FABRICATION AND STUDY OF MECHANICAL PROPERTIES OF Al 6061-B_4C METAL MATRIX COMPOSITES

[1] Dr. Ghanaraja S, [2]Sukruth Sagar B P, [3]Kiranakumara K M, [4]Madhu G

[1] Professor, [2]Assistant Professor, Dept. of Mechanical Engineering, PESCE, Mandya,
[3]Assistant System Engineer, TCS, Chennai, [4]Trainee, ABC for Technology Training, Bengaluru
[1]ghanaraja08@gmail.com, [2]sukruthsagar1991@gmail.com, [3]kiranmanju0808@gmail.com, [4]madhuinjc@gmail.com

***Abstract*—This work focuses on influence of reinforcements on microstructure and mechanical properties when compared to the base material (Al 6061). Boron carbide (B_4C) was the reinforcement by varying the weight percentage as 0%, 2%, 4% and 6% using stir casting technique. Tensile and Hardness tests were carried out to evaluate the mechanical properties. XRD studies show the chemical composition of Boron carbide (B_4C) particles and micro structural images reveal uniform distribution of reinforcement in the matrix. It is concluded that tensile strength and hardness of the cast composites increases with increase in the B_4C particle wt.% in the cast composites.**

Index Terms— ***Al6061, Boron carbide, Stir Casting, XRD, SEM, Mechanical properties.***

I. INTRODUCTION

Many of the applications in the world today require materials with unusual combination of properties that cannot be met by the conventional metal alloys, ceramics or polymers. This is especially true for materials that are needed for aerospace and transportation applications. With a wide choice of materials which are available for engineers, they are posed with a big challenge of selecting the appropriate material and manufacturing process for their applications. Metal Matrix Composites (MMCs) have the potential to replace conventional materials in many engineering applications such as aerospace, automobile and marine industries as structural engineering materials. Light metals such as aluminium, magnesium, copper and their alloys are the most widely used matrix materials in the production of MMCs. Among the various MMCs, Aluminium based alloys are widely utilized in the production of MMCs and have reached the industrial production stage due to their superior properties.

Aluminium Matrix Composites (AMCs) are the competent material in the industrial world. Aluminium matrix being lighter can be strengthened by reinforcing less dense, hard ceramic particles such as SiC, Al_2O_3, B_4C, etc. which shows improvements in properties. Based on the type of reinforcement, size and morphology, the AMCs are fabricated by different methods such as Stir Casting, Squeeze Casting, Spray Deposition, Liquid Infiltration and Powder Metallurgy, out of which stir casting has an attractive economic aspect combined with wide selection of materials and processing conditions. Aluminium metal matrix reinforced with Boron Carbide (B_4C) is a novel composite, which is used in automotive industries (ex. Brake pads and brake rotor) due to high wear resistance, high strength to weight ratio, elevated temperature, toughness and high stiffness. B_4C is also used in the nuclear industry as radioactivity containment vessels and control rod fixture, since B_4C is a neutron absorber, also high-temperature thermoelectricity conversion and ballistic protections.

II. EXPERIMENTAL PROCEDURE

A. Selection of matrix alloy

Al 6061 is one of the most widely used alloy in the 6000 series. 6061 is a precipitation-hardened aluminum alloy, containing magnesium and silicon as its major alloying elements. Originally called "Alloy 61S", it was developed in 1935. It has good mechanical properties, exhibits good weldability, and is very commonly extruded (second in popularity only to 6063). This standard structural alloy, one of the most versatile of the heat-treatable alloys, is popular for medium to high strength requirements and has good toughness characteristics. Applications range from transportation components to machinery and equipment applications to recreation products and consumer durables. Alloy 6061 has excellent corrosion resistance to atmospheric conditions and good corrosion resistance to sea water. This alloy also offers good finishing characteristics and responds well to anodizing.

