PREDICTION OF THERMAL SHOCK OF CERAMIC SHELLS USING FUSED SILICA AS REINFORCING FILLER AT CASTING CONDITIONS

P. Martin Jebaraj* and A. Chennakesava Reddy**

*Professor, Department of Mechanical Engineering
Dr. Ambedkar Institute of Technology, Bangalore, Hyderabad, India

**Assistant Professor, Department of Mechanical Engineering
M.J. College of Engineering & Technology, Banjara Hills, Hyderabad, India

Abstract: The ceramic shells were fabricated with ceramic slurry containing fused silica as filler material and colloidal silica binder. The shell characteristics in terms of hot bending strength and thermal expansion were measured. The non–linear nature of thermal expansion in the ceramic shells is on account of α to β phase transmission of stuccoing sand between 500 to 600°C. The ceramic shells which were sintered at 700°C were observed to have cracks.

Keywords: Ceramic shells, rutile, colloidal silica, hot strength, hot permeability.

1. Introduction

The materials used to build the ceramic shell, especially binders and refractories, play a vital role in the production of quality castings [1-4]. The properties of refractory fillers, which affect the shell quality, are filler particle size and shape, melting point, thermal expansion, density and metal - mould interaction. The refractoriness (or melting point) of filler material in dip-coating slurry determines the maximum weight of the casting to be produced with the shell, as well as the metal alloy to be cast [5]. For instance, shells of sillimanite have good bending strength after firing, but are unstable for casting of alloys with a higher melting point. Since at 1545^0C a change of sillimanite to mullite with a liquid phase takes place, silimanite shells, therefore, are suitable for casting of nonferrous alloys. The refractory filler materials should have low coefficient of thermal expansion to provide resistance to thermal shocks [6]. Yttria and rutile are found to have good thermal stability at casting temperatures of non-ferrous materials [7, 8].

The objective of the present work was to predict thermal shock of the ceramic shells fabricated by fused silica as a filler material added to the colloidal silica binder.

2. Materials and Methods

The colloidal silica binder was used to fabricate the ceramic shells from fused silica as a reinforced filler material. The crystal structure of fused silica is shown in figure 1. If the silicon dioxide is synthetically derived, the material is often called Fused Silica. Fused Quartz is very pure, has a high chemical resistance, good thermal shock resistance and is very strong in compression. The specifications of colloidal silica binder and fused silica are, respectively, given in table 1 and table 2. Two grades (primary and backup sands) of stuccoing sand were employed in the present investigation.

Primary sand: A finer grade silica sand having AFS grain fineness number 120. This is a synthetic sand. This sand was used for first two coats, called prime coats to get good surface finish and every detail of the wax pattern.

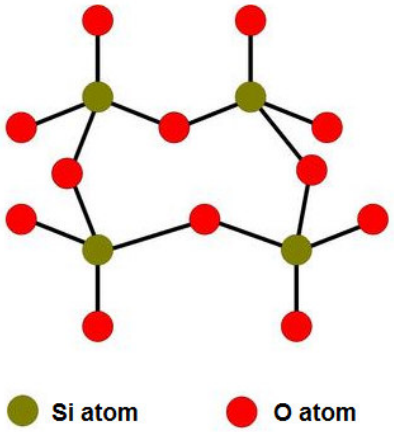

Figure 1. Crystal structure of fused silica.

Table 1. Specifications of silox binder

Property	Amount
Silica (SiO_2) Wt%	30
P^H at 25^0C	10.5
Titrable Alkali (Na_2O)	0.6
Chlorides/ Sulphates	Traces
Specific gravity, g/cc	1.23

Backup sand: A coarser grade sand having AFS grain fineness number 42. This sand was used for the rest of coats, called backup coats on the ceramic shells. This is a river sand. The backup sand was employed to develop more thickness to the shell walls with minimum coats.

