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Effect of Chill Size and Material on Temperature Gradient in Aluminium Alloys Casting

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Abstract: *Directional solidification is important for casting process. It is achieved by sequence of solidification of casting different regions of the casting. This study depicts investigation on hot spot during sand casting of aluminum alloy. The study on hot spot was done, using side feeder and chill with different size and material. Different materials of chill include cast iron, aluminum and copper. Casting simulation is a powerful tool to analyze casting process. Simulation process reduces time and money compared to actual process used in foundry. This study mainly focuses on different size and material of chills, keeping size of side feeder constant while simulating casting process. Variations on hot spot were seen in different chills which were studies using Procast software in terms of temperature-time graph. Later optimum results were discussed to end the defects in the casting process.*

Keyword: *Sand Casting, Aluminium alloy, Chill, Solidification Simulation.*

1. INTRODUCTION

In many years foundry industry facing the problem related to casting defects, these problems occur due to uneven filling and cooling of cast part. Every foundry men want to defect free casting .It has led to the need to develop reliable tools for process evaluation. In shop floor trail casting takes much time and money so many industry uses casting simulation software. Simulation is a process of simulating the real phenomenon using a set of mathematical equations implemented in a computer program. Simulation is power tool to analyze the casting process. In casting simulation the mould filling and solidification analysis is done by using an algorithm or program based on finite volume method, to identify the hot spots and hence defects like shrinkage porosities, hot tears, cracks, etc**.** The simulation programs are based on finite element analysis of 3D models of castings and involve sophisticated functions for user interface, computation and display [8]. Casting defects can be minimizing by feeder. When progressive directional solidification cannot be achieved by feeder alone then feedaids are used. Feed aids are chill, insulating and exothermic sleeve, fins and padding.

The use of metallic to control the casting solidification and reduce shrinkage porosity is common in casting industry [9]. Chill material change the cooling profile and porosity location. Cooling capacity of material depend on latent heat, thermal conductivity of material, specific heat and density of material. Chill/metal interface IHTC value is also important parameter.it can define by according to interface material [6].

Chill decrease the local solidification time and remove porosities and improve the mechanical properties. Chill also increase the effective range of feeding or even may omit the need to use feeder in castings. Chill increase the local heat transfer for the material or cast part. This differential cooling rate produces uneven contraction of parts and gives rise to internal strains in the metal it may even produce cracks if the cooling of thinner parts is too severe. For rapid solidification of heavy casting and achievement directional solidification, which ensure controlled freezing towards the riser, chills are commonly used.

The use of chills during freezing of aluminium alloys plays a major role in promoting the directional solidification. One of the important factors that affects heat transfer from solidifying casting to chill is the resistance offers by the casting /chill interface[3].

At a definite point of the cooling phase, the thermal shrinkage of the cast produces a gap which is partially compensated by the thermal dilatation of the chill (which in turn depends on its constitutive material). The dimension of the gap and its atmosphere are, here, responsible for the heat transfer, which is based essentially on convection and, for higher melting point metals, irradiation [7]. Chill effects on the solidification rate with respect to gravity [2].Chill size does not have a great effect on solidification at the being of solidification time but have a large effect after a period of time [4].

Superheat had important effect on the rate of increase of temperature of chill in contact with solidify casting. Increase the rate of heating of chill material during solidification by increasing the temperature of molten metal the effect of chill material thickness after only heat diffused into interior of the chill material and affected the external surface temperature of chill [3]. The interfacial heat-transfer coefficients played a major role in the accurate simulation of casting cooling curves but were of minor importance to the accurate simulation of mold [5].

The temperature change in the chill is violent near the interface at the casting-chill. Moreover, the heat flux in the chill close to the interface transfers vertically against the interface and may be considered as a one dimensional problem [1].

Mechanical properties of a casting can be related to the microstructure which includes grain size and secondary dendrite arm spacing. Improved mechanical properties can be achieved through control rate, local solidification time and temperature gradient within casting [10].

