EXPERIMENTAL STUDY ON MECHANICAL PROPERTIES OF HYBRID METAL MATRIX COMPOSITES IN STIR CASTING PROCESS

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Abstract: The composite materials have been extensively used in automotive, aerospace and defense fields because of its high strength to weight ratio and other mechanical properties like improved hardness and tensile strength, higher wear strength and corrosion resistance.This study is focused to investigate the mechanical properties of LM13 reinforced with Aluminium oxide (Al_2O_3) and Boron Carbide (B_4C) particulate in order of (3+2), (3+2), (3+4), and (3+4) volume % respectively. The specimen was fabricated by stir casting process with optimized process parameters say melting temperature, reinforcement preheat temperature and percentage addition of B_4C (2% & 4%) by employing Taguchi quality design concept.

Keywords: B_4C, Al_2O_3, particulate, reinforcement, optimization.

I. INTRODUCTION

Composites are made up of individual materials referred to as constituent materials with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure. There are two main categories of constituent materials: matrix and reinforcement. At least one portion of each type is required. Composites consist of one or more discontinuous phases embedded in a continuous phase. The discontinuous phase is usually harder and stronger than the continuous phase and is called the 'reinforcement' or 'reinforcing material', whereas the continuous phase is termed as the 'matrix'. Properties of composites are strongly dependent on the properties of their constituent materials, their distribution and the interaction among them. Saravanan et al., [1] summarized the effect of particulate reinforced aluminium metal matrix composites based on various journals and guides the researchers and engineers towards proper selection of materials by their properties in the relevant field and different techniques involved in manufacturing of metal matrix composites, particularly on the liquid state metal processing technique and criteria for selecting process parameters like stirring speed, time, melt temperature, reinforcements and die preheat temperature etc. Arun kumar et al., [7] investigated using aluminium alloy LM24 as the base metal (matrix) with graphite, mica and Al2O3 as the reinforcements and the result reveals that the incorporation of graphite acts as self-lubricating material and it reduces the wear. Al2O3 particles increase the tensile strength of the material and mica increases hardness of the material. R. Ashiri et al., [9] summarized effect of casting process on wear behavior of LM13 alloy was investigated. First, samples were produced using two casting processes and heat treated. Then wear behavior of these samples under dry sliding condition was examined. Results of hardness and strength tests indicated that squeeze cast specimens exhibited higher mechanical properties. Wear experiment results showed that in both squeeze and gravity cast specimens, amount of weight loss increases with increase in sliding distance which is accompanied by reduction in wear rate and friction coefficient.

MATERIAL SELECTION

Aluminium is selected as the metal matrix for the composite due to its abundance, low cost and already proven track record for the similar purpose. It is relatively soft, durable, light weight, ductile, malleable metal and has high corrosion resistance, excellent heat conductivity. The selected aluminium alloy LM13 bears excellent characteristics for piston in engines. The composition is shown in the table 1. It has major alloying elements Silicon, Copper which contributes for better strength, machinability and cast ability. The properties are listed in table 2.

Table .1 LM13 chemical composition specification

Si	Fe	Cu	Mn	Mg	Ni	Zn	Sn	Ti	Pb	Al
12	1.0	0.7	0.5	1.5	1.5	0.5	0.1	0.2	0.1	Bal

Table .2 LM13 properties

Density	2.79 g/cm3
Elastic Modulus	73000 N/mm2
Melting Point	695 °C
Specific Heat Capacity	890 J/Kg-K
Tensile Strength: Ultimate (UTS)	170-200 Mpa
Vickers Hardness	130
Thermal Conductivity	0.28 Cal /cm2

BORON CARBIDE (B_4C)

Boron Carbide (B4C) is taken as one of the particulate reinforcement for the composite considering the factors which has a low density, a hardness just below that of diamond, excellent thermal stability and remarkable chemical inertness, is an attractive strengthening agent for aluminium-based composites.

ALUMINA (Al_2O_3)

Aluminium oxide is a chemical compound of aluminium and oxygen with the chemical formula Al2O3. It is the most commonly occurring of several aluminium oxides, and specifically identified as aluminium oxide.

DESIGN OF EXPERIMENT

Design of experiment is a powerful analysis tool for modelling and analyzing the influence of process variables over some specific variable, which is an unknown function of these process variables. The most important stage in the design of experiment lies in the selection of the control factors. As many process variables influencing the process should be included, so that it would be possible to identify the most significant variables at the earliest opportunity.

