Optimization of Squeeze Casting Parameters of Aluminium Alloy Composite Material by Response Surface Methodlogy

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Abstract— Aluminium metal matrix composites (MMCs) have gained importance in all the field of engineering application. Aluminium has a favourable strength to weight ratio, and compared to other materials used in bicycle and automotive industries. In this project work, composites were fabricated by using squeeze casting method. Aluminium 6013 alloy as matrix material and 15% SiC as reinforcing material. The mechanical properties of aluminium alloys are highly improved by adding SiC particles as reinforcement. From the investigation the various squeeze casting parameters of composite materials samples has been subjected to find the mechanical properties such as hardness, tensile and wear test. Experiments were conducted on response surface methodology by varying the input squeeze casting parameters. The experimental results showed that squeeze pressure is most influence factor on Tensile strength, hardness and wear resistance

Key words: Al6013 alloys, silicon carbide, stir casting, stir casing parameter, mechanical properties, RSM

I. INTRODUCTION

Composite materials are new generation materials to meet the demands of rapid growth of technological changes of the industry. Composites are engineering materials made from two or more constituents' materials. One constituent is called matrix phase. Other is called reinforcing phase. Reinforcing phase is embedded in the matrix to give desired characteristic. Non-continuous phase called the reinforcement. MMCs are made by dispersing a reinforcing material into a metal matrix. The advantages metal matrix composites over the polymer matrix composites include are higher operating temperature, do not absorb moisture, better electrical and thermal conductivity.

The super alloys, as well as alloys of aluminum, titanium, and copper, are employed as matrix materials. The reinforcement may be in the form of particulates, continuous and discontinuous fibers. Aluminium alloy 6013 is a new medium strength alloy that provides improved formability and corrosion resistance for use in aerospace applications. Al 6013 alloy has (aluminum-magnesium-silicon-copper) yield Strengths 12% higher than Al 2024.Uses for 6013 include primary structural applications including fuselage panels, Bicycle frame and mobile phone application. Silicon carbide is ceramic material maintain their strength over high temperatures, approaching 1600°C with no strength loss.

The squeeze casting process has the capability of producing near net shape castings that are essentially pore free. The high pressure during solidification keeps the molten metal in direct contact with the die surface providing true to die dimensions in the casting, the close contact with the die surface during solidification results in rapid solidification of the casting. This rapid solidification produces a fine secondary dendrite arm spacing in the castings, so that good strength and ductility can be attained.

II. REVIEW WORK CARRIED OUT

Senthil et al., studied the influence of squeeze pressure, melt temperature, die preheating temperature, die insert material and compression holding time on mechanical properties of LM24 aluminium alloys and concluded that squeeze pressure is the major contributing factor for the improvement of mechanical properties [1]. While preparing metal matrix composites, the selection of reinforcement particle size also influences the strength of material in the squeeze casting process. The smaller the grain size the better the improvement in properties [2].In squeeze casting the major parameters influencing the casting density and surface roughness are applied pressure, pressure duration, die and pouring temperature. Increase in squeeze pressure and pressure duration improves surface finish and casting density but it affects die life [3]. Vijian et al. reported that squeeze casting exhibited remarkable grain refinement and substantial improvement in mechanical properties [4].

Though many research works on squeeze cast aluminum alloys have been reported in literature, some gaps have been identified from the literature. Previous studies using squeeze casting technology to fabricate alloys only. It is understood that addition of ceramic materials can enhance the mechanical properties and life of components. This study aims at optimizing the fabrication process in order to achieve improved strength and mechanical properties. The effect of squeeze casting process parameters like squeeze pressure, pouring temperature, die preheating temperature on mechanical properties of Al6013/SiC aluminium composites was investigated. Optimum parameters are found by response surface methodology.

