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RESEARCH ARTICLE

Investigations on Mechanical Behaviour of Micro B_4C Particles Reinforced Al6061 Alloy Metal Composites

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Abstract

Objective: To develop and evaluate the mechanical behavior of 3, 6, 9 and 12 wt. % of B_4C reinforced Al6061 alloy composites. **Method:** These composites were produced by utilizing stir cast process. The prepared metal composites were characterized by SEM, EDS and XRD analysis to know the distribution of particles as well as presence of particles in the Al6061 alloy. Various mechanical properties were evaluated as per ASTM standards to know the impact of boron carbide particles on the properties of metal composites. **Findings:** By adding B_4C particles the hardness, ultimate tensile, yield strength and compression strength of the Al6061 alloy matrix was enhanced 23.9%, 15.4 14.9% and 34.7% respectively. Further, there was slight decrease in the percentage elongation of B_4C reinforced composites. **Novelty:** In the present research Al6061 alloy with 3 to 12 wt. % of B_4C composites were synthesized by novel stir casting method called as two stage reinforcement addition process. In this process 80 micron sized boron carbide particles added in two stages into the molten Al6061 alloy to improve the wettability between the matrix and reinforcement particles.

Keywords: Al6061 Alloy; B 4 C Particles; Hardness; Tensile Strength; Microstructure

1 Introduction

Metal composites are widely used materials in the field of automotive and aerospace sectors[1–3]. Especially, aluminium based metal materials are more suitable for these industrial applications. Hence, it is required to develop ceramic, oxides or nitride particles reinforced metal composites[4]. Several investigators evaluated the various properties of metal composites. Zhou et al.[5] fabricated the ZrO_2 reinforced copper matrix composites. ZrO_2 abrasive particulates reinforced copper MMCs were investigated for the tribological properties. The addition of ZrO_2 particles lowers the co-efficient of friction and enhanced the wear resistance of the matrix material. Prabhu et al.[6] prepared composites of Cu with SiC and Gr were prepared by multi layered method using pressure sintering and layer compaction technique. At different sliding speeds of (5, 10, 30 and 35m/s) tribological performance and wear confrontation were evaluated. Using SEM, XRD and stereoscopy were surface morphology were studied. The inclusion of SiC and graphite particulates improved the wear behavior of copper alloy. Zebarjad & Sajjadi[7] arranged the Al-Al_2O_3 composite materials alloying technique and on examination of its microstructure. For this reason, a level ball mill was structured and fabricated. Aluminum and alumina powders, with indicated size and weight percent, were added to the plant. The blended powders were processed at various occasions. The processed powders were squeezed and sintered under argon gas control. Microstructures of delivered composite were examined by checking scanning electron microscope. The outcomes demonstrate that expanding processing time causes to make fine alumina powders just as uniform conveyance inside aluminum. Rajesh et al.[8] discussed the wear behavior of hybrid aluminium metal matrix composites subjected to heat treatment. Aluminium 7075 was reinforced with SiC and Al_2O_3 and processed through stir casting. It is observed that age hardened hybrid composite gain the hardness by 24 % for 10 wt. % reinforcement as compared with as- cast composites. The age hardened Al7075/ (SiC+ Al_2O_3) composite shows appreciable improvement in resistance to wear as compared to as-cast hybrid composite. Based on the literature maximum investigations were carried out on metal matrix composites prepared by using conventional stir casting process. Usually, by using conventional stir casting process it is very difficult to have proper wettability between matrix and reinforcing particles, hence to improve the wettability, in the present research novel two steps or stage casting method is adopted to prepare the various Al6061-B_4C composites. Further, several investigators were carried out experiments on tensile, hardness and wear behavior of metal composites, but very minimal research was conducted on impact of particles on the compression strength of the metal matrix composites. In the current investigations an attempt has been made to evaluate the impact of 80 micron sized B_4C particles on the compression strength of Al6061 alloy metal composites.

