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Evaluation of Mechanical Properties of Aluminium 6063 - Borosilicate Reinforced Metal Matrix Composite

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Abstract. The Aluminium 6063 have found wider applications in architectural fabrications, frames, pipe and tubing because of their intrinsic properties The Mechanical behavior of Aluminium alloy 6063 metal matrix composites (AMMC) reinforced with Borosilicate powder of 75 microns is investigated in this study. The Metal Matrix Composites (MMC's) were prepared using various percentages of borosilicate reinforcements of 0, 2.5, 5, 7.5 and 10 % by wt. The main aim of the research was to determine the impact of borosilicate powder (75 microns) on the mechanical behavior of Al 6063. Mechanical tests such as tensile test, Vickers micro hardness measurements and compression tests were performed on the produced composite samples to determine the influence of the powder in the Aluminium alloy. The test results of the reinforced samples were compared with non-reinforced samples. By comparing all the test values it is inferred that AA 6063 has better properties when reinforced with 7.5% of 75micron size borosilicate reinforcements.

INTRODUCTION

Composite materials are a combination of two distinctive phases namely matrix phase and a reinforcement phase and leads to distinctive characteristic features which are difficult to achieve from a normal base metal. They have wide applications ranging from aerospace, automotive industries to structural applications because of its multifarious properties such as high specific strength, wear resistance, strength-to-weight, which are very unique (1). Aluminium 6063, one of the most easily heat treatable and weld able alloy is majorly used in the structural engineering of automobiles parts, architectural frames and tubing in constructional engineering because of above mentioned reasons (2). In addition, the alloy has also other notable properties such as intensive wear and corrosive resistance, light weight, low density, high specific modulus properties. Further enhancement of the mechanical properties will lead to usage in many such applications (3). Many efforts are being continuously carried out to introduce hard ceramic particulates like SiC, Al_2O_3 and B_4C into aluminium based matrices (4). The need for development of metal matrix composites (MMCs) with low density and low cost reinforcements has always lead to the development and production of different composite materials with unique properties (5).

The addition of glass particulates as reinforcements has resulted in obtaining MMC's with improved properties (6). Borosilicate powders are a combination of boron trioxide and silica which is a variety of glass powder with very low coefficients of thermal expansion. The addition of borosilicate powder to Aluminium Alloys leads to increased mechanical properties (7). Many techniques are being developed to produce MMC's. Some of them are diffusion bonding, powder metallurgy, casting, pressure infiltration etc., but the simplest method with low cost of production is by stir casting method. Stir casting of Al 6063 is the mostly sought production method next to the process of extrusion. For the high volume of production, casting is best way to cut cost to one-tenth of the projected value (8).

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The tensile and fracture characteristics of as-cast and age-hardened AA 6063, silicon carbide particulate composites were produced using borax additive. Two step stir casting method was investigated where AA 6063composites having 3, 6, 9, and 12 volume percent of SiC were tested. The UTS of the samples increased as the % of SiC increased and at 12 % reinforcement there was no increase compared to 9 % reinforcement samples (9).

Squeeze casting process was used for the production of composites. Carbon fibers were added as reinforcements. From the mechanical test results, it is noted that the magnitude of micro hardness and ductility (3 point bend test) values were increasing where the impact strength decreased on carbon fiber addition (10).

MMC's with various amounts of Cu and TiO2 particles were reinforced in proper combinations using conventional stir casting technique. Marginal increase was observed in hardness values in the composites as the percentage of reinforcement increased. Tensile strength of the samples increased with increase of Cu where maximum strength of 119 MPa was obtained for composite with 15% Cu addition. Ductility decreased on further increase of reinforcements (11).

Substantial improvements were noted in the mechanical properties of the alloy when the effect of high carbon steel addition was investigated. UTS of 167 MPA were achieved for an addition of 10% high carbon steel addition by weight compared to a UTS of 160 MPa for the base alloy. Hardness increased with the increase of addition of reinforcement. Maximum hardness was also obtained for the 10 % wt reinforcement samples (12).

In this research, Aluminium alloy 6063 is introduced with borosilicate reinforcements. Borosilicates have low co efficient of thermal expansion which makes it more resistant to thermal shocks and has good resistance to abrasion. Tensile studies, Vickers's micro hardness measurements, compression tests were performed on samples to determine the influence of the borosilicate powder of 75µm with the Aluminium alloy.