III. PROJECT SCHEME METHODOLOGY

A. *Squeeze Casting:*

The squeeze casting setup consists of two stainless steel spacers, stainless steel plunger, die, and base as shown in Figure-1. The cylindrical die is designed in order to minimize leakage, provide uniform pressure, and ensure smooth ejection of the cast. The die cavity has an internal diameter of 50 mm with length 250 mm. White graphite is used as lubricant. Main purpose of using lubricant is, it prevents adhesion and sticking of the composite specimen to the inner die wall. Pressure is applied by using the hydraulic plunger. A ceramic electric heater of capacity 400 °C was used to preheat the die. Aluminium 6013 alloy was melted in electric resistance crucible furnace. Homogenous distribution of reinforcement particle into the matrix material is the major factor which decides the final quality of casting. To attain the uniform distribution, silicon carbide and alumina powders are added with molten metal in the furnace and thoroughly mixed with the help of mechanical stirrer. After degassing the melt, a metered quantity of molten alloy was poured into the preheated die cavity.

Fig. 1: Squeeze casting die

B. Tensile Test:

Test specimens were prepared according to ASTM E8 standards, each specimen having 20mm in diameter and 50mm gauge length, as shown in Figure-2. The specimen was loaded in Universal Testing Machine until the failure of the specimen occurs. Tests were conducted on composites of different combinations of aging parameter and ultimate tensile strength and yield strength were measured.

For conducting a standard tensile test, a specimen that has been measured for its cross-sectional area and gauge length is placed in the testing machine. Simultaneous readings of load and elongation are taken at uniform intervals of load. Figure-2 shows some tensile test specimen after testing.

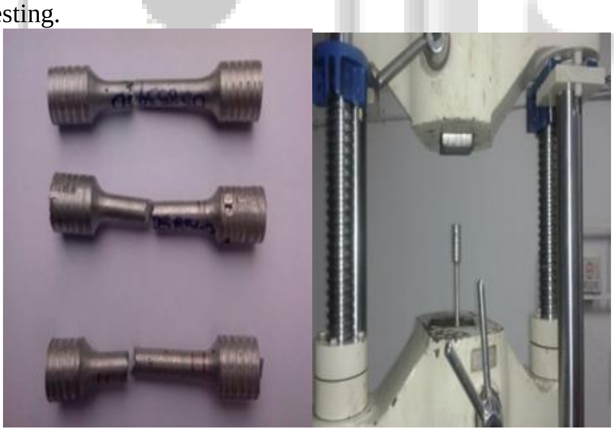

Fig. 2: Tensile test specimen

C. Hardness Test:

The hardness test specimens were prepared as per ASTM E10-15 test standards. The Brinell hardness test method consists of indenting the test material with a 5 mm diameter ball subjected to a load of 250 kg. The full load is applied for 1 minute. For harness results, test was repeated three times to obtain a precise average value.Fig 3 showed the Brinell hardness apparatus and test specimen.

Fig. 3: Brinell hardness tested specimen

D. Wear Test:

Pin on disc wear testing is a commonly used technique for investigating abrasive wear of the material. As the name implies that the apparatus consist of a “pin” in contact with a rotating disc. Either the pin or disc can be the test piece of interest. The contact surface of the pin may be flat, spherical or indeed of any convenient geometry, including that of actual wear components.

In a typical Pin on disc experiment, the coefficient of friction is continuously monitored as wear occurs and the material removed is determined by weighing and / or measuring the profile of the resulting wear track. Fig 4 showed the pin on disc apparatus. The wear test was conducted according to ASTM-G99 test standards. Three different compositions of wear specimens are shown in fig 4

Fig. 4: Pin on disc wear tested specimen.

IV. RESULTS AND DISCUSSIONS

Experiment having 3 factors which have three levels, then total number of experiment is 27. Then results of all experiment will give 100 accurate results. In comparison to above method the RSM Box-Behnken make list of thirteen experiments in a particular order which cover all factors in Table1.Thosethirteen experiments will give 99.96% accurate result. The analysis was done using MINITAB 15. The squeeze casting cast process parameters, namely squeeze pressure, pouring temperature and die preheating temperature at 3 levels are arranged in Box-Behnken method.

