Investigation of Casting Parameters and External Chills Performance onMechanical Properties of Aluminum Silicon Alloy (LM6) Castings

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ABSTRACT

This paper present the experimental investigation conducted on aluminum-silicon cast alloy (LM6) cast using sand casting process. The main objective of the research is to find the effect of pouring temperature and chill thickness on the sand casting of aluminum-silicon alloy. The casting parameters such as pouring temperature and external chills are considered for the experimental work. The pouring temperatures 700°C, 750°C and 800°C are considered for experiment along with the varying chill thickness. The use of end chills during casting not only allows directional solidification but also expedites solidification. Rapid cooling rate gives a good structures and better mechanical properties. In this work, an attempt has been made to obtain the better cooling rate of Al-Si alloy cast using mild steel chills. The mechanical properties such as hardness and ultimate tensile strength (UTS) are analysed. It is found that the chill has a good influence on the properties of the casted specimens. The design of experiment has been set up and experiments were conducted as per full factorial array. Castings are made under the constraint of the process and methodical parameters at three different levels. The mathematical model for UTS and hardness were developed. The better mechanical properties were obtained with application of external chills.

KEY WORDS: External Chills, Pouring Temperature, Cooling Rate, Mechanical Properties.

1. INTRODUCTION

Casting is a metal object produced by allowing molten metal to solidify in a mold. The shape of the object is known by the shape of the mold cavity. Aluminum alloy castings are mainly used in the automobile and aerospace industries and are taking the place of heavier forged steel or cast iron for the lighter and lower fuel consumption vehicles Stuart (2004). It possesses some distinctive properties such as high resistance to corrosion, ease of machining, high electrical and thermal conductivity, light weight and bright color. Aluminum alloy casting has melting temperature 660°C. The information of melting temperature of metals and alloys is necessary to find their corresponding pouring temperature. When the pouring temperature is lesser than its optimum value, the mold cavity does not filled because the riser or ingate will solidify too rapidly and this will interrupt directional solidification. On the other hand, high pouring temperature can cause shrinkage of the casting and mold warping Datau (2012). The better metallurgical properties can be obtained such as the porosity, hardness and microstructure from the combination of 80:20 coarse fine sand ratio and 750 ± 10°C pouring temperature. Ajibola (2015). The solidification rate is one of the very important parameters used for assessing the properties of the material. The effect of various casting parameters such as pouring temperature and external chills has been studied to enhance the mechanical properties of metal castings. Kanthavel (2014), has studied that the use of chill not only accelerates the solidification process but also enhances directional solidification in the sand casting which results in minimized casting defects. Chills are used in the mold so as to increase the ability of heat extraction from the sand mold. A chill normally provides a steeper temperature gradient so that the directional solidification as required in a casting can be obtained. The rapid cooling rate has been achieved by applying cooling aids, which helps in enhancing the mechanical properties of castings. The Design of Experiment (DOE) is used to optimize the casting parameters. The regression models have been developed for Ultimate Tensile Strength (UTS) and hardness.

Literature Review: The literature survey has been carried out to study the mechanical properties of casting by controlling the casting and methodical parameters during the solidification process. Ramesh (2011), studied the effect of chills on the solidification behavior which is an important promoter of directional solidification. Directional solidification results in minimized solidification defects. Hemanth (2014), obtained the cooling curves at chill/melt interface and at various locations of the solidifying melt indicates that the chills have a definite effect on the solidification. The solidification at chill/melt interface starts at lower temperatures compared to their locations along the length of the casting. This indicates that the chills have established asteep temperature gradient along the length of casting and promote directional solidification. Spinelli (2012), carried out directional solidification experiments, and interrelations of thermal parameters, microstructure, and tensile properties are established. Linear relationships between the interfacial heat transfer coefficient and ultimate tensile strength have been obtained for hypo eutectic Al-Fe and Al-Sn alloys. Mojaver (2011), investigates the changes in wear behaviors of microstructures of as-cast Zn-Al-Cu alloys were explained based on the relative contribution of each micro structural characteristic on fracture properties, crack nucleation mechanism and crack growth rate. Karimian (2011), investigate the effect of section thickness, pouring temperature and melt treatment on the microstructure of the Al-Si alloy casting. The finding shows that quality as well as the microstructure of casting has been affected by pouring temperature of casting. The finer microstructure was produced at low pouring temperature and the grain refiner AlTiB has shown less effect on produced castings in terms of microstructure and quality of castings. Anantha Prasad (2015), investigated the effect of reinforcement characteristics and use of chill and compared with the hybrid composite without chill material. The findings confirm the good relationship between mechanical behavior and the dispersiod content. The cast composite of copper chill was obtained to enhance the mechanical properties. The literature review shows that by controlling casting and methodical parameters the microstructure and mechanical properties of castings can be enhanced.

