Investigations on mechanical behavior of Al7075 - nano B₄C composites

T H Manjunatha¹, Dr. Yadavalli Basavaraj², Madeva Nagaral³, Dr. V Venkataramana⁴, Jayasheel I Harti⁵

¹Assistant professor, Department of mechanical engineering, BITM, Ballari-583104, Karnataka, India
²Professor and Head, Department of mechanical engineering, BITM, Ballari-583104, Karnataka, India
³Aircraft Research and Design Centre, HAL, Bangalore-560037, Karnataka, India
⁴Professor, Department of mechanical engineering, BITM, Ballari-583104, Karnataka, India
⁵Department of Mechanical Engineering, East Point College of Engineering and Technology, Bangalore-560049, Karnataka, India

*corresponding author: manjuforeverthree@gmail.com

Abstract. The paper is the result of investigations made on microstructure and mechanical behavior of 3 and 6 weight percentage of nano sized B₄C particulate reinforced to Al7075 alloy composites. Al7075 matrix composite having nano boron carbide was fabricated by liquid stir casting method. The microstructure of the composites was examined by scanning electron microscopy. Further, mechanical behavior of Al7075 alloy, Al7075-3wt. % B₄C and 6 wt. % B₄C composites were studied. Tensile properties like hardness, ultimate tensile strength; yield strength, percentage elongation and compression strength were evaluated as per ASTM standards. Micro structural observation revealed uniform distribution of B₄C particles in the matrix. The analysis disclosed hardness, ultimate tensile strength, yield strength and compression strength of composites increased due to increase in percentage of nano boron carbide particles and percentage elongation of the composites decreased with increase in B₄C particulates in base alloy matrix.

Keywords: Al7075 Alloy, B₄C Nano Particulates, Ultimate Tensile Strength, Yield Strength, Stir casting, Percentage Elongation

1. Introduction

Aluminium based metal matrix composites (AMCs) have found greater applications in the field of automotive, aircraft industries owing to their low density and concomitant high wear resistance, strength, corrosion resistance, stiffness and thermal conductivity [1, 2]. AMCs are fabricated by incorporating micro and nano sized ceramic particles, such as SiC, Al₂O₃ and B₄C, into the aluminium matrix. Boron carbide is a superior reinforcement material due to its high hardness, low density, high strength, high wear and impact resistance, high melting point, low coefficient of thermal expansion and good chemical stability [3]. Pankaj et al. synthesized the A356-B₄C (4 wt %) and graphite...
particulate metal matrix composite by stirring process and reported that hardness was higher in case of 4wt. % of B$_4$C and shown improvements in ultimate and yield tensile strength with addition of B$_4$C and graphite particulates [4]. Krishna Dama et al. investigated the effects of adding micro size B$_4$C particles to ZA27 alloy on the mechanical properties, observed that the hardness, ultimate tensile strength and yield strength of alloy increased as the level of addition of B$_4$C particulates increased in steps of 3wt. %, 6wt. % and 9wt. %. Further, researchers concluded that the percentage of elongation decreased for the same % wt. with the addition of B$_4$C [5]. Several methods are currently used to fabricate the metal matrix nano composites (MMNCs), viz mechanical alloying [6, 7] high-energy ball milling [8], spray deposition, powder metallurgy, nano-sintering and various casting techniques [9]. The conventional mechanical stir casting method can be used to disperse B$_4$C particles in molten aluminium without agglomeration and clustering. Recent studies, Jiang et al. investigated for the best anticorrosive property by preparing and characterizing nickel nano B$_4$C composite coating, Harichandran et al. investigated the mechanical properties of B$_4$C nano particle reinforced aluminium metal matrix composites and stated ductility, impact energy were better with nano B$_4$C reinforcement along with significant increase in wear resistance up to 8% of B$_4$C. Further researchers like A. Alizadaeh, Morteza etc., have investigated the influence of nano particles reinforcement on the mechanical and microstructural properties of MMC’s. The present research work is aimed to investigate the mechanical behavior of Al7075 alloy with 3 and 6 wt. % of nano B$_4$C composites.

2.Experimental Work:

2.1 Material: The current study used nano sized B$_4$C as reinforcement and Aluminium 7075 as matrix material with chemical composition (using optical emission spectrometer-BAIRD - DV 6E) as shown in the table 1 below.

| Element | Al+ | Cu  | Mg  | Si  | Fe  | Mn  | Ni  | Zn  | Pb  | Sn  | Ti  | Cr  |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| % by Wt | Bal | 1.22| 2.20| 0.09| 0.16| 0.05| 0.01| 5.62| 0.01| 0.01| 0.06| 0.24|

2.2 Preparation of Al7075 – B$_4$C nano Composites: The nano composites containing 3 and 6 wt. % of nano B$_4$C particulates were prepared from two step stir casting process technique. Initially the required amount of nano B$_4$C and the cast iron die are preheated to a temperature of 300-400°C. On the other part, the calculated amount of Al7075 was weighed and placed in a graphite crucible inside an electric furnace and heated to temperature of 750°C. After the complete melting of Al7075, the degassing powder known as Solid Hexa Chloro Ethane (C$_2$Cl$_6$) [10] is introduced into the molten melt so that the unwanted adsorbed gases are forced out from the melt. The molten melt is disturbed by dipping a zirconium coated mechanical stirrer to form a clear vortex by stirring mechanism at a speed of 300rpm. Once the vortex is formed then the preheated nano ceramic particles along with the proper proportion ratio of K$_2$TiF$_6$ is introduced into the molten melt in steps of two stages by a constant feed rate, which involves in dividing the entire weight mixture of nano B$_4$C and K$_2$TiF$_6$ in two equal weights. At every each stage the continues stirring process is carried out before and after the pouring of mixture of nano B$_4$C and K$_2$TiF$_6$ to avoid clustering of particulates and to have uniform homogenous distribution of nano particulates in the melt. After continues stirring, the entire molten metal was poured into preheated cast iron die. The prepared nano composites were machined as per the standards for characterization purpose.