Table 1 Physical properties of Al 6061

Properties	Values
Elastic Modulus (GPa)	68.8
Density (g/cc)	2.70
Poisson’s ratio	0.33
Tensile strength (MPa)	120
Melting temperature	585°C

B. Selection of reinforcement

Boron carbide (B_4C) is an extremely hard boron-carbon ceramic. It is an extremely hard, synthetically produced material that is used in abrasive and wear-resistant products, in lightweight composite materials, and in control rods for nuclear power generation. Plants use trace amounts of the boron, as well as a few other chemical elements, as micronutrients. B_4C is a robust material having excellent chemical and thermal stability, high hardness and low density. B_4C is having hardness of 3800 HV considered as third hardest material next to diamond and C-boron nitride with good impact and wear resistance, low specific density (2.52 g/cc), low thermal conductivity (35 W/mK) and high stiffness (445 GPa) which makes it to find applications like ballistic armor, as abrasive, nozzles.

Table 2 Properties of B_4C powder

Properties	Boron carbide
Molar mass	55.255 g/mol
Melting Point	2763°C
Boiling Point	3500°C
Crystal Structure	Rhombohedral
Flash point	Non-Flammable
Appearance	Black powder
Solubility in water	Insoluble

C. Stir-casting and its experimental set-up

A batch type stir-casting furnace cum pouring set-up has been used for solidification processing of Al 6061 based composites. The photograph of the experimental set-up is as shown in Fig.1

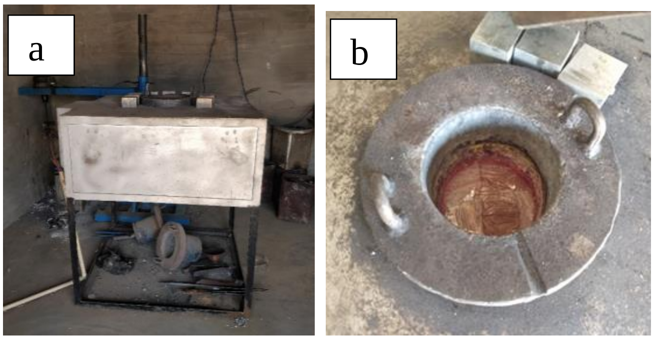

Fig.1(a) Stir casting apparatus (b) Clay graphite crucible

D. Solidification Processing of Composites

In this study, Al 6061 was used as the matrix material and it was alloyed with 3 wt.% of magnesium to impart wetting to the boron carbide particles, added as reinforcements in amounts of 0, 2, 4 and 6 wt.%.

About 1800 g of commercially pure Al 6061 was melted and superheated to a desired processing temperature in a clay-graphite crucible inside the muffle furnace. Before any addition, the surface of the melt was cleaned by skimming. After that base aluminium pieces were added into the crucible for heating. The crucible was covered by flux and degassing agents to improve the quality of aluminium composite casting. The weighed amount of powder was added into molten Al 6061 at a processing temperature of 900°C. The boron carbide particles were pre-heated to a temperature of 500°C before adding to the melt to remove the moisture content in the powder. A coated curved radial blade stirrer was used to disperse the boron carbide particles in the melt. The speed of the stirrer was kept constant at 500 rpm. A non-contact type speed sensor was used to measure the stirring speed. The temperature of the melt was measured by using a digital temperature indicator connected to a chromel-alumel thermocouple.

During stirring, the temperature of the slurry was maintained within 10°C of the processing temperature. A magnesium lump of 3 wt.% was wrapped by aluminium foil and plunged into the melt-particle slurry after the addition of boron carbide particles. When the desired time of the stirring elapsed (10-15 minutes), reduce the stirrer speed. After completion of processing steps, the crucible is taken out from the furnace to pour the melt-particle slurry into split type graphite coated and preheated permanent steel one mould of size four cavities of 24 mm and length of 190 mm. Another mould of size 20 mm and length of 200 mm cavities provided in the mould is as shown in Figure 3.3. Mould is kept right below the graphite stopper, the mould containing that cast ingot is allow to cool in air, in order to achieve better uniformity in distribution of the particles throughout the casting, the Pieces of Al 6061 prepared for casting and cast composite is as shown in Fig.2(c) & (d). respectively. No degassing practice of the melt or the slurry was carried out at any stage of processing.

