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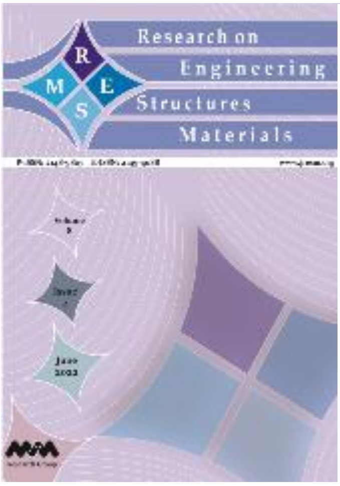

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Research Article

Synthesis, microstructure and tensile characterization of B_4C particulates reinforced Al7085 alloy aerospace composites

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Abstract

In the current studies microstructure and mechanical behavior of Al7085 metal alloy with 4 and 8 wt. % of B_4C composites. Liquid metallurgy method was used to create composites of Al7085 alloy with 4 and 8 weight percent of B_4C particles. Microstructural analysis by SEM/EDS was performed on the prepared composites. Furthermore, ASTM E8 and E10 standards were used to examine the tensile and hardness properties of Al7475 alloy reinforced with B_4C composites. The SEM analysis revealed that the particles were uniformly dispersed throughout the base alloy. EDS spectrums confirmed the reinforcement particles presence in the Al7085 alloy in the form of boron and carbon elements. Moreover, the incorporation of B_4C particles into Al7085 alloy has enhanced the material's mechanical behavior. The hardness and tensile strength of Al7085 alloy was improved 27.59% and 35.91% respectively with the combination of boron carbide particles. After boron carbide particles were added to Al7085, the alloy lost some of its ductility and density. The prepared composites were then subjected to tensile fractured surfaces to investigate ductile and brittle modes of fracture.

1. Introduction

Ceramic particle reinforcement of aluminium alloys is a solution to the problem that standard aluminium alloys don't give the necessary characteristics under all service situations. AMCs [1-3] are the common name for these aluminium alloys with reinforcements. The acronym "AMC" (aluminium metal composite) describes a group of aluminum-based materials that are both lightweight and high-performing. The metal matrix composites currently use aluminium as one of the most common matrices [4]. Due to their high specific strength and stiffness and outstanding wear resistance, AMCs have garnered a lot of attention over the past three decades, even among metal matrix composites. Aerospace, automotive, marine, and other industries frequently employ AMCs. Increased strength, high specific modules, improved stiffness, low thermal expansion coefficients, high thermal conductivity, tunable electrical properties, increased wear resistance, and improved damping capabilities [5] are just a few of the benefits of using particles reinforced AMC's materials rather than unreinforced ones.

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Improved wear resistance, high strength qualities, suitable sliding characteristics, resistance to thermal shocks and fatigue phenomena, and a decreased final product weight are all characteristics of composite materials in relation to the matrix, depending on the specific application. Therefore, the technological features of the composite, as well as the costs of its production and the ecological aspect of the product, all play a role in determining the scope of application of composites reinforced with hard ceramic particles [6, 7].

Due to their high specific strength and stiffness, aluminum alloys are a promising material among the several matrix materials now accessible. However, their usefulness is limited by their low resistance to wear. Particulate reinforced aluminum matrix composites have achieved widespread use in the automotive and aerospace industries as a result of their superior mechanical and tribological qualities compared to those of traditional alloys. Affordable Al-based MMCs with hard and soft reinforcements including SiC, Al_2O_3, B_4C, Zircon, Tungsten Carbide, Graphite, and Mica have been a primary focus of research and development [8, 9].

Reinforcement in MMCs serves primarily as a load carrier, with the matrix acting as a binding agent and a means by which external loads are transmitted and distributed to the individual reinforcement [10]. In order to transfer and distribute load from the matrix to the reinforcements without failure, good wetting is a necessary condition for the creation of a successful bond between particle reinforcements and liquid Al metal matrix during casting composites [11].

Ceramic particles have been shown to improve mechanical and other properties of aluminum alloy by serving as reinforcing materials. Ceramic reinforcements are commonly used in MMCs, and can be broadly classified into two categories: continuous and discontinuous. They are known as continuously (fibre) reinforced composites and discontinuously (fibre) reinforced composites, respectively, for the MMCs they yield [12, 13]. Continuous fibres, short fibres (chopped fibres, not always the same length), whiskers, particle, and wire (only for metal) are the five main groups into which they can be further classified. Reinforcements, with the exception of wires, are typically made of ceramics, specifically oxides, carbides, and nitrides. These are put to use because they combine excellent strength and stiffness in both cold and hot conditions.

