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Characterization of Mechanical Properties of Al-B_4C Composite Fabricated by Stir Casting

Sunil Kumar Tiwari
Assistant Professor, Department of Mechanical Engineering, DBIT, Dev Bhoomi Group of Institutions, Manduwala, Dehradun, India.

Harsh Sharma
Assistant Professor, Department of Mechanical Engineering, DBIT, Dev Bhoomi Group of Institutions, Manduwala, Dehradun, India.

KM Deepmala
Assistant Professor, Department of Mechanical Engineering, DBIT, Dev Bhoomi Group of Institutions, Manduwala, Dehradun, India.

Rahul Chamola
Assistant Professor, Department of Mechanical Engineering, DBIT, Dev Bhoomi Group of Institutions, Manduwala, Dehradun, India.

Abstract
This study shows the fabrication and characterization of Al7075t6-B_4C composite. Three samples with different weight% of B_4C have been fabricated as Al-2.5wt%B_4C, Al-5wt%B_4C and Al-0wt%B_4C through stir casting process. Cast samples were prepared for mechanical characterization namely tensile testing and hardness testing. Results of mechanical characterization showed that the tensile strength of the composite increased with increase in weight percent of reinforcement in the matrix. Tensile strength of the composite was increased by 24.64% and 38.56% with 2.5wt% and 5wt%B_4C reinforcement respectively and the Vickers hardness was increased by 10.81% and 25.67% with 2.5wt% reinforcement and 5wt%B_4C respectively Optical microscopy was done to confirm the homogeneous distribution of B_4C in Al matrix and to validate the increase in mechanical properties.

Keywords: stir casting, optical microscope, micro hardness, reinforcements, tensile strength.

Introduction
In recent scenario, authors and researchers have moved towards the fabrication and application of Aluminum composites over Al-alloys because of their high strength to weight ratio (2-5 times stronger than alloy), resistance to scratches and wear, specific modulus, resistance to corrosion and long life [8]. S. Rama Rao et al., (2012) have worked on fabrication of Al-B_4C composite and they have gone for compressive and hardness test. They have found that, with increase in the percentage of B_4C, compressive strength and hardness of the composite have increased [2]. Yiicel et al., (1997) found an increase in the hardness and decrease in the flexure strength along with fall down in fracture toughness of the Aluminum composite reinforce by B_4C [3]. K. Kalaiselvan et al., (2011) investigated an increase in micro hardness of Al-B_4C composite by near about 60% as compared to un-reinforced aluminum [3]. Raj Kumar et al., (2013) synthesized and fabricated Al-B_4C composite and concluded that, with increase in the reinforcement, hardness of the composite was increased [4]. In this research, we have used boron carbide (B_4C) as reinforcement because of its high hardness just after diamond and boron nitride, high stability against chemicals and resistance to wear [2] and Al-7075t6 as a matrix metal. Moreover, the selection of ceramic (B_4C),as reinforcement has been done keeping in mind the poor endurance of Aluminum or its alloy towards high temperature. Particle size of B_4C was 40~50μm and aluminum 7075t6 used was 100% ultrasonically tested. Different authors have gone through different methods for the fabrication of Al-B_4C composite namely, powder metallurgy, ECAP, friction stir processing etc., ball milling. We have gone through stir casting keeping in mind the problem of homogeneous mixing of reinforcement in the matrix and mass production. In this experiment, crucible, mold and stirrer all were made up of graphite so as to prevent contamination of metals. We have used stirrer having four blades.

Experimental details
In this section, we have discussed about the composition and properties of matrix and reinforcing material. This section also covers the detail of fabrication methods and approaches and mechanical characterization thus done on the fabricated composite.

