A NOVEL CONCEPT FOR CERAMIC INJECTION MOLDING —SIMSE PROCESS—

H. Nishio, A. Kato, T. Kawashima
Advanced Technology Research Center,
NKK, Kawasaki/Japan

Abstract

A novel ceramic-injection-molding process recently developed by NKK is reviewed. This process is comprised of slip-injection molding, and supercritical extraction. A slip in injected under pressure less than 1MPa into a mold, and allowed to set up on cooling. The molding thus obtained are subjected to supercritical extraction where injection-molding binders are removed in drastically short time. This process has inherent advantages over conventional injection molding process:(1)it makes possible the fabrication of thicker, and larger components; (2)it reduces such component inperfections as weld lines, and cracking; (3)it makes possible to apply cheaper molds.

1. INTRODUCTION

Ceramic-injection molding consists of five stages. The first stage, powder preparation, consists of processing the ceramic powder to obtain the desired particle size, and distribution. The ceramic powder is then mixed with the organic binder, in the second stage, to from a molding mix. The molding mix is then placed in the injection-molding machine, heated above the melting point of the binders, and injection into cold mold in the third stage, to obtain moldings through the setting of the molding mix. The fourth stage is to remove the injection-molding binders from the moldings through a slow-heat treatment, followed by the final stage of firing the green components. Although ceramic injection molding is potentially a high volume production process which has the capability of producing complex-shaped articles to net shape, it has several disadvantages;

(1)The application of conventional injection-molding process is limited to only mass production, since the tool is extremely costly

(2)The removal of injection-molding binders is very time consuming; periods as long as several days and weeks are mentioned in the literature.(1)

(3)Due to the difficulty of the binder removal the size of the component is very limited.[2]
(4)The difficulty in control of flow, and pressure in injection will result in such component inperfections as voids, and weld lines, where the most important machine variable is the gate geometry which exerts an influence on the molding mix flow in the cavity.[3]
(5)Ununiform shrinkage of the green body takes place during the binder removal and firing stage, due to the ununiform density, and residual stresses of the green body. Sugano describes the local shrinkage in the green body during sintering.[4] The shrinkage increases with the distance from the gate of the mold, which suggests than the pressure applied to the gate in not transmitted in the molding without significant losses.
NKK has developed a novel ceramic-injection-molding (SIMSE) process capable of removing almost all problems mentioned above. This paper will review SIMSE process.

2.SIMSE PROCESS

SIMSE process consists of two stage: slip-injection molding, and supercritical extraction(Fig.1). The slip-injection-molding stage is in principle identical with Peltsman process,[5] where a slip in applied, instead of a highly viscous molding mix in the common injection molding process. Therefore, injection pressures less than 1MPa are applicable, which are much lower than those applied in the common injection molding process over 50MPa. In the supercritical extraction stage a supercritical fluid is used to solve the injection-molding binders in the molding, and allow them to diffuse outward. Carbon dioxide is most preferable as extractant, because of its low critical temperature of 31.1℃, nontoxicity, and low material cost. The binder system of slip for SIMSE process must be designed to optimize moldability, and supercritical-extraction capability. As shown in Fig. 2, the viscosity of the slip designed for silicon nitride ceramics is in 10^2, Pa s order of magnitude, and the change in shear is small enough, which enables to injection-mold the slip with a low injection pressure less than 1MPa.

2.1. Slip- Injection Molding

Fig. 3 shows a slip-injection-molding machine used for experiments. Ceramic powders previously milled to break up the agglomerates are mixed with organic binders to make a slip. The air entrapped in the slip is removed by evacuation, and compressed nitrogen is supplied onto the slip to transport it though the heated hose to the water-cooled mold. The pressure supplied by the nitrogen is kept until the setting of the slip is completed. Then, the mold is disassembled to obtain a molding. Fig.4 shows the fill patterns of short shots injected into a simple rectangular test piece die. It will be seen that the slip goes up gently from the bottom to the top end. No jetting occurs, in spite in area from the gate to the cavity as shown in Fig. 4 middle. Therefore, the resultant moldings hardly pick up such inperfections as weld lines, and air entrapment.

