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Effect of Top and Bottom Gating System in Sand Casting of Aluminum Alloy Al 6063-T5

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Abstract

During casting process of light metals mold filling significantly affect the casted part. Top and bottom gating system is the most significant design consideration in sand casting. It directly effects the mold filling pattern and solidification time. In this research work, the effect of varying gate sizes with top and bottom configuration on the ultimate tensile strength, solidification time and mold filling time was analyzed. For this purpose, eight experiments were performed by varying top and bottom gating sizes while keeping all other parameters constant. ASTM standard samples were prepared and MTS machine was used to observe the UTS of samples. The Matlab software was used to draw the graphs to analyze the effect of top and bottom gating system on UTS. Bottom gating system exhibits better UTS contrary to top gating system.

***Keywords**: Top and bottom gating system, solidification time, Ultimate tensile strength, Aluminum Alloy6063 T5,*

1. Introduction:

In casting process, there are number of parameters which effect the performance of the mechanical properties. During casting, quality of a casted part highly depends upon Mold Filling Time (MFT) [1]. The importance of MFT and gating design has convinced many researcher to contribute on it [2]. It has been studied that proper gating system design can reduce metal turbulence flow as well as minimize gas inclusion. Top and bottom gating system in casting process has considerable effects on the final casting which includes: MFT, solidification time & Ultimate Tensile Strength (UTS). Solidification time depends upon surface area and volume. Firstly, the relationship between surface area and volume is given by Chvorinov's Rule and secondly, casting quality can be indicated by the cooling rate. Low Cooling rate is necessary to achieve better grain structure which is liable to better casting properties. In this research work, top and bottom gated system of the casting process were varied to study their effect on the UTS of the final casting, which is to a great extent dependent on the solidification time.

Section II outlines literature review related to the research conducted in the areas of Top and Bottom gate casting system. Section III explains the experimental details while experimental design is discussed in Section IV. Lastly, results and discussion are presented in Section V.

2. Literature Review

Precise mold filling operation has a significant effect on the quality and geometry of casted parts. It

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also effects on the mechanical properties of material. . Gating system flow pattern and cooling system all participate in mold filling operation. Knowing this important phenomenon, a number of researchers have investigating the effect of gating system, flow pattern and cooling system of molten material.[1]

For designing a proper gating system, geometrical features of casting such as location of thick regions of casting, cores, boundaries and flow pattern have primary importance [3]. Reference [1] studied the effect of gating system design on the flow pattern in casting process. It shows that geometry, gating ratio and size of gating system has greater effect on mold filling. It has been identified that optimum gating system design could decrease the turbulent extent of the Metal flow minimize the gas and entrap presence of dross [4]. Gating system also effects on different casting defects in mold filling. For instance rigorous steam can become a reason of mold erosion, air and insertions entrapments can be occurred due to high turbulent flow and relatively measured filling could produce cold shuts. Therefore, for good pattern filling, it is required to take into considerations the design of gating system.

Reference [5] defined an approach to position the gating system, pouring cavities and finally the whole geometry of mold. Similarly [6] investigated the impact of gate sizes and shapes on the entering velocity of pouring metal. The non-horizontal plate mold was employed as a bottom gate. The results indicated that critical entering velocity during mold filling operation minimizes the oxide entrapment. The gating system ratio has more influence than gating sizes on mold filling operation [7]. Furthermore, the geometry of gating system is another important factor which influences the mold filling operation.

Gating system consist of a pouring cup and a sprue which receive the melted fluid, having a runner through which melt flows and enters the mold cavity [8]. Gating system also contain a riser that is used to avoid shrinkage effect. Different waste gases are produced in the mold on metal contraction. They can be avoided through vents available in the mold.

The quality of casted parts is highly dependent on solidification time of casting and molds. Casting areas which solidifies slowly poor material properties are observed there [9]. Solidification time can be controlled mathematically through chvorinov's rule. It shows the relationship of solidification time of casting with volume and surface area of casting. The casting with large volume and small surface area will have larger solidification time.

