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MOLD FILLING BEHAVIOR OF DOUBLE GATING SYSTEM IN ALUMINUM LFC PROCESS

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Abstract: *The mold-filling behavior in the casting of aluminum alloy (A413) using lost foam casting (LFC) was explored. The effects of gate numbers, type of gating and casting thickness on the filling behavior were evaluated. Although, unlike convectional casting process, the gating system showed little effect on filling ability, casting thickness created a greater effect on the mold filling. In contrast with convectional casting process, the mold filling seems to be controlled by casting geometry as a consequence of combined influence of heat and mass transfer. The melt used to enter from the first gate instead of last gate which is in contrast with convectional casting process*

Keywords: *Lost foam casting, Al-Si Alloy, Fluid flow, Mold filling, Gating system.*

1.INTRODUCTION

In the lost foam casting (LFC) process molten metal is poured against a foam pattern that has been coated with a refractory and surrounded with unbounded sand. The combination effects of all of the four elements involved in the LFC process including pattern, coating, sand and molten metal will control the lost foam mold filling behavior.

Butler and Pope recorded steps of the lost foam mold filling behavior for the first time in 1964 [1]. They studied the lost foam filling process through a transparent glass window in the wall of a flask. Dieter et. al. [2], Lee [3] used the same technique to study the flow behavior. However, their observations using the "glass window" technique improved our understanding from the LFC process.

Unlike green sand casting, where the mold filling rate is controlled by the gate size, mold filling in the LFC is controlled by the pattern decomposition rate. The pattern evapouration rate is, in turn, controlled by coating permeability, pattern density, pattern geometry and metal front temperature [4-10].

Askeland and Hill [11-12] reduced the gate size to the degree that it became the controlling parameter in mold filling; The size of gating in their experiment seems to be too small to treat the pattern easily during further steps in mold preparation. When the gating system is sufficiently robust to permit handling of the cluster, the metal filling 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 far greater effect on the filling time, metal velocity and casting quality than any other variable. Sun et. al. [14] reported that the area of the gate has little effect on the mold filling but coating permeability has a greater effect.

Since coating properties vary and the degradation rate of the foam pattern is temperature dependent, there should be certain operating regimes for mold filling in the LFC process. Liu and Warner [15-16] suggested that there are three controlling regimes in foam decomposition and transport: Wetting, Foam-Decomposition and Backpressure.

When the coating permeability is sufficiently high, the transport of the foam decomposition products through the coating would not be 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 [5].

When the coating permeability is very low or the metal temperature is very high, backpressure may

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control the mold filling process. Mold filling will then be controlled by the rate at which the refractory coating can allow air and 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 [5, 14, 16]. The purpose of this study is to investigate the effect of gating system and pattern geometry on mold filling.

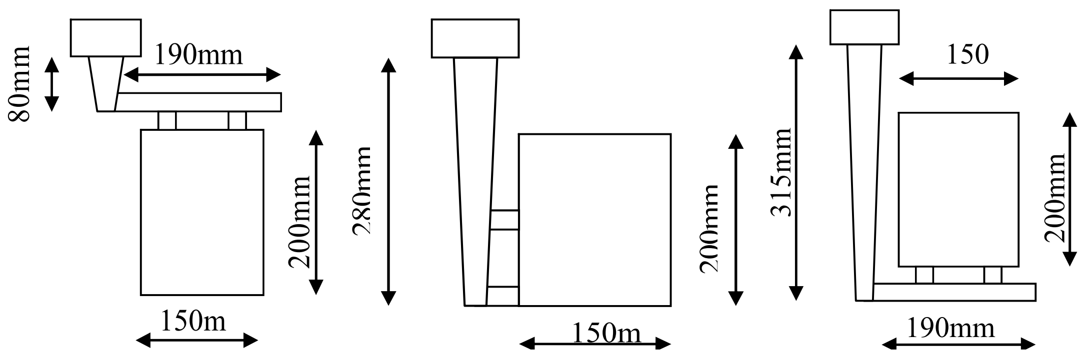
2. EXPERIMENTAL PROCEDURE

Rectangular foam plate patterns (200×150 mm) were used with two different thicknesses of 5 and 10 mm. The foam plates were cut using a hot wire with ± 0.5 mm accuracy.

