Design and development of ceramic mould for high precision investment casting

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Abstract

The investment casting is recognized and used worldwide as a technique for producing close tolerance metal parts at highly competitive costs. To our knowledge, for the first time in Sri Lanka modeling of complex engine parts by the rapid prototype technique and subsequent mould making for investment casting using ceramic materials were performed. The design and development of ceramic mould of complex engine parts for investment casting process is described in this work. The design of pattern for Aluminium casting was done using Pro-engineer modeling software and actual polycarbonate model was done by rapid prototype machine. The ceramic mould composition was determined with Zirconium silicate, Alumina, Refined Kaolin, Grog and binders as high refractory and high density materials are required. To obtain the excellent surface finish of the inner most surface of the mould, slurry of Zirconium silicate, Alumina, refined kaolin and binders were used. Zirconium silicate and alumina used for this layer were very fine in order to get smooth and even surface finish. Further the slip used for this layer was kept at high density to minimize drying shrinkage to avoid cracking. On top of the inner most surface a fine Grog layer was deposited by spraying. The second layer and the subsequent layers of the ceramic slip were prepared with coarser alumina and zirconium silicate and the grog used was coarser for subsequent layers. This ceramic slip and the grog were applied alternatively until the required mould thickness was achieved. Finally the ceramic mould was fired to burn off the polycarbonate pattern leaving the design required for aluminium casting.

1. Introduction

Investment casting process is a well established manufacturing process with greater product design freedom from very simple to highly complex parts with tight dimensional tolerances and excellent surface finish than other casting processes. Therefore expensive machining, wastage of material could be reduced or eliminated while providing the design economy and flexibility than other casting process.

The investment casting is widely used for producing of complex geometries of ferrous and non ferrous materials [1]. Many researches have been performed on this subject during past four to five decades. The ancient method of investment ("lost wax") casting of metal components has been transformed into a near net shape forming technique offering the designer at the forefront of metal casting economy and flexibility [2].

McGuire [3] had developed a method for forming investment casting shell and obtained the US patent for it. In his study slurry of colloidal silica, zircon flour and fused silica had been used to build the mould around wax pattern, wherein the slurry was included particles of varying size. The surface quality of the casting is determined by particle size and composition of the slurry in mould making. (PC Sharma) [4].

This research reports the systematic investigation carried out to build the ceramic shell around the polycarbonate pattern with fine particle size zirconium silicate, alumina, refined kaolin and grog. Use of colloidal silica and fused silica were avoided and refined kaolin and alumina were used instead. Today, the investment casting is recognized and used worldwide as a technique for producing close tolerance metal parts at highly competitive costs.

The Ceramic moulds are used to cast pieces or tools with fine details, very smooth surfaces, high dimensional accuracy and good metallurgical integrity, in a diversity of metallic materials. The surfaces of this type of ceramic moulds have refractory properties which allow them to withstand the high temperatures of casting, as is the case of ferrous alloys. Furthermore, the excellent thermal stability of these ceramic moulds is very important. The ceramic moulds are produced by mixing in variable proportions, depending on the type of ceramics employed, strength desired and other properties [5].

To our knowledge for the first time in Sri Lanka, modeling of complex engine parts using by rapid prototype technique and subsequent mould making for investment casting using ceramic materials were performed. Since investment casting uses expendable patterns and ceramic shells, it is excellent for complex and detailed part designs. The process manufactures intricate parts that are difficult to machine, form or forge [6].

Castings are used in areas like transportation, aerospace, defense, mining, construction, fluid power, & domestic household. Some cast components include engine blocks, suspension parts for automobiles & fluid flow components like valves, pumps, pipes, and fittings. There is a need to improve the fuel efficiency and make the vehicle lighter in weight. Aluminium is no ferrous metal which is lighter than steel and has density one third of that of steel. Aluminium has a lower density of 2.7 gm/cc compared to 7.8 gm/cc of steel. Aluminum and aluminum alloys are lightweight with good corrosion resistance, ductility and strength. Aluminium castings are more expensive than ferrous based castings. The greater use of them can decrease vehicle weight, improve its performance and reduce fuel costs. Pure aluminium possesses relatively poor casting features and for this reason castings are prepared from aluminium alloys [7].

