# STUDIES ON MECHANICAL BEHAVIOR OF AA7030-$B_4C$ METAL MATRIX COMPOSITES WITH HEAT TREATMENT

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**Abstract -** *Metal matrix composites (MMCs) have been created to meet demands of lighter materials especially suited for applications requiring high strength to weight ratio with high specific strength, dimensional stability, structural rigidity, and stiffness for different applications like automotive, space, aircraft, defence, and in other engineering sectors. In the present work an investigation has been made to study the mechanical properties of as cast AA7030-$B_4C$ composites and heat treated AA7030-$B_4C$ particulate composites. The composites containing 3, 6 and 9 wt. % of $B_4C$ will be prepared using liquid metallurgy route in particular stir casting technique. Microstructural study was done by using scanning electron microscopy and EDS, which revealed the uniform distribution of $B_4C$ particulates in the AA7030 alloy matrix. Solution heat treatment is carried out on cast samples at 525 degree Celsius for 1 hour duration. After solution, T6 heat treatment (Artificial Ageing) was performed on the samples at 175 degree Celsius for 10 hours duration. Mechanical properties like ultimate tensile strength, yield strength, compression and fatigue strength were evaluated as* per ASTM standards.

**Key Words: AA7030 alloy, $B_4C$, Tensile Strength, Fatigue, Compression, Heat Treatment**

## 1. INTRODUCTION

Aluminum matrix composites possess many advantages such as low density, high specific stiffness, high specific strength, good thermal stability, electromagnetic shielding capacities and good wear resistance with the development of some non-continuous reinforcement materials, whisker, fibers or particles. In particular, particles reinforced aluminum matrix composites not only have good mechanical and wear properties, but also are economically viable [1-3].

There are many methods for fabrication of particles reinforced aluminum matrix composites such as powder metallurgy, squeeze casting [4] and compocasting [5]. Among all the techniques to fabricate particles reinforced aluminum matrix composites, the melt stir casting is one of the most economical and versatile [6].

Addition of hard ceramic particles like $SiO_3$, SiC, $Al_2O_3$, $TiB_2$, $B_4C$ etc. to Al matrix lead to strengthening of the matrix with improved properties. Ceramic particles such as $Al_2O_3$ and SiC are the most widely used materials for reinforcement with aluminium. Boron carbide ($B_4C$) could be an alternative to SiC and $Al_2O_3$ due to its high hardness (the third hardest material after diamond and boron nitride). Boron carbide has an attractive properties like high strength, low density (2.52 g/cm3), extremely high hardness, good wear resistance and good chemical stability. Hence reinforcing the aluminium with boron carbide particles confers high specific strength, elastic modulus, good wear resistance and thermal stability [7]. From the Literaure survey it can be concluded that, most of the studies on aluminium based MMCs are devoted to SiC and $Al_2O_3$ particulate reinforcements; however, use of $B_4C$ particulates as reinforcements in aluminium matrix is relatively limited. $B_4C$ is considered to be the third hardest material and is an extremely promising material for a variety of applications like bullet proof vests, armor tanks and as neutron absorber material.
In the present work, an attempt has been made to develop the light weight AA7030-$B_4C$ composites. The weight percentage of $B_4C$ particulates is taken in steps of 3, 6 and 9%. Further, properties like UTS, YS, compression and fatigue strengths were evaluated as per ASTM standards before and after heat treatment process.

## 2. EXPERIMENTAL DETAILS

The matrix material used in the experimental investigation is aluminium 7030 alloy whose chemical composition is listed in Table 1. Al7030 alloy is one type wrought aluminium alloy, containing zinc as a major alloying element. The theoretical density of Al7030 is taken as 2.80g/cm$^3$.

The main advantage of introducing reinforcement material to base metal or alloy is to increase the properties there by enhancing the mechanical and tribological properties of composites. In the current research Boron Carbide particulates of size 70 microns (μm) were used as a reinforcement material, which was procured from Speedfam (India) Pvt. Ltd., Chennai. The density of $B_4C$ is 2.52 g/cm$^3$ which is lower than the base Al matrix, contributes in weight saving.