From the available literature it is observed that many researchers have attempted to study the effects of addition of SiC, Al_2O_3, TiB_2, TiC and TiO_2 reinforcement on mechanical, tribological characteristics of aluminium based AMC's. A limited work has been done to develop and study the behavior of Al 6061-B_4C metal composites and hence in this research work attempts are made fabricate and study the mechanical and tribological behavior of Al6061- B_4C composites.

2 Experimental Details

2.1 Materials Used

Aluminum is one of the most used metals on the earth; it stands out of all other materials because of its properties like corrosion resistance, thermal and electrical conductivity etc. Al 6061 is renowned to have remarkable mechanical properties like high strength to weight ratio, higher corrosive resistance, higher stiffness, decent abrasive wear resistance etc. The chemistry of Al6061 alloy is shown in Table 1.

Table 1. Chemical composition of Al6061 alloy

Elements (wt. %)	Al6061(actual)
Mg	0.89
Si	0.64
Fe	0.23
Cu	0.17
Ti	0.10
Cr	0.07
Zn	0.03
Mn	0.07
V	0.01
Al	Balance

Al metal composites with 3, 6, 9 and 12 wt. % of boron carbide with 80 micron size were made by stir strategy. Aluminum 6061 matrix is picked as alloy because of its more prominent, strength, formability, heat-treatment nature, great obstruction to wear, machinability and wide applications in a few areas and so forth while B_4C particles were used as reinforcements (Figure 1). Figure 2 is showing the energy dispersive spectrograph of B_4C particles utilized in the investigation. Boron carbide contains the boron (B) and carbon (C) components as uncovered in the range.

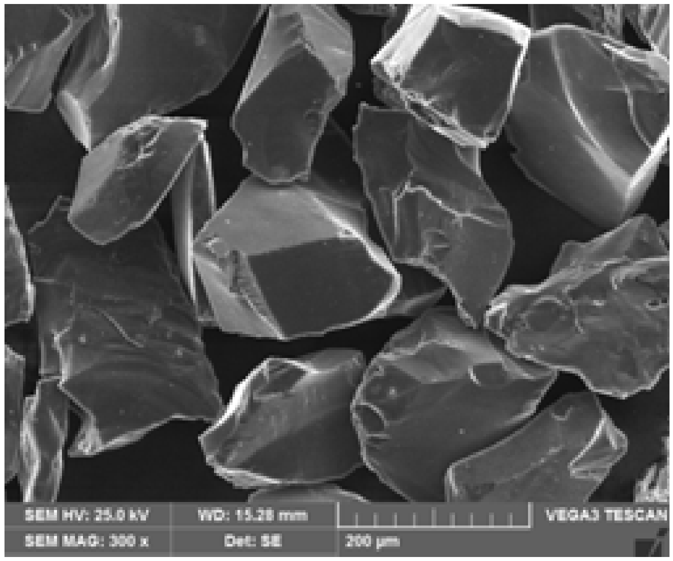

Fig 1. SEM micrograph of B_4C particles

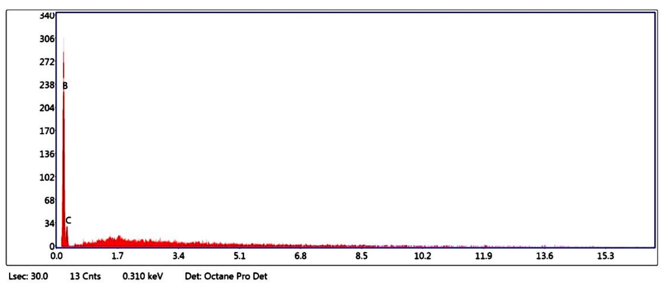

Fig 2. EDS spectrum of B_4C particles

2.2 Synthesis of Al6061-B4C Composites and Testing

At first a deliberate amount of Al6061 matrix is put in graphite made crucible and located in an electrical furnace and melted (at temperature of 750°C). For temperature measurements thermocouples are used. The molten metal in the crucible is then degassed up to 2 minutes with the help of a hexa-chloro-ethane (C_2Cl_6) to extract the undesirable by-products. A ceramic material known as zirconia is coated on the steel impeller used to stir the molten metal to form a vortex. The stirring process is conducted at a speed of 300 rpm and from the top of the melt; the impeller is plunged inside the melt of around sixty percent height of the molten metal. At the same time, the pre-calculated reinforcement quantity has been added into the vortex in two-stages to ensure a strong wet-ability agitation has been continued for up to ten minutes. The B_4C reinforcing particles are pre-heated in the oven to 500°C, before being applied to the vortex of molten metal to extract the moisture content. Now, Al6061 alloy has been transferred into the solid cast iron mold along with 3 wt. % of B_4C particles to get a composite after complete solidification. Likewise, Al6061-6, 9 and 12 wt. % B_4C composites are created for further experiments.