2. **Procedure**

2.1. Design of pattern

Initial models of the engine components were designed using Pro-engineer modeling software and actual polycarbonate model was done by rapid prototype machine. The gating system was selected as the metal pouring from the top of the mould for aluminuim casting. The gating system was made of the same modeling materials as that used for the mould cavity.

2.2. Development of ceramic slurry

The composition of the ceramic mould for investment casting was determined with 65% of zirconium silicate, 25% of quartz, 10% of refined kaolin and sodium silicate. The particle sizes of the refractory materials are about 325 mesh. Carboxymethyl Cellulose (CMC) was used as binder of the ceramic slurry and the specific density of the slurry was about 2.40. The viscosity of the slurry was maintained about 305 units (Torsion viscometer with probe size 11x16). The slurry was mixed properly with the help of stirrer and maintained its optimum quality and consistency by regular monitoring.

2.3. Development of ceramic mould

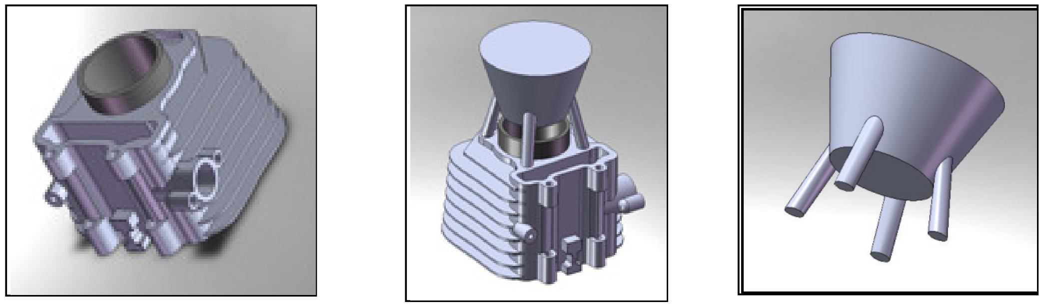
A two-step process was used including dipping the pattern into the slurry, then spraying binders and refractory powders on it. The first coat of the mould was developed by dipping the pattern into the ceramic slurry. It was a fine, dense and uniform layer avoiding the entrapment of air bubbles. The pattern was lifted and held above to remove excess fluid from the pattern. Once the first layer is fully dried, the pattern is dipped again in the same slurry to ensure any missed area of the pattern. It was allowed to air dry and the on top of the inner most surface PVA (Polyvinyl acetate) was applied. A fine grog layer of 150µm was deposited by spraying.

The mould was dried again and the second layer was built by dipping in the same slurry to increase the shell thickness. The mould was allowed to dry 10- 20 minutes after each dipping. Then PVA was applied and the particle size of 250µm grog layer was deposited. The process of dipping the investment in the slurry, air drying, applying PVA and grog layer was repeated to build the shell mould.

This ceramic slip and the grog were applied alternatively until 6-7 mm wall thickness was achieved. The sealing coat was applied to the mould without adding a further grog layer on it. The sealing coat was applied to bind any residual refractory material to the surface, preventing loose particles falling away from the finished investment mould. The smooth surface of a sealed mould made easier to handle. The process of shell building was time consuming as each coat of slurry need to be air dried prior to application of subsequent layers. The air drying period of the ceramic investment was reduced using the electric fans, but higher drying rate can cause the shell to crack.

