FLOW BEHAVIOR OF MOLTEN METAL IN ALUMINUM LFC PROCESS

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Abstract: *The effects of gating system and pattern geometry on the metal flow in the lost foam casting (LFC) process have been investigated using glass covered mold and video recording system. Unlike convectional casting process, the type of the gating system showed little effect on fillability in lost foam, but pattern thickness had large effect on mold filling. The mold filling behavior seems to be controlled by the combined influences of heat and mass transfer. The flow rate increased with increasing pattern thickness*

Keywords: *Lost foam casting, Aluminum, Fluid flow, Mold filling, Gating system*

1. INTRODUCTION

In the lost foam casting process molten metal is poured into an unbounded sand mold containing a refractory coated foam pattern. The combination effects of all of the four elements involved in LFC process; pattern, coating, sand and molten metal will control the lost foam mold filling behavior. Butler and Pope recorded visualization of lost foam mold filling behavior for the first time in 1964 [1]. They observed the lost foam filling process through a transparent glass window in the wall of flask. Dieter et. al [2], Lee [3] and other researchers used the same technique for cast iron, aluminum and zinc to study the flow behavior.

Unlike green sand casting, where the mold filling rate is controlled by the gating system, mold filling in LFC is controlled by the pattern decomposition rate. In turn, the pattern decomposition rate is controlled by coating permeability, pattern density, pattern geometry and metal front temperature [4-10]. Askeland and Hill [11-12] reduced the gate size until it became the controlling parameter in mold filling, typically too small to be able to support the pattern during coating and molding stage. When the gating system is sufficiently robust to permit handling of the cluster, the metal fill rate is controlled by the coating properties or by the recession rate of the polymer foam. Lawrence [13] suggested that the coating permeability has a much greater effect on fill time, metal velocity and casting quality than any other variables. However, Sun et al. [14] reported that the area of the gate has little effect on the mold filling but coating permeability has an important effect. Since coating properties can vary and the degradation rate of the foam pattern is temperature dependent, there should be certain identifiable operating regimes for mold filling in the LFC process. Warner [15] suggested that there are three mechanisms which control the foam decomposition and its transport, a) wetting regime, b) foam-decomposition, and c) backpressure in the system. In the foam-decomposition regime, the coating permeability is sufficiently high and transport of the foam decomposition products through the coating is not the limiting process. The mold filling rate in this regime is limited by the rate at which the foam pattern can degrade. This rate is a function of the foam type, foam density and metal front temperature. When the coating permeability is very low or the metal temperature is very high, backpressure may control the mold filling process. Mold filling will then be controlled by the rate at which the refractory coating allows gaseous products to escape into the sand. These results show that coating permeability and interactions between the molten metal and the foam pattern are very important in the LFC process.

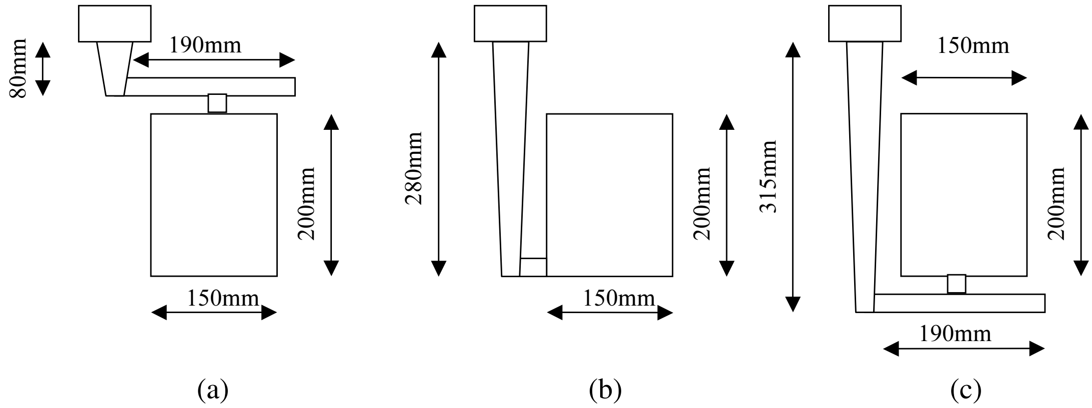

Fig. 1. Schematic illustration of the gating systems: (a) top gating. (b) side gating (c) bottom gating

