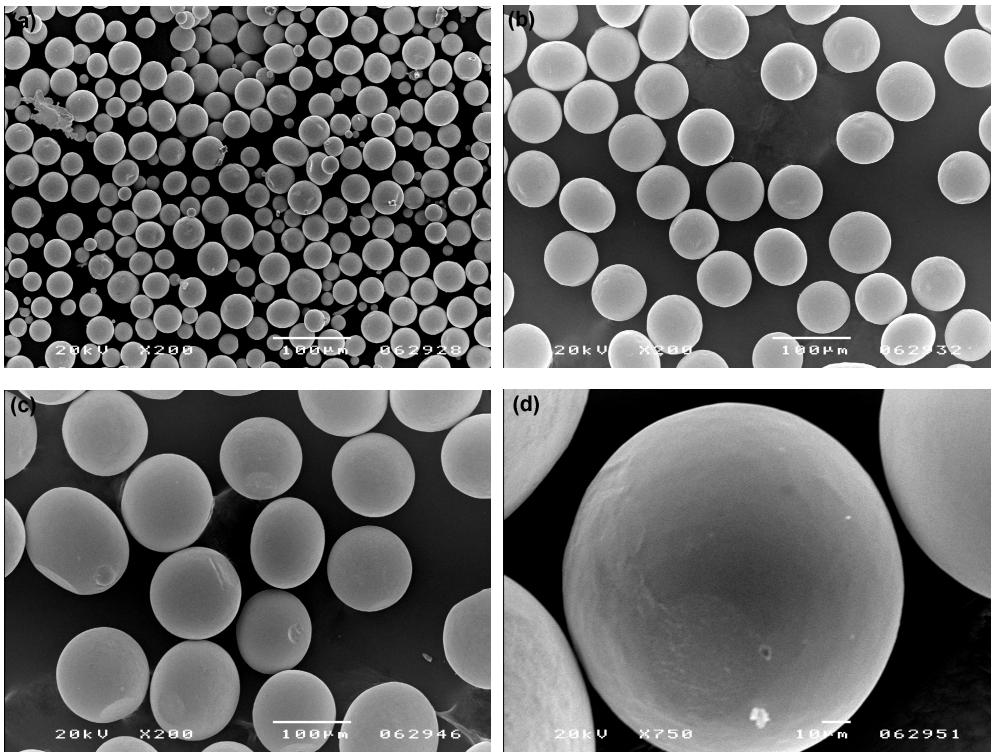

Fig. 1. Photographs showing the shape of atomized U-Zr alloy powder : (a) -325 Mesh, (b) 230-270 Mesh, (c) 140-170 Mesh, (d) the surface of atomized alloy powder.

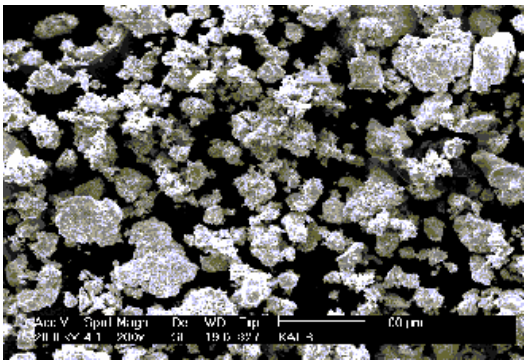

Fig. 2. Photograph of the Zr powders.

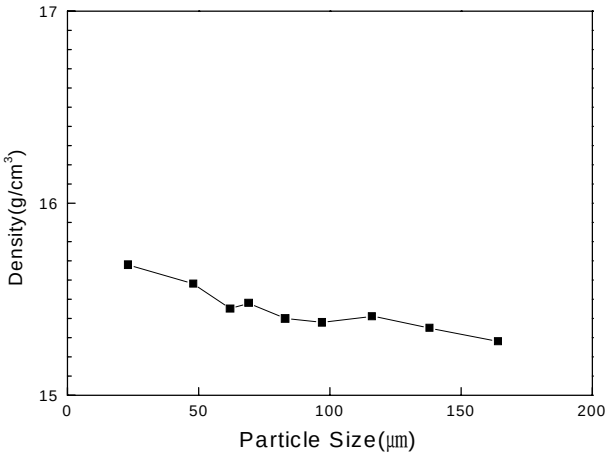

Fig. 3. Variation of density according to particle size in the atomized U-Zr alloy powder.

