Optimization of Squeeze Cast Process Parameters for Better Mechanical Properties by Taguchi Technique

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Abstract - *Squeeze casting for MMC fabrication is known to defeat the defects that acquire during the conventional casting processes. The near-net shape manufacturing ability and potential to yield higher hardness are the capability of the squeeze casting provided technical parameters are accurately controlled. In this research, optimization technique for squeeze casting process parameter is established by Taguchi technique to explore the correlation among the hardness and tensile strength. Three different process parameters namely melt temperature, die temperature and squeeze pressure, were selected to perform the experiments using L9 orthogonal array. The composites obtained for optimum cast conditions were squeeze pressure 100 MPa, melt temperature 700 oC and die temperature 300⁰C exhibited better hardness and tensile strength. The identified process parameters provide a favorable condition for processing the alloys directly on the melt up to the time of complete solidification. The results indicate that there exists a strong correlation between hardness and tensile strength.*

Key Words: Squeeze casting, Taguchi, Mechanical properties

1. INTRODUCTION

Now day's aluminum alloys are extensively used in range of different applications such as automobile, marine and aerospace industries due to the outstanding mechanical properties and low density [1]. Casting is the one of the manufacturing process to fabricate alloy in inexpensive and easiest process. But some casting products produce defect such as shrinkage, porosity, miss run and blow hole [2]. Squeeze casting process has led to defeat these defects, because of the pressure applied during solidification, porosities set off by both gas and shrinkage can be removed [3]. Quality of the casting product depends on the squeeze cast process parameters used in manufacturing. The influence on the quality of the casting listed are melting quality, equipment and tooling, melting temperature, die temperature and time delay before pressurization, applied squeeze pressure and time duration. Better results were found, when the pressure applied is near the zero fluidity temperature. The time delay reported is 10 to 20 sec prior to the closure of die and application of pressure [4]. However, the timing for application of pressure is the critical component that is applied at the start of crystallization [5]. LM24 aluminium alloys squeeze casted identified the best combinations of process parameters using L9 orthogonal array of Taguchi technique. The optimized values obtained were squeeze pressure of 100 MPa, die pre-heat temperature 35 °C and duration of pressure 15 s improved the ultimate tensile strength and hardness [6]. AC2A aluminium alloy cast using squeeze casting technique reported 65% improved tensile strength, for the process parameters, squeeze pressure (100 MPa), mold temperature (200°C) and duration of pressure (60S) through optimization [7].

The increasing prominences of Al alloys in the fabrication of lightweight materials have connected to squeeze casting. It is found that Al-based metal matrix composites (AMMC) offer a broad potential for extensive utilization and development. The reinforcements used were Al_2O_3, SiC, TiC, TiB_2, graphite and other ceramics. SiC reinforcements are increasingly used in automotive and aerospace applications. Silicon carbide (SiC) and aluminium oxide (Al_2O_3) are most commonly used reinforcements [9]. Gr are used for lubrication purpose.

Al alloy-SiC reinforced composites increased the toughness, ductility and wear resistance. While, Gr reinforced metal matrix composite (MMC) offered poor strength and better wear resistance [10].

2. EXPERIMENTAL PROCEDURE

Samples will be fabricated as per table no 2. As the reinforcement increases by 10 wt % the agglomeration increases due to dislocation density of reinforcement. Increasing wt % of reinforcement also increases the density of reinforcement due to which homogenous mixture production is not possible, as the reinforcements settle down due to higher density as compares to matrix phase (Al6061).

Table -1: Segregation of MMC samples

	Al6061	SiC	Gr
Sample 1	90%	5%	5%

A pre-specified amount of Al6061 is melted in crucible furnace. The melting temperature of Al alloy was 700, 750 and 800 ⁰C. The SiC and Gr reinforcement particles having 15 micron size are pre-heated upto 500⁰C temperature to remove the impurities. The pre-heated reinforcement is added to molten metal and stirrer. The stirrer is carried out on 500RPM for 5 min. The slurry is then transmitted to die through pathway pre-heater, which was set for 150, 300 and 400⁰C. The pathway also maintains some temperature so that the mixture will not solidifies. This slurry is poured into a preheated die cavity, located on the bed of a hydraulic press through pathway. The press is activated to close off the die cavity and to pressurize the liquid metal. The pressure applied for this study was taken are 70, 100 140 MPa. This is carried out very quickly, rendering solidification of the molten metal under pressure. The pressure is held on the metal until complete solidification. This not only increases the rate of heat flow, but also most importantly may eliminate macro or micro shrinkage porosity. In addition, since nucleation of gas porosity is pressure-dependent, the porosity formation due to dissolve gases in the molten metal is restricted. Finally the punch is withdrawn and the component is ejected.

Fig -1: Squeeze casting machine set up

This research is focused to produce better mechanical properties in squeeze casting components. Hence, the larger the better characteristic is implemented in this study. The squeeze cast process parameters namely, squeeze pressure, melting temperature and die preheating temperature each at three levels is considered in this work and the details are presented in Table 2.