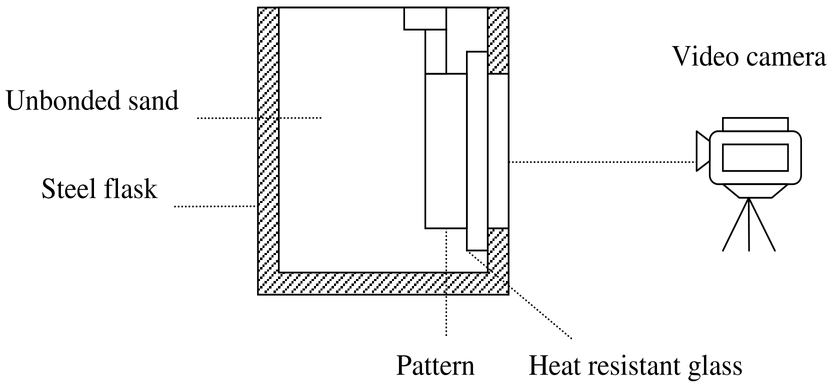

Fig. 2. Schematic of the experiment method

The purpose of this work was to investigate the effect of gating system type and pattern geometry on mold filling [15]

2. EXPERIMENTAL PROCEDURE

Rectangular plate patterns, 200*150*mm in two different thicknesses 5 and 10 mm were used. They were cut using a hot wire with tolerance of $\pm$ 0.5 mm. Three types of pouring system were selected as shown in Fig. 1. In the top, side and bottom gating system the sprue height of 80 mm, 280 mm and 315 mm were selected respectively. In all three cases the cross section of the top side of the sprue was 30*30 mm and the bottom side was 20*20 mm. The pouring cup size was (40*60*60 mm).

The final cluster of the gating system and vertical plat patterns were assembled using a hot melt adhesive. The foam density was 0.021 gr/cm with the average bead size of 2 mm .The pattern assembly was coated with a water-based coating (Styromol 702 FM) to a thickness of 0.5 mm and dried in ambient temperature. Then the pattern was placed in the steel flask and vibrated while filling the flask with unbounded silica sand. The aluminum alloy ingots (Al-Si12) were melted in a crucible furnace. The molten metal poured at 720 ± 5 C. A steel flask was also fabricated with a heat resistant glass window in one of its side walls (Fig. 2). One side of the pattern faced to glass window remained without coating. The unbonded silica sand was poured into the flask, and vibration was applied for final compaction. Pre-cut pieces of (Al-Si12) alloy were melted in the crucible furnace. A VHS video camera was used for recording the flow of liquid metal into the mold.

3. RESULT AND DISCUSSION

Mold filling behaviors of the top gating system for the thickness 5, 10 mm are shown in Figs. 3 and 4 respectively. In the thickness 5 mm, mold filling time from the entrance of the gate to the end of casting was 3.32s, and for thickness 10 mm, it took 3.36s. Here two phenomena are noticeable, firstly, in contrast to convectional casting in which the melt fills the mold from bottom to the top, in LFC process the melt fills the mold from top to the bottom which is, of course due to the polymer pattern resistance; and secondly, at the early stage of the filling in both thickness, the melt has a uniform filling behavior but later it loss its uniformity in 10 mm thickness which may lead to the forming of folds defects in the casting. It seems that the surface tension of the molten metal has a greater effect in the 5 mm thick plate in comparison with 10 mm thick plate, therefore the molten metal shows a uniform movement from the beginning to the end of mold filling process. Such a uniform movement in top pouring of thin wall casting, (under 3 mm thickness), has also been reported in conventional casting process [16]. The relation between these parameters could be seen in Equation 1;

$$\Delta P= 2\gamma(1/r +1/R) \tag{1}$$

In which ΔP is the pressure difference, γ is surface tension (N/m), r and R are two radii of the liquid stream curvatures.