2.2. Supercritical Extraction of Organic Binders from Moldings

Fig. 5 shows an experimental apparatus for supercritically extracting organic binders. The operations are as follows: the moldings are put in the extractor. Liquified carbon dioxide is supplied by pumping to the extractor to attain a prescribed pressure, after adjusting the temperature to a prescribed temperature. When a supercritical state of carbon dioxide is reached, the fluid is allowed to flow out from the extractor though the separator at a prescribed flow rate. The organic binders are extracted from the moldings by the supercritical fluid, transported to the pressure control valve delivering this fluid to atmospheric pressure, allowed to precipitate, and entrapped in the separator. By use of SIMSE process it was attempted to fabricate thick green bodes: a powder mix was prepared (92wt%Si_3N_4(UBE-SN-E10), 6wt%Y_2O_3, 2wt%Al_2O_3), mixed with organic binders to obtain a slip (52.5vol%powder). An acrylic resin tube (44mm inner diameter, 70mm high) was used as mold, into which slip was injected with an injection pressure of 0.4MPa, and allowed to stand at room temperature.

Thus, cylindrical moldings (43mm diameter, 70mm high) were obtained. The moldings were subject to the supercritical extraction.

Fig.6 shows the change in extraction degree with time: 85% of extraction degree was attained after 97ks. As shown in Fig. 7, the green body picked up on cracking during this supercritical extraction, in spite of such an extraordinary thickness of 43mm.

3. FABRICATION OF BOLTS AND NUTS

Bolts (16.5mm screw diameter), and nuts were fabricated by use of SIMSE process. In extraction time of 14ks, extraction degrees of bolts, and nuts are 85%, and 95%, respectively, which are about 30 tomes larger than those of the thermal extraction commonly used. These green components debinderized were subject to sintering. As shown in Fig. 8, bolts, and nuts sintered are well matched in size, as those just debinderized are. It can be seen that SIMSE process results in more uniform shrinkage than the common injection molding process.

4. CONCLUSIONS

A novel injection-molding process, SIMSE process, has been developed, which is comprised of slip injection molding, and supercritical extraction. This process has the following advantages over the common injection molding process: (1)it makes possible the fabrication of thicker and larger components; (2)it reduces such component imperfections as weld lines, and cracking; (3)it makes possible to apply cheaper molds. These advantages may encourage use of SIMSE process in fabricating large complicated components such as gas turbine rotors.

5. REFERENCES

(1)E. L. Kennard, Ceramic Eng. Scien. Proc. Sept.-Oct.,1986, "Ceramic Component Fabrication", the American Ceramic Soc. Westerville, OH, 1986, pp.1095,1111.

(2)Y. Shibata, Y. Hattori, and M. Kawamura, "Development of Ceramic Turbocharger Rotor", New Ceramics, No. 1, 1988, PP. 91, 98.

(3)J. A. Mangels, and W. Trela, "Ceramic Components by Injection Molding", Advanced in Ceramics, vol.9, Forming of Ceramics, the American Ceramic Soc., Westerville, OH, 1984, pp. 220, 233.

(4)T. Kanno, "Development of High Strengh Silicon Carbide Ceramics by Injection Molding", Proceeding for 4th Symposium on Basic Technologies for Future Industries-Fine Ceramics, Tokyo, 1986, pp. 91, 103.

(5)L. Reltsman, and M. Peltsman, " Low Pressure Moulding of Ceramic Materials", InterCeram, pp56.

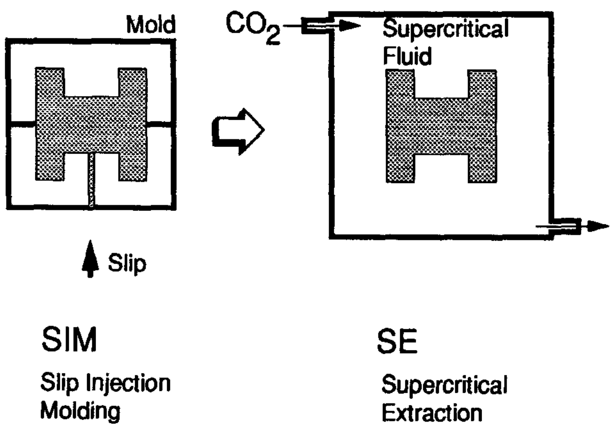


Fig. 1 Concept of SIMSE process.

