Performance evaluation of HfO_2/xGnP composites for improved thermal conductivity of nuclear fuel

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1. Introduction

The commercial nuclear power industry is interested in advanced fuels and claddings that can produce higher power levels with a higher safety margin and be manufactured at low cost [1]. Requirements of advanced fuels are as follows: high thermal conductivity, chemical stability (low reactivity with water) and low manufacturing cost. Although UO_2 fuel is chemically stable, its thermal conductivity is low. In the nuclear engineering field, the thermal conductivity of fuels is a very important parameter for the optimum design and safety analysis of a nuclear system. This is because the thermal conductivity of fuels significantly affects the internal energy of the nuclear fuel by heat transfer through the coolant. Higher thermal conductivity of nuclear fuel means that the fuel would be able to operate at lower temperatures, which would limit fission gas release and reduce the stored energy thus improving its safety margin [1]. Therefore, the safety analysis using fuel thermal conductivity is necessary for the prediction of thermal-hydraulic behavior [2]. If xGnP is mixed in UO_2 fuel, it is chemically stable and its thermal conductivity will be enhanced. Advantages of xGnP are a high thermal conductivity and a low absorption cross section [3]. In present work, HfO_2 is selected as a substitute of UO_2 due to the similar density of HfO_2 and UO_2. HfO_2/xGnP composites were made by adding 10 vol. % of xGnP having a high thermal conductivity and the thermal conductivity of HfO_2/xGnP composites were measured by LFA 447 NanoFlash.

2. Experiment

2.1 Compacting and Sintering Process of HfO_2/xGnP Composites

The process of preparation of HfO_2/xGnP composites is as follows: (1) weigh the mass of xGnP nanoparticle with a digital electronic balance; (2) put xGnP nanoparticle into the weighed HfO_2 and prepare the HfO_2/xGnP composites; (3) mill and mix the HfO_2/xGnP composites to mix uniformly. 10 vol. % HfO_2/xGnP composites were prepared. These values are calculated by the following conversion formula and this conversion formula is used conventionally, as it is very difficult to measure the precise volume of nanoparticles.

$$\varphi = \frac{1}{(\frac{1-\varphi_m}{\varphi_m})\frac{\rho_p}{\rho_f}+1} \quad (1)$$

where, φ_m is the mass concentration of nanoparticles, ρ_p is the density of nanoparticle and ρ_f is the density of base fluid.

HfO_2/xGnP composites were applied pressure at 3 ton/cm^2 by the press (Fig. 1 (a)) and was sintered by the furnace (Fig. 1 (b)) through the following process:

1. five hours for heating
2. three hours for keeping temperature at 1300 or 1500 °C
3. five hours for cooling

(a)

(b)

Fig. 1. Press (a) and furnace (b) equipments

2.2 Thermal Conductivity Measurement of HfO_2/xGnP Composites

The thermal conductivity of HfO_2/xGnP composites was measured by LFA 447 NanoFlash. Laser Flash Analysis (LFA) method is that the front surface of a plan-parallel sample is heated by a short light or laser pulse, the temperature rise on the rear surface is measured versus time using an IR detector and the thermal conductivity is calculated by following equation in Fig. 2.

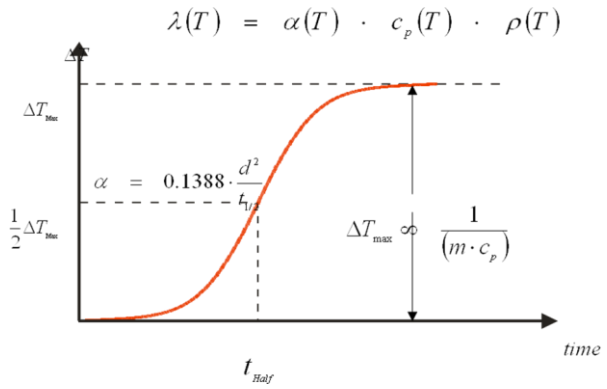

Fig. 2. The diagram explaining thermal conductivity calculation by LFA method.

