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A new in situ process in precision casting for mold fabrication

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Abstract

A new in situ process for mold fabrication in precision casting has been developed to decrease processing time and production costs, and produce an environmentally friendly mold, compared with the conventional process. In the new process, the starting powder is fastened by an inorganic binder, whereas the mold in the conventional process takes its form by using an organic binder. The fixing of powders by the inorganic binder is caused by a sol–gel reaction of precursor materials. Therefore, the new mold process is more environmentally friendly and simpler than the conventional process. The inorganic binder system for the in situ process was prepared from a mixture of tetraethyl orthosilicate and poly(dimethyl siloxane) as SiO_2 precursor, and sodium methoxide as Na_2O precursor. The prepared samples show a fracture strength of about 5 MPa, indicating that the in situ process can be applied to the fabrication of molds having high mechanical properties.

Keywords: Composites; Firing; Microstructure-final; Mold; Precursors-organic; Sol–gel processes

1. Introduction

Recently, the convert mold process in precision casting, which uses a mixture of alkyl silicate and sodium alkoxide, has been introduced to fabricate shell molds.[1,2] This convert mold process has many advantages, such as high strength, enhancement of collapse, easy processability, and high thermal stability, making it useful in many different applications, for example, in automobiles, and aerospace materials. Typically, mold fabrication has been accomplished using the convert mold process of six steps: (1) a coating process of starting materials with an organic binder, (2) preparation of the mold by heat treatment at 200 °C, (3) a dipping process into inorganic binder precursors, (4) a first drying process at 80 °C, (5) a second drying process at 200 °C, and (6) heat treatment at 1000 °C, resulting in the conversion of the organic-bonded mold to the inorganic-bonded mold.[3-5] The new method for mold fabrication has several advantages, such as a decrease in the processing time and production costs and the production of an environmentally friendly mold, due to the omission of three of the above steps, (1), (3), and (5) in the convert mold process using.

The new mold process introduced in this work is called an in situ process because the mold can be prepared by direct mixing starting powder and inorganic binder. The binder system for fabricating the mold by the in situ process was prepared with tetraethyl orthosilicate (TEOS) and poly(dimethyl siloxane) (PDMS) as a precursor of silicon dioxide (SiO_2) and sodium methoxide (NaOMe) as a precursor of sodium oxide (Na_2O). The mold could be shaped by a solid-state phase reaction (SiO_2, Na_2CO_3) generated by the sol–gel reaction of TEOS and NaOMe during a drying process. These sol–gel reactions were investigated as functions of binder composition and viscosity of the SiO_2 precursor in an attempt to study the mechanical properties of the prepared mold and the reactivity of the precursor, considering the differences between the mold-fixing effects of the organic and inorganic binders. The relationship between strength and binder composition is discussed based on the microstructures observed.

2. Experimental details

A composite binder for the new in situ process was prepared using two types of SiO_2 precursor: tetraethyl orthosilicate (η(viscosity) = 0.0179 cP at 25 °C, Sigma–Aldrich Korea,

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Table 1
The chemical composition and various physical properties of starting powder.

Chemical composition (%)		Porosity (%)	Bulk specific gravity	Water absorption (%)
Al_2O_3	60.59	2.2	2.72	0.8
SiO_2	36.44			
Fe_2O_3	1.08			
TiO_2	0.72			
CaO	0.20			
MgO	0.08			
K_2O	0.20			
Na_2O	0.35			
P_2O_5	0.27			
Total	99.93			

Table 2
Formulations of binder systems to prepare the mold in processes I and II.

Process	Run number	TEOS [wt%]	PDMS [wt%]	PVA [wt%]	NaOMe [wt%]	Isobutyl alcohol [wt%]
I	1	38	–		56	6
	2[a], 3[b]	30.4	7.6		56	6
II	4[a], 5[b]	30.4	7.6	1	56	6
	6[b]	–	38	1	56	6

[a] Viscosity (η) of PDMS used is 25 cSt.
[b] Viscosity (η) of PDMS used is 200 cSt.

