International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

Development of Alumino-Silicate Investment Shell Moulds to Cast 6061 Al-Alloy

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Abstract: ***The investment shell moulds were fabricated with ceramic slurry containing alumino-silicates as filler materials and colloidal silica binder. The investment shell moulds were characterized in terms of hot bending strength and thermal shock. The flow time of slurry solution through the Ford cup is directly proportional to the amount of filler added the liquid binder. The Al_2O_3 / SiO_2 ratio of 60/40 has greater bonding strength than those of ratios of 50/50 and 40/60 respectively. As the Al_2O_3 content in the filler material, the metastability of the investment shell mould increases leading cracks. The microstructure of 6061 Al-alloy reveals some undissolved Mg_2Si.***

Keywords: Investment shell moulds, alumino-silicates, hot strength, thermal expansion, metal-mould reaction.

1. Introduction

The materials used to build the investment shell moulds, especially binders and refractories, play a vital role in the production of quality castings. With regard to binders many references are available to the industry today are, in general, conventional colloidal silica, sodium silicate, ethyl silicate and hybrids using ethyl silicate. Colloidal silica [1-4] is the most widely used. In addition to the binders, refractories are also used in the construction of investment shell mould. There are two grades of refractories used: flours (fillers) for use in the slurries and grains for stuccoing the shell mould. The refractory filler materials in the dip-coating slurries range from 200 to 600 mesh in particle size. Coarser materials ranging up to 325 mesh are used in backup slurries. The refractory filler materials used today to prepare the investment slurries are silica, zirconia, alumina, aluminum silicates, yttria, titania, graphite, magnesia and cristobalite [5-12]. The recrystallization of fused silica to cristobalite results in a softening of the investment shell mould [13, 14]. Alumina has poor resistance to thermal shock. Castings poured in the alumina shell moulds are relatively difficult to clean. The most important factor of refractory filler material is its density; which in fact, results the sedimentation of filler in the dip-coating slurry [15]. The sedimentation of filler in the slurry leads to non-uniform density and consequently non-uniform viscosity, which promotes non-uniform strength and permeability of investment shell moulds.

In the present work, aluminum silicates were used as refractory filler materials to fabricate investment shell moulds for casting of 6061 Al-alloy.

2. Materials and Methods

In the present work, the colloidal silica binder was used to fabricate the ceramic shells from aluminum silicates as reinforced filler materials. The specifications of colloidal silica binder are given in table 1. Two grades (primary and backup sands) of stuccoing sand were employed in the present investigation. Finer grade silica sand having AFS grain fineness number 120 was employed for primary coats. This is 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. Coarser grade sand having AFS grain fineness number 42 was employed for back up coats. This is river sand. The backup sand was employed to develop more thickness to the shell walls with minimum coats.

2.1 Manufacture of investment shell moulds and 6061 Al-alloy castings

The preparation of investment shell moulds and casting is shown in figure 1. The dip coating slurries were prepared by adding the refractory filler powder to the binder liquid, using sufficient agitation to break up agglomerates and thoroughly wet and disperse the powder. The filler/binder ratio in the slurry was according to the design of experiments. The investment shell moulds 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 magnesia 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 shell moulds of each treatment were made.

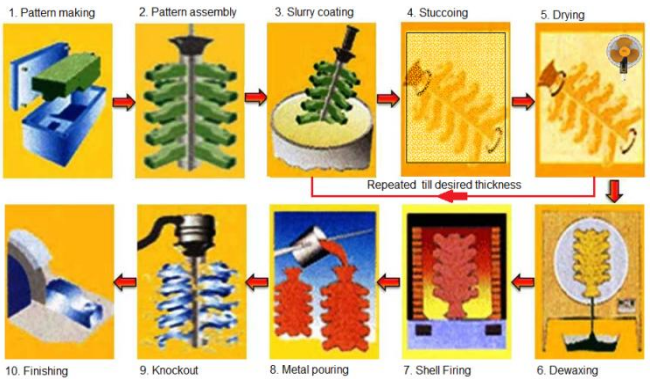

Figure 1: Fabrication investments shells and casting of 6061 aluminum alloy.