2.3 Testing of Composites: The micro structural study was carried out on the prepared composites using Vegas Tescan made scanning electron microscope. The test sample is 10 -12 mm in diameter cut from the castings and polished thoroughly, for etching the sample Keller’s reagent was used. Indentation response of as cast Al matrix alloy and its nanocomposites were evaluated by Brinell hardness tester.
The required specimens were prepared according to standard metallographic procedures. The experiments were carried out by applying a load of 250kgf and dwell time of 30 seconds. The indentation load depth values were recorded and the hardness was determined. For each sample, the indentation test was repeated 3 times and the averaged data were reported. Tensile and compression specimens were machined from the cast samples. The tensile specimens of circular cross section with a diameter of 9 mm and gauge length of 45mm were prepared according to the ASTM E8 standard testing procedure using Instron made Universal Testing Machine. All the tests were conducted in a displacement control mode at a rate of 0.1 mm/min. Multiple tests were conducted and the best results were averaged. Various tensile properties like ultimate tensile strength, yield strength and percentage elongation were evaluated for as cast Al7075 alloy, Al7075- 3 and 6 wt. % B₄C composites. Compression test was conducted on the same machine as per ASTM E9 standard. Figure 1 showing the tensile test specimen dimensions used to conduct the experiments.

![Figure 1: Tensile specimen and its dimensions in mm.](image)

3. Results and Discussion:

3.1 Microstructure Study: Figure 2 (a-b) shows the SEM microphotographs of Al7075 alloy as cast and Al7075 with 6 wt. % of nano B₄C particulate composites. This reveals the uniform distribution of B₄C particles and very low agglomeration and segregation of particles, and porosity. Fig. 2 b clearly shows the even distribution of nano B₄C particles in the Al7075 alloy matrix. There is no evidence of casting defects such as porosity, shrinkages, slag inclusion and cracks which is indicative of sound castings. In this, wetting effect between particles and molten Al7075 alloy matrix also retards the movement of the B₄C particles, thus, the particles can remain suspended for a long time in the melt leading to uniform distribution.

![Figure 2: (a)-(b) Showing the scanning electron microphotographs of (a) as cast Al7075 alloy (b) with 6 wt. % of B₄C.](image)
In order to confirm the presence of $\text{B}_4\text{C}$ energy dispersive spectroscopy analysis was carried out at the edge of the $\text{B}_4\text{C}$ particle and Al alloy matrix. The EDS spectrum reveals the presence of Al, Zn, Cu, Mg, B and C in the interface reaction layer (figure 3).

3.2 Tensile Properties:

Figure 4: Ultimate tensile strength of Al7075-3 and 6 wt. % of nano $\text{B}_4\text{C}$ composites. Figure 4, shows there is gradual increase in the UTS from 227.2MPa to 279.2MPa with 3 - 6 % wt. addition of $\text{B}_4\text{C}$ due to the fact that the properties of $\text{B}_4\text{C}$ particulates control the mechanical properties of the composite showing the intense tensile strength.
Al 7075 Alloy and Nano B₄C Composites

Figure 5: Yield strength of Al 7075-3 and 6 wt. % of nano B₄C composites.
Figure 5 indicates yield strength improved from 176.6 MPa to 217.5 MPa with addition of B₄C from 3% to 6% wt. The enhancement in the yield strength is due to the close packing of B₄C particles providing molecule strength with the aluminum lattice in turn composite [11].

Figure 6: Elongation of Al 7075-3 and 6 wt. % of nano B₄C composites.
Figure 6 illustrates the impact of B₄C with reference to malleability of the composite. It can be observed that the graph is falling down with addition of 3 and 6 wt.% of B₄C particulates but the rate of diminishing is less, between 3 – 6 % wt addition. This is due to the strength acquired by the composite with addition of B₄C owing to its properties [12].
3.3 Compression Strength:

The plot 7 indicates the compression strength of the test specimens with 3 and 6 wt.% of B₄C in Al7075 alloy. It is clearly evident that the compression strength is varied from 629.5 to 711.3MPa. Approximately 13 % increase is noticed with 6 % wt. of B₄C.

3.4 Hardness Study: Brinell hardness test was conducted on the specimens of Al 7075 alloy, 3 and 6% B₄C nano composites, with ball diameter 5mm, load 250Kg and the values obtained are in the range 65.7 to 84.2 BHN evident from the graph 8. The values indicate that there is gradual increase in the hardness because of the hard boron carbide inclusion. As the percentage of particulates increased the hardness also increased parallel.
4. Conclusions

The mechanical investigations of the Al7075-3 and 6 wt.% of nano B₄C composites materials produced by stir casting are remarked as below:

- The liquid metallurgy technique was successfully adopted in the preparation of Al7075-3 and 6 wt.% nano B₄C composites.
- The micro structural studies revealed the uniform distribution of the nano B₄C particulates in the Al7075 alloy matrix.
- The ultimate tensile strength and yield strength properties of the composites found to be higher than that of base matrix.
- Improvements in compressive strength of the Al7075 alloy matrix were obtained with the addition of nano B₄C particulates. The extent of improvement obtained in Al7075 alloy after addition of 6 wt.% nano B₄C particulates is 13%.
- Hardness of the Al7075-nano B₄C composite was found to be more than compared to base Al matrix.

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