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COMPARISON OF MICROSTRUCTURE OF AL-CU ALLOYS CAST IN CALCITE INVESTMENT SHELL AND DRY SAND MOULDS

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ABSTRACT
The investment shell moulds were fabricated with ceramic slurry containing calcite as a filler material and colloidal silica binder. The shell characteristics in terms of hot bending strength, thermal expansion and thermal conductivity were measured. The microstructure and tensile strength of Al-Cu alloys cast in calcite investment shell and dry sand moulds were compared. The thermal conductivity of calcite investment shell moulds decrease with increase of temperature. In the 5-10% Cu alloys there is little difference in structure between the as-cast alloys.

KEYWORDS: Investment shell moulds, dry sand moulds, calcite, hot strength, thermal expansion, microstructure.

INTRODUCT
One of the latest methods of investment casting is based on the principle of dewaxing patterns to form self-supporting ceramic shells. The strength of shell at casting relates to the ability of the shell system to retain the molten metal and maintain the dimensional integrity of the cast part. At casting temperatures some shells crack due to thermal shocks. The refractory filler materials used today to prepare the investment slurries are fused silica [1], zirconia [2], alumina [3], yttria [4], titania [5], graphite [6] and magnesia [7].

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 [8, 9]. The refractory filler materials should have low coefficient of thermal expansion to provide resistance to thermal shocks [10]. When shells of silica flour are used, it is necessary to take into account the lowered dimensional accuracy of castings in comparison with shells made of alumina or zircon. Silica flour shells are always more distorted by thermal shock in the course of casting as a result of the emerging crystallographic phases of silica.

Another important factor is the reactivity of the refractory material of the shell with the cast metal [11]. For instance, shells made of silica flour are not suitable for casting of large pieces of steel with a high content of manganese and chromium without nickel and nickel alloy. Because of the reactivity of silica flour with metals under extremely low pressures, no vacuum casting is possible with shells of silica flour. Dendrite cell size is one of the most important microstructural variables that determine the quality of a cast metal of commercial aluminum alloys. It showed that the casting thickness, mold thickness and mold surface temperature have profound effect on the dendritic cell size [12].

In the present work, calcite was used as a refractory filler material to fabricate investment shell moulds for casting of Al-Cu alloys without modification and with Ti modification.

MATERIALS AND METHODS
In the present work, the colloidal silica binder was used to fabricate the investment shell moulds from calcite as reinforced filler material. The silica content in the colloidal silica binder was 30%.

Investment shell moulds were made by applying a series of ceramic coatings to the patterns. The pattern was first dipped into the dip-coating slurry bath. The pattern was then withdrawn from the slurry and manipulated to drain 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 for 4 hours in the open air. The operations of coating, stuccoing, and drying were repeated six times. The seventh coat was left unstoccoed to avoid the occurrence of loose particles on the shell surface. The

first two coats were stuccoed with a sand of AFS fineness number 120 and the next four coats were stuccoed with a sand of AFS fineness number 50. After all coats, the shells were air dried for 24 hours.
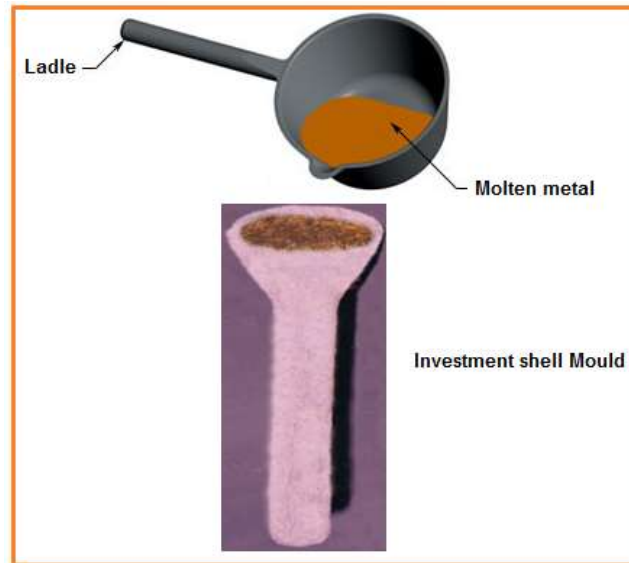

Figure 1. Investment casting of Al-Cu alloy.

