Optimization of Squeeze Casting Process Parameters Using Taguchi in LM13 Matrix B₄C Reinforced Composites

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Abstract. Aluminium metal matrix composite has widely used in aerospace and automobile industry due to its high strength to weight ratio. Aluminium LM13 matrix B₄C reinforced composites are mainly manufactured by Squeeze casting process. The present work optimizes squeeze casting process parameters using Taguchi method. The control factors used for the experiments were Squeeze Pressure, Die Preheat Temperature and weight percentage of Boron Carbide (B₄C) along with multiple performance characteristic of Hardness, Ultimate Tensile Strength (UTS) and Yield Strength (YS). The L27 orthogonal array was used for experimental design. Analysis of variance (ANOVA) is used to determine the significant factor and found out that Squeeze pressure is the most significant factor followed by percentage of B₄C.

1. Introduction
Mechanical properties of aluminium alloy amended by reinforcing with hard ceramic particles like SiC, Al₂O₃ and B₄C etc. This work optimize squeeze casing process parameters using Taguchi method in Aluminium LM13 Matrix B₄C reinforced composites. Composite is manufactured using squeeze casting process by varying process parameters Squeeze pressure, Die preheating temperature and percentage of B₄C. Biswajit et al. concentrated their study on optimization of stir casting parameters like pouring temperature, stir speed and reaction time for titanium carbide reinforced MMC. They have conducted ANOVA analysis for finding out the percentage contribution of each process parameters. They also formulate regression equation for each output parameters [1]. Prosenjit, et al. conducted study on degree of sphericity optimization of A356 Al casting using cooling slop. Slope angle, pouring temperature and wall temperature of the melt are the input factors selected for the above analysis. They have also conducted ANOVA analysis and finally formulated regression equations for each output parameters [2]. Apparao et al. has studied the effect of porosity on die casting parameters and he optimized die casting parameters of Al-Si8Cu3Fe alloy for minimum porosity [3]. Shailesh, et al. optimized the process parameters of centrifugal casting and found out that pouring time and mechanical properties have converse relationship with die speed [4]. Patel et al. optimized squeeze casing parameters for LM20 alloy and he reported that process parameters Pouring
temperatur, die temperature and squeeze pressure have significant effect on the cast product quality [5]. Zhang, Lintao, et al. investigated the effect of parameters on continuous casting mold performance and found out that alternating current is the most significant factor contributing for magnetic field level in the mold[6]. Mohiuddin et al. use statistical techniques to study the process parameters of Al7SiMg alloy casting. They found out that the amount of degasser is the most significant factor for improving density and quality index in castings [7]. Singh, Rupinder, et al investigated the dimensional accuracy of Al-MMC developed by combining stir casting and investment casting [8]. Mei, Sen, et al. optimized the process parameters of cordierite-based glass ceramics using Taguchi method. Type and concentration of the dispersants and the binders, and the solids loading were selected as input parameters for optimizing homogeneous and crack-free green tapes [9]. J. Gokulachandran and Mohandas K use computing techniques for the assessment of tool life are neuro-fuzzy logic and support vector regression (SVR) techniques. They have set experiments used Taguchi approach for obtaining tool life [10,11]

2. Materials and Experimental Methods
Aluminium LM13 Matrix B4C reinforced composites are widely used in aerospace and automobile industries. Aluminium LM13 matrix B4C Reinforced composite is manufactured using squeeze casting techniques by varying process parameters, Squeeze pressure (75MPa, 100MPa and 150Mpa), Die heating Temperature (150°C, 200°C and 250°C) and percentage of B4C (3%, 6% and 9%). Experimental setup consisting of a squeeze casting furnace in which temperature of die is measured using a type thermo couple. The Squeeze pressure is controlled by hydraulic power press, which is controlled during solidification. Experiment is repeated with 3 percentage, 6 percentage and 9 percentage B4C for each level of Squeeze pressure and Die preheating temperature. B4C is pre heated before adding to casting furnace. Final finished cast specimens were machined to ASTM standard for measuring mechanical properties Hardness, UTS and YS.

2.1. Experimental Design
Squeeze casting processes were conducted using Taguchi L27 Orthogonal array. The process parameters selected for the given study are Squeeze Pressure, Die preheating temperature and percentage boron carbide respectively. Process input parameters of Squeeze casting with their levels are given in Table 1. Since each process parameters has three levels, 27 experiments will be there with 26 degrees of freedom for studying the effects on output responses Hardness, UTS and YS. The Experimental design using L27 orthogonal array is given in Table 2.

