Sintering Behavior of Zr-U Pellets at High Temperatures

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1. Introduction

Zr-U alloys have been considered as one of candidate nuclear fuels for fast reactors due to their excellent thermal conductivity [1-3]. They have usually been fabricated by sintering process at high temperatures and in high-vacuum environments [4]. The sintering temperatures could act to determine the physical and mechanical properties of sintered Zr-U alloys. The sintering temperature should be regarded as one of very important parameters in the manufacturing processes of sintered Zr-U alloys. In this study, the effects of sintering temperature on the sintering behavior of Zr-U pellets were evaluated.

2. Methods and Results

2.1 Sintering of Zr-U pellets

The Zr and U powders were mixed and then compacted to form cylindrical-type pellets with 25 mm in diameter and 34.5 mm in height. The compacted Zr-U pellets were put in the crucible placed in the vacuum furnace for sintering. The sintering of pellets was performed in the temperature range from 1100 to 1500^{o}C under high-vacuum environment (Fig. 1).

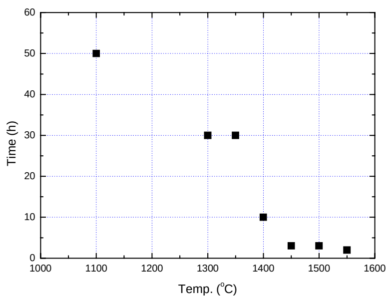
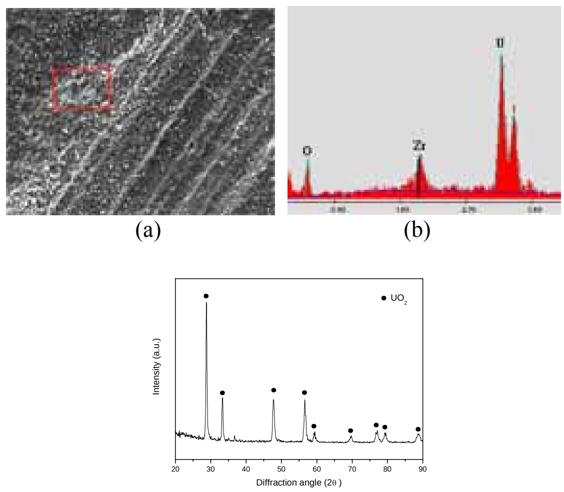


Figure 1. Sintering conditions of Zr-U green pellets.

The deposited products at the surface of crucible during sintering were examined using SEM/EDS. Their crystal structures were observed by a XRD. After sintering, the dimension and density of the sintered Zr-U alloy were examined. The alloys were subject to cut to their longitudinal directions, and the longitudinal sections were then polished. The microstructure was examined using a SEM.

2.2 Vaporization behavior of U during sintering

Figure 2 shows SEM/EDS results of film deposited at the surface of crucible during sintering at 1450^{o}C for 3 hours. The deposited film mainly consisted of U, O and Zr components (Fig. 2b), and their phases were analyzed to be a UO_2 (cubic, a=0.5466 nm) (Fig. 2c). This means that the metallic uranium would vapor at 1450^{o}C. During sintering, the vacuum should be done around 10^{-6} torr to avoid the oxidation of Zr-U pellets. Actually, the vapor phenomena of U during sintering were always apparent when the sintering temperatures over than 1300^{o}C were applied. The equilibrium vapor pressure of pure uranium is possible to know as well known formula; $\log P\,(atm) = -(26{,}210 \pm 270)/T + (5.902 \pm 0.135)$. Theoretical temperature and vacuum degree for the vapor of uranium during sintering could be possible to explain the vapor of uranium during sintering. However, little vaporization of uranium was observed if the sintering was performed at 1100^{o}C that was less than the melting point of pure uranium (1132^{o}C). It is thus concluded that the vaporization of uranium during sintering could be possible to avoid if the sintering temperatures as low as less 1100^{o}C are applied.