2.4. Firing of the ceramic mould

The mould was allowed to dry 07-10 days to remove the moisture and fired in an electric furnace to melt out the pattern maintaining 1090^0C for 2 hours. The mould was allowed to sinter to obtain required hardness for 1 hour. During the firing of the mould, the substrate was melted or burned away leaving the shell and any substrate. During the burning process of the polycarbonate the Different Thermal Analyse (DTA) curve was recorded and observed. The DTA and TG curves are shown in the Figure 02.



(a) (b) (c)

Figure 01: 3D patterns of fabricated mould

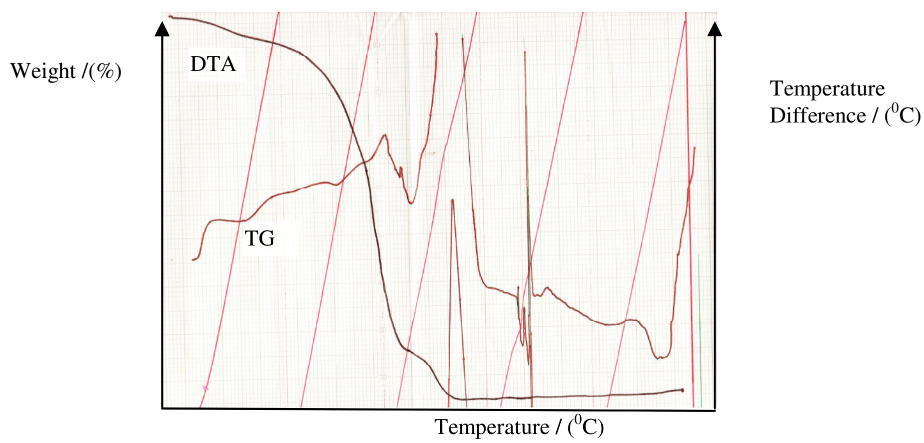


Figure 02: Different Thermal Analysis (DTA) and Thermogravimetric analysis (TG) curve of polycarbonate pattern during burnout process

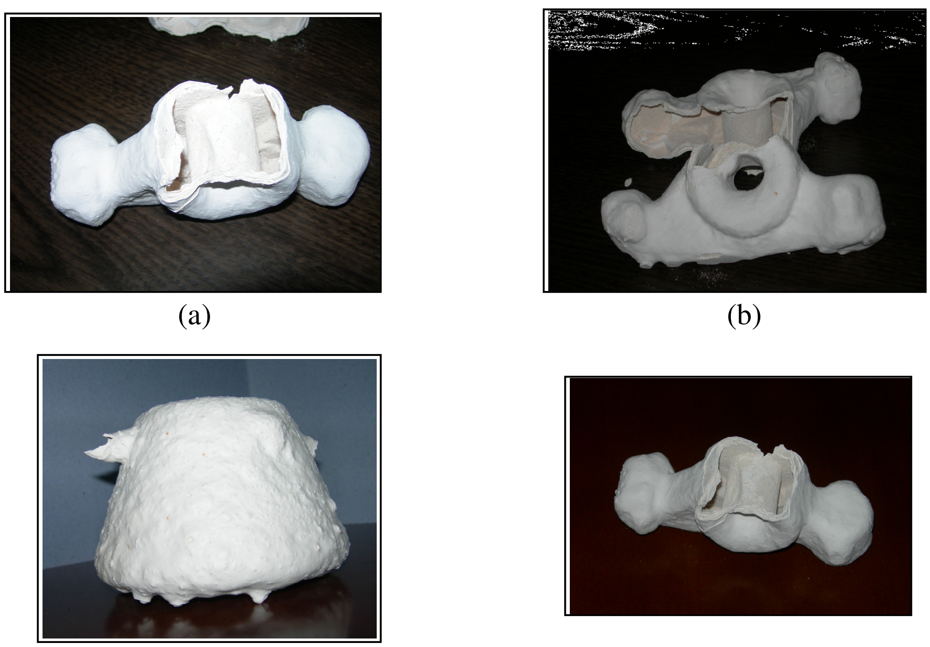
3. Results and Discussion

The use of carefully developed ceramic compositions with precisely control mould making procedure is required to make a mould of complicated shape which requires high degree of precision and smooth surface finish. In order to get excellent surface finish materials of high density and fine particle sizes are necessary. The slurry consists of fine refractory materials which capable of depositing a uniformly dense coating over the pattern. Zirconium silicates and alumina in fine forms are ideal materials to be used for the above purpose. A fine deposit is essential to the formation of microscopic details of face coat. Fine grog made a good backup layer as it gives the strength and the thickness to the mould. The composition of the ceramic mould is shown in the Table 01.

