Optimization of Process Parameters to enhance the Hardness on Squeeze Cast Aluminium Alloy AA6061

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Abstract --The automotive and aerospace industries have been the main driving force behind the search of new production processes which are capable of producing components with high integrity. Squeeze casting is one such novel metal processing technique which combines the advantages of both casting and forging in one operation. Squeeze casting process is suited for all melting ranges of metals varying from lead to iron. But nowadays, light weight materials like aluminium and magnesium are mostly used in the industries. Aluminium alloy AA6061 is one such futuristic material that is widely used to produce automotive and aerospace components. Although the squeeze casting process has many obvious advantages in producing parts of light metals that can be utilized in structural applications, the full potential can only be realized after the process parameters have been optimized. In this attempt, cylindrical components of AA6061 were produced using squeeze casting process and their hardness values were found out. The optimal process parameter combination to obtain maximum hardness was calculated using Taguchi method and Genetic Algorithm approaches. It was observed that Genetic Algorithm yielded better solution when compared to the solution provided by Taguchi Method.

Keywords -Squeeze casting, Hardness, Taguchi Method, Genetic Algorithm

I. INTRODUCTION

Squeeze casting is a relatively new and developing casting technology that has got number of advantages, including the elimination of gas and shrinkage porosities, the reduction or elimination of metal wastage due to the absence of feeders or risers[1-3]. Squeeze casting combines the shape and economic capabilities of castings with the strength and the confidence levels of forging [4].In squeeze casting process, the molten metal solidifies under the application of pressure within the die halves. The process has the capability of producing pore free near net shape castings [5]. The high pressure during solidification keeps the molten metal in direct contact with the die surface thereby enhancing the heat transfer rate [6]. Thus the close contact with the die surface during solidification results in a rapid solidification of castings. The rapid solidification produces fine secondary arm spacing in the castings, so that good strength and ductility can be obtained [7]. Since the process minimizes both gas porosity and shrinkage cavities, excellent mechanical properties are obtained in the parts produced through squeeze casting method. The squeeze casting of aluminium alloys is a rapidly developing technical process that offers the potential for widespread utilization and growth.

II. NEED FOR STUDY

Casting is the most economical route to produce metallic components. But the conventional casting processes cannot produce the high strength components and cannot eliminate the casting defects. Of the many casting techniques available, Squeeze Casting has got greater potential to produce less defective components [8-9].It is found that the development of squeeze casting in the recent times is linked to the fabrication of light weight materials particularly in the field of Al and Mg based alloys and composites that offers the potential for widespread utilization and growth [10-11]. Though several researches applying Aluminium alloys have been reported in literature, it appears that very limited works have been carried out by optimizing the process parameters involved in squeeze casting of aluminium alloys.The objective of the work is to optimise the process parameters using Taguchi Method and Genetic Algorithm approaches while producing squeeze cast components of AA6061 to enhance the hardness exhibited by the components.

III. TAGUCHI METHOD

In the globalized market, manufacturing companies have to counter the challenges in producing high quality products while simultaneously improving the processes with a significant slash in time and cost. One of the most efficient tools to counter the challenge is Taguchi method, an off line quality control concept [12-14]. The main theme of Taguchi method is stated as, “quality variation is the main enemy and that every effort should be made to reduce the variations in quality characteristic”. There are three types of quality characteristics in the Taguchi methodology namely smaller the better, larger the better and nominal the best. This research is focused to produce maximum hardness in SC components. Hence, the larger the better characteristic is implemented in this study. For this purpose, concepts like orthogonal array, S/N ratio i.e. ratio of the mean (signal) to the standard deviation (noise) and Pareto ANOVA of Taguchi method were employed in this research. In order to observe the influencing process parameters in squeeze casting of AA6061, three process parameters namely, squeeze pressure, die preheat temperature and pressure applying duration each at three levels were considered in this research and the details were presented in Table I.The squeeze cast process parameters namely squeeze pressure (*A*), die preheat temperature (*B*) and pressure applying duration (C) were assigned to the first, second and fourth columns of ($L_9 3^4$) orthogonal array respectively.