Matrix and reinforcement
We have used 100% ultrasonically tested aluminum alloy Al-7075t6 scrap billets whose detailed composition has been

given in table 1. Mechanical properties of the Aluminum alloy used as matrix have been shown in table 2. Boron carbide is odorless in nature whose properties have been shown in table 3

Table 1: Chemical composition of Al-7075-t6 by weight percent

Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Zr
0.4	0.5	1.2-2.0	0.3	2.1-2.9	5.1-6.1	0.2	0.18-0.28	0.05

Table 2: Mechanical properties of Al-7075-t6

Tensile strength	Yield strength	Elongation
550.00 MPa	440.00 MPa	5%

Table 3: Properties of B_4C

Density	Melting point	Boiling point	Crystal structure
2.52g/cm^3	2763ºC	3500ºC	Rhombohedral

Composite preparation

All Al-B_4C composite samples have been prepared using stir casting method. We have fabricated three samples using different weight percent of B_4C as Al-2.5wt%B_4C, Al-5wt% B_4C, Al-0wt% B_4C. Aluminum billets were melted in crucible of graphite in muffle furnace. Temperature of the furnace was kept at a constant temperature 700ºC.The molten material (Al matrix) was stirred by four blade stirrer of graphite at rpm of 500 for 5 minutes so as to make vertex in the matrix. Preheated B_4C particles at 500ºC for 1 hour were mixed in the vertex of the matrix material (Aluminum) thus formed [1]. The molten material with reinforcement inside it was further stirred at rpm of 550-600 for next 8 minutes and then poured in the mold of graphite which was preheated at temperature of 300ºC to solidify. All the three samples were prepared using same parameters except the base metal which was melted and stirred for 13 minutes without reinforcement.

Mechanical and microstructural characterization

To investigate the mechanical properties, we have prepared subsize specimen for tensile test according to ASTM-E8 standard as shown in figure 1. Universal testing machine (ASTM-638) was used for tension test at 23 degree C RH 54% at central institute of plastic engineering and technology, Amritsar which had a maximum load capacity of 100kN. Prepared samples were subjected to the UTM at a strain rate of 50mm/min. Micro hardness was investigated through Vickers hardness testing machine at DAV college of engineering, Jalandhar. Load applied on the sample was of 100kgf for dwell time of 12 seconds. Samples prepared for hardness were in the form of cube (10x10x10) mm as shown in figure 2. Samples were initially cut in the size of required dimensions and then they were polished by files followed by different grades of emery papers so that the mark of the diamond indenter tip of the Vickers testing machine can be easily seen through microscope. We have also gone through Rockwell hardness test for these samples. All the samples for Rockwell hardness test were prepared with same parameters and same process. For this test, load of 100 kg was applied for dwell time of 15 seconds.

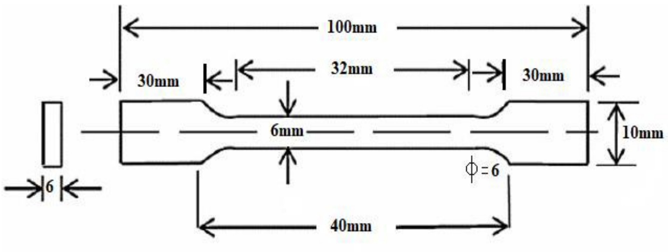

Figure 1: Dimension of tensile specimen

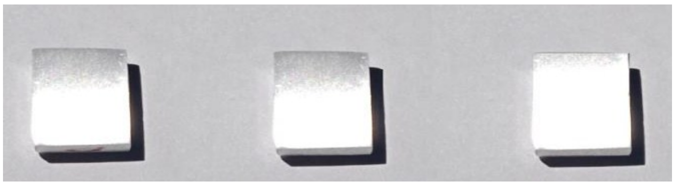

Figure 2: samples for Vickers hardness test

Microstructural and morphological characterization was done using optical microscope. Samples were prepared according to the space available at the stand of microscope. Initially sample preparation started with filing and then polishing with emery papers of different grades of emery papers as, 180, 320, 400,800, 1000, 1200, 1500, 2000 and 2500. Finally these polished samples were cleaned and mirror polished with the help of diamond paste of 1µm gran size followed by etching with keller's reagent as shown in table 4.

Table 4: Chemical composition of Keller's reagent

S.N	Constituents	Composition
1	HF	2 ml
2	HCL	3 ml
3	HNO_3	20 ml
4	Distilled water	175 ml

Results and discussion

In this section we have discussed about the results we have got after characterization of composite. Moreover we have tried to explain the theories and mechanism behind the properties thus achieved.