2. METHODOLOGY

Rectangular shaped green sand molds were prepared using cope and drag boxes with end chills. Experiments were carried out withand withoutchills sandcast Al-Si (LM6) alloy. The temperature of the solidifying melt was recorded at intervals of 30 seconds by using K-type thermocouple located at the edge of casting and chill. A temperature data logger was used to measure the temperature with the help of thermocouple. The impact of casting process parameters and methodical parameters have been considered for the study. The design calculations of pattern and gating system have been done for getting correct design parameters. The simulation software Autocast X1 has been used for identifying the correct location of the riser.This helps in finding the hotspot location, which ultimately reduces the shrinkage defect. The experimental work is carried out on a rectangular component of Al-Si alloy. The casted component has been machined and converted as per ASTM- B557 standard for tensile test measurement.The ultimate tensile strength and hardness have been measured. The Design of Experiment(DOE) has been set up at three different levels.The material aluminum silicon alloy (LM6) was selected for the experimental work.The chemical composition of raw material has been done in testing labas shown in Table.1

Table.1. Chemical Composition of LM6 Alloys (As per BS 1490:1988 Std.), Source: Cast-alloys.com

Alloy Composition Percentage	Cu	Mg	Si	Fe	Mn	Ni	Zn	Pb	Sn	Ti	Al
LM6 (Standard)	0.1	0.1	10.0-13.0	0.6	0.5	0.1	0.1	0.1	0.05	0.2	Remainder
LM6 (Tested)	0.0406	0.0098	12.04	0.58	0.458	0.0081	0.033	0.0036	0.001	0.0177	Remainder

The simulation work is carried out on a rectangular bar of size 200 x 30 x 30mm using the Autocast-X1 software.

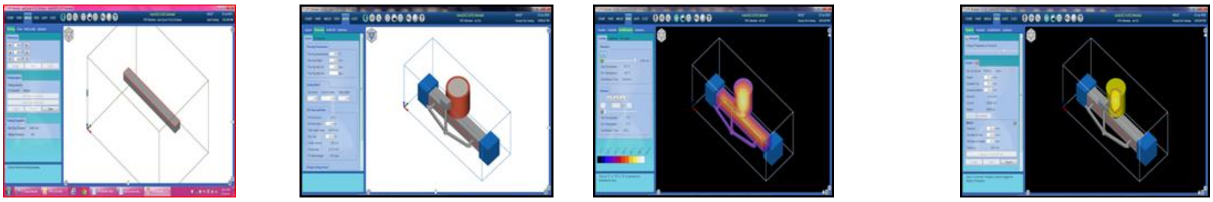


Figure.1. a) Casting sample b) Melt filling process c)Simulation Process d) Hotspot and elimination of shrinkage defect.

The simulation has been done on AutoCastX1 software for correct design parameters such as runner, riser, ingate and sprue sizes. The 30mm square rectangular bar of length 200mm is cast with simulation process. The mild steel chills are used on both sides for directional solidification and enhancing the mechanical properties of castings. The simulation helps in identifying the proper placement of the riser. This helps in eliminating the shrinkage and porosity defects. The hot spot is shifted to the riser to avoid shrinkage defect by Autocast X1 simulation software. The simulation process is as shown in Figure 1 (a), (b), (c) and (d).

Experiments with Chills: The experiment has been carried out in the foundry. In total nine casting were taken out with varying pouring temperature and chill thickness. An experiment was conducted using mild steel (MS) chills with different thicknesses, i.e 35mm, 45mm and 55mm. The pouring temperatures were taken 700 °C, 750°C, and 800°C. The mild steel chills were used on both sides of castings. The temperature of casting has been measured using K-type thermocouple at the end of casting. The experimental work is as shown in figure 2 and 3 (a), (b), (c) and (d).

Figure.2. (a) Pattern with gating parts b) Casting mold cavity c) Riser Placement d) Actual Casting with a gating system

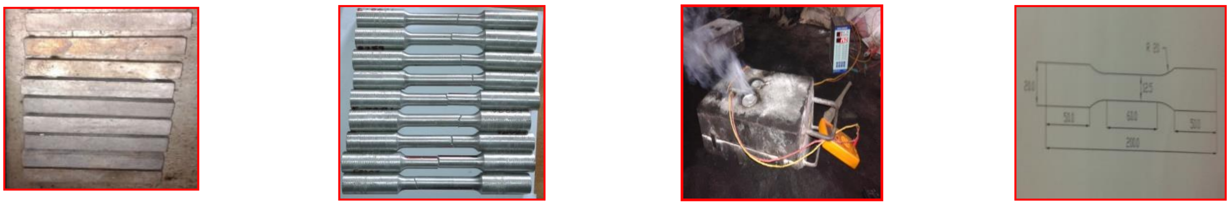


Figure.3. (a) Final casting samples (b) Tensile Test casting samples (c) Casting with Data logger and MilliVoltmeter (d) ASTM B557 drawing Specification

Design of Experiment: Based on literature survey and discussion with foundry expert's two factors (as pouring temperature of molten metal and chill thickness) and their levels have been identified for investigation. Experiments have been arranged for all possible combination of these factors and their levels using design of experiment. All the design parameters are considered for the simulation to shift the hot spot in the riser and avoid shrinkage defect. Table 2 shows the input factors and their levels.

