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Application of High-frequency Induction Heating to Fabrication of Nuclear Fuel Materials

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1. Introduction

Transuraniums (TRUs) containing advanced nuclear fuels are being studied in order to utilize the spent fuels. Among these, ceramic fuels including oxide, nitride and carbide are expected as potential fuel materials adapted to fast reactors and the accelerator driven system (ADS).

The fabrication of TRU containing fuel materials is a real challenge because it is difficult to handle the highly radioactive TRUs by the traditional fuel fabrication process. Therefore it requires the development of new fabrication technologies.

In this paper, we propose sintering process of ceramic fuels by high-frequency induction heating. High frequency induction heating is known to be an energy efficient heating method [1, 2]. Moreover, it is expected that high frequency heating apparatus can be easily installed and maintained in the hot-cell.

The porous graphite housing was used as a pre-heater. The heat generation characteristics of several uranium oxide containing powders under a high frequency induction heating were measured and compared at an elevated temperature. The effects of high heating rate on the density and microstructure of sintered UO_2 pellet were investigated. The pellet densities and grain structures for sintered pellet have been compared with those of sintered pellets obtained using conventional electric furnace with similar heating conditions.

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 on the densification of pellet was examined. The appearance, density and microstructure of rapidly heated oxide 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 oxides powders. Then the temperature evolutions of the oxide powders during the induction heat processing were measured at an elevated temperature. Fig 1. shows the plots of the measured surface temperatures for Al_2O_3, ZrO_2, UO_2 and the empty crucible, respectively. It can be seen that the temperatures of oxide containing crucibles are about 100~150 ^{o}C higher than that of the empty crucible. Higher temperature of the oxide containing crucible reveals that the oxide powders spontaneously emit an additional heat under an induction heating in the measured temperature range. The cooperative heating effects between the graphite insulating housing and the oxide sample itself are expected to be helpful for a rapid densification of an oxide sample at the initial stage of a sintering.

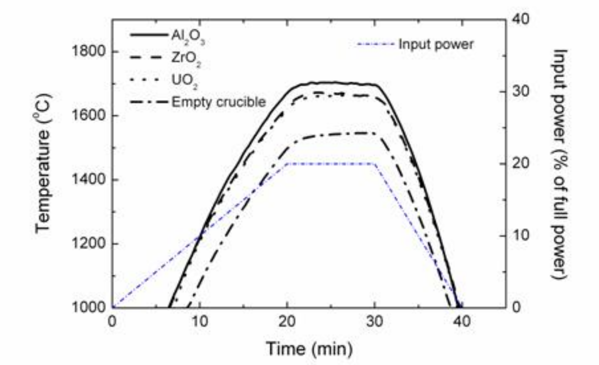

Fig. 1. Time-temperature graphs showing a temperature increase in the oxides powder containing alumina crucibles

Using the synergism of induction heating, the densification behaviors of UO_2 green pellets under different heating rates have been investigated. UO_2 green pellets were sintered by heating those to 1700 ^{o}C in H_2 and Ar mixture atmosphere with a different heating rate. Fig. 2 shows the density of the sintered UO_2 pellets obtained by adopting different heating rates. An increase in the pellet density was observed with an increasing heating rate. At a higher heating rate some decrease in the density was observed. The sintered pellet having relative density of more than 96% could be obtained by a high frequency induction heating with a heating rate from 120 and to 309 K/min.

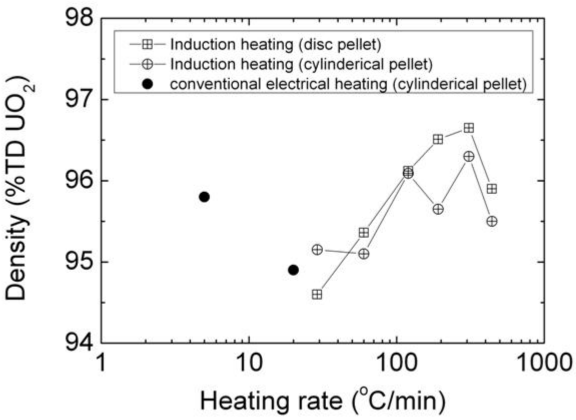

Fig. 2. Density of sintered UO_2 pellets as a function of the heating rate in the temperature range.

Fig. 3 shows the grain size of the sintered UO_2 pellets obtained by adopting different heating rates. The grain size evolution with a heating rate is similar to the density change with a heating rate. The grain size increases with an increasing heating rate. At a higher heating rate some decrease in the grain size was observed.

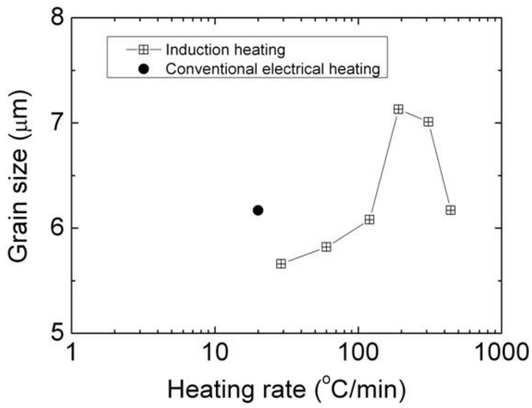

Fig. 3. Grain size of sintered UO_2 pellets as a function of the heating rate in the temperature range**.**

3. Conclusions

A high frequency induction heat sintering system has been successfully demonstrated for sintering of UO_2 ceramics that can possibly be extended to other oxide ceramics, too. High frequency current generator which operates at a frequency of 60 kHz and a graphite insulation housing were used for the sintering process. When the heating rate and sample dimension were properly controlled, UO_2 pellets with a density of more than 96% TD and an average grain size of ~6μm could be produced within a few minutes. The induction heat sintering process can be a potential candidate for the rapid fabrication of ceramics and composites. Moreover, this process can be applied to the fabrication of TRU containing radioactive nuclear fuel materials.

Acknowledgements

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REFERENCES

[1] S. Zinn, S.L. Semiatin, I.L. Harry, and R.D. Jeffress, "Elements of Induction Heating", pp.4-8, EPRI, California, 1988.
[2] W. Hermel, G. Leitner and R. Krumphold, "Review of induction sintering: fundamentals and applications", Powder metallurgy 23[3] 130-135 (1980).