Tension test

The specimen prepared for tension test was in the form of plate with dimensions as shown in figure 1 according to ASTM-E8 standard. The effect of boron carbide in the composite has been shown in the form of percentage elongation which defines that whether the composite has become ductile or brittle. Tensile strength of the base (heat treated) specimen Al-0wt%B_4C was initially 550MPa, which was found to have 102 MPa when cast because of the processing conditions which was completely different from the ideal working conditions [5]. All samples Al-2.5wt%B_4C, Al-5wt%B_4C, Al-0wt%B_4C were subjected to UTM to investigate the tensile strength. Figure 3, figure 4 and figure 5 show the graph and values of the tensile test along with the percentage elongation generated by UTM.

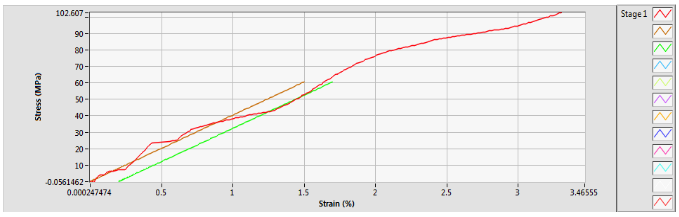

Figure 3: Graph of Al-0wt%B_4C specimen

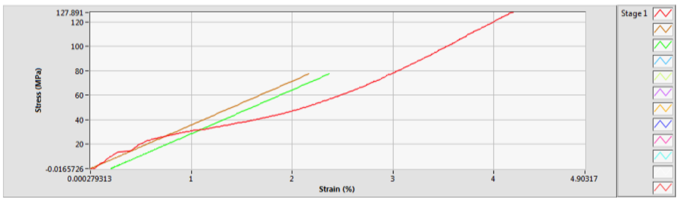

Figure 4: Graph of Al-2.5wt%B_4C specimen

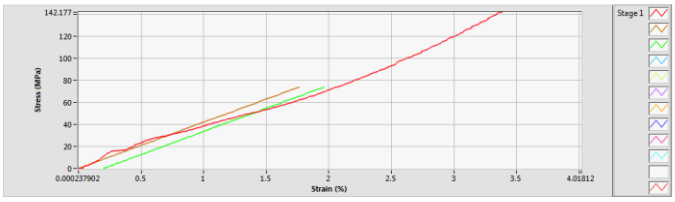

Figure 5: Graph of Al-5wt%B_4C specimen

As a result of tensile test, we found that with increase in the percentage of B_4C as reinforcement, tensile strength and young's modulus of the composite increased continuously. With reinforcing 2.5wt%B_4C, tensile strength of the composite was increased by 24.64% while reinforcing with 5wt%B_4C, it increased by 38.56% [10]. Increase in the young's modulus was seen because of high young's modulus of B_4C. Reinforcing 2.5wt% B_4C in Al matrix, percentage elongation in the composite increased while with 5wt%B_4C in the matrix, percentage elongation in the composite decreased which indicates that with increase in B_4C as reinforcement, the composite became brittle. Table 5 shows the value of tensile strength and percentage elongation of three specimens.

Table 5: Results of Tensile test through UTM

Specimen	Tensile strength at peak (MPa)	Percentage elongation	Young's modulus
Al-0wt%B_4C	102.607	3.321	4040.8
Al-2.5wt%B_4C	127.891	4.211	5066.24
Al-5wt%B_4C	142.177	3.406	5122.382

Hardness test

Hardness is the property of material which resists local stresses and scratches. Micro hardness of the composite samples was tested on Vickers hardness testing machine at room temperature. Twelve values (six on each face of the sample, up and down face only) of hardness were taken and were calculated so as to give an average value for each sample [6]. This was done to confirm the homogeneous mixing of boron carbide in the aluminum matrix. Hardness values of the composites and base material has been shown in table 6. Table 7 shows the values of hardness tested through Rockwell hardness testing machine. The values through Rockwell hardness tester has been taken same as Vickers hardness test (average of 12 values; 6 values on each face of composite, up and down face only).

