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Experimental Investigation on the Effect of Casting Parameters on Thin walled Castings of Metal Matrix (LM21-SiC) Composite

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ABSTRACT

Metal matrix composites (MMCs) are widely used in several applications owing to their high strength, high specific stiffness, greater wear resistance and light weight. Normally, MMCs are processed through stir casting which exhibits poor wet ability and bonding between metal matrix and ceramic reinforcement, porosity and hot tears. These drawbacks can be overcome by squeeze casting process. Here an attempt was made on processing LM21-Sic composite for making hollow casting through squeeze casting process. Four process parameters are chosen namely squeeze pressure, stirring speed, melt temperature and reinforcement percentage. The primary objective was to experimentally investigate the influence of casting parameters on hardness & wear. Samples were cast for each experiments condition based on L9 orthogonal array. From the analysis of variance (ANOVA), it was observed that stirring speed, reinforcement percentage and Squeeze load were the process parameters making a noticeable improvement in hardness and wear. The mechanical properties such as hardness and wear are evaluated and optimum casting condition was obtained.

Keywords

LM21-Sic, MMCs, Hollow casting, Wear, Hardness, ANOVA.

1.Introduction

Metal-matrix composites (MMCs) have been developed by various fabrication processes. The conventional foundry processes of making MMC components lend themselves to the manufacture of large numbers of complexly-shaped components at high production rates and at the low cost required by the automotive industries. Fabrication of metal matrix composites (MMCs) by casting processes are very promising for manufacturing near net shape components at a relatively low cost. The reinforcements may be in the form of continuous fibers, chopped fibers, whiskers, or particulates. Extensive industrial applications of these composites have been hindered by the high manufacturing cost associated with the high cost of the reinforcement fibers. Utilization of these materials has been limited, almost exclusively, to military and other highly specialized applications.

Al alloy parts are lighter than those made of cast iron (brake disk, engine bracket mounting), but as their strength and frictional resistance are lower, it is very difficult to apply them in the automotive industry. This study concentrates on establishing the basic data of Al alloy matrix composites to improve the weakness of A1 alloy.

A composite material is the tailoring of two or more material to improve strength to weight ratio. Composite material consists of two phases; a matrix phase and a reinforcement phase. Matrix (Al) and reinforcement (Sic) phase in combination of good material properties produce composite material with better properties. In common, various reinforcements are added to matrix of the composite for improving the strength as well as the stiffness.

2. Direct Squeeze casting (DSC)

DSC is the name given to that casting process in which molten metal is solidified under the direct action of a pressure that is sufficient to prevent the appearance of either gas porosity or shrinkage porosity. DSC is unique in this respect, all other casting processes leave some residual porosity. The process is also known, variously, as liquid-metal forging, squeeze forming, extrusion casting and pressure crystallization. DSC, essentially, combines the best of gravity die casting and closed-die forging, yielding products of complex geometry and the highest quality which also have isotropic properties. This technique, inevitably, gives the most rapid heat transfer, yielding the finest grain structure. Squeeze casting is an ideal process to produce high quality light metal alloy components with near net shape (1). Here the squeeze casting machine is shown in fig1.

The following steps are essential for this process,

- A amount of molten metal is transferred into a female die cavity or mould.

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- The male die, or punch, of the appropriate shape is driven into the die cavity to exert a pressure on the molten metal, while it is solidifying and to form the required shape
- After the casting has solidified under the applied pressure, the punch is withdrawn

  The solid casting is ejected from the die.

2.1. Optimization Technique

The optimum parametric condition can be determined through optimization techniques to reduce the manufacturing cost and for good quality. Here Taguchi method (2) was employed to find the optimum parametric condition of squeeze casting process. (3)The details of all parameters and their levels are given in Table 2.

3. Experimental Work

Table1. Mechanical Properties of LM21

Properties	Chill Cast
0.2% Proof Stress (N/mm^2)	80 – 140
Tensile Stress (N/mm^2)	150 - 200
Elongation (%)	2
Brinell Hardness	70 - 100
Endurance Limit ($5x10^7$ cycles, N/mm^2)	70
Modulus of Elasticity ($x10^3$ N/mm^2)	71
Shear Strength (N/mm^2)	175

3.1 Silicon Carbide

Silicon Carbide is the only chemical compound of carbon and silicon. It was originally produced by a high temperature electro-chemical reaction of sand and carbon. Silicon carbide is an excellent abrasive and has been produced and made into grinding wheels and other abrasive products for over one hundred years. Today the material has been developed into a high quality technical grade ceramic with very good mechanical properties. It is used in abrasives, refractoriness, ceramics, and numerous high-performance applications