The size, shape and distribution of B_4C present in Al6061 composites are finished using SEM contraption (TESCAN VEGA, Czech Republic). The contraption is associated with JED 2300 assessment programming program for EDX examination. For SEM, samples are machined to get 15 mm in breadth and 5 mm in length. To quantify the hardness Vickers hardness analyzer having a load scope of 25 to 1000 g is utilized. The ASTM E384[9] standard is utilized for testing. A diamond indenter on the material is utilized and a load of 100 g is applied over the specimen of size 15 mm in diameter and 10 mm height for a time of 30 seconds. Three readings have been recorded on each sample at different areas and mean value has been noted.

By the usage of automated general testing machine (UTM) of Instron make, with 60 kN capacity with least check of 4 N, malleable tests are done. The tensile sample having an element of 30 mm gauge length according to ASTM E8-13a [10] standard is shown Figure 3(a-b). Compression test is carried out on the same machine as per ASTM E9 standard. Figure 4 is indicating the compression specimen used for the study.

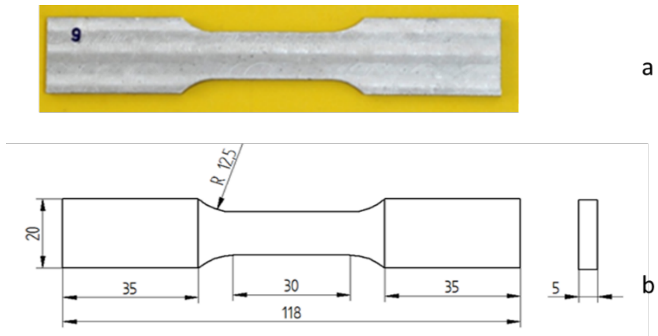

Fig 3. (a) Tensile machined specimen (b) Dimensions of the tensile specimen

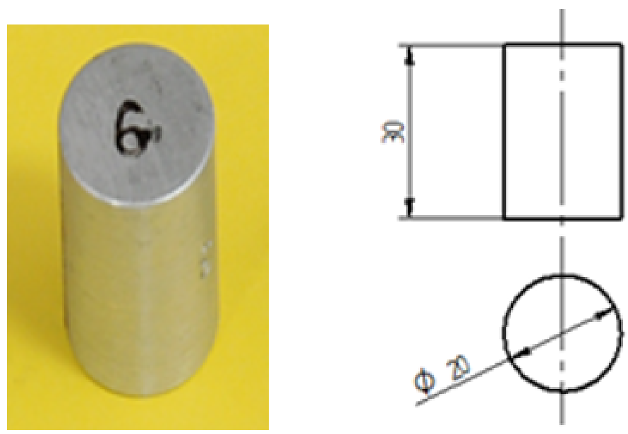

Fig 4. Compression test specimen

3 Results and Discussion

3.1 Microstructural Details

Figure 5(a-e) is the pictures of scanning electron microphotographs of as cast Al6061 alloy and Al6061 with 3 to 12 weight % B_4C reinforced composites. Figure 5(a) is the SEM of casted Al6061 without any particles, but the grains are visible properly throughout the surface of the specimen. Figure 5(b-e) shows the SEM micrographs of Al6061 alloy with 3, 6, 9 and 12 wt. % of B_4C reinforced composites respectively. The presences of hard B_4C particles are clearly visible on the surface of the specimen, which indicates the proper wetting between the matrix and utilized reinforcement material due to novel two stage stir casting method adopted to prepare the composites. Also, all the micrographs are demonstrating more number of ceramic particles as the weight % of B_4C increases from 3 to 12 wt. % in the Al6061 matrix. These images representing the sound casting technique used to process the metal composites. Due to the more number of particles presence and strong wetting between the matrix as well as reinforcement the properties of the Al6061 alloy composites have enhanced.