Table 2. Specifications of fused silica

Density, g/cc	2.2
Refractoriness, ^0C	1715
Chemical composition	SiO_2
Sieve analysis	200-mesh (74 μm) 325-mesh (45μm)

2.1 Manufacture of ceramic shells

The ceramic shells were made of applying a series of ceramic coatings to the wax patterns. The pattern was first dipped into the dip-coating slurry bath. The pattern drains off excess slurry and to produce a uniform layer. The wet layer was immediately stuccoed with coarse silica sand. Each coating was allowed to dry in the open air. The operations of coating, stuccoing, and drying were repeated six times. The seventh coat was left unstuccoed to avoid the occurrence of loose particles on the shell surface. The first two coats were stuccoed with sand of AFS fineness number 120 and the next four coats were with sand of AFS fineness number 42. After all coats, the shells were air dried for 24 hours. Two shells of each treatment were made.

2.2 Hot strength of ceramic shells

The dimensions of specimens are 25mm X 32mm X t mm, where t is the thickness of the shell. The specimens used for bending test are shown in figure 2. The test of hot modulus of rupture was conducted on the universal sand- strength testing machine with attached

electrical oven as shown in figure 2. The temperature of the oven was measured with a thermocouple attached to it. To find hot modulus of rupture, the ceramic shell specimens were heated to various temperatures and the same was tested simultaneously in the oven for the bending strength.

Figure 2. Hot bending strength test

2.3 % thermal expansion of ceramic shells

It was measured in terms of %volume expansion of the ceramic shells. The length, width and thickness of the shells were measured using vernier calipers before and after sintering in the electrical oven. The % thermal expansion was computed using the following formula:

$$\% \text{ thermal expansion} = \frac{V_2 - V_1}{V_1} \times 100$$

where, V_1 is the volume of the shell before sintering and V_2 is the volume of the shell after sintering.

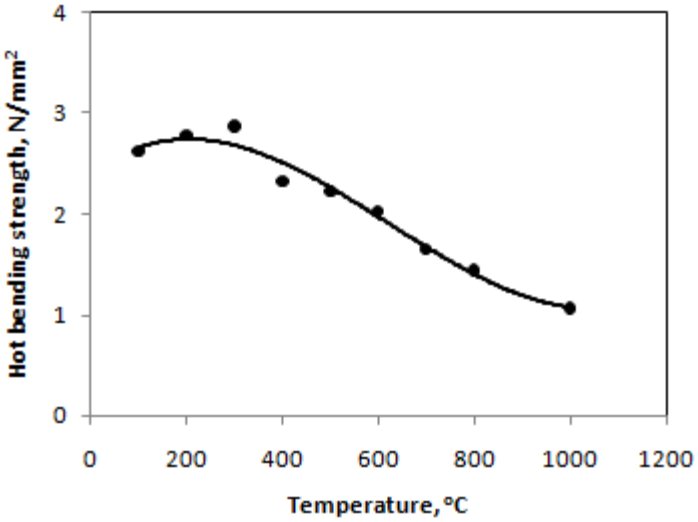

Figure 3. Effect of temperature on hot strength of ceramic shells.

3. Results and Discussion

The effect of sintering temperature on the hot bending strength of ceramic shells is shown in figure 3. The filler to binder ratio was 0.75 cc/ml. The hot bending strength fused silica shells increases with increasing temperature up to 300 °C and latter on the bending strength starts decreasing with increasing temperature. This is due thermal shock

experienced by the ceramic shells. Of all silica polymorphs, quartz is the only stable form at normal ambient conditions, and all other silica polymorphs transform into quartz. In theory, at normal pressure trigonal quartz (α-quartz) will transform into hexagonal β-quartz at 573°C, upon further heating the SiO_2 will transform into hexagonal β-tridymite at 870°C and later to cubic β-cristobalite at 1470°C. At 1705°C β-cristobalite finally melts:

	573°C		870°C		1470°C		1705°C	
α-Quartz	⇔	β-Quartz	⇔	β-Tridymite	⇔	β-Cristobalite	⇔	Silica Melt
trigonal		hexagonal		hexagonal		cubic		
2.65 g/cc		2.53 g/cc		2.25 g/cc		2.20 g/cc		

The changes in crystal structure lead to changes in the specific density: an increasing temperature corresponds to increasing vibrations of the atoms in the crystal lattice, and as these need more and more space, more open crystal structures are favored. Because the structure must also be in accordance with constraints on the geometry of the covalent bonds, in particular the angled Si-O-Si bond that connects SiO_4 tetrahedra.