The Al-Cu alloy was melted in oil-fired furnace. The liquid alloy was gravity poured into the pre-heated investment shell moulds and dry sand moulds under vacuum. The moulds were knocked off by hand hammer after solidification of the molten. The castings were cleaned with soft brush.

Strength of Investment Shell Moulds

The dimensions of specimens are 25mm X 32mm X t mm, where t is the thickness of the shell. The three-point bending test was conducted on the universal sand- strength testing machine with attached muffle furnace as shown in figure 2 [13].

Figure 2. Hot bending strength test of investment shells.

% Thermal Expansion of Investment Shell Moulds

It was measured in terms of %volume expansion of the investment shells [14]. 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:

$$\% \text{ thermal expansion} = \frac{V_2 - V_1}{V_1} \times 100 \qquad (1)$$

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

2.3 Thermal Conductivity of Investment Shell Moulds
ASTM E1225 standard procedure was employed to determine thermal conductivity of investment shell moulds. This test method describes a steady state technique for the determination of the thermal conductivity.

RESULTS AND DISCUSSION
The calcite powder and its morphology are shown in figure 3. It may occur as fibrous, granular, lamellar, or compact. The chemical formula of calcite is $CaCO_3$. Aragonite and vaterite are polymorphs with calcite. Aragonite is orthorhombic, vaterite is hexagonal and calcite is trigonal. Aragonite is the more stable at most temperatures and pressures and in most environments. Aragonite (figure 3d) will over time convert to calcite.
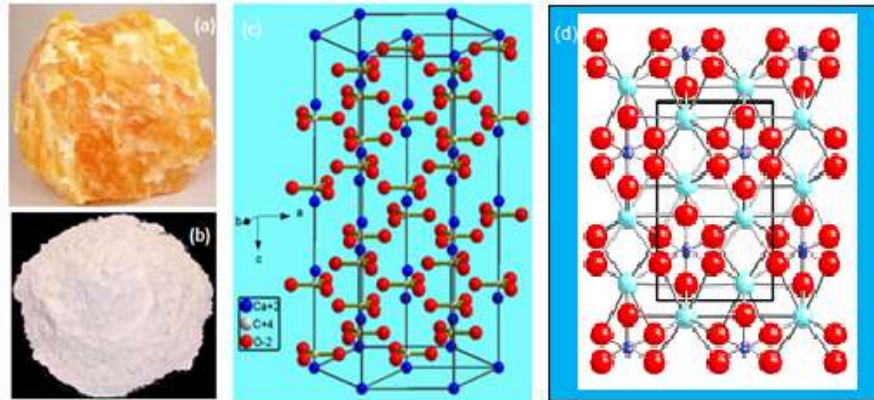

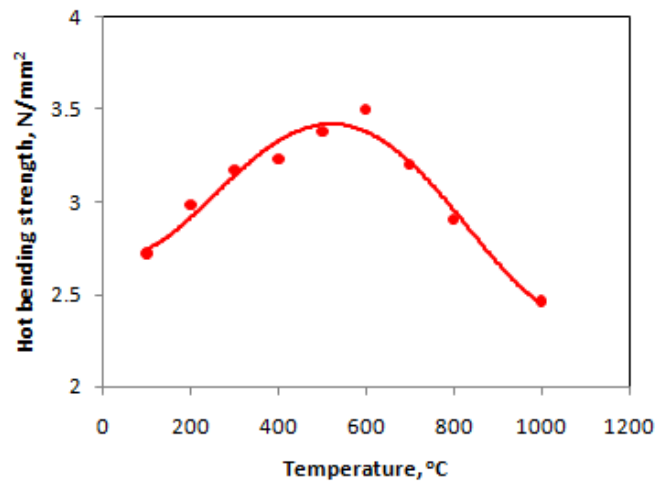*Figure 3. Calcite: (a) crystal, (b) powder, (c) crystal structure and (d) crystal structure of aragonite.*

Figure 4. Effect of temperature on hot bending strength of investment shell moulds.