Figure 6(a-b) is containing the EDS analysis of Al6061 alloy and Al6061 with 12 wt. % of B_4C reinforced composites respectively. Since the Al6061 alloy is a wrought alloy with magnesium and silicon are the major alloying elements, these

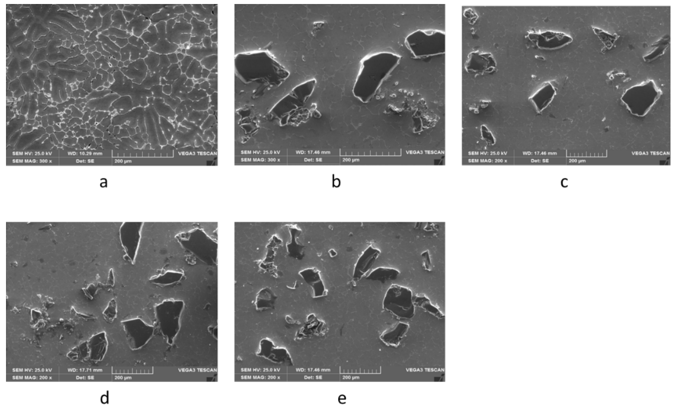

Fig 5. SEM micrographs of (a) Al6061 (b) Al6061-3 wt. % B_4C (c) Al6061-6 wt. % B_4C (d) Al6061-9 wt. % B_4C (e) Al6061-12 wt. % B_4C composites

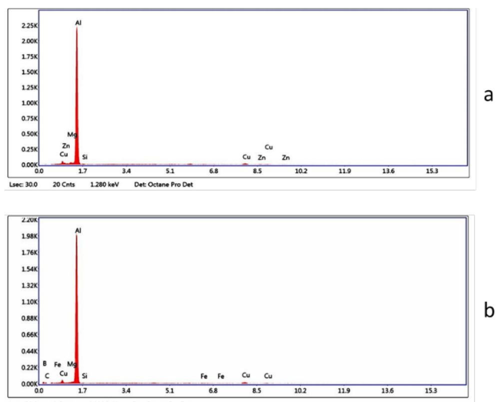

Fig 6. EDS analysis of (a) Al6061 (b) Al6061-12 wt. % B_4C composites

elements are confirmed by the EDS spectrum as in Figure 7(a) along with aluminium. Further, Figure 6(b) is showing the spectrum of 12 wt. % of boron carbide particles reinforced composites. These ceramic B_4C particles are visible in the form of Boron (B) and Carbon (C) peaks along with Al peak.

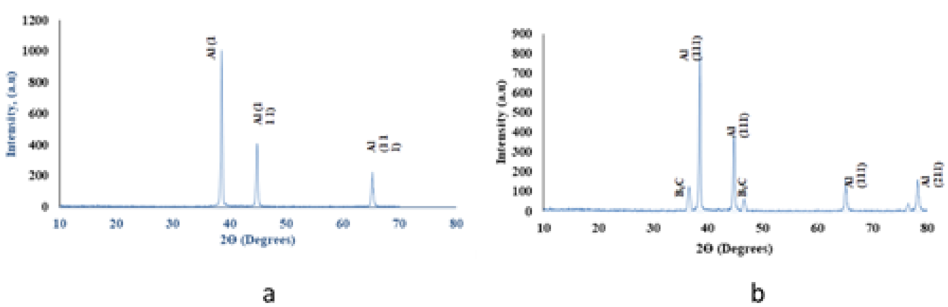

Fig 7. XRD patterns of (a) Al6061 (b) Al6061-12 wt. % B_4C composites

The XRD pattern of Al 6061 and 12 wt. % of B_4C reinforcements are as show in the Figure 7(a-b), the density peaks of Al and B_4C phases are formed at the interface between the matrix and the reinforcement. The presence of the reactive elements was relatively low. It is noticed that as the B_4C weight percentage increases, both peak magnitudes and peak areas noticeably increased for the B_4C. It is observed from the X-ray diffraction pattern a peak ranging from 100 to 800 and the peaks at 2θ

