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Cake growth control in slip casting

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Abstract

A control technique of cake growth in slip casting was studied. The influence of geometrical features of the gypsum mold upon the cake growth pattern was examined in experimental slip casting using T-shaped gypsum molds. The T-shaped molds were of two types; one had walls inside and the other did not. These walls were formed from silicone rubber and did not transmit water. A water flow in the gypsum mold was controlled by silicone rubber walls, so that cake growth was controlled. Cake growth during slip casting using T-shaped mold was predicted by computer simulation.

Keywords: Slip casting; Shaping; Computer simulation; Al_2O_3

1. Introduction

Slip casting is useful in forming ceramic parts with complicated shapes. The mechanism of slip casting was studied by many authors and theoretical formulae were proposed.[1–5] Furthermore, computer simulations based on these formulae have been attempted.[6–9] Many studies of the slip casting process treated simple geometrical systems, such as one-dimensional or axisymmetrical geometries. Actually, in slip casting using a complicated shaped gypsum mold, the cake surface between the cake and the mold is copied from the mold surface, but that between the cake and the slurry is not similar to the mold surface. If it is possible to control the cake surface between the cake and the slurry, slip casting can be applied to more cases where cakes have more complicated shapes. The mechanism of slip casting is the same as the filtration process. During the slip casting process, the water flow in the cake and the gypsum mold obeys Darcy's law. Cake growth is influenced by the water flow direction and water flow velocity. According to Darcy's law, the water flow can be controlled by changing the permeability and the suction pressure of the gypsum mold. However, it is difficult to make the gypsum mold having desirable characters, which are the permeability and the suction pressure. On the other hand, the water flow can be controlled also by geometrical features of the gypsum mold. The amount of absorption of water by the gypsum mold is proportional to the volume of the cake. Cake growth is restricted by reducing the volume of the gypsum mold. Furthermore, water flows in continuous porous bodies, which are the cake and the gypsum mold. When a wall that does not transmit water is in the gypsum mold, water does not pass through the wall and the water flow takes a turn along the wall. And, the gypsum mold having these geometrical features can be made.

In the present work, a control technique of cake growth in slip casting was examined. Two types of T-shaped gypsum mold were used in slip casting. The thickness of the T-shaped mold was thin at both sides and thick at the center. One type of the T-shaped mold was formed with a single part and the other was assembled with three gypsum parts. Gypsum parts bonded together with silicone rubber. Silicone rubber layers in the gypsum mold do not transmit water. The influence of two geometrical features of the gypsum mold, which are T-shaped and inside silicone rubber walls, upon cake growth was observed. In addition, the computer simulation was carried out to predict the cake growth pattern.

2. Experiment procedure

Fig. 1 shows the schematic illustration of the slip casting system used in this work. Casting molds were

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made of gypsum and silicone rubber. Gypsum molds were T-shaped, and two types of mold were used; One [Fig. 2(a)] had a single part and the other [Fig. 2(b)] had three parts. The T-shaped mold having three parts was assembled from a center part and two side parts. Gypsum parts were bonded with silicone rubber. Gypsum molds were prepared as follows:100 mass% of gypsum raw powder (Reagent Grade, Kanto Chemical Co., Ltd., Tokyo, Japan) and 70 mass% distilled water were carefully mixed in vacuum for 5 min in a vessel held in a water bath kept at 25°C. The mixture was poured into a rubber mold, so that gypsum plates were obtained. The parts of T-shaped molds were formed from gypsum plates by whittling.

A well-dispersed alumina slurry having a high solid-content and a low viscosity was used in slip casting. A mixture of 70 mass% alumina (purity : 99.8%, median particle size: 0.5 μm, AES-11C, Sumitomo Chemical Co., Ltd., Tokyo, Japan), 0.15 mass% (alumina basis) dispersant (polyacrylicammonium salt, Aron A6114, Toagosei Chemical Industry Co., Ltd., Tokyo, Japan) and 30 mass% distilled water was agitated in a ball mill (1 l) for 16 h, and the slurry was used for the experimental slip casting.

A computer simulation for two-dimensional cake growth during slip casting, which based on the method of finite differences, was used.[8] The values of the controlling parameters for the computer simulation have been reported in a previous paper.[9] Cake growth patterns and water flows in the slip casting systems were calculated by the computer simulations.

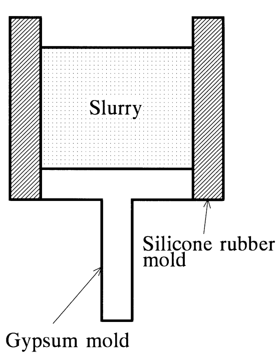

Fig. 1. Schematic illustration of slip casting system.

