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MODELLING AND MULTI OBJECTIVE OPTIMIZATION OF LM13 ALUMINIUM ALLOY SQUEEZE CAST PROCESS PARAMETERS USING TAGUCHI AND GENETIC ALGORITHM

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This present investigation deals with squeeze casting process in order to produce a component with good mechanical properties such as micro-hardness(VH), tensile strength(R_m), and density(ρ) on LM13 by varying squeeze pressure(P), molten temperature(T_m) and die temperature(T_d). Taguchi experimental design L9 orthogonal array was used to determine the signal to noise ratio. The results specified that the squeeze pressure and die preheat temperature are the most influencing parameters for mechanical properties improvement. Genetic algorithm (GA) has been applied to optimize the casting parameters that simultaneously maximize the responses.

Keywords: die casting, aluminum alloy, microstructure, mechanical properties, taguchi

INTRODUCTION

Aluminum alloys are used in aerospace, automobile and train companies because of their attractive characteristics like lighter high strength alloy, stiffness and wear resistance.[1,2]suggested that optimization effort has been encourages to produce defect free and complex engineering components. [3] Investigated the effect of process parameters on the mechanical properties exhibited by the castings produced though squeeze casting process.

[4] Investigated mechanical and micro-structure properties of cast components by varying process variables. [5] Used squeeze casting to create less defective cast components. [6] Effects applied pressure intensity, the melt temperature and the die preheating temperature to study casting parameters. [7] Identified that higher pressures decreased the percentage of porosity and increased the density of the cast alloy [8].

Found that casting temperature had an effect on the mechanical properties. [9] Analyzed the effect of squeeze cast process variables. [10] Conducted experiments by varying Squeeze pressure, die pre-heat temperature and pressure duration using L9 orthogonal array of Taguchi method. [11] Identified that squeeze pressure, die preheating temperature and compression holding time were the parameters making significant improvement in mechanical properties. [8] Used different casting temperatures to measure tensile, impact and density values. [6] Investigated the effects of applied pressure and melts and die temperature on the microstructure of squeeze cast. Measured the micro-hardness values in three spots of the cast specimen areas [3, 10] suggested that Taguchi method is an efficient problem-solving tool. [9] Analysis of variance tests were conducted to evaluate the statistical suitability of the models. [11] Developed mathematical models using the data collected. Genetic algorithm has been proven as one of the most popular multi-objective optimization techniques for the parametric optimization of any processes.

Most of the studies on squeeze casting have been reported on the shaping of aluminum alloy on improvement of mechanical properties such as LM24, LM25, A357, A535 and AA603 and some of the wrought Aluminum alloys like 6061 and 7010.

EXPERIMENTAL METHODOLOGY

Experimental setup and materials

The experiments have been performed on metallic H13 die steel seated over 50 Ton capacity hydraulic unit base plates. The punch was inflexibly fitted on hydraulic unit to apply a necessary squeeze pressure. The maximum preheating capacity about 500 °C has coupled with thermocouple arrangements to control the temperature.

A pathway unit with 400 °C capacity is inbuilt in the setup. The degasser hexacloro-ethylene was used to eradicate the entrapped gases and slag/impurities in the molten metal. An electric furnace provided with maximum capacity of 1 200 °C was inbuilt in bottom pouring to melt the metal of 2 - litre capacity. After pouring molten metal, compressive loads were applied at time delay of five seconds and retained on the solidifying molten metal for a duration of 60 seconds to produce sound casting of size 50 mm diameter and 200 mm height.

Experimental Procedures

Squeeze casting experimentation was performed to investigate the input parameters on responses. The response variables selected for this study are tensile

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strength, micro - hardness and density. The molten metal transferred through the bottom pouring furnace into preheated die within limited seconds to avoid melt temperature loss and turbulence of metal flow. The samples of casting were machined according to the testing conditions, Vickers micro-hardness tester with 100 g load (HV_{100}) was applied for 5 to 10 seconds on the polished surface and micro-hardness values were noted at three different positions in polished specimen surface. The density of the specimen was determined by using Archimedes principle.