The 6061 aluminum alloy was melted in an oil fired furnace. During melting, the alloy was coated with flux (covral-11S)

to prevent the oxidation of the metal. The liquid metal was degasified with tetrachlorethane tablets and also modified with sodium. The liquid alloy was gravity poured into the pre-heated ceramic shells. The shells were knocked off by hand hammer after solidification of the molten. The castings were cleaned with soft brush and visually inspected for pins and projections.

2.2 Measurement Viscosity Dip Coating Slurry

The ford viscosity cup to measure the slurry viscosity was designed and fabricated as per the dimensions mentioned in the ASTM Hand Book [16]. The ford cup was adjusted in the stand as shown in figure 2, so that its upper edge was horizontal. The orifice of the cup was blocked by a finger, and the cup was filled by thoroughly mixed slurry, until a convex meniscus appeared above the upper edge. Excess slurry was scraped off with a straight edge. With the opening of the orifice, a stopwatch was started simultaneously to measure the time from the beginning of outflow until the first break in the stream. The kinematic viscosity was also computed. Following each determination, the cup was cleaned by methanol, water and a soft brush. The formula to convert the time of flow in seconds, t to kinematic viscosity, ν is given by

$$\nu = 12.1 [t - 2.00] \quad (1)$$

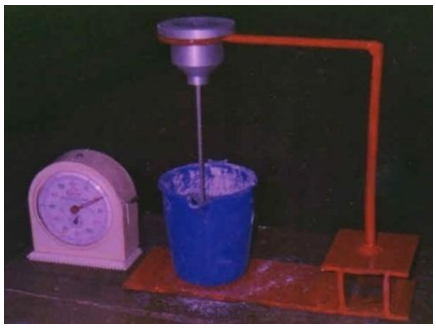

Figure 2: Measurement viscosity of investment slurry.

2.3 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 3. The three-point bending test was conducted on the universal sand- strength testing machine [17].

Figure 3: Bending strength test of investment shell moulds.

2.4 % thermal expansion of ceramic shells

It was measured in terms of %volume expansion of the investment 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:

$$\% \text{ thermal expansion} = \frac{V_2 - V_1}{V_1} \times 100 \quad (2)$$

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

2.5 Thermal conductivity of investment shells

ASTM E1225 standard procedure was employed to determine thermal conductivity of investment shells. This test method describes a steady state technique for the determination of the thermal conductivity.

3. Results and Discussion

Aluminum silicate powder is a type of fibrous material made of aluminum oxide and silicon dioxide figure 4. Silicon atoms or ion tend to be bonded to 4 oxygen atoms in a tetrahedral fashion, but aluminum ions tend to be bonded to 6 oxygen atoms in an octahedral fashion. In the present work three types of aluminum silicates as refractory filler in the investment slurries were used, namely: 60% Al_2O_3 + 40% SiO_2, 50% Al_2O_3 + 50% SiO_2, and 40% Al_2O_3 + 60% SiO_2.

Figure 4: Aluminum silicate powder.

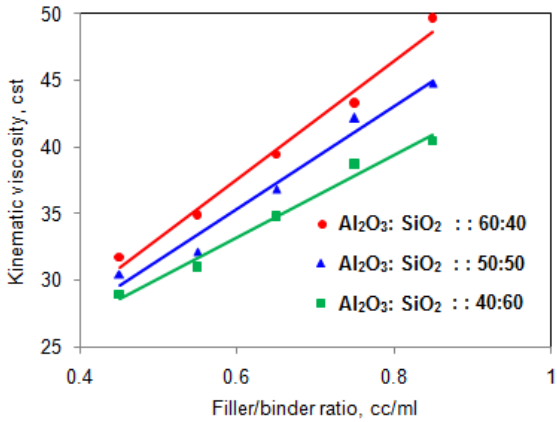

Figure 5: Effect of filler/binder ratio on slurry viscosity.

3.1 Effect of filler/binder ratio on slurry viscosity

Viscosities of slurries having different composition are shown in figure 5. It is observed that the flow time of slurry solution through the Ford cup is directly proportional to the amount of filler added the liquid binder. The slurry viscosity

also increased with the increased content of alumina content in the filler reinforcement. This may be attributed to the increase of filler density with increased content of alumina.

