The squeeze casting parametric effect on magnesium metal matrix composite

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Abstract. The reinforced Metal Matrix Composite (MMC) was broadly used in various engineering applications. The light weight and high strength metal matrix components were used in aerospace and automotive applications. The silicon carbide, boron carbide, aluminum oxide and carbon fiber were used as common reinforcement materials. The magnesium and its alloys were recently has a maximum role in MMC due to its high strength and light weight. In addition to the magnesium, the aluminium and copper was included through the reinforcement of boron carbide (B4C). It was formulated through squeeze casting technique. The copper has good electrical conductivity and it has more corrosion resistance. The magnesium metal matrix was fabricated through squeeze casting technique. The Vickers hardness was determined through the different input squeeze casting factors such as pressure, pouring temperature and die temperature. The Response Surface Methodology (RSM) optimization was used to analyze the parametric effects.

Keywords: Magnesium MMC, boron carbide, squeeze casting, Vickers hardness, RSM optimization

1. Introduction
The two processes were involved in squeeze casting such as casting and forging. It was applied in automotive and boat engine components. Due to its favorable substance properties aluminium, silicon, magnesium and copper were used as matrix materials. The squeeze casting process and its parameters, applications, factors affect the quality of the fabricated components were discussed [1]. The applied pressure was used to refine the grain structure of aluminium and its solidification rate was also increased [2-3]. The effect of microstructures and mechanical behaviors were investigated on Al-Cu
alloy under squeeze casting [4]. The parametric effect and optimization were applied in squeeze casting of magnesium MMC [5]. The microstructure and substance behaviors were analyzed in squeeze casted Al–Zn–Mg–Cu [6]. Squeeze casting factors were optimized and influential factor was found on Al-Si alloy [7]. The boron carbide reinforces magnesium MMC fabrication method and its structure was characterized [8]. The die temperature was produced maximum effect on mechanical behavior [9]. The mechanical properties and its applications were reported [10-12]. Many researchers based on the Taguchi approach of SN ratio and variance analysis to evaluate optimum conditions [13-35].

In the present topic was discussed about the squeeze casting parametric effects and optimization of magnesium metal matrix composite.

2. Material fabrication method

The squeeze casting was a suitable fabrication technique for magnesium MMC. It has more advantages such as allowed high volume weight percentage of material, no casting defects, high density components and quality products with better substance properties. It has two die unit namely as upper and lower dies. The lower die has cavity and it has receives the molten metal. The upper die has act as a punch and it has provided the pressure. The magnesium MMC has consists of different alloying elements such as copper, silicon, nickel, iron, zinc, tin and titanium. The boron carbide has added to the alloying elements with 1.5 weight percentages. The squeeze casting was shown in Fig.1. The molten metal was kept under a preheated lower die and then it was covered by upper die. The steam pressure (120 MPa) was applied to the molten metal in between the die units. The purpose of the pressure was used to provide complete solidification of material and maintained uniform rate of heat flow. Finally, the solidified metal piece was removed and it was converted in to desired shape.

3. Experimental result and discussion

The final casting component has fine grains and higher density which was used to increase the substance behaviors. The strength and the micro structure were related to the squeeze casting pressure. The Vickers LV-900 was used to measure the composite hardness. For these experimental works, the different input factors were chosen and it was exposed in Table 1.
Table 1. Squeeze casting experimental results

| Std | Run | A: Pressure (MPa) | B: Pouring temperature (°C) | C: Die temperature (°C) | Hardness (HV) |
|-----|-----|------------------|---------------------------|------------------------|--------------|
| 1   | 14  | 60               | 600                       | 200                    | 140          |
| 2   | 12  | 120              | 600                       | 200                    | 160          |
| 3   | 10  | 60               | 800                       | 200                    | 150          |
| 4   | 11  | 120              | 800                       | 200                    | 152          |
| 5   | 1   | 60               | 700                       | 150                    | 148          |
| 6   | 4   | 120              | 700                       | 150                    | 172          |
| 7   | 15  | 60               | 700                       | 250                    | 166          |
| 8   | 7   | 120              | 700                       | 250                    | 210          |
| 9   | 3   | 90               | 600                       | 150                    | 250          |
| 10  | 17  | 90               | 800                       | 150                    | 250          |
| 11  | 9   | 90               | 600                       | 250                    | 220          |
| 12  | 13  | 90               | 800                       | 250                    | 236          |
| 13  | 8   | 90               | 700                       | 200                    | 190          |
| 14  | 5   | 90               | 700                       | 200                    | 202          |
| 15  | 6   | 90               | 700                       | 200                    | 241          |
| 16  | 2   | 90               | 700                       | 200                    | 212          |
| 17  | 16  | 90               | 700                       | 200                    | 198          |

4. Optimization process

The Response Surface Methodology was used to analyze the squeeze casting process parameters and its effects on hardness. The developed model was used to predict the response such as hardness. The different models such as linear, cubic and quadratic types were analyzed and finally it has decided the suitable model for input and output factors. The design of expert 12 version was used to run the squeeze casting experimental results. The quadratic model was selected for the experiment and it was revealed in Table 2.