It is clear that turbulent filling would happen in the thicker section especially in the top pouring in conventional casting. In the case of LFC process not only surface tension but also the back pressure as a result of vaporization of foam would act in the favor of a uniform and laminar instead of turbulent flow.

Mold filling behaviors of side gating system with the thicknesses of 5, 10 mm are shown in Figs. 5 and 6 respectively. In the thickness 5 mm, mold filling time when the melt entered to the mold from the gate until the end of the filling was, 3.28s and for thickness 10 mm, it was recorded about 3.76s. Again in the early stages of the filling at both thicknesses, melt shown a uniform filling behavior but later uniformity was decreased, but still was better than the top gating system.

Mold filling behaviors of bottom gating for the thicknesses of 5, 10mm are shown in Figs. 7 and 8 respectively. In the 5 mm, mold filling time when the melt enter to the mold from the gate to the end was 3.64s and for thickness 10 mm, time was reached to 4.58s. The best uniformity in the filling could be seen in the bottom gating system.Figs. 9, 10 and 11 show the effect of gating system in two different thicknesses.The molten weight in the mold cavity increases with increasing of the time in all of the cases. In the top pouring system the time of filling is equal in both thickness, but in two other cases, namely side and bottom pouring system, the time of filling of the 10 mm thick plate is higher in comparison to 5 mm thick plate. The shorter time of filling in the top pouring system is due to higher hydrostatic pressure of liquid metal. This pressure could facilitate the escape of gaseous products, in the interface of molten metal and the foam pattern.Fig 12 shows the flow rate in the top pouring system. The flow rate reaches to a maximum after two seconds and then it decreases. One may also note that flow rate in the beginning of the filling process is sharply increasing. Bottom pouring shows nearly the same trend in both 5 and 10 mm thicknesses, except the maximum of flow rate, which have appeared in the first second of the filling time especially in 10 mm thick casting. The maximum flow rate in three different running systems also has clear difference in the Fig 12, top pouring system in 10 mm thick plate, the flow rate stand in 400 gr/sec which is nearly two times of the maximum flow rate in the side gate system. Still it is quite higher than maximum flow rate in the bottom pouring system, which is shown in Fig 14. There is not too much difference in the filling rates of side and bottom pouring systems in the plates with 5 mm thickness, but in the top pouring system the maximum flow rate, in 5 mm thickness is somewhat higher than those of other two previously mentioned cases. The overall heat of the molten metal depends to its volume, which influenced system as follow . In the case of 10 mm thick casting the heat capacity of the plate is doubled in comparison with 5 mm thick casting.

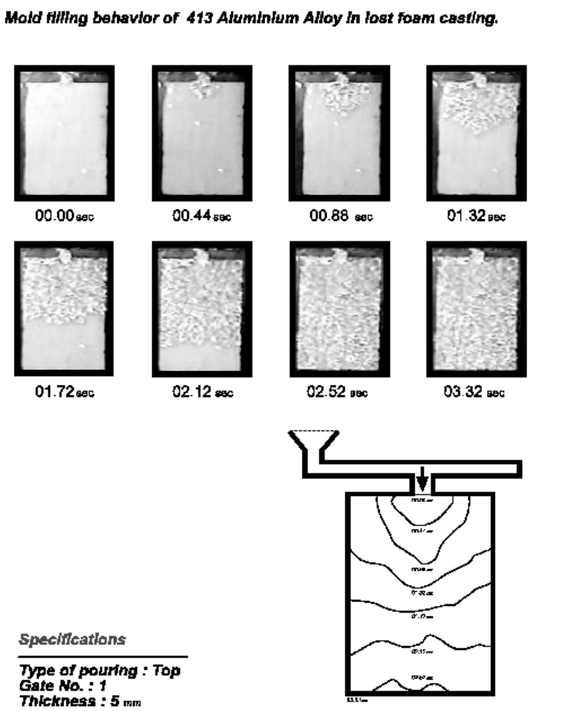

Fig. 3. Mold filling sequences in the top pouring of a 5 mm thick plate in the LFC process

