Optimization of Sand Casting Process Parameters: An ANOVA Approach

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Abstract

ANOVA is a systematically structured tool for the tactical study of process parameters and their effect on the mechanical characteristics of cast aluminum alloy. The two process parameters included the sand permeability and the aluminum alloy cooling temperature. The effect of these selected parameters on the impact force of alloys has been proposed to ANOVA. The results show that the terminology and use of this approach is an effective tool for evaluating sand casting and help find to Medium Square and response mean square and Medium Square of errors respectively as 8.54, 8.255 and 0.435. The work has concluded that the permeability of the sand is the most significant factor with an effect intensity of 5 percent.

Keywords: Sand Casting; Mechanical Property; Pouring Temperature; Permeability of Sand; ANOVA.

1. Introduction

Aluminium is one of the most common elements in earth crust. It has many desirable properties, including high corrosion resistance, high thermal and electric conductance, low weight and bright color that give it a lead in the other aerospace, electrical, construction and automotive products [1]. The important aluminum alloy used in industries is Al-Si in which the percentage change of silicon (4.0-13%) contributes to good casting. On the other hand, sand casting is the oldest and most widely used casting process due to its property of collapsibility and recycling. Casting is the process used to manufacture the product through solidification of molten metal in the mould [2]. The casting product is then machined to remove surface imperfections.

Over the decades, the application of different statistical tools has increased in the design and analysis of casting process [3-5]. Analysis of variance (ANOVA) is an extremely useful technique in the industrial experiments. In this considered multiple factors are altering with respect to different given conditions for the summarization of a classical linear model associated along with a test(the F-test) of the hypothesis [6]. As there are many casting parameters such as permeability of sand, mould conditions(temperature, moisture, types of sand and binders used) melting temperature of charge, pouring temperature, pouring speed, gate design, size of casting and the type of cast alloy. It has been observed that the variation in most of these parameters affects on the mechanical factors of the cast material such as impact strength, tensile strength, hardness, percentage elongation and so on [7]. This assertion leads to the differences in microscopic structure of casting. Because of these differences which cannot be eliminated completely, the varying effect of such parameters on mechanical properties needs to be investigated. In this work, the only two parameters such as permeability of sand (is the amount of air can trapped through the sand and it depends upon the size of sand grains) and pouring temperature (ranging 700 ^{0}C to 900 ^{0}C) are considered. The ANOVA aims to study the effect of these process parameters on casting impact intensity under similar conditions.

2. Material and Method

2.1 Composition of the Charge

The chemical configuration of the aluminium alloy adopted for the casting is highlighted in the Table 1 (appendix).

2.2 Research Experiment

This research experiment for current study is conducted in foundry shop for the moulding having low (30 Darcy) and high(60 Darcy) permeability of sand respectively. The pattern of square slab was placed in the mould box (drag). Further the sand was filled in cope and drag and rammed appropriately. After ramming, the other mould box (cope) was kept over the drag by applying the parting sand between them. At the end when sand was properly rammed, the cope and pattern were removed. The next, poring of molten metal happens into the mould. This process was repeated three times each at low permeability and high permeability with the different pouring temperature of 700 ^{0}C, 800 ^{0}C & 900 ^{0}C respectively. A total 18 samples were produced.

2.3 Determination of Impact Test

The castings were machined to the required shape (shown in figure 1) using the shaper machine. The impact testing machine has the capacity of 150 joule. The pendulum was raised to the maximum height and the test piece was then placed horizontally at the specimen holder. After noting the reading of the pointer, the pendulum was released which strikes the specimen at the notch. The pointer's reading was noted again. The difference between the readings is the energy that was used to fail the specimen. This process was repeated for other specimens also.