Stir casting, squeeze casting, liquid metal infiltration, and spray co-deposition are just some of the cutting-edge manufacturing methods that were used in the production of MMC materials [14]. The simplest and most cost-effective method is the 'vortex technique' or 'stir casting technique,' which is appealing due to its simplicity, low processing cost, flexibility, and being the most cost-effective method for preparing large sized components and producing near net shaped components. Chen et al. [15] looked at the AA6061-B4C composites made with the friction stir weld technique. Mechanical characteristics and microstructure of AA6061-B4C composites were studied as well. Scanning electron microscopy was utilized to look at how the B_4C particles were distributed throughout the AA6061 matrix. Mechanical characterization of stir cast LM24-B_4C composites was investigated by Keshav Singh [16]. The ultimate tensile strength of LM24 alloys rises at 3, 5, and 7 wt.% of B4C particles. The effect of adding boron carbide particles of 40- and 90-micron size on the mechanical behaviour of A356 composites was studied by Zeeshan Ali et al. [17]. Composites of A356 alloy with 3 wt.% of 40- and 90-micron boron carbide pares were made by a standard stir casting procedure. As cast A356 combination composites with 3 wt% B_4C composites (40 & 90 µm) were also examined for their mechanical conduct. Particles in the A356 composite were found to be uniformly dispersed across the microstructure. The analysis revealed that the presence of B_4C particles in the composite increased the composite's hardness, UTS, and YS.

Moreover, the reinforcement's size and form play a crucial influence in improving the characteristics of metal matrix composites. Grain refinement and improvement of characteristics are also the result of secondary operations including rolling, shaping, and extruding.

Aluminum-boron carbide composites serve an important purpose due to the rising need for lightweight materials in cutting-edge industrial applications. In light of these findings, it is suggested that Al7085 alloy composites containing micro-particle-sized B_4C particulates and varied B_4C weight percentages be developed. Mechanical characteristics of Al7085-B_4C micro composites will be studied using ASTM protocols.

2. Materials and Methods

2.1. Materials Used

Aluminum alloy Al7085 also known as Al-Cu alloy (Procured at Fenfe Metallurgical, Bangalore) was adopted as base matrix metal because of its outstanding castability, fluidity, weldability and ability to counteract corrosion. The following image (Fig. 1) shows the Al7085 ingot procured from Fenfe Metallurgicals, Bangalore, which was used to develop composite material by melting it down and adding reinforcement.

Fig. 1. Ingot of Al7085 alloy used to prepare the composites

The Table 1 shows Al7085 alloy chemistry of selected as matrix in the current study.

Table 1. Chemical composition of Al7085 alloy

Elements (wt. %)	A7085 (actual)
Si	0.05
Fe	0.08
Cu	1.90
Mg	1.80
Cr	0.04
Zn	7.85
Ti	0.06
Mn	0.04
Al	Balance

Some important physical, mechanical and thermal properties of Al7085 alloy is listed in the Table 2.

Table 2. Properties of Al7085 alloy

Density (g/cc)	2.85
Melting point (˚C)	660
Poisson's Ratio	0.33
Modulus of Elasticity (GPa)	70-80
Hardness (HV)	65
Tensile Strength (MPa)	180-190
Co-efficient of Thermal Expansion µm/m˚C	24.3
Thermal Conductivity W/mK	190

Boron carbide (B_4C) is a very hard ceramic made by synthetically combining boron and carbon; it is the third hardest significant material, after cubic boron nitride (CBN) and diamond, and is used as an abrasive material and to fight wear. The material's exceptional hardness and low density make it ideal for usage as particles in aluminum matrix alloy to create composition material. In the present work B_4C particulates with 10 µm were used which was purchased from Speed Fam India Pvt. Ltd., Chennai. Fig. 2 is representing B_4C particles and Table 3 showing the typical properties of B_4C.

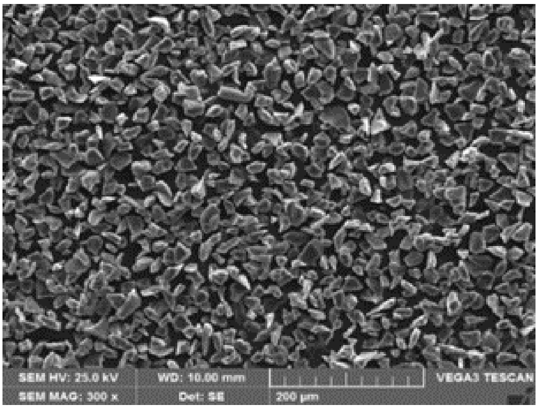


Fig. 2. Scanning electron microphotographs of 10-micron B_4C particles

Table 3. Typical properties of B_4C

Properties	Boron Carbide
Melting point	2445˚C
Hardness (BHN)	2900-3580
Density (g/cm3)	2.52
Coefficient of thermal expansion (10-6 ºC)	5
Fracture toughness (MPa-m1/2)	2.9 – 3.7
Poisson's ratio	0.21
Color	Black