The main objective of casting is to manufacture the product with optimum mechanical properties. Many researchers have worked on this to obtain the optimum strength by varying different parameters in casting process. Reference [10] studied the effect of different molds (Co2 processing mold, sand mold and metal mold) on the hardness, impact and tensile strength of Aluminum Alloy 6063. Sand mold (naturally bonded) gives improved strength. It is due to heat loss at slow rate. Co2 and metal molds gives high hardness due to chilling effect. Reference [11] studied the effect of pouring temperature and velocity on the mechanical properties of aluminum alloy. The results shows that casting with pouring temperature close to melting temperature have the highest hardness and tensile strength and it provides the good quality. Reference [12] studied the casting parameters and check their effect on the mechanical properties of material (Aluminum Alloy and medium carbon steel).

Yuan et all developed a multiple-gate runner system during gravity casting system[7]. Equal velocities of three streams were found equal In this multiple-gate design. Wang et al calculated relative displacement of gates[13]. They performed numerical simulations and also performed experimentation. It was found that proposed method can fix problems associated with filling system . Mohammaed et al developed a method to analyses erosive wear damage in casting process[14]. It was concluded that, proposed method removed erosion during casting process. S. Singh and R. Singh worked on investment casting to develop graded material. From analysis, Al2O3 particles were found at the bottom most surface of the casting[15]. Sanitas el al. performed numerical and experimental study to analyze filling behavior in aluminum casting. It was found that higher pressure range is responsible for unsteady flow. Kasprzak et al. focused on solidification rate of Al-Si HPDC casting alloy. In their study, microstructure refinement and tempering parameters were studied in depth to understand solicitation time. Wang et al. worked on submerged gate method to improve filling condition. It was noted that flow velocity decreases from gate to the mold of casting system[16].

In this study, the effect of gating system including gate geometry and size on the mold filling pattern and ultimate tensile strength in horizontally casted plate mold has been investigated. From the literature review, it is investigated that less work have been done on the gating system. This research work emphasis on the effect of different sizes of top and bottom gating system on the ultimate tensile strength, solidification time and mold filling time. The paper has been structured as follows.

3. Experimentation

This section describes the detail regarding material composition, experimental apparatus, mold making and methodology adopted of this study. The casting material used for the experiment was Al 6063 T5. Pouring temperature was set at 700C because highest tensile elongation is achieved at that temperature (Samson O. Adeosuna2013). Chemical composition of the material is provided in Table 1, which was verified before experimentation through XRF analyzer and wet analysis technique. Silica sand with AFS90 and 5% sodium silicate, a binding agent was used for mold making. Wooden pattern was used to make mold cavity having dimension 18x18x2 cm3 as shown in Figure 1.

Table 1: Chemical composition of Aluminum Alloy 6063T5.

Table 1
Chemical composition of Aluminum alloy 6063T5.

Comp.	Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn
	97.5	0.10	0.10	0.4	0.45-0.9	0.1	0.2-0.6	0.1	0.1

The size of the pouring basin is 18*6.5*3 cm. Surface area of top and bottom of the sprue were 5.40 cm^2 and 3.46 cm^2 respectively. The geometry of the sprue base kept cylindrical having top to bottom diametric ratio (2:1). Length of sprue was 3 cm which is 1.5 times of thickness of runner. The complete detail of the gating design system is listed in Table 2. Two types of allowance are of prime importance while developing pattern for casting which helps in restrained from high manufacturing cost and part rejection, which includes shrinkage and machining allowance. If casted material dimension are up to 365.76 cm then shrinkage allowance is 0.393 in/cm.

The complete experiments list has been provided in Table 2. The effect of temperature on casting volume is shown in Figure 2.

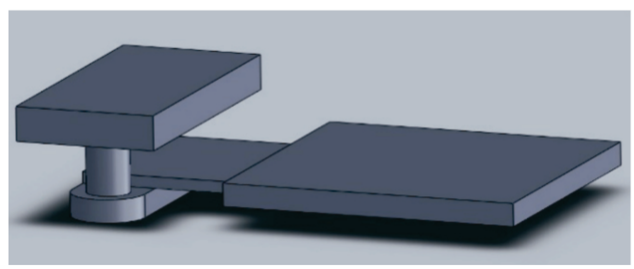

Figure 1: *Wooden pattern for casting*

The parameters used for experiments were sprue surface area (cm^2), runner surface area (cm^2), gate surface area (cm^2) and gating ratio. In this research, total eight experiments were performed. Out of which four were carried out for top gating system and remaining four for bottom gating system. In all experiments, sprue surface area and runner dimensions were kept constant; whereas, gate surface area and gating system ratio were change to identity the optimized UTS. The complete experiment detail has been provided in Table 2.