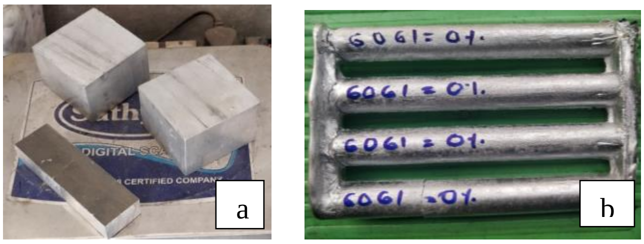

Fig.2 (a) Aluminium 6061 ingots and (b) Cast Composite

The composite has been designated on the basis of its constituents and the first letter A indicates the base metal of Al 6061 and the next letter M indicates the alloying element of magnesium, which was kept at 3 wt.%. AM is followed by a letter P indicates the boron carbide powder followed by the number indicating the wt.% of boron carbide powder added. Different composites synthesized by solidification processing and their designations are given as AM for unreinforced cast composite, AMP2 for composite with reinforcement of 2 wt.% of B_4C particles. Similarly, AMP4 for 4 wt.% of B_4C and AMP6 for 6 wt.% of B_4C particles as reinforcement.

Al6061-Mg alloy has also been synthesized using a vertical electric resistance furnace as shown in Fig.1(a)&(b). Pieces of commercially pure Al6061 have been heated in a graphite crucible to attain molten state. The melt is then cleaned by taking out the dross collected on the melt surface with a perforated flat coated spoon. When the temperature of the melt reaches 900°C, the magnesium pieces wrapped by aluminium foil were into the molten Al 6061. The melt was stirred to make the alloy homogenous before it was cast into preheated mould.

III. RESULTS AND DISCUSSION

A. Scanning Electron Microscope (SEM)

Micro structural characterization of studies was conducted on unreinforced and reinforced samples. This is accomplished by using scanning electron microscope. The composite samples were metallographic alloy polished prior to examination. Characterization is done in etched condition. The SEM micrographs of composite were obtained using the scanning electron microscope. Samples are mounted on the aluminum holder stubs using a double sticky carbon Tape and coated with Au/Pd in a BIORAD Polaron E5400 High resolution sputter coater and examined in a ZEISS Scanning electron microscope at 15 kV.

Microphotographs clearly revealed the presence of B_4C particles in the Al matrix composite. However, the distribution of the particles in matrix is homogeneous, a rare clustering of the particles is seen. It is clear that two step addition has resulted in fairly homogeneous distribution of B_4C reinforcing particles in the Al matrix. Also, no clustering or agglomerations of the particles were seen throughout the specimen which could be due to better stirring action achieved via two step addition along with magnesium pieces.

Fig.3 shows SEM microphotographs composites of Al 6061 reinforced with B_4C particles prepared with two step addition of preheated mixture.