Fig.1 Squeeze casting machine

Table.2 Selected machining parameters and their levels

Serial No.	Parameters	Levels		
		Level 1	Level 2	Level 3
A	Reinforcement percentage (%)	5	10	15
B	Melt temperature (^{o}C)	670	720	770
C	Stirring speed (rpm)	300	400	500
D	Squeeze load (Tons)	30	40	50

3.2 Experiments and Test

An orthogonal array L_9 (3^4) was selected to conduct experiments. A set of casting samples were cast for each experimental condition based on the orthogonal array as per the following experimental conditions. (5)

The Squeeze casted samples are shown in fig2

1. $A_1B_1C_1D_1$
2. $A_1B_2C_2D_2$
3. $A_1B_3C_3D_3$
4. $A_2B_1C_2D_3$
5. $A_2B_2C_3D_1$
6. $A_2B_3C_1D_2$
7. $A_3B_1C_3D_2$
8. $A_3B_2C_1D_3$
9. $A_3B_3C_2D_1$

The following metal matrix and reinforcement materials were selected to conduct experiments.

Metal matrix : Aluminum (LM21) = 1kg each

Reinforcement: Silicon carbide

Fig.2 Squeeze casted samples

3.3 Brinell Harness Testing

The Brinell scale is a hardness scale based on indentation hardness of a material. The Brinell test determines the hardness by measuring the depth of penetration of an indenter under a large load compared to the penetration made by a preload. There are different scales, denoted by a single letter, that use different loads or indenters. The indenter is forced into the test material under a preliminary minor load usually 10 kgf. When equilibrium has been reached, an indicating device, which follows the movements of the indenter and so responds to changes in depth of penetration of the indenter, is set to a datum position. While the preliminary minor load is still applied an additional major load is applied with resulting increase in penetration. When equilibrium has again been reach, the additional major load is removed but the preliminary minor load is still maintained. Removal of the additional major load allows a partial recovery, so reducing the depth of penetration. The permanent increase in depth of penetration, resulting from the application and removal of the additional major load is used to calculate the Brinell hardness number. The S/N ratio for harness test is shown in Table 3.

Table.3 S/N Ratio Values for Hardness Test

Expt .no	Parameters				Mean hardness (BHN)	S/N ratio (dB)
	Reinforcement % (Sic)	Melt Temperature (^{0}C)	Stirrer speed (rpm)	Squeeze load		
1.	5	670	300	30	86	38.69
2	5	720	400	40	109	40.75
3	5	770	500	50	90	39.08
4	10	670	400	50	129	42.21
5	10	720	500	30	102	40.17
6	10	770	300	40	95	39.55
7	15	670	500	40	86	38.69
8	15	720	300	50	96	39.64
9	15	770	400	30	119	41.51

Table.4 Average S/N Ratio Response Table for Harness Test

	Parameters			
	Reinforcement %	Melt temperature (◦c)	Stirrer Speed (rpm)	Squeeze load
Level 1	39.51	39.86	39.30	40.12
Level 2	40.65	40.19	41.49	39.66
Level 3	39.95	40.05	39.32	40.31
Max-Min	1.14	0.32	2.19	0.65
Rank	2	4	1	3
Optimum Level	A2	B2	C2	D3

3.4 Wear Testing

Wear test specimens were machined in the functional volume of samples shown in fig. 3. The S/N ratio for wear test is shown in Table 5.

The Nine specimens (pins), each of 10 mm diameter and 25 mm length were prepared from each sample. Wear test was conducted in a pin on disc type apparatus under dry sliding conditions at room temperature. An EN24 steel disc of 250 mm diameter in size and 57 HRC in hardness was used for conducting the test. The test specimen was tightly clamped in the specimen holder and held against the rotating steel disc. Load of 10 N, sliding speed of 7 cm/s and sliding distance of 100 m were taken while testing all specimens. A fresh disc was used and cleaned each time with acetone for the removal of oil, grease and other surface contaminants. The specimen was cleaned with ethanol and weighed before and after the test using an electronic balance accurate to 0.0001 g. The dry sliding wear loss was computed using the weight loss of the specimen.