In the Present work Analysis of Influence of Chill Size and Material on Temperature Gradient in Aluminium Alloys Casting has been investigated movement of porosity with side feeder use of different size of chill and material.

2. METHODOLOGY

In this proposed method of effect chill size and material on temperature gradient and porosity defect. Casting simulation is used for predict the defects and remove by the use feeder and feedaids. Simulation is use to minimize the cost and time compare to shop floor trails. Chill used to decrease local solidification time. It produces directional solidification. Many chill give different effect because it's have different thermal conductivity. Well located chill increase the rate of heat transfer and also remove the defects, made sound casting. Feeder and feedaids is more effective compare to separate use. Flow chart of method of casting defect analysis is shown in Figure 1.

3. EXPERIMENTAL ANALYSIS (SIMULATION)

Simulations were performed with a LM6 alloy, cooled on chills made of cast iron, copper, steel and aluminum. All chill materials and sand properties are summarized in Table 1. Outline of experimental setup show in the Figure 2. Cast material composition and properties show in Table 2. The main design criteria were to ensure a dominating uneven flow of heat during the casting solidification in same time and to repeat the process condition and typical foundry environment. In order to investigate the influence of chill thickness on heat transfer, four different chills thickness were used (*H*= 10, 20, 30 and 40 mm).

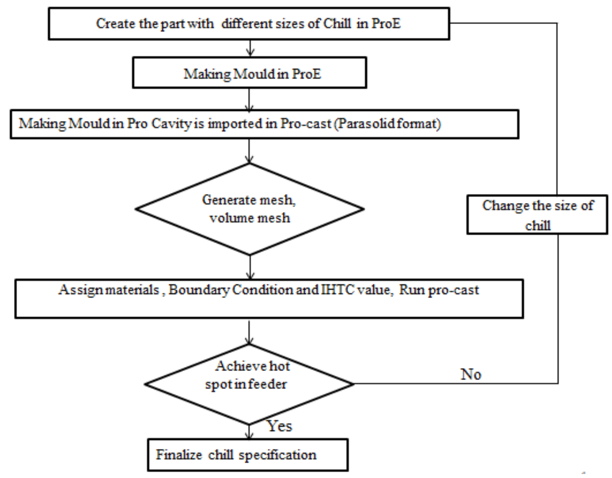


Fig. 1: Flow chart of analysis of influence of chill size and material on temperature gradient in Aluminium alloys

Three nodes were used in cast part as a thermocouple.

3 nodes are used in this experiment. T1 chill side and this located in 20 mm distance to chill. T2 located on the feeder side. it also put in 20 mm distance to feeder side. Last T3 put on the middle point of the cast part. Node T1 was used for find out the chill effect in chill side, while T2 was used to find out the chill effect in feeder side. T3 node was used to midpoint for find out the cooling effect of chill.

In these Experiments green sand used as mold sand. All the simulation work was done in ProCast. All the boundary condition is same for all experiments. The total weight of the casting is 5.0 kg. The pouring temperature was about 650ºC. First experiment is conducted without chill and feeder which detect shrinkage defect in the cast part. When this defect is overcome by the feeder but feeder is not eliminate completely. So we can use chills. Increasing the chill thickness effectively eliminated the shrinkage porosity defect. Using simulation procedure knows the result. How to defect eliminated. Geometry of part made in ProE 5.0. and convert into PARASOLID format. The procedure at the finite differences then evaluates the Temperature gradient by minimizing by difference of the first node of without chill and use of different size of chill at each chill or each node.

