FLUIDITY OF Al-Cu ALLOYS IN FUSED SILICA AND CRISTOBALITE INVESTMENT SHELL MOULDS

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Abstract

The objective of the present work was to find the influence of Cu content, superheat and mould preheat temperature on the fluidity. The fluidity spirals were made using cristobalite/fused silica filler materials and the colloidal silica binder. The fluid increases with the increase of Cu content, super heat and shell mould preheat temperature. The flow of Al-Cu eutectic alloy ceases due to the pinching by the grains. The flow of Al-Cu hypoeutectic alloy stops due to the choking effect.

Keywords: *Al-Cu alloy, fluidity spiral, super heat, mould preheat temperature, fused silica, cristobalite.*

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1. INTRODUCTION

The Al−Cu alloys are widely used in light-weight constructions and transport applications requiring a combination of high strength and ductility. The major problem of Al-Cu alloys is micro cracking during casting. The addition of copper as main alloying element range 3–6 wt. %, allows material strengthening by precipitation hardening, resulting in very strong alloys. Up to 12 wt. % copper the strength of the alloy can increase through precipitation hardening. Above 12 wt. % Cu the alloy becomes brittle. Reliable fluidity data Al-Cu are not readily available for investment casting process. Such data are important in the optimization of mould filling calculations during solidification [1]. A primary requirement for all casting processes is for the metal alloy to fill the mold cavity and to replicate the details in the mold cavity walls. Fluidity is a widely accepted measure of the alloy's ability to fill the mold cavity. Because of its importance in casting, the fluidity of casting alloys has been studied extensively over decades [2-4]. Generally, whether a mold cavity can be filled completely or its details can be replicated depends not only on the alloy's characteristics but also on the mold properties, such as its dimensions, geometry, material, temperature, etc, and casting process parameters, such as temperature and pressure. Due to the mould roughness, an air gap forms and strongly influences the heat transfer coefficient values.

The objectives of the present work was to study the influence of superheat of liquid metal, content of Cu and preheat temperature and filler material of investment shell mould on the fluidity.

2. MATERIAL AND METHODS

Different Al-Cu alloys were gravity cast in the investment shell moulds. The Cu content was varied to get hypoeutectic, eutectic and hypereutectic Al-Cu alloys. Fused silica and cristobalite were employed as the filler materials to make investment shell moulds. The investment slurry was prepared by adding the filler materials to the colloidal silica binder. The silicon radicals in the colloidal silica binder were 30%. The primary coats (first two coats) were stuccoed with fine silica grains of AFS fineness number 120 and the remaining backup coats with sand grains of AFS fineness number 50. All the investment shell moulds were preheated as per the design of experiments before pouring the liquid metal. The Al-Cu alloys were melt in an induction furnace and they were super heated before pouring into the moulds [5-7].

The fluidity spirals were made from the fused silica and cristobalite filler materials as shown in figure 1. The length of fluidity spiral was 500 mm. The investment shell moulds are shown in figure 2.

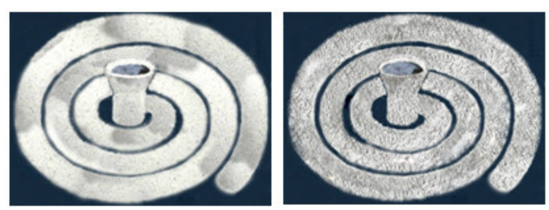

Figure 1: Fluidity spirals: (a) fused silica and (b) cristobalite.

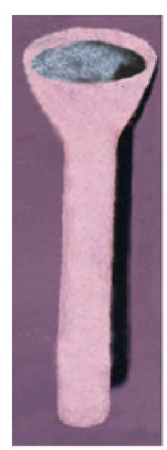

Figure 2: Alumina investment shell moulds.

