

PRODUCTION OF FUSED SILICA CORES USING POWDER INJECTION MOULDING TECHNIQUES

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ABSTRACT

A core is a separable part of the mould used to create openings and internal configuration in the casting that cannot be provided by the use of the pattern alone. Cores may be made of metal, plaster, graphite, core sand and ceramic materials. In the present study, Powder Injection Moulding techniques were used for producing various cores employing a fine fused silica powder. A composite binder comprising a major fraction of different molecular weight poly ethylene glycols (PEGs) and minor fraction of very finely dispersed poly methyl methacrylate (PMMA) derived from an emulsion was used for preparing the feedstock. Different trials were carried out to identify optimum conditions for various processing steps involved; such as feedstock preparation, injection moulding, debinding and firing. The cores were impregnated with a proprietary chemical to improve their strength. These cores had adequate strength and good collapsibility and did not produce harmful gases.

Key Words: Core, Powder Injection Moulding, Feedstock, Debinding, Collapsibility.

INTRODUCTION

Most simply defined, cores are sand shapes which form the casting contour that cannot be moulded with a pattern alone. In sand casting process, drawing the pattern from the mould limits the casting exterior to a contour that can be freed from the sand vertically as it is done with moulding equipment. Forming internal configuration of the castings, thus depends mainly on cores which can be inserted into a mould of the casting exterior. Through their use in forming complex internal cavities, cores provide the casting process its ability to make the most intricate of shapes which would be impossible to machine. A wide variety of methods and materials are used for making cores [1]. Thus, cores may be made of metal, plastic, graphite and investment and ceramic materials as well as core sand. To achieve the utmost of intricacy in castings, cores must be collapsible after the metal is poured. Metal cores used in permanent-mould or die-casting, do not have collapsibility and therefore have shape limitations. However, sand cores and some other materials do not have this handicap and can therefore produce almost any desired shape [2]. Due to relatively low cost, sand cores are more frequently used. The sand cores give relatively poor surface finish due to the coarse

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grains of the sand. Refractory coatings are frequently applied to cores to enhance the casting surface finish and to reduce casting defects at the mold/metal interface. In the last two decades, a relatively new process known as Powder Injection Moulding has been used for making complex shaped cores. The use of fine refractory powders in this process gives good surface finish and high refractoriness. In the present study, Injection moulding of fused silica powder has been described for manufacturing cores.

EXPERIMENTAL

During the present study, a fused silica powder was used for making cores. Scanning electron microscopy was used to study the morphology of the powder. A Coulter LS 130 Particle Size Analyzer was used for measuring particle size distribution. Several ways of preparing feedstocks of different compositions were investigated. These included changing the sequence in which the binder constituents were added, their amounts and the temperature used during mixing. A horizontal, hydraulically operated plunger type of machine was used for injection moulding bar-shaped test specimens having dimensions 125 x 12 x 6 mm. Different trials were carried out to identify optimum conditions for various processing steps such as, feedstock preparation, injection moulding, debinding and firing. Some complex shaped components were also made. The cores were impregnated with a proprietary chemical to improve their strength.

EXPERIMENTAL RESULTS AND OBSERVATIONS

The SEM micrograph (Figure 1) shows that the particles were of irregular shape. The cumulative particle size distribution of the fused silica powder is given in Table 1 and plotted in Figure 2.

Table 1: The cumulative particle size distribution of the fused silica powder.

| | | | | | |
|--------------------|-------|-------|-------|------|------|
| % > | 10 | 25 | 50 | 75 | 90 |
| Size μm | 55.61 | 32.48 | 12.82 | 4.36 | 1.87 |

