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Investigation of Mechanical Properties of Aluminum 6063 with Boron Carbide and Fly Ash Composite Material

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Abstract: Inclination towards the light-weight material in manufacturing sector, the study of Aluminum based Boron carbide composite is becoming needful. Metal matrix Composites (MMC's) have induced strong interest in researchers for its use in aerospace and automotive sector due to its high strength to weight ratio and high resistance to temperature. In this paper an effort has been made to develop Aluminum 6063 based Boron Carbide and Fly Ash composite material using Sir Casting Technique. Experiments were conducted based on Taguchi's L9 orthogonal array (OA) with three process parameters viz. stirring speed, stirring time and % reinforcement of Boron Carbide with three levels each on Al 6063. The performance measures considered were tensile strength and hardness [1]. After that morphological analysis of structure under Scanning Electron Microscope (SEM) would be observed. Increased value of tensile strength (MPa) and hardness (HV) are 149 MPa and 55.46 HV respectively.

Keyword: Aluminum Matrix Composites, Boron Carbide, Fly Ash, Stir Casting.

I. INTRODUCTION

Scientists are continuously trying to improve various properties of engineering materials. This led to new category of materials called Composite Materials. They are composed of combination of distinctly different two or more micro or macro elements that vary in their composition and it is insoluble in each other [2]. The two main constituents of composite are reinforcement and matrix. The merit of composite is its good strength and stiffness, combined with low density when compared with other materials. Aluminum Metal Matrix Composite (AMMC) are always on the forefront of research [3]. Reinforcement usually adds rigidity and greatly impedes crack propagation. The role of the reinforcement in a composite material is basically one of increasing the mechanical properties of the tidy resin system. Boron Carbide, SiC and fly ash are some of the reinforcement materials used. Boron Carbide is the hardest materials known, ranking third behind diamond and cubic boron nitride. Its particles are characterized by its extreme hardness, high wear resistance and low density [4]. This ceramic is used in abrasive Grit Blasting Nozzles, used for shaping hard surfaces. Fly ash reinforcement with commercially aluminum improving their properties in strength and hardness and reduces the weight of the commercially aluminum, more over it is good radiation absorber [5].

Aim of the many researchers is to fabricate MMC to achieve better mechanical properties. Number of researchers have fabricated and tested Aluminum Alloy based MMC. In this respect Singla and Mediratta [6] and Rahman et al. [7] has developed AMMC (Aluminum Metal Matrix Composite) using silicon carbide as reinforcement. Mohanty et al. [8] and Ashok et al. [9] have improved mechanical properties like tensile strength, shear strength and toughness of AMMC by using Boron Carbide and Calcium Carbide. Xiu et al. [10] investigated XRD and SEM along with mechanical properties for 2024 Al (AMMC) with Boron Carbide. Parsad and Ramachandra [11] studied abrasive wear of fabricate LM6 Aluminum Alloy with 7.5% by weight fly ash as reinforcement. Researchers have mostly used stir casting method for fabrication of composite materials [12]. Moreover, it has many advantages over other composite fabrication methods Sijo and Jayadevan [13].

In present work an effort has been done to cast Aluminum 6063 with boron carbide and fly ash composite material using stir casting process. The parameters stirring timing, stirring speed and percentage of combination of boron carbide and fly ash as reinforcement has been optimized for mechanical properties using Taguchi method. For each parameter three levels have been considered.

II. TAGUCHI METHOD

Taguchi methods are statistical methods developed by Genichi Taguchi to enhance the quality of different products [14]. The main assurance of Taguchi's techniques is the use of parameter design to evaluated parameter settings for producing the best quality characteristic with least variation. Taguchi designs help in controlling all noise factors that cause inconsistency. During

experimentation, by manipulating noise factors variability is forced to arise and determine optimal factor settings to reduce variation from the noise factors. High output consistent can be achieved if process is designed with this goal. Taguchi's designs aimed to allow understanding of variation in comparison to the other experiment designs from the analysis of variance.
Taguchi method is based experiments to test the efficacy of response variable to control parameters (or independent variable) [15]. To define an orthogonal array, one must recognize first number of factors and levels for each such factors.

III. EXPERIMENTATION WORK

The experimentation has been carried out first is processing of MMCs by stir casting.

A. Raw material

The base material used is Aluminum Alloy 6063 of which chemical composition evaluated before performing experiment is shown in table 1.