TABLE I
Process Parameters and their levels

Process parameters	Level 1	Level 2	Level 3
Squeeze pressure - A (N/mm²)	35	70	105
Die Preheat Temperature - B (°c)	150	200	250
Pressure Duration - C (s)	15	30	45

IV. EXPERIMENTAL

A 30 ton Hydraulic press shown in Fig.1 was employed for the application of pressure over the molten metal during solidification. The die set was made up of H11 die steel since the die steel has got the ability to withstand high temperatures and high pressures for maximum number of production settings. A ceramic electrical heater of capacity 400^{o}C was used to preheat the die set made up of H11 die steel. The muffle furnace shown in Fig.2 was used to melt the aluminium alloy AA6061. After degassing the melt, a metered quantity of molten metal alloy was poured into the preheated die cavity. The squeeze pressure was directly applied on the molten alloy through the punch fitted on to the hydraulic press, and the pressure was maintained for predetermined time. The punch was then withdrawn and the casting was separated from the die. Nine experiments were conducted by varying the process parameters at certain levels according to the chosen ($L_9 3^4$) orthogonal array. Two components were produced for each experiment (Trial 1 and Trial 2) and a total of 18 components were produced.

Fig.1. Hydraulic Press

Fig.2.Muffle Furnace

V. RESULTS AND DISCUSSION

A. Hardness Testing

Brinell hardness tester was used to measure the hardness of the squeeze cast components. As per the standards, a load of 500 kg was applied for duration of 30 seconds and the indentation is measured. The diameter of the ball is 10 mm. The diameter of the indentation left in the test material is measured with a microscope. The Brinell harness number is calculated by dividing the load applied by the surface area of the indentation. The hardness values exhibited by the squeeze cast AA6061 components were given in the Table II.

TABLE II
Hardness values

S.No	Squeeze pressure A (N/mm²)	Die Preheat Temperature B (°c)	Pressure Duration C (s)	Hardness (BHN)	
				Trial 1	Trial 2
1	35	150	15	65	66
2	35	200	30	74	73
3	35	250	45	65	64
4	70	150	45	63	65
5	70	200	15	76	76
6	70	250	30	72	73
7	105	150	30	77	79
8	105	200	45	78	79
9	105	250	15	84	84

B. Computation of S/N – ratio

Taguchi's emphasis on minimizing deviation from target resulted to develop measures of the process output that incorporate both the location of the output as well as the variation. These measures are called signal to noise ratios. The signal to noise ratio provides a measure of the impact of noise factors on performance. The larger the S/N ratio, more robust the product is against the noise.The formula for finding larger-the better S/N ratio is as follows:

$$\frac{S}{N_{(LTB)}} = -10\log\left[\frac{\Sigma\left(\frac{1}{y_1{}^2}\right)}{n}\right]$$

Where, n = number of trials

Y_i = The value of the hardness obtained in the respective trial

The S/N ratio values for hardness were calculated using the above formula and the values were tabulated in Table III.

Table III
S/N ratio for hardness

Expt No.	Process parameter				S/N (dB)
	A	B	E	C	
1	1	1	1	1	36.3241
2	1	2	2	2	37.3251
3	1	3	3	3	36.1904
4	2	1	2	3	36.1204
5	2	2	3	1	37.6163
6	2	3	1	2	37.2061
7	3	1	3	2	37.8398
8	3	2	1	3	37.8969
9	3	3	2	1	38.4856

C. Computation scheme of Pareto ANOVA for three level parameters

The general scheme of computation of Pareto ANOVA was given in the Table IV. Pareto ANOVA computation was done by using the S/N ratios of the process parameters to predict the optimal parameter level combination as well to determine the most influencing process parameter involved in this study.

TABLE IV
General Scheme for Pareto ANOVA computation

Parameter		A	B	E	C	Total
Sum	1	$\sum A_1$	$\sum B_1$	$\sum E_1$	$\sum C_1$	$T = \sum A_1 + \sum A_2 + \sum A_3$
	2	$\sum A_2$	$\sum B_2$	$\sum E_2$	$\sum C_2$	
	3	$\sum A_3$	$\sum B_3$	$\sum E_3$	$\sum C_3$	
SSD		S_A	S_B	S_E	S_C	$S_T = (S_A + ... + S_C)$
Degrees of freedom		2	2	2	2	S
Contribution Ratio		S_A / S_T *100	S_B / S_T *100	S_E / S_T *100	S_C / S_T *100	100