Table 3. Process parameters and levels

PROCESS PARAMETERS	LEVELS	
	LEVEL 1	LEVEL 2
Melting Temperature (°C)	725	750
Pre heat temperature (°C)	300	400
Reinforcement %	2	4

Table 4. Design of experiment

S.No	Sample	LM13 (%)	Boron carbide (%)	Aluminium oxide (%)	Pre heat temperature(˚C)	Melting temperature(˚C)
1	1	95	2	3	300	725
2	2	93	4	3	400	725
3	3	95	2	3	400	750
4	4	93	4	3	300	750

MICROSTRUCTURAL ANALYSIS

The dispersion of reinforcement particles in the matrix alloy is analyzed by means of inverted microscope. An inverted microscope is a microscope with its light source and condenser on the top, above the stage pointing down, while the objectives and turret are below the stage pointing up. The stage of an inverted microscope is usually fixed, and focus is adjusted by moving the objective lens along a vertical axis to bring it closer to or further from the specimen, fig 1, 2, 3 & 4 shows the microstructure of the sample

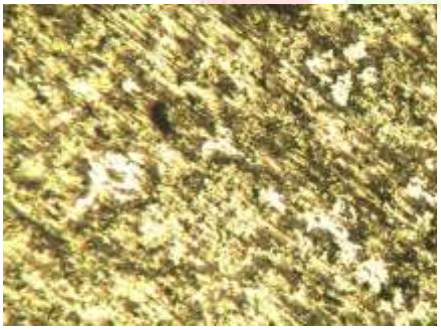

Fig.1. Sample 1

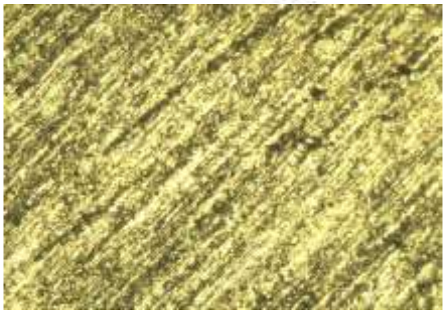

Fig.2. Sample 2

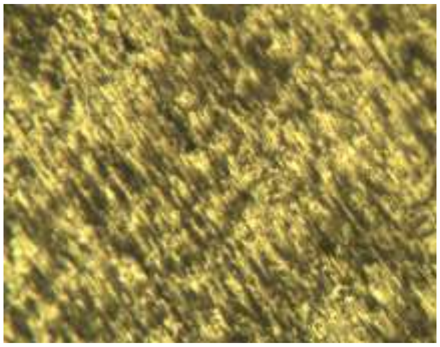

Fig.3. Sample 3

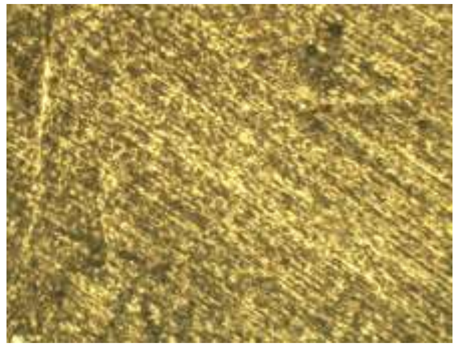

Fig.4. Sample 4

Overall analysis of structure indicates that the reinforced particles are uniformly distributed in the alloy matrix. The good bonding between particles and alloy matrix is also revealed in the microstructural analysis. Moreover, porosity is at minimum level and not observed in the optical examination, although clustering is seen at some places in the composite. The most prominent feature observed in all composite in the absence of dendritic growth which is accounted for better stir casting processing of composites.

TENSILE TEST

Table 5. Tensile test values

S. No	Sample	LM13 (%)	B_4C (%)	Al_2O_3 (%)	Pre heat temperature (˚C)	Melting temperature (˚C)	Tensile strength (N/mm2)
1	1	95	2	3	300	725	206.8
2	2	93	4	3	400	725	220
3	3	95	2	3	400	750	218.92
4	4	93	4	3	300	750	225

Tensile test results are compared that the variation of hardness in the locations due to the uncertainty of reinforcement particles presence at the indentation location. The sample '4' with combination of 4% boron carbide and 3% aluminium oxide with remaining LM13 is having higher hardness and LM13 sample '1' has the lower tensile strength because of the absence of the reinforcement particulates.

RESULT AND DISCUSSION

OPTIMIZATION OF PROCESS PARAMETER

The optimization of process parameter of Tensile test is carried with minitab software shows the optimal result as melting temperature, preheat temperature, reinforcement %, which is shown in table 6 , 7 & 8 and Figure 5.7 & 5.8 shows the graph of Mean of SN ratio and Levels of Factors.

Table 6. SN ratio for Ultimate tensile strength

RUN	A	B	C	UTS (MPa)	SNRA UTS
1	2	300	725	206.8	46.311
2	4	400	725	220	46.848
3	2	400	750	218.92	46.805
4	4	300	750	225	47.043

