Flow Patterns in Green Bodies Made by High-Speed Centrifugal Compaction Process

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Abstract

High-Speed Centrifugal Compaction Process (HCP) is a wet compacting method, in which powders are compacted under a huge centrifugal force. The HCP was well applied to small alumina specimens, but the compact easily cracked when we applied the HCP to other materials. We clarified how the cracks introduced and found that the formation of such a flow pattern was related to the Colioli's force in the centrifugal field.

Keywords : Centrifugal force, Immersion Liquid Technique, Flow in centrifugal field, Colioli's force

1. Introduction

High-Speed Centrifugal Compaction Process (HCP) is a kind of wet compacting method suitable for fine ceramics. In the HCP, powders are first prepared as slips, then compacted under a huge centrifugal force of about 10,000 *g*. We performed several researches on the HCP heretofore (revised in several papers[1-3]) using alumina as the standard material, and obtained dense and fine sintered microstructures with superior bending strength of about 1000 MPa.

As we applied the HCP to other ceramic systems, however, we found that some specimens were constantly cracked during sintering (Fig. 1).

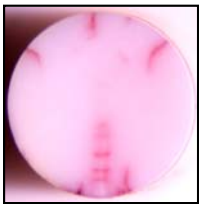

Fig. 1 Cracks observed on a cross section of sintered HCP zirconia.

In the present study, we are trying to clarify the mechanism involved in the introduction of inhomogeneity during the HCP and consider a remedy for their suppression.

2. Experimental

We performed experimental observations and numerical simulations. For the observation, a dyeing powder is added to the alumina to reveal the flow pattern in the compact, or a half-sintered alumina is observed by Immersion Liquid Technique (ILT) to reveal internal flaws along the flows. For the simulation, a two dimensional one component flow in the HCP is calculated to reveal the droving force of the flows.

Powders

The main powder was 0.2 μm high purity alumina (TM-DAR, Taimei Chem. Co., Japan). For additional powders, an iron (III) oxide of 0.2 micron (FRX-6952, Toda Kogyo Co., Japan) and another alumina of 0.5 micron (ZAKP-20, Sumitomo Chem. Co., Japan) were used.

Slip preparation and compaction

For the standard slip (Slip I), 0.2μm alumina powder was dispersed in 25 mass% of ion-exchanged water and ball-milled for 48 hours. A dispersing agent and a binder were added.

For dyeing, a minimum amount of iron oxide powder was added to the Slip I, and then stirred with a glass rod (Slip II). A minimum amount of 0.5μm alumina was also added to the SlipI, by hand stirring (Slip III) or by ball milling (Slip IV).

Prepared slips were compacted by the HCP. The Slips werepoured in the die assembly, then it was rotated up to 11,500 rpm for 3.6 - 46.8 ks in a high-speed centrifuge (# 7820, Kubota, Japan) with a rotor of 120 mm in radius.

Observation

For dyed bodies (made with SlipII), the specimens were pre-sintered at 1073 K for 3.6 ks, then cut to several parts and observed. For more detailed observations, the Immersing Liquid Technique (ILT) was used. The principle and detailed procedure of the ILT is shown in previous studies [4, 5]. Here we mention only the preparation of the specimens. Firstly, alumina green compacts were half-sintered at 1423 K for 5.4 ks, some lower than the best sintering point, to maintain open pore network. Then the specimen was soaked in di-iodomethane to archive transparency. The soaked specimens were observed with an optical microscope by transmission light mode.

Simulation

The MAC code was used. Basic equations used in the calculation are Poisson's pressure equation and Navier Stokes equation.

3. Results

Appearance of flow apttern

The Slip II was compacted by the HCP at 11,500 rpm for 3.6 ks (Fig. 2). Most of the iron oxide powder were sharply separated to the bottom (arrow A) but some were rolled into the compact, forming a specific “Y” shape flow pattern. The pattern becomes more obvious in the cross sections. These patterns have a linear symmetry with a central axis parallel to the compacting direction. The central flow seems to go forward, namely towards the rotational direction, then returns to backwards along the circumference. The pattern was stronger at the bottom and weaker in the top.

The formation of the “Y” pattern became weak with lower centrifugal fields. The pattern disappeared at 2000 rpm for 46.8 ks compaction. However, many bubbles are remained in the cross sections since the defect removing function of the HCP deteriorates with such a low centrifugal field.

Simulation

We first calculated with an initial condition of stationary fluid but no remarkable flow was formed. Then we presume a constant bidirectional flow across the cross section. The flow that went to the bottom (top part of the figure) represents the settling movement of the powders, and the counter flows represents that of water. The presumed flows and the calculated results are shown in Fig. 3. In both conditions, linear symmetrical flows, which are similar to the “Y” pattern, are formed. However, the directions of the flows are opposite in both, and the result with Flow II (right one) coincides with the experimental observation.

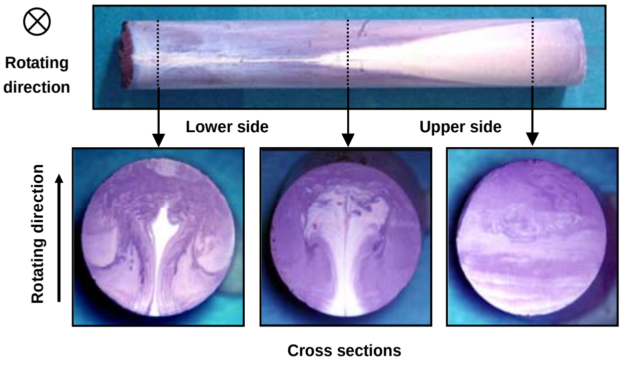

Fig. 2. Appearrance of the HCP green body compactted at 11,500 rpm for 3.6 ks using Slip II.

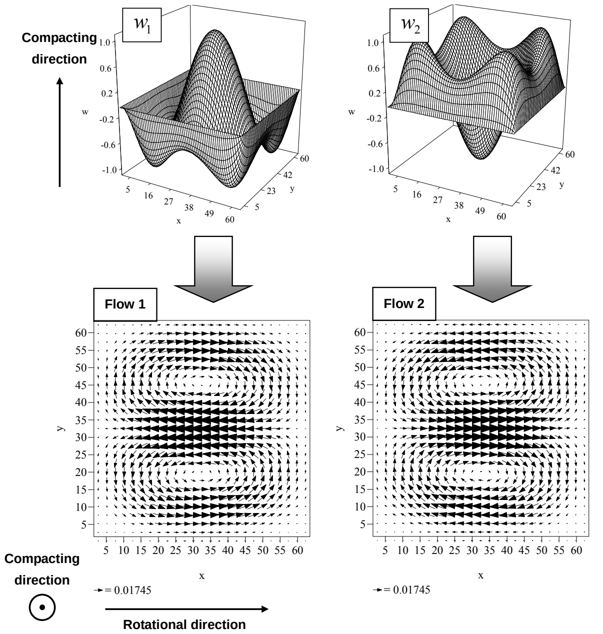

Fig. 3. Initial frow across the cross section and flow formed on the cross section.

4. Summary

The microstructure of the HCP alumina was observed by dyeing to reveal flow formation during compaction. In the HCP green compact, a “Y” shaped flow pattern was formed. The pattern became stronger with higher centrifugal fields.

A simple simulation revealed that the formation of such a flow pattern was strongly related to the Colioli’s force. Since the Colioli’s force was essential and proportional to the centrifugal force, it became obvious and hard to suppress in the huge centrifugal field.

5. References

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