The Pareto ANOVA computation was performed for hardness and was given in Table V. From the Table V, it can be inferred that the process parameter A (Squeeze pressure) is the most influential parameter with the contribution ratio of 60.95% towards the improvement of hardness exhibited by the squeeze cast components. The optimal parameter level combination to conduct the experiments such that the values of hardness should be high is A_3 B_2 C_1 i.e. squeeze pressure of 105 N/mm^2, die preheat temperature of 200˚C and pressure duration of 15 seconds respectively

TABLE V
Pareto ANOVA computation for hardness

Parameters		A	B	C	E	Total
Sum at parameter levels	1	109.8396	110.2843	112.426	111.4271	335.0047
	2	110.9428	112.83833	112.371	111.9311	
	3	114.2794	111.8821	110.2077	111.6465	
Sum of squares of differences		31.1802	9.99	9.6037	0.3831	51.157
Degrees of freedom		2	2	2	2	8
Contribution Ratio		60.95	19.528	18.186	0.7488	100
Cumulative contribution Ratio		60.95	80.478	98.664	100	100
Optimal parameter level combination		$\mathbf{A_3}$	$\mathbf{B_2}$	$\mathbf{C_1}$	$\mathbf{E_1}$	

D. Response curve for hardness

Response curve for hardness was shown inFig.3. The response curve was obtained using Minitab software by considering the mean of S/N ratios of the process parameters considered in this research. The response curve indicates the effect of varying a process parameter from one level to the other. From the Fig.3, it can be inferred that the S/N ratio is maximum at squeeze pressure (A) of 105 N/mm^2, Die preheat temperature (B) of 200ºC and pressure duration (C) of 15 seconds respectively. When the squeeze casting was done at the above specified optimal parameter level combination, the hardness of the components was higher.

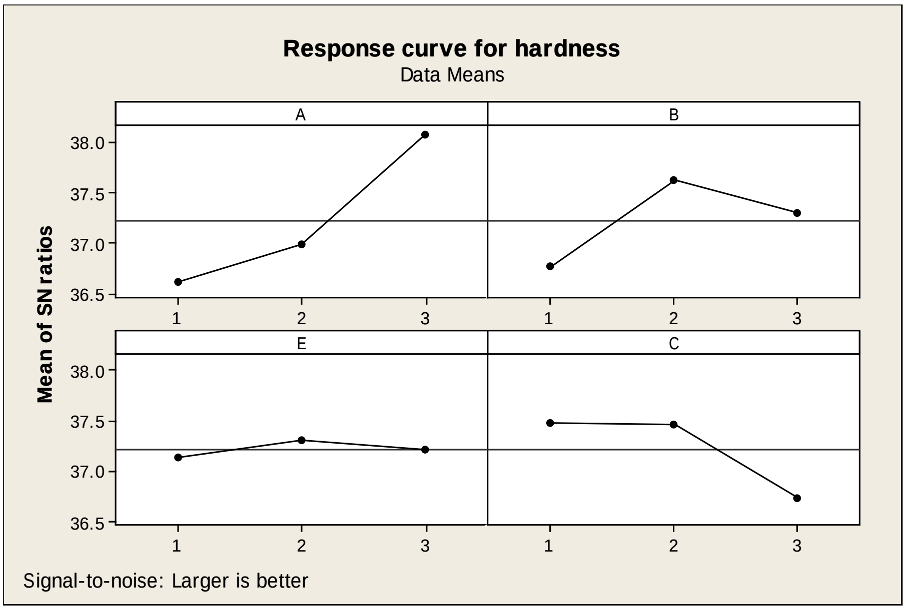

Fig.3. Response Curve of Hardness

E. Confirmation Test for Taguchi Method

The confirmation test for Taguchi Method at the optimised process parameter levels was done and the hardness exhibited by the squeeze cast cylindrical component of AA6061 was found to be 84.5 BHN.