Universal testing machine capacity up to 100 KN with accuracy 0, 01 % was used for testing tensile strength on the specimens. The tensile test specimens were prepared as per the ASTM-E1012 standard Tensile strength were noted for each specimens through conducting tensile test shown in Figure.1

Microscopy

Microstructural examinations were carried out following standard metallography techniques using metallurgical microscope having 500 x magnifications. The specimen samples of 10 mm radius and 10 mm thickness were grinded using emery papers of grit size 400, 600, 800, 1 200 and 1 500 followed by 6 micrometer diamond paste. Further, the polished samples were color tint etched with Weck's Reagent 100 ml distilled water, 4 g $KMnO_4$, 1 g NaOH used at room temperature and immersed up to 20 s or longer until surface is colored to achieve better contrast . Cast samples and tested specimens are shown in Figure.1

Experimental Design

The number of experimental trails increases in full factorial design as the number of parameters and their levels increases. This required a large sum of experimentation cost and extensive time. So, in order to involve these two opposing factors and to examine the optimal process condition through limited number of experimental trails Taguchi L_9 (33) orthogonal array including of 9 sets of design was selected to optimize the multiple performance characteristics of VH_{100}, R_m and ρ. The casting parameters used in this study were selected for maximizing the responses are squeeze pressure (60, 100, and 140 MPa), die temperatures (150 °C, 225 °C, and 300 °C), and melt temperatures (660 °C, 730 °C, and 800 °C). Experimental values as per L_9 orthogonal array with responses presented in Table 1.

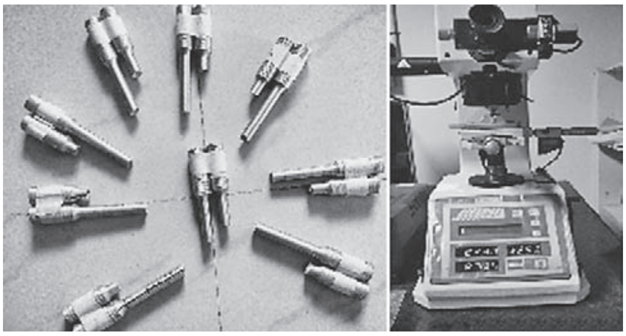

Figure 1 Tensile tested specimens and hardness measurement

Table 1 **Casting parameter and responses**

P / Mpa	T_m / °C	T_d / °C	HV_{100}	R_m / Mpa	ρ / g / cm^3
60	150	660	115	240	2,741
60	225	750	118	251	2,749
60	300	800	111	230	2,715
100	150	750	124	258	2,760
100	225	800	122	273	2,756
100	300	660	120	248	2,757
140	150	800	125	265	2,767
140	225	660	126	283	2,777
140	300.000	750.000	123	268	2,720

RESULTS AND DISCUSSION

Taguchi Analysis

A statistical software Minitab V.16 was used to calculate the values of these coefficients. Anova was performed to find significant factors which affect the hardness, tensile strength and density. Based on the highest values of the signal to noise ratio delta levels 1,95 and 1,02 for significant factors squeeze pressure(P) and die preheat temperature (T_d), the overall optimum conditions thus obtained where P3, T_m2 and T_d2 shown in Figure.2 - 4. The square value of correlation coefficient (R) are S(2,48745), R^2 (84,4 %), adj R^2 (75,0 %) for the modeling equation of average micro hardness; S(11,8260), R^2 (68,9 %), adj R^2 (50,3 %) for the modeling equation of average tensile strength; S(0,0177234), R^2 (53,8 %), adjR^2 (26,2 %) for the modeling equation of average density. The value of R^2 indicates the closeness of the model representing the process. The Figure.5 shows that the Quantitative metallographic analysis shows that micro-porosity and other defects are eliminated significantly with the increase in applied squeeze pressure. The correlations between the factors P, T_m, T_d is obtained by multiple linear regression are given below in equation 1, 2 and 3.