Three types of gating system: top, side and bottom were implemented. In all experiments a runner with size of L190 × W20 × H20 mm were used. The height of the sprue was different regarding the type of the gate. In the top pouring one, the sprue height was 80 mm, in the side gated one was 280 mm and in the bottom gated one was 315 mm. In all three cases, the top side cross section of the sprue was 30×30 mm and the bottom side was 20×20 mm. In all cases the pouring cup size was L40 × W60 × H60 mm (Table 1 and Fig. 1).

The final cluster of the gating system and vertical plate patterns were assembled using a hot melt adhesive. The foam density was 0.021gr/cm3 with an average bead size of 2 mm. The pattern assembly was coated with a water-based coating (Styromol 702 FM) up to a thickness of 0.5mm. The coated patterns were dried in an ambient temperature. The dried-coated pattern was placed in the steel flask and vibrated while filling with unbounded silica sand. The aluminum alloy ingots (Alloy A413) were melted in a crucible furnace. The melt was poured at 720 ± 5°C.

A steel flask was fabricated with a heat resistant glass window in a vertical position (Fig. 2). The side view of the pattern faced to glass window remained without coating. The unbounded silica sand was poured into the flask, and vibrated to suitable compaction. Pre-cut pieces of the A413 alloy ingots were melted in a crucible furnace. A VHS video camera was used to record the flow pattern of liquid alloy in each cases.



(a) **(b)** **(c)**

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

Table 1. Dimentions of castings and gating systems in this study.

No.	Foam Plate Size (mm)	Foam Plate Thickness (mm)	Gate Type	No of Gates	Sprue Height (mm)	Sprue Cross Section Size (mm)	Pouring Cup Size (mm)
1	200 x 150	5	Top	2	80	Top 30 x 30 , Bottom 20 x	40 x 60 x 60
2	200 x 150	10	Top	2	80	Top 30 x 30 , Bottom 20 x	40 x 60 x 60
3	200 x 150	5	Side	2	280	Top 30 x 30 , Bottom 20 x	40 x 60 x 60
4	200 x 150	10	Side	2	280	Top 30 x 30 , Bottom 20 x	40 x 60 x 60
5	200 x 150	5	Bottom	2	315	Top 30 x 30 , Bottom 20 x	40 x 60 x 60
6	200 x 150	10	Bottom	2	315	Top 30 x 30 , Bottom 20 x	40 x 60 x 60

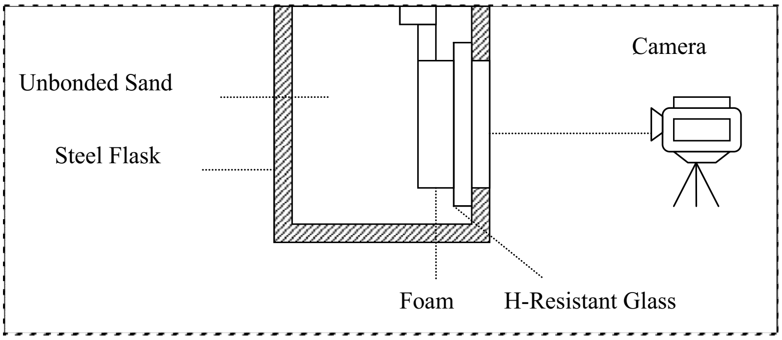


Fig. 2. Schematic view of the experiment method.

3. RESULTS AND DISCUSSION

The mold filling behaviors of the top gating system for 5 mm and 10 mm thicknesses are shown in Figs. 3 and 4, respectively. Mold filling durations, from the start to the end were 4.84 and 3.34 seconds in 5 mm and 10 mm thickness, respectively. Two phenomena are noticeable, (i), unlike convectional gravity casting, where in the top pouring systems, the melt fills the mold from bottom to the top, in LFC process the melt fills the mold from top to the bottom; and (ii), at the early stage of the filling at both thicknesses, the melt has a uniform filling behavior but later it losses its uniformity in 10 mm thickness which may lead to the forming of folded defects in the casting.

For the side gating system, the mold filling behaviors for 5 mm and 10 mm thicknesses are shown in Figs. 5 and 6, respectively. Mold filling durations were 4.74 and 4.96 seconds in 5 mm and 10 mm thickness, respectably. Again in the early stages of the filling process at both thicknesses, the melt has shown a uniform filling behavior but later its uniformity decreased, although the filling behavior was still better than the top gating system, regarding the flow lines.

Mold filling behaviors of bottom gating system for the 5 mm and 10 mm thickness are shown in Figs. 7 and 8, respectively. Mold filling durations were 4.10 and 4.72 seconds in 5 mm and 10 mm thickness, respectively. The best uniform filling was shown in the bottom gating system.

