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Effect of bamboo char and boron carbide particles on mechanical characteristics of Aluminum 6061 hybrid composites

Chethan K N[1]*, Anand Pai[2], Padmaraj N H[2], Ashish Singhal[3], Shubham Sinha[3]
[1]Assistant Professor, Department of Aeronautical and Automobile Engineering Manipal Univeristy, India
[2]Assistant Professor-Senior Scale, Department of Aeronautical and Automobile Engineering Manipal Univeristy, India
[3]UG Student, Department of Aeronautical and Automobile Engineering Manipal Univeristy, India

E-mail: chethanknarayan@gmail.com

Abstract. In present day Metal matrix composites(MMCs) are widely used in automotive and aeronautical domains due their superior mechanical properties compared to base metal. The current study evaluates the potentiality of conventionally prepared bamboo char particulates along with commercial grade B_4C particulates as micro fillers dispersed into the Aluminium 6061 matrix. Three different compositions are fabricated through mechanical stir casting. Density measurements, tensile tests and Brinell hardness tests were carried out along with SEM fractographical analyses. It has been observed that addition of B_4C and bamboo char led to an increase the hardness and tensile properties of aluminium 6061. But higher content of B_4C caused a quasi-brittle mode of fracture.

1. Introduction.

Aluminium was first produced on a lab-scale in1825 by reducing aluminium chloride.[1]Since the 1960s metals have been strengthened and stiffened by the incorporation of reinforcements in the form of continuous fibres, particles, or whiskers. Adding particles to metal was called dispersion strengthening; this family of engineering materials is now called metal matrix composite (MMCs). There was a pervasive trend in the 1970s and 1980s to reduce the weight of automobiles, and use of aluminium in automobiles increased many times in this same period. If aluminium could be made to have the strength and toughness of steel and the ferrous metals most automotive parts would be made from such material.[2] This is one of goal of aluminium metal matrix composites. Aluminum is the most preferred base metal for the matrix of its light weight. The Al-MMC's shows better mechanical properties such as high stiffness to density ratio, better elevated temperature and improved wear resistance. [3]

* Corresponding author: chethanknarayan@gmail.com

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2. Materials and Methods

The present study involves the fabrication of conventionally prepared bamboo char particulates along with commercial grade B_4C particulates as micro fillers dispersed into the Aluminum 6061 matrix through mechanical stir casting method. Three different samples are fabricated varying in weight composition of B_4C particulates and bamboo char particles. Al 6061 chemical composition is given in Table 1.[4]The alloying elements silicon and magnesium contribute to high strength and hardness of the material. Al6061 being easily cast-able, preheating was not required before casting process or testing. [5]Bamboo charcoal has enormous surface area to mass ratio (1 gm of charcoal ~ surface area of 600 m^2) and the ability to attract and adsorb wide range of chemicals, minerals, radio waves and other harmful substances. Char is a light, black, porous material resembling coal, composed of about 80% carbon. Good-quality char with the following characteristics can be produced from bamboo as shown in Table 2[6]. Charcoal made from bamboo has good properties, similar to wood and other ligno-cellulosic material in terms of high carbon content and calorific value. The Calorific value of bamboo charcoal is 6,900–7,000 kcal/kg. Boron carbide is popular as a robust ceramic material having high hardness compared to most of the materials. Boron carbide when used as a reinforcement helps increase the hardness of the composites and tends to counter the softness induced by bamboo char. It is insoluble in water with a melting point of 2763°C. [7]

Table 1. Composition of Aluminium 6061[4]

Chemical Composition	Si	Mg	Cu	Cr	Fe	Ti	Zn	Mn	Al
%	0.4-0.8	0.8-1.2	0.15-0.4	0.04-0.35	0.70 Max	0.15 Max	0.25 Max	0.15 Max	Balance

Table 2. Composition of Bamboo Charcoal [6]