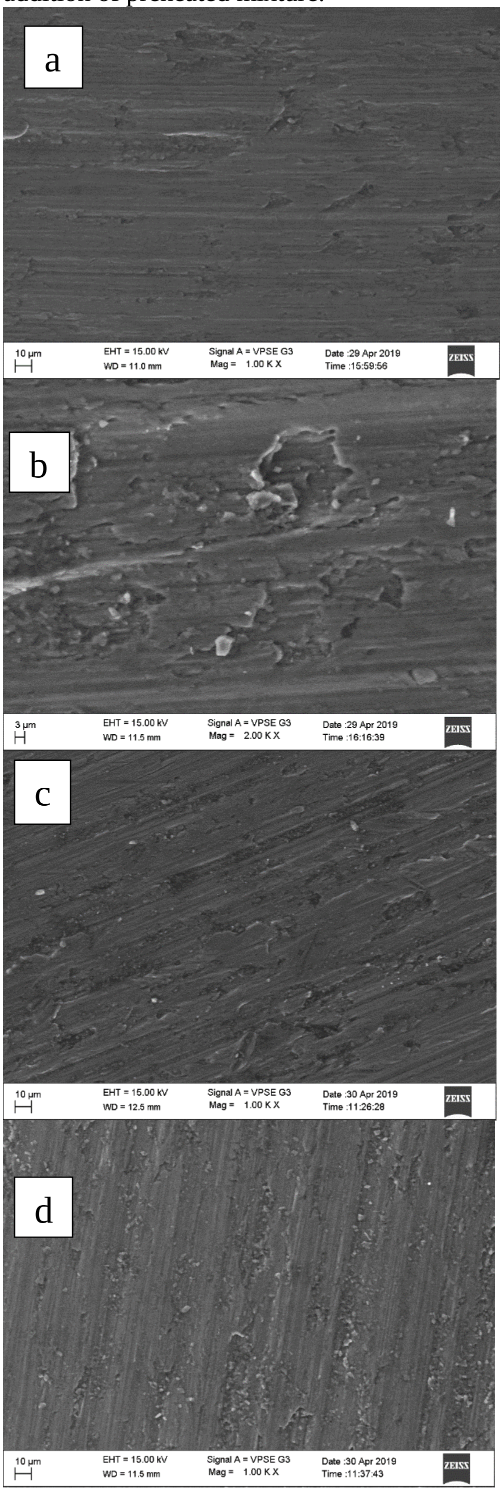

Fig.3 SEM micrographs of different composites developed by increasing amounts of Boron Carbide (B4C) powder designated as (a) AM (b) AMP2 (c) AMP4 and (d) AMP6

B. Mechanical properties of Al 6061 (Mg)-B4C

a) Brinell Hardness

Brinell hardness has been measured for reinforced alloy and hybrid composites developed using Al 6061 3 wt.% of Mg as the matrix material (alloy) with the B4C particles added as reinforcements in amount of 0, 2, 4 and 6 wt.% respectively.

The Brinell hardness has been measured for unreinforced alloy and cast composites with 5 mm hardened steel ball indenter of 100 Kg load was applied for 30 seconds on a sample and then the diameter of indentation was measured with help of tool maker's microscope.

For each indentation, an average of two diameters measured perpendicular to each other was used to find the corresponding hardness. On each sample at-least eight indentations for hardness measurement were made at different locations and the average of these readings is reported as the average hardness value of the material.

Addition of reinforcement particles in the matrix increases the surface area of the reinforcement and the matrix grain sizes are reduced. The presence of such hard surface area of particles offers more resistance to plastic deformation which leads to increase in the hardness of composites. It is reported that the presence of hard ceramic phase in the soft ductile matrix reduces the ductility of composites due to reduction of ductile metal content which significantly increases the hardness value.

The average hardness of unreinforced alloy and cast composites is given in Table 3. The results of Brinell hardness test have shown that the composites developed by addition of 6 wt.% of B_4C have higher hardness of 64.9576 BHN than the hybrid composite developed by addition of 0, 2 and 4 wt.% of B4C powder. However, the alloy without any reinforcement has the lowest hardness of 47.6158 BHN. The Brinell hardness test concluded that the hardness of the hybrid cast composites increases with increasing addition of B_4C particles compared to base alloy. The variation of Brinell hardness number of cast composites with different wt.% reinforcement is given in Fig.4 and Fig.5.

Hardness test results

Table 3 Average hardness of reinforced alloy cast composite

Designation of composites/Alloy	BHN
AM	47.6158
AMP2	52.1717
AMP4	59.0012
AMP6	64.9576