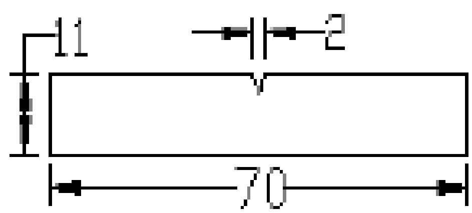

Figure. 1 Specimen for Impact Test

3. Formulation for Two – Factor Experiments

Data classification based on two factors uses the ANOVA technique in two ways. This dissertation has been formulated according to [8]. We presented "a" as permeability of sand and "b" for the pouring temperature here. This value is X_{jk} for row j and column k. In the jth row the mean of the entities is denoted as being $\bar{X}_j$, where j= 1,...a, whereas in the kth column the mean of entries is denoted $\bar{X}_k$, where k= 1,...,b). $\bar{X}_j$ is indicated by the overall or large mean.
In symbols:

$$\bar{X}_j = \frac{1}{b}\sum_{k=1}^{b} X_{kj}$$

$$\bar{X}_k = \frac{1}{a}\sum_{k=1}^{a} X_{jk}$$

$$\bar{X} = \frac{1}{ab}\sum_{j,k} X_{jk}$$

4. Variation for Two Factor Experiments

We define the variation to be:

$$V = \sum_{j,k}(X_{jk} - \bar{X})^2$$

Therefore,

$$V = \frac{1}{b}\sum_{jk} X_{jk}^2 - \frac{T^2}{ab}$$

$$V_R = \frac{1}{b}\sum_{k=1}^{b} T_j^2 - \frac{T^2}{ab}$$

$$V_C = \frac{1}{a}\sum_{k=1}^{b} T_k^2 - \frac{T^2}{ab}$$

$$V_E = V - V_R - V_C$$

Where**,** V is total variation, V_E is variation due to error, V_R is variation between rows (permeability of sand) and V_C is variation between columns (pouring temperature).
Tj is also the total number of entries in the jth row, Tk is the total number of entries in the kth column and T is the total number of entries.

5. Analysis of Variance

The generalized mathematical exemplary for one factor experiment is given by Equation 1.

$X_{jk}= \mu + \alpha_j + \beta_k + \varepsilon_{jk}$ (1)

where $\Sigma \alpha_j = 0$ and $\Sigma \beta_k = 0$. Here μ is the population grand mean, α_j is that part of X_{jk} due to the different permeabilities of sand, β_k is that part of X_{jk} due to the different pouring temperatures and ε_{jk} is that part of X_{jk} due to chance or error.To calculate the more effective variable for the impact strength of sand casting product, the authors considered the permeability of sand as the null hypothesis and also the more effective variable. So here,
H_0 = Permeability of Sand (Row wise) influences impact strength: that is $\alpha_j = 0$ and j = 1,…..a.
H_a = Pouring Temperature (Column wise) influences impact strength: that is $\beta_k = 0$ and k= 1,…b.
At the first, the correction factor:

Correction Factor= $(T)^2 / n$

where T is total value of individual items and n is the total number of experiments.

Now square all the items one by one and make a total of all. Then subtract the correction factor from this total added squared values to obtain the total variance:

Total variance $V = \sum T_{jk}^2 - (T)^2/n$

Similarly, calculate the value of variations between the rows (V_R) and variations of columns (V_C) respectively. Also the value of error of deviations for variance by subtracting the results of variations of rows and columns as shown below:

V for residual or error variance (V_E) = Total $V - (V_R + V_C)$

By defining the degree of freedom for rows and columns respectively, calculate the value of mean squares (MS) as shown below:

MS = Variation / Degree of freedom

Therefore;

Mean square of rows (MS_R) = $V_R/ (a-1)$ [a=2, number of rows]

Mean square of columns (MS_C) = $V_C/ (b-1)$ [b=3, number of columns]

Mean square of residual error (MS_E) = $V_E/ (a-1) (b-1)$

To test the hypothesis, consider the statistics MS_R/ MS_E and MS_C /MS_E between the rows and columns respectively. Under the hypothesis H_0, the statistics of mean square between rows and mean square of residual error has the F ratios with *a-1* and *(a-1)(b-1)* as degree of freedom. And under the hypothesis H_a, the statics of mean square between columns and mean square of residual error has the F ratios with *b-1* and *(a-1)(b-1)* as degree of freedom. Both F- ratios are compared with the table values for the given degree of freedom at specified level of significance. If the calculated value of F-ratio is more than the tabled value then the hypothesis H_0 is rejected and variable is significant.

