Microstructure and Tensile Behaviour of B₄C Reinforced ZA43 Alloy Composites

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Abstract. The work is carried out to investigate and study the mechanical properties of B₄C reinforced ZA43 alloy metal matrix composites. In the present work ZA43 alloy is taken as the base matrix and B₄C particulates as reinforcement material to prepare metal matrix composites by stir casting method. For metal matrix composites the reinforcement material was varied from 0 to 6 wt. % in steps of 3 wt. %. For each composite, the reinforcement particulates were preheated to a temperature of 300ºC and dispersed into a vortex of molten ZA43 alloy. The microstructural characterization was done using scanning electron microscope. Mechanical properties like hardness, ultimate tensile strength and yield strength were evaluated as per ASTM standards. Further, scanning electron microphotographs revealed that there was uniform distribution of B₄C particulates in ZA43 alloy matrix. Hardness, ultimate tensile strength and yield strength increased as wt. % of B₄C increased in the base matrix.

1. Introduction
Metal matrix composites are increasingly becoming attractive materials for aerospace, automobile industries due to light weight, low cost, easy fabrication and ever increasing demands of modern technology. Metal matrix composites are the combination of soft base metal with hard refinement material and have recently found special interest because of their specific strength and specific stiffness at room or elevated temperature. With the advancement of modern technology, there is a everlasting demand for an economical, light weight, harder, stronger and energy saving material in the area of space, aircraft, advanced defence fighter jets and automobile applications [1-3]. Zinc-aluminium alloy matrix composites (ZAMC) found application in these areas. Many modern fabrication techniques where in use for the manufacture of MMC materials according to the type of base material and the type of reinforcement used like stir casting; squeeze casting, liquid metal infiltration and spray co-deposition. Among the above, stir casting technique is the simplest and most economically used technique, it is also known as ‘vortex technique’. Stir casting technique is attractive because of simplicity, low cost of processing, flexibility, most economical for large sized components to be prepared as well as production of near net shaped components [4, 5].

Due to advancement in technology, there is enlarged demand for an economical, light weight, harder, stronger and energy saving material in the area of space, aircraft, defence and automotive application and zinc-aluminium matrix found applications in these areas. ZA alloy reinforced with hard ceramic particles of WC, SiC, Al₂O₃, B₄C and graphite for forming a composite to realize improvements in mechanical properties such as hardness, young’s modulus, yield strength and ultimate tensile strength of the MMCs. The composites finds application in aerospace and automobile industries [6-8]. Though stir casting is the most commonly methods employed for the MMCs, wettability is the main problem associated with stir casting. To overcome the problem of wettability many researchers have used magnesium as wetting agent.
ZAMCs with SiC as the reinforcement particle, SiC has a tremendous advantage of improving the properties like low density, high strength, low thermal expansion, high thermal conductivity, high hardness, high elastic modulus, excellent thermal shock, resistance and superior chemical inertness. Priority has been emphasized for developing affordable ZA-based MMCs with various hard and soft reinforcements like SiC, Al₂O₃, zircon, graphite and mica [9].

There has been tremendous research work carried for the mechanical behaviour and for the wear. As per the research carried out so far, it was revealed that the reinforcement particulate graphite increases the wear resistance and with another reinforcement of Al₂O₃ in a hybrid matrix, mechanical properties where improved and also at elevated temperatures. Even for the Al alloy A356 and reinforcement of SiC composites; it has been investigated for dry sliding wear studies shows better mechanical behaviour compared to those without coating.

From the literature survey, there is a lack of data available for mechanical behaviour of ZA43 alloy reinforced with B₄C particulates. The microstructure and the mechanical behaviour of ZA43 alloy matrix with reinforced B₄C particulates have been studied. Mechanical properties like hardness (BHN) and tensile strength of ZA43 alloy and ZA43 alloy with 3 and 6 wt. % of B₄C composites were evaluated as per ASTM standards.