3.1. Effect of Pattern Geometry (Thickness) on Mold Filling Behavior

The metal front in the experiments with the 10 mm thick foam was always ahead of the metal front in the experiments with the 5 mm thick foam (Figs. 9 to 14). Although the difference in the beginning is not too much, but gradually it becomes more obvious during the experiment. There are two key factors which are considered to be effective in this process:

1. Temperature difference: the melt front that is closer to the mold wall, where the heat extracts, looses more heat while the temperature of the mid-part of the melt front dosen’t. It means that in 10 mm thickness the melt looses its temperature slowly. In the initial steps this effect would not be considerable because of the smallness of melt front.

Figs. 12-14, compare the change of flow rate in the top, side and bottom gating system. In these graphs, the effect of thickness is also shown.

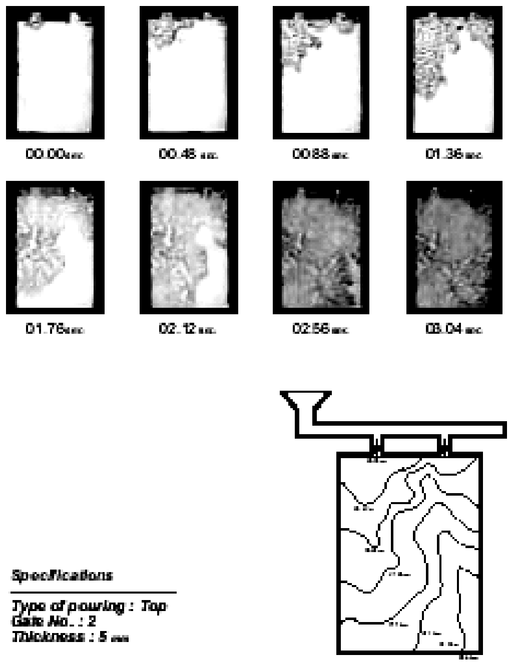


Fig. 3. Mold filling behavior in the top gating system with 5 mm thickness.

2. Geometry of the mold: casting thickness has a key role on mold filling rate. However in convectional casting, the geometry of mold doesn't have a direct role on mold filling rate and other variables like choke area or metallostatic head pressure play more important roles [18].

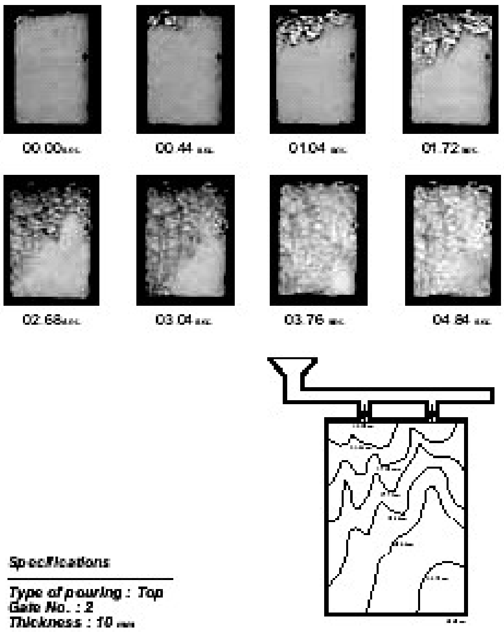


Fig. 4. Mold filling behavior in the top gating system with 10 mm thickness.

Saghi et. al. [17] showed that with the increase of the thickness from 5 to10 mm, in the single-gate system, the weight of the melt introduced and replaced the foam pattern might dramatically increased. In double-gated system, this difference is lower than with the single-gated system. However, when gates are close to the walls the melt looses its temperature faster. It means that the gates' location plays an important role in filling behavior.

Figs. 9-11, show variation of the molten weight (the weight of the melt introduced and replaced the foam pattern) versus time in the top, side and bottom gating system with two different thicknesses. In these graphs, the influence of heat transfer on the mold filling rate is clearly shown, as the weight of the melt introduced would increase versus time when the thickness increase from 5 mm to 10 mm. The heat capacity of 10 mm thick casting is roughly twice the heat capacity of 5 mm thick casting but the heat transfer area is nearly the same in both cases. This means that less exerted surface tension on the melt surface and also less dendrite mesh which may reduce the flow rate in the mold.

