

Fabrication of Large-Scale UO_2 Blocks via Slip Casting to Improve Interim Storage Efficiency

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1. Introduction

The continuous accumulation of spent nuclear fuel has increased the demand for efficient interim storage technologies, particularly as existing storage facilities approach their capacity limits [1]. Various approaches, including rod consolidation, oxidation–reduction processes, and reprocessing technologies, have been investigated to reduce the volume of spent nuclear fuel or facilitate resource recovery [2]. However, these approaches generally require complicated processing steps and are not readily applicable to near-term improvements in storage efficiency. Therefore, a practical approach for converting spent nuclear fuel into a more compact form is required to improve storage efficiency. One potential approach is to convert spent nuclear fuel into a compact oxide form. High-temperature treatment can convert spent nuclear fuel into oxide powder by removing volatile components. The resulting oxide powder can then be consolidated into a compact form for storage. Conventional powder-compaction processes, such as pelletization, however, require high external pressures and are generally limited to relatively small geometries [3]. These limitations make conventional pelletization unsuitable for the fabrication of large-scale monolithic structures. Therefore, a forming process capable of producing large oxide structures without high compaction pressure is required. Slip casting is a pressureless forming technique in which a concentrated ceramic slurry is introduced into a porous mold. Liquid is removed from the slurry through capillary forces generated by the porous mold, resulting in particle consolidation and the formation of a shaped green body. Because slip casting does not require high mechanical compaction pressure, it can be used to fabricate relatively large ceramic structures and provides a potential alternative to conventional pelletization.

In this study, a slip-casting process was investigated for the fabrication of large-scale uranium dioxide (UO_2) blocks using cerium dioxide (CeO_2) as a surrogate material. The fabricated blocks were evaluated in terms of their microstructure, relative density, and compressive strength to assess the feasibility of the proposed process.

2. Methods and Results

2.1. Materials

Depleted uranium dioxide was used as the UO_2 oxide material. CeO_2 powder (96% purity, REO, Stock No. 40581, Alfa Aesar, USA) was employed as a non-radioactive surrogate for spent nuclear fuel UO_2 . Deionized (DI) water was supplied from Direct-Q® 3 water purification system with resistivity of 18.2 M Ω cm at 25 °C. Argon gas (99.999%) was obtained from Sejong Industrial Gases Co., Ltd.

2.2. Fabrication of Large-scale Oxide Blocks

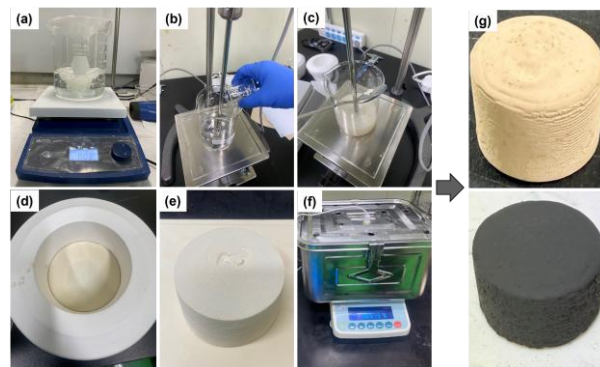


Fig. 1. Fabrication procedure for large-scale oxide blocks via the slip-casting process: (a) preparation of the CMC binder solution, (b) mixing the binder solution with deionized water, (c) preparation of the concentrated oxide slurry, (d) pouring the slurry into a porous plaster mold, (e) demolding of the green body, (f) controlled drying under humid conditions, and (g) the final oxide block obtained after heat treatment.

The fabrication procedure for the large-scale oxide blocks is illustrated in Fig. 1. A 1 wt% CMC binder solution was first prepared and maintained at 80 °C overnight to obtain a homogeneous solution (Fig. 1a). The prepared binder solution was then mixed with deionized water at a volume ratio of 10:90 (binder solution) (Fig. 1b). The oxide powder was subsequently added to the mixture until a highly concentrated and viscous slurry was obtained (Fig. 1c). The prepared slurry was poured into a porous plaster mold (Fig. 1d) and dried for 2 h. The resulting green body was then removed from the mold (Fig. 1e). To minimize cracking

caused by rapid moisture removal, the demolded green body was subjected to controlled drying under humid conditions for 2 weeks (Fig. 1f). After drying, the green body was heat-treated in a furnace to obtain the final oxide block (Fig. 1g). For the heat treatment, the green body was heated from room temperature to 300 °C at a heating rate of 2 °C min⁻¹ and held at 300 °C for 2 h. The temperature was subsequently increased to 1600 °C at the same heating rate and held for 6 h. The heat treatment was performed under an Ar atmosphere with a flow rate of 50 mL min⁻¹.

