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Optimization of the Wet Drying Process in Slip-Casting Using Wet Wipes

Yunmock Jung, Kweonho Kang, Jae Sun Han, Jae Soo Ryu*
Korea Atomic Energy Research Institute
**Corresponding author: jym@kaeri.re.kr*

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1. Introduction

Korea Atomic Energy Research Institute is currently conducting research on the fabrication of spent nuclear fuel oxide blocks. Slip casting is a widely used technique in ceramic manufacturing that involves pouring a slurry into a porous mold to form a solid structure as water is removed. The drying process after casting is a crucial step that significantly influences the mechanical properties and dimensional stability of the final product. Improper drying conditions can lead to defects such as cracking, warping, and density variations, which reduce the quality and yield of production. This study investigates the optimization of the wet drying process in slip-cast bodies by utilizing wet wipes to regulate moisture evaporation. By analyzing drying rates and the mechanical integrity of dried bodies, we seek to determine optimal drying conditions that enhance product quality while reducing defects. These results can provide a basis for controlling the drying rate of oxide blocks in the future applications.

2. Theory and Methods

Slip casting is a widely used technique for fabricating ceramic bodies, where a slurry of ceramic particles is poured into a mold and allowed to solidify through liquid absorption. After casting, the drying process plays a crucial role in determining the final quality of the ceramic product. Wet drying is often used instead of conventional dry drying due to the following reasons:[1]

2.1 Prevention of Cracking and Warping

Rapid drying leads to non-uniform shrinkage, causing internal stresses that result in cracks or warping. Wet drying provides a controlled humidity environment, allowing for gradual moisture removal and minimizing stress development.

2.2 Uniform Moisture Distribution

In conventional drying, the outer layer dries faster than the inner part of the slip body, leading to differential shrinkage. Wet drying ensures a more uniform drying rate throughout the body, reducing defects.

2.3 Improved Microstructure and Density Control

Fast evaporation can create large, irregular pores, compromising mechanical strength. A controlled wet drying process, however, promotes uniform pore distribution, leading to improved mechanical properties.

2.4 Minimization of Residual Stress

Residual stress from uneven drying can weaken the final product and wet drying helps in stress relaxation, improving overall stability.

2.5 Optimization of Sintering Process

A well-dried green body results in better sintering behavior, leading to improved densification and mechanical performance.

2.6 Methods

A 10L stainless steel kimchi container was used as a wet drying vessel(295×240×145 mm), and 10 holes with a diameter of 13.5 mm and 10 holes with a diameter of 5.5 mm were drilled in a 5×4 pattern on the lid. The number of open and closed holes was adjusted to control the evaporation rate. A sensor was attached to the central hole to measure the temperature and humidity inside the wet drying vessel, allowing for comparison with the outside temperature and humidity. Commercially available wet wipes were used prior to experimenting with the oxide blocks and 3 wet wipes were used for each experiment. The used wet wipe had a basis weight of 60 g/m² and dimensions of 170 × 200 × 0.4 mm. A microbalance with a resolution of 10 mg was used, and it was connected to a laptop for continuous monitoring of real-time weight changes. The experiment was conducted by measuring the evaporation rate when all the holes were open, 50% of the holes were open, and 25% of the holes were open. The experiment continued until there was no noticeable weight reduction of the wet wipes for approximately two hours. The external temperature during the experiment was maintained at approximately 25 ± 1°C, and the humidity was kept at around 60 ± 5%.

Fig 1. Real-time evaporation measurement system (left)
Lid and holes of the wet drying container (right)

3. Results and Analysis

Figure 2. shows the differences in moisture evaporation as a function of the lid opening ratio. A curve fitting was applied to the graph to derive a correlation equation for time and the lid opening ratio.

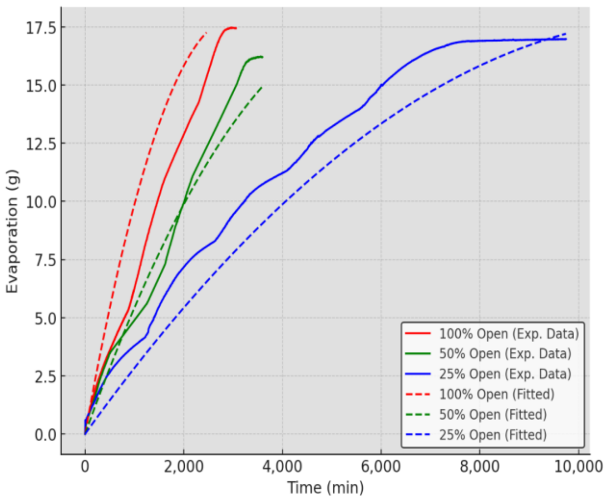

Fig 2. Evaporation rates for wet wipes at hole opening ratios

To establish a quantitative relationship between evaporation, time, and the lid opening ratio, experimental data were analyzed using curve fitting. The governing equation is given as $E(t) = f(A_f, t)$.

The moisture evaporation process in influenced by both time (t) and the opening area ratio (A_f), which represents the fraction of the lid that is open. The parameters are defined as follows:

- $E(t)$: The amount of evaporation at time t (g)
- t : Time (hour)
- A_f : Opening area ratio

A quadratic function was selected to best represent the observed evaporation behavior:

$$E(t) = k_1 \cdot A_f \cdot t + k_2 \cdot (A_f \cdot t)^2$$

where:

- k_1 represents the primary rate of evaporation,
- k_2 accounts for non-linearity in the evaporation behavior over time.

The experimental data were fitted using least-squares regression, and the optimized coefficients were determined:

$$k_1 = 0.7097 \text{ g/hr}, \; k_2 = -0.007 \text{ g/hr}^2$$

Accordingly, the final correlation equation can be formulated as follows:

$$\underline{E(t) = 0.7097 \times A_f \times t - 0.007 \times (A_f \times t)^2}$$

4. Conclusion

This study concludes that the derived correlation equation is only applicable until the complete evaporation of moisture from the wet tissue, i.e., up to the maximum evaporation amount of about 17 g(initial moisture content of the wet tissue). In future applications, the maximum evaporation amount for oxide blocks is expected to be larger, necessitating further adjustments to the model. This research is significant as it quantitatively measures moisture evaporation as a function of time and open area, providing a predictive correlation equation for further applications.

REFERENCES

[1] Kwen Ho Kang, Optimization of slip casting fabrication condition using CeO_2, KAERI/TR-10239, 2023