Table1. Chemical composition of Al7030 alloy

| **Element** | **Symbol** | **Wt. Percentage** |
|---|---|---|
| Zinc | Zn | 5.9 |
| Copper | Cu | 0.4 |
| Manganese | Mn | 0.1 |
| Magnesium | Mg | 1.5 |
| Ferrite | Fe | 0.4 |
| Chromium | Cr | 0.35 |
| Silicon | Si | 0.3 |
| Titanium | Ti | 0.1 |
| Aluminium | Al | Bal |

In the engineering materials, the MMC's can be manufactured by a unique technique such as casting, as it is inexpensive and suitable for mass production of components. The synthesis of metal matrix composite used in the study was carried out by liquid metallurgy route in particular stir casting technique. Initially $B_4C$ particulates were preheated for 300°C. In the present work, an attempt has been made to study the mechanical properties of as cast Al7030 alloy and Al7030- $B_4C$ particulate composites. The composites containing 3, 6 and 9 wt. % of $B_4C$ particulates were prepared. Initially required amount of charge or matrix material was placed in a graphite or silicon carbide crucible, which was placed in electric resistance furnace at a temperature of around 730 degree Celsius. After complete melting of Al7030 alloy matrix, degassing was carried out by using Solid Hexa Chloroethane [8], which helps to remove unwanted adsorbed gases from the melt. Once degassing is over, the preheated ceramic reinforcement particles were introduced into matrix in a novel way which involves two-stage additions of reinforcement during melt stirring. This novel two stage additions of reinforcement into matrix Al7030 will increase wettability of the matrix and ceramic reinforcement and further, which helps in uniform distribution of the particles. A continuous stirring process was carried out during addition of reinforcement into matrix. Normally for all composite preparation, stirring speed was maintained at 300rpm. After 10 minutes of continuous stirring, entire molten metal was poured into cast iron die. The prepared composites were machined and tested for micro structural studies.

These prepared specimens were subjected to two different heat treatment conditions. Initially specimens were subjected to solution treatment at 525̊ C for one hour and quenched in water and peak aged at 175̊ C for 8 hours and allowed to cool in air. Now the artificially aged composite is subjected to various tests as per ASTM standards. Tensile, compression and fatigue behavior of as cast Al7030 alloy and its composites were evaluated as per ASTM standards.

## 3. RESULTS AND DISCUSSION

Microstructural Studies

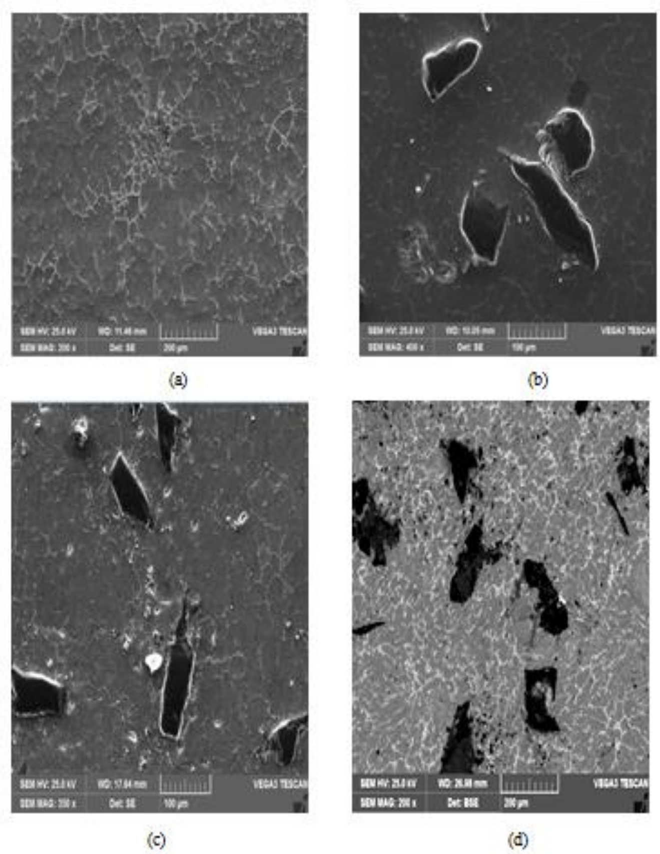
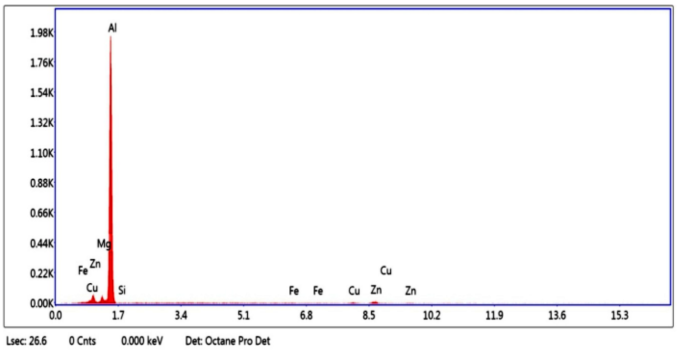