After solidification, the casted parts were cleaned and adjacent excess material was removed carefully. For cleaning purpose, the adhered sand was removed by shaking out manually; whereas, fettling process was performed for the removal gates, sprues, runners & chipping of any of redundant projections on castings surface.

For measuring UTS, ASTM standard was followed. Samples were prepared with dimensions (18x18x2) according to ASTM standard. The testing of sample was carried out on a tensile testing machine by keeping gauge length constant for all experiments and stretching the sample by same force.

Figure 2: *Bottom gating system*

In the bottom gating system, gate lies below the runner and in the top gating system gate lies on the top of the runner. They are shown in Figure 2 and 3 respectively.

3.1 Mathematical Calculations

This section describes the detail calculations for sand casting parameters used for this research work. The total mold filling time for the top gating system is illustrated by the following equation.

In order to increase the strength of casted parts top gates and bottom gates were designed. A comparison was also performed to analyze their performance.

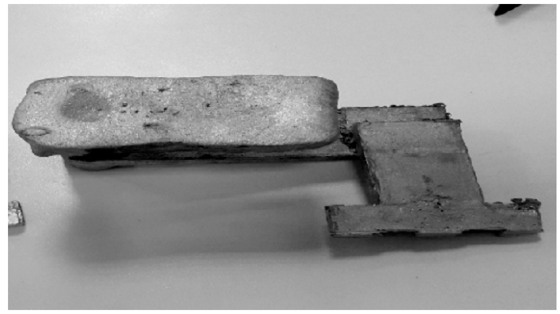

Figure 3: *Top gating system*

For top and bottom gate design purpose, mold filling time and solidification time was calculated mathematically. The mold filling time for top gate is shown in (1). Similarly the mold filling time is given in (2).

$$T_{Ft} = \frac{A_m}{A_g} \times \frac{1}{\sqrt{2g}} \times 2\left(\sqrt{h_t} - \sqrt{h_t - h_m}\right) \ldots .(1)$$

Where

T_{pt} = *mold cavity filling time for top gating system*

A_g = *ingate are*

A_m = *cross section of casting*

h_t = *filling height*

h_m = *height of casting*

$$v. = \sqrt{2gh} \ldots\ldots.. (2)$$

where

H = total height from the top fo casting pattern

v = fluid velocity

Table 2: Specifications for the used gating system

Exp.#	Sprue surface area. (cm^2)	Runner dimension. (cm)	Gate surface area. (cm^2)	Gating system ratio.
Top Gating system				
1	3.46	4.50*2	5.0	1:2.6:1.450
2	3.46	4.50*2	7.0	1:2.6:2
3	3.46	4.50*2	9.0	1:2.6:2.60
4	3.46	4.50*2	11.0	1:2.60:3.18
Bottom Gating system				
5	3.46	4.50*2	5.0	1:2.6:1.450
6	3.46	4.50*2	7.0	1:2.6:2
7	3.46	4.50*2	9.0	1:2.6:2.6
8	3.46	4.50*2	11.0	1:2.6:3.18

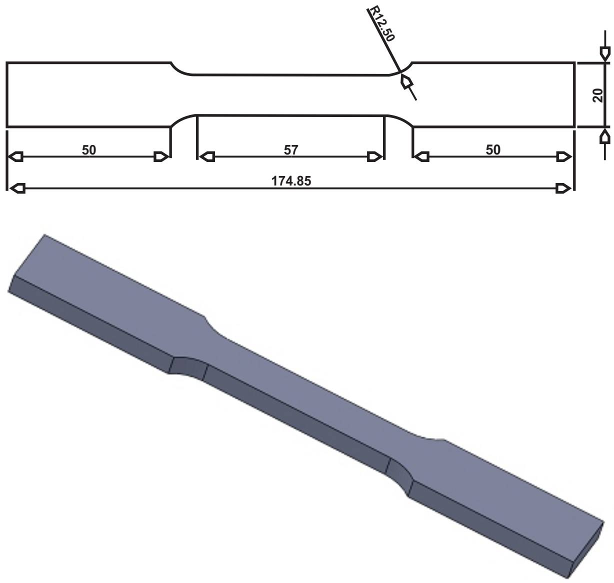

Figure 4: *Standard sample size with dimensions*

The mold filling time for the bottom gating system is illustrated by the following equation.

$$T_{Fb} = \frac{A \times h_m}{A_g \times \sqrt{2g}} \text{.........} \quad (3)$$

Where

T_{Fb} = *mold cavity filling time for bottom gating system*
A_g. = *Ingate area.*
h_m.=*mold filling height*

In this research, the mold filling time is calculated by the following expressions.