2. Experimental Details

2.1 Materials Used

For the metal matrix composite the base alloy ZA43 is reinforced with Boron Carbide powder of 60-70 microns in size and is fabricated as ZA43-B₄C metal matrix composites. Density of ZA43 is 4.2 g/cc and that of the reinforcement particle is 2.54 g/cc. The chemical composition of ZA43 base alloy is shown in Table1.

| Elements | Wt. Percentage |
|----------|----------------|
| Al       | 43.0           |
| Cu       | 2.5            |
| Mg       | 0.02           |
| Fe       | 0.012          |
| Zn       | Bal            |

2.2 Composites preparation

The metal matrix composites of ZA43-B₄C have been produced by stir casting technique. ZA43 is heated to the temperatures of 500°C in the electrical resistance furnace. The addition of reinforcement particulate B₄C varied from 3wt % to 6wt % in steps of 3wt %. Due to the increase in the weight percentage of reinforcement particulates B₄C porosity defect may occur during metal matrix composite where as increasing the stirring time reduces the porosity level. The temperature of the electric furnace was controlled to an accuracy of ± 20°C using a digital temperature controller. Degassing agent solid hexa-chloroethane (C₂Cl₆) is added to expel all absorbed gases from the molten metal once the temperature has been reached [10]. Before the addition of B₄C particulates, mechanical stirring process is carried out with the help of zirconia coated stirrer to form a fine vortex. The speed of the stirrer is rotated for 5-8 minutes at a spindle speed of 250 rpm. The B₄C particulate is preheated to a temperature of 300°C in a pre-heater to increase the wettability. The stirrer was immersed into the molten metal in the crucible at a depth of 2/3 from the bottom. The addition of the B₄C particulates to the molten metal is divided into two equal weights rather adding all at once to avoid agglomeration of
the matrix. At every stage, stirring is carried out before and after introduction of reinforcement particulate $B_4C$ to the molten metal. Figure 1a showing the cast iron die used to fabricate the composites and figure 1b showing the $B_4C$ reinforced ZA43 alloy composites after casting.

![Image](image1.jpg)

**Figure 1.** showing the (a) cast iron die (b) ZA43-$B_4C$ composites after casting

### 2.3 Testing

Microstructure and mechanical behaviour of the ZA43 alloy and ZA43-$B_4C$ composite were carried out. A metallographic examination was carried out by using scanning electron microscope. The sample preparation for microstructure study was carried out first by polishing the sliced samples with emery paper up to 1000 grit size, followed by polishing with $Al_2O_3$ suspension on a grinding machine using velvet cloth. Finally, the samples were polished by using 0.3 microns diamond paste. The polished surface was etched with Keller’s reagent and examined with a scanning electron microscope. The tensile properties of the specimen were measured by using an electronic tensile testing machine at room temperature based on ASTM E8 M88 standard [11]. Hardness tests were performed on ZA43 alloy and ZA43-$B_4C$ composites to know the effect of $B_4C$ particles in the matrix material as per ASTM E10 standard. The polished specimens were tested for their hardness, using Brinell hardness testing machine having ball indenter for 62.5 kg load and dwell time of 30 sec. Five sets of readings were taken at different places of the specimen and an average value was used for calculation.

### 3. RESULTS AND DISCUSSION

#### 3.1 Microstructure Studies

Figure 2 (a) - (c) shows the scanning electron microscope micrographs of as cast ZA43 alloy and its composites. Figure 2(b) – (c) shows the SEM micrographs of 3 & 6wt. % of $B_4C$ particulate composites. This reveals the uniform distribution of $B_4C$ particles and very low agglomeration and segregation of particles. The vortex generated in the stirring process breaks solid dendrites due to higher friction between particles and ZA matrix alloy, which further induces a uniform distribution of particles. Figure 2 b and 2c shows the good interfacial bonding between the ZA43 matrix alloy and $B_4C$ particulates. Further, this good interfacial bonding helps in enhancing the hardness and tensile strength of composites.
3.2 Hardness Measurements