of 280, 44.770, and 64.940 belongs to aluminium and peaks are shifted to right with the addition of the reinforcement which indicates the presence of B_4C in the composite. Similarly, B_4C was observed at 36^0, 46^0 and 76^0 for 12 wt. % of the reinforcement. Further, it is noticed that addition of the reinforcement increases the intensity of peaks which are belongs to JCPDS card number 33-0225 of B_4C.

3.2 Hardness

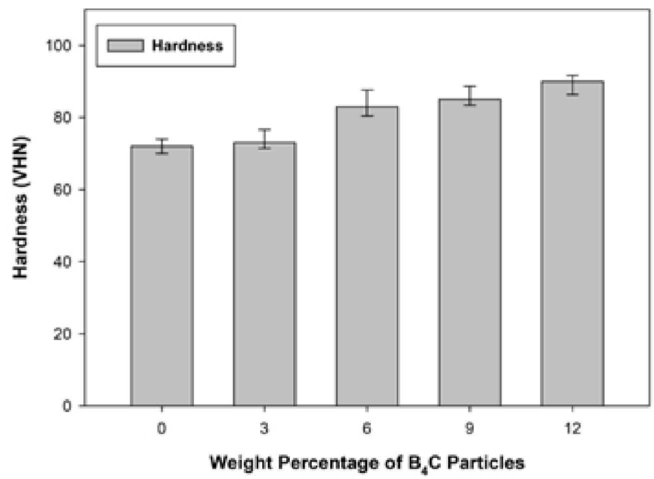

Fig 8. Hardness of Al6061 alloy and B_4C composites

Figure 8 addresses the qualities for hardness of Al6061 matrix, Al6061 alloy with 3 to 12 wt. % of B_4C reinforced composites. From Figure 7 as the weight percentage of support B_4C particulates is expanded from 3 to 12 weight rate, there is an expansion in the hardness of Al6061. The hardness estimation of base material of cast Al6061 combination is 72 VHN, after the addition of B_4C particulates by two step novel strategy there is an increment in hardness from 72 VHN to 89 VHN. There is an improvement of 23.6% of hardness for Al6061-12 wt. % of B_4C composites. The improvement in hardness of Al6061 is because of the presence of hard particles of B_4C in the delicate pliable lattice[11]. The hardness expanded in the delicate framework as the hardness of B_4C particles is 3500 VHN, which builds the hardness of Al6061- B_4C grid. Veersha et al[12] investigated the effect of 44 micron sized B_4C particles on the hardness of Al2618 alloy composites synthesized by stir casting method. The hardness of Al2618 alloy was improved by adding boron carbide particles which acts as a resistant to plastic deformation during hardness testing.

3.3 Tensile Properties

Figure 9 shows the values of ultimate strength by the impact of supported B_4C particles in 6061 alloy. Figure 9 indicates as the wt. % of supported B_4C particles is expanded there is an increment in ultimate strength of Al6061- B_4C composites. The UTS of Al6061 alloy is 142.9 MPa, this strength is enhanced with addition of 3 to 12 wt. % of B_4C particles. The strength of Al6061-3 wt. % of B_4C composites is 179.17MPa; Al6061-6 wt. % of B_4C is 181.1 MPa, Al6061-9 wt. % of B_4C is 183.02 MPa and with 12 wt. % of composite is 164.9 MPa. The increment in the strength is mainly due to addition of ceramic particles which enhances the load carrying capacity of Al6061 alloy. Further, there is a decrease in the strength of the Al6061-12 wt. % of composites as compared to Al6061-9 wt. % of B_4C composites as but higher than the as cast Al6061 alloy. The decrease in the strength at higher weight percentage is mainly due to clustering of reinforcement particles. Madeva et al.[13] conducted the experiments on ceramic B_4C reinforced composites Al2024 alloy composites have observed the increased strength with the incorporation of B_4C particles.