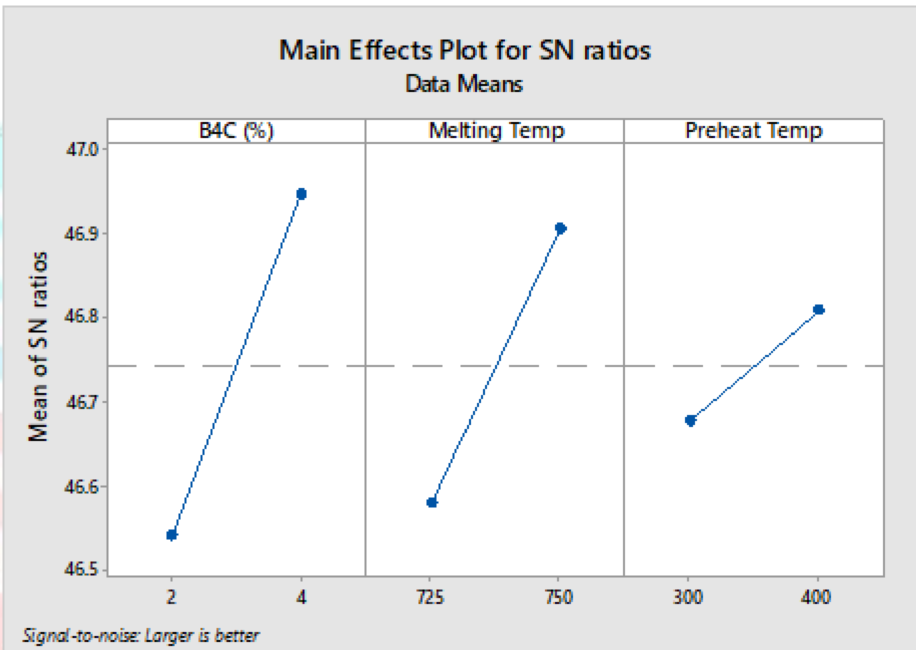

Figure 5. Main effect plot for SN ratios of Tensile Test

Table 7. Response for signal to noise ratio- larger is better

Level	B4C (%)	Melting Temperature (˚ C)	Preheat Temperature (˚ C)
1	46.54	46.58	46.68
2	46.95	46.91	46.81
Delta	0.41	0.33	0.13
Rank	1	2	3

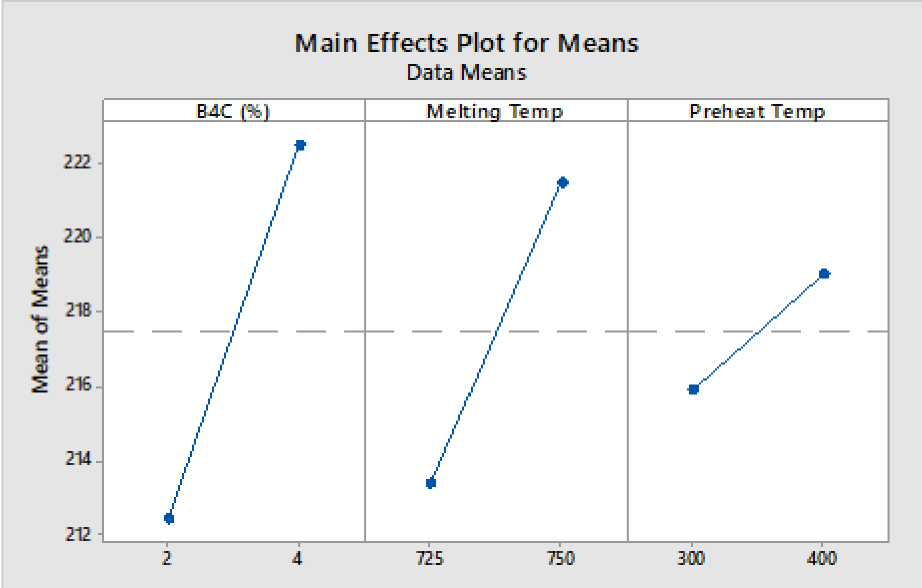

Figure 6. Main effects plot for mean of Tensile Test

Table 8. Response for mean ratio- larger is better

Level	B4C (%)	Melting Temperature (˚ C)	Preheat Temperature (˚ C)
1	212.4	213.4	215.9
2	222.5	221.5	219.0
Delta	10.1	8.1	3.1
Rank	1	2	3

Based on the analysis of these experimental results with the help of signal to noise ratio, the optimum condition resulting in Ultimate tensile strength are shown in the figure 5 & 6. The figure clearly indicate that the second level of addition of B4C percentage, melting temperature, pre heat temperature.

OPTIMUM LEVEL PROCESS PARAMETER:

From the above figure 5and 6 shows the optimum process parameter for UTS, is shown in the table 5.9

Table 9.Optimum level process parameter

RUN	A	B	C	SNRA (UTS)
4	4	750	300	46.7517

CONCLUSION

The Hybrid composite samples of LM13 as matrix, B_4C and Al_2O_3 particulates as reinforcements were fabricated using stir casting process. The experiments were conducted according to Taguchi design of experiments (L4 Orthogonal array) by considering three factors processing temperature, preheat temperature and percentage addition of B_4C (2% and 4%). The optimum conditions for ultimate tensile strength is identified and microstructure were investigated from the fabricated samples. The following are the conclusions drawn from the present study.

- From the results it is observed that the microstructure of the dual particulate reinforcements have shown an impact in hardness and tensile strength of composite combinations. The microstructure analysis shows fairly even distribution of particles and some agglomerations of B_4C and Al_2O_3.
- Optimum Ultimate tensile strength, obtained from the experiment, that the second level of processing temperature , pre heat temperature and percentage addition of B_4C are the optimum points, it was found that the fourth run is optimum.

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