Fig 3.Specimens used for wear test

Table.5 S/N Ratio for Wear Test

Expt .no	Parameters				Wear loss (gm)	S/N ratio (dB)
	Reinforcement % (Sic)	Melt Temperature (^{0}C)	Stirrer speed (rpm)	Squeeze load (Tons)		
1	5	670	300	30	0.0025	46.92
2	5	720	400	40	0.0017	50.27
3	5	770	500	50	0.0017	50.27
4	10	670	400	50	0.0017	50.27
5	10	720	500	30	0.0025	46.92
6	10	770	300	40	0.0035	43.99
7	15	670	500	40	0.0017	50.27
8	15	720	300	50	0.0017	50.27
9	15	770	400	30	0.0017	50.27

Table.6 Average S/N Ratio Response Table for wear Test

	Parameters			
	Reinforcement %	Melt temperature (◦c)	Stirrer Speed (rpm)	Squeeze load (Tons)
Level 1	49.16	49.16	47.06	48.04
Level 2	47.06	49.17	50.27	48.18
Level 3	50.27	48.18	49.16	50.27
Max-Min	3.21	0.97	3.22	2.23
Rank	2	4	1	3
Optimum Level	A3	B2	C2	D3

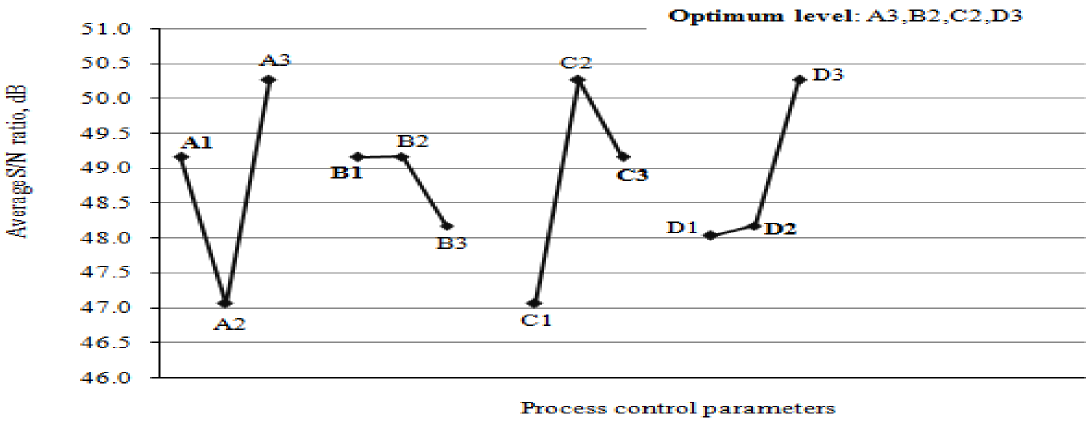

Fig 4. Average S/N Ratio Response vs. Process Control parameter

4. Results and Discussion

Optimum Condition via Taguchi method

S/N Ratio Response:

Hardness and wear rate was selected as output response with category of quality characteristics for hardness "higher the better", and for wear smaller the better. (3) In order to find optimum level of the process parameters, average S/N ratio response was determined and corresponding details are given in table 3 & 5.The response graph shown in Fig.5 & Fig 6 depicted the variation of each process parameter on the overall process performance of stirrer speed (4). The optimal casting condition A3B2C2D3 (stirrer speed of 400rpm,Reinforcement percentage of 15%,Squeeze load of 50 Ton, Melt Temperature of 720°c) , was then obtained. From the response graph shown in fig .4, it's observed that stirrer speed, Reinforcement percentage and Squeeze load were the important parameters having better control on the overall performance of the squeeze casting process (6)