Table 1: LM6 Material Property and Composition

LM6 alloy	**Al-86%, Si-10-13%, Cu 0.1% Mg 0.10% Fe-0.4-0.6%, Ni- 0.1%,Ti- 0.1 and other**		
	Thermal conductivity (W/m ◦C)	k	155
	Density (kg/m3)	ρ	2680
	Specific heat (J/kg ◦C)	c	960
	Liquids temperature (◦C)		572
	Solidus temperature (◦C)		570

Table 1: Chill Material and Sand Property

Material	Density (kg/m3)	Thermal conductivity (w/m°c)	Specific Heat (j/kg°c)
Aluminium	2660	211	1090
Copper	8940	391	394
Cast Iron	7870	55	471
Steel	7872	65	481
Green Sand	1370	0.44	1030

4. RESULTS AND DISCUSSION

4.1 Solidification Time

Solidification time change when the chill size and chill material change. 10 mm Copper chill, Aluminium chill, Cast iron chill and Steel chill is not provide great effect compare to without chill in solidification time. All 10 mm chills solidification time approximate same for without chill. Main effect of chill in detect shrinkage defect in the cast part. Solidification time when use 20 mm chill for all material. Copper chill solidification time is decrease when the size of chill change. When used Aluminium chill it give similar effect to copper chill but it's solidification time compare to copper chill very less. Cast iron chill have less thermal conductivity when it used solidification time decreases. It is more effect compare to Al. Cast iron suddenly decreasing solidification time. Steel chill perform well. It deceases solidification time in 30 mm size then use 40 mm chill size further increase solidification time. Copper chill is best of decreasing the solidification time because its thermal conductivity is higher compare to other chill and it transfer heat more and early solidify the cast part. Figure 3 show the comparison between chill size and solidification time for all chill material.

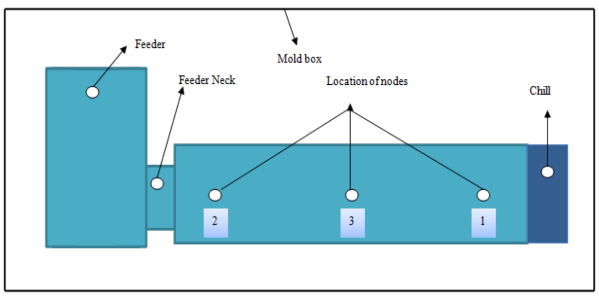


Fig. 2: Experimental Setup Outline

4.2 Temperature Gradient with Time

Temperature gradient changed when use chill. Side feeder and without chill take the simulation so shrinkage porosity occur in the cast part. Figure 4 how the simulation when porosity is occur. Copper is used to remove porosity and which size of chill porosity in also an important parameter. Temperature gradient shows the behavior of copper chill. Size of copper chill changed the porosity move toward the feeder. When use 10 mm cu chill little amount of porosity shift to the feeder then use 20 mm chill ½ porosity is shift to feeder. Then use of 30 mm cu chill ¾th porosity is eliminated. When use 40 mm cu chill whole porosity move toward the feeder and cast part make defect free. All nodes show the time temperature profile. Measure the temperature in all nodes. Time-Temperature graphs show the actual effect of chills on casting part. Cooling curve generated at each nodes. Cooling profile shown in figure 5. Comparision of all copper chill size related to temperature and time. After simulation Position of all node shown in Figure 6 to 8. Similar Procedure followed on the Aluminium chill in simulation. Al chill has low thermal conductivity compare to cu chill so it rate of heat transfer is also low compare to cu chill. Cooling of cast part take too much time. Temperature gradient of Al chills vary with respect to time. It appears that small differences arise with cu and al chills. 40 mm al chill take very less time compare to 10 mm or without chill. After simulation all nodes position had shown in Figure 9 to 11. Cast iron chill give excellence result because cast iron chill have low thermal conductivity so feeder have enough time to fill the porosity. Behavior of cooling profile changes on using 30 mm chill size.