2.2. Preparation of Composites

The stir casting process is well-known as a very promising route for producing near-net-shape hybrid metal matrix composite components at a normal cost, and it is one of the most often used liquid metallurgical route methods. In this study, we employed a stir casting technique to create Al7085 containing between 4% and 8% B_4C particulate MMCs with a size of 10 microns. In this investigation, Al7085 alloy serves as the matrix material. Composites were made using B_4C particles that were 10 microns in size. The Al7085 alloy was superheated to a temperature of 750˚C in an electrical resistance furnace after being charged into a graphite crucible. Using a digital temperature controller, we were able to maintain a temperature tolerance of 10°C in the boiler.

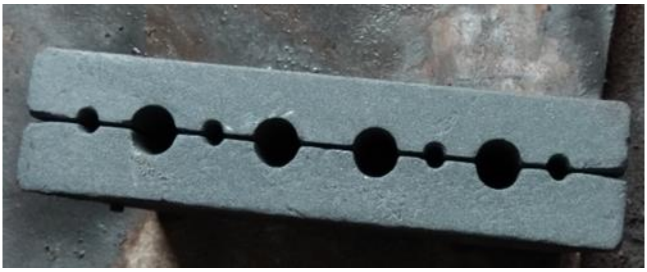


Fig. 4. Cast iron die

Fig. 5. Al7085 alloy -B_4C composites after casting

Table 4. List of various composites prepared

Matrix	Reinforcement	Compositions of composites prepared
Al7085	B_4C	Al7085-4 wt. % of B_4C composites
Al7085	B_4C	Al7085-8 wt. % of B_4C composites

An innovative two-stage mixing procedure is used, and the reinforcing particles are preheated as well. To remove the adsorbed gases from the particle surface and to prevent a high drop in temperature after adding the particulates, ceramic B_4C particles were warmed in an oven to 300˚C. After the molten alloy was effectively degassed with solid hexachloroethane (C_2Cl_6) [18], B_4C particles were injected into the vortex. A zirconia-coated steel impeller was used to create the vortex. Mechanical stirring was performed for 5 minutes at each stage before and after reinforcement was added. The stirrer, which was heated before being submerged in the molten metal, is placed about two-thirds of the way up from the bottom of the vessel and rotates at a rate of three hundred revolutions per minute. The composite material was poured into the cast iron, making it permanent.

Al7085-B_4C composites were prepared by using micro B_4C particulates and varying percentages like 4 and 8 wt. %. Cast iron die used for the study is shown in Fig. 4. Fig. 5 is showing the Al7085 ally and B_4C composites after casting. Table 4 indicates the various composites prepared in the current research.

2.3. Testing of Composites

The composite casting used in this study was cut into multiple pieces from various locations, and then polished at low speed using polishing materials made of abrasive particles less than 3 microns in size. Scratches on the surface of composites were eliminated through polishing. Polishing was accomplished using films composed of abrasive SiC and Al_2O_3. A fine microstructure can only be achieved with the help of high-quality abrasive films and polishing cloth. To improve the optical visibility of microstructural features including phase features and grain size, the polished material was etched using Kellar's reagent ($HCl+ HF+ HNO_3+ H_2O$). Kellar's reagent was applied to the cleaned and polished surface with cotton swabs soaked in etchant, employing light, rotating motions to ensure even distribution of the reagent. After drying, the etched surface was cleaned with rubbing alcohol. The features of the etched surface of the dried specimen were examined using a scanning electron microscope (SEM) and an energy dispersive spectrometer.

The ASTM D792 method is used to determine density, with standard test pieces of 12 mm in diameter and 30 mm in length (within 0.15 mm of each end). To estimate mass, we soak the sample in distilled water at room temperature and use a digital balance with a resolution of 0.001 g. The density of a composite can be evaluated empirically with the help of a physical offset and instruments that have been calibrated in line with ASTM: D792-66.

Brinell hardness testing according to ASTM E10 [19] norms is used in this research. The Brinell test is used when a material's surface is too rough for a standard hardness tester. The hardness of as cast Al7085 alloy and Al7085 alloy with B_4C particles reinforced composites was measured using a 5 mm ball indenter and a load of 250 kgf applied at a dwell duration of 30 seconds in different spots on each sample composite.

A universal testing machine (UTM) that complies with ASTM E8 [20] is used for the tension test. Under precise conditions, the sample is stretched to the point of failure. Tensile testing, while destructive, can reveal useful information about a material's strength and pliability. The results of this test reveal crucial details, such as the metal's tensile strength. The goal of a tension test is to locate the breaking point of a material when subjected to a high level of tension. This technique can be used to calculate the safety factor of a material and the most force that can be applied to it before it breaks. Additionally, it helps engineers choose which materials are most suited for a project.