Table 1.Composition of Aluminum Alloy 6063

Alloy type	Composition weight (%)								
	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn	Al
6063	0.017	0.048	0.17	0.59	0.002	0.72	0.016	0.002	98.40

Figure 1: Raw material Al6063

B. Reinforcement

For the processing of MMCs, Boron Carbide substantially enhances the hardness of metal matrix, strength and thermal stability etc. Boron Carbide is used as a reinforcement having mesh size 400.

C. Fly Ash Powder

To decrease the density, Fly ash is added during the stir casting composites process. Figure 2 shows Fly Ash powder used in experiment work. It is low-cost and low-density reinforcement exist in abundant as leftover [16].

D. Stirrer speed

It is one of the significant parameter in stir casting process for a vortex formation for the uniform dispersion of particles. Figure 3 shows stirrer setup used in experiment work. The function of a stirrer was to stir up liquid for speeding up reactions. Stirrer is preferred to homogenous mixing of liquid, oilment, solution, viscous material and solid- liquid. It has been equipped with voltmeter to control the rpm of stirring [17].

Figure 2: Fly Ash Powder

Figure 3: Stirrer Setup

E. Processing Steps of stir casting

The following are the steps of making composite using stir casting technique: -

1) Aluminum has been melted at 800°C for an hour in crucible
2) The Boron Carbide particle and Fly Ash are preheated at 900°C for an hour to make their surface oxidized and to removed impurities and water content
3) Furnace temperature is raised close to about 750°C for melting Aluminum and then cooling down to 600°C to keep the slurry in semi solid state
4) Further stirring is done for three times interval, i.e. 15 min, 20 min and 15 minutes at different speed rate of 1300rpm, 1400rpm and 1500 rpm which as regulated by a voltmeter.
5) During stirring, the preheated BC particles and Fly Ash particles are added.
6) The furnace temperature is controlled within limit and proper mixing is carried out further to produce consistent mixture.
7) After it, mixture had poured in to the die.
8) Three different flat plates of different composition of Boron carbide and Fly Ash were prepared. Weight percent of BC carbide is increased from 10% to 30% on the other hand weight percent of Fly Ash is reduced from 30% to 10%. Composition used for metal matrix composite is shown in table 2.

Table 2: Composition used for metal matrix composite

Name of sample	Aluminum (6063) (gm)	Boron carbide gm (%)	Fly Ash gm (%)	Total Weight (gm)
1.	500	50 (10%)	150(30%)	700
2.	500	100(20%)	100(20%)	700
3.	500	150 (30%)	50(10%)	700

Three flat plates of different composition are obtained after casting as shown below in Figure 4.5 sample 1 shows composite consist of Al 500gm, Boron Carbide 50gm and Fly ash 150gm. similarlySample2 shows composite consist of Al 500gm, Boron Carbide 100 gm and Fly ash 100gm and Sample 3 shows composite consist of Al 500gm, Boron Carbide 150 gm and Fly ash 50gm.

Sample 1 Sample 2 Sample 3

Figure 4: Sample of composite after casting

F. Tensile Testing

The prepared composite is evaluated by tensile testing, which has been performed on Universal Testing Machine. Model - UTN-100, R. No. 4587, Make Blue Star Ltd Capacity – 1000kN.

Sample 1

Sample 2

Sample 3

Figure 5: Tensile Specimen of Three Samples

G. Hardness Testing

Hardness test has been done at room temperature on Vicker hardness tester machine [18]. Load of 200 gm for 20 second have been applied for determining the hardness of the composites. Three samples of each composition have been tested and the mean result has been reported. All the tests had been conducted within 72 hours of casting so, as to standardize the effect of natural aging on the material, as the delay in sample preparation as inevitable.

In the present work, L9 orthogonal array had been taken. Therefore, nine experiments were conceded to study the optimization of process parameters. Reinforcement weight %, stirring time (minutes) and stirring speed (rpm) have been considered as process parameter. Accordingly, table 4 shows the process parameters along with their levels. In present work as per L9 orthogonal array nine different composites have been casted with respected parameters and levels shown in table 3. The consequence of parameters on responses (tensile strength and Vicker hardness) of the composites have been studied by means of analysis of variance (ANOVA).