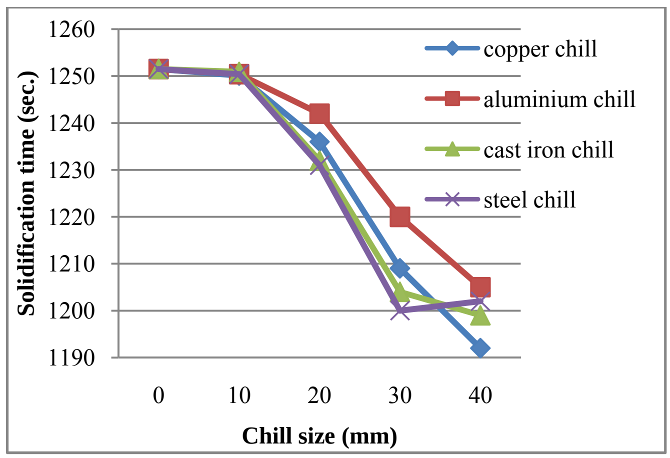
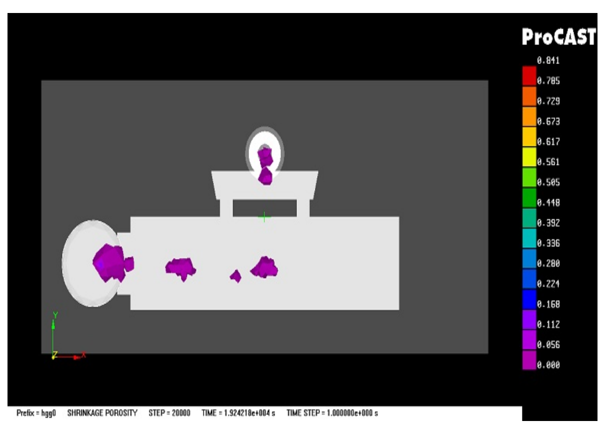
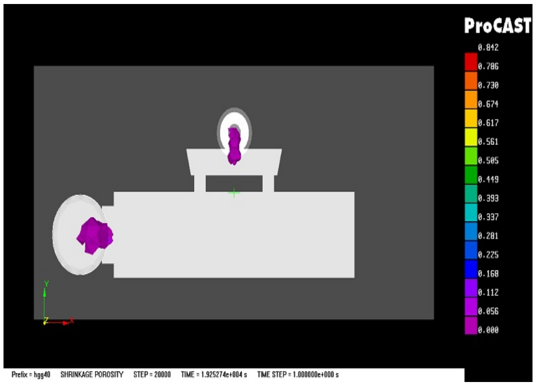


Fig. 3: Comparison b/w chill size and solidification time



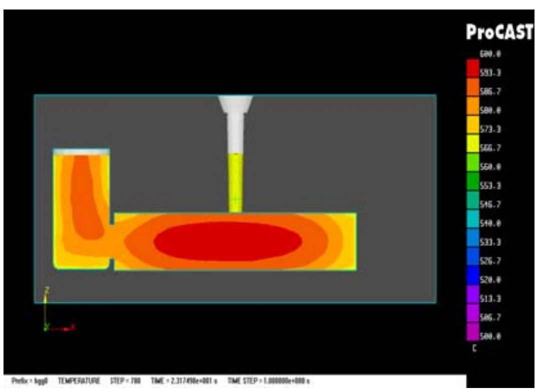
(a)



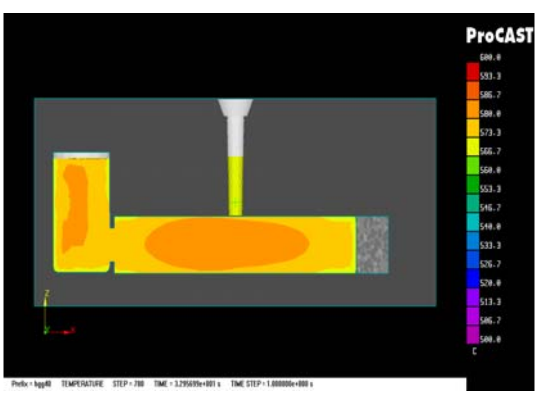
(b)

Fig. 4: (a) Without chill simulation shrinkage porosity in cast part (b) use of 40 mm chill simulation.