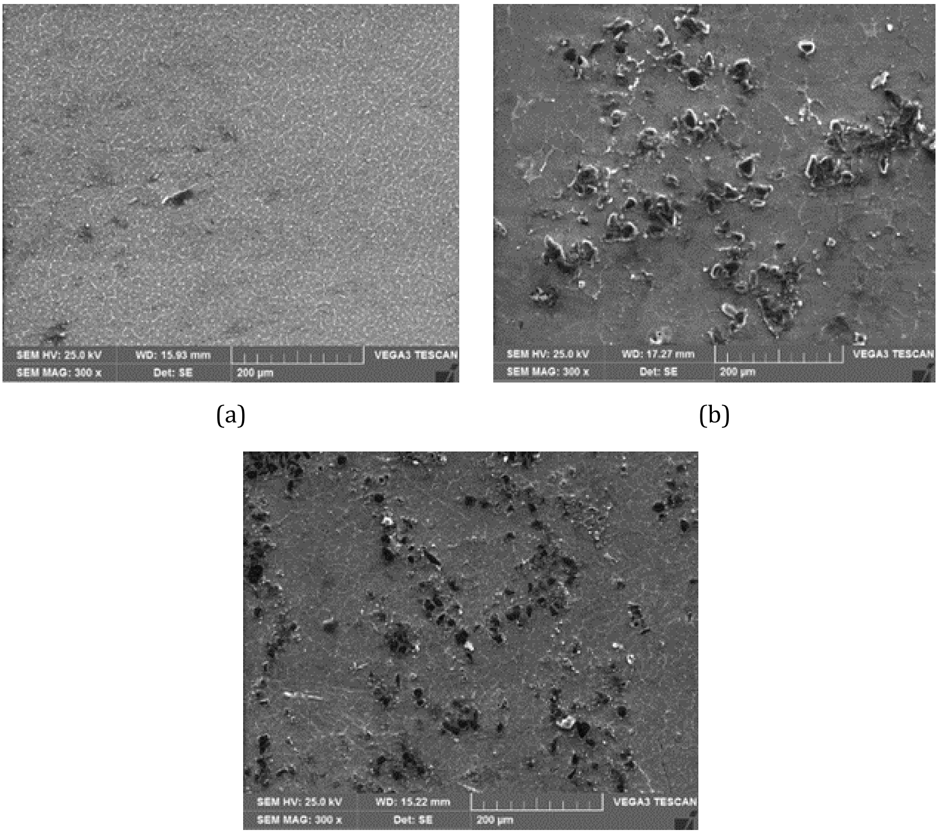
Fig. 6. Tensile test specimen

Uni-axial tensile testing was performed on specimens that had been prepared in accordance with ASTM E8 requirements for tension testing. The 9 mm diameter circular specimen was made with a 45 mm gauge length. Fig. 6 shows a cutaway view of the tensile test specimen. Instron's servo-hydraulic machine with a cross head speed of 0.28 mm/min was used to conduct the tensile test on the specimen. Composite samples undergo testing at room temperature.

3. Results and Discussion

3.1. Microstructural Analysis

The microstructure properties of the sample are examined by SEM. Fig. 6 (a-c) shows SEM images of Al7085 alloy and micro B_4C reinforced composite. Fig. 6 (a) shows the SEM of a pure Al7085 alloy. Figure 6 (b-c) shows Al7085-4 wt. % and Al7085-8 wt. % of boron carbide composites. These figures also show the uniformity of the composite material produced.