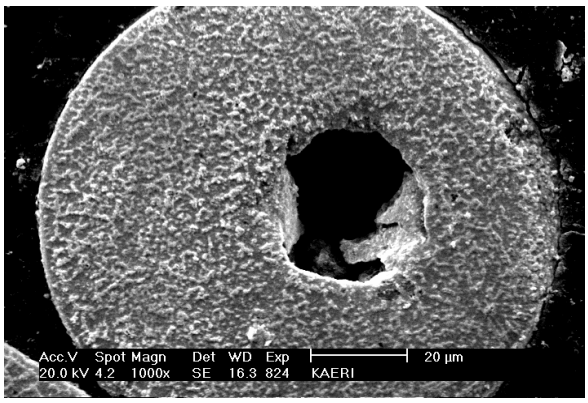

Fig. 4. Photograph showing the pore of atomized U-Zr alloy powder.

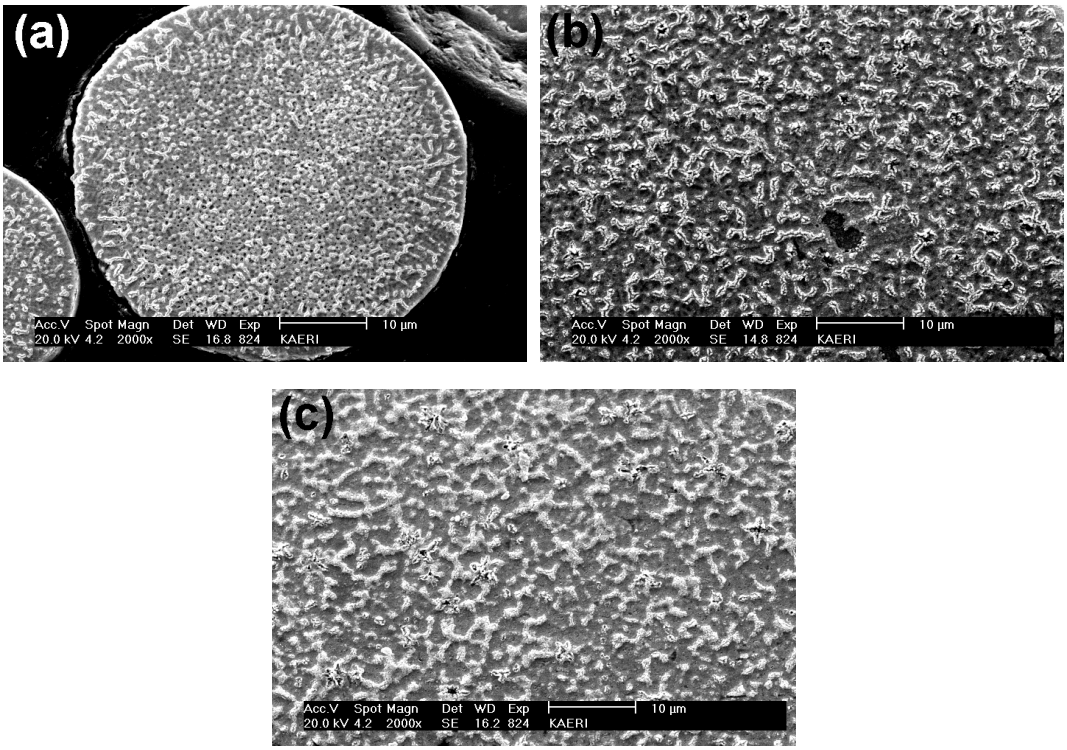

Fig. 5. Photographs of atomized U-10wt.%Zr. (a) -325 Mesh, (b) 230-270 Mesh, (c) 140-170 Mesh.