MATERIALS AND METHODS

TABLE 1. Composition of AA 6063 by weight percentage

Composition	Percentage
Si	0.2 to 0.6
Fe	0.35
Cu	0.10
Mn	0.10
Mg	0.45 to 0.9
Cr	0.10
Zn	0.10
Ti	0.05 to 0.15
Remaining	Al

Commercially available Borosilicate powder of 75 microns is used in the study. The composition of the powder is given in Table 2. The samples of AA 6063 with reinforcements in required percentages of 0, 2.5, 5, 7.5 and 10 % by wt were produced. Metallic dies required for the fabrication of the samples were initially prepared using green sand moulding technique as per standards.

TABLE 2. Chemical Composition of Borosilicate Powder of 75 µm

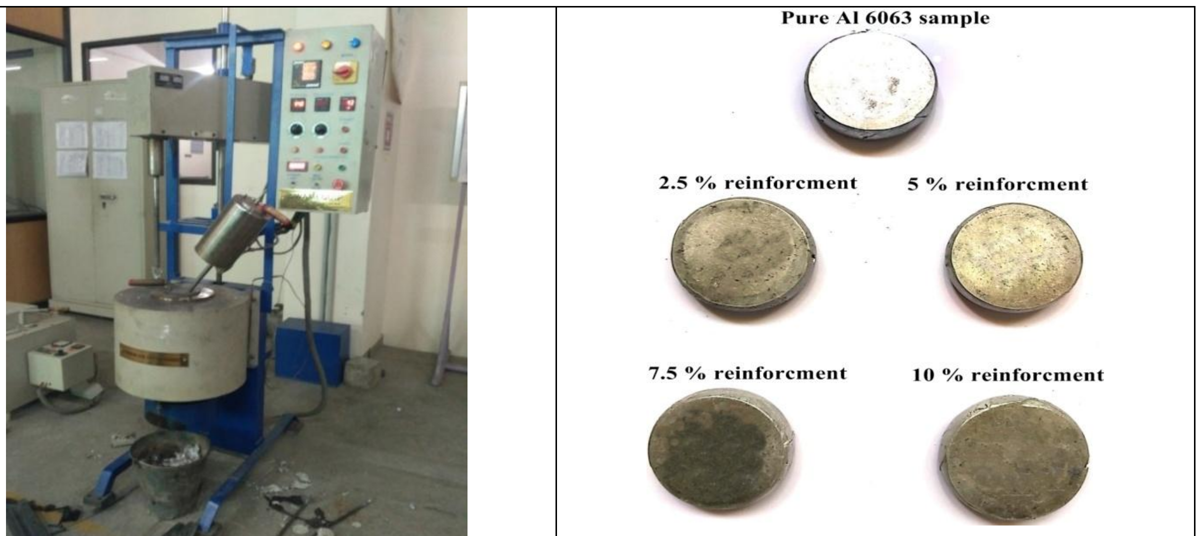
Composition	Percentage
SiO_2	80.6
B_2O_3	13
Na_2O	4
Al_2O_3	2.3

Composite production and characterization

The MMC's were produced using regular stir casting machine which has provision for mechanical stirrer setup as shown in the figure 1. Initially AA 6063 was melted to a temperature of 750oc. A mechanical stirrer was employed to stir the molten metal at 250 rpm. The borosilicate powder was preheated to 300oc and added to the molten metal according to the desired weight percentage and was stirred for a period of 3-4 minutes in order to achieve uniform distribution. Molten metal was poured into the metallic dies and were allowed to solidify.

Samples were made of borosilicate reinforcements of 0%, 2.5%, 5%, 7.5% and 10% compositions by weight in Aluminium 6063 alloy. The percentages were selected based on literature reviews. Finally the produced samples were machined and various mechanical tests were carried out to determine the percentage in which the desired mechanical properties were achieved.

Tensile tests were performed according to ASTM E 370- 14 standards (13) and the compression tests were conducted according to ASTM E9-16 standards. Microstructure analysis were performed through regular polishing process where the samples were polished using emery sheets of grit between 220 and 2000 and followed by disc polishing using Alumina. Keller's reagent was the etchant used for revealing the microstructure. De Winter optical microscope was used to analyze the samples. Micro hardness measurements were performed using Mitutoyo hardness tester.



(a) (b)

FIGURE 1. Showing (a) Stir casting set up used for producing composites (b) Sectioned as cast samples for metallurgical examinations

RESULTS AND DISCUSSION

Compression test

Table 3 gives the compressive stress values for respective composites. From the test results, it is observed that a maximum compressive stress value of 465.5 MPa is achieved at 7.5% of Borosilicate reinforcement**.** On increasing the reinforcement the property shows a decreasing trend.

TABLE 3. Compressive Strength values of composites with various levels of reinforcement

% Reinforcement	Compression strength values (MPa)
0	350.5
2.5	393.4
5.0	458.5
7.5	465.5
10	437.4

Tensile test

The tested samples of tensile test are shown in Fig 2. The fracture regions are clearly visible and can be seen that in all the samples that the plane of fracture is inclined in nature, owing to a ductile failure.