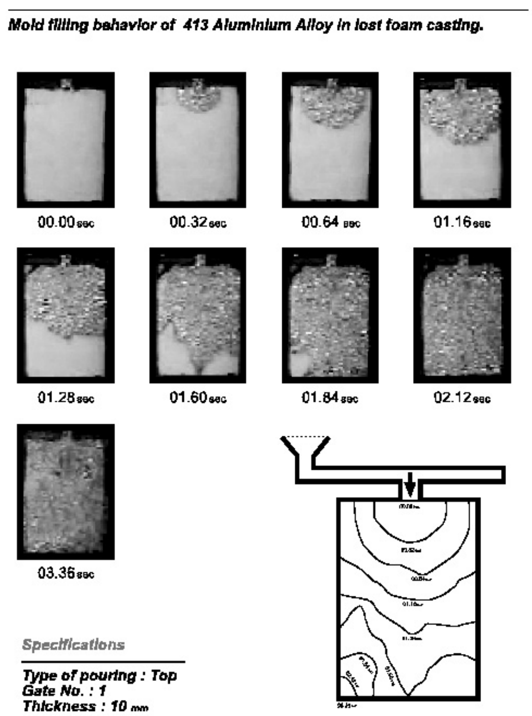

Fig. 4. Mold filling sequences in the top pouring of a 10 mm thick plate in the LFC process

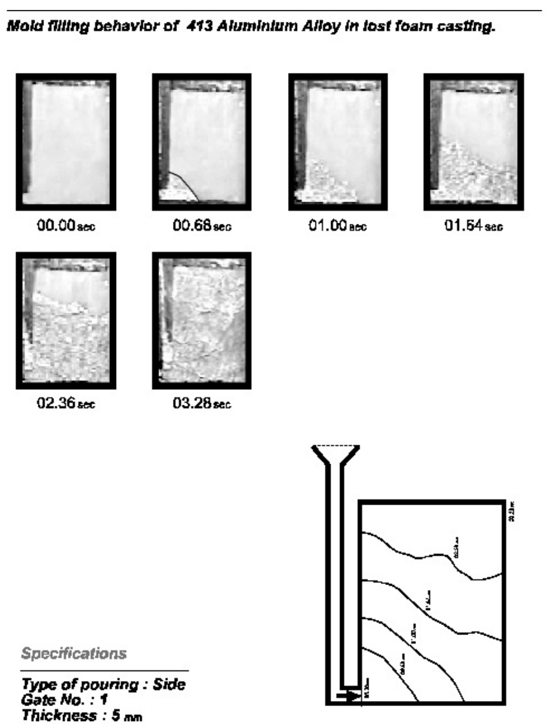

Fig. 5. Mold filling sequences in the side pouring of a 5 mm thick plate in the LFC process

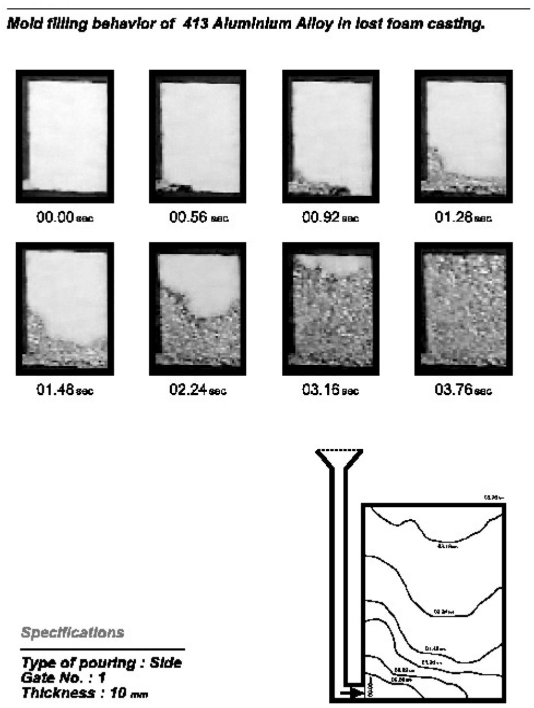

Fig. 6. Mold filling sequences in the side pouring of a 10 mm thick plate in the LFC process