Table 2. Developed model for response

| Source                  | Sum of Squares | DF | Mean Square | F-value | p-value |
|-------------------------|----------------|----|-------------|---------|---------|
| Mean and Total          | 6.317E+05      | 1  | 6.317E+05   |         |         |
| Linear and Mean         | 1321.00        | 3  | 440.33      | 0.2926  | 0.8301  |
| 2FI and Linear          | 185.00         | 3  | 61.67       | 0.0318  | 0.9919  |
| Quadratic and 2FI       | 16608.86       | 3  | 5536.29     | 13.98   | 0.0024  |
| Cubic and Quadratic     | 1209.00        | 3  | 403.00      | 1.03    | 0.4684  |
| Residual                | 1563.20        | 4  | 390.80      |         |         |
| Total                   | 6.526E+05      | 17 | 38386.88    |         |         |

The variance analyze was used to predict the model whether it has significant or not and it was shown in Table 3. At the same time the influential factor of pressure for squeeze casting was attained. It has produced maximum effect on hardness. The combined factors effects were also reported.

Table 3. Variance analysis for squeeze casting

| Basis             | SS   | DF  | MS   | F-value | P-value |
|-------------------|------|-----|------|---------|---------|
| Model             | 18114.86 | 9   | 2012.76 | 5.08    | 0.0217  | significant |
| A-Pressure        | 1012.50  | 1   | 1012.50 | 2.56    | 0.1539  |
| B-Pouring temperature | 180.50  | 1   | 180.50  | 0.4558  | 0.5213  |
| C-Die temperature | 128.00  | 1   | 128.00  | 0.3232  | 0.5875  |
| AB                | 81.00  | 1   | 81.00  | 0.2045  | 0.6648  |
| AC                | 100.00 | 1   | 100.00 | 0.2525  | 0.6307  |
The actual values of the experiments and expected values were also fit on the straight line and it was exposed on Fig. 2. It was shown that only little deviation was maintained between the values.

![Normal Plot of Residuals](image)

**Figure 2.** Definite and Expected values for squeeze casting

The hardness effect between pouring temperature and pressure was exposed in Fig. 3. The design points were achieved at the pouring temperature of 700ºC and pressure of 90 MPa. The hardness and pressure was directly proportional to the material hardness.
The hardness effect between die temperature and pressure was exposed in Fig. 4. The optimal points were achieved at the die temperature between 190-210ºC and pressure of 90 MPa. The die temperature was also produced the sufficient effect on hardness.

The hardness effect between die temperature and pouring temperature was exposed in Fig. 5. The optimal points were arrived at the die temperature between 190 - 210ºC and pouring temperature of 700ºC. The hardness effect was increased with the raise of pouring temperature.
5. Point prediction and optimal outcome

The optimal squeeze hardness of 162 HV was predicted and it was shown in Table 4. The two side test including confidence level of 95% and population level of 99% was conducted. The standard deviation of 19.9005 was obtained.

| Solution of 100 | Predicted Mean | Predicted Median | Observed Mean | Std. Dev | SE | 95% CI Low | 95% CI High | 95% TI Low | 95% TI High | 95% Pop Low | 95% Pop High |
|----------------|----------------|----------------|---------------|----------|----|------------|------------|------------|------------|------------|------------|
| Hardness       | 162            | 162            | 19.90         | 17.23     | 43 | 37.22      | 286.7      | 59         | 74         |

The optimal solutions were found through response surface methodology and it’s was shown in Table 5. The optimal squeeze hardness of 162 HV was gained at pressure of 120 MPa, die temperature of 200ºC and pouring temperature of 800ºC.

6. Conclusions

The following conclusions are drawn from the above experimental study:
The magnesium MMC reinforced with boron carbide was produced with squeeze casting method. The aluminium and copper was the other major elements were accumulated to the Mg MMC. The Vickers hardness was the output factor. The squeeze parameters were optimized through RSM. The optimal squeeze hardness of 162 HV was gained at pressure of 120 MPa, die temperature of 200ºC and pouring temperature of 800ºC. Pressure has produced maximum effect on hardness. Through point prediction the optimal hardness was validated.

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