Table.2. Levels of casting parameters

Casting Parameters	Code	Level 1	Level 2	Level 3
Pouring Temp	X_1	700°C	750°C	800°C
Chill Thickness	X_2	35mm	45mm	55mm

The selection of a particular orthogonal array is based on the number of levels of various factors.

Table.3. Experimental Design

Expt. No	Pouring Temp °C, X_1	Chill Thickness (mm), X_2	Tensile Strength, Y_1 (N/mm^2)	Hardness, Y_2 (HV)
1	700	35	148.57	85.21
2	700	45	142.08	88.58
3	700	55	158.67	96.95
4	750	35	138.94	97.96
5	750	45	148.53	102.00
6	750	55	153.12	101.00
7	800	35	134.39	98.71
8	800	45	142.98	101.08
9	800	55	140.57	100.45

The main input factors and the corresponding experimental values of tensile strength and hardness are as shown in Table.3. The main effect plots for ultimate tensile strength are as shown in figure 4.(a) and (b) and of hardness in figure.5 (a) and (b).The interaction plot of UTS and hardness is as shown in figure 6.(a) and (b).

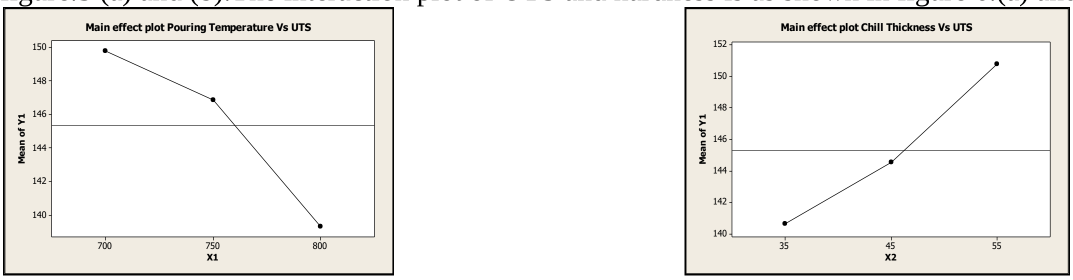


Figure.4.(a) Main Effects plot of PT Vs UTSFigure.4.(b)Main Effects plot of Chill Thickness Vs UTS

The regression equation of Tensile Strength Y_1 is

$$Y_1 = 201 - 0.105\, X_1 + 0.508\, X_2$$

Figure.5.(a) Main effect plot of Hardness Vs PT, (b) Main effect plot ofHardness Vs CT

The regression equation of hardness Y_2 is

$Y_2 = 10.7 + 0.0983\, X_1 + 0.275\, X_2$

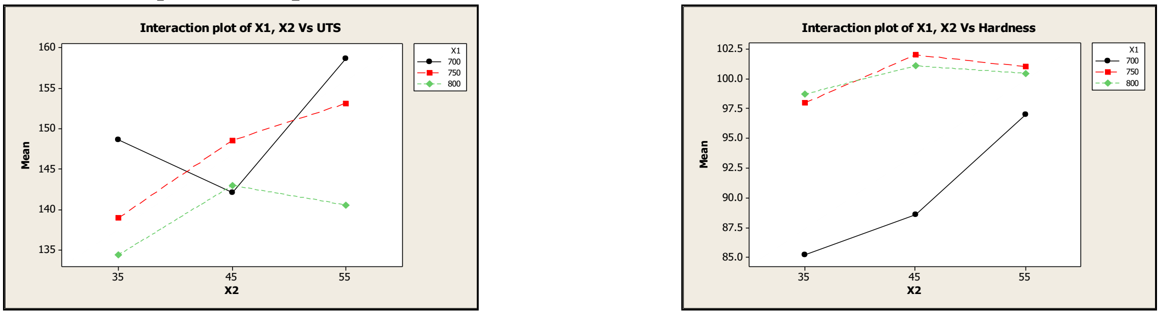


Figure.6. Interaction plots of (a) UTS Vs PT & CT, (b) Hardness Vs Chill Thickness and PT

Experiments without Chills: The simulation work is carried out using AutocastX1 software. The experiment work is carried out on nine castings in the foundry. The pouring temperature has been maintained as per the three specified levels. The experiment has been carried out without using chills. The tensile and hardness test has been carried out for all castings are as shown in Table.4. The graphs of pouring temperature versusmechanical properties are as shown in figure.7 and figure.8. The pouring temperature of molten metal and temperature of casting have been measured using TC 1600F data logger.