Table 01: composition of the ceramic mould

Material	Composition
Zirconium silicate	65%, 325 mesh
Refined kaolin	10%
Quartz	25%, 325 mesh
Grog	1~2 kg, 150µm & 250µm
Polyvinyl acetate (PVA)	10 g
Carboxymethyl Cellulose (CMC)	20~30 g
Sodium silicate	20g

The developed ceramic moulds are shown in the Figure 02 and 03.



(a) (b) (c) (d)

Figure 02: The developed ceramic mould of different engine parts

Figure 03: Microscopic view of different layers in the ceramic mould

The composition of 65% of zirconium silicate and 35% of refined kaolin provide thicker and dense ceramic slurry which made faster shell building. The ceramic moulds tend to crack during drying as the slurry containing more refined kaolin. The pattern material is amorphous polymer which has sudden increase of volume at glass – transition temperature ($T_g = 58^0C$). Therefore the ceramic mould should have strength to withstand at that pressure.

The investment must be able to withstand temperature fluctuations with minimal or no adverse effect. The investment mould is exposed to temperatures of between 550-1200^{0}C during pattern burnout, firing and metal pouring. Ceramic shell investments in particular are exposed to very rapid fluctuations of temperature. The investment mould must be strong enough to withstand internal and external forces. It must expand as it heats up during the kiln burnout.

The secondary layers of the mould are built up with an increasingly coarse and less costly refractory body as the coarse particles of the backup layers are not in direct contact with the polycarbonate pattern and no effect on the surface quality of the metal cast. In forming less dense wall than the first layers allow casting gases to more easily permeate through the investment wall.

After applying the face coat of the mould which is allowed to air dried. Failure to allow this first deposit to dry before applying a second of slurry may cause the initial layer to lose the adhesion with the underlying pattern lading to deposit slippage and a poor quality cast surface.

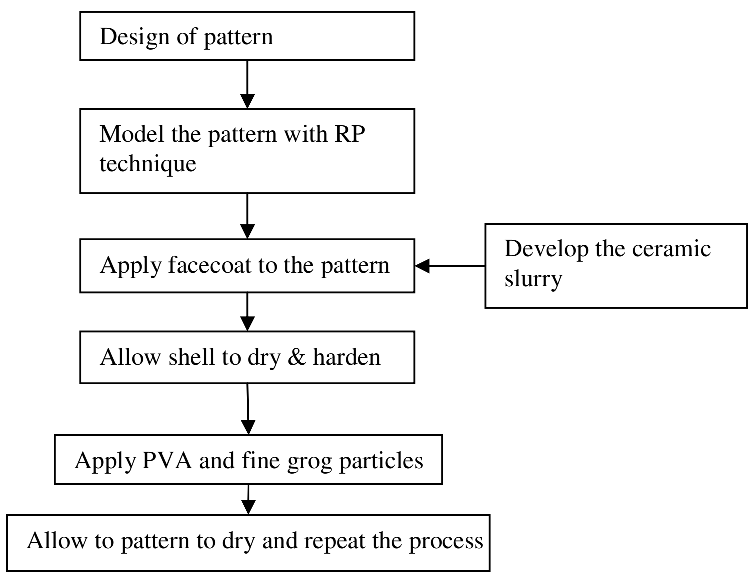


Figure 04: Process flow diagram of the invention

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