F. Need for Genetic Algorithm

In the absence of global optimization tools, engineers and researchers are often forced to settle for feasible solutions, often neglecting the optimum values. In practical terms, this implies inferior designs and operations, and related expenses in terms of reliability, time, money, and other sources. The genetic algorithm approach provides the solution for the above said problems.The objective of global optimization is to find the "best possible" solution in decision models that frequently have a number of sub-optimal (local) solutions. The genetic algorithm solves optimization problems by mimicking the principles of biological evolution, repeatedly modifying a population of individual points using rules modelled on gene combinations in biological reproduction [15]. Due to its random nature, the genetic algorithm improves the chances of finding a global solution. Thus they prove to be very efficient and stable in searching for global optimum solutions. The mathematical model that best describes the relationship between Input and output parameters has to be developed in order to be used as objective function in GA to aid the global optimization. The Mathematical model was obtained using the *Regression* function in Minitab software. The regression equation hence obtained using Minitab software is as follows.

$$\mathrm{H} = 58.9 + 0.186\mathrm{X1} + 0.0367\mathrm{X2} - 0.200\mathrm{X3}$$

The proposed mathematical model was used to formulate the objective functions, which was the pre-requisite of genetic algorithm. The objective function was solved using MATlab software as shown in Fig. 4. The optimised process parameter level of Genetic algorithm was obtained from the Fig. 4.

G. Confirmation Test for Genetic Algorithm

The confirmation test for Genetic algorithm approach at the optimised process parameter levels (Squeeze Pressure in N/mm^2 = 104.76, Die pre Heat Temperature in °c = 247.15, Pressure Duration in sec = 15.31s) was done and the hardness exhibited by the squeeze cast cylindrical component of AA6061 was found to be 86 BHN.

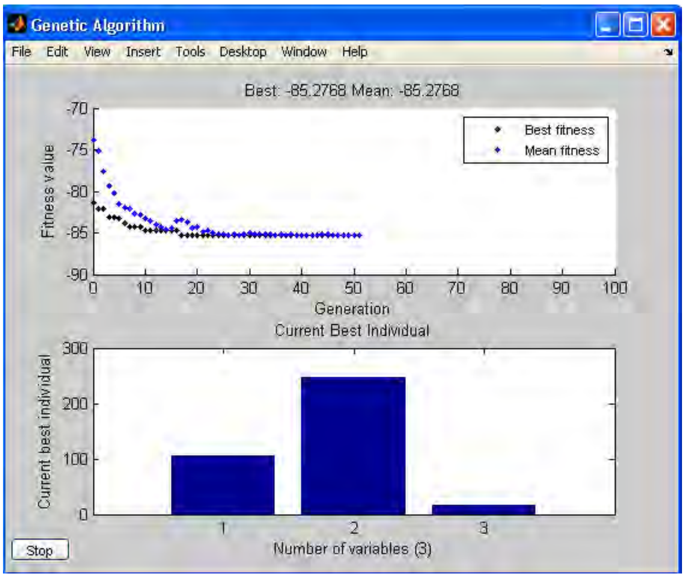

Fig.4. Solution of Genetic Algorithm

H. Comparison of Taguchi and Genetic Algorithm approaches.

From the Tables VI and VII, it was found that in comparison with Taguchi method, the genetic algorithm gives better optimized solution for the present research as the component produced at the condition of confirmation test of genetic algorithm yielded better hardness value as 86 BHN.

Table VI
Comparison table of Taguchi Method and Genetic Algorithm with the process parameters

S.No.	Process parameters	Taguchi Method	Genetic Algorithm
1.	Squeeze pressure – A (N/mm^2)	105	104.76
2.	Die preheat temperature – B (°c)	200	247.15
3.	Pressure duration – C (s)	15	15.31

Table VII
Comparison table of confirmation tests

S.No.	Confirmation test	Taguchi Method	Genetic Algorithm
1.	Hardness (BHN)	84.5	86

VI CONCLUSION

Squeeze casting of AA6061 cylindrical components were done by varying squeeze pressure, die preheat temperature and pressure duration at certain levels. The hardness of the squeeze cast components was evaluated. The optimal process parameters levels for obtaining maximum hardness was carried out using Taguchi method and Genetic algorithm approaches and the final solutions were compared. It was observed that the Genetic algorithm yielded better optimized solutions for the present research. Further, it was found that squeeze pressure was the most significant parameter of the squeeze casting process as squeeze pressure with the contribution ratio of 60.95% favours the enhancement of hardness exhibited by the squeeze cast components of aluminium alloy AA6061.Thus Squeeze cast technology has the potential to play an important role in the near future for improving the quality of the engineering components.

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