Hot Bending Strength of Investment Shell Moulds
The effect of filler/binder ratio on the bending strength of calcite investment shell moulds is shown in figure 4. The filler/binder ratio was 0.75 cc/ml. The hot bending strength increased with increase of temperature upt 600ºC anf later on it dcreased. Above 600ºC the bending strength decreased owing to thermal shock.

Thermal Shock in Investment Shell Moulds
The thermal expansion curve for investment shell moulds is demonstrated in figure 5a. The linear thermal expansion increased with increase of temperature. Figure 5b demonstrates the increase in interatomic separation with rising temperature. Relatively strong interatomic bonding forces are found in many ceramic materials as reflected in comparatively low coefficients of thermal expansion. For noncrystalline ceramics and also those having cubic crystal

structures, linear thermal expansion is isotropic. For calcite the thermal expansion is anisotropic because of its triangular crystal structure.
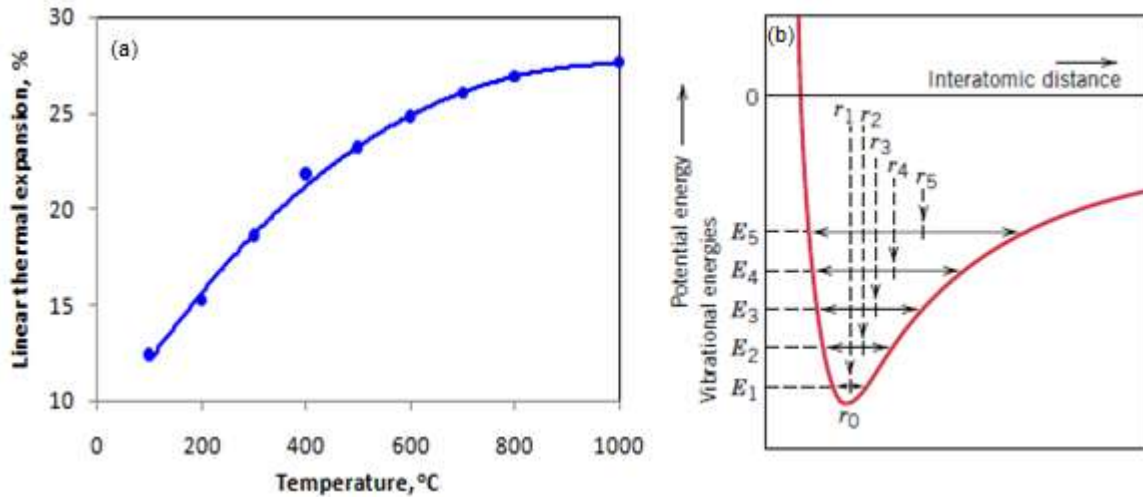

Figure 5. Effect of temperature on thermal expansion of calcite investment shell moulds (a) and schematic presentation of potential energy versus interatomic distance.

Thermal Conductivity of Investment Shell Moulds

The thermal conductivity of calcite investment shell moulds decrease with increase of temperature as shown in figure 6. Heat is transported in solid materials by both lattice vibration waves (phonons) and free electrons. A thermal conductivity is associated with each of these mechanisms, and the total conductivity is the sum of the two contributions,

$$k = k_l + k_e \qquad (2)$$

where k_l and k_e represent the lattice vibration and electron thermal conductivities, respectively; usually one or the other predominates. The thermal energy associated with phonons or lattice waves is transported in the direction of their motion. The k_l contribution results from a net movement of phonons from high to low-temperature regions of a body across which a temperature gradient exists. Nonmetallic materials are thermal insulators inasmuch as they lack large numbers of free electrons. Thus the phonons are primarily responsible for thermal conduction: k_e is much smaller than k_l. Again, the phonons are not as effective as free electrons in the transport of heat energy as a result of the very efficient phonon scattering by lattice imperfections.
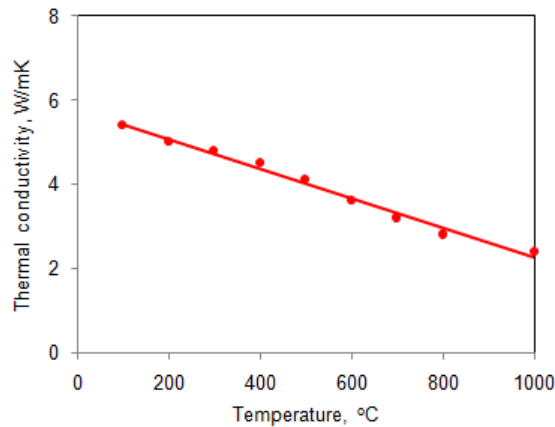