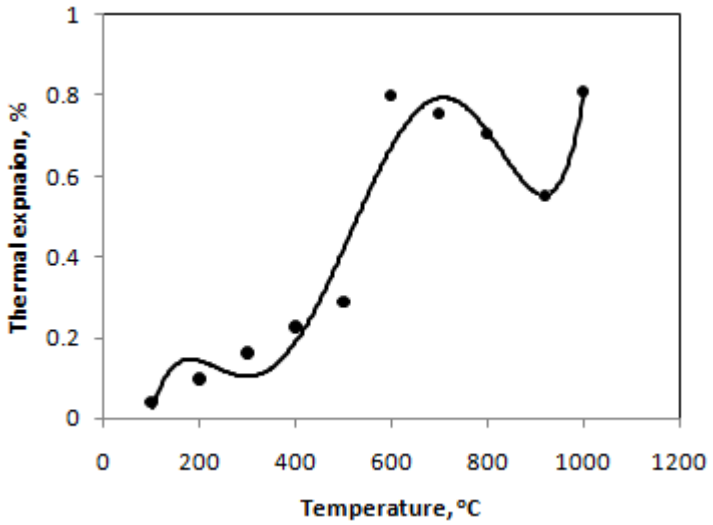

Figure 4. Effect of temperature on thermal expansion of shells.

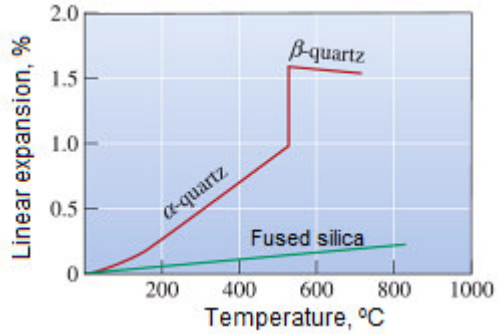

Figure 5. Effect of temperature on thermal expansion of fused silica and quartz.

The thermal expansion curve for fused silica is non–linear (figure 4). The non–linear nature of thermal expansion is due to phase transmission of stuccoing sand (primary and back up sand used for sprinkling during preparation ceramic shells) between 500 to 600°C. The thermal expansion of coefficient of fused silica is lower than that of crystallize quartz (figure

5). The discontinuity in the curve for crystalline quartz occurs on account of *α* to *β* phase transition. The ceramic shells which were sintered at 700°C were observed to have cracks. These cracks were owing to thermal shock. These cracks were not only limited to the surface but also penetrated into the thickness of shells.

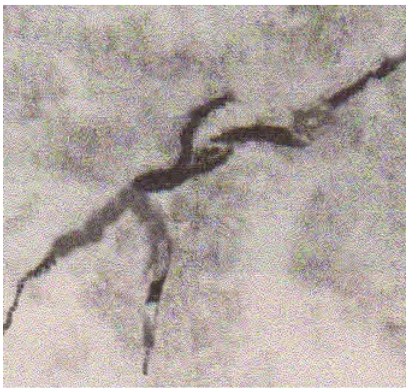

Figure 6. Optical photograph of sintered ceramic shell at 700°C.

4. Conclusions

The hot bending strength fused silica shells increases with increasing temperature up to 300 °C and latter on the bending strength starts decreasing with increasing temperature. The non–linear nature of thermal expansion in the ceramic shells is on account of *α* to *β* phase transmission of stuccoing sand between 500 to 600°C. The ceramic shells which were sintered at 700°C were observed to have cracks.

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