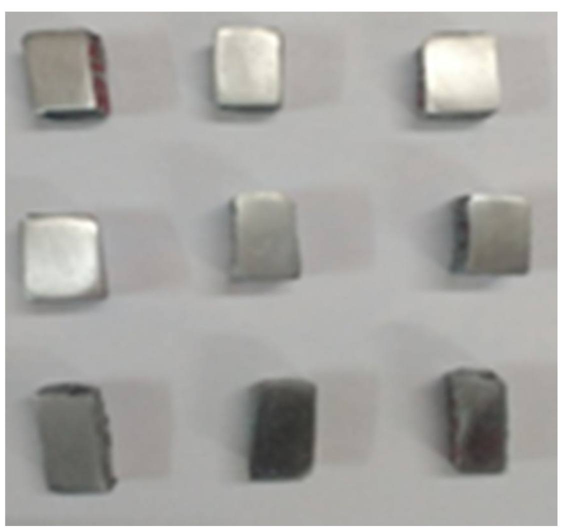

Figure 6: Samples from Testing Side

Table 3: Process parameters and their levels

S. No	Factor (Units)	Parameter Design	Level 1	Level 2	Level 3
1.	Reinforcement weight of BC (%)	A	10	20	30
2.	Stirring time (minutes)	B	15	20	25
3.	Stirring speed (rpm)	C	1300	1400	1500

IV. RESULTS AND DISCUSSION

The responses have been analyzed using standard commercial statistical software package MINITAB17. The result obtained after performing tensile strength and hardness testing are listed in table 4. The analysis of experimental results table 4 has been obtained [19].

A. Analysis Of Tensile Strength

The S/N ratio for level 1, 2 and 3 have been considering as average of S/N ratio for the experiment 1-3, 3-6, 6 -9. The plot shown in Figure 7 depicts effect of parameters on tensile strength of specimens in terms of mean S/N ratio. It is observed that individual parameter has dissimilar effect on tensile strength of composite specimens. Reinforcement weight (%) is foremost parameter which has most effect on the tensile strength. Table 5 illustrates that, when weight (%) of Boron Carbide is increased, the S/N ratio for the tensile strength increases from 141.0 (MPa) to 146.0 (MPa). However, it gets decreased for the level 2. From 20% to 30% of BC tensile strength again increases. It is also observed that as stirring time increases from 20 minutes to 25 minutes tensile strength also rises from 134.0 (MPa) to 146.0 (MPa). As the stirring speed increase till 1400 rpm tensile strength false and that rise at 1500 rpm. Composite casted with 1500rpm stirring speed have higher tensile strength than 1300rpm and 1400rpm.

Table 4:- Experimental Result

Stirring time (min)	Stirring Speed (rpm)	% Reinforced Weight of BC	Tensile strength (MPa)	Hardness (HV)
15	1300	10	140	55.46
15	1400	20	133	41.56
15	1500	30	148	46.25
20	1300	20	139	43.44
20	1400	30	149	47.72
20	1500	10	146	54.57
25	1300	30	141	49.93
25	1400	10	137	55.45
25	1500	20	130	42.65

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Table 5: - Response for signal to noise ratios (Larger is better)

Level	Stirring Time (min)	Stirring Speed (rpm)	% reinforcement Weight of BC
1	140.3	140.0	141.0
2	144.7	139.7	134.0
3	136.0	141.3	146.0
delta	8.7	1.7	12.0
Rank	2	3	1

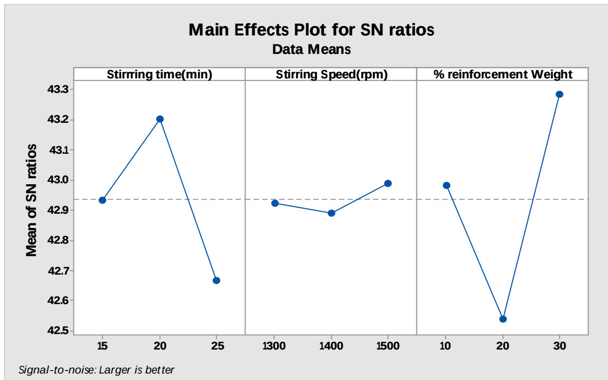

Figure 7: Main Effect Plot S/N ratio for Tensile strength

The main effect plot between tensile strength and stirring speed (rpm) a stirring speed is increased from 1400 rpm to 1500 rpm tensile strength is increased. The main effect plot between tensile strength and reinforcement weight percentage (%) of Boron Carbide show that a BC is increased from 20% to 30% tensile strength increased drastically. The optimal parameters of tensile strength are A2B3C3. According, to present investigation, 20 minutes of stirring time, 1500 rpm of stirring speed and 30 weight (%) reinforcement are optimum parameters for tensile strength, it can be inferred that the parameter reinforcement weight of Boron Carbide have the most significant effect on tensile strength.