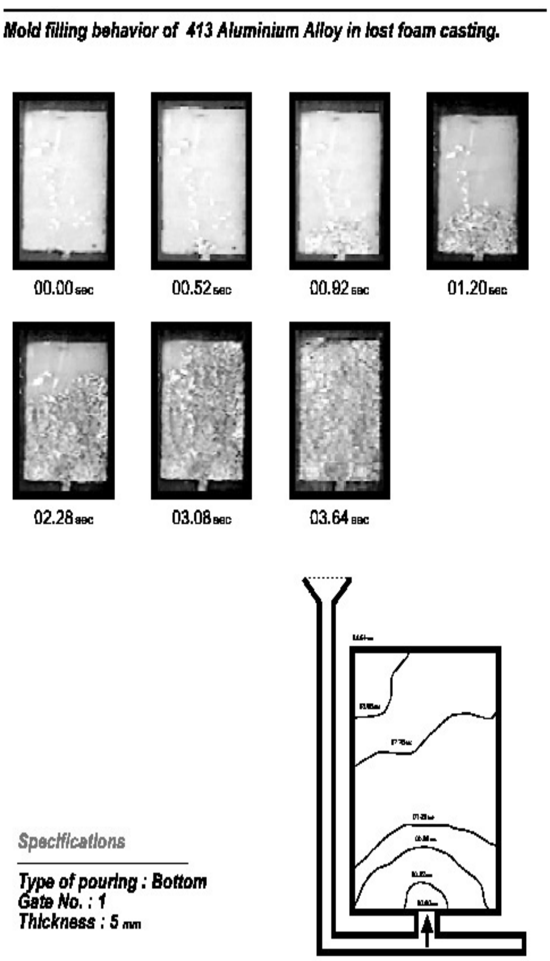

Fig. 7. Mold filling sequences in the bottom pouring of a 5 mm thick plate in the LFC process

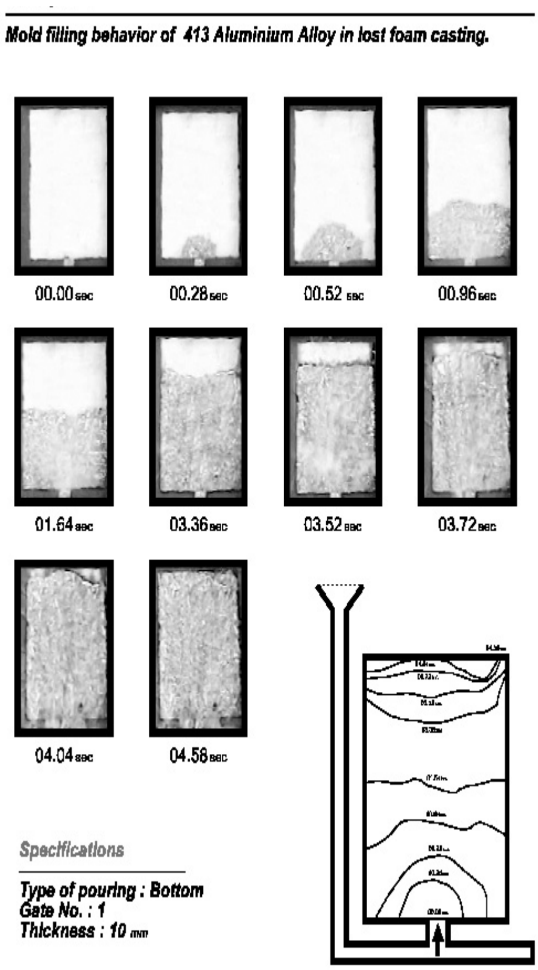

Fig. 8. Mold filling sequences in the bottom pouring of a 10 mm thick plate in the LFC process

This heat is extracted in two ways, one is heat transfer through mould walls and other is heat consuming during foam degradation. The later is doubled here but the former is not doubled. This is the reason why the filling rate of the mould is higher in the 10 mm thick casting in comparison to 5 mm one. One may also consider the effect of surface tension although its amount is not too much here, but it would be more serious parameter in the thickness under 2 mm [16].