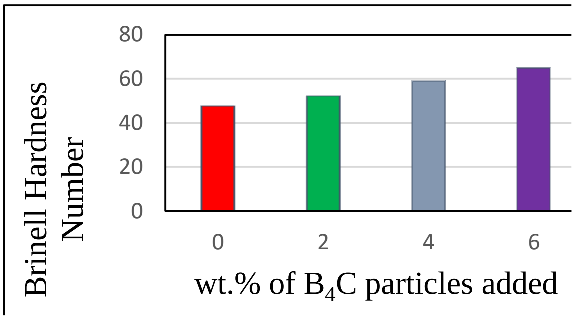

Fig.4 Variation of average hardness of Al 6061 alloy and cast composites

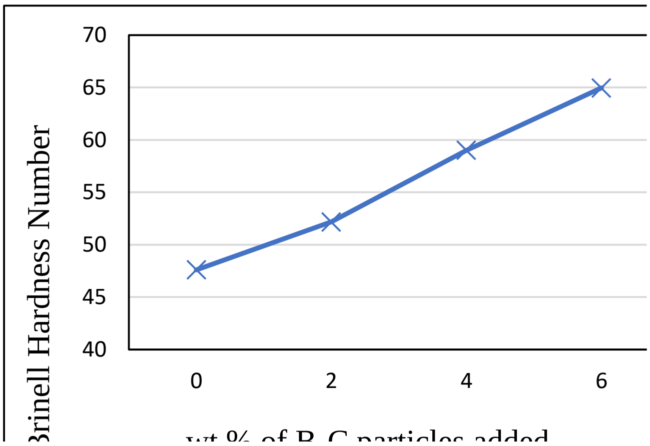

Fig.5 Variation of average hardness of Al 6061 alloy and cast composites

b) Tensile Properties in Cast Composites

Stir casting aluminium matrix composites have been synthesized by the addition of B_4C powder into aluminium melt followed by addition 3 wt.% of magnesium to promote wetting. The tensile properties of the alloy and hybrid composites developed by addition of 0, 2, 4 and 6 wt.% of B_4C to Al 6061-Mg alloys are given in Table 4.

It can be inferred that B_4C particles are very effective in improving the tensile strength of composites from 174.9 MPa to 287.6 MPa. It may be due to the strengthening mechanism by load transfer of the reinforcement. The addition of B_4C particles in the matrix induces much strength to matrix alloy by offering more resistance to tensile stresses. It is well known that the thermal expansion coefficient of aluminium alloy is 23×10-6/oC and for B_4C particle is 5×10-6/oC. The thermal mismatch between matrix and the reinforcement causes higher dislocation density in the matrix and load bearing capacity of the hard particles which subsequently increases the composites strength.

Composite AMP6 synthesized by addition of 6 wt.% of Boron carbide powder shows the highest yield strength of 204.6 MPa, tensile strength of 287.6 MPa and elongation of 15.38% compared to all other composites is as shown if fig. 6, 7 and 8 respectively. Composites synthesized by addition of 2, 4 and 6 wt.% of B_4C powder shows increase in yield strength, tensile strength and percentage elongation compared to the base alloy. The increase in yield strength and tensile strength may be due to the variables, such as distribution of particle in the matrix, mechanical properties of the matrix, bonding between the matrix and reinforcement and also due to the presence of hard boron carbide particles which impart strength to the Al 6061 matrix. The increase in ductility is probably may be uniform distribution of B_4C particles, dynamic process of recovery, re-crystallization and it is expected due to closed packing of the reinforcement.

Generally, in MMCs, loss of strength and ductility is caused by debonding of the particles due to shear stress generated by difference in flow behaviour across the interface between the matrix and the particle. The magnitude of shear stress depends on size of particle. The larger is the particle, the larger is the shear stress and the debonding takes place at lower strain.

Table 4 Tensile properties of alloy and Al 6061-B_4C composites

Designation of Alloy /composites	Yield Stress (MPa)	Tensile Strength (MPa)	Percentage of Elongation
AM	158.8	174.9	6.15
AMP2	171.8	194.0	7.69
AMP4	177.4	200.4	11.54
AMP6	204.6	287.6	15.38