$$HV = 116 + 0,125 * P - 0,0222 * T_m - 0,0045 * T_d \qquad (1)$$

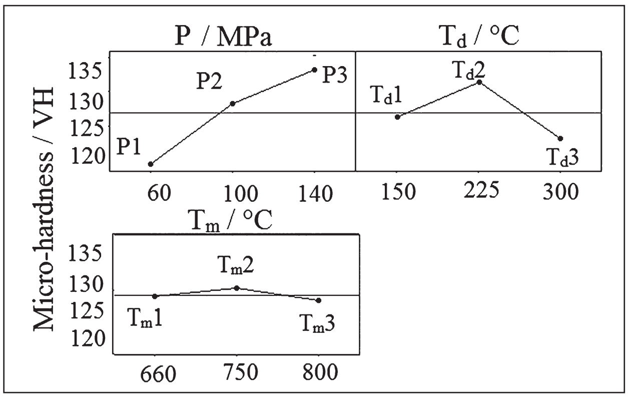

Figure 2 Micro-hardness vs. casting parameters

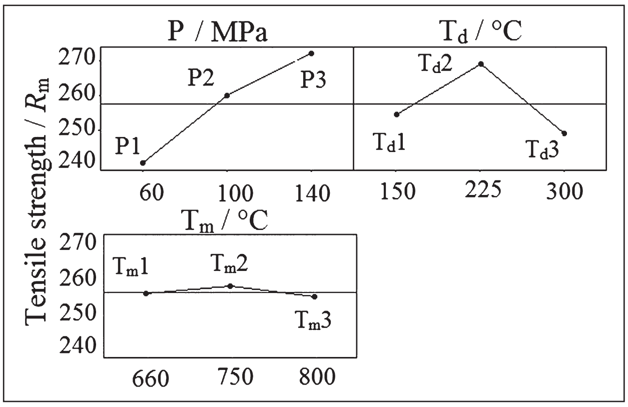

Figure 3 Tensile strength vs. casting parameters

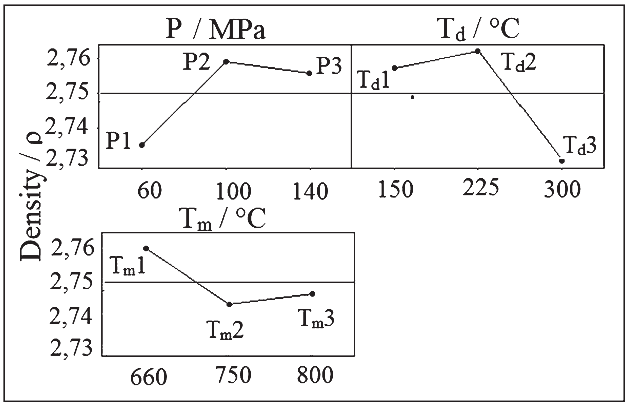

Figure 4 Density vs. casting parameters

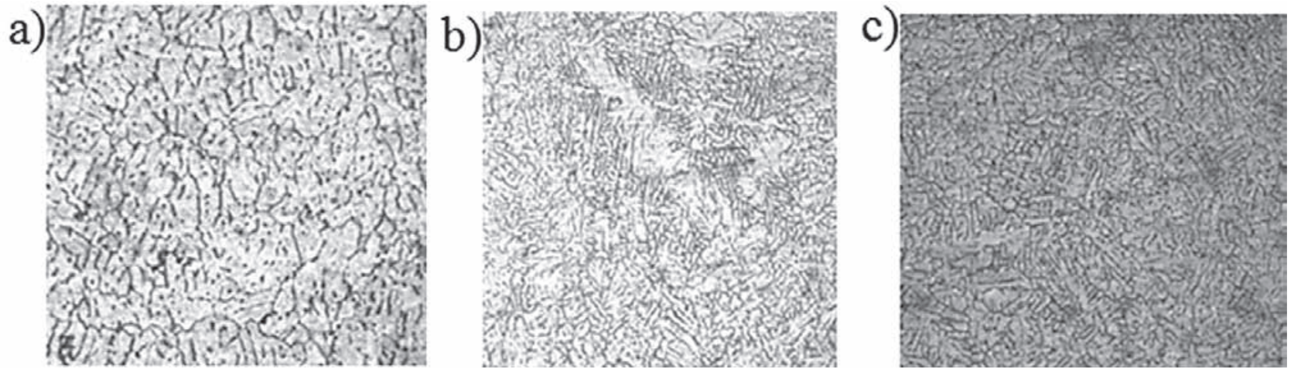

Figure 5 Microstructure 500 X at squeeze pressure: (a) 60, (b) 100, (c) 140 MPa

$$R_m = 229 + 0,396 * P - 0,0378 * T_m - 0,0036 * T_d \quad (2)$$

$$\rho = 2,83 + 0,000246 * P - 0,000169 * T_m \; 0,000098 * T_d \quad (3)$$

Genetic algorithms

In this study, genetic algorithm has been adopted for multi objective optimization. The linear mathematical model has been utilized to calculate the optimal relationship between the casting parameters and responses with applying constrained limits. This function was input to the GA Toolbox of MATLAB 2 010 a as the objective function.

Find: Optimal P, T_m, T_d

To minimize: HV, R_m, ρ

Figure.6 shows the Pareto optimal frontier distributed points produced from the optimization of responses. The response hardness was scattered between 126 and 128 HV. It is also illustrious that the tensile strength and density was distributed between 275 and 278 Mpa, and between 2, 69 and 2,82 g / cm^3. The parameter combinations of 8 non-dominated Pareto optimal solutions obtained with the application of constraint limits such as lower and upper boundary presented in Table 2.

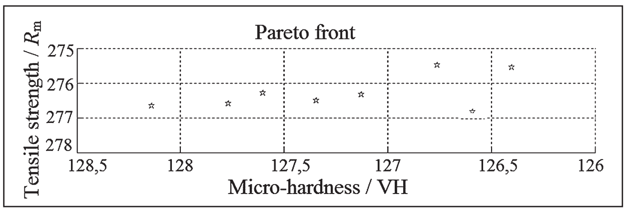

Figure 6 Pareto optimal frontier chart

All the achieved solutions of squeeze casting parameters are verified and found error lies under considerable.

Table 2 **Pareto optimal solutions**