Composition	Carbon	Ash	Moisture	Others
%	80-85%	4.5- 6.5%	6-9%	2-3%

2.1 *Preparation of reinforcement phases*

Industrial graded boron carbide was used as micro filler (~60µm). Boron carbide (with stiffness value of 445 GPa and 3700 HV hardness) has been popularly used to reinforce aluminium[8][2][9][10]. . Latest research has seen application of naturally available materials like egg shell, fly ash particles rich in carbon content[11][12][13]. Hence charcoal derived from bamboo was selected as the secondary reinforcement. For the preparation of charcoal, 5 to 6-year-old bamboo tree was selected. The stems were severed into uniform pieces of 25cm x 10cm x 10cm. The samples were dried under sun light for 7 to 10 days, followed by heating in muffle furnace for 15 min at a temperature of 700^{0}C. Before placing the samples within the muffle furnace, the dried samples were covered with aluminium foil with minute perforations on the outer layer to avoid the bursting of trapped air which normally expands after heating. The charcoal is crushed into small particles size and it is subjected to electron dispersion spectroscopy to know the carbon content. The carbon content was found to be 43.23% of weight for 15 min dry sample after the EDS analysis and Table 3 shows the composition of different elements in bamboo char.

Table 3. Result of elemental analysis on EDS for Bamboo char.

Element	Carbon	Oxygen	Aluminum	Silicon	Potassium
Weight (%)	43.23	35.06	0.31	17.58	3.82
Atomic (%)	55.15	33.59	0.18	9.59	1.50

2.2 Stir casting of Al 6061 reinforced with Bamboo charcoal- Boron Carbide particles

Industrial graded commercially available aluminium 6061 bars (1 inch. Diameter) were used. These bars are severed into the required size of crucible and melted at a temperature of 800^0C[14]. After it reaches to molten state nitrogen gas is used for degasification from the molten liquid[15]. Mean time the moulds are prepared. The mould were preheated in furnace at 550^0C for 3 hours to avoid shrinkage defects during casting process[16]. The reinforcement is added into the molten aluminium periodically and stirrer is used to create vortex during mixing reinforcements. After complete mixing of reinforcements the samples were heated for around one hour in 800^0C before pouring into the moulds.

Table 4. Details of the different composites fabricated using bamboo char and boron carbide

Composition designation	Bamboo char (wt.%)	Boron carbide (wt.%)	Al6061 (wt.%)
S-I	1	1	98
S-II	2	2	96
S-III	3	3	94

After pouring into moulds it is left for 12 hours for cooling. This as-cast is subjected to homogenisation at 570^0C for 8 hours and normal cooling outside the furnace for uniform grain size within the composites. Three compositions were fabricated, details have been shown in Table 4.

2.3 Mechanical characterization

To analyze the effect of the increasing filler content on mechanical response of the composites, the density measurements, tensile tests in adherence to ASTM-E8 standard[17], and hardness tests were carried out using Brinell hardness test (500 kgf load with 10 mm ball indenter). SEM fractography with EDS was taken up to understand the mode of failure of each composition.

3. Results and Discussion

3.1. Mechanical characterization

The mechanical response of the different compositions has been displayed in Figure 1. On increasing the content of the micro-fillers i.e. B_4C and bamboo char particulates, the hardness, density and tensile strength were found to increase monotonically. But the tensile elongation was found to decrease on increase of the micro-filler content. B_4C being a ceramic is naturally hard and on solidification of the stir-cast sample, micro-sized particles get distributed along the grain boundaries of the base Al6061 alloy[15][18]. The strengthening mechanism can be characterized from micro-mechanics of deformation comprising of higherwork hardening rates as well as modification in the grain size and dislocation density. Involvement of fine-sized particles can cause dislocation strengthening due to difference in coefficient of thermal expansion of reinforcement particles and matrix, dispersion strengthening due to resistance offered by closely spaced hard particles to the progress of dislocation and to some extent work hardening due to strain misfit between the reinforcement particles and the plastic matrix material i.e. Al6061[10]. The presence of bamboo char particulates as a dry lubricant (expected function similar to graphite[19] caused some slackening in the improvement of the mechanical properties for higher reinforcement content. Figure 2 for EDS analysis of S-III composition showed the presence of the elements- Boron (present in B_4C), C (present in B_4C, bamboo char), O (present in bamboo char), Mg, Si and Al (present in Al6061 alloy). This confirmed that the micro-fillers B_4C and bamboo char have been dispersed throughout the Al6061 matrix.