| Table 1. Process input parameters of Squeeze casting |
|-----------------------------------------------|
| Factors                        | Level 1 | Level 2 | Level 3 |
| Squeeze pressure (MPa)         | 75      | 100     | 125     |
| Die preheating temperature (°C)| 150     | 200     | 250     |
| Boron carbide (wt. %)          | 3       | 6       | 9       |
Table 2. Experimental design using L27 orthogonal array

| Exp. No. | Pressure | Die Preheating Temperature | B4C % |
|----------|----------|----------------------------|-------|
| 1        | 75       | 150                        | 3     |
| 2        | 75       | 150                        | 6     |
| 3        | 75       | 150                        | 9     |
| 4        | 75       | 200                        | 3     |
| 5        | 75       | 200                        | 6     |
| 6        | 75       | 200                        | 9     |
| 7        | 75       | 250                        | 3     |
| 8        | 75       | 250                        | 6     |
| 9        | 75       | 250                        | 9     |
| 10       | 100      | 150                        | 3     |
| 11       | 100      | 150                        | 6     |
| 12       | 100      | 150                        | 9     |
| 13       | 100      | 200                        | 3     |
| 14       | 100      | 200                        | 6     |
| 15       | 100      | 200                        | 9     |
| 16       | 100      | 250                        | 3     |
| 17       | 100      | 250                        | 6     |
| 18       | 100      | 250                        | 9     |
| 19       | 125      | 150                        | 3     |
| 20       | 125      | 150                        | 6     |
| 21       | 125      | 150                        | 9     |
| 22       | 125      | 200                        | 3     |
| 23       | 125      | 200                        | 6     |
| 24       | 125      | 200                        | 9     |
| 25       | 125      | 250                        | 3     |
| 26       | 125      | 250                        | 6     |
| 27       | 125      | 250                        | 9     |

2.2. Taguchi method

Statistical analysis is carried out using Minitab 16 Software. Taguchi method converts experimental result into signal-to-noise (S/N) ratio. The object of the study is to maximize the mechanical properties Hardness, UTS and YS hence Signal to Noise ratio Larger is better is taken for this study. The S/N ratio for all levels of the Hardness, UTS and YS are computed using S/N analysis.
3. Results and Discussion
Experiments were conducted using Taguchi L27 array. Table 6 gives the output response and S/N ratio computed for Hardness, UTS and YS. Analysis of the variance for Hardness, UTS and YS using Adjusted SS for tests are given by Table 3, Table 4, and Table 5 respectively. Figure 1, Figure 2 and Figure 3 shows the main effect plot of S/N ratios of Hardness, UTS and YS respectively.

3.1. Analysis of variance (ANOVA)
ANOVA analysis indicate that the percentage contribution for Squeeze pressure (Hardness is 46.22%, UTS is 44.38 and YS is 46.49%), Die Preheating Temperature (Hardness is 6.37%, UTS is 15.65% and YS is 14.52%) and Percentage B4C (Hardness is 43.17%, UTS is 43.17% and YS 33.58%) respectively. Squeeze pressure is the most significant factor which contributing for Harness, UTS and YS followed by Percentage of B4C. Die Preheating temperature is the least significant factors among three inputs which contributing for the above output responses.

| Source                     | DF | Seq SS  | Adj SS  | Adj MS  | F      | % Contribution |
|----------------------------|----|---------|---------|---------|--------|----------------|
| Squeeze Pressure           | 2  | 3859.9  | 3859.9  | 1929.9  | 109.63 | 46.22          |
| Die Preheating Temperature | 2  | 532.5   | 532.5   | 266.3   | 15.13  | 6.37           |
| B4C %                      | 2  | 3605.4  | 3605.4  | 1802.7  | 102.4  | 43.17          |
| Error                      | 20 | 352.1   | 352.1   | 17.6    |        |                |
|                           | 26 | 8349.9  |         |         |        |                |

| Source                     | DF | Seq SS  | Adj SS  | Adj MS  | F      | % Contribution |
|----------------------------|----|---------|---------|---------|--------|----------------|
| Squeeze Pressure           | 2  | 7970.7  | 7970.7  | 3985.3  | 95.29  | 44.38          |
| Die Preheating Temperature | 2  | 2810.9  | 2810.9  | 1405.4  | 33.61  | 15.65          |
| B4C %                      | 2  | 6340.7  | 6340.7  | 3170.3  | 75.8   | 43.17          |
| Error                      | 20 | 836.4   | 836.4   | 41.8    |        |                |
|                           | 26 |         |         |         |        |                |

| Source                     | DF | Seq SS  | Adj SS  | Adj MS  | F      | % Contribution |
|----------------------------|----|---------|---------|---------|--------|----------------|
| Squeeze Pressure           | 2  | 2887.19 | 2887.19 | 1443.59 | 86.48  | 46.49          |
| Die Preheating Temperature | 2  | 902.74  | 902.74  | 451.37  | 27.04  | 14.52          |
| B4C %                      | 2  | 2085.63 | 2085.63 | 1042.81 | 62.47  | 33.58          |
| Error                      | 20 | 333.85  | 333.85  | 16.69   |        |                |
|                           | 26 |         |         |         |        |                |
From the S/N ratio values given by the Table 6 and the main effects plots of S/N ratios shown by Figures 1, 2 and 3 indicates that experimental number 24 gives maximum fitness value of Hardness, UTS and YS. The optimized process parameters values are Squeeze Pressure (125MPa), Die preheating Temperature (200 °C) and Percentage of B4C (9%) for the range of values selected for the study.