6. Results and Discussion

The experiment was performed by taking different pouring temperature and permeability of sand as shown in the Table 2 (Appendix). This shows that the impact strength of aluminium alloy is decreased with the increase of permeability of sand and pouring temperature. The Table 3 (Appendix) represent the mean value of different samples at the one level of permeability of sand and pouring temperature and their total effect on the impact strength of the aluminium alloy.

By using the table given above, the values of correction factor, variations are calculated.

Correction Factor = $(73.2)^2/ 18$

$= 5358.24/18 = 297.68$

Total Variation (V) = $(6)^2+ (6.1)^2+ (5.8)^2+ (5)^2+ (5.1)^2+ (5.2)^2+ (3.2)^2+ (3.3)^2+ (3.1)^2+ (4.3)^2+ (4.1)^2+ (4.2)^2+ (3.6)^2+ (3.4)^2+ (3.7)^2+ (2.4)^2+ (2.4)^2+ (2.3)^2 - 297.68$

$= 323.6 - 297.68 = 25.92$

$V_R = (42.8)^2+ (30.4)^2/ 9 - 297.68 = 306.22 - 297.68 = 8.542$

$V_C = (30.5)^2+ (26)^2+ (16.7)^2 / 6 - 297.68 = 930.25+678 = 16.51$

$V_E = 25.92 - 8.542 - 16.51 = 0.87$

The analyses of variance in numerical calculations are shown in Table 4 (Appendix). Mean squares values are determined by dividing by the corresponding degree of freedom the sum of each origin square. The F-ratio shows how well the variables reflect the statistical variance and how it is determined by adding the mean variable square to the mean error square. At the 5% level, the F- distribution table (statistical table) values are:

$F_{0.05}$ at V (1,2) = 18.513 which is less than calculated F-ratio (19.63).

$F_{0.05}$ at V (2,2) = 19.00 which is more than the calculated F- ratio (18.97).

The table above shows that at 5% level of significance, the calculated value of F-ratio exceeds 18.513, therefore the null hypothesis is rejected and conclude that the permeability of sand has the significant effect on the impact strength of the aluminum cast alloy. In accordance with the work carried out in [9], the simple method developed by Dantzig[10] has been employed for optimisation of the mechanical properties of the aluminum alloy by sand casting process parameters.

7. Conclusion

The research indicates that the selected process parameters have different affects on the impact strength of the aluminium alloy. The permeability of sand at the 5 percent level of significance is more significant and effecting more to impact strength of Al-Si alloy. This result can be applied in foundry shop if the numbers of casting defects are on the high side. In future, ANOVA can be applied to other casting parameters (mould temperature, runner size, pouring speed, etc.) to analyze the effect on other mechanical properties i.e. hardness, tensile strength etc.

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Appendix

Table 1: Chemical composition of Al alloy.

Element	Al	Si	Fe
Concentration(Wt %)	93.9	4.0	1.5

Table: 2 Impact Strength at different levels of process parameters.

Permeability of Sand (Darcy)	Pouring Temperature(^{0}C)								
	700			800			900		
30	6	6.1	5.8	5	5.1	5.2	3.2	3.3	3.1
60	4.3	4.1	4.2	3.6	3.4	3.7	2.3	2.4	2.4

Table: 3 Mean Impact Strength.

Permeability of Sand(Darcy	Pouring Temperature(^{0}C)			Mean Impact Strength (Joule/mm^2)
	700	800	900	
30	$(6^2+6.1^2+5.8^2)/3=$ 17.9	$(5^2+5.1^2+5.2^2)/3=$ 15.3	$(3.2^2+3.3^2+3.1^2)/3=$ 9.6	42.8
60	$(4.3^2+4.1^2+4.2^2)/3=$ 12.6	$(3.6^2+3.4^2+3.7^2)/3=$ 10.7	$(2.3^2+2.4^2+2.4^2)/3=$ 7.1	30.4
Mean Impact Strength (Joule/mm^2)	30.5	26	16.7	73.2

Table: 4 ANOVA table

Source of variation	Variation	Degrees of Freedom	Mean Square	F- Ratio
Between the rows	8.542	1	8.54	19.63
Between columns	16.51	2	8.255	18.97
Residual Error	0.87	2	0.435	
Total	25.92	5		