Table 6: Vickers hardness value of fabricated composite

Specimen	Al-0wt%B_4C	Al-2.5wt%B_4C	Al-5wt%B_4C
Hardness (Hv)	74	82	93

Table 7: Rockwell hardness value of fabricated composite

Specimen	Al-0wt%B_4C	Al-2.5wt%B_4C	Al-5wt%B_4C
Hardness (Hv)	36	41	56

We have seen continuous increase in the hardness value of the composite (both Vickers and Rockwell hardness) with increase in the percentage of reinforcement. This is because of the presence of hard reinforcement B_4C in soft Aluminum matrix [6] which renders its properties to the matrix metal.
Figure 6 shows the graph of Vickers and Rockwell hardness values of the composite samples.

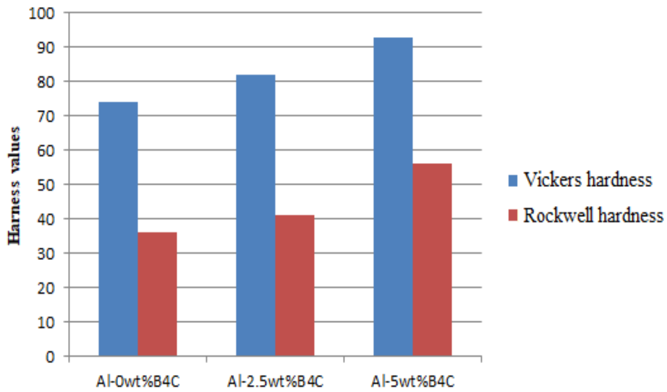

Figure 6: hardness values of composite samples.

Microstructural investigation

To investigate the microstructural morphology, we have used optical microscope zoomed at 500x and 1000x. Etched samples were subjected to microscope to see the structure of the composite. It was found that particles of boron carbide were homogeneously mixed in the aluminum matrix. With increase in weight percentage of boron carbide, the probability of clustering of reinforcement increased which also resulted in formation of cavities and pores shown as dark spot in figure 7 which can be even seen with naked eyes [7]. With increase in percentage of reinforcement, increase in fracture surface has been seen and moreover grain size of the material has also decreased. This is because of the strong bond between boron carbide and aluminum matrix which separates each grain at very small size. Grain size of the composite has been shown in figure 8. With decrease in grain size of the material, number of grain boundaries increases which ultimately help in increasing the strength of material.