From figure 3, it is observed that there is an increase in the hardness of ZA43 with addition of 3 and 6 wt % of B₄C particulate. The graph shows the variation of hardness of ZA43 alloy with B₄C reinforcement particulate. It can be concluded that the addition of wt. % of B₄C particulate results in increasing the hardness. The hardness of a soft material such as zinc-aluminum matrix is increased when it is reinforced with a hard particulate i.e., B₄C. The percentage improvement in the hardness of ZA43-6 wt. B₄C composite is 48% compared to base alloy ZA43. In fact, the hardness of composite depends on the hardness of the reinforcement and the matrix. This increase in hardness is mainly due the coefficient of thermal expansion (CTE) of ceramic particles is less than that of aluminium alloy [12]. So, an enormous amount of dislocations are generated at the particle-matrix interface during solidification process, which further increases the matrix hardness. The higher the amount of particle-matrix interface, the more is the hardening due to dislocations.

Figure 2. Showing SEM micrographs of (a) ZA43 Alloy (b) ZA43- 3 wt. % B₄C (c) ZA43- 6 wt. % B₄C composites
3.3 Ultimate Tensile Strength

Figure 4 shows the variation of ultimate tensile strength (UTS) of base alloy, when reinforced with 3 and 6 wt. % of B₄C particulates. The ultimate tensile strength of ZA43- B₄C composite material increases as compared to the cast base ZA43 alloy. The microstructure and properties of hard ceramic B₄C particulates control the deformation of the composites. Due to the strong interface bonding, load from the matrix transfers to the reinforcement resulting in increased ultimate tensile strength. This increase in ultimate tensile strength mainly is due to presence of B₄C particles which are acting as barrier to dislocations in the microstructure. The improvement in ultimate tensile strength of ZA43-3 wt. % B₄C and ZA43-6 wt. % B₄C composites is found to be 11 and 27 % respectively. The improvement in ultimate tensile strength may also be due to alloy strengthening of the matrix, followed with a reduction in grain size of the composites, and the formation of a high dislocation density in the ZA43 alloy matrix due to the difference in the thermal expansion between the metal matrix and the B₄C reinforcement [13, 14].
3.4 Yield Strength

Figure 5 shows variation of yield strength (YS) of ZA43 alloy matrix with 3 and 6 wt. % of B₄C particulate reinforced composite. It can be seen that by adding 6 wt. % of B₄C particulates yield strength of the ZA43 alloy increased from 275MPa to 350MPa. This increase in yield strength is in agreement with the results obtained by several researchers, who have reported that the strength of the particle reinforced composites is highly dependent on the volume fraction of the reinforcement. The increase in YS of the composite is obviously due to presence of hard B₄C particles which impart strength to the soft zinc-aluminum matrix resulting in greater resistance of the composite against the applied tensile load. In the case of particle reinforced composites, the dispersed hard particles in the matrix create restriction to the plastic flow, thereby providing enhanced strength to the composite.

![Graph showing yield strength variation](image-url)

**Figure 5.** The yield strength of ZA43 alloy and varying wt. % of B₄C composites

4. CONCLUSIONS

The present work on microstructure and tensile behaviour of B₄C reinforced ZA43 alloy composites has led to some important conclusions. ZA43 alloy-B₄C particulate composites were successfully produced by liquid stir casting route with different weight percentage (3wt. % and 6wt. %) of reinforcement. Zinc-aluminum based metal matrix composites have been successfully fabricated by liquid stir casting method by two step addition of reinforcement combined with preheating of particulates. The hardness of ZA43-B₄C MMC is increased with increase in wt. % of B₄C particulates. The improvement in hardness of ZA43 alloy is 48% after addition of 6 wt. % of B₄C particulates. The extent of improvement obtained in B₄C alloy after addition of 3 and 6 wt. % B₄C particulates were 11 and 27 percentages respectively. Improvements in yield strength of the ZA43 alloy matrix were obtained with the addition of B₄C particulates. The extent of improvement obtained in ZA43 alloy after addition of 3 and 6 wt. % B₄C particulates were 8 and 26 percentages respectively.

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