Figure 10 exhibits the impact of boron carbide particulates on yield strength of Al6061 alloy. With the expansion in wt. % of B_4C particulates, there is an increment in the yield strength estimation of Al6061 with B_4C composites. The yield strength of Al6061alloy is 117.9 MPa, with the addition of 3, 6, 9 and 12 wt. % of B_4C particles it is 149.11 MPa, 150.61 MPa, 152.3 MPa and 135.5 MPa respectively.

From Figures 9 and 10 it is obvious that ultimate strength and yield strength is expanded with the expansion of boron carbide particles. Increase in strength of Al matrix was because of B_4C component presence in the structure. The boron carbide particle

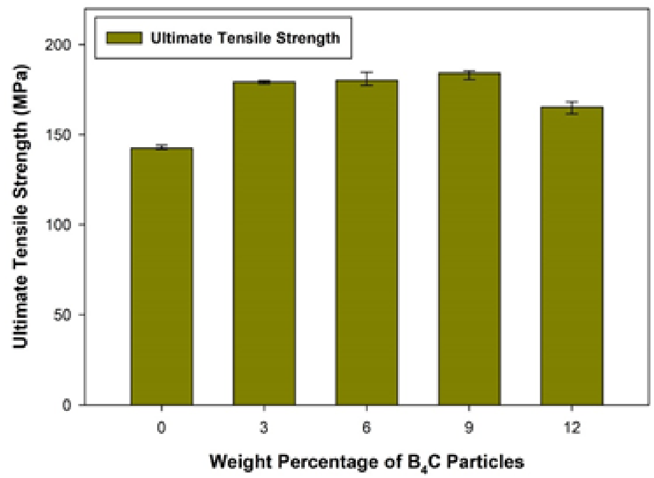

Fig 9. Ultimate tensile strength of Al6061 alloy and B_4C composites

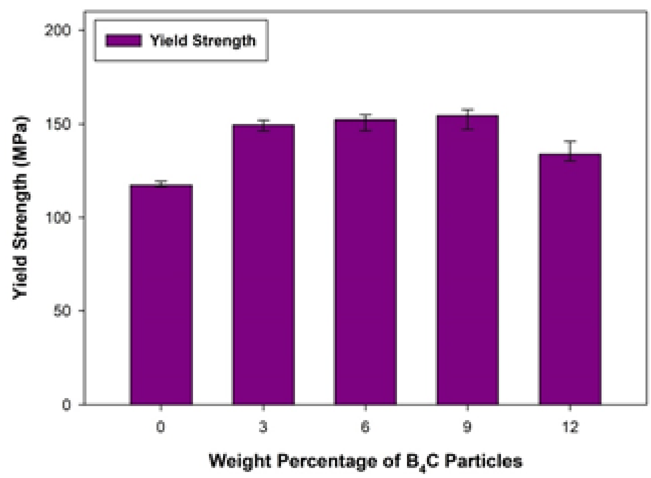

Fig 10. Yield strength of Al6061 alloy and B_4C composites

makes the delicate grid weak and turns the lattice matrix to remain in the direction of higher loads. These hard particles go about a load conveying components and the structure, which boosts the strength of matrix. As per Hall-Petch[14,15] effect with the addition of particles in the aluminium lattice diminishes the size of grain, this helps in expanding strength of the material. Krishna et al[16] investigated the impact of B_4C particles on the tensile behavior of ZA27 alloy composites, and observed the improved strength.

Figure 11 is demonstrating the elongation of Al6061 alloy with 3, 6, 9 and 12 weight percentages of B_4C composites. By adding ceramic particles in the Al6061 alloy there is decrease in the ductility of soft Al matrix. The elongation of as cast Al6061 alloy is 6.69%, this is decreased to 1.5% with the addition of 12 weight % of hard ceramic particles. The strong bonding between the particle and matrix material enhances the strength meanwhile decreases the ductility due to formation of high stress concentration around the particles[17,18].