Yongin, Korea) of silicate type with hydrolysis and condensation reactions (sol–gel reaction), and poly(dimethyl siloxane) (PDMS, $\eta = 25$ and 200 cSt at 25 °C, $\rho = 0.95$–0.97 g/ml, Sigma–Aldrich Korea, Yongin, Korea) of siloxane type without the sol–gel reaction. The SiO_2 precursor mixtures were prepared by mixing the silicate and/or siloxane types. Sodium methoxide (NaOMe, Sigma–Aldrich Korea, Yongin, Korea) and 10% poly(vinyl alcohol) aqueous solution (PVA, $\eta = 450$ cP at 25 °C, Sigma–Aldrich Korea, Yongin, Korea) were used as the precursors of Na_2O and organic binder, respectively. Powder with complex composition (Cerabeads, nominal particle size 0.39 mm, Seto, Japan), which is an artificial ceramic sand, was used as a starting powder. The chemical composition and fundamental physical properties of starting powder are shown in Table 1. In this work, two different methods were employed for preparing the mold samples: in one method, the starting powder was simply fixed by glassification of the inorganic binder (process I), in particular TEOS with the sol–gel reaction; in the other method, the organic binder was added in an appropriate composition to prepare the sample (process II), in particular PDMS without the sol–gel reaction. The powders mixed with precursors with and without organic binder were formed using a high pressure of 60 MPa with a cuboid shape of $10 \times 10 \times 50\ mm^3$. The formed samples were dried at 80 °C for 1 h, and then heat-treated at 1000 °C for 1 h. In addition, in the case of process II, the starting powders was heat-treated at 80 °C for 0.5 h before forming, owing to the evaporation of water used to dissolve the PVA. Schematic diagrams for the new in situ methods without (process I) and with (process II) the organic binder are shown in Fig. 1. The basic formulations and experimental ranges of binder systems to prepare the shell mold through the in situ process are shown in Table 2. The hydrolysis reaction of the precursor mate-

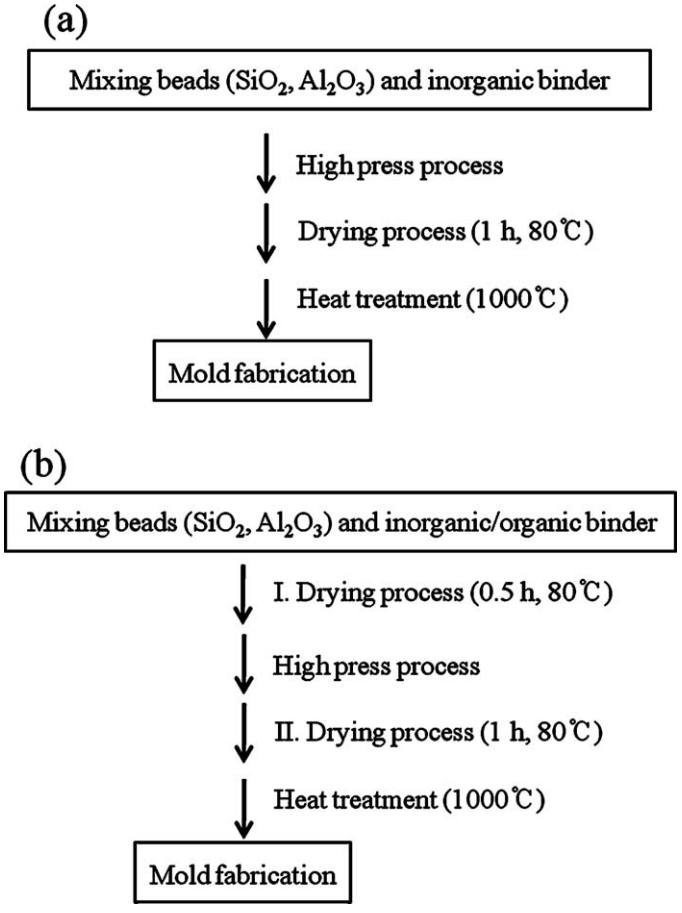

Fig. 1. Schematic diagram of mold fabrication for precision casting: (a) process I and (b) process II.