Effect of fabrication conditions on a density & reactivity of NdYO₃ powder as a reaction preventing

raw material for metal fuel casting

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1. Introduction

Fast reactor in nuclear systems is an important attractive energy source [1,2]. Metallic fuel of U-Zr system for the fast reactor has been developed with the pyro-processing of spent fuel [3,4]. Metal fuel is manufactured using an injection casting and uses an induction heating process for the melting due to various advantages. [5,6]. The problem of loss of nuclear material due to the high reactivity of metal fuel and melting crucible in the metal fuel casting process must be solved for loss control and waste reduction. To this end, it is necessary to optimize the process for reducing the reaction loss and secure a crucible manufacturing technology capable of controlling the reaction loss. In particular, it is necessary to develop a new coating material that can minimize high reactivity in order to develop new material casting parts capable of reducing reaction loss.

In this study, fabrication test was conducted to develop a new material NdYO₃ to improve the degree of anti-reactivity of the crucible. For the powder composition, five conditions of Nd₂O₃ and Y₂O₃ molar ratio standards (60:40, 50:50, 45:55, 40:60, 30:70) were selected to investigate the formation behavior and phase transformations in NdYO₃. The correlation between phase and pore rates were also considered.

2. Methods and Results

Figure 1 shows the phase diagram according to the molar composition ratio of Y_2O_3 in the Nd_2O_3 - Y_2O_3 system [7]. Based on the sintering temperature of 1550°C used in this study, the predicted phases of each sample were monoclinic for NdY1, monoclinic+cubic for NdY2, NdY3, and NdY4, and cubic for NdY5. In general, in a metal fuel manufacturing process with a U-10Zr composition, the metal of the U-Zr composition is heated to 1600°C and melted, and then manufactured through a casting process. When comparing the composition and phase diagram of the materials used in this study, all samples are considered to be able to maintain a uniform phase under processing conditions.



Fig.1 Phase diagram of Nd2O3-Y2O3 system from Shuigen Huang et al.[7].

Table 1 shows the density and porosity of each sample. Comparing the density change of each sample, it can be seen that the density increases as the mole fraction of Nd2O3 increases regardless of the phase change due to the atomic mass of Nd that is relatively higher than that of Y.

TABLE 1. Density & porosity of the samples.

Specimen	NdY1	NdY2	NdY3	NdY4	NdY5	
Compact ρ (g/cm ³)	6.48	6.27	6.09	5.82	5.25	
Apparent ρ (g/cm ³)	6.36	5.99	5.89	5.74	5.07	
Pore (%)	1.77	4.36	3.27	1.46	3.43	

In order to confirm these expected results, XRD pattern analysis was performed on the prepared samples.(Fig.2) For pattern analysis, refer to 41-1105 for Nd₂O₃ having a monoclinic structure and 28-671 for Y₂O₃ having a cubic structure in the JCPDS card. In the case of NdY1, which was expected to have a monoclinic phase, it was shown that it had a typical monoclinic phase through the 310 peak (501), 420 peak (013), and 47° peak (702). In the case of NdY1, but it was

analyzed that the intensity of the 47° peak (440) in the simple cubic became stronger and the monoclinic and cubic phases began to coexist. When analyzing the XRD pattern of NdY4, the peak of the cubic phase appears much more clearly than that of NdY2 and NdY3, and peak (501) is observed in 30°-32° region, confirming that the cubic phase and monoclinic phase are still mixed. Finally, NdY5 was analyzed to have a typical cubic phase. The XRD analysis results were found to be in good agreement with the previously reported results of the phase diagram, and it was confirmed that the cubic crystal structure gradually changed as Y_2O_3 was added.



Fig. 2 X-ray diffraction patterns of the samples

The density and porosity changes according to the Nd₂O₃ content are shown in Figure 4. In the section where the Nd₂O₃ content is low (30 mol%), it shows the relatively lowest density and high porosity. Looking at the SEM picture (NdY5), it is thought that high porosity appears inside because the sintering is not completed completely after the powders are mixed. This will be supplemented through additional experiments in the future. In the section where the cubic and monoclinic phases were mixed (40-50 mol% Nd₂O₃), the density and porosity increased linearly as the content of Nd₂O₃ increased, which was due to the continuous inflow of Nd₂O₃ (Monoclinic) into Y₂O₃ (Cubic). It is thought to be a phenomenon in which the crystal structure difference between the cubic phase and the monoclinic phase gradually changes. However, when the content of Nd2O3 is further increased and goes to the monoclinic single phase section, the porosity decreases and it can be confirmed that it changes to a dense monoclinic single phase. When examining the characteristics of each sample, from the viewpoint of porosity, NdY4 may be advantageous, but the condition of NdY1, which shows a stable low porosity in the complete monoclinic single phase region, is considered to be the most advantageous in terms of stability and porosity.



Fig. 4. Summary of the density & porosity of NdYO3 with increasing Nd2O3 contents.

3. Conclusions

In this study, fabrication test was conducted to develop a new material NdYO₃ to improve the degree of antireactivity of the crucible. Cubic crystal structure gradually changed as Y_2O_3 was added. The density and porosity increased linearly as the content of Nd₂O₃ increased, which was due to the continuous inflow of Nd₂O₃ (Monoclinic) into Y_2O_3 (Cubic). NdY1 (60 mol% Nd2O3 - 40 mol% Y_2O_3) seems to be the most advantageous material in terms of stability and porosity.

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REFERENCES

- [1] T. Abram, S. Ion, Energy Policy 36, 4323–4330 (2008).
- [2] Generation IV International Forum, A Technology
- Roadmap for Generation IV Nuclear Energy Systems, 2002.
- [3] H. Lee, G.I. Park, E.H. Kim, Nucl. Eng. Technol. 43, (317–328) 2011.
- [4] J.I. Jang, Nucl. Eng. Technol. 43, 161-170 (2007).

[5] G. Ledergerber, F. Ingold, R.W. Stratton et al., Nucl. Tech. 114, 194–203 (1996).

[6] G. Bart, F.B. Botta, C.W. Hoth, G. Ledergerber, R.E. Mason, and R.W. Stratton, J. Nucl. Mater. 376, 47–59 (2008).
[7] S. Huang, O. V. Biest, and J. Vleugelsw, J. Am. Ceram. Soc., 89, 2596–2601 (2006)