A binder having composition 8 wt. % PEG₆₀₀, 8 wt. % PEG₁₀₀₀, 64 wt. % PEG₁₅₀₀ and 20 wt. % PMMA, incorporated in the form of an emulsion (binder No. 1), was used [3]. A feedstock batch of 2kg using 60 vol. % powder loading and binder No. 1 was mixed as slurry by hand and dried before injection moulding. This was easily injection moulded at temperatures of 130 °C and 135 °C for the barrel and nozzle respectively, using the water cooled test bar mould. The feedstock was not completely dry and generated steam at the moulding temperatures. This caused the surfaces of the bar to be undulated. In addition, the appearance of the bars suggested that some separation of the lower molecular weight PEGs had occurred. Thorough drying of the feedstock reduced the tendency of the surfaces of the moulding to be undulated. However, when left in air (room temperature ~

28 °C), the low molecular weight PEGs 'sweated out' of the moulded samples, which caused their surfaces to sink inwards and to become undulated. After firing, the bars were slightly bent.

In the second trial, A feedstock batch weighing 2 kg and having 62 Vol. % powder loading was mixed by hand as a slurry which was then dried and mixed again in a heated Z-blade mixer at 80 °C. In this trial, the amount of the lower molecular weight PEGs was reduced. PEG₁₀₀₀ was not available from the supplier and so was left out of the formulation. Thus the binder used for this study consisted of 78 wt. % PEG₁₅₀₀, 2 wt. % PEG₆₀₀, and 20 wt. % PMMA (binder No. 2). The feedstock was easily moulded at 135 °C barrel and 140 °C nozzle temperatures, respectively. To avoid the 'sweating out' of PEGs, the moulded specimens were immediately immersed in water for removal of PEGs. The leached samples were dried and heated at a rate of 5 °C/min. to the firing temperature. The fired samples did not show any swelling or cracking. A slight bending in the center of some of the bars was observed, however, many bars did not show any bending. A uniform shrinkage in all dimensions was observed.

A few leached test bar samples were left in open air for about 60 days and were heated at 2 °C/min. up to firing temperature (1180 °C) without drying prior to firing. The samples showed swelling and cracking at the surface. However, no swelling or cracking was observed when the samples were dried prior to firing.