Run Order	Squeeze Pressure (Mpa)	Melting Temperature (°C)	Die preheating Temperature (°C)	Tensile strength (MPa)	Hardness (BHN)	Wear Rate (mm3/m)
1	75	750	150	233	70	0.00053
2	75	700	200	235	68	0.00055
3	50	700	250	228	73	0.00049
4	75	650	250	204	78	0.00041
5	100	650	200	221	75	0.00044
6	75	650	150	232	71	0.00051
7	50	700	150	201	83	0.00038
8	50	650	200	238	67	0.00057
9	100	750	200	234	72	0.0005
10	75	750	250	227	74	0.00047
11	50	750	200	219	77	0.00043
12	100	700	150	240	66	0.0006
13	100	700	250	236	74	0.00045

Table 1: Different level of parameters & output Responses

Effect of each control factor on tensile strength, hardness and wear rate was carried out with the S/N response table. The response tables for tensile strength, hardness and wear rate are also presented in table 2, 3, 4. It could be seen from these tables that the factor squeeze pressure have strongest influence on UTS, hardness and wear rate. Regardless of the category of performance characteristics, the greater S/N ratio gives better performance. Therefore, the optimal level of process parameters is the level with the greatest S/N value. The response graph shows the change of the S/N ratio when the setting of the control factor is changed from one level to the other. The best tensile strength, hardness and wear rate were at the higher S/N values in the graphs.

It could be seen in Fig. 5 that the optimum process condition became A3B2C2 for main control factors. That is, the optimal process parameters for the tensile strength, hardness and wear rate are the squeeze pressure at level 3, pouring temperature at level 2 and die preheating temperature at level2

Level	Squeeze Pressure (Mpa)	Melting Temperature (°C)	Die preheating Temperature (°C)
1	46.89	47.08	46.98
2	47.08	47.21	47.14
3	47.33	46.98	0.18
Delta	0.44	0.22	0.18
Rank	1	2	3

Table 2: S/N ratio response table for hardness

Level	Squeeze Pressure (Mpa)	Melting Temperature (°C)	Die preheating Temperature (°C)
1	37.47	37.22	37.17
2	37.16	37.21	37.11
3	37.11	37.29	37.47
Delta	0.37	0.08	0.36
Rank	1	3	2

Table 3: S/N ratio response table for hardness

Level	Squeeze Pressure (Mpa)	Melting Temperature (°C)	Die preheating Temperature (°C)
1	66.05	66.7	66.41
2	66.11	66.17	66.23
3	66.86	66.13	66.36
Delta	0.81	0.57	0.17
Rank	1	2	3