3. RESULTS

In the present investigation three Al-Cu alloys were considered. Alloy-1 was the solid solution without formation of eutectic; Alloy-2 was hypoeutectic alloy; Alloy-3 was eutectic alloy. For alloy-1, the composition of the liquid phase varies during solidification along the liquidus; that of the solid phase varies along the solidus (figure 3). When it is completely solid, alloy-1 will consist only of α solid solution crystals. Upon further cooling to temperature T5, the solid solution will become supersaturated and, at low temperature it will decompose and the surplus component Cu will be separated as θ ($CuAl_2$) crystals whose amount increases as the temperature falls further. Therefore, the alloy-1 will consist of two phases α + θ at room temperature (figure 4).

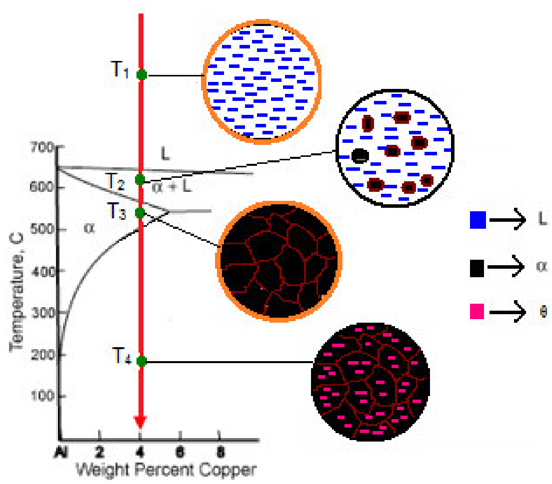

Figure 3: The solidification of alloy-1.

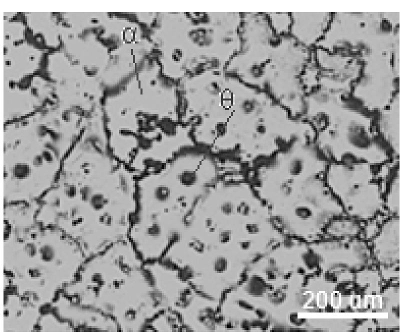

Figure 4: Microstructure of Al-4%Cu alloy at room temperature.

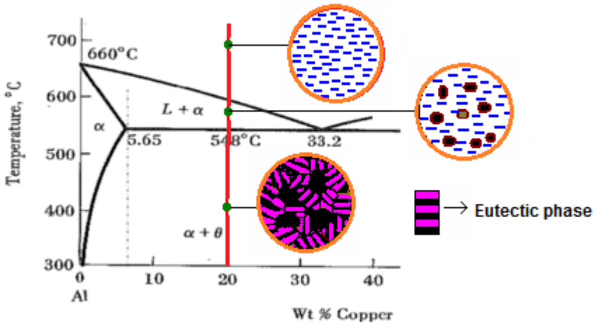

Figure 5: The solidification of alloy-2.

For alloy-2 during solidification (figure 5), the composition of the liquid part of the alloy varies continuously along the liquidus, approaching the eutectic composition; the composition of the solid phase varies along the solidus moving toward the maximum solubility. The α crystals, both primary and those in the eutectic decompose upon further drop in temperature below solidus line due to the decrease in solubility. As a result θ solid solution crystals precipitate from α crystals (figure 6).

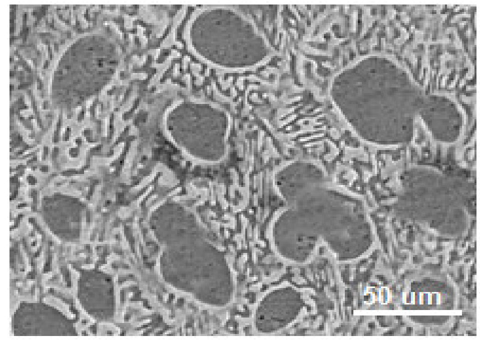

Figure 6: Microstructure of Al-20%Cu alloy at room temperature.

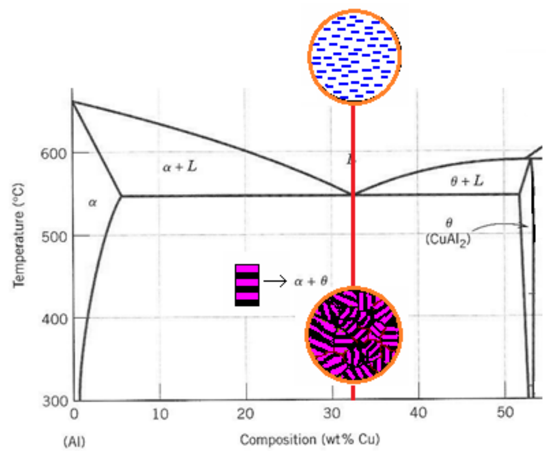

Figure 7: The solidification of alloy-3.