Table -2: Process Parameters and their levels

Process Parameters	Coding	Level 1	Level 2	Level 3
Squeeze pressure (MPa)	A	70	100	140
Melting Temperature (^{0}C)	B	700	750	800
Die temperature (^{0}C)	C	150	300	450

Selection of an appropriate orthogonal array based on the chosen process parameters is the prime aim in the Taguchi method. The total degrees of freedom for three parameters in each of three levels are six. Then, a three level orthogonal array ($L_9 3^3$) with nine experimental runs [degrees of freedom = 9−1 = 8] is selected for the present research. Orthogonal array (OA) is nothing but the shortest possible matrix of combinations in which all the parameters are varied at the same time and their effect and performance interactions are studied simultaneously.

In this work L9 is sufficient. Taguchi experimental design of experiments suggests L9 orthogonal array, where 9 experiments are sufficient to optimize the parameters. Based on main factor, the variables are assigned at columns, as stipulated by orthogonal array.

2.1 Materials characterizations

Fig. no 2 shows the tensile test samples which are machined from the fabricated rods. The samples are fabricated as per Taguchi orthogonal array and the tensile and hardness was tested. The hardness was tested at three different locations and the average value is taken for the analysis. The tensile test needed specimens were machined and prepared from the casting. The tensile tests were carried out for the specimen in the universal testing machine at room temperature.

Fig -2: Tensile strength samples

3. RESULTS AND DISCUSSION

3.1 Taguchi design of experiment

The Statistical Taguchi technique was found to be the useful tool in optimizing the squeeze casting method process parameters, by decreasing, the variations in the robust design of experiments to produce quality products. This paper analyzes and studies the effect of process parameters on hardness and tensile strength of Al6061/SiC/Gr composites. The process parameters such as squeeze pressure (A), melt temperature (B) and die temperature (C), at three levels considered for the analysis is shown in Table 3.

A signal-to-noise ratio is a measure of robustness, which can be used to identify the control factor settings that minimize the effect of noise on the response. Minitab calculates a separate signal-to-noise (S/N) ratio for each combination of control factor levels in the design. You can choose from different S/N ratios, depending on the goal of your experiment. In all cases, you want to maximize the S/N ratio.

Table -3: L9 Orthogonal array with design factors and S/N Ratio for hardness and tensile strength

Squeeze pressure	Melting Temp. (^{0}C)	Die Temp. (^{0}C)	Hardness (Hv)	Tensile (MPa)	S/N Hardness	S/N tensile
80	700	150	131.7	385.1	42.4	51.7

80	750	300	129.7	377.4	42.3	51.5
80	800	450	130.4	382.2	42.3	51.6
100	700	300	140.9	412.7	43.0	52.3
100	750	450	135.7	398.1	42.7	52.0
100	800	150	138.2	403.6	42.8	52.1
120	700	450	134.6	394.8	42.6	51.9
120	750	150	132.4	386.2	42.4	51.7
120	800	300	136.2	397.6	42.7	52.0

Table -4: Response Table for Signal to Noise Ratios for Hardness (Larger is better)

Level	Squeeze pressure (MPa)	Melting Temp. (^{0}C)	Die Temp. (^{0}C)
1	42.32	42.65	42.55
2	42.81	42.45	42.64
3	42.57	42.60	42.51
Delta	0.49	0.20	0.13
Rank	1	2	3

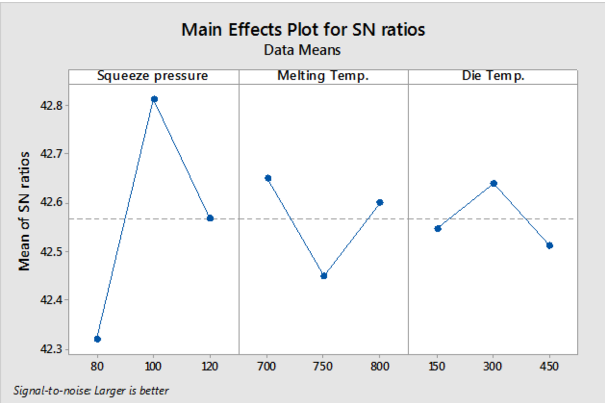

Fig -3: S/N ratio response curve of hardness

The process parameters analyzed using MINITAB 18 was arranged in L9 orthogonal array. Table 3 shows the response table of S/N ratio for hardness and tensile strength. The effect of control factors on hardness and tensile strength established with the S/N ratio response is presented in table 4 and 5. The results showed that squeeze pressure have linked on tensile hardness and strength. The higher S/N ratio is known for better performance. Hence, the optimum level of process parameters is the level which has maximum S/N value. Fig. 3 indicated the response curve in S/N ratio.