30 mm cast iron chill remove all porosity and temperature gradient profile show the effect. 40 mm sizes of cast iron chill reduce the porosity in cast part. It is provide better effect compare to both chills. It is take time to solidify the cast part. Casting simulation of cast iron chill give these result. Simulation show the actual cooling profile when chill is used. After simulations positions of all nodes shown in figure 12 to 14



(a)



(b)

Fig. 5: (a) Cooling profile for without chill, (b) Use of 40 mm chill cooling profile.

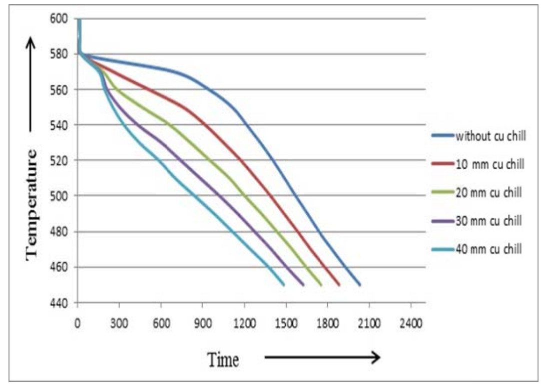


Fig. 6: Compare all cu chill size in node T1

In this simulation steel chill use on the place of cast iron chill. We perform experiment with side and without chill. Shrinkage porosity is occurring on the cast part. Show the shrinkage porosity defects. First of all 10 mm steel is use to remove shrinkage porosity defect. 10 mm cast iron chill not remove completely shrinkage. It only shifts porosity towards the feeder side. Calculate its effect in terms of Temperature. Now 10 mm replaced by 20 mm steel chill and Perform simulation. 20 mm steel chill is more effective compare to 10 mm steel chill. Use to 20 mm steel chill move the shrinkage porosity toward the feeder. But not completely eliminated. Some porosity remains in the casting. After that use 30 mm steel chill and perform same simulation on Pro-CAST a little shrinkage porosity is remains and most of the shrinkage porosity shift to feeder. It is more effective compare to both previous used chills. Remaining porosity remove by 40 mm steel chill.

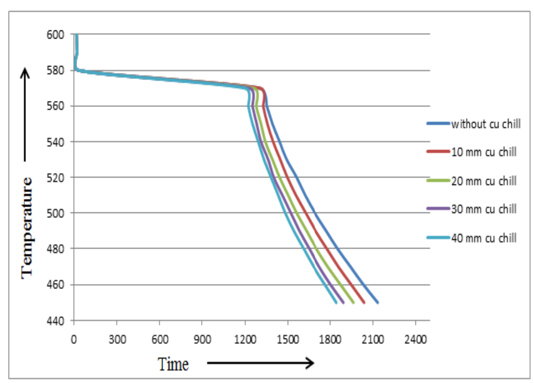


Fig. 7: Compare all cu chill size in node T2

All shrinkage porosity shifts to feeder. Casting is free form defects Time temperature graph show 15 to 17. Steel chill and Cast iron chill show the best effect on 30 mm chill size but the temperature gradient of steel give the best result compare to all chill. Steel chill have lower thermal conductivity and lower specific heat from all chill.