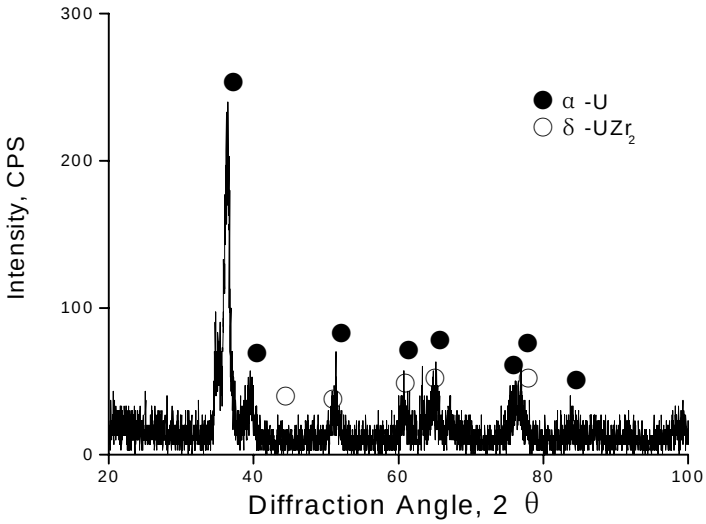

Fig. 6. X-ray diffraction patterns of atomized U-Zr powders.

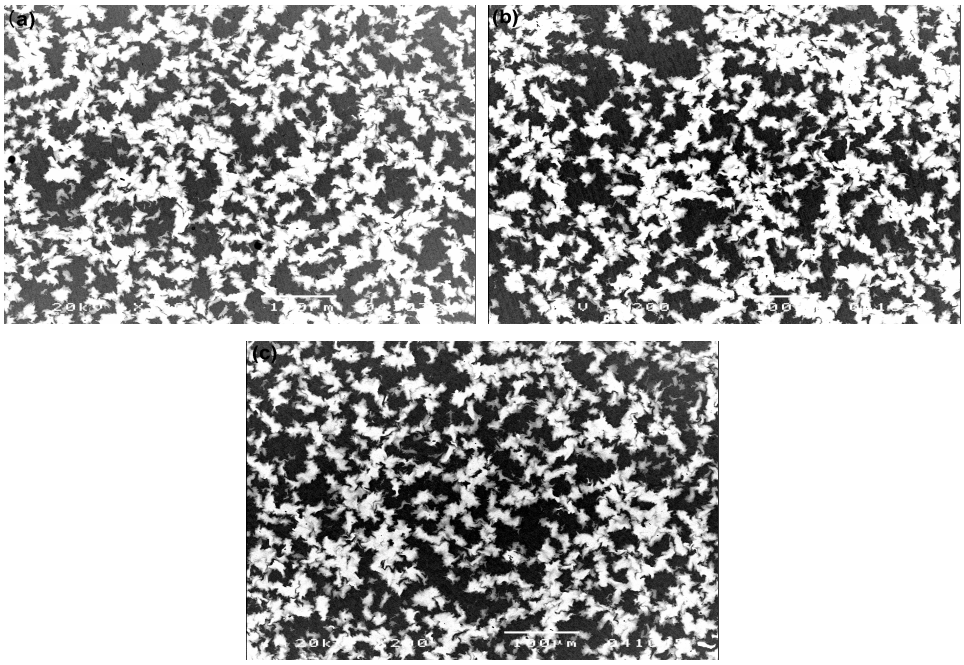

Fig. 7. Photographs of dispersion type (U-10wt%Zr)-xZr(x=50,55,60wt%) fuels : (a) (U-10wt%Zr)-50Zr, (b) (U-10wt%Zr)-55Zr, (c) (U-10wt%Zr)-60Zr (d) EDS line scanning of Zr matrix and U-10wt%Zr powder extrudate.