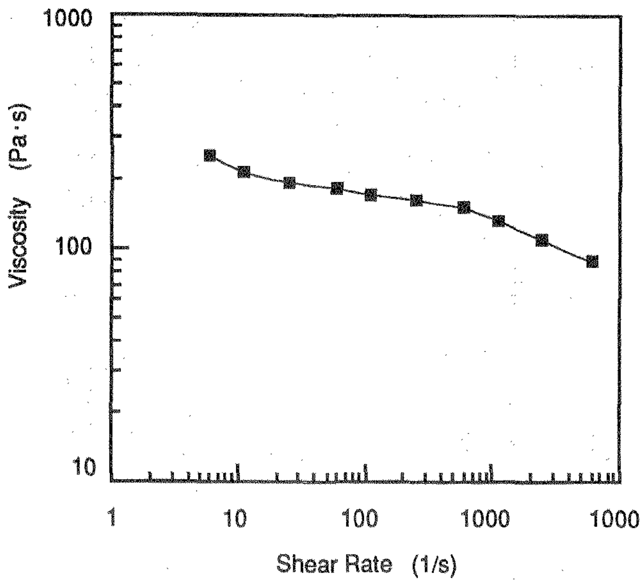


Fig. 2 Log viscosity as a function of shear rate.

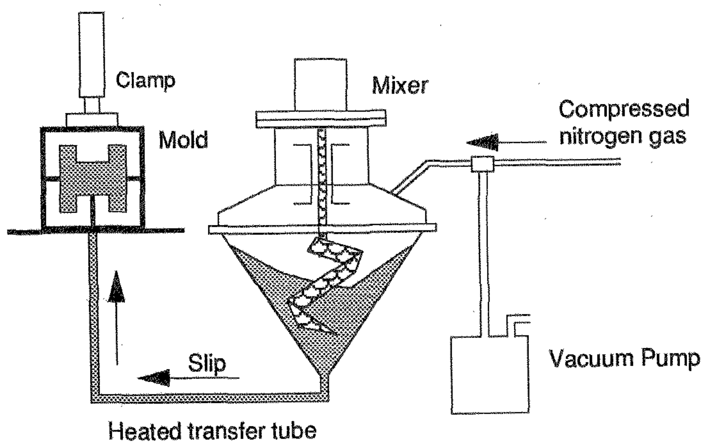


Fig. 3 Schematic of slip-injection-molding machine.

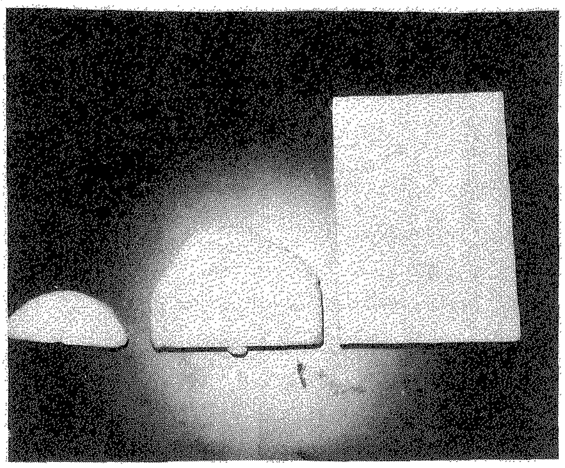


Fig. 4 Sequence of short shorts in slip-injection molding.