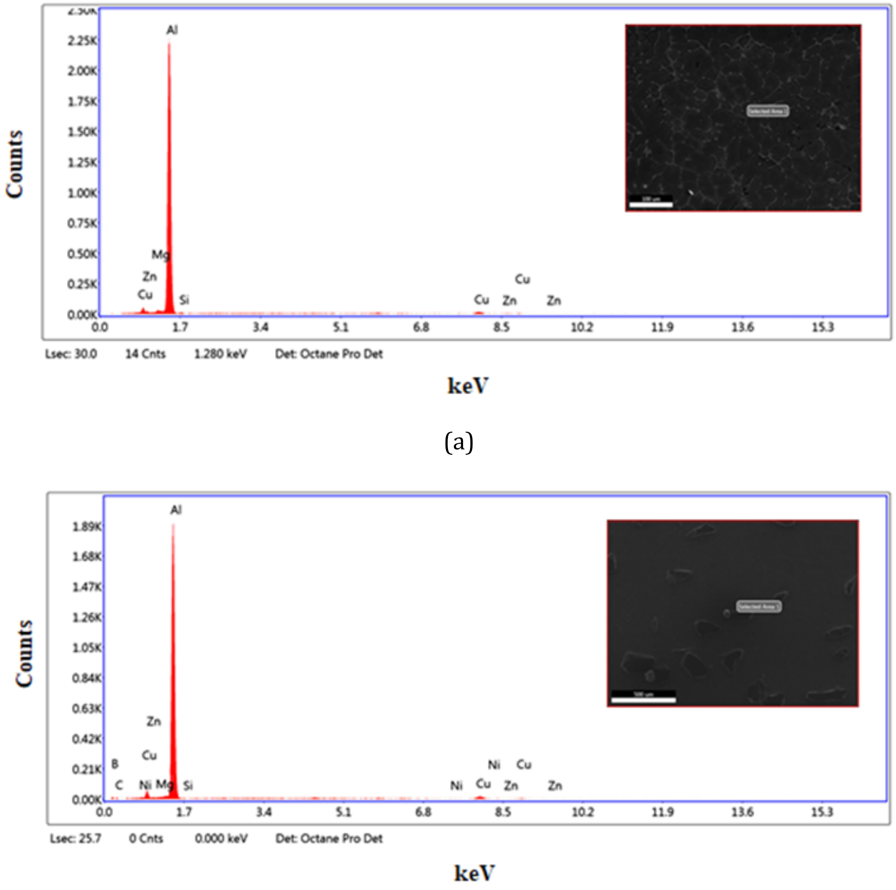
(a) (b)

(c)

Fig. 6. Scanning electron microphotographs of (a) as cast Al7085 alloy (b) Al7085-4% B4C (c) Al7085-8% B4C composites

The scanning electron microscopy (SEM) of as cast Al7085 alloy shows that the material is completely free of particles because it is not reinforced. Given that zinc is the primary alloying component in Al7085, the matrix displays a characteristic leafy structure that is indicative of zinc's presence. Additionally, the homogeneity of the B_4C particles in the finished composites is shown in Fig. 6 (b-c). Micrographs also show how the composites of Al7085 alloys have far more reinforcement than their initial designs did. As can be observed in Fig. 6 (c), the microstructure of the composite has been greatly enhanced by the addition of 8 wt.% of 10-micron sized B_4C to the Al7085 alloy matrix in two separate steps. Also, a close inspection of Figure 6 (b-c) reveals that the B_4C particles are easily distinguishable, indicating strong bonds between the Al7085 alloys.

EDS is one of the influential and valuable techniques for identifying elements and their relative proportion presence [21]. Although it is possible to determine which elements are present in a sample through chemical analysis, the percentages assigned to those elements cannot be determined with great precision without the help of EDS. Elements in Al7085 alloy and Al7085 with 4 and 8 wt.% of 10 µm B_4C composites are analyzed using EDS.



(a)

(b)

Fig. 7. EDS spectrums of (a) as cast Al7085 alloy (b) Al7085-8% B_4C composites

Figures 7 (a-b) display EDS spectrographs of Al7085 supplemented with boron carbide particles of 10 micron size, at 8 weight percent. Al and Zn are shown in Fig 7 (a); Zn is the principal alloying constituent in the Al 7XXX series alloys. The presence of boron carbide particles in the produced Al7085 with B_4C composites is further demonstrated by the presence of boron (B) and carbon (C) components alongside the Al peaks (Fig. 7b).

3.2. Density Measurements

The theoretical and experimental values obtained for of as cast Al7085 and Al7085 with varying wt. % of B_4C particles composites are detailed in Fig. 8. The calculated theoretical values are close to the values obtained via the experimental method, and it is anticipated that the experimental values will be close to the theoretical values in this study. Due to the standardization of methods used to calculate theoretical values, it is extremely unlikely that experimental values will match those predicted by theory. If we look at Fig. 8, we can see that the density of Al7085 alloy decreases as the percentage of micron-sized B_4C increases from 4 to 8 wt.%. This decrease in density is due to presence of low density materials in the Al27085 alloy. The density of base matrix Al7085 alloy is 2.85 g/cm^3, but the densities of B_4C reinforcements are 2.52 g/cm^3 [22]. Due to the effect of lower densities materials addition in the Al7085 alloy contributed in decreasing the theoretical densities of the composites to 2.82 g/cm^3 with the addition of 8 wt. % of boron carbide particles in the Al7085 alloy. Further, same trend has been observed in the case of experimental densities also. Both the theoretical and experimental densities are very close to each other.