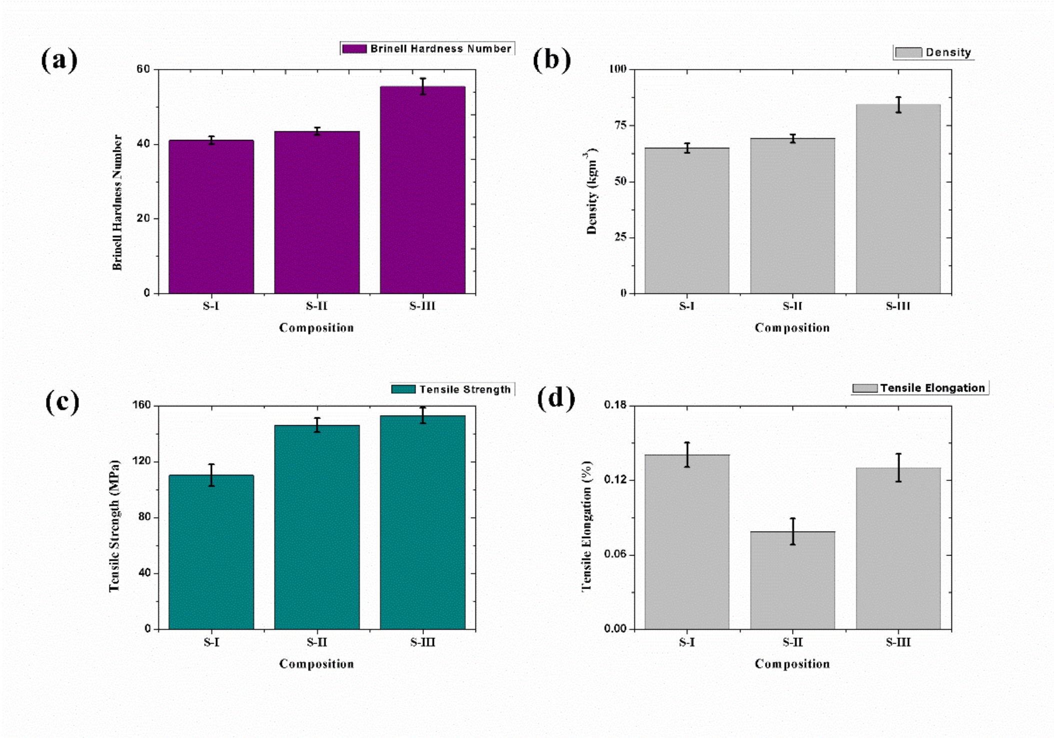

Figure 1 Mechanical response of the different compositions (a) Brinell Hardness (b) Density (c) Tensile Strength (d) Tensile Elongation