Table 4: S/N ratio response table for wear rate

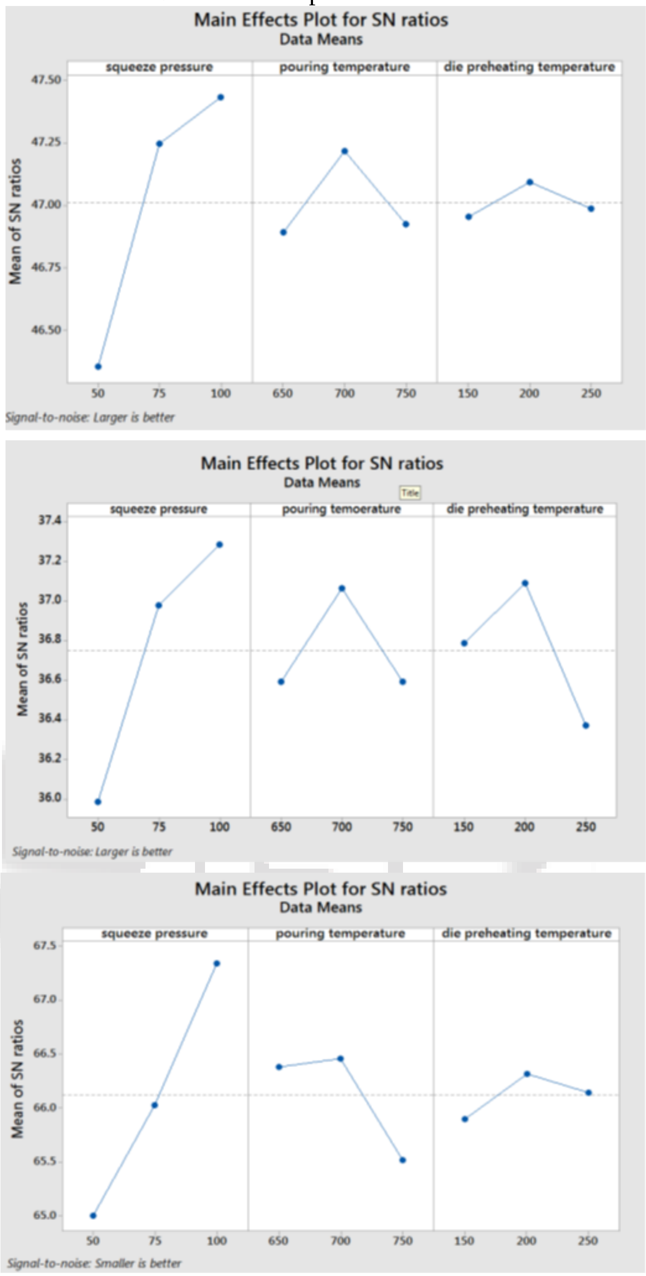

Fig. 5: Response curve for Tensile strength, Hardness, Wear rate

A. Analysis Of Variance:

Using Minitab 15, ANOVA is performed to determine which parameter and interaction significantly affect the performance characteristics. Table 5 shows the ANOVA results for tensile strength hardness and wear rate respectively. ANOVA calculates the F- ratio, which is the ratio between regression mean square and mean square error. In general when the F- value increases, the significance of the parameter also increases. From ANOVA results it is seen that squeeze pressure is the most significant factor influencing the UTS, hardness and wear rate.

Source	SS	DOF	MSS	F Ratio	P value
Squeeze Pressure	1270	2	635.4	15.84	0.059
Melting Temperature	118.2	2	59.11	1.47	0.404
Die preheating temperature	14.89	2	7.44	0.19	0.843
Error	80.22	2	4.11		
Total	1484	8			

Table 5: Analysis of variance- tensile strength

B. Regression Analysis:

The correlations between the factors (squeeze pressure, pouring temperature, die preheating temperature) and the measured parameters (tensile strength hardness and wear rate) were obtained by multiple linear regressions. Eventually, the following equations were fitted for UTS, hardness and wear rate.

Tensile Strength (Mpa) = 184+ 0.225 Squeeze Pressure+0.0450
Melting Temperature – 0.0275 Die preheating Temp.
Hardness (BHN) = 69.8- 0.0650 Squeeze Pressure + 0.0050
Melting Temperature + 0.0225 Die Preheat Temp.
Wear rate (mm3/m) = 0.000542+0.00001 Squeeze Pressure

V. Conclusion

Following conclusions were drawn based the experiments conducted to study the influence of squeeze casting parameter on the mechanical behaviour of Al 6013 metal matrix composites reinforced with silicon carbide.

– The optimal squeeze casting parameters of Al6013-SiC composites have been specified using the RSM.
– RSM method, the experiments were conducted based on Box-Behnken by considering three factors and three levels. The parameters considered in this work are squeeze pressure, pouring temperature and die preheating temperature
– The combination A3 B2 C2 that means squeeze pressure 100MPa, melt temperature 700 °C and die temperature 200 °C are recommended to obtain higher mechanical properties in squeeze casting of Al6013-SiC composites.
– From ANOVA. It was found that the influence of squeeze pressure has the large impact on UTS, hardness and wear.

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