3. Results and Discussion

HfO_2/xGnP composites were sintered by the furnace through five hours for heating, three hours for keeping temperature at 1300 or 1500 ˚C and five hours for cooling. Fig. 3 shows the thermal conductivity of pure HfO_2 and HfO_2/xGnP composites which are sintered at 1500 ˚C.

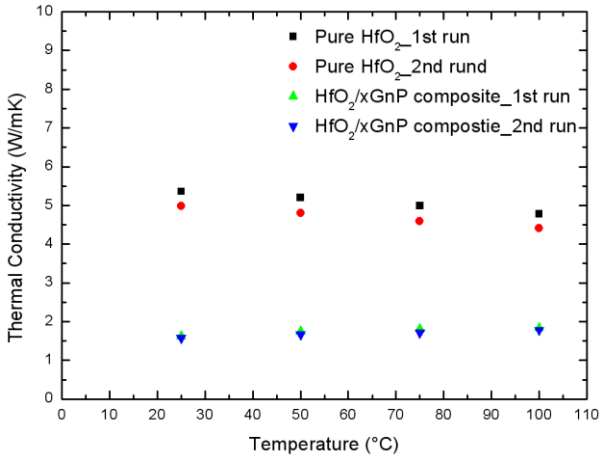

Fig. 3. Thermal conductivity of pure HfO_2 and HfO_2/xGnP composites which are sintered at 1500 ℃.

As shown in Fig.3, the thermal conductivity of pure HfO_2 is decreased and that of HfO_2/xGnP composites is increased according increasing of temperature.

Fig. 4 shows the thermal conductivity of pure HfO_2 and HfO_2/xGnP composites which is sintered at 1300 ˚C. As shown in Fig.4, the thermal conductivity of pure HfO_2 is decreased and that of HfO_2/xGnP composites is increased according increasing of temperature. The lower thermal conductivity of 10 vol. % HfO_2/xGnP composites compared to that of pure HfO_2 is due to the porosity formed in HfO_2/xGnP composites.

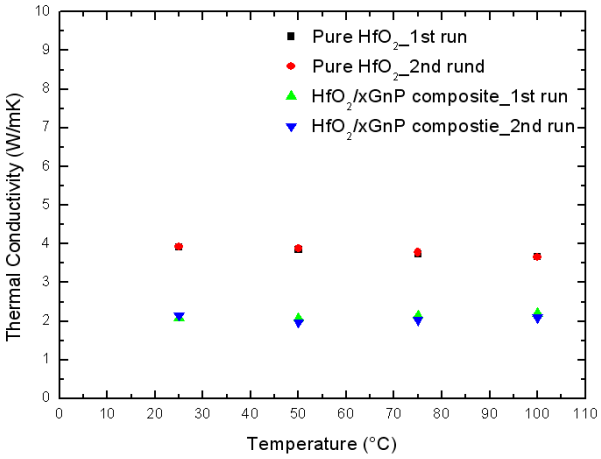

Fig. 4. Thermal conductivity of pure HfO_2 and HfO_2/xGnP composites which are sintered at 1300 ℃.

4. Conclusions

The present works were conducted to investigate performance evaluation of HfO_2/xGnP composites for improved thermal conductivity of nuclear fuel. HfO_2/xGnP composites were made by adding 10 vol. % of xGnP having a high thermal conductivity and the thermal conductivity of HfO_2/xGnP composites were measured by LFA 447 NanoFlash.

The following results are obtained.

(1) The thermal conductivity of pure HfO_2 is decreased and that of HfO_2/xGnP composites which are sintered at 1300 and 1500 ℃ is increased according increasing of temperature.

(2) The lower thermal conductivity of 10 vol. % HfO_2/xGnP composites compared to that of pure HfO_2 is due to the porosity formed in HfO_2/xGnP composites.

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