Figure 6. Effect of temperature on thermal conductivity of calcite investment shell moulds.

Microstructure analysis of Al-Cu alloys

As seen from phase diagram (figure 7a) of Al-Cu, the eutectic reaction occurs with Cu content 32.7 % at 548ºC in Al-Cu alloys. The micrographs (figure 7b & c) show primary Al dendrite arms (white). Between the dendrites is the Al - $CuAl_2$ eutectic (figure 8). Initially dendrites would have formed from the liquid, the regions between the dendrite arms known as the mushy zone transforming to a eutectic solid (L to Al + $CuAl_2$). These two phases form cooperatively as

neighboring lamellae with the lateral diffusion of material across the growing interface. The relative amounts of the two phases (Al and $CuAl_2$) within the eutectic are determined by applying the Lever Rule at the eutectic temperature. The tensile strength was in the range of 150 -180 MPa. The tensile strength increased with increasing content of Cu. Thus, in the 5-10% Cu alloys there is little difference in structure between the as-cast alloys in sand moulds (figure 7c). The grains are coarse in dry sand moulds as compared to microstructure of Al-Cu alloys cast in the calcite investment shell moulds.
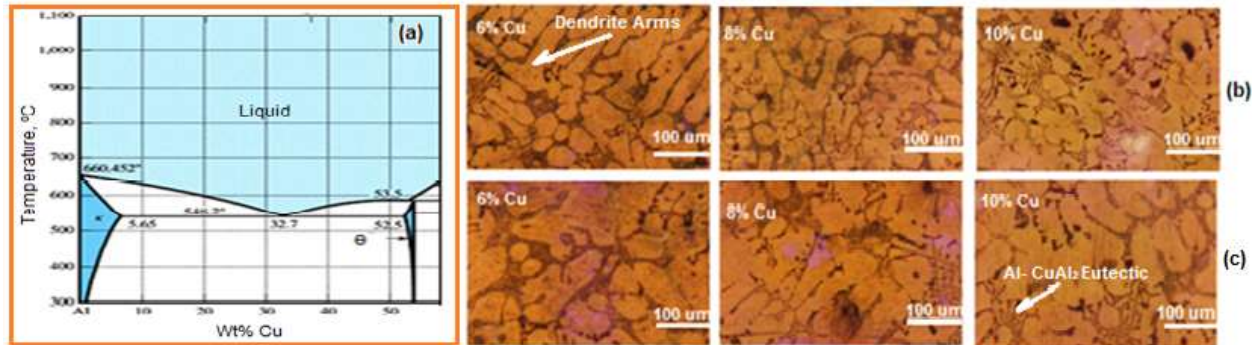

Figure 7. Phase diagram of Al-Cu alloy (a) microstructure of as- cast Al-Cu alloys in: (b) the investment shell moulds and (c) dry sand moulds.
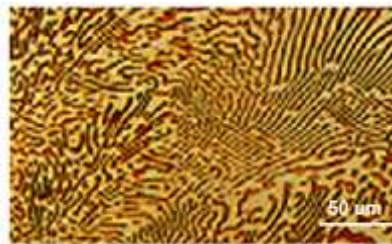

Figure 8. Eutectic network of Al-CuAl₂.

CONCLUSIONS

For calcite, thermal expansion is anisotropic because of triangular crystal structure. The thermal conductivity of calcite investment shell moulds decrease with increase of temperature. In the 5-10% Cu alloys, there is little difference in structure between the as-cast alloys in investment shell and sand moulds.

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