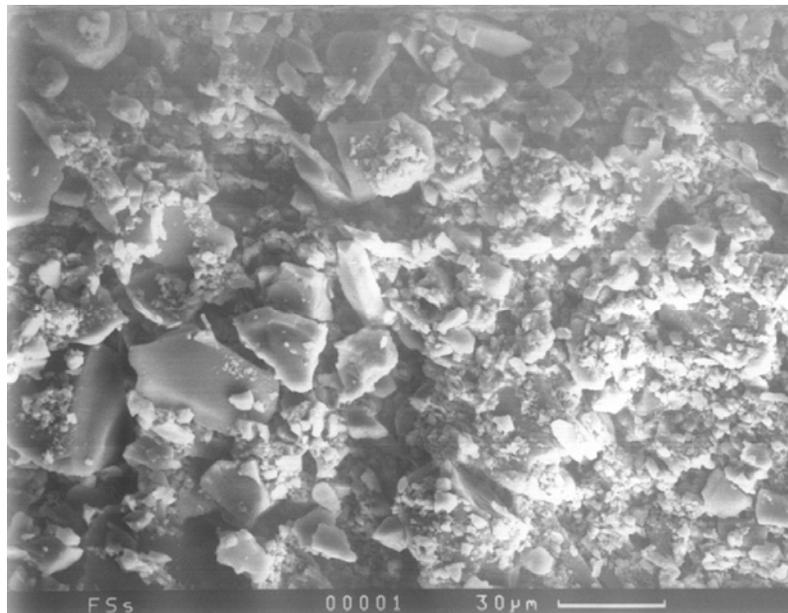


Figure 1: Scanning electron micrograph of the fused silica powder

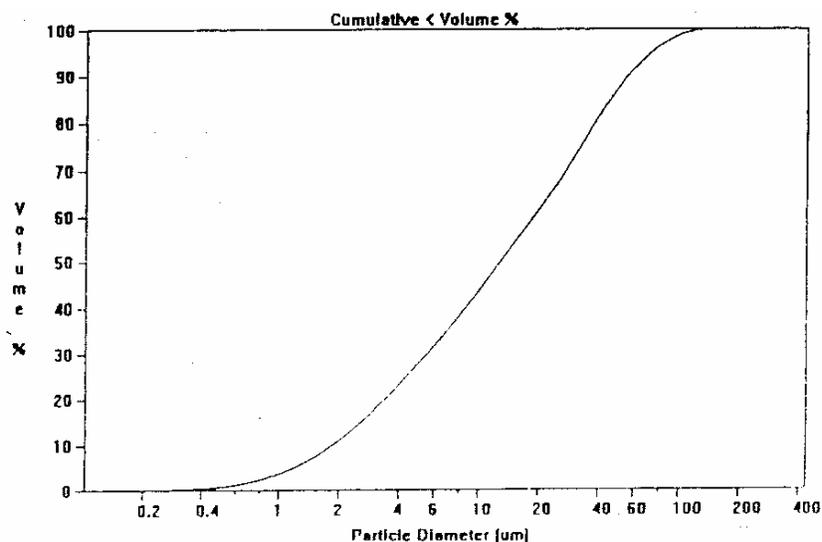


Figure 2: The cumulative volume percent and particle size distribution of the fused silica powder particles.

DISCUSSION

During the injection moulding of the fused silica powder, it was found that steam was generated in the feedstock and the surfaces of the green bars became undulated. However, these problems were eliminated by thorough drying of the feedstock. The colour of the green bars suggested that some separation of the binder occurred especially at the gate of the mould. It is thought that low molecular weight PEGs have comparatively low viscosities and, thus, there is a greater possibility of their separation. Therefore, it was decided to reduce the amount of low molecular weight PEGs in the binder formulation. Complete drying of the large batches of the feedstocks at low temperatures takes a long time because PEGs have a high affinity for water. Therefore, it was decided to use alternative methods of mixing without employing any water. Two methods were investigated, as given in the flow diagrams (Figures 3 & 4). The feedstocks produced using these methods did not generate steam at the moulding temperatures and produced defect-free mouldings. Most of the work was carried out in the summer. It was observed that when green bars were left in air (room temperature $\sim 28^\circ\text{C}$), some PEGs 'sweated out' at the surfaces. It is thought that low molecular weight PEGs were in the liquid form at this temperature and came to the surface. To avoid this sweating, the moulded specimens were immediately immersed in water for leaching. A very low overall shrinkage of about 0.1 % was measured for leached specimens and, no localised swelling or distortion was observed. To expose all the surfaces of the component to water and to remove the PEGs simultaneously from all the surfaces, the moulded bars were placed on a bed of ~ 1 mm glass beads.

The leached specimens were dried at $60\text{--}70^\circ\text{C}$ for one to two hours prior to firing. Heating rates of $3\text{--}5^\circ\text{C}/\text{min.}$, from ambient to the firing temperatures (1180°C), were successfully used. No intermediate soaking was employed. The samples were held at the firing temperatures for different times to achieve the required densities and strengths. A number of complex-shaped components were also produced. One of the components had thickness varying from 3.35 to 1.00 mm, with variable curvatures. While another had various section thicknesses, one end being

6.8 mm thick and the other 1.0 mm thick. About 2-3 days are used in industry for the thermal debinding and firing of these components whereas, during the present study, the thermal debinding and firing cycles were typically about 12-14 hours.