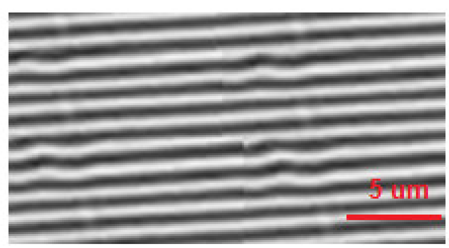

Figure 8: Microstructure of Al-33%Cu alloy at room temperature.

The microstructure of Al-20%Cu alloy is shown in figure 7. Alloy-3 of the composition corresponding to 30%Cu will contain only grains of the eutectic (α + θ) after solidification (Fig-8). The microstructure of eutectic is shown in figure 8. The structure of the θ-phase with the composition $CuAl_2$ was originally revealed by Friauf [8] and found to be tetragonal. According to Murray [9] the phase is stable up to 591 °C.

3.1 Effect of Cu content on fluidity

As the Cu content increases the fluidity of Al-Cu alloy increases as shown in figure 9. Maximum fluidity is achieved at the eutectic composition. The fluidity was measured at constant pouring temperature of 800^{o}C and mould-preheat temperature of 400^{o}C. The change of the liquidus temperature due to increasing solute concentration is fairly small [10].

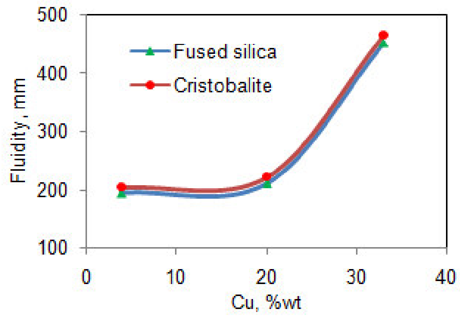

Figure 9: Effect of Cu content on the fluidity.

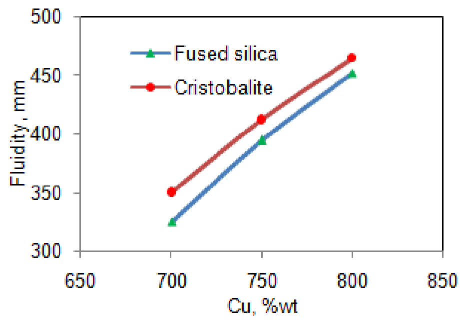

Figure 10: Effect of superheat on the fluidity.

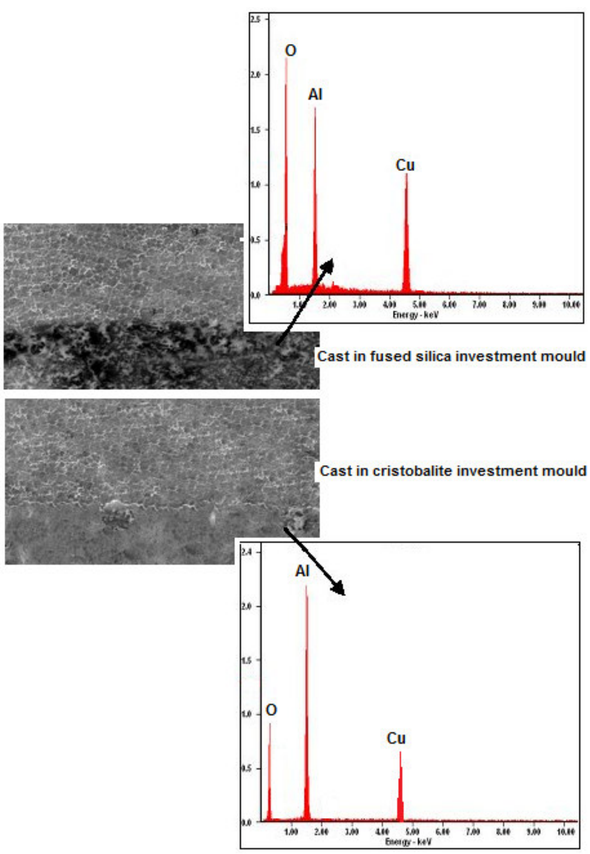

Figure 11: Metal-mould reactions.