3.2 Bending strength of investment shells

The effect of filler/binder ratio on the bending strength of alumina investment shells is shown in figure 6. The bending strength of investment shells was found to be high for filler/binder ratio of 0.75 cc/ml. The Al_2O_3 / SiO_2 ratio of 60/40 has greater bonding strength than those of ratios of 50/50 and 40/60 respectively. This was mainly due to status of electrostatic bonds between silicon radicals in the binder, filler particles and stuccoing sand grains at different slurry compositions [18].

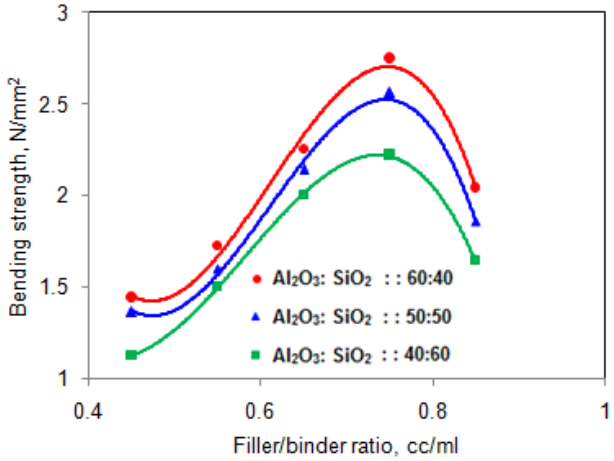

Figure 6: Effect of filler/binder ratio on bending strength of investment shells.

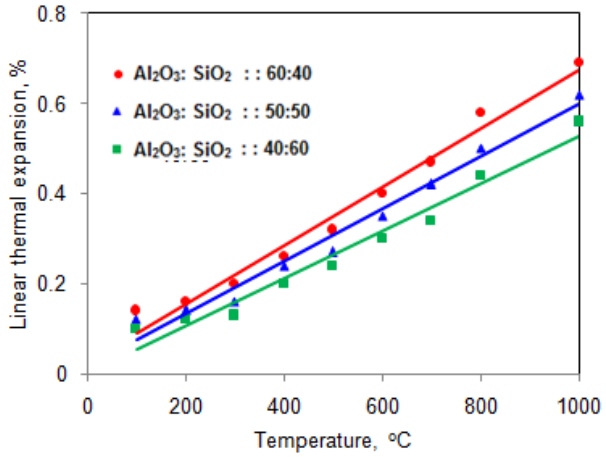

Figure 7: Effect of temperature on thermal expansion of shells.

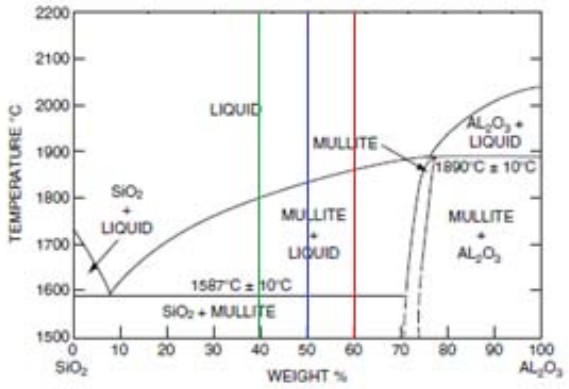

Figure 8: Phase diagram of SiO_2 and Al_2O_3

3.2 Thermal shock in investment shells

The thermal expansion curve for investment shells is illustrated in figure 7. As the Al_2O_3 content increased the thermal expansion was increased. Below 1600°C, the three mixtures used in the present work consists of mullite and SiO_2 (figure 8). This may be attributable to the presence or absence of α-Al_2O_3 in the starting materials. As the Al_2O_3 content in the filler material, the metastability is widened as shown in figure 9. Mullite is a solid solution phase of alumina and silica. Mullite is a solid solution compound with stoichiometries ranging from relatively silica-rich $3Al_2O_3$.$2SiO_2$ (3:2 mullite) to alumina-rich $2Al_2O_3$ .SiO_2 (2:1 mullite). Mullite structures consist of chains of distorted edge-sharing Al−O octahedral at the corners and center of each unit cell running parallel to the *c*-axis (figure 10). The chains are cross-linked by Si−O and Al−O corner-sharing tetrahedral.