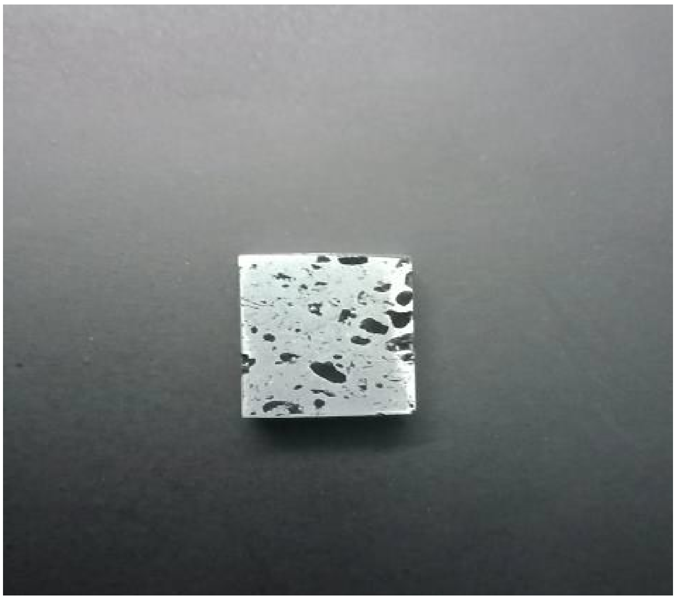

Figure 7 (a): Cavities and porosity in composite sample

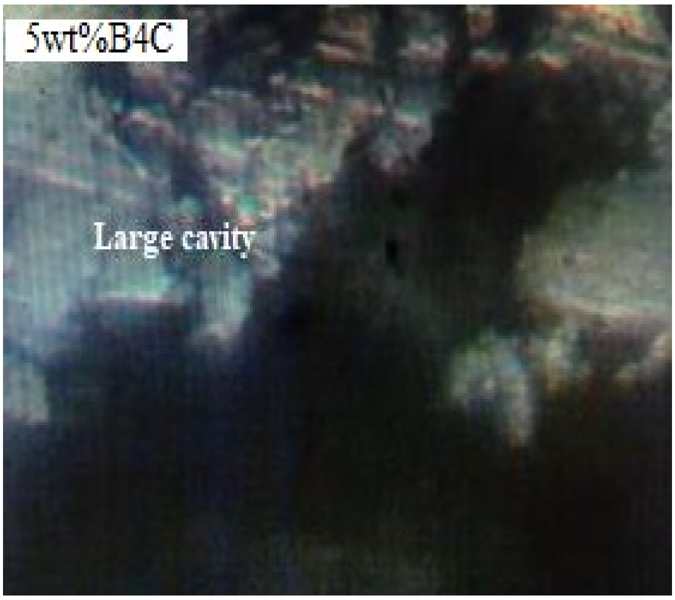

Figure 7 (d): Cavities and porosity in Al-5wt%B_4C

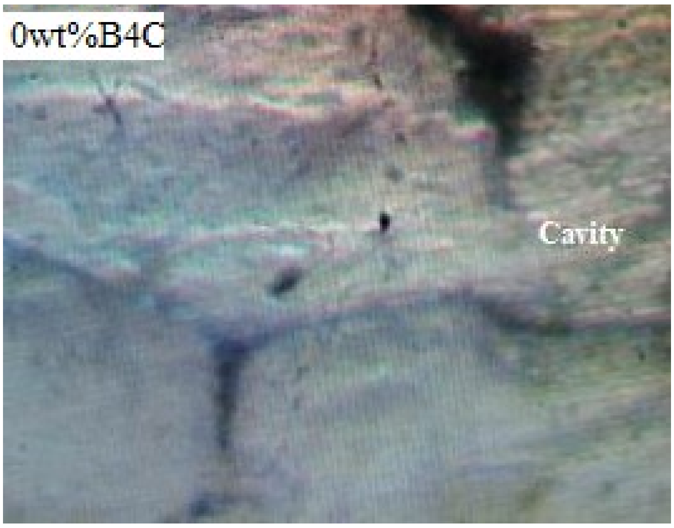

Figure 7 (b): Cavities and porosity in Al-0wt%B_4C

Figure 8(a): Grain size Al-2.5wt%B_4C at 500x

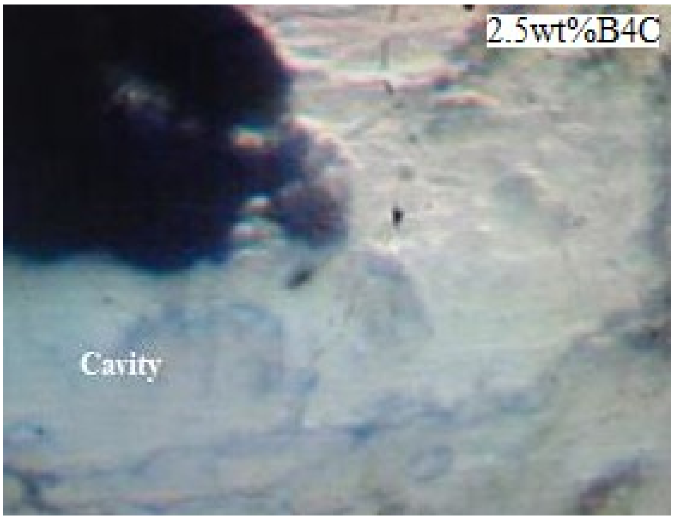

Figure 7 (c): Cavities and porosity in Al-2.5wt%B_4C

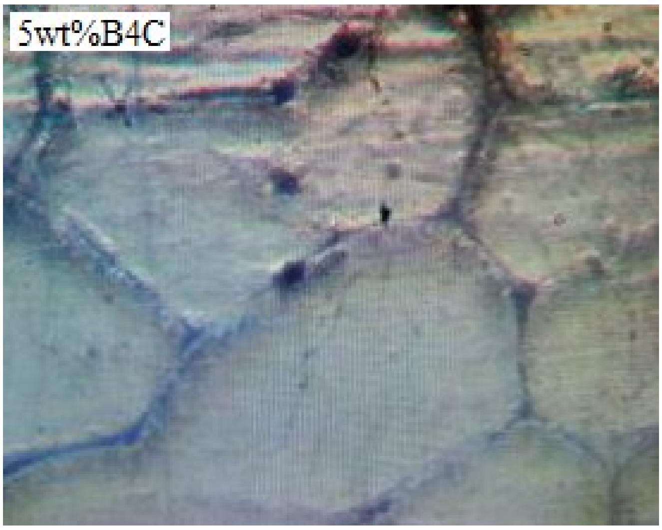

Figure 8(b): Grain size Al-5wt%B_4C at 500x

Hence, growth in tensile strength of the composite with increase in percentage of reinforcement is justified [8]. Figure 9 (a) and 9 (b) shows the distribution of B_4C in Al matrix. From figure, it is confirmed that B_4C particles are homogeneously distributed in the Al matrix.

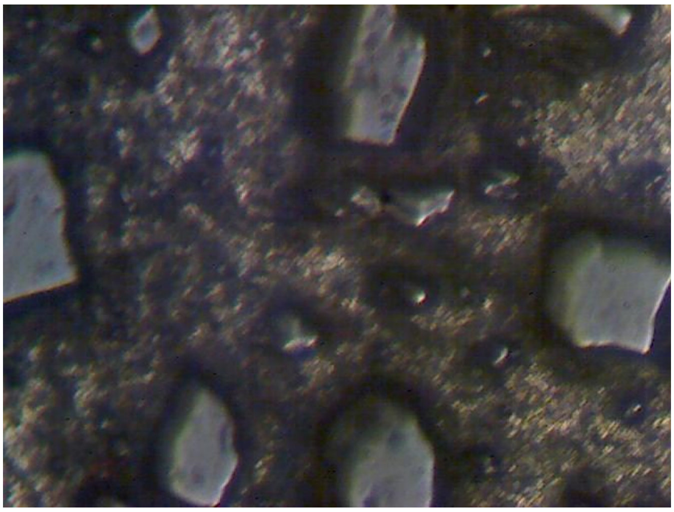