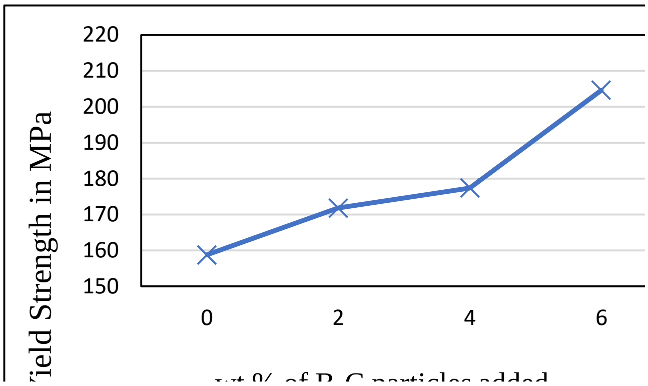

Fig.6 Variation of yield strength in Al 6061 alloy and cast composites

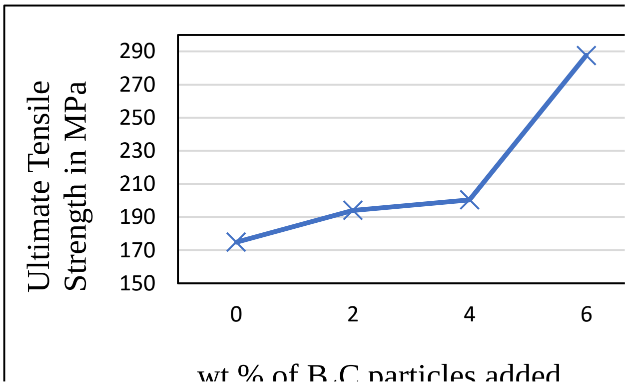

Fig.7 Variation of Ultimate tensile strength in Al 6061 alloy and cast composites

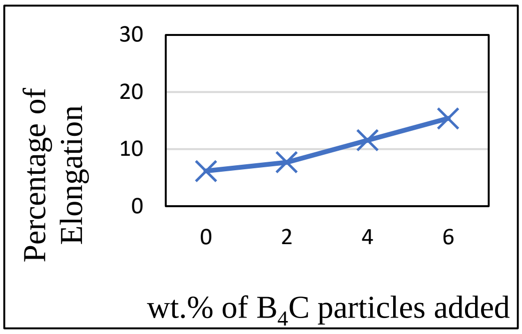

Fig.8 Percentage elongation variation in Al 6061 alloy and cast composites

CONCLUSION

A conclusion section is not required. Although a The aluminum metal matrix composites have produced successfully by the addition of 0, 2, 4 and 6 wt.% of Boron Carbide (B_4C) powder to molten Al 6061 alloy by liquid stir casting method followed by casting in permanent mould. The influence of increasing amount of B_4C powder addition on evolution of cast microstructure and their impact on the mechanical properties of the resulting composite has been investigated.

The conclusions of the present study are outlined below. Stir casting technique (Liquid Metallurgy) was successfully adopted in the preparation of Al 6061 (Mg)-B_4C alloy and composites containing 0, 2, 4 and 6 wt.% of B_4C powder reinforcement.

XRD analysis shows the B_4C particles are fairly pure and SEM metallographic study revealed the presence of B_4C particles in the composites with fairly homogeneous dispersion.

The hardness of the composites is found to increase with the increase in reinforcement of B_4C and the higher hardness noticed for the 6 wt.% of B_4C powder addition.

The composite with 6 wt.% of B_4C powder addition exhibited good yield strength of 204.6 MPa, tensile strength of 287.6 MPa and percentage of elongation around 15.38% compared to all other composites.

Percentage of elongation is found to increase with the increase in percentage of reinforcement.

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AUTHORS PROFILE

Dr. Ghanaraja S B.E., M.Tech., Ph.D., MIE, MISTE, Professor, Dept. of Mechanical Engineering, PESCE, Mandya.
Email-ghanaraja08@gmail.com

Sukruth Sagar B P B.E., M.Tech.,
Assistant Professor, Dept. of Mechanical Engineering, PESCE, Mandya
Email-sukruthsagar1991@gmail.com

Kiranakumara K M B.E.,
Assistant System Engineer, TCS, Chennai
Email-kiranmanju0808@gmail.com

Madhu G B.E.,
Trainee, ABC for Technology Training, Bengaluru
Email-madhuinjc@gmail.com