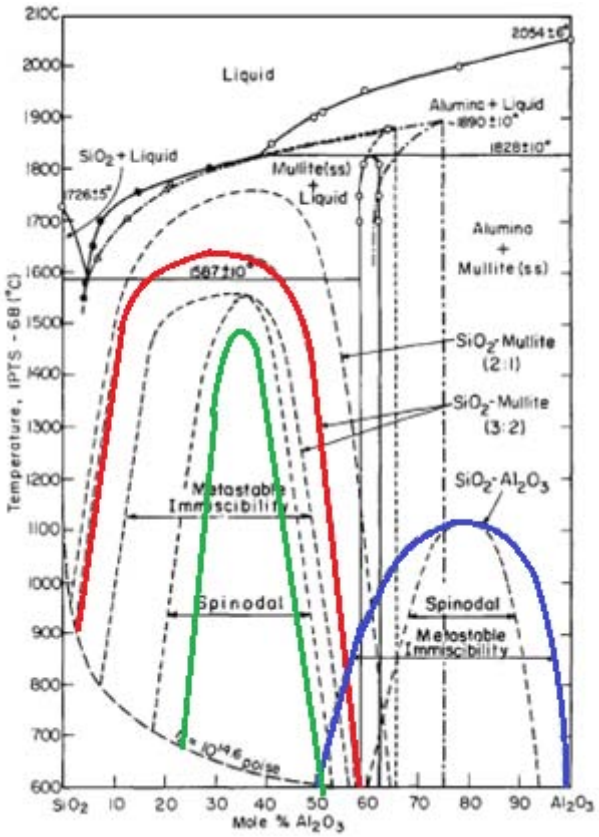

Figure 9: Metastable regions of SiO_2 – Al_2O_3 system.

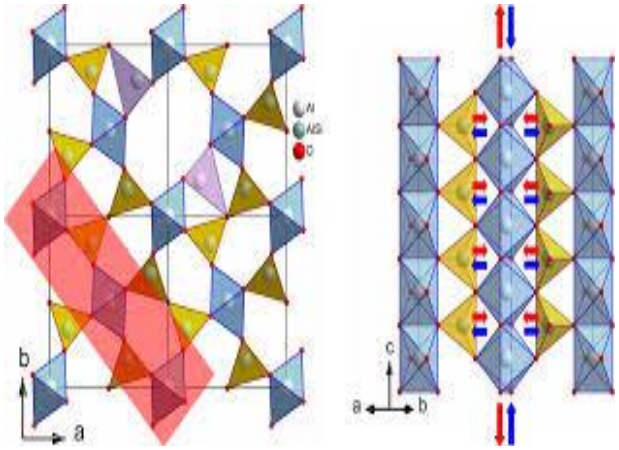

Figure 10: Crystal structure of mullite.

Due to thermal shock, the cracks are observed in the investment shell moulds. More cracks are induced in the investment shell moulds with Al_2O_3 / SiO_2 ratio of 60/40 filer loading in the slurry (figure 11). This is confirmed with scanning electron microscopic observation of investment shells as shown in figure 12.

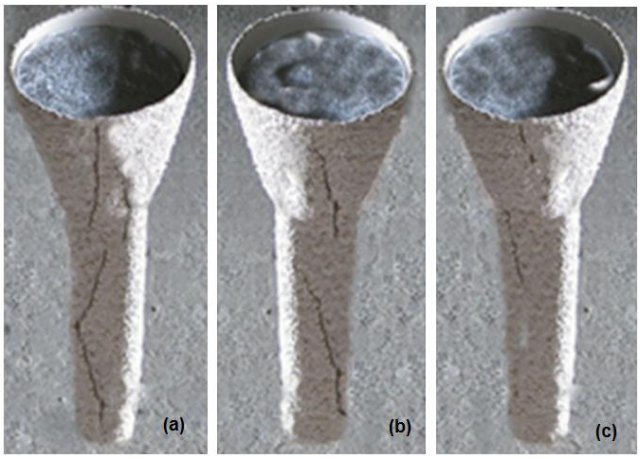

Figure 11: Thermal shock in the investment shells (a) Al_2O_3 / SiO_2 ratio of 60/40 (b) Al_2O_3 / SiO_2 ratio of 50/50 and (c) Al_2O_3 / SiO_2 ratio of 40/60

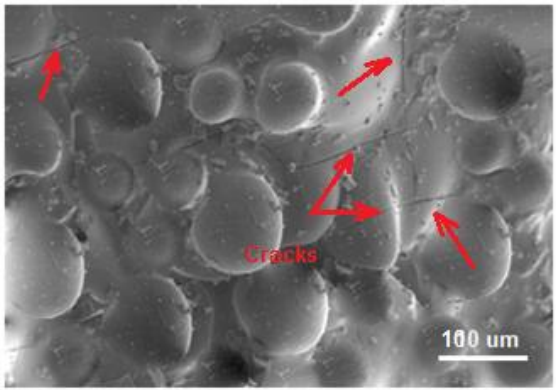

Figure 12: SEM image showing crack due to thermal shock in shells having Al_2O_3 / SiO_2 ratio of 60/40 at 1000°C.