Table.4. Experimental values of UTS and Hardness

Expt. No	Pouring Temp °C	TensileStrength(N/mm^2)	Hardness(HV)
1	700	123.84	60.9
2	750	115.86	58.8
3	800	108.33	56.6

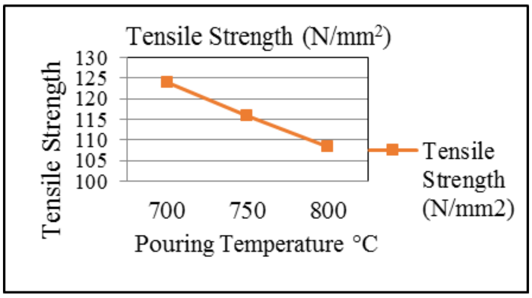


Figure.7. Plot for PT Vs UTS

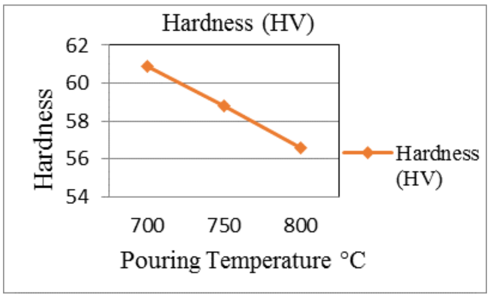


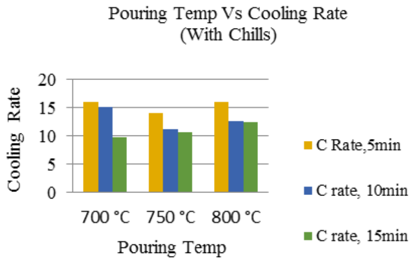
Figure.8. Plot for PT Vs Hardness

The improvement in ultimate tensile strength and hardness percentage with and without external chills has been compared for a casting is as shown in Table 5. The improvement in the cooling rate of castings has been obtained with chills, which helps in improving the microstructure and ultimately the mechanical properties of castings.

Table.5. Comparison of improvement in UTS and Hardness percentage with and without external chills

		Without Chills		With Chills			Improvement in UTS %	Improvement in HD %
Sr. No	**Pouring Temp°C**	**UTS N/mm^2**	**Hardness (HV)**	**Chill Thickness**	**UTS N/mm^2**	**Hardness (HV)**	**(UTS) in percent**	**(HD) in percent**
1	700	123.84	60.9	35	148.57	85.21	16.65	28.53
2	700	123.84	60.9	45	142.08	88.58	12.84	31.25
3	700	123.84	60.9	55	158.67	96.95	21.95	37.18
4	750	115.86	58.8	35	138.94	97.96	16.61	39.98
5	750	115.86	58.8	45	148.53	102.00	22.00	42.35
6	750	115.86	58.8	55	153.12	101.00	24.33	41.78
7	800	108.33	56.6	35	134.39	98.71	19.39	42.66
8	800	108.33	56.6	45	142.98	101.08	24.23	44.00
9	800	108.33	56.6	55	140.57	100.45	22.94	43.65

The graph of pouring temperature versus cooling rate for every five minutes during casting solidification of no chills and after using chills are as shown in figure.9 (a) and (b) respectively.



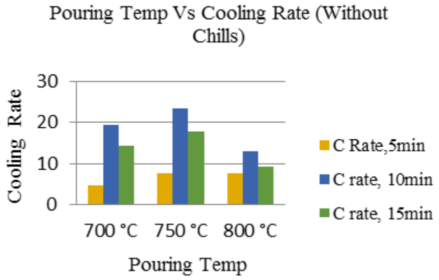


Figure.9. (a) Graph for PT Vs Cooling rate (Chills) (b) Pouring Temp Vs Cooling rate (Without Chills)

4. CONCLUSIONS

The various casting parameters can be controlled during casting process in the foundry. The paper focused on improving the mechanical properties of metal casting by controlling the various casting parameters such as process parameters and application of cooling aids. By controlling these casting and methodical parameters the mechanical properties of casting can be enhanced during the solidification. The external chills help to get the directional solidification and also have a significant impact on mechanical properties of aluminum silicon alloy castings. The experimental work has been done using mild steel chills. The cooling rate has been drastically increased during the initial period of solidification after application of chills. The rapid cooling rate helps in getting the good grain structure and ultimately better mechanical properties. The ultimate tensile strength has increases with increase in chill size and reduces with rise in pouring temperature. The hardness reduces with rise in pouring temperature and increases with increase in chill size. The mathematical models have been developed which gives the relation between response, chill thickness and pouring temperature.

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