B. Analysis Of Hardness

The S/N ratio for level 1, 2 and 3 has been considered by averaging S/N ratio for experiment 1-3, 3-6, 6 -9 respectively. The mean S/N ratio for hardness of composite as given in table 6 is used in graphical representation to represent the effect of individual parameter at each level on response. S/N ratio shows that individually parameter has different consequence on the hardness of composite.

Table 6: - Response for signal to noise ratios (Larger is better)

Level	Stirring Time (min)	Stirring Speed (rpm)	% reinforcement Weight of BC
1	47.76	49.61	55.16
2	48.58	48.24	42.55
3	49.34	47.82	47.97
Delta	1.59	1.79	12.61
Rank	3	2	1

It is clear from the Figure 8 that as, the weight (%) of Boron Carbide increases from 10% to 20% hardness decreases continuously but as reinforcement weight is further increases from 20% to 30% hardness starts increasing. The Hardness of composite have rised with increase in stirring time. The Figure 8 shows that at 25-minute stirring time maximum hardness is obtained a 55.450. As the stirring speed increase S/N ratio for hardness of composite decreased continuously. Composite contain 1500 rpm stirring speed have lower hardness mean of S /N ratio value of 32.5984.

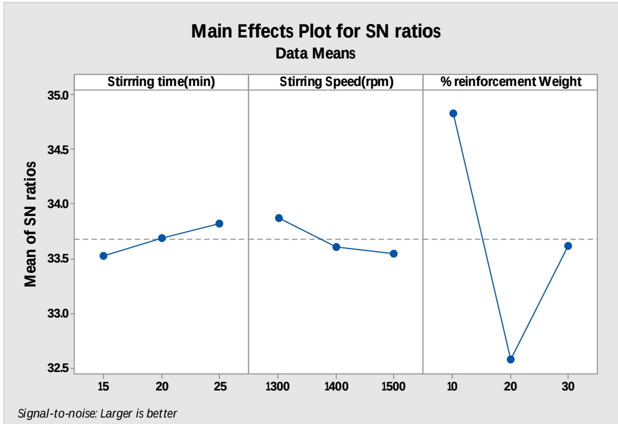

Figure 8: Main effect plot for Hardness

This show that the main effect plot between hardness and stirring time, a stirring time increase hardness also increase and reaches maximum value at 25 minutes [20]. The main effect plot between hardness and stirring peed (rpm) a stirring speed is increased from 1300 rpm to 1500 rpm hardness is decreased. The main effect plot between hardness and reinforcement weight percentage (%) of Boron Carbide shows that as BC is increased from 10% to 20% hardness decreased and from 20% to 30% of weight percentage (%) of Boron Carbide, Hardness increased [21]. The optimal parameters of hardness are **A3B1C1**. According, to present investigation, 25 minutes of stirring time, 1300 rpm of stirring speed and 10 weight (%)of reinforcement gives optimum result for hardness. It can be inferred that the parameter reinforcement weight of Boron Carbide has the most significant effect on hardness.

C. Morphological Analysis Using Scanning Electron Microscope (Sem)

The main principle of SEM is the bombarding of electrons and the secondary electrons which are reflected are formed as an image [22]. Figure 9 shows the microstructure of sample 1 at 1000× magnification. The general arrangement of aluminum molecules and reinforcements of the aluminum alloy are faintly visible in the image [23]. The darker particles are boron carbide and the lighter ones are fly Ash particles. Figure 10 shows the microstructure of sample 2 at 1000× magnification.