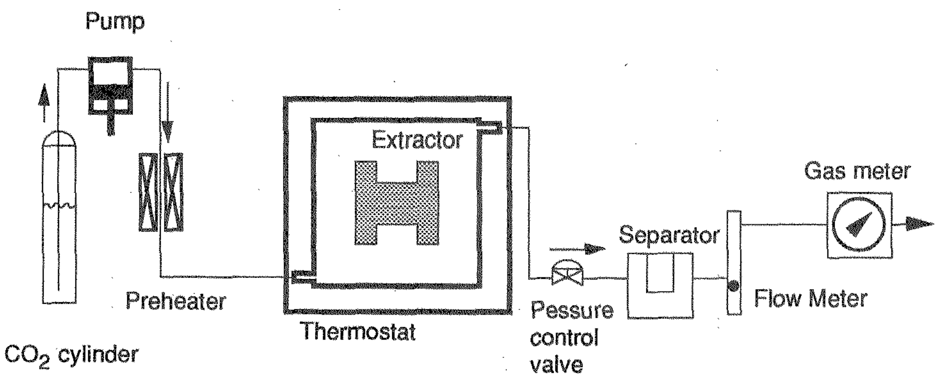


Fig. 5 Schematic of apparatus for supercritical extraction.

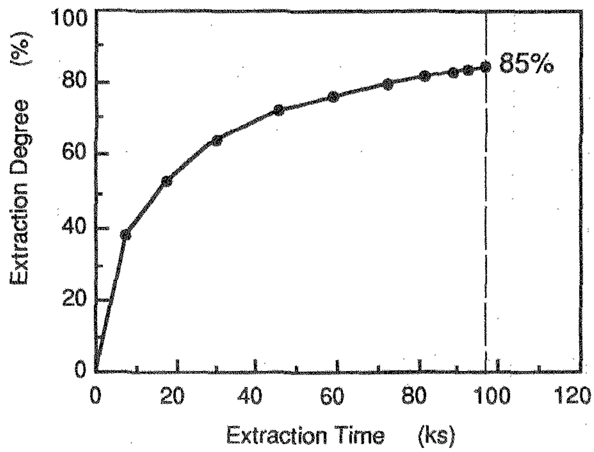
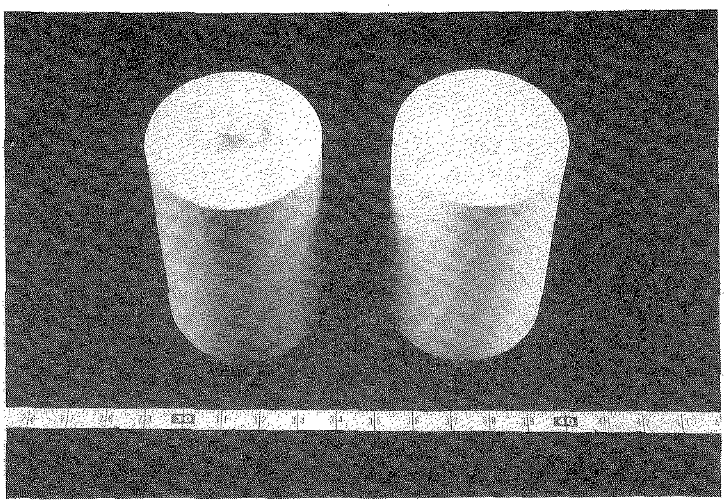
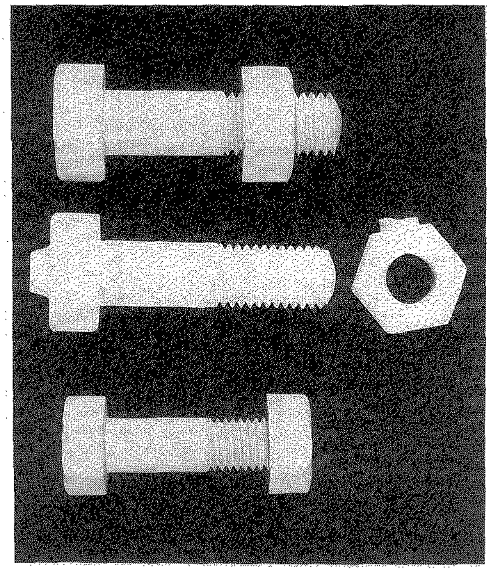


Fig.6 Extraction degree vs extraction time.



Left: before supercritical extraction
Right: after supercritical extraction

Fig. 7 Thick cylindrical green bodies before and after supercritical extraction (43mm diameter, 70mm high).



Upper:
Green component
mol ded

Middle:
Green component
debinderized

Lower:
Sintered component

Fig. 8 Bolts, and nuts fabricated by use of SIMSE process.