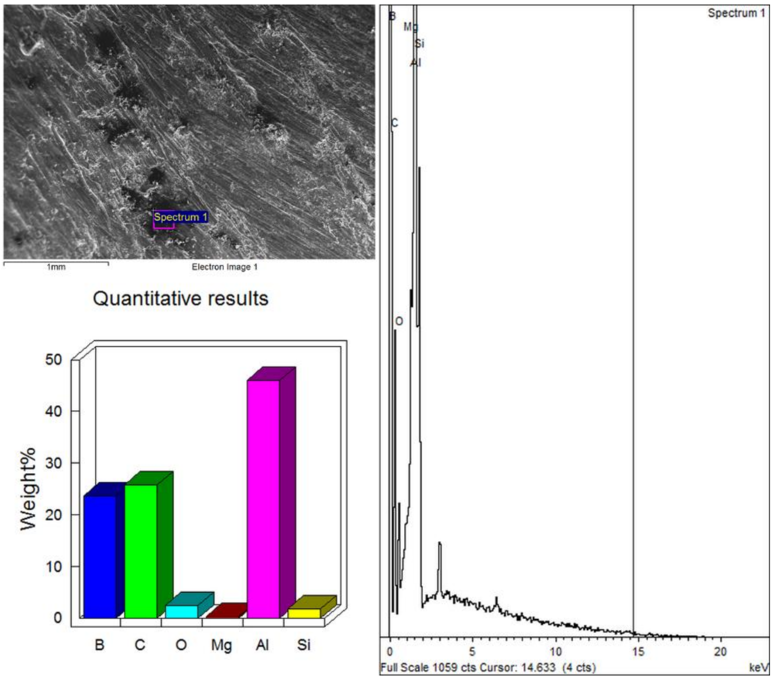

Figure2SEM-EDS Analysis for S-III Composition

3.2. SEM Fractographical Analysis

The ductile or brittle behavior of the fabricated compositions were determined by SEM Fractography. A material is said to have failed by ductile fracture, when the deformation is visible to naked eye i.e. through yielding or necking. On the other hand, a brittle failure occurs suddenly and without negligible deformation. Since Aluminum has F.C.C. structure, ductile fracture could be expected for Al6061 which majorly contains Aluminum. The addition of B_4C and bamboo char micro-fillers showed an enhancement in the mechanical properties, but since the tensile elongation was found to decrease, fractographical analysis was essential to categorize the ductile-brittle behavior. Figure 2 displays the fractographs of the three compositions. S-I composition showed rupture zones with fine dimples suggesting a near-ductile fracture. The fracture surfaces of S-II and S-III compositions showed transgranular cracks but no signs of cleavage fracture which indicated a quasi-brittle mode of fracture. Hence higher content of B_4C and bamboo char particulates imparts greater brittleness to the Al6061 hybrid composites.

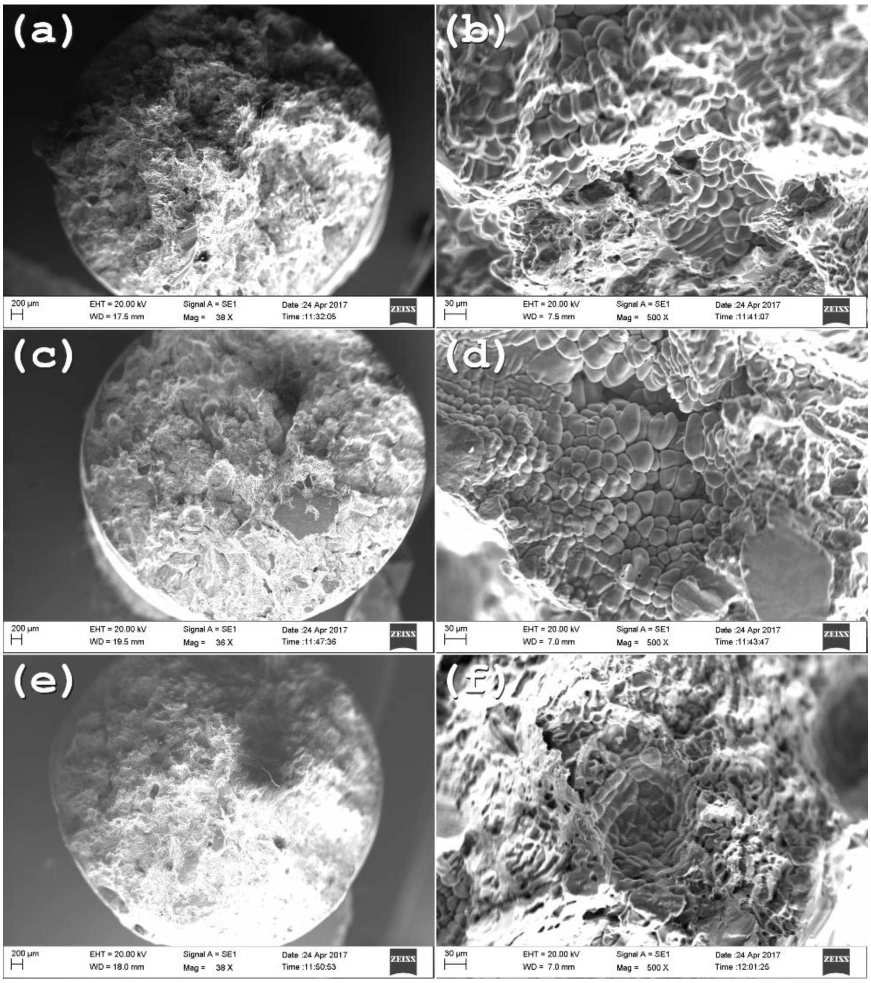

Figure3.SEM Fractographs (a)& (b) S-I ,(c)& (d) S-II, (e)& (f) S-III

4. Conclusions

The fabrication of three different compositions of Al6061 hybrid composites reinforced with bamboo char and boron carbide micro-fillers was completed. From the analysis of mechanical behavior and SEM Fractography, it could be summarized that as the weight fraction of the bamboo char and boron carbide was increased, the tensile strength, hardness and density increased while the tensile elongation was found to decrease. There was a deterioration in the ductile nature of the hybrid composites towards quasi-brittleness fracture at higher weight fractions of boron carbide and bamboo char micro-fillers.

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