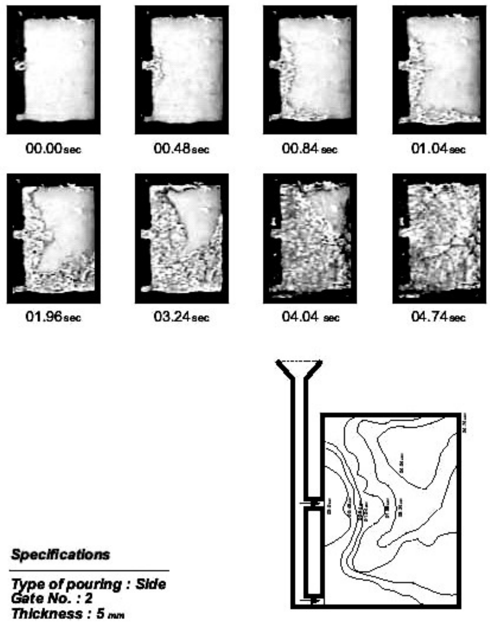


Fig. 5. Mold filling behavior in the side gating system with 5 mm thickness.

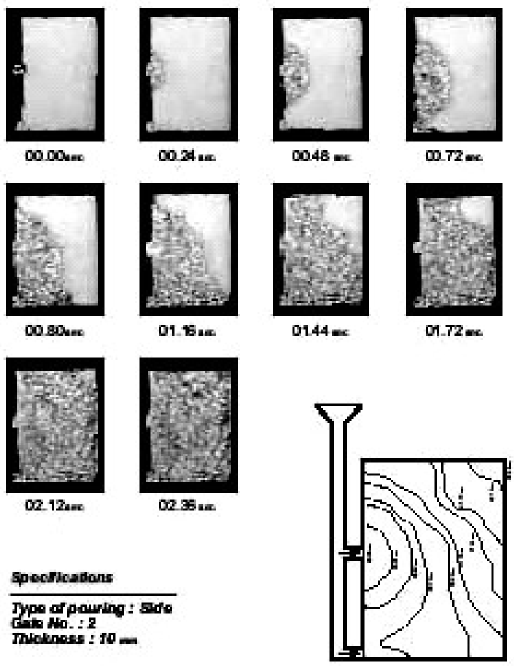


Fig. 6. Mold filling behavior in the side gating system with 10 mm thickness.

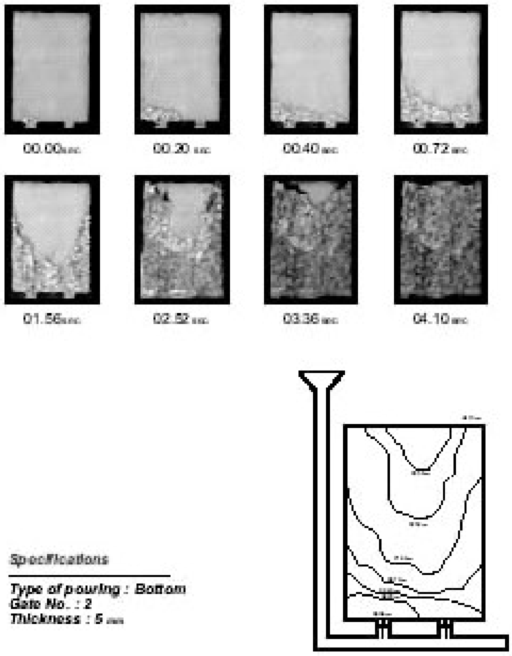


Fig. 7. Mold filling behavior in the bottom gating system with 5 mm thickness.

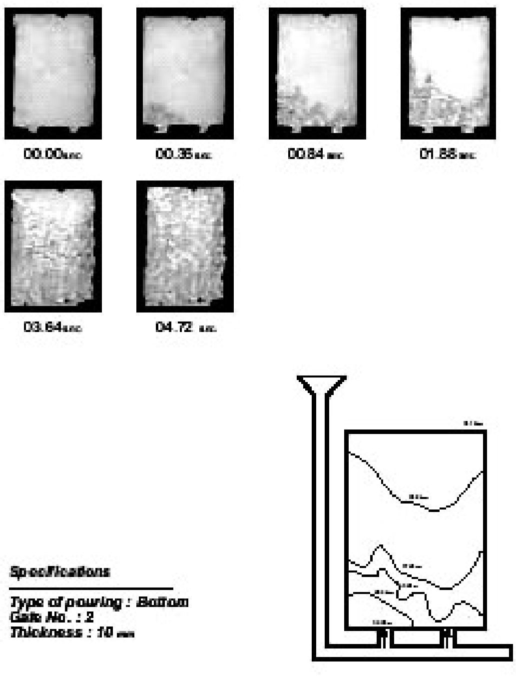


Fig. 8. Mold filling behavior in the bottom gating systemwith 10 mm thickness.