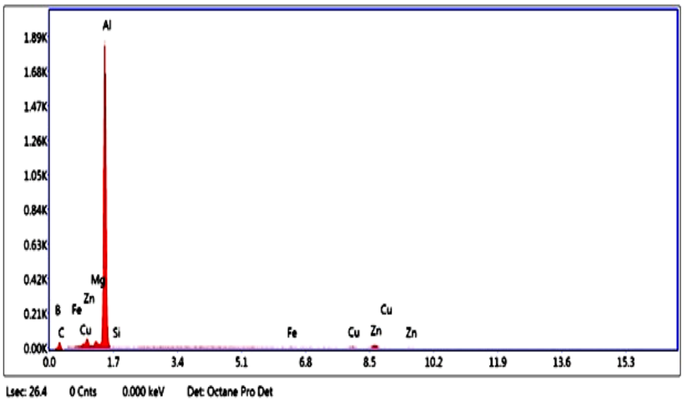
Figure 1: Shows the SEM photographs of (a) as cast AA7030 alloy (b) AA7030-3% $B_4C$ (c) AA7030-6% $B_4C$ (d) AA7030-9% $B_4C$ composites

Figure 1a-d shows the SEM micrographs of as cast AA7030 alloy and AA7030-3, 6 and 9 wt. % $B_4C$ composite respectively. The grain size of the composite was much smaller than that of the alloy because particles act as nucleation sites. Figure 1d reveals good distribution of reinforcements and there is no agglomeration in the composite. From the optical microphotograph, it is clear that a good crack free bonding was formed at discrete locations between the reinforcement and the matrix alloy.

Figure 2a-b indicates the energy dispersive spectrographs of AA7030 alloy and AA7030-9 wt.% $B_4C$ composite. From the fig. 2b it is revealed that the presence of Boron and Carbide elements in the AA7030 alloy composites. Further, Zn, Cu and Mg are available in the matrix.



(a)



(b)

Figure 2: Shows the EDS graphs of (a) as cast AA7030 alloy (b) AA7030-9% $B_4C$ composites

### Ultimate Tensile Strength

Table 1: UTS and YS of AA7030-$B_4C$ composites

| Composition | Un-heat treated tensile strength (MPa) | Un-heat treated yield strength (MPa) | heat treated tensile strength (MPa) | heat treated yield strength (MPa) |
|---|---|---|---|---|
| Al7030 | 163.89 | 156 | 184 | 161 |
| Al7030+3 % $B_4C$ | 178 | 171 | 193 | 174 |
| Al7030+6 % $B_4C$ | 184 | 176 | 213 | 191 |
| Al7030+9 % $B_4C$ | 207 | 184 | 224 | 199 |

Table 1 and figure 3 and 4 shows variation of ultimate tensile strength (UTS) and yield strength of 3, 6 and 9 wt. % of $B_4C$ composites. The ultimate tensile strength of AA7030-9 wt. % $B_4C$ composite material increases by an amount of 26% as compared to as cast AA7030 alloy matrix. The microstructure and properties of hard ceramic $B_4C$ particulates control the mechanical properties of the composites. Due to the strong interface bonding load from the matrix transfers to the reinforcement exhibiting increased ultimate tensile strength [9].

This increase in UTS mainly be due to $B_4C$ particles acting as barrier to dislocations in the microstructure. The improvement in UTS may be due to the matrix strengthening following a reduction in AA7030-$B_4C$ grain size, and the generation of a high dislocation density in the AA7030 alloy matrix a result of the difference in the thermal expansion between the metal matrix and the $B_4C$ reinforcement.

Further, AA7030-$B_4C$ composites with heat treatment exhibited the superior properties as compared to un heat treated composites.