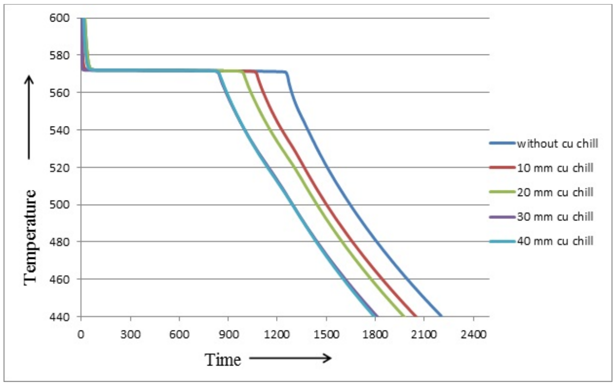


Fig. 8: Compare all cu chill size in node T3

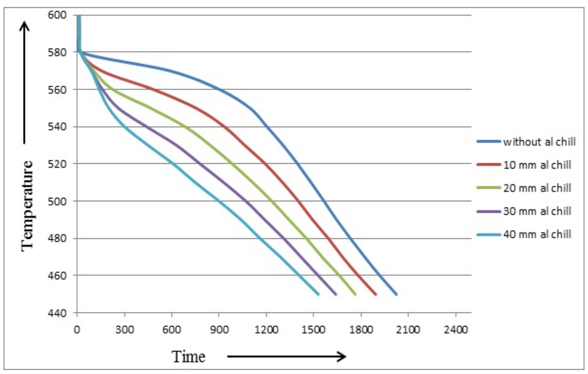


Fig. 9: Compare all al chill size in node T1

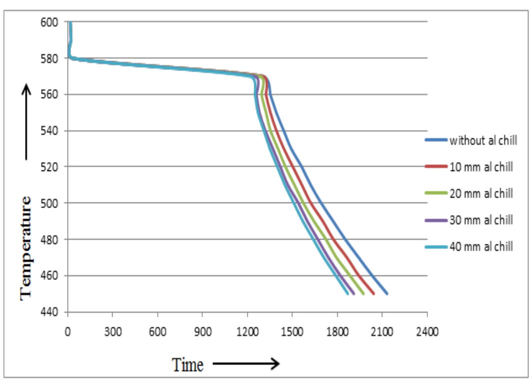


Fig. 10: Compare all al chill size in node T2

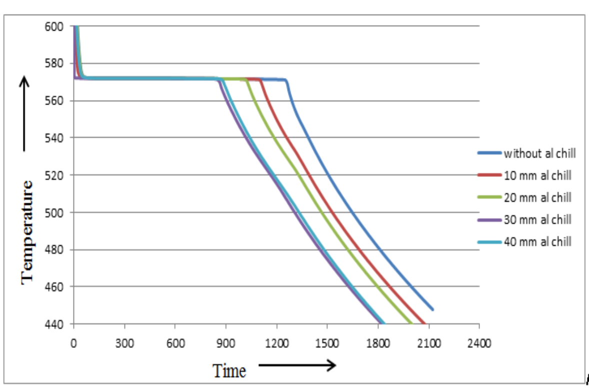


Fig. 11: Compare all al chill size in node T3

4.3 Regression Analysis

Multiple regression analysis is performed using Minitab 16 statistical analysis software. It makes the linear relationship between chill size, chill material and temperature gradient. The regression equation given below:

Temperature gradient = 3.30 + 1.54 chill size + 2.96 chill material……… (1)

S = 6.55042, R-Sq = 88.2%, R-Sq(adj) = 87.9%.

The P-value in ANOVA table (0.000) show that the model obtained by the multiple regression analysis procedure significant at the level of α- level of 0.005. α- level, or level of significance, is the maximum acceptable level of risk rejection a true hypothesis. Its low value indicates that the chance of finding an effect that does not exist, is very low. They are significantly related to temperature gradient.