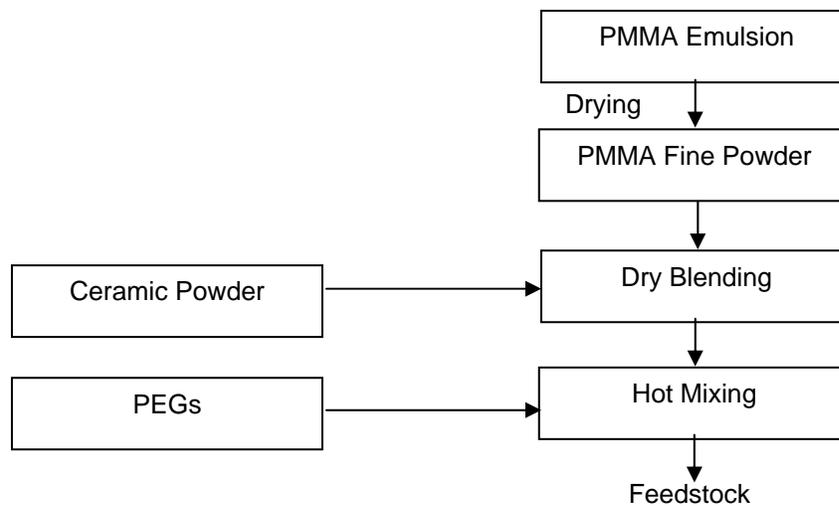


Figure 3: Flow diagram for mixing of feedstock employing dry PMMA powder particles

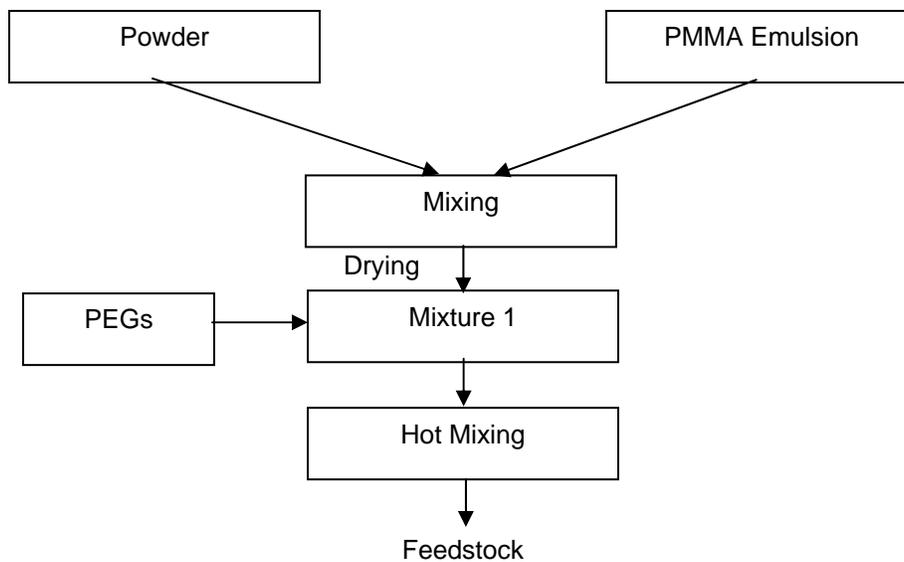


Figure 4: Flow diagram for hot mixing of feedstock

CONCLUSIONS

From the results of the present study, it can be concluded that:

- 1) The feedstocks produced by using binder Nos. 1 & 2 showed good mouldability in the temperature range of 140 – 150 °C. The moulded parts have adequate green strength.
- 2) The mixing methods (Flow diagrams, Figures 3 & 4) did not employ any water. Thus, the lengthy drying process was eliminated. The feedstock produced by these methods did not produce steam.
- 3) It was observed that low molecular weight PEGs can be ‘sweated out’ at the surface when using coarse powder, especially in summer. The ‘sweating’ problem can be overcome by reducing or eliminating the low molecular weight PEGs in the binder formulations. The other possible solution is that the green parts should immediately be immersed in water for removal of PEGs.
- 4) Higher heating rates than for conventional binder systems can be used for thermal debinding and sintering/firing heat-treatments, which shorten the total cycle time. Thermal debinding and sintering/firing can be carried out in one heating cycle and no separate debinding stage or equipment is required for ~ 10 mm thick sections.

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