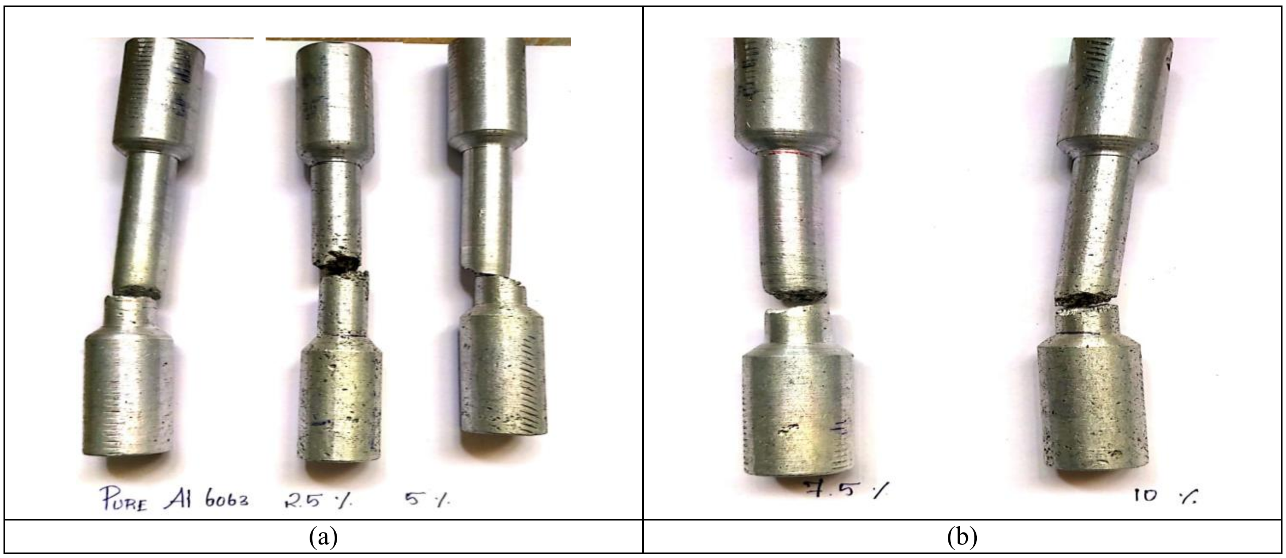


FIGURE 2. Showing (a) Tensile samples of pure Al, with 2.5% and 5 % reinforcements (b) Tested samples of 7.5 % and 10 % reinforcements respectively

The UTS and elongation values are given in Table 4. It is to be noted that as reinforcement increases UTS values increase and reaches maximum for 7.5% reinforcement and further drops at 10 % reinforcement. % of Elongation also decreases further. This might be due to the formation of adverse inter metallic phases in the grain boundary region as can be seen from Fig.3 (d).

TABLE 4. Ultimate tensile strength (UTS) of composites

% Reinforcement	UTS values in MPa	% Elongation
0	114	8
2.5	118	4
5.0	132	6
7.5	141	12
10	98	3.5

Hardness measurements

Table 4 shows the results of obtained Vickers Hardness value which are the average values of three readings taken for repeatability. A load was given 200gf was given according to ASTM standards. From the graph it is evident that the hardness value increases on increasing the volume of reinforcements. The property shows an increasing trend in hardness values proportionately with respect to increasing reinforcement values. This could be due to the increase in the Al_2O_3 in the borosilicate powder.

TABLE 5. Average Vicker's micro hardness values of reinforced composites

% Reinforcement	Observed Values In HV
0	94.1
2.5	94.7
5.0	98.5
7.5	99.8
10	108.4

Microstructure Analysis

The microstructures of the composites with 2.5, 5, 7.5 & 10% reinforcements are shown in Fig. 3(a-d) respectively. It is evident from the same that the reinforcements are almost homogenous in all samples produced between 2.5 and 7.5% reinforcements. There are no segregation effects and are distributed in an even manner.

