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Composite binders for precision casting shell molds

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Abstract

The convert mold process has been investigated, focusing on preparation of shell molds using different composite binder systems. The glassification efficiency of binder systems with different SiO_2 precursor structures were investigated in terms of the Si content and dipping time, and the subsequent effects on fracture strength. Two types of the SiO_2 precursor were used: tetraethyl orthosilicate of the silicate type; and hexamethyl disiloxane (HMDS), octamethyl trisiloxane, and polydimethyl siloxane of the siloxane type. Use of the siloxane type precursor does not produce a hydrolysis reaction, whereas the silicate type precursor is converted into SiO_2 by a hydrolysis and condensation reactions during the drying process. The samples based on the siloxane type (except HMDS) have a much higher fracture strength, nominal value of 8 MPa, than that of samples based on the silicate type. This is a result of the enhancement of glassification. When the siloxane is added to the silicate the fracture strength is as high as about 6 MPa, independent of the Si content and dipping time. Results indicate the importance of the reaction mechanism in achieving fracture strength with related to glassification efficiency.

Keywords: A. Sol–gel processes; B. Composite; C. Mechanical properties; Shell molds; Microstructure; Precision casting

1. Introduction

The convert mold process has been used to prepare shell molds for precision casting, because of the fast processing time, high thermal and dimensional stability, mechanical properties, and collapsibility of the products [1,2]. These features have lead to its use for precision casting in many different applications, for example in automobile and aerospace. Ethyl silicate and colloidal silica aquasols, combined with sodium alkoxide, are used as conventional binders in the convert mold process [3]. The convert mold process is typically divided into four main processes: (1) fabricating the starting mold coated with organic binder, (2) dipping the coated mold into a precursor slurry containing inorganic binders, (3) drying for 1 h at 80 °C, and (4) heat treating for 1 h at 1000 °C [4,5]. A hydrolysis and condensation reactions (generally called a sol–gel reaction) and glassification take place during the above (3) and (4) processes, respectively. Even though the convert mold process affords improved mold collapsibility and thermal stability compared with the conventional mold process, the hydrolysis reaction of inorganic binder precursor needs the control of atmospheric moisture during the process. The hydrolysis reaction of the silica (SiO_2) precursor leads to a reduction in the conversion efficiency of the precursor to the glass phase, which subsequently results in a deterioration of the mechanical and thermal properties of the mold. Therefore, a new convert mold process in which a solid-state binder is used has been proposed [6].

In the present study, a new binder system, which does not produce the hydrolysis reaction, is proposed to increase the glassification efficiency of inorganic binder precursor. It includes a mixed binder system of the silicate and siloxane types. The effects of the SiO_2 precursor structure and dipping time on the glassification and fracture strength were investigated.

2. Experimental

New binder systems were prepared by mixing two precursors of SiO_2 and sodium oxide (Na_2O). The two types of SiO_2 precursor were a silicate type and a siloxane type. For

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Table 1
The chemical composition and various physical properties of substrate.

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			

the silicate, tetraethyl orthosilicate (TEOS, T_b: 166–169 °C, Sigma–Aldrich Korea, Yongin, Korea), which undergoes the hydrolysis reaction, was used. For the siloxane, hexamethyl disiloxane (HMDS, T_b: 101 °C), octamethyl trisiloxane (OMTS, T_b: 153 °C), and polydimethyl siloxane (PDMS, T_b: 182 °C, Sigma–Aldrich Korea, Yongin, Korea) were used (separately); these do not produce the hydrolysis reaction. Sodium methoxide (NaOMe, Sigma–Aldrich Korea, Yongin, Korea) was used as the precursor of Na_2O. The SiO_2 precursor mixtures were prepared by mixing the silicate and siloxane types, as a function of siloxane species. The sample size used for the substrate was 10 mm × 10 mm × 50 mm (according to Metia Co., Ltd., Changwon, Korea); it was prepared using an organic resin binder. The chemical composition and fundamental physical properties of substrate are shown in Table 1. The samples were dipped into the prepared binder systems for 0.5, 1, and 2 h (separately) at room temperature. Dipped samples were first dried at 80 °C for 1 h, and then heat treated at 1000 °C for 1 h. Basic formulations and the experimental ranges of the binders used for preparing samples, which involved converting the organic binders to inorganic binders, are given in Table 2. The cross-sectional microstructure was revealed using a scanning electron microscope (SEM, JEOL Model JSM-5610, Tokyo, Japan). The fracture strength of samples after the final heat treatment was measured with a universal testing machine (UTM, Instron 5560, Seoul, Korea). Tests were carried out at room temperature, at a rate of 0.5 mm/min. At least five measurements were recorded for each condition in order to obtain the standard deviation of the fracture strength.

3. Results and discussion

The fracture morphologies and surfaces of samples prepared with the different SiO_2 precursors are shown in Fig. 1. All heat-treated samples had white areas, irrespective of the dipping

Table 2
Formulations and experimental ranges of binder systems.

Run number	TEOS (wt%)	HMDS (wt%)	OMTS (wt%)	PDMS (wt%)	NaOMe (wt%)	Isobutyl alcohol (wt%)	Degree of glassification (%)	Dipping time (h)
1–1	38	N/A	N/A	N/A	56	6	6.20	0.5
1–2								1
1–3								2
2–1	N/A	38	N/A	N/A	56	6	3.69	0.5
2–2								1
2–3								2
3–1	N/A	N/A	38	N/A	56	6	15.02	0.5
3–2								1
3–3								2
4–1	N/A	N/A	N/A	38	56	6	20.35	0.5
4–2								1
4–3								2
2–1–1	30.4	7.6	N/A	N/A	56	6	–	0.5
2–2–1								1
2–3–1								2
3–1–2	30.4	N/A	7.6	N/A	56	6	–	0.5
3–2–2								1
3–3–2								2
4–1–2	30.4	N/A	N/A	7.6	56	6	–	0.5
4–2–2								1
4–3–2								2