The total solidification time for casting and Reynolds number is given as follows.

$$T_{Fb} = K[\tfrac{V}{A_s}]^2 \qquad (4)$$

Where
T_{Ft} = *Total Solidification time for casting*
K = *Solidification constant*
V. = *Casting volume*
As = *Surface Are of casting*

$$Re. = \frac{vD\rho}{\eta} \text{...........} \quad (5)$$

Where
$Re.$ = *Renold number*
$v.$ = *fluid velocity*
$D.$ = *Sprue diameter*
ρ = *density of fluid*
η = *viscocity of fluid*

Table 3: Calculations for casting parameters

Pouring Rate (kg/sec)	Net weight of casting (kg)	Reynolds Number	Fluid Velocity (cm/s)	Total Weight of Scrap (kg)
0.25-0.30 for <10kg of casting weight	1.75	.00279 (Flow is laminar)	135.5	2.22

3.2 Sample Preparation

Standard Samples were prepared from casted plate having size 18*18*2 cm as shown in Figure 4. 8 trials were run and three samples were obtained from each trial. After preparation of 24 samples as shown in Figure 5, ultimate tensile strength of samples on MTS machine was analyzed. 3 values were obtained from each trial and then average value is mentioned in Table 4. Experiments were performed in a foundry shop. Material testing system (MTS) with force capacity 100KN and dynamic stroke 6 in. was used for testing UTS.

Figure 5: *Prepared Samples for Testing*

The broken samples after testing is shown in Figure 6

Figure 6: *Broken Samples after Testing*

3.3 Graphical Representation

To analyze the mechanical properties (Ultimate tensile strength) of aluminum alloy, the graphs are drawn between true stress and true strain. These graphs analyze the effect of top and bottom gating system on the UTS of material. Matlab software was used to draw the graphs presented as shown in Figure 7.

Figure 7 shows UTS of Top and Bottom gating system. The UTS of the sample is minimum when gate size is 5cm and it increases as gate size increases. The average UTS for the 11 cm gating system is maximum i.e. 156.25 Mpa. The UTS trend is same in top gating system except to the last sample having 11 cm gate size. Whose UTS should be maximum but actually its UTS is minimum. The minimum value for 11 cm Gating system, may be due porosity or some other defect in casting.

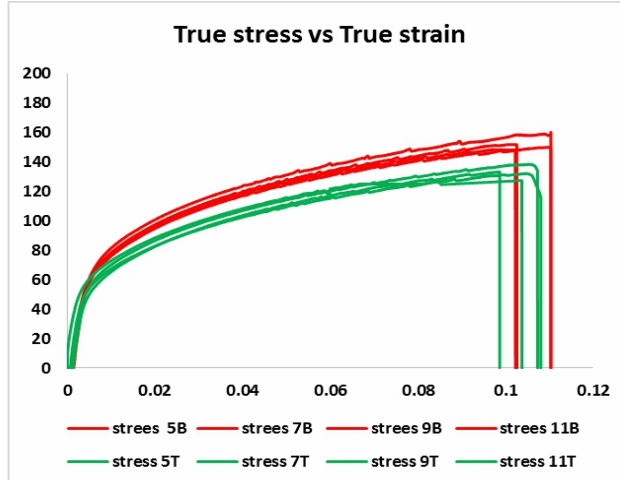

Figure 7: *Graphs for Top and Bottom gating*

4. Results And Validations

Gauge length was kept constant for all samples and UTS of all sample is mention. The values of output parameter ultimate tensile, MFT and total solidification time are mentioned in Table 4 & 5.

The values of output parameter for top gating system are also mentioned in Table 4 & Table 5 consists of values for bottom gating system. In 1st column experiment runs are mentioned. 4 experiments are conducted for each top and bottom gating system. For each experiment there are 3 samples and average values are mentioned in Table.

