Evaluation of Measurement Uncertainty of Thermal Diffusivity of UO_2-Mo Micro-plate Pellets

Jae Ho Yang*, Dong Seok Kim, Dong-Joo Kim, Ji-Hae Yoon, Ji Hwan Lee, Yunsong Jung
KAERI, 111 Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, 34057, Korea
* Corresponding author: yangjh@kaeri.re.kr

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1. Introduction

At KAERI, the development of UO_2-Mo micro-plate composite pellets is underway as part of accident tolerant fuel research. In this design, thin Mo plates are aligned parallel to the heat transfer direction to enhance heat dissipation from center to the surroundings, as illustrated in Fig.1 [1].

Thermal conductivity is one of the most critical properties governing the performance of nuclear fuel. This paper identifies factors contributing to the uncertainty in thermal conductivity measurement. Additionally, we evaluate the measurement uncertainty of the thermal diffusivity for UO_2-Mo composite pellets.

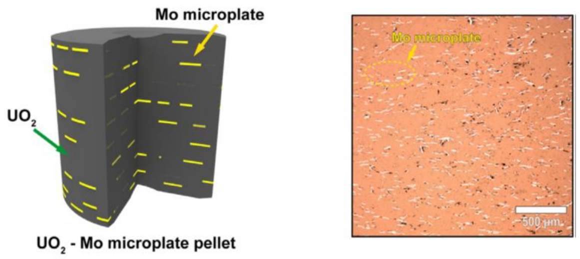

Fig. 1. Schematic UO_2-Mo micro-plate pellet (left) and cross-sectional optical microscope image(right).

2. Experimental

The uni-axially pressurized green body, composed of 3vol% Mo microplate particles and UO_2 powders, was sintered at 1730 °C for 4 h in H_2 atmosphere. The diameter of the Mo microplate was 70 ±18 μm and the thickness was about 3μm. The sintered pellet had high pellet densities pertaining to 97% of the theoretical density. The thermal diffusivity was measured using the laser flash method (Netzsch, LFA 427) [2].

3. Measurement Uncertainty Evaluation

3.1 Factors Contributing to the Uncertainty

Table 1 categorizes the factors influencing measurement uncertainty. Certified reference materials (CRM) are used to calibrate measuring equipment. In addition to uncertainty introduced by the equipment itself, the properties of the standard materials also contribute significantly to measurement uncertainty. The density of the sintered body varies slightly between batches. Due to incomplete mixing of UO_2 and Mo powders, the Mo content may differ locally. Additionally, not all Mo plates are perfectly aligned with the heat transfer direction; some may be oriented at different angles. As shown in Fig. 2, these variations in pellet properties impact thermal conductivity measurements. Consequently, when evaluating the thermal conductivity of sintered bodies through limited sampling, variations introduced by different sintering batches can contribute to increased measurement uncertainty.

Table I: Factors Contributing to the Uncertainty

Equipment	· Calibration (Uncertainty of CRM) · Environment · Uncertainty of Equipment
Skill	· Proficiency of operator · Test procedure
Sample	· Property variation · Appropriate sampling

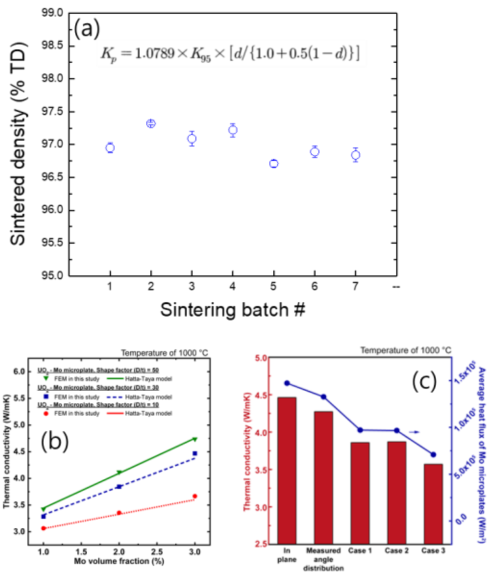

Fig. 2. (a) Density variation according to the Batch#, (b) Effect of Mo volume[1] (c) Effect of angular distribution of Mo[1].

3.2 Evaluation of Measurement Uncertainty of Thermal Diffusivity for UO_2-3vol% Mo Micro-plate Pellets

The LFA equipment was calibrated, and the measurement uncertainty was assessed using a graphite CRM (NMIJ CRM 5804-a No.60). For the thermal diffusivity measurement of UO_2-3vol% Mo pellets, sintered pellets were prepared from five different batches, with a specimen selected from each batch for measurement.

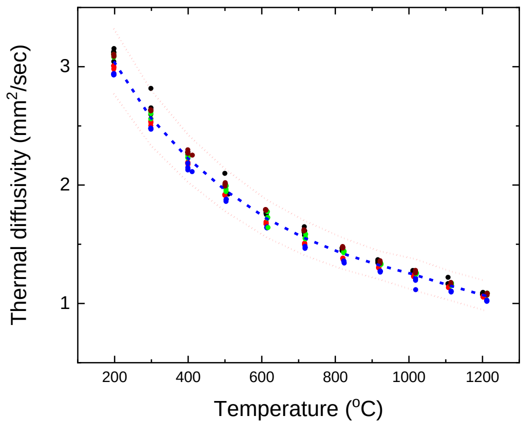

Fig. 3. Thermal diffusivity with an evaluated uncertainty range of UO_2-3vol% Mo micro-plate pellet.

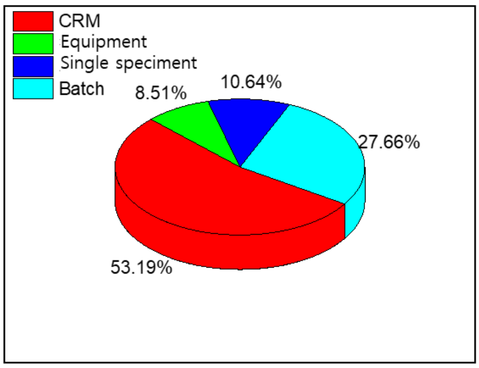

Fig. 4. Factors and their contribution to the range of measurement uncertainty.

At each measurement temperature, five repeated measurements were performed. After estimating the measurement uncertainty of individual specimens, the uncertainties of the five specimens were combined to determine the overall measurement uncertainty. The uncertainty range at each step was then compared. Fig.3 illustrates the uncertainty range estimated from the thermal diffusivity measurements of the five batch specimens. Fig.4 highlights the factors influencing the uncertainty range shown in Fig.3. The measurement uncertainty of an individual specimen is primarily affected by the uncertainty of the graphite CRM. Meanwhile, the overall uncertainty is significantly influenced by variations in the measured values across batches, which result from differences in specimen quality, leading to an increase in measurement uncertainty.

4. Conclusions

The measurement uncertainty of the thermal diffusivity of UO_2-Mo micro-plate composite pellets was evaluated. The uncertainty of the CRM was found to have the greatest impact on the uncertainty of individual measurements. Additionally, variations in the quality of the sintered body across different manufacturing batches were identified as a major factor contributing to the expansion of the measurement uncertainty range. Efforts to minimize quality variations between batches and the establishment of quality standards that account for batch-related uncertainty are necessary.

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