3.2. Effect of the Gating System Type on Mold Ffilling Behavior

Figs. 15-18 show the effect of the gating system type on the mold filling behavior in two different thicknesses of 5 mm and 10 mm (melt weight-time and flow rate-time).

In the top gating system, when the thickness increased, the weight and flow rate of the melt seems higher than the other gating system. The direction of the metal front is parallel with sprue and also with the mold in the top gating system, therefore the incoming melt is faced with positive metallostatic head pressure while in the side and bottom gating systems the incoming melt is faced with negative metallostatic head pressure and therefore the flow rate and the melt weight are lower than the top gating system. Finally, based on Hill [12] and Tschopp [19] results, the effect of the gating system on mold filling behavior is related to different metallostatic head pressures.

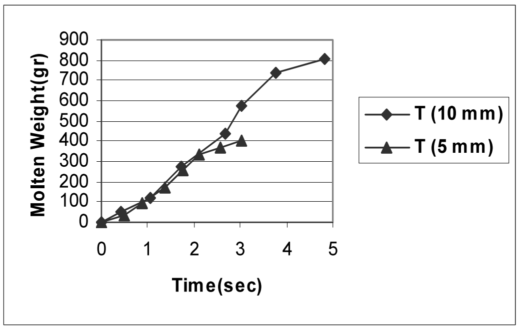


Fig. 9. Effect of the pattern geometry on mold filling in top (T) gating system.

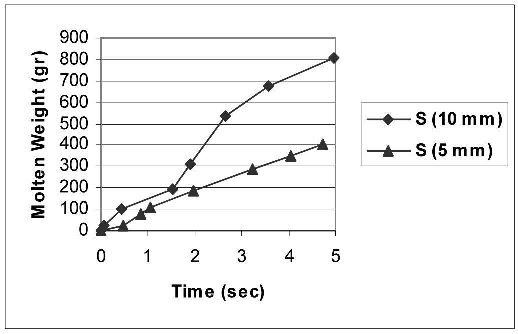


Fig. 10. Effect of the pattern geometry on mold filling in side (S) gating system.

4.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 behavior are also different between these

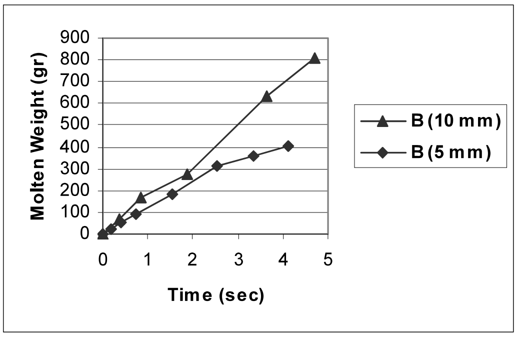


Fig. 11. Effect of the pattern geometry on mold filling in bottom (B) gating system.

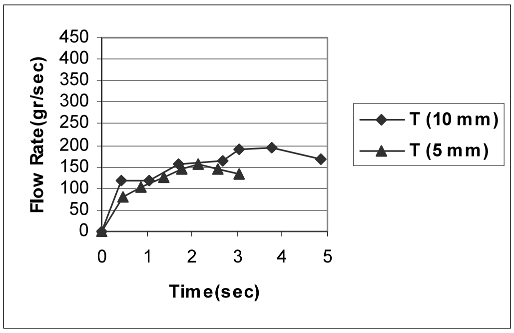


Fig. 12. Effect of the pattern geometry on flow rate in top (T) gating system.

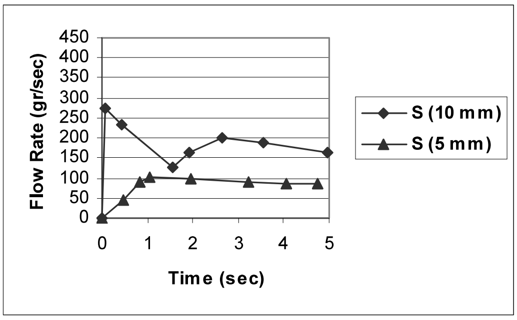


Fig. 13. Effect of the pattern geometry on flow rate in side (S) gating system.