Figures 15 and 16 show the metal weights in the mold in two different thickness. One aspects is that the time of filling is not doubled although the casting thickness is doubled which was discussed. Interestingly the major volume of the molten metal has filled the mold in shorter time in 10 mm casting in comparison to 5 mm one, which shows the effect of heat extraction and also extraction of gaseous products. The molten metal weight in other two cases; side and bottom pouring, shows similar trends.

The main difference between the flow behavior of these three systems become apparent in the Figs 17 and 18. The top and bottom gating system show a sharp rate at the beginning and also a lesser time of filling. Also there are maximums in their filling curves and some fluctuations in their filling behavior. It seems that the discharge of the gas generated in the metal front has been faster, so the overall time of the filling is lesser than other case. In both cases the metallostatic pressure is higher than the side gate system. It means that the mass transfer and discharge of the generated gases have also an important role in the filling behavior of the mold in EPC process [12, 17].

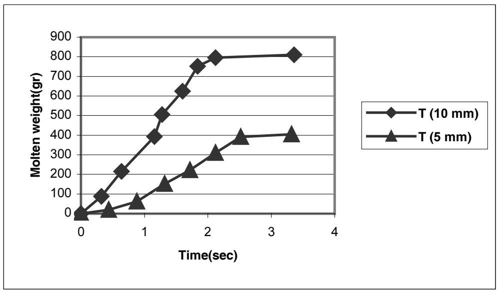

Fig. 9. Effect of the pattern geometry on mold filling in top gating system

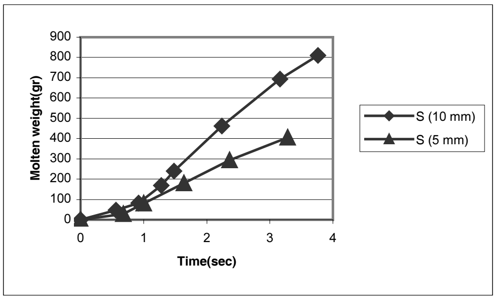

Fig. 10. Effect of the pattern geometry on mold filling in side gating system

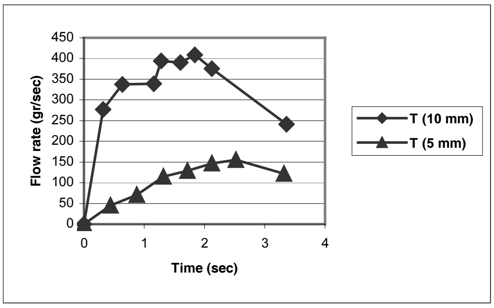

Fig. 11. Effect of the pattern geometry on mold filling in top gating system

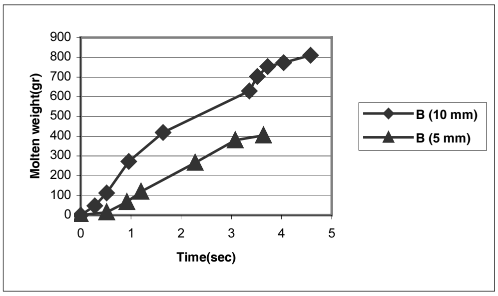

Fig. 12. Effect of the pattern geometry on mold filling in bottom gating system