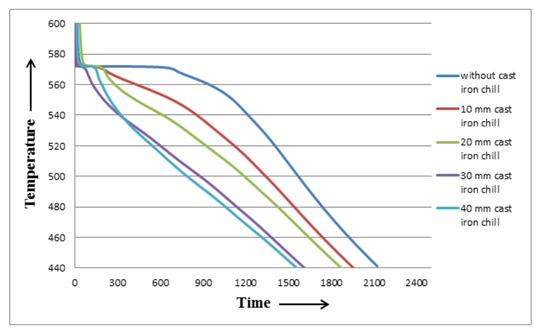


Fig.12. Compare all cast iron chill size in node T1

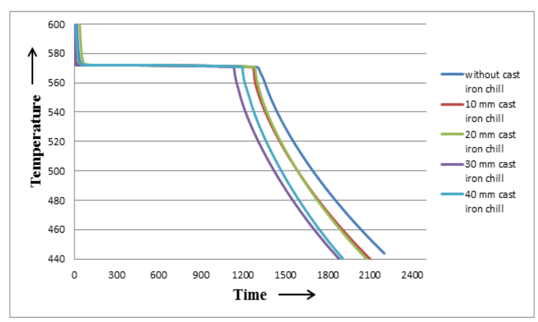


Fig.13. Compare all cast iron chill size in node T2

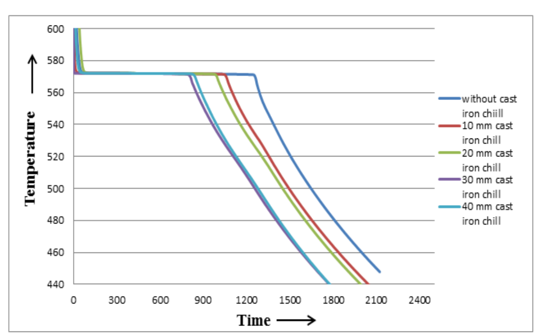


Fig.14. Compare all cast iron chill size in node T3

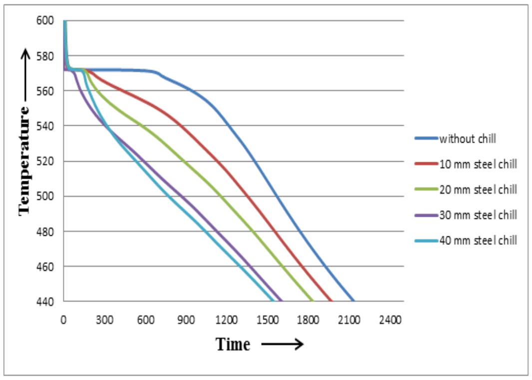


Fig.15. Compare all steel chill size in node T1

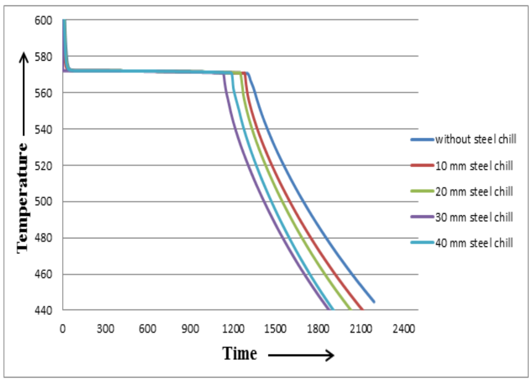


Fig.16. Compare all steel chill size in node T2

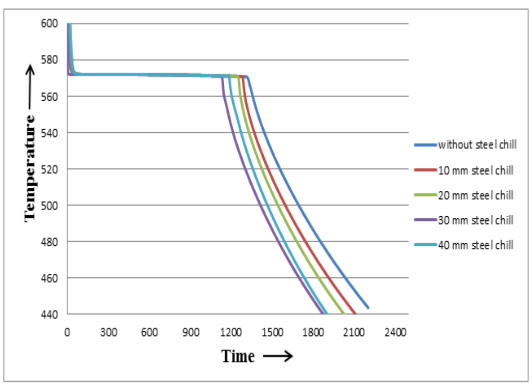


Fig.17. Compare all steel chill size in node T3

Table 3: Analysis of Variance for data sets of chill material and chill size.