3.2 Effect of superheat on fluidity

The effect of superheat of liquid metal on the fluidity is shown in figure 11. The mould-preheat temperature was 400^{o}C. The fluidity of eutectic Al-Cu alloy increases with the increase of superheat. If the melt was at a higher temperature relative to its freezing point, it would remain in the liquid state longer throughout the metal casting operation, and hence its fluidity would increase. However, there are disadvantages with an increased superheat. It increases the possibility of the liquid metal to react with the gases resulting into the formation of oxides. It may also increase the liquid metal ability to penetrate into the surface of the mold material. The metal-mould reactions are shown in Fig-12. The quantities of metal oxides: Al_2O_3 and CuO were found higher at the interface between fused silica layer and Al-Cu alloy than at the interface between cristobalite layer and Al-Cu alloy.

3.3 Effect of mould preheat on fluidity

The effect of superheat of liquid metal on the fluidity is shown in figure 12. The fluidity was measured at constant pouring temperature of 800^{o}C for eutectic alloy. The fluidity increases with the increase of mould pre-heat temperature. The fluidity length of alloy is inversely proportional to the difference of pouring and mold temperature, so the fluidity increases with increasing of mold temperature.

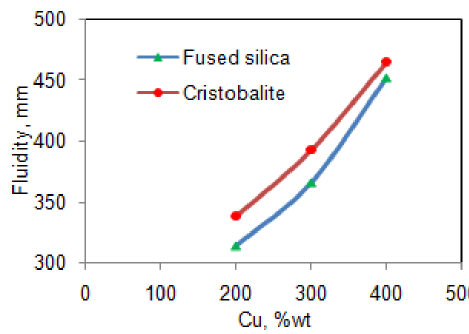

Figure 12: Effect of superheat on fluidity.

34. Effect of mould Filler material on fluidity

As seen from figures-9 & 10, the fluidity was higher in the cristobalite investment shell moulds than that in the fused silica shell moulds. The thermal conductivity of cristobalite is lower than that of fused silica. If the thermal conductivity is low the heat dissipated to the surrounding becomes less. Hence, the heat retained in the liquid metal keeps the melt for long duration consequently increasing the fluidity.

4. DISCUSSION

In the solute rich alloys with a wide solidification range, fluidity is limited by choking. The flow is choked by precipitation of equiaxed grains at the leading tip of the flowing stream and by the accumulation of solid crystallites. In a fluidity spiral test, solid particles form during flow and travel downstream with the liquid. The flow stops when the mean solid fraction reaches a so-called "critical solid fraction" [11]. During solidification of Al-Cu alloy as it flows into the investment shell mould, the mushy volume formed on the liquid metal would solidify on the inner walls of the shell mould. The liquid metal experiences resistance to the flowing metal due to mushy volume formed on the shell mould walls. This increases the apparent viscosity and reducing the fluidity of the metal. A mathematical model for estimating fluidity length [9] is given below:

$$L_f = \frac{A\rho V_o\left(f_{scr}D_h + C_p D_t\right)}{hS(T-T_0)}(1+0.5K) \qquad (1)$$

where, A is the mould cross sectional area; ρ is the liquid density; V_o is the flow velocity; f_{scr} is the critical fraction solid for flow stoppage; D_h is the heat of fusion; C_p is the specific heat of the metal; D_t is the melt superheat; h is the heat transfer coefficient between mould and metal; S is the circumference of the mould channel; T is the temperature of the liquid; T_o is the room temperature; K is a constant depending on h, the heat transfer coefficient and, hence, the resistance to heat flow (metal-mould interface).