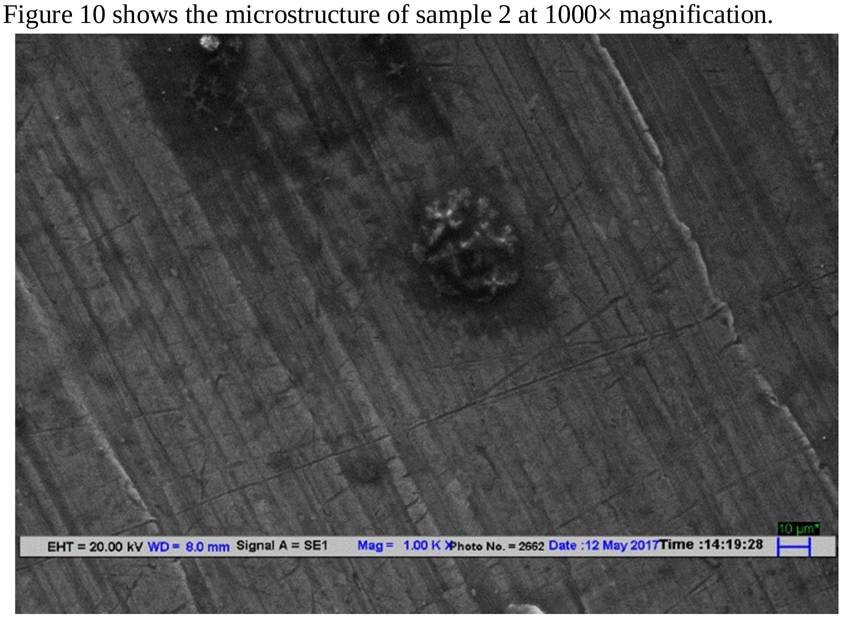

Figure 9: Sample 1 at 1000× magnification

It is observed that reinforcements of matrix are predominantly located in the center of the image and aluminum molecules at the outer region, suggesting that the reinforcements are unevenly distributed in matrix. The uneven distribution of matrix and reinforcement is attributed to poor stirring during the manufacturing of the sample. The specimen shows a ductile fracture appearance with shearing effects on the surface [24].

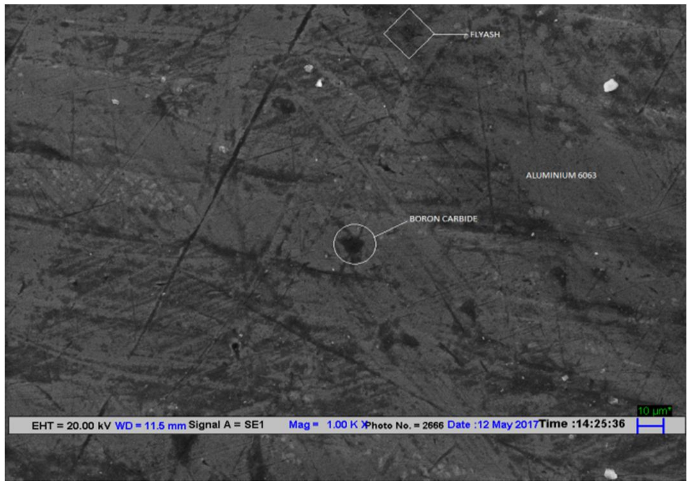

Figure 10: Sample 2 at 1000× magnification

Figure shows 11 the microstructure of sample 3 at 1000× magnification. The general arrangement of the composite is clearly visible in the image. Many micro cracks and porous sites are observed in the sample which is attributed to poor manufacturing of the composite.

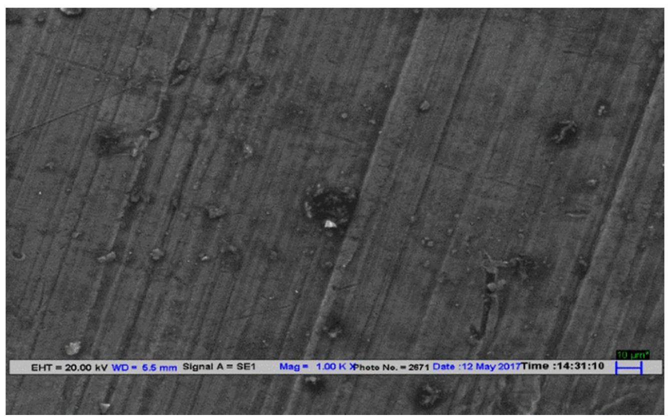

Figure 11: Sample 3 at 1000× magnification

V. CONCLUSIONS

Aluminum 6063 reinforced with Boron Carbide BC and Fly Ash at different levels and parameters have been successfully casted using stir casting method. The tensile strength improves with increase in weight (%) of the reinforcement of BC as well as with stirring speed but decrease with increase of stirring time [25]. It has been exposed that hardness of composite decreased when weight (%) of BC, stirring speed and stirring time is increased, due to better reinforcement and uniform distribution of particle in the matrix. SEM test reveals that there is uneven spreading of matrix and reinforcement is attributed to poor stirring during the manufacturing of the samples at low speed [26]. Increased value of tensile strength (MPa) and hardness (HV) are 149 (MPa) and 55.46 respectively. Taguchi method has predicted the optimum casting parameters successfully. This work can be further extended by varying geometric angle of stirring and by varying reinforcement mesh size. Application of heat treatment can be further study to improve the mechanical properties. Experimentation on turning and drilling operation with metal matrix composites can also be explored. More test such as wear, fatigue behavior, creep etc. should be carried out on the prepared composites.

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