3.4 Compression Strength

Figure 12 shows the compression strength for Al6061 alloy and Al6061 combination with 3 to 12 wt. % of B_4C particulates composites. From Figure 12 it is reasoned that as the presence of B_4C particles is expanded in base Al6061 alloy, there is an expansion in compression strength of Al6061-B_4C composites. Since the carbide or oxide grid is totally masterminded the strength of framework is controlled by the compression strength. Always the particles strength is very high in terms of

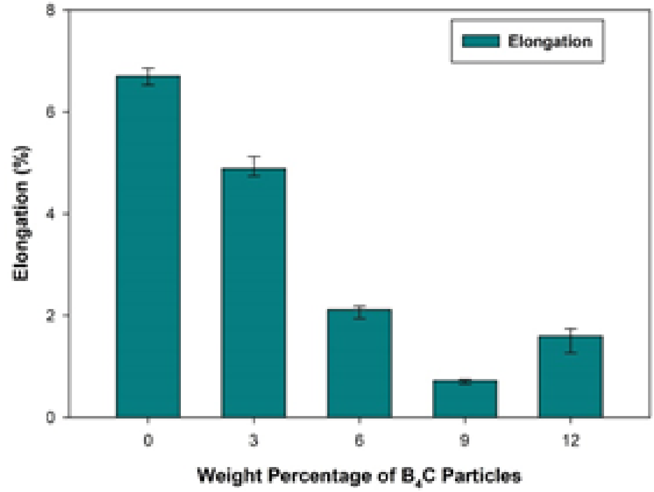

Fig 11. Elongation of Al6061 alloy and B_4C composites

compression, these high compression strength particles helps in improving the crushing strength of the base Al material [19,20]. The compression strength of Al2219 alloy was enhanced with the incorporation of B_4C particles investigated by Shashidhar et al [21] which acts as a barrier for the plastic deformation during compression loading.

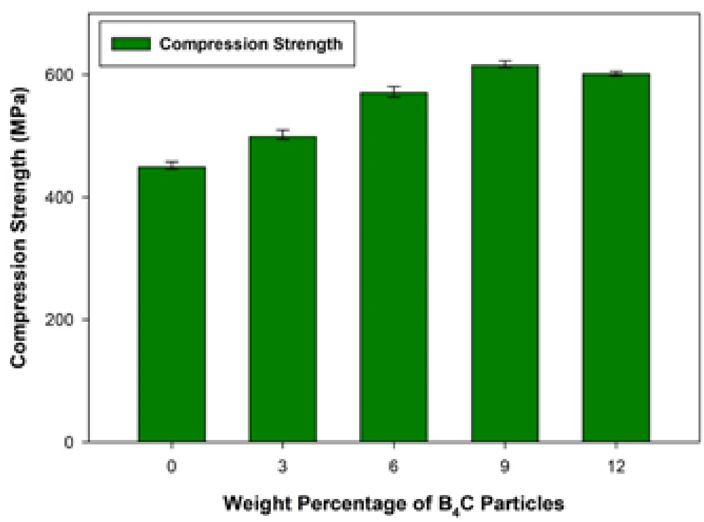

Fig 12. Compression strength of Al6061 alloy and B_4C composites

4 Conclusions

In the current work Al6061-B_4C composites were successfully synthesized with 3 to 12 wt. % of micro B_4C with an average particle size of 80 microns by the utilization of stir casting technology. The composites were synthesized by novel two step stir casting method which helps in improving the wettability between the matrix Al6061 alloy and B_4C reinforcing particles. Microstructural characterization and mechanical behavior of thus prepared composites were evaluated successfully as per ASTM standards. As cast-alloy and equally distributed B_4C composite, the matrix is practically pores-free, as can be seen from SEM micrographs. The EDS and XRD analysis indicates that the Al6061 alloy matrix includes B_4C particles. The properties of Al6061 with varying wt. % B_4C composites were superior and improved compared with unreinforced Al6061 as-cast alloy.

The enhancements in all these mechanical properties were achieved mainly due to improved wettability by novel stir casting process adopted to fabricate composites. With the addition of higher wt. % of boron carbide particles there is decrement in the ductility.

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