Optimization of Shrinkage Porosity in AlSi5Cu1Mg Alloy using Response Surface Methodology

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Abstract. Zero defects are the ultimate aim of any manufacturer casting aluminium alloys. Shrinkage porosity is the major defect in casting AlSi5Cu1Mg alloy using Gravity Die Casting (GDC) process. This paper deals with development of effective approach to describe the optimal condition to reduce the shrinkage porosity formation. Solidification time, metal temperature, and preheat molten temperature are varied using Response Surface Methodology (RSM) based Box-Behnken Design (BBD) and conducted experiments. Solidification time and pouring metal temperature are directly proportional and solidification time and preheat temperature of the mould are indirectly proportional. Theoretical approach is validated with the experimental approach and the predicted values from RSM based BBD is useful and effective in determining the optimized process conditions in GDC process.

1. Introduction

Wide range of Intricate components are efficiently produced with Gravity Die Casting [1]. Lighter weight and good corrosion resistance with higher dimensional accuracy Aluminium components are cast from GDC with good mechanical properties [2]. Maximum benefits can be obtained from optimizing the process parameters. Past experience and trial & error methods will be useful in identifying the correct process parameter [3].

Void or hole in cast object are described as shrinkage porosity and occurs due to gas formation and solidification. Even after considerable research shrinkage porosity formation is the main issue in aluminium alloys casting using GDC [4]. Supplier trying hard to meet the increasing demand for aluminium alloy but due to shrinkage porosity meet of demand is becoming virtually impossible [5]. Many experiment might be needed which will be costly and time consuming process to optimize the process parameter to produce aluminium die cast components with minimum porosity percentage and validate the optimum parameters [6][7].

New method for experimental optimization for the effects of process parameters in GDC using RSM was established and focused by many researchers in the recent year [8]. Clear information of the process was described in the above technique and it have very less possibility to associate the findings [9]. Structural and property improvement of aluminium has enhanced the use of aluminium various applications [10]. Micro structure and grain distribution are studied with help of SEM in modern era[11]. The present paper aims in investigating the influence of process parameter on shrinkage porosity formation in GDC using RSM.
2. Experimental Procedure

High efficient and accurate equipment or experimental procedure needed to predict the correct parameter of GDC. Hence an automated mould GDC compares of molten furnace with automatic ladle for pouring along with data acquisition and monitoring system was employed. Different process parameters that influences GDC process will be analysed and investigated. Aluminium Alloy chemical composition used in this investigation is shown in the table 1.

Table 1. Composition of Aluminium Alloy

| Alloys       | Cu % | Si % | Mg % | Zn % | Fe % | Mn % | Ni % | Ti % | Pb % | Sn % | Al % |
|--------------|------|------|------|------|------|------|------|------|------|------|------|
| AlSi5Cu1Mg   | 1    | 4.5  | 0.35 | 0.15 | 0.65 | 0.55 | 0.25 | 0.05 | 0.15 | 0.05 | Remainin |
| GDC          | 1.5  | 5.5  | 0.65 | max  | max  | max  | max  | max  | max  | max  | g    |

2.1. Response Surface Methodology

In machining and manufacturing engineering RSM is used to model and analyse the input variable and output response. In practice, second order polynomial is used to fit the experimental value. Equation 1 describes the second order polynomial followed for the casting defects in GDC.

\[
R = b_1 f_1 + b_2 f_2 + b_3 f_3 + b_4 f_4 + b_5 f_5 + b_6 f_1 f_2 + b_7 f_1 f_3 + b_8 f_1 f_4 + b_9 f_1 f_5 + b_{10} f_2 f_3 + b_{11} f_2 f_4 + b_{12} f_2 f_5 + b_{13} f_3 f_4 + b_{14} f_3 f_5 + b_{15} f_4 f_1 + b_{16} f_4 f_2 + b_{17} f_4 f_3 + b_{18} f_4 f_5 + b_{19} f_5 f_1 + b_{20} f_5 f_2 + b_{21} f_5 f_3 + b_{22} f_5 f_4 + C \quad (1)
\]

Using the proposed scheme the response coefficient was determined and second order response accurately fits the proposed model. Replication was eliminated to determine the error term. 20 experiments was designed using RSM based BBD in design expert 1.0. The table 2 shows the maximum and minimum value of input factors like cooling time, limit distance, inter-facial pressure, metal temperature and die temperature. Table 3 depict the experimental design.

Table 2. Maximum and Minimum of input factors

| Parameter       | Cooling Time | Limit Distance | Interfacial Pressure | Metal Temp | Die Temp |
|-----------------|--------------|----------------|----------------------|------------|----------|
| Notation        | f_1          | f_2            | f_3                  | f_4        | f_5      |
| Unit            | sec          | mm             | kg/cm^2              | °C         | °C       |
| Min             | 4.31         | 44.86          | 15.54                | 612.43     | 84.86    |
| Max             | 6.69         | 235.14         | 134.46               | 707.57     | 275.14   |

Under the same test conditions duplicate tests were performed to ensure the repeatability of test data and the deviation was found to be 5% with maximum standard deviation of 0.018.

2.2. Analysis of developed quadratic models

Analysis of variance (ANOVA) is used to estimate statistically the developed second order equation for shrinkage porosity [13]. Grand means of the responses is used to find the sum of square and SS3 to degrees of freedom ratio fetch the mean square in the ANOVA table. F value in the ANOVA table is used to identify the accuracy of the model. The assessment for level of fit as well as significance are performed to evaluate the accuracy of the model.

