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Effect of Casting Parameters on the Impact Energy of Aluminium Alloy Components

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ABSTRACT

Sand casting is the most widely used metal casting process in manufacturing. Several metallic components have the tendency to be sand cast. Taguchi Orthogonal array is used to develop a layout for the sand casting experiment applied in this study. Multiple linear Regression technique is used to develop models for the impact energy responses. The mathematical model developed by the multiple linear regression technique was adequate with a statistical adjusted R^2 value of 89.59%. The mathematical model generated is inputted into the Genetic algorithm tool box which yielded optimal levels for the process parameters. The results of optimization from the Genetic algorithm showed that the pouring rate, pouring temperature and runner size are 5.0cm/s,759.99°C and 231.38mm² respectively. An impact energy fitness value of 45.41 Joules is determined from the experimental study. Validation test conducted shows that the values obtained from the actual experiment are similar to that yielded by the predictive models.

Keywords: *Multiple linear regression, Taguchi design, Design of Experiment, Genetic Algorithm and Sand casting*

INTRODUCTION

The sand casting process involves the pouring of molten metal into the sand mould, the solidification of the casting within the mould, and the removal of the casting (Ozioko, 2011). Sand casting is the most widely used metal casting process in manufacturing. Almost all casting metals can be sand cast. Sand castings range in size from very small to extremely large (Mohiuddin, Krishnaiah and Hussainy, 2015). Examples of components manufactured by sand casting process in

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modern industry are engine blocks, pistons, cylinder heads, machine tool bases, pump bases and valves (Ozioko, 2011).
In examining the importance of sand casting on aluminium alloys a robust comparison was done between Single aluminium blank sand casting and double aluminium blank sand casting by Upadhye and Keswani (2012) . The study shows that single aluminium blank sand casting process thrived better than the double aluminium blank sand casting process. The experimental result confirms the effects of applying sand casting process parameters in the aluminium blank casting process. The process parameters investigated are sand grain size, moisture content, riser size, clay content and sprue size.

The need to optimize process parameters involved in sand casting is paramount in achieving efficient cast products (Kumar and Grewal, 2013). Optimization technique is a mathematical method of finding a maximum or minimum value of a function of a set of variables subject to some constraints (Oji, Sunday and Adetunji, 2013). In casting, optimization of process parameters are carried out by the following techniques, Taguchi design, Response surface Methodology, Genetic algorithm, Artificial Neural network and Particle swarm Algorithm (Patel, Krishna, Vundavilli and Parappagouder, 2016).

It appears sometimes in an attempt to optimize process parameters conflicting objectives may erupt in the process which makes it important for multi-objective optimization to be conducted so as to arrive at optimal level of the process parameters irrespective of the conflicting responses. In addressing the challenge posed by the conflicting objectives, an optimization evolutionary algorithm tool known as Genetic Algorithm which uses the tendency of natural selection and genetics was applied (Mudakappanavar and Nanjundaswamy, 2013). The Genetic algorithm works with mechanics of copying and swapping binary strings. The algorithm involves genetic processes like reproduction, selection, crossover and mutation. These processes are applied to the developed models to generate optimal levels for the process parameters and fitness values for the response variables (Azhagan, Mohan and Rajadurai, 2014).

The evolutionary algorithm was used by Mudakappanavar and Nanjundaswamy (2013) to study the multi-objective optimization of hypoeutectic Al-Si alloys . The study shows that the optimal values of process parameters involved in the casting of the aluminium alloy are 700°C for pouring temperature and 10Hz for vibration frequency. The optimized process parameters yielded maximum hardness and minimum wear on the cast hypoeutectic Al-Si alloy.

Similarly, genetic algorithm was widely used in multi-objective optimization for proffering optimal solutions for conflicting objectives as applied in Patel, Krishna, Vundavilli and Parappagouder (2016). In the study, genetic algorithm was used to optimize cast process parameters inherent in Taguchi Designed developed linear model. Much work has not been done in developing predictive model for the impact strength of aluminium alloy components. Also, optimal levels of sand cast process pararmeters which can influence impact energy of aluminium alloy had not been given adequate attention by researchers in the manufacturing of engine components. This study aims at determining the effect of casting parameters on the impact strength of aluminium alloy components. Specifically, the following objectives are pursued:

i. Determination of chemical composition of aluminium alloy scraps
ii. Development of L9 Taguchi Design for the conduction of experiments
iii. Development of sandcast aluminium silicon alloy component
iv. Determination of Impact energy of the various casting using Charpy Testing machine
v. Development of an empirical mathematical model that can predict Impact energy
vi. Determination of the optimal levels of the sandcast process parameters using Genetic algorithm.