The highest tensile strength and hardness was observed at larger the better S/N values (Fig. 4 and 5). The optimized process parameters for hardness and tensile strength are squeeze pressure at level 2, melt temperature at level 1 and die temperature at level 2.

Table -5: Response table for signal to noise ratio for Tensile strength (Larger is better)

Level	Squeeze pressure (MPa)	Melting Temp. (^{0}C)	Die Temp. (^{0}C)
1	51.63	51.98	51.86
2	52.14	51.76	51.95
3	51.88	51.92	51.86
Delta	0.51	0.23	0.09
Rank	1	2	3

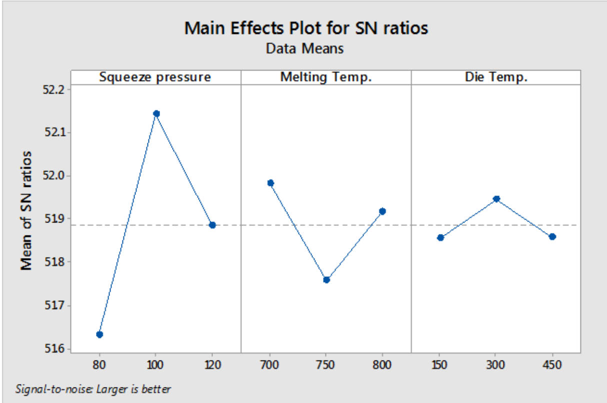

Fig -4: S/N ratio response curve of Tensile strength

3.2 Analysis of variance

The main purpose of the ANOVA is the application of a statistical method to identify the effect of individual factors on the process response. Results from ANOVA can determine very clearly the impact of each factor on hardness and tensile strength. Using Minitab 18, ANOVA performed determines the parameter and interaction that significantly affect the performance characteristics. ANOVA is a computational technique to quantitatively evaluate the comparative involvement of parameters. ANOVA is described by the total sum of squares of the standard deviation equal to the sum of squares of the standard deviation produced by the respective parameter.

Source	DF	% Contri.	Seq SS	Adj SS	Adj MS	F	P
Squeeze pressure	2	79.41	88.169	88.1689	44.0844	298.3	0.003
Melting Temp.	2	14.32	15.902	15.9022	7.9511	53.8	0.018
Die Temp.	2	6.01	6.669	6.6689	3.3344	22.56	0.042
Residual Error	2	0.27	0.296	0.2956	0.1478		
Total	8	100	111.036				

Table -6: ANOVA Variance table for hardness

Table 6 and 7 shows the ANOVA results for hardness and tensile strength respectively. It determines the F-ratio. The F-Ratio is defined as the ratio between regressions mean square and mean square error. Comparing all the process parameter, squeeze pressure plays a main role in determining the mechanical properties; depend upon the squeeze pressure, the mechanical properties are varied. Squeeze pressure was 79.41% representing the highest contribution, melting temperature and die temperature were 14.32 and 6.01% contributions for Hardness. Squeeze pressure was 79.44% representing the highest contribution, melting temperature and die temperature were 16.46 and 3.52% contributions for tensile strength. From ANOVA results it is clearly seen that squeeze pressure is the most major factor control the hardness and tensile strength value.

Table -7: ANOVA Variance table for tensile strength

Source	DF	% contri.	Seq SS	Adj SS	Adj MS	F	P
Squeeze pressure	2	79.44	809.88	809.882	404.941	137.06	0.007
Melting Temp.	2	16.46	167.82	167.816	83.908	28.4	0.034
Die Temp.	2	3.52	35.85	35.849	17.924	6.07	0.142
Residual Error	2	0.58	5.91	5.909	2.954		
Total	8	100	1019.46				

3.3 Regression analysis

A complete model of regression completed using Minitab 18 software. Three operational parameters and three levels consider in this present study. The complete regression equations are shown in equation 1 and 2. The relationship between the squeeze casting factors and the measured parameters such as hardness and tensile strength were found by multiple linear regression equation 1 and 2.

(1)Hardness = 131.5 + 0.0950 Squeeze pressure - 0.0080 Melting Temp. - 0.0018 Die Temp.

(2) Tensile Strength = 387.8 + 0.283 Squeeze pressure - 0.031 Melting Temp. + 0.0002 Die Temp.

4. CONCLUSION

The effect of squeeze casting process parameters on mechanical properties of Al6061 alloy and SiC/Gr with 5 wt % each was investigated using Taguchi technique. The experiments are conducted using L9 orthogonal array by considering three parameters and three levels. The process parameters consider are squeeze pressure, melting temperature and die pre-heating temperature. The increase in the squeeze pressure resulted in smaller grain size, improved mechanical properties such as hardness and tensile strength in metal matrix composites. The optimum process parameters for better mechanical properties are, squeeze pressure 100MPa, Melting temperature 700^{o}C and die pre-heating temperature was 300^{o}C.

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