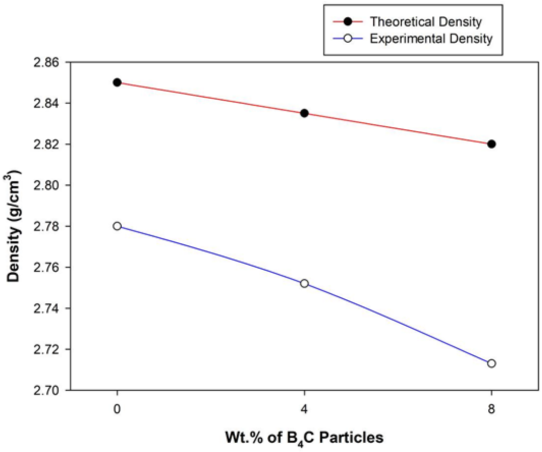


Fig. 8. Comparison of theoretical and experimental densities of Al7085 alloy and B_4C composites

3.3. Hardness Measurements

From the Fig. 9 it can be seen that the hardness of alloy Al7085 increases as the weight percent of B_4C particles increases from 4% to 8% by weight. The hardness of the cast Al7085 alloy is 67.93 BHN. The percentage of B_4C particles increased the hardness of the Al7085 alloy to 92.33 BHN. The hardness improvement of the Al7085 alloy is 35.9% with the addition of 8% by weight. % of B_4C particles. The increased hardness is due to the presence of solid B_4C particles that act as obstacles to the movement of dislocations within the Al7085 matrix. Usually, after the addition of fine particles, the strain energy at the edges of the B_4C particles increases, this increases the hardness of the composite. The same observations can be found in the studies of other researchers.

Other researchers have reported similar outcomes, and also it was determined that the improvement in hardness may be caused by the existence of reinforced particles, which make dislocation movement within the base matrix more challenging. The grain refining based on the Hall-Petch process is primarily responsible for the increase in hardness value [23]. Additionally, particles can have a particle strengthening effect, which increases hardness value while preventing dislocations from moving. The kind, size, quantity, and dispersion of ceramic hard ceramic particles all affect how hard something is. The main causes of the sample's greater hardness value are mechanical churning that breaks -Al dendrites and the use of B_4C particles as reinforcements.

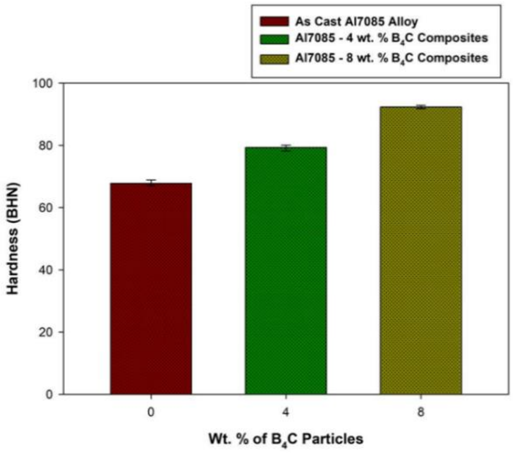


Fig. 9. Hardness of Al7085 alloy and B_4C composites

3.4. Tensile Properties

Tensile tests were conducted at room temperature with varying percentages of micro B_4C particles, and the findings are displayed in Fig. 10. Figure 10 show that when B_4C content in Al7085 alloy rises, so does the average UTS value. The Al7085 matrix alloy is protected from damage by the tiny B_4C particle. Al7085 alloy has a UTS of 211.97 MPa when cast.

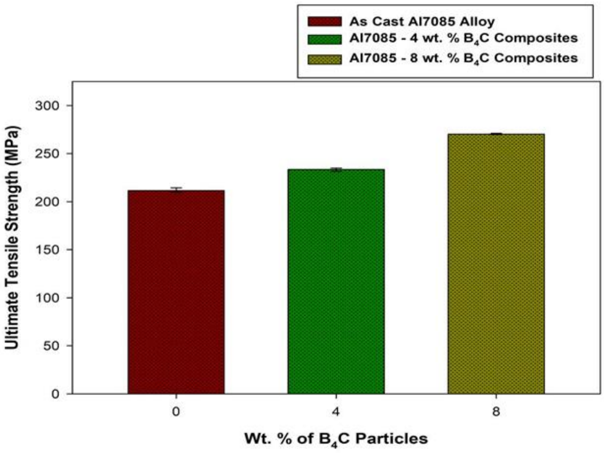


Fig. 10. Ultimate tensile strength of Al7085 alloy and B_4C composites

Furthermore, as shown in Fig. 10, the UTS values increased as the weight percentage of micro B_4C particles was increased from 4 to 8 wt.% insteps of 4 wt.%. The UTS value of B_4C composites in Al7085 alloy at 4 wt. % is measured to be 233.27 MPa. After 8 wt. % of micro B_4C particles were added to Al7085 alloy, the ultimate strength of the material increased by 27.5%. The difference in thermal co-efficient of expansion between the Al7085 matrix alloy and the uniformly dispersed micro B_4C particles contributes to an increase in ultimate strength of the alloy following integration of 4 and 8 wt.% of B_4C particles [24]. By interacting with dislocations, the addition of non-shearable tiny boron carbide particles raise the strength of Al7085 alloy from 4 to 8 wt. %.