2.3. Optimization processes using RSM

The casting of aluminium alloy using GDC method was conducted based on RSM BBC method for modeling and analyzing the porosity in the casting processes. Design points was formulated using the model developed in terms of shrinkage porosity. Solidification time and preheat temperature of die reduces the shrinkage porosity. The corresponding desirable value of AlSi5Cu1Mg is obtained from the optimal condition.
me in GDC. Similarly the phyer to die distance (limit distance) is more to reduce the porosity percentage. The it causes turbulence in flowing metal which leads to minutes air hole in the solidified cast object. Porosity percentage decreases with increase in the limit distance and decrease in cooling time, it causes turbulence in flowing metal which leads to minutes air hole in the solidified cast object.

| Trial | f1 | f2 | f3 | f4 | f5 | R  |
|-------|----|----|----|----|----|----|
| 1     | 5.5| 140| 134.6| 660| 180| 36 |
| 2     | 6  | 180| 50  | 640| 220| 35 |
| 3     | 6  | 100| 50  | 640| 140| 32 |
| 4     | 6.68|140| 75  | 660| 180| 30 |
| 5     | 6  | 180| 100 | 680| 140| 32 |
| 6     | 6  | 180| 100 | 680| 220| 27 |
| 7     | 5.5| 140| 75  | 660| 180| 34 |
| 8     | 5  | 100| 50  | 680| 220| 38 |
| 9     | 5.5| 140| 75  | 660| 180| 33 |
| 10    | 5  | 100| 100 | 680| 140| 34 |
| 11    | 5.5| 140| 75  | 660| 180| 39 |
| 12    | 5  | 180| 100 | 680| 220| 25 |
| 13    | 6  | 180| 50  | 680| 140| 45 |
| 14    | 5  | 180| 100 | 640| 140| 57 |
| 15    | 5  | 180| 100 | 640| 220| 28 |
| 16    | 4.31|140| 75  | 660| 180| 39 |
| 17    | 5  | 180| 50  | 680| 140| 60 |
| 18    | 6  | 100| 100 | 680| 140| 42 |
| 19    | 5.5| 140| 75  | 660| 180| 46 |
| 20    | 5.5| 140| 75  | 707.56|180| 47 |
| 21    | 5  | 180| 50  | 680| 220| 34 |
| 22    | 5.5| 140| 75  | 612.43|180| 38 |
| 23    | 5.5| 235.1|140| 75  | 660| 180| 39 |
| 24    | 5.5| 140| 75  | 660| 84.86|33 |
| 25    | 6  | 180| 50  | 640| 140| 36 |

3. Results and Discussion
Porosity percentage decreases with increase in the limit distance and decrease in cooling time, it is clearly displayed in figure 1 a). Solidification will be uniform with lesser cooling time and will be non-uniform for greater solidification time. There for cooling time plays a vital role in porosity percentage in GDC.

5.5 sec is the optimal cooling time in GDC. Similarly the phyer to die distance (limit distance) is more the it causes turbulence in flowing metal which leads to minutes air hole in the solidified cast object. The limit distance is to be kept at 100-150mm through out the metal pouring process to reduce the porosity percentage.
Figure 1. a) Effect of cooling time and limit distance on porosity and b) Effect of cooling time and interfacial pressure on porosity

Porosity percentages reduced with increase in inier-facial pressure and decrease with cooling time, it is clearly displayed in figure 1 b). As the interfacial pressure increases the metal will flow in all the direction at higher velocities and removes the air holes and pushes towards the opening end and leaves to the atmosphere. 5.5 sec is optimized for the cooling time.

Porosity percentages reduced with increase in metal temperature and decrease with cooling time, it is clearly displayed in figure 2 a). As the metal temperature increases, solidification rate will be reduced and non uniform solidification will be followed leads to creating blow holes in casting. The furnace is maintained at 660oC to get optimal results.

Figure 2. a) Effect of cooling time and metal temperature on porosity and b) Effect of cooling time and die temperature on porosity

Porosity percentages reduced with increase in die temperature and decrease with cooling time, it is clearly displayed in figure 2 b). The graph gives a conclusion that increase in die temperature will decrease the porosity of the metal. Die temperature is maintained at 200oC to get optimal results. Porosity percentages reduced with increases in inter-facial pressure and decrease in limit distance, it is clearly displayed in figure 3 a).

Figure 3. a) Effect of limit distance and inter-facial pressure on porosity and b) Effect of limit distance and metal temperature on porosity

Porosity percentages reduced with increases in metal temperature and decrease in limit distance, it is clearly displayed in figure 3 b). Porosity percentages reduced with increases in die temperature and decrease in limit distance, it is clearly displayed in figure 4 a).
Porosity percentages reduced with increases in metal temperature and interfacial pressure, it is clearly displayed in figure 4 b). Porosity percentages reduced with increases in die temperature and interfacial pressure, it is clearly displayed in figure 5 a).

Porosity percentages reduced with increases in metal temperature and die temperature, it is clearly displayed in figure 5 b). Figure 6 a) and 6 b) shows the SEM image of the structure before optimisation and after optimisation process respectively. It clearly shows the reduction of pores after optimization process. Figure 6 a) shows the pores of upto 20 micrometer in length before optimisation with 20x magnification and it is clearly noticed that the pores have been reduced in the fig 6 b) after optimisation.

4. Conclusion
In this research, the process parameter that affects the porosity of the casting is studied in detail. The basic parameter that affects the porosity of the casing such as interfacial pressure, limit distance, metal time and cooling time are optimized as follows. The comprehensive technique urged in industry for optimization is used for predicting the values. Further ANOVA is performed to find out the experimentation procedure for the conduction of analytical experiment in order to validate the results obtained from RSM. The optimized parameters was based on Industrial problem raised on GDC of AlSi5Cu1Mg alloy which has been solved in the current work.
5. References

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