Low temperature and rapid sintering of UO_2 fuel pellet by induction heating

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1. Introduction

Transuraniums(TRUs) containing advanced nuclear fuels are being studied in order to utilize spent fuels. Among these, ceramic fuels including oxide, nitride and carbide are expected as potential fuel materials to be adapted to fast reactors and the accelerator driven system. The fabrication of TRU containing fuel materials is a real challenge. TRU bearing fuel materials are highly radioactive and should be treated in a hot cell. So, the fabrication process should be compatible with hot-cell technology. Another difficulty is the volatile nature of TRU elements. Especially, Am has high vapor pressure and ease to evaporate at high temperature. It is important to decrease the overall processing time and temperature in order to prevent the loss of Am. In this study low temperature and rapid sintering behaviors of UO_2 pellet have been studied using a high frequency induction heating apparatus. The porous graphite housing has been used to prevent heat loss and to preheat the uranium oxides, simultaneously. The effects of high heating rate and low sintering temperature on the density and microstructure of the sintered pellets were investigated. A high frequency induction heat sintering system has been successfully demonstrated for the sintering of UO_2 pellet. Induction heating process is simple, clean, energy-efficient and compatible with hot-cell technology so that it can be a potential candidate process for the low temperature and rapid fabrication of radioactive nuclear fuel materials.

2. Experimental

The high frequency induction heating apparatus consists of a vacuum chamber and a high frequency current generator which can continuously change the power from 0 to 40 kW at a frequency of 60 kHz. A cylindrical insulation housing to prevent thermal loss was made of porous graphite. It simultaneously acts as a pre-heater. Al_2O_3 crucible was placed in the insulation housing. This assembly was mounted in the working coil containing vacuum chamber. Working samples are loaded into the Al_2O_3 crucible. The temperature of the working samples was measured by using a pyrometer.

The effect of the induction heating rate and sintering temperature on the densification of pellet was examined. The appearance, density and microstructure of rapidly heated UO_2 pellets were investigated. The sintering atmosphere was a mixture of hydrogen and argon. For comparison, a sintering was made for the same green pellets by a conventional electrical heating method. The density of the specimens was determined by the Archimedes method using water. The pore and grain structures of the longitudinally sectioned and polished pellets were observed with an optical microscope.

3. Results

Alumina crucible was filled up with a UO_2 green pellet. The sample temperature was increased by increasing the induction generator power with constant rate of 1.2kW/min. The target sintering temperatures were from 1300 to 1700℃ in 100K interval. Fig 1 shows the temperature curves of samples during the induction heat sintering. We can find that the samples were rapidly heated-up to the target temperatures.

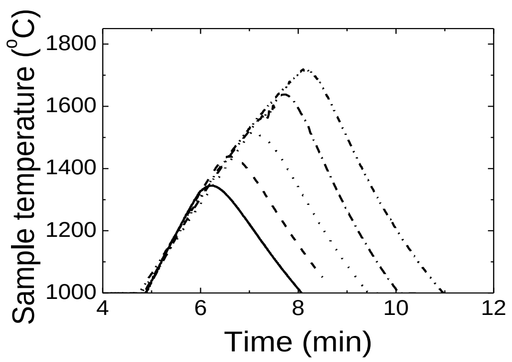

Fig. 1. Time-temperature graphs showing a temperature increase of UO_2 pellets

Fig. 2 shows the sintered pellet density according to the sintering temperature of induction heat sintered UO_2 pellets. For comparison, the densities of conventionally sintered pellets were also shown. When the sintering temperature was higher than 1500℃, the UO_2 pellet densities obtained by induction heat sintering and conventional sintering were compatible to each other. However, when the sintering temperature was decreased, the densities of induction heat sintered pellets were significantly higher than those of conventionally sintered pellets. The densities of conventionally sintered pellet decreased rapidly with decreasing the sintering temperature. Whereas, in induction heat sintering process, 93% TD pellet could be obtained at low temperature below 1400℃.

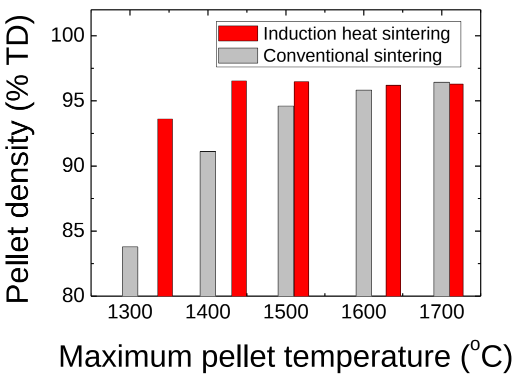

Fig. 2. Density of sintered UO_2 pellets as a function of the sintering temperature.

The effect of heating rate on the UO_2 pellet property in a high frequency induction heat sintering had been investigated. Fig. 3 shows the typical heating curves for selected sample pellets adapting different heating rates. The heating rate was controlled by applying a different constant power up rate of induction power. The measured heating rate was ranged from 50 to 400K/min. So, we can achieve very fast heating rate more than 400K/min by induction heating. Total process time ranged from 10min to 40min.

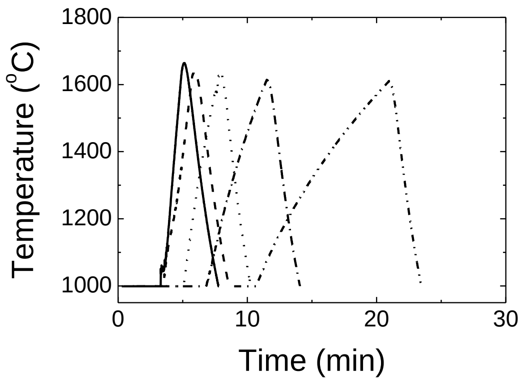

Fig. 3. Typical heating curves for selected sample pellets adapting different heating rates.

Fig. 4 shows the effects of sintering temperature and heating rate on the relative density of UO_2 pellets. The pellet density closely depends on the heating rate and heating temperature. The pellet density has a tendency to increase with increasing the heating rate. This increase is not usual in conventional sintering process. In conventional sintering process, the low heating rate resulted in high density pellets. At higher heating rate, some decrease in density was observed.

In principle, the density of pellet increased with increasing the sintering temperature. At low temperature, the measured pellet densities are broadly distributed. However, this density band width decreases with increasing the sintering temperature. The sintered pellet density is very sensitive to the heating rate, especially at low temperature. When we properly control the heating rate we can obtain a high density pellets even at low temperature below 1400℃ with in a few ten minutes.

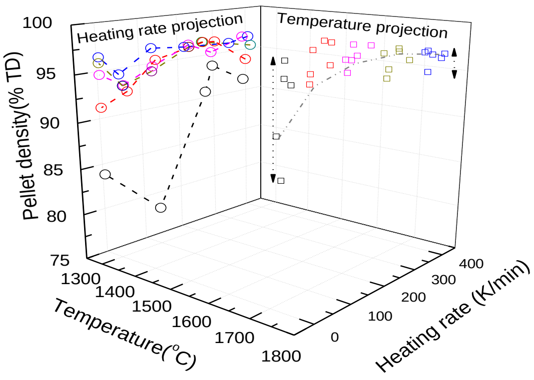

Fig. 4. Densities of sintered UO_2 pellets as a function of the heating rate and sintering temperature.

3. Conclusions

A high frequency induction heat sintering system has been successfully demonstrated for a low temperature and rapid sintering of UO_2 pellet. When the heating rate and sample dimension were properly controlled, UO_2 pellets with a density of more than 95% TD could be produced by sintering at 1450℃ within a few ten minutes.

Acknowledgements

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