Table 4 consist of the outputs of bottom gating system. 5T-1 is written to represent a sample 5 represent gating size and T means Top gating system. Numeric 1, 2 and 3 are used for classification of samples.

Table 4: Results for UTS of Top Gating System.

Exp. No	Tensile Specimen	Avg. UTSM	Mold filling time (MFT)	Total solidification time
1.	5T-1 5T-2 5T-3	133.21	1.77	3.10
2.	7T-1 7T-1 7T-2	134.54	1.22	2.73
3.	9T-3 9T-1 9T-2	135.18	1.00	2.42
4.	11T-1 11T-2 11T-3	126.71	0.81	2.17

Table 5: Results for UTS of Bottom Gating System.

Exp. No	Tensile Specimen	Avg. UTSM	Mold filling time (MFT)
1.	5B-1 5B-2 5B-3	148.47	10.12
2.	7B-1 7B-1 7B-2	149.18	7.23
3.	9B-3 9B-1 9B-2	151.00	5.6
4.	11B-1 11B-2 11B-3	156.25	4.6

Table 5 consist of the outputs of bottom gating system. 5B-1 is written to represent a sample 5 represent gating size and B means bottom gating system. Numeric 1, 2 and 3 are used for classification of samples.

Mold filling pattern of plate changes as gate size changes [1] The graph between gate size and Mold Filling time for top and bottom gating system is below in Figure 8. This shows that as the Gate size increases Mold filling time also increase pattern having gate size 11 cm have the highest value of MFT. Same trend is found in bottom gating system. Mold filling time for bottom gating system is less than top gating system.

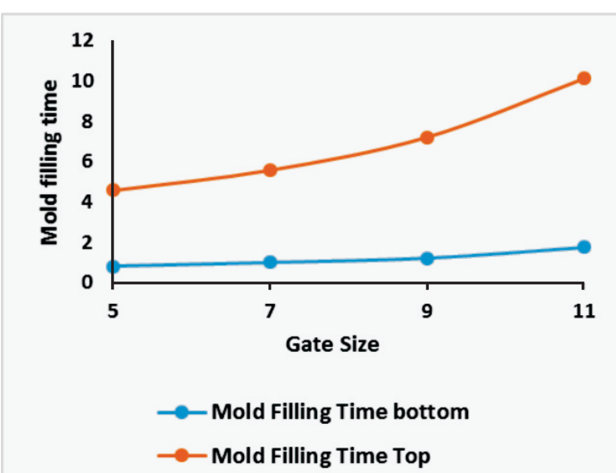

Figure 8: *Mold filling time for top and bottom gating system*

The below graph is between gate size and total solidification time. Total solidification time also increase as the gate size increases. Pattern having gate size 5 Cm has a least solidification time. Figure 9 shows the graph between solidification time and gate size.

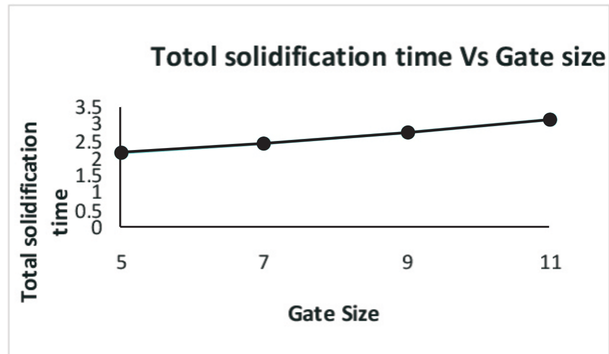

Figure 9: *Solidification time of the casted plates.*

5. Conclusion:

The whole work is done successfully. It is inferred from the result that as solidification time increases, Ultimate tensile strength decreases which preliminary is due to increase of casting size.
It has been observed that:

- UTS of Top gating system is lower than bottom gating system.
- UTS varies as function of Mold filling time (MFT).
- Top gating system has lesser Mold filling time contrary to Bottom gating system.
- In bottom gating system, Gate size variation directly impacts the Ultimate tensile strength.
- UTS of sample having 11 cm gate size in Top gating system should be larger according to trend. Low value of UTS shows that there may be some casting defects in that sample.
- With the increase in the gate size Mold filling time also increase

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