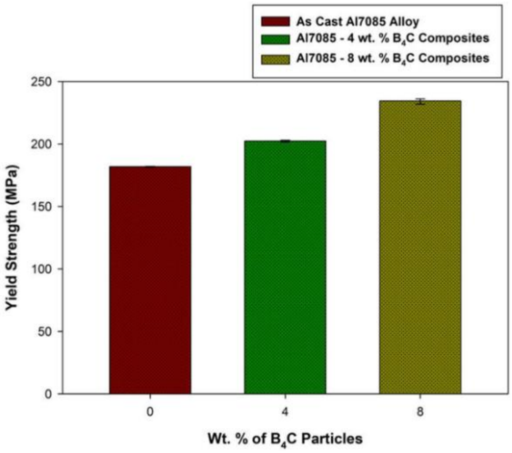


Fig. 11. Yield strength of Al7085 alloy and B_4C composites

From the Fig. 11 the yield strength of the Al7085 alloy is enhanced with the addition of B_4C particles. As the wt. % of B4C particles increases from 4 wt. % to 8 wt. %, there is an increase in the yield strength of Al7085 alloy. The YS of as cast Al7085 alloy is 181.77MPa, this strength is increased to 202.17 MPa and 234.03 MPa respectively in 4 and 8 weight % of B_4C reinforced composites. Similar kinds of observations were made by other authors [25] with the incorporation of B_4C particles in the Al alloy matrix. In the case of Al7085 – 8wt. % of B_4C reinforced composites, the improvement in the yield strength is 28.7%. The improvement in yield strength is demonstrated by the hard B_4C particles. This adds value to the framework mixture in this way by giving it better solid stiffness.

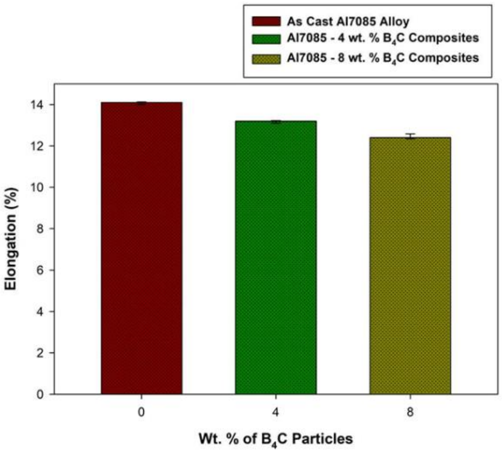


Fig. 12. Elongation of Al7085 alloy and B_4C composites

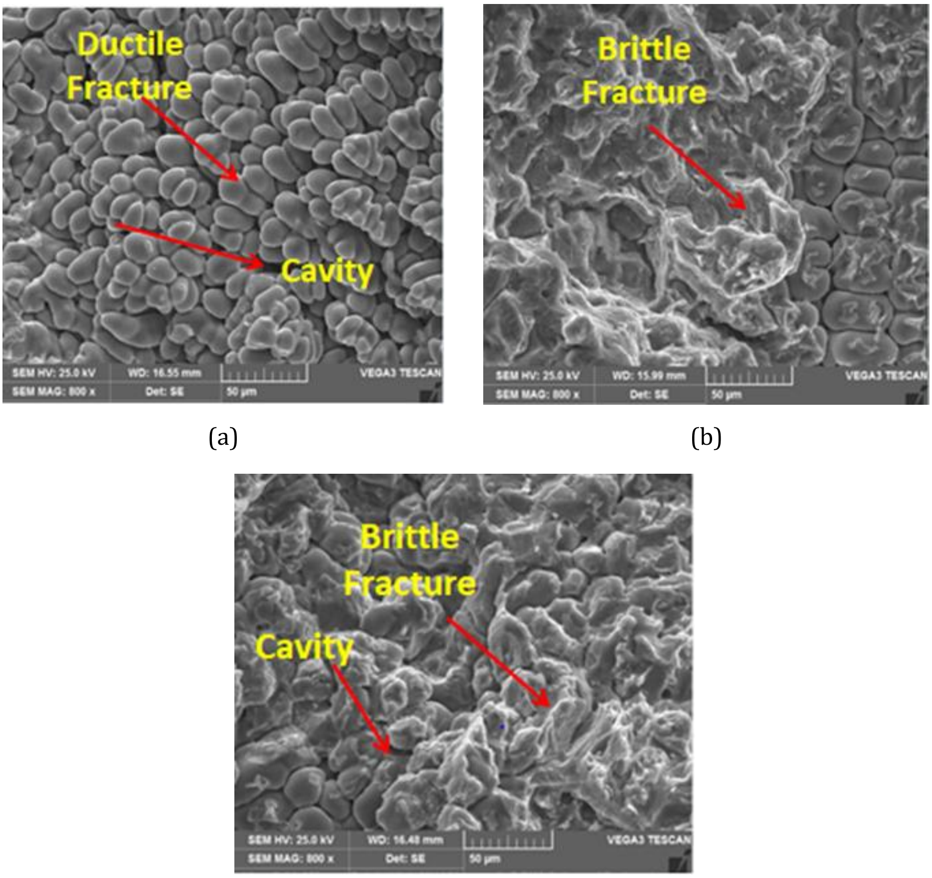
The expansion of these hard particles may have resulted in a tremendous persistent compression failure created with cementation due to the contrast of the evolving coefficients between the flexible matrix and the brittle particles. The improved quality is also due to the tight packing of the stiffeners and therefore the small spacing between the particles in the grid [26].