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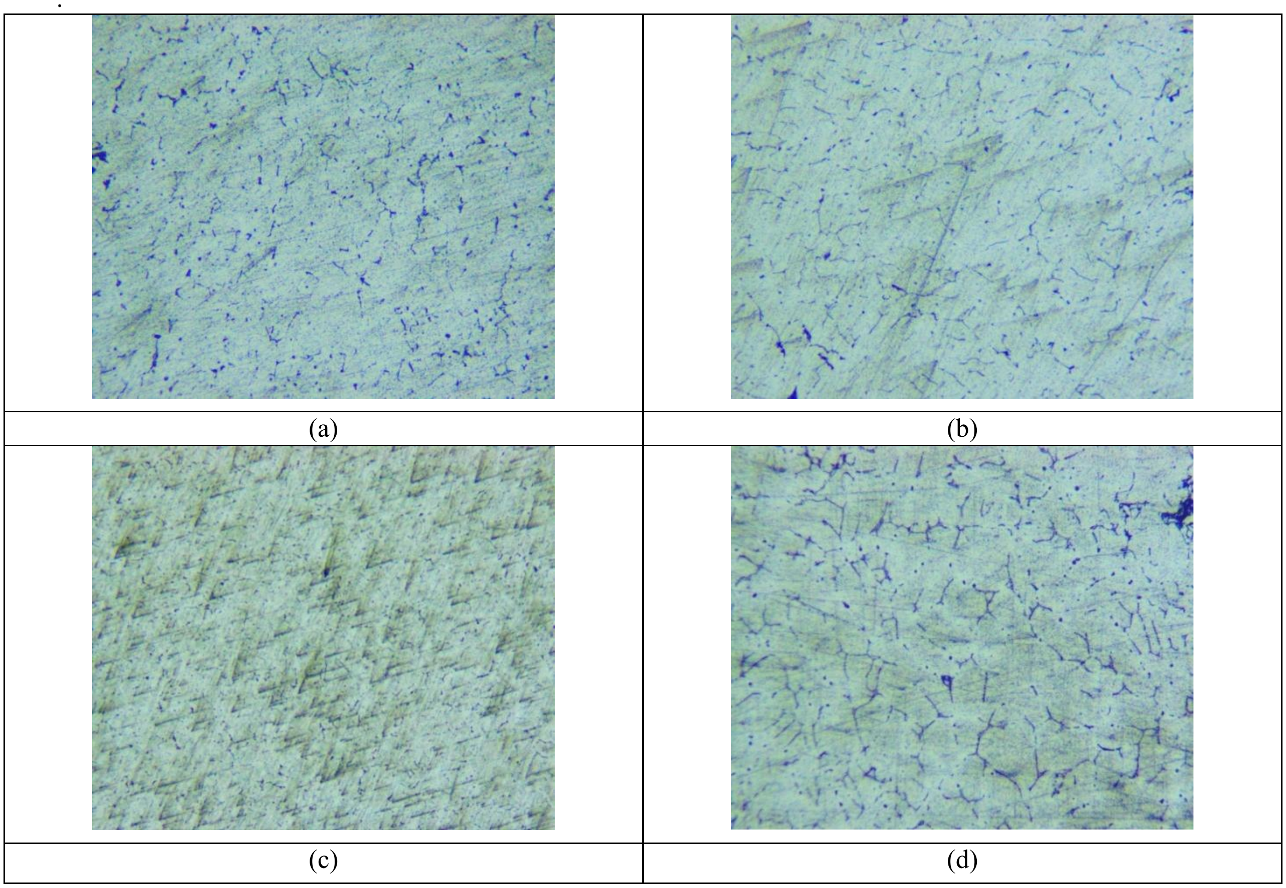

FIGURE 3. Microstructures of samples produced of (a) 2.5% (b) 5% (c) 7.5% (d) 10% borosilicate reinforcements

It can also be inferred from the microstructures that as the reinforcement increases, presence of secondary alloying elements decreases on the grain boundary region. This could be due to the fact that on solidification borosilicate extends its presence in grain boundary regions. As the reinforcement increases (from 7.5 to 10%) the segregation of secondary alloying elements increases thereby presenting a decreasing strength to the samples.

It can be noted from Fig. 3(c) that the presence of alloying elements are uniformly spread in nodular form, especially in relatively smaller sizes than compared to the 2.5% reinforcement samples. This is directly attributed to the commendable bonding property of borosilicate powder to Aluminium, thereby rendering a uniform distribution of Matrix. Similar trends were noted in 10% reinforcement samples. However referring to Fig 3(d) a micrograph taken near the fracture zone of a sample reveals that there is relatively high agglomeration of secondary alloying elements and that has had a detrimental effect on the mechanical performance of the sample. Segregation of elements always has an adverse effect

CONCLUSIONS

From the obtained test results it can be noted that the fabricated Metal Matrix Composite with borosilicate reinforcements have improved mechanical properties than the pure AA 6063. It is evident that borosilicate powder of 75µm acts as an effective reinforcement. Within the casted samples, it can be ascertained that 7.5% reinforcement of borosilicate powder produces good results and there is decline in the properties on further additions. The additions of Borosilicate powder lead to enhanced mechanical properties as compared to its base metal with less reinforcement and on further additions it weakens the composite due to formation of weaker inter metallic phases.

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