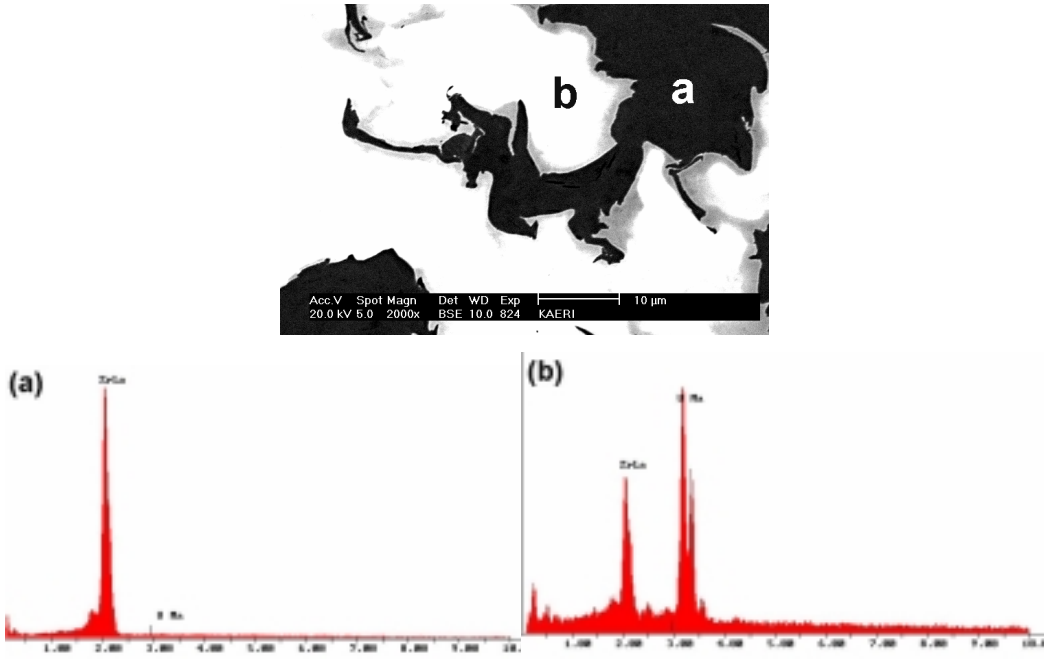

Fig. 8. SEM micrograph and EDS analysis results for dispersion type (U-10wt%Zr)-50wt%Zr fuel. (a) Zr matrix, (b) α-U and δ-UZr_2 in U-10wt%Zr powder particles.

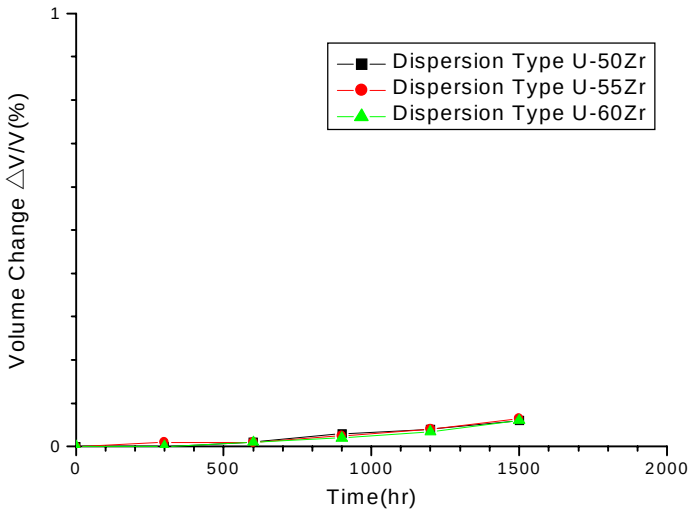

Fig. 9. Volume changes of the (U - 10wt%Zr) - xZr(x=50,55,60wt%) samples heat - treated at 903K.

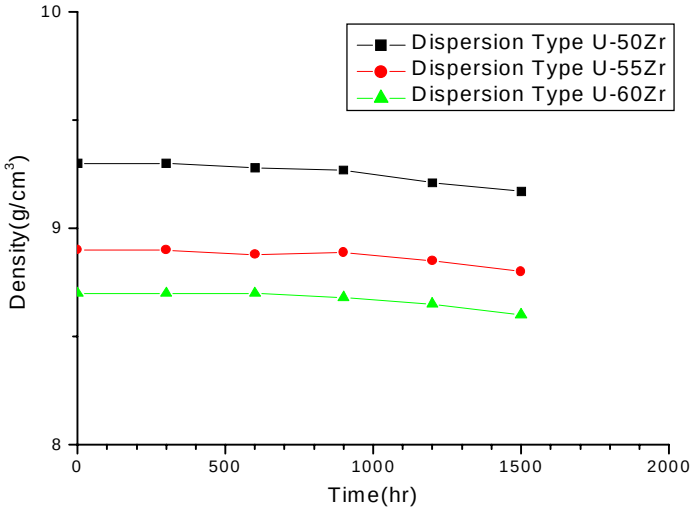

Fig. 10. Density changes of the (U - 10wt%Zr) - xZr(x=50,55,60wt%) samples heat - treated at 903K.