MATERIALS AND METHOD

The materials employed in this study are aluminium alloy scraps, digital thermocouple graphite crucible furnace, runners, stop watch and Charpy testing machine (Oji, Sunday and Adetunji, 2013). The Design of experiment Taguchi L9 orthogonal array was applied in creating an experimental layout for the various conditions. The Taguchi Design is reputable for few numbers of experimental runs when compared with Response Surface Methodology (RSM) and Full factorial Design. Minitab 17 software was used in getting the experimental matrix. The design matrix has a stipulated 9 runs for a 3-process parameter and 3-level experiment. The multiple linear regression technique was used to develop the mathematical model for predicting impact strength of aluminium alloy. The general form of regression equation for representing a 3-parameter response (Y) in a Taguchi Design is (Montgomery and Runger, 2003).

$$Y = \beta_0 + \beta_1 A + \beta_2 B + \beta_3 C \quad (1)$$

Where A, B, and C are the process parameters. While B_0, β_1,β_2, and β_3 are the regression coefficients.

The process parameters and levels used in this study resulted from deep review of related literature of Patel (2014) and Oji, Sunday and Adetunji (2013). The process parameters and their levels are shown in table 1.

Table 1: Process parameters and their levels

	Pouring rate (cm/s)	Pouring temperature (°C)	Runner size (mm^2)
Level 1	2.0	700	180
Level 2	3.5	730	200
Level 3	5.0	760	280

A chemical composition test was carried out on the aluminum alloy scrap. The Aluminium-Silicon alloys scraps components were recycled by melting process. The experiment was carried out in accordance with the parametric conditions prescribed by the Taguchi Design. The Al-Si alloy scraps was charged into a crucible furnace and heated to a temperature of 770°C as indicated by a digital thermocouple. Charpy testing machine shown in figure 1 was used to measure the impact energy of the sand cast component (Oji, Sunday and Adetunji, 2013).

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Figure 1: Charpy Impact machine

RESULTS AND DISCUSSION

The spectrographic test was conducted to determine the chemical composition of the melted aluminium silicon alloy. The test result is shown in table 2.

Table 2: Chemical composition of Al-Si alloys

Element	Si	Mg	Al	Ti	Cr	Mn	Fe	Ni	Cu	Zn	Pb	Sb
Composition	10.01	0.05	79.78	0.01	0.03	0.86	2.44	0.30	2.04	4.28	0.38	0.01

Source: Experimentation, 2018

The Taguchi Design experimental values are shown in Table 3

Table 3: Taguchi Design experimental values

Run order	Pouring rate (cm/s)	Pouring temperature (°C)	Runner size (mm^2)	Impact energy (J)
1	2.0	700	180	24
2	2.0	730	200	26
3	2.0	760	280	25
4	3.5	700	200	32
5	3.5	730	280	34
6	3.5	760	180	37
7	5.0	700	280	41
8	5.0	730	180	39
9	5.0	760	200	49

Source: Experimentation, 2018

Developed Mathematical Model

The developed mathematical model for predicting impact strength of aluminium alloy is given as

Impact energy = -41.8 + 6.000A + 0.0778B - 0.0083C (2)

Where A = pouring rate

B = pouring temperature

C = runner size

Significance Test

Also, an Analysis of Variance (ANOVA) test was carried out to determine the significance of the developed mathematical model and the individual process parameters. Table 4 shows the ANOVA test result

Table 4: Analysis of Variance

Source	Degree of freedom	Adj. SS	Adj.MS	F-value	P-value
Regression	3	519.830	173.278	23.38	0.002
A	1	486.000	486.000	65.58	0.000
B	1	32.667	32.667	4.41	0.009
C	1	1.167	1.167	0.61	0.708
Error	5	37.056	7.411		
Total	6				

Source: Experimentation, 2018

The result shows that the developed mathematical model is adequate with a p-value of 0.002, R^2= 93.35% and R^2(adj)=89.35%. Also, the ANOVA table indicates that the pouring rate and pouring temperature are significant with p-values of 0.000 and 0.009 respectively using a statistical significant value of 0.05. Furthermore, a normality probability plot shown in figure 2 was developed so as to ascertain the distribution of the residual points along the normal distribution diagonal line. The result shows that the residual points of the process parameters satisfy the normality conditions.