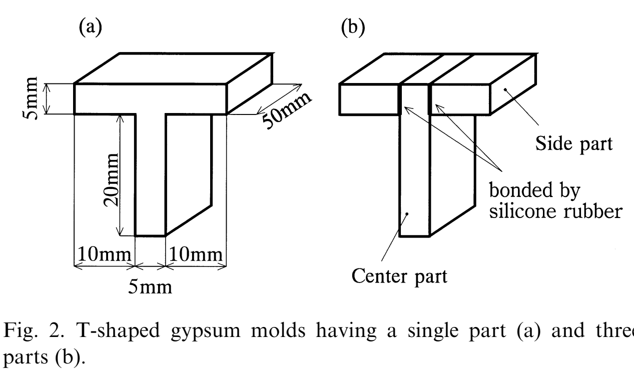

Fig. 2. T-shaped gypsum molds having a single part (a) and three parts (b).

3. Results and discussion

The characters of the slurry, the cake and the gypsum and the controlling parameters in slip casting have been measured and reported in the previous work.[9] The volume fractions of solid in the gypsum f_G, the slurry f_S and the alumina cake f_C were 0.62, 0.37 and 0.60 respectively. The capillary suction pressure of the gypsum was 0.03 MPa. The permeability of the gypsum and the alumina cake were 2.3×10^{-14} m^2 and 1.2×10^{-16} m^2. Fig. 3 shows the relationship between cake thickness L_C and slip casting time t in one-dimensional experimental slip casting. Referring to the Aksay and Schilling model,[2] this relation was expressed by using the cake buildup constant k

$$L_C = \sqrt{kt} \qquad (1)$$

The value of k was determined to be 1.14×10^{-8} m^2 s^{-1}. Water infiltration depth into the gypsum mold was related to cake thickness, and the ratio of cake thickness to water infiltration depth corresponds to the ratio of $f_S/(f_C-f_S)$ to $1/(1-f_G)$. The relationship between water infiltration depth and slip casting time was calculated as shown in Fig. 3. In the present work, the head thickness of the T-shape mold is 5 mm. It is considered that the water infiltration into the gypsum mold and cake growth are nearly one-dimensional until the head of the T-shaped mold is filled with water. It takes about 800 s

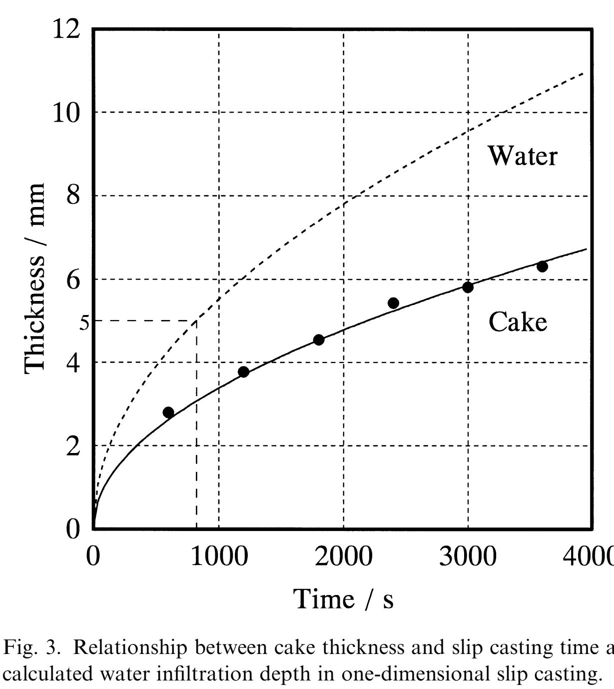

Fig. 3. Relationship between cake thickness and slip casting time and calculated water infiltration depth in one-dimensional slip casting.

for the water front line to advance 5 mm from the boundary between the cake and the gypsum mold as shown in Fig. 3. After 800 s, the water flow in the T-shaped mold is not one-dimensional.

Fig. 4 shows cake growth patterns observed experimentally in slip casting using T-shaped molds having a single part (a) and three parts (b) for a period of 3600 s. The cake growth pattern using the T-shaped mold having a single part had a flat surface between the cake and the slurry. In this case, the slip casting time is over 800 s, so that the water flow in the T-shaped mold was not one-dimensional. However, the cake grew upward as a one-dimensional slip casting. On the other hand, in slip casting using the T-shaped gypsum mold having three parts, cake thickness at the center was thicker than at the edge. These findings indicate that silicone rubber walls in the gypsum mold have an influence on cake growth. The reason is described later.

Fig. 5 shows cake growth patterns calculated by computer simulations in slip casting using T-shaped gypsum molds having a single part (a) and three parts (b). In slip casting using the T-shaped mold having a single part, the cake surfaces between the cakes and the slurry were flat at slip casting times of 600, 1800 and 2700 s, and slip casting had finished at 2700 s. On the other hand, in slip casting using the T-shaped mold having three parts, slip casting had not finished at 3600 s, and cake thickness at the center was thicker than the edge at slip casting times of 1800 and 3600 s. These cake growth patterns were similar to the experimental results.