Heat of fusion is the amount of energy involved in the liquid-solid phase change. With a higher heat of fusion, the solidification of the metal casting takes longer and fluidity is increased. If a melt is at a higher temperature relative to its freezing point, it remains in the liquid state longer and hence its fluidity increases [12]. The time to cool to the freezing temperature depends upon heat content and thermal properties rather upon the temperature alone. The fluidity is thus affected by the specific heat and latent heat of fusion of the liquid metal and also upon the thermal conductivity of the liquid metal and the shell mould material.

When the Al-Cu alloy at the eutectic composition enters the channel, solidification begins at the wall and continues by the growth of columnar grains with a planar interface as metal flows through the channel (figure 13a). Flow ceases when the columnar grains meet and the pinching by the grains from the channel wall stops the flow (figure 13b). For the solid solution alloy composition the flow effect is nearly same as that of eutectic alloy.

In the hypoeutectic Al-Cu alloy, the mode of solidification changes from growth of columnar grains to the formation of equiaxed dendrites or columnar dendrites. These grains flow downstream with the liquid metal, until a critical fraction solid is reached and the flow stops by choking at the tip of the freezing metal (figure 14b).

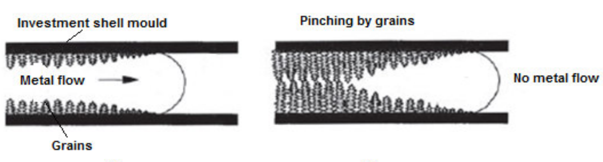

Figure 13: Schematic representation of solidification in Al-Cu eutectic composition.

Figure 14: Schematic representation of solidification in Al-Cu hypoeutectic composition.

Turbulence is inconsistent and irregular variations in the speed and direction of flow throughout the liquid metal as it travels though the casting. The random impacts caused by turbulence, amplified by the high density of liquid metal, can cause mold erosion. An undesirable effect in the manufacturing process of metal casting, mold erosion is the wearing away of the internal surface of the mold. It is particularly detrimental if it occurs in the main cavity, since this will change the shape of the casting itself. Turbulence is also bad because it can increase the formation of metal oxides which may become entrapped, creating porosity in the solid casting. The fluid spirals cast in fused silica and cristobalite investment shell moulds are shown in figure 15. The length of fluid spiral increases with increase of cu content. The eutectic alloy has longest spiral.

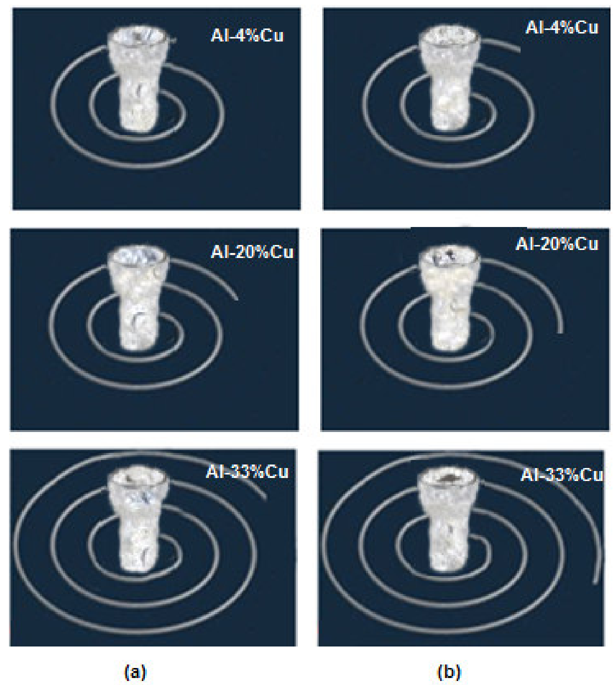

Figure 15: Fluid spirals cast in (a) fused silica and (b) cristobalite investment shell moulds.

5. CONCLUSIONS

The fluidity increases with the increase of Cu content, super heat and shell mould preheat temperature. For the Al-Cu alloy at the eutectic composition the flow ceases due to the pinching by the grains. For the hypoeutectic Al-Cu alloy, the flow stops by choking at the tip of the freezing metal.

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