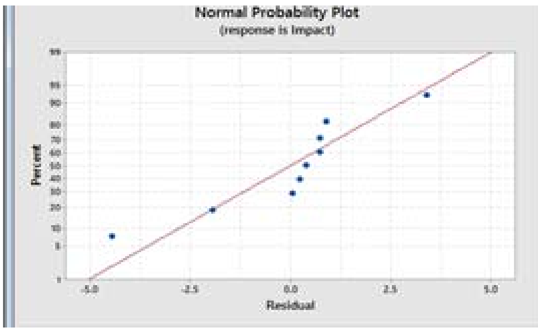

Figure 2: Normality plot

Optimization Analysis

The Genetic algorithm technique was applied in developing optimal levels for the sandcasting process parameters. The regression model obtained through multiple linear regression technique was used as the objective function in the MATLAB genetic algorithm tool. The population size used was 40, number of variable used is 3, crossover and mutation probability adopted are 80% and 0.01 respectively. A number of 100 generations and 50 seconds time limit were used for the optimization (Azhagan, Mohan and Rajadurai, 2014).

The Lower bound of the process parameters = {2,5, 700, 180}
The Upper bound of process parameters = {5.0, 760, 280}

The table 5 shows the tested levels and best optimal levels for the parameters used in the impact strength model from the genetic algorithm tool.

Table 5: Optimal levels of the process parameters

Factor	Process Parameter	Level range	Optimal level
A	Pouring rate (cm/s)	2.5-5.0	5.00
B	Pouring temp(^oC)	700-760	759.99
C	Runner size(mm^2)	180-280	231.386

Source: Experimentation, 2018

The optimal value of the impact energy is 45.41 joules. The impact energy optimization plot from the evolutionary algorithm depicting the fitness value and number of generations is shown in Figure 3

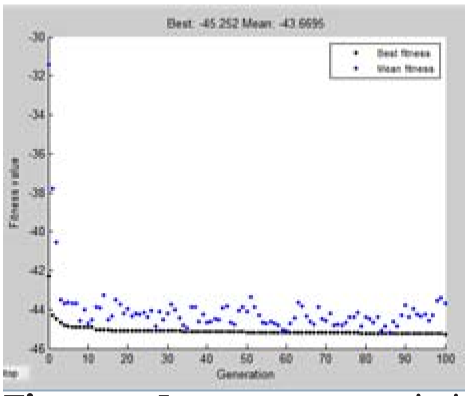

Figure 3: Impact energy optimizaton plot

Confirmation test

The optimal levels developed from the evolutionary algorithm were used to conduct experiment at the foundry. A pouring rate of 5.00cm/s and a runner size of 231.39mm^2 were used to prepare a sandcasting at a pouring temperature of 759.98^{o}C. The casting was measured for Impact energy using the Charpy testing machine. The value of Impact strength from the actual experiment was determined to be 45.15 joules which was noticeably similar to that predicted by the developed model (45.41 joules).

The spectrographic test carried out on the aluminium alloy scraps showed that the alloy had 10.01% silicon content which infers that the alloy is eutectic. The developed mathematical model showed that 89.35% of the variation in impact energy response is explained by the predictor variables. This indicates that the developed regression model is adequate. Also, the difference between the R^2 and adjusted R^2 values indicates that over fitting scarcely exist in the developed model. In addition, the probability plot shown in figure 3 reveals that normality conditions were satisfied. The results of optimization from the Genetic algorithm showed that the pouring rate, pouring temperature and runner size which are 5.0cm/s, 759.99^{o}C and 231.39mm^2 respectively yielded impact energy fitness value of 45.41Joules which was very close to the confirmatory test value obtained for Charpy impact energy experiment.

CONCLUSION

Optimal levels of sand cast process pararmeters which can influence impact energy of aluminium alloy had not been given adequate attention by researchers in the manufacturing of engine components. Hence, this study on effect of casting parameters on the impact energy of aluminium alloy components. A Taguchi orthogonal array was used to create an experimental layout for the conditions employed in the study. Experiments were conducted using the Charpy testing machine and the test result was used to develop a model for the impact energy. ANOVA test conducted shows that the developed mathematical model is adequate and significant. Optimal levels of the process parameters were determined and used to carry out confirmatory test whose actual experimental values align with predicted values of the mathematical model.

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