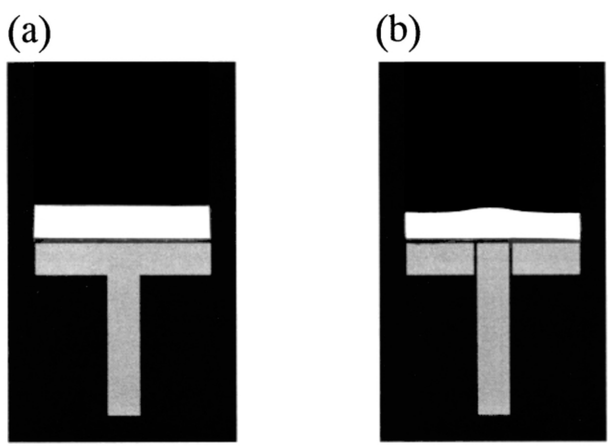

Fig. 4. Cake growth patterns in slip casting using T-shaped gypsum molds having a single part (a) and three parts (b) for a period of 3600 s.

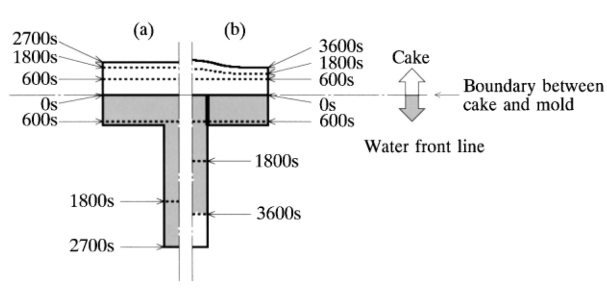

Fig. 5. Cake growth patterns calculated by computer simulations in slip casting using T-shaped molds having a single part (a) and three parts (b).

Fig. 6 shows the vectors of water flows in cakes and T-shaped molds calculated by computer simulations at a slip casting time of 1800 s. In slip casting using the T-shaped mold having a single part [Fig. 6(a)], water flowed vertically toward the mold in the cake. Inside the T-shaped mold, water flowed toward the center at the side and flowed downward at the center. This tendency is explained as follows: since the permeability of the gypsum is larger than that of the cake, pressure drop in the cake is larger than in the gypsum mold. Pressure at the boundary between the cake and the gypsum mold is negligible as compared with the pressure at the boundary between the cake and the slurry. As a result, water flowed downward vertically in the cake, and the cake grew directly upward. In short, when the surface between the gypsum mold and the cake is flat and the gypsum mold is formed from a continuous part, the shape of the gypsum hardly influences the shape of the cake.

In slip casting using the T-shaped mold having three parts [Fig. 6(b)], the water flow in the T-shaped mold was discontinuous at the silicone rubber wall. The side part of the T-shaped mold received water at the edge and discharged water at the vicinity of the center. After the side part of the T-shaped mold was filled with water, it played the role of bypass for the water flow as shown in Fig. 6(b). Water rate at the center of the boundary between the cake and the slurry was faster, so that cake thickness at the center was thicker.

As a whole, the cake growth pattern formed by slip casting is related to the water flow in the gypsum mold. The control of cake growth is possible by combination of

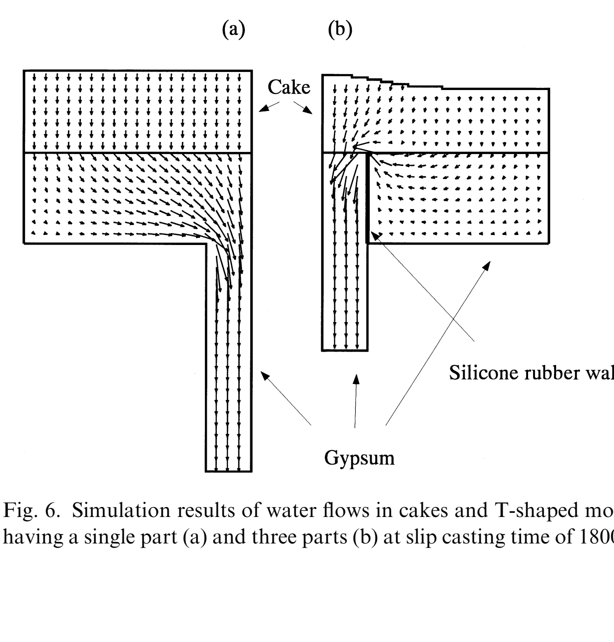

Fig. 6. Simulation results of water flows in cakes and T-shaped molds having a single part (a) and three parts (b) at slip casting time of 1800 s.

gypsum molds with different thickness and the presence of silicone rubber walls in gypsum molds. Furthermore, the cake growth pattern was predicted by computer simulation. The computer simulation method is useful to design the gypsum mold having desirable geometrical features.

4. Conclusion

Two types of T-shaped gypsum mold, one with a single part and the other with three parts bonded by silicon rubber, were used in slip casting. The presence of the silicone rubber wall in the gypsum mold influenced the water flow in the gypsum mold and the cake. The cake surface between the cake and the slurry was flat in slip casting using the T-shaped gypsum mold having a single part. On the contrary, cake thickness was thicker at the center than at the edge in slip casting using the T-shaped gypsum mold having three parts. Both cake growth patterns were predicted by computer simulation. If the water flows are the different in gypsum molds having the same external appearance, cake growth patterns are the different. In a word, the cake growth pattern can be controlled by using the gypsum mold having desirable geometrical features.

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