Table 6. Experimental Results and S/N ratio for Hardness, UTS, YS

| Exp. Numbers | Experimental Inputs | Experimental Outputs | S/N Ratio |
|--------------|---------------------|----------------------|----------|
|              | Pressure | Die Preheating Temperature | B4C % | Hardness | UTS | YS | Hardness | UTS | YS |
| 1            | 75       | 150                   | 3     | 83       | 277  | 172 | 38.3816  | 48.8496 | 44.7106 |
| 2            | 75       | 150                   | 6     | 102      | 303  | 187 | 40.172   | 49.6289 | 45.4368 |
| 3            | 75       | 150                   | 9     | 109      | 325  | 200 | 40.7485  | 50.2377 | 46.0206 |
| 4            | 75       | 200                   | 3     | 86       | 288  | 178 | 38.69    | 49.1878 | 45.0084 |
| 5            | 75       | 200                   | 6     | 112      | 321  | 197 | 40.9844  | 50.1301 | 45.8983 |
| 6            | 75       | 200                   | 9     | 115      | 328  | 195 | 41.214   | 50.3175 | 45.8007 |
| 7            | 75       | 250                   | 3     | 72       | 268  | 166 | 37.1466  | 48.5627 | 44.4022 |
| 8            | 75       | 250                   | 6     | 99       | 292  | 180 | 39.9127  | 49.3077 | 45.1055 |
| 9            | 75       | 250                   | 9     | 100      | 301  | 186 | 40       | 49.5713 | 45.3903 |
| 10           | 100      | 150                   | 3     | 104      | 323  | 198 | 40.3407  | 50.1841 | 45.9333 |
| 11           | 100      | 150                   | 6     | 122      | 334  | 205 | 41.7272  | 50.4749 | 46.2351 |
| 12           | 100      | 150                   | 9     | 132      | 353  | 216 | 42.4115  | 50.9555 | 46.6891 |
| 13           | 100      | 200                   | 3     | 108      | 318  | 196 | 40.6685  | 50.0485 | 45.8451 |
| 14           | 100      | 200                   | 6     | 124      | 358  | 219 | 41.8684  | 51.0777 | 46.8089 |
| 15           | 100      | 200                   | 9     | 130      | 355  | 217 | 42.2789  | 51.0046 | 46.7292 |
| 16           | 100      | 250                   | 3     | 92       | 287  | 175 | 39.2758  | 49.1576 | 44.8608 |
| 17           | 100      | 250                   | 6     | 128      | 332  | 204 | 42.1442  | 50.4228 | 46.1926 |
| 18           | 100      | 250                   | 9     | 126      | 325  | 200 | 42.0074  | 50.2377 | 46.0206 |
| 19           | 125      | 150                   | 3     | 112      | 325  | 200 | 40.9844  | 50.2377 | 46.0206 |
| 20           | 125      | 150                   | 6     | 129      | 348  | 213 | 42.2118  | 50.8316 | 46.5676 |
| 21           | 125      | 150                   | 9     | 140      | 361  | 220 | 42.9226  | 51.1501 | 46.8485 |
| 22           | 125      | 200                   | 3     | 123      | 327  | 201 | 41.7981  | 50.291 | 46.0639 |
| 23           | 125      | 200                   | 6     | 131      | 348  | 213 | 42.3454  | 50.8316 | 46.5676 |
| 24           | 125      | 200                   | 9     | 141      | 367  | 224 | 42.9844  | 51.2933 | 47.005  |
| 25           | 125      | 250                   | 3     | 101      | 316  | 195 | 40.0864  | 49.9937 | 45.8007 |
| 26           | 125      | 250                   | 6     | 126      | 330  | 203 | 42.0074  | 50.3703 | 46.1499 |
| 27           | 125      | 250                   | 9     | 129      | 341  | 209 | 42.2118  | 50.6551 | 46.4029 |
**Figure 1.** Mean S/N ratio graph for Hardness

**Figure 2.** Mean S/N ratio graph for UTS

**Figure 3.** Mean S/N ratio graph for Yield Strength
4. Conclusions

The presented work optimize the multiple performance characteristic Hardness, UTS and YS of squeeze casting for range of Squeeze pressure, Die preheat temperature, percentage weight of B4C. Taguchi method is implemented for optimizing input parameters. Conclusions drawn from these studies are.

1. The optimized process parameters which maximize the response hardness, UTS and YS are Squeeze pressure 125MPa, Die pre heating temperature(200°C) and Weight percentage of B4C(9%) for the range of values selected for the study.

2. The ANOVA result analysis indicate that Squeeze pressure is the most significant factors which has highest contribution on performance characteristics followed by weight percentage of B4C.

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