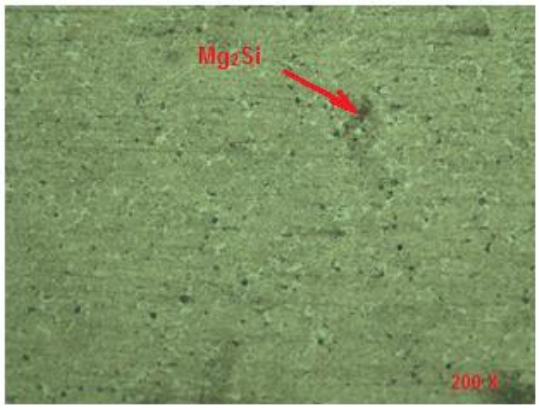

Figure 13: Microstructure of as-cast 6061 Al-alloys in the investment shells having (a) Al_2O_3 / SiO_2 ratio of 60/40 (b) Al_2O_3 / SiO_2 ratio of 50/50 and (c) Al_2O_3 / SiO_2 ratio of 40/60.

3.3 Microstructure of 6061 Al-alloy

The microstructure (figure 13) of 6061 Al-alloy cast in three investment shell moulds is nearly same. The discrepancy in grain size is due to marginal difference in thermal conductivity (figure 14) of investment shell moulds. The microstructure reveals some undissolved Mg_2Si. The true stress-true strain curve of 6061 Al-alloy is shown in figure 15. The tensile strength, yield strength and elongation at breakage are, respectively, 145 MPa, 59 MPa, and 25%.

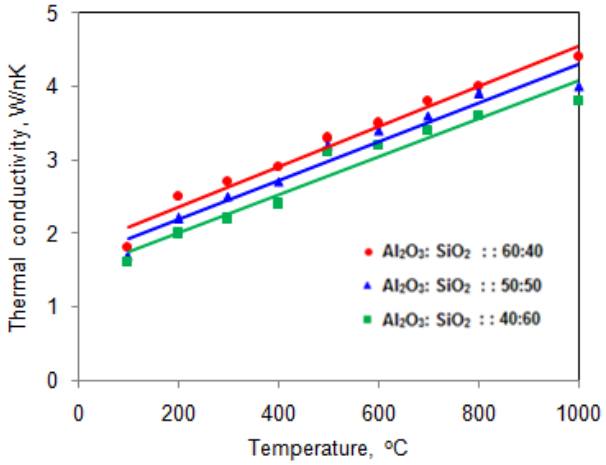

Figure 14: Thermal conductivity of investment shells

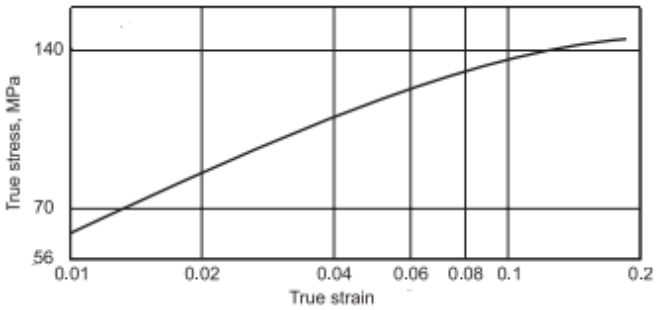

Figure 15: True stress-true strain curve of 6061 Al alloy.

4. Conclusions

The Al_2O_3 / SiO_2 ratio of 60/40 has greater bonding strength than those of ratios of 50/50 and 40/60 respectively. As the Al_2O_3 content in the filler material, the metastability

of the investment shell mould increases leading cracks. The microstructure of 6061 Al-alloy reveals some undissolved Mg_2Si.

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