Figure 9 (a): Optical image of Al-2.5wt%B_4C at 1000X

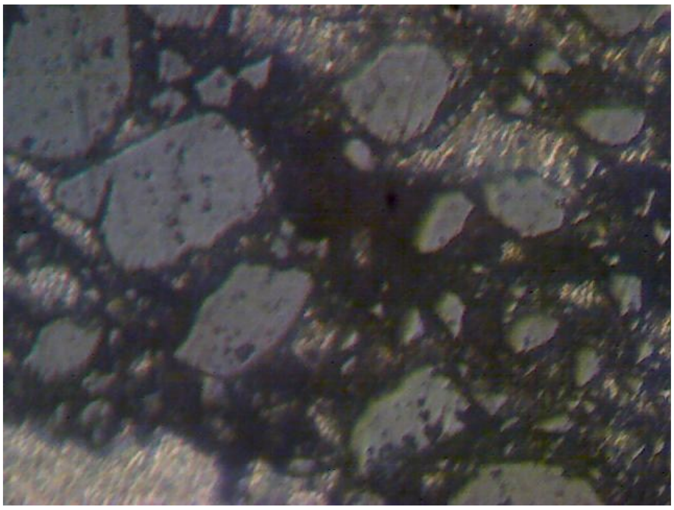

Figure 9 (b): Optical image of Al-5wt%B_4C at 1000X

Conclusion

In this work, we have introduced ceramic as reinforcement in metal matrix. As B_4C is third hardest material after diamond and boron nitride. The fabricated composites have become brittle because of the properties of B4C rendered to Al matrix. Young's modulus of the composites has increased because of high young's modulus of B_4C. With introducing 2.5wt%B4C and 5wt%B4C in matrix, tensile strength of the composites has increased by 24.63% and 38.56% respectively. With introducing 2.5wt%B4C and 5wt%B4C in matrix, micro hardness of the composites has increased by 10.81% and 25.67% respectively.

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