Overall				
DF	**SS**	**MS**	**F**	**P**
2	25662	12831	299.04	0.000
Predictor	Coef	SE Coef	T	P
Constant	3.304	2.290	1.44	0.153
Chill size	1.53616	0.06437	23.86	0.000
Chill Material	2.9554	0.6470	4.57	0.000

The R^2 value indicates that the predictors explain 88.2% of variance in temperature gradient estimation. The adjusted R^2 is 87.9 %. Which accounted for number of predictors in the model both value indicate model fits the data well.

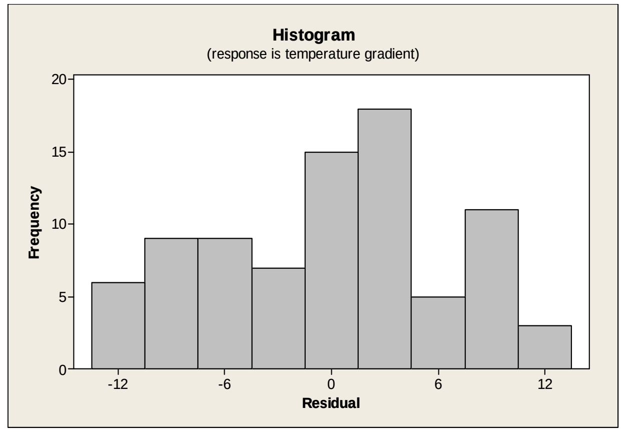


Fig. 18: Histogram of residuals for Temperature gradient

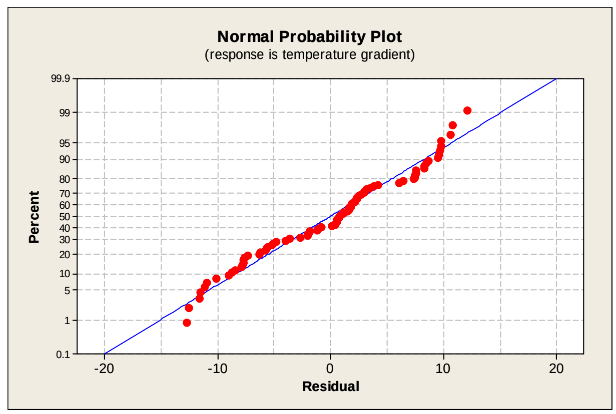


Fig. 19: Normal Probability plot of Residuals for Temperature gradient

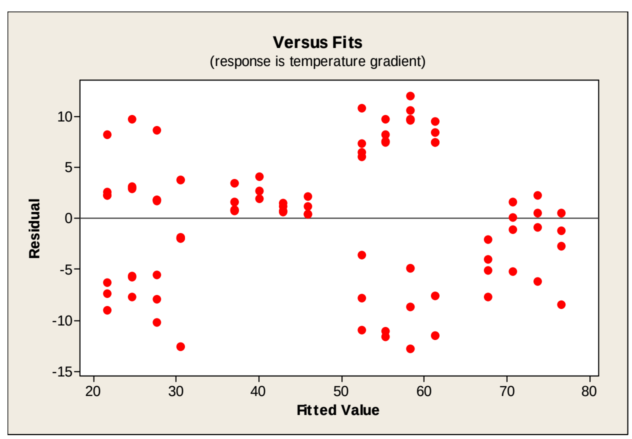


Fig. 20: Residual v/s fits Residuals for Temperature gradient

5. CONCLUSION

A simulation investigation on the temperature gradient during sand casting of LM6 alloy was performed, evaluating the effect of chill material and size. It was found that:

1. Steel chill gives more effective results compare to cast iron, copper and aluminum chill. As steel chill take more time to solidify the part so side feeder have enough time easily to fill porosity. Thus, it makes casting part free from defects.
2. Copper chill has low solidification time to other chill. Copper chill takes 1192 sec. aluminium chill solidify 1205, cast iron chill solidify 1199 and steel chill solidify 1202 sec.
3. Steel and cast iron higher temperature gradient in 30 mm chill size.

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