2.3. Scanning Electron Microscopy Analysis

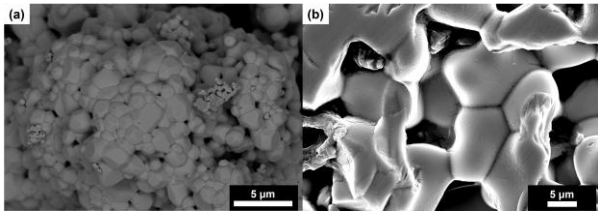


Fig. 2. SEM images of CeO₂ specimens: (a) before heat treatment (CeO₂ powder), and (b) after heat treatment at 1600 °C.

The microstructures of the CeO₂ blocks before and after heat treatment were examined using scanning electron microscopy (SEM, SU-8020, Hitachi) at a landing energy of 15 kV. The SEM images are presented in Fig. 2. Before heat treatment, the CeO₂ particles exhibited relatively distinct interfaces (Fig. 2a). After heat treatment, the particles were consolidated and well-defined grain boundaries were observed (Fig. 2b), indicating the formation of interparticle bonding and microstructural consolidation during heat treatment.

2.4. Determination of Relative Density

The relative density of the fabricated blocks was determined using the Archimedes method. The apparent density of each specimen was obtained from its dry mass, saturated mass, and suspended mass in water, and the relative density was calculated by comparing the measured density with the theoretical density of the corresponding oxide. The specific gravity was additionally measured using an MDS-3000 specific gravity meter (Alfa Mirage). The relative densities obtained for DU and CeO₂ are summarized in Table 1. The DU block exhibited a relative density of 83%, whereas the CeO₂ block exhibited a relative density of 77%. Under the investigated fabrication and heat-treatment conditions, the DU block therefore showed a higher relative density than the CeO₂ block.

Table I: Densities of the fabricated UO₂ and CeO₂ blocks

	Specific gravity (g cm ⁻³)	Relative density (%)
UO ₂	9.09	83
CeO ₂	5.55	77

2.5. Compressive Strength Measurement

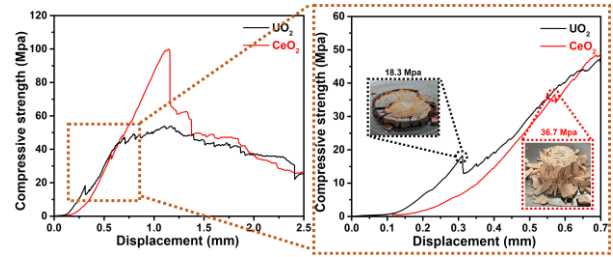


Fig. 3. Compressive strength of the UO₂ and CeO₂ blocks.

The compressive strength of the fabricated blocks was measured using a laboratory-scale compression testing apparatus. The compressive strength was determined from the maximum load applied to the specimen before failure divided by the initial cross-sectional area. The compressive strength results are presented in Fig. 3. The DU and CeO₂ blocks exhibited compressive strengths of 18.3 and 36.7 MPa, respectively. The CeO₂ block showed a higher compressive strength than the DU block, although its relative density was lower. This result indicates that the compressive strength was affected not only by the overall density but also by the microstructural characteristics of the fabricated blocks, including particle bonding and pore structure.

3. Conclusions

In this study, a slip-casting process was successfully demonstrated as a practical approach for fabricating large-scale oxide blocks without the need for high compaction pressure, aiming to improve the interim storage efficiency of spent nuclear fuel. Using UO₂ and CeO₂, followed by heat treatment at 1600 °C, the process achieved successful interparticle bonding and microstructural consolidation. The fabricated UO₂ and CeO₂ blocks reached relative densities of 83% and 77%, respectively. Interestingly, the CeO₂ block exhibited a higher compressive strength (36.7 MPa) than the UO₂ block (18.3 MPa), indicating that the mechanical strength of the blocks is heavily influenced by specific microstructural characteristics and pore structure rather than overall density alone. Ultimately, the proposed slip-casting process proves to be a promising alternative to conventional pelletization, overcoming size limitations to produce structurally stable, large-scale oxide blocks for spent nuclear fuel management.

REFERENCES

- [1] R. C. Ewing, Long-Term Storage of Spent Nuclear Fuel, *Nature Materials*, Vol.14, pp. 252-257, 2015.
- [2] M. S. Yang, et al., Characteristics of the DUPIC Fuel Fabrication Process, *Nuclear Engineering and Technology*, Vol.38, pp. 359-366, 2006.
- [3] T. R. G. Kutty, et al., Effect of Compaction Pressure on the Sintering Behaviour of Uranium Dioxide, *Journal of Nuclear Materials*, Vol.295, pp. 133-140, 2001.