The influence of B_4C particles on the ductility of Al7085 alloy and its composites is shown in Fig. 12. The material tends to lengthen when an axial load is applied to a specimen.

Elongation is calculated in tensile testing by comparing the gauge length of the specimen before and after it cracks. A larger percentage of elongation indicates greater ductility, and elongation is typically represented as a percentage of the specimen's original length [27]. Tensile testing results are shown in Fig. 12 for as cast Al7085 alloy, Al7085 alloy with 4 wt.% of B_4C particulates composites, and Al7085 alloy with 8 wt.% of B_4C particulates composites. After B_4C particles are added to as cast Al7085 alloy, the percentage elongation decreases; further reductions occur as the weight percentage of reinforcement increases in Al7085 alloy.

3.5. Tensile Fractography

Fractured SEM surfaces of Al7085- B_4C composites at 800X magnification are shown in Figure 13, and broken faces of tensile test samplings of as cast Al7085 and Al7085- B_4C composites are shown in Figures 13a–13c. The purpose of this fracture analysis is to determine how B4C modifies the fracture characteristics of composites.



(a) (b)

(c)

Fig. 13. Tensile fractured surfaces of (a) as-cast Al7085 alloy (b) Al7085-4 wt. % B_4C (c) Al7085-8 wt. % B_4C composites

Trans granular and intergranular regions in a fracture of an Al7085 alloy (see Figure 13a) are indicative of brittle fracture. The SEM images in Figure 13 (b-c) are of Al7085- B_4C composites with 4 and 8 wt.% B_4C. Fracture zones show plastic deformation, including ripped edges and cleavage facets. Dimples in the matrix are visible in some places along composite fracture surfaces.

These dimples may have formed as a result of void nucleation and subsequent coalescence brought on by the extreme shear distortion, fragmentation, and decohesion of B_4C. Perhaps there is some fundamental problem in the matrix. As can be shown in Fig. 13c, the particle-matrix interface functions as intended, as micro fractures did not propagate through the B_4C particle but instead to the matrix via the Al7085- B_4C contact. If dislocations build at the contact because of a load, localized high stress can result. De-bonding at the reinforcement/matrix interface, leading to cracks and dimples [28, 29], occurs when the stress exceeds the interfacial binding forces.

4. Conclusions

The stir cast method is suitable for producing Al7085 alloy with B_4C particles of 10 microns in size and MMCs of 4 and 8 wt. percent. Scanning electron microscopy images show that B_4C particles are evenly dispersed across the Al7085 alloy. This study analyzed the EDS patterns of composites made from Al7085 alloy and B_4C particles at 8 weight percent. The presence of boron and carbon elements in Al7085 alloy with B_4C composites are confirmed by EDS spectrums. The incorporation of B_4C particles reduced the density of Al7085 alloy composites. The lowest density is observed in the Al7085 alloy with 8 wt. % of boron carbide particles reinforced composites. Further, theoretical and experimental densities are very nearer to each other, which indicate the proper casting method of Al7085 alloy and B_4C composites. The hardness of Al7085 alloy has increased with the incorporation of B_4C particles. The highest hardness is observed in the case of Al7085 alloy with 8 wt. % of B_4C composites. Improvements in the hardness of Al7085 alloy with 8 wt. % of B_4C particles is 69.6%. Ultimate and yield strengths of Al7475 alloy have enhanced with the 2 to 10 wt. % of boron carbide particles reinforced addition. Improvements in the UTS and YS with 10 wt. % of B_4C particles in Al7475 alloy is 51.8% and 61.6% respectively. Further, UTS and YS values of as cast Al7475 alloy and its 2 to 10 wt. % of boron carbide composites decreased at elevated 50˚C and 100˚C. The ductility of Al7475 alloy has been slightly reduced with the incorporation of boron carbide particles in the Al7475 alloy matrix. The ductility has been improved in the case of elevated temperatures as compared to the room temperature experimental values.

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