(a) (b)

(c)

Figure 2. SEM/EDS results of film deposited at the surface of crucible during sintering of Zr-U pellets at 1450^{o}C for 3 h; (a) surface appearance, (b) spectrum and (c) X-ray diffraction pattern of the deposited film.

2.3 Dimensions and density

Figure 3 shows the variation of dimension of sintered Zr-U alloy with sintering temperature. The dimensions of the alloys appeared to correlate with the sintering temperature, and the height and diameter decreased as the sintering temperature increased. From these results, it could be possible to control the dimensions of the alloys.

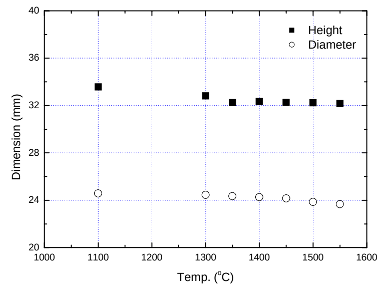


Figure 3. Variation of dimensions of sintered Zr-U alloys with sintering temperature.

Figure 4 shows the variation of density of sintered Zr-U alloys with sintering temperature. It was shown that the sintered density was mainly determined by the sintering temperature, and increased continuously in proportion to the sintering temperature.

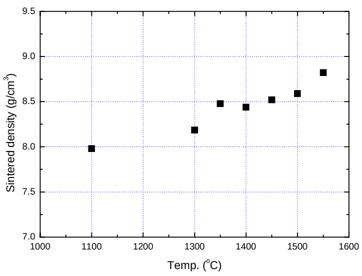


Figure 4. Variation of density of sintered Zr-U alloys with sintering temperature.

2.4 Microstructure

Figure 5 shows the microstructures of Zr-U alloys after sintering at various temperatures. The alloys consisted of a hcp δ-UZr_2 (white) and a hcp α-Zr (dark) phases which were confirmed by the X-ray diffraction patterns. The α phase forms first at the original β grain boundaries, followed by a decomposition of the β phase into δ and α phases during cooling [5]. It was possible to observe that the grain size increased as the sintering temperature increased. The area fraction of pore in the alloy after sintering at 1450°C for 3 h (Fig. 4c) was analyzed to be about 0.16%.

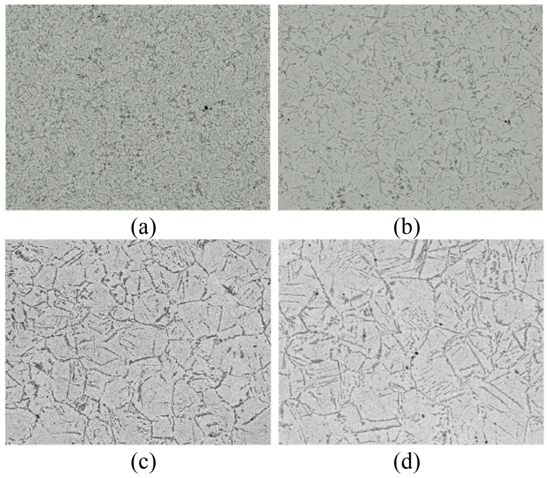


Figure 5. Microstructures of Zr-U alloys after sintering at (a) 1350°C for 30 h, (b) 1400°C for 10 h, (c) 1450°C for 3 h and (d) 1500°C for 3 h.

3. Conclusion

During sintering of Zr-U pellets, the vaporization phenomena of uranium appears to be inevitable if the sintering temperatures above 1300°C and vacuum degree about 10^{-6} torr are applied. However, the application of sintering temperatures as low as 1100°C would be possible to avoid undesirable vaporization phenomena of uranium during sintering. It is also observed that many physical properties of sintered Zr-U alloys (dimension, density, grain size and porosity) could be mainly controlled by the sintering temperatures.

Acknowledgements

The authors would like to express their appreciation to the Ministry of Science and Technology (MOST) of the KOREA for the support of this work.

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