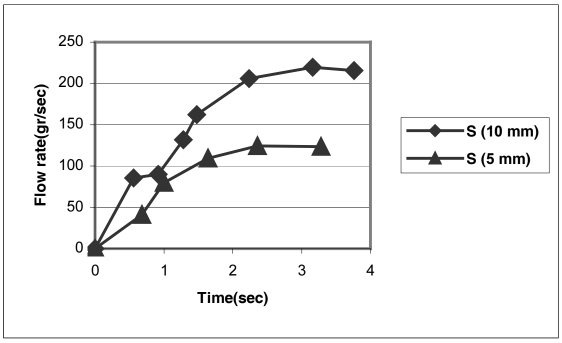

Fig. 13. Effect of the pattern geometry on mold filling in side gating system

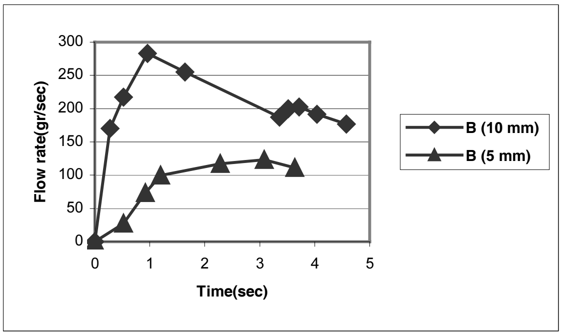

Fig. 14. Effect of the pattern geometry on mold filling in bottom gating system

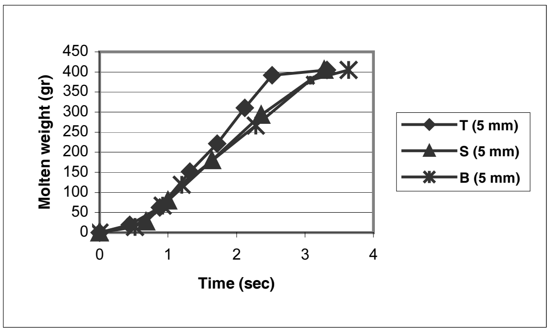

Fig. 15. Effect of the gating system on mold filling in 5mm thickness

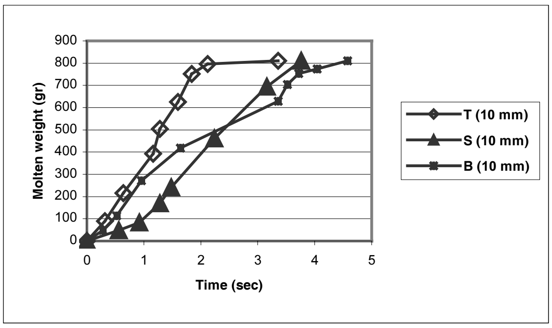

Fig. 16. Effect of the gating system on mold filling in 10 mm thickness

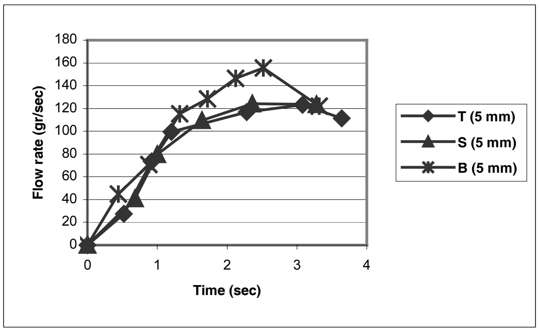

Fig. 17. Effect of the gating system on mold filling in 5 mm thickness

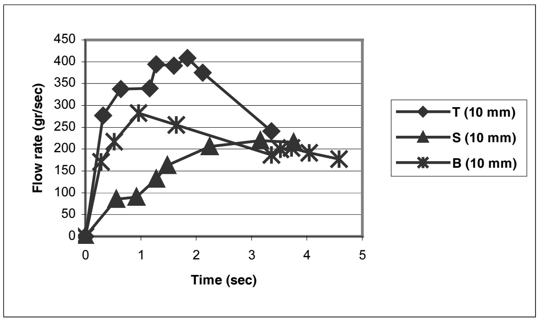

Fig. 18. Effect of the gating system on mold fillin in 10 mm thickness

4. SUMMARY AND CONCLUSIONS

Unlike the empty-mold casting process, the LFC process has a different filling mechanism, mainly because of the existence of the foam pattern in the cavity. The controlling factors for mold filling are also quite different between these two processes. This work shows the combined effect of both heat and mass transfer during mold filling and pattern displacement in producing aluminum casting with the LFC process.

A profound effect of pattern geometry on mold filling was found. It is believed that amount of heat that must be removed and the rate at which it can be removed and the permeability of the coating to remove the decomposition products, all are reflected in the flow stream, which has been shown in this work.

One interesting aspects of the mold filling behavior in the EPC process is the flow of molten metal against gravity which could clearly be seen in the side gating system.

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