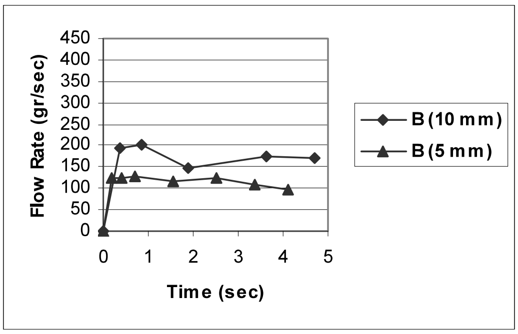


Fig. 14. Effect of the pattern geometry on flow rate in bottom (B) gating system.

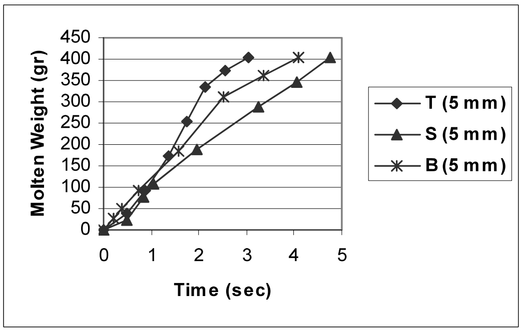


Fig. 15. Effect of the pattern geometry on mold filling in 5mm thickness.

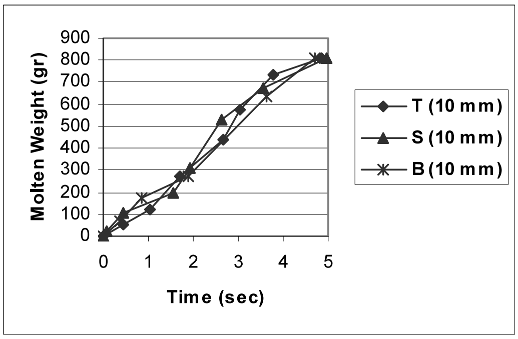


Fig. 16. Effect of the pattern geometry on mold fillingin 10mm thickness.

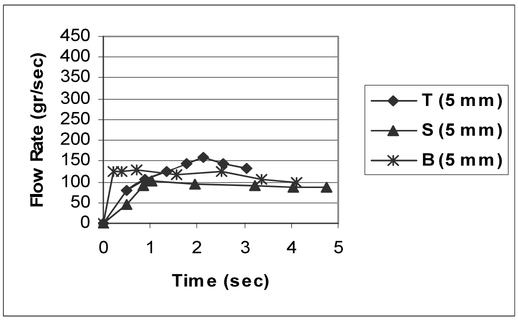


Fig. 17. Effect of the pattern geometry on mold filling in 5mm thickness.

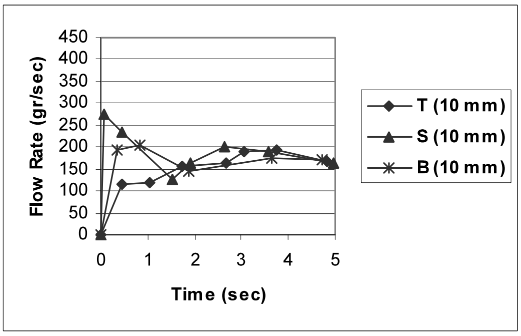


Fig. 18. Effect of the pattern geometry on mold filling in 10mm thickness.

two processes. In this investigation, some other methods were considered to interpret the combined influence of heat and mass transfer (or the influence of pattern thickness) during mold filling and pattern evaporation in aluminum casting with the LFC process.

The research found a profound effect of pattern geometry on the mold filling process. It is believed that the heat amount that must be removed, the rate at which it can be removed and the capacity of coating to remove the decomposition products, depends to the pattern geometry. The gating system have a minor effect on the mold filling process, compared to the size and geometry of the pattern and the coating permeability; probably because the filling process is controlled by decomposition and mass transfer process rather than the flow of the molten metal through the gate. The only case that the gating design was effective is the top gating in comparison with bottom gating. Its effect could be due to metallostatic pressure.

Unlike convectional casting process, at first the liquid flow enters to mold cavity through the first gate, and liquid can flow into the mold cavity even if runner has not been fully filled.

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