P / Mpa	T_m / °C	T_d / °C	HV_{100}	R_m / Mpa	ρ / g/ cm^3
138,43	163,68	675	127,60	275,06	2,70
138,56	164,16	675	126,62	276,20	2,71
139,53	166,15	678	127,62	277,20	2,82
140,64	163,19	676	127,60	276,07	2,72
139,54	165,16	675	127,63	278,10	2,69
138,4	163,6	676	127,61	276,09	2,75
140,48	166,76	678	128,48	277,20	2,81
138,04	163,5	677	127,61	276,08	2,70

CONCLUSION

Taguchi analysis based GA was used to predict the responses by optimizing the casting parameters. From this investigation of direct effect surface plots, the following conclusion has been drawn.

- The linear regression model developed will give appreciated data for prediction of responses.
- In the analysis of micro hardness, it was found that the maximum VH_{100} can be achieved at optimal process parameters such as P3, T_m2, T_d2 (140 MPa, 225 °C, 730 °C)
- In the analysis of tensile strength, it was found that the maximum R_m can be achieved at optimal process parameters such as P3, T_m2, T_d2 (140 Mpa, 225 °C, 730 °C)

- In the analysis of density, it was found that the maximum VH_{100} can be achieved at optimal process parameters such as P2, T_m2, T_d1 (100 Mpa, 225 °C, 660 °C)
- Parameter combinations of eight non dominated Pareto optimal solutions obtained has been verified and found, that all the solutions generated are equally good.
- The Pareto optimal solution was validated and found that error lies in acceptable range between of 1 - 1,8 %.
- From the ANOVA analysis, the most significant parameters were identified as squeeze pressure and die preheating temperature.

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Note: The responsible translator for English language is Dr. C. Arumugam, Coimbatore Institute of Technology, India