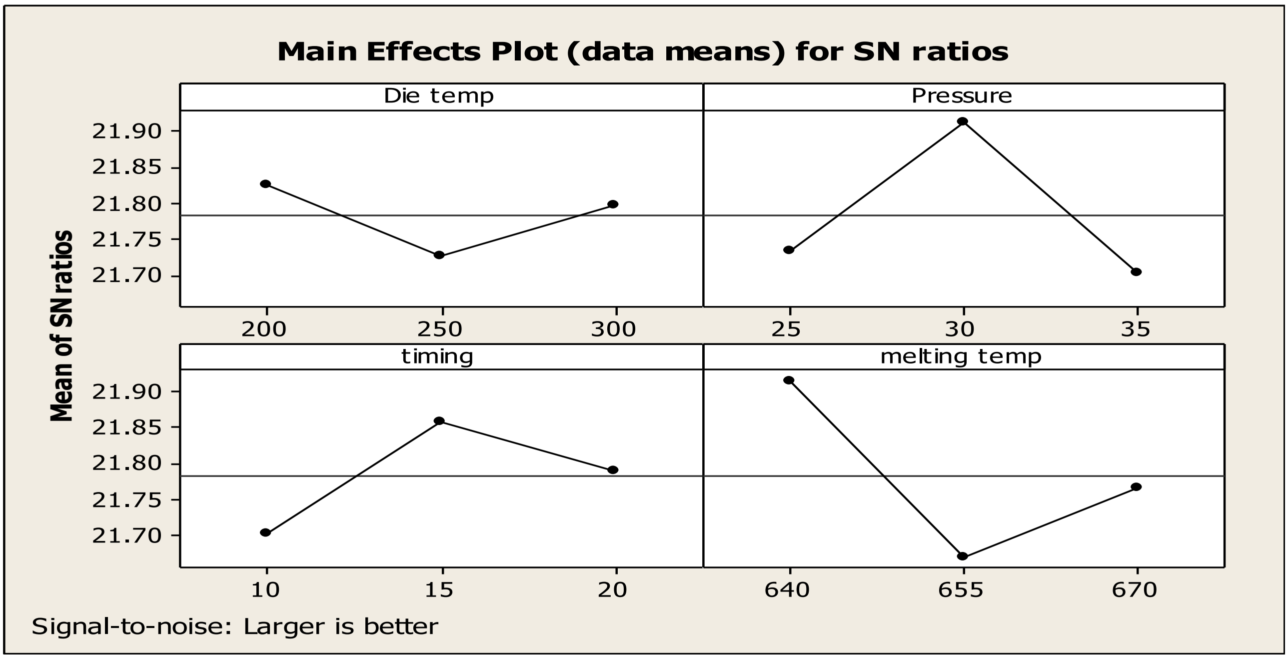

Fig 5.Response Graph (Hardness)

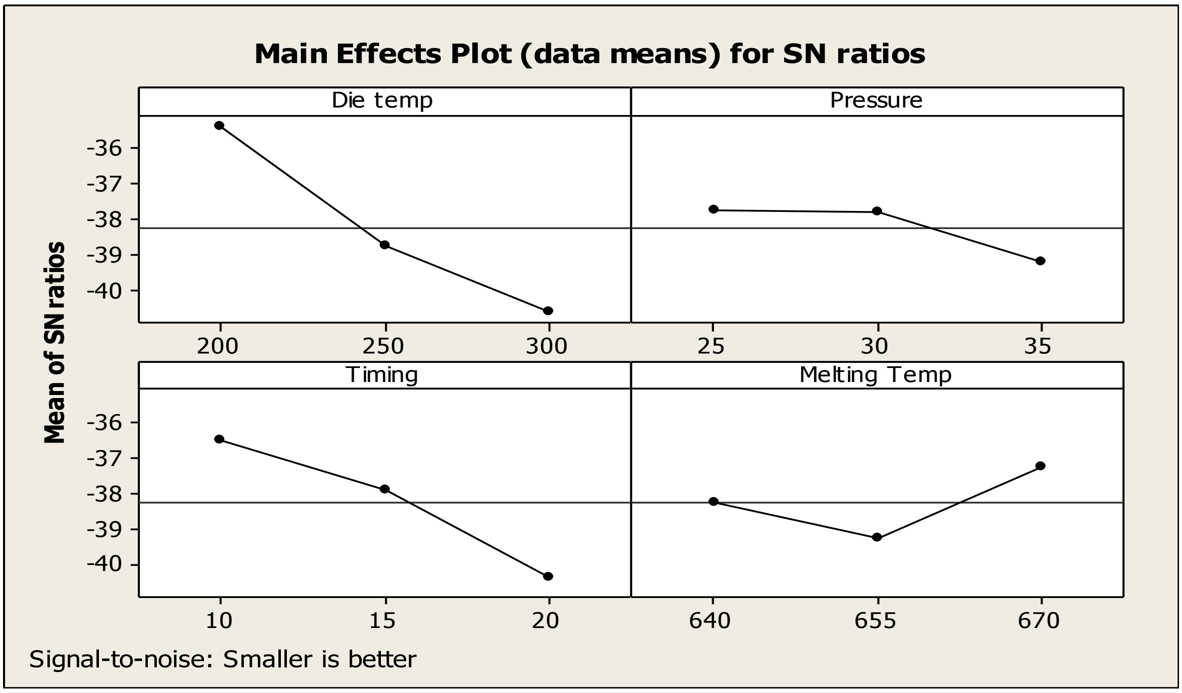

Fig 6.Response Graph (Wear)

5. Conclusion

Squeeze casting is noted to be suitable for processing LM21 & Sic composite with certain parametric condition. From ANOVA, stirrer speed, reinforcement percentage, squeeze load, and melt temperature were identified as significant process control parameters for making a noticeable improvement in hardness and wear. From the percentage contribution analysis, it was noted that stirrer speed was the most important parameter making a significant improvement in hardness and wear.

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