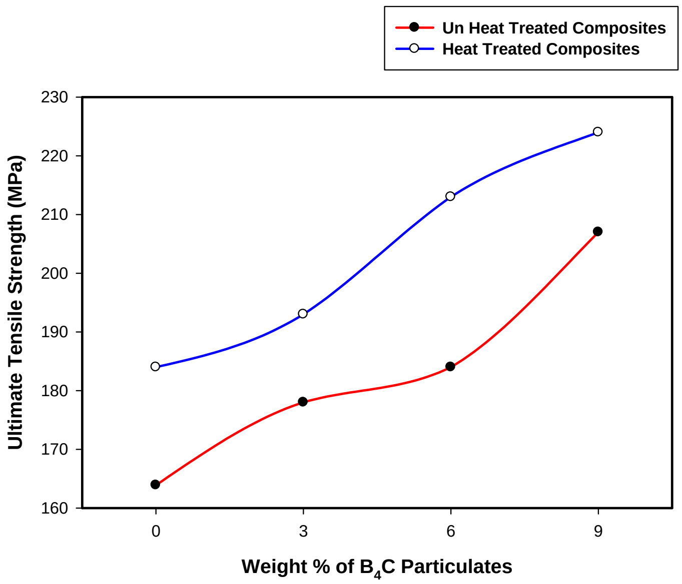



Figure 3: Ultimate tensile strength of AA7030-$B_4C$ composites with and without heat treatment

Figure 4 shows variation of yield strength (YS) of AA7030 alloy matrix with 3, 6 and 9 wt. % of $B_4C$ particulate reinforced composite. It can be seen that by adding 9 wt. % of $B_4C$ particulates yield strength of the AA7030 alloy increased from 156 MPa to 184 MPa. This increase in yield strength is in agreement with the results obtained by several researchers [10], who reported that the strength of the particle reinforced composites is more strongly dependent on the volume fraction of the reinforcement. The increase in YS of the composite is obviously due to presence of hard $B_4C$ particles which impart strength to the soft aluminium matrix resulting in greater resistance of the composite against the tensile stress. In the case of particle reinforced composites, there is a restriction to the plastic flow due to the dispersion of the hard particles in the matrix, thereby providing enhanced strength to the composite.

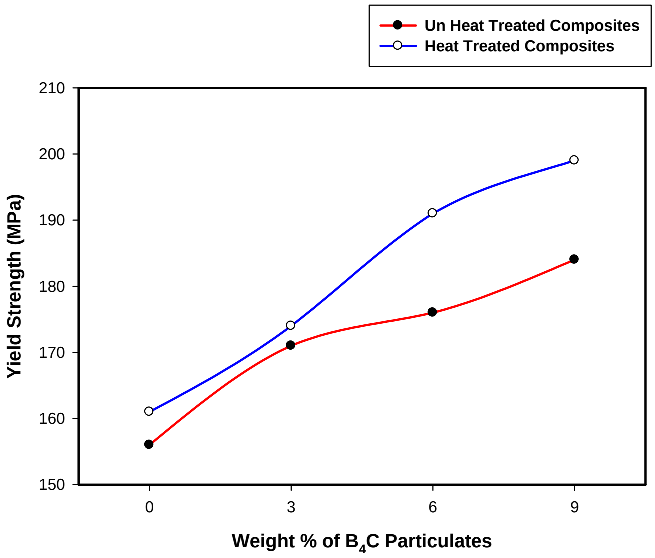



Figure 4: Yield strength of AA7030-$B_4C$ composites with and without heat treatment

## Compression Strength

Among the various mechanical testing, compression testing is one of the most important and widely used one. One can obtain important information concerning the materials ductile properties, the character and extant of plastic deformation, ultimate strentgh and toughness. The response of materials to other type of loading can sometimes be explained or predicted on the basis of their behavior under simple compression. So much information can be obtained from a single test justifies its extensive use not only in engineering materials research but also in engineering industries for quality control and design purpose. Different materials respond differently to uniaxial compressive forces.

Table 1: Compression strength of AA7030-$B_4C$ composites

| Sl. No. | Sample | Un-heat treated Compression Strength (MPa) | Heat treated Compression Strength (MPa) |
|---|---|---|---|
| 1 | Al7030 Alloy | 575.3 | 653 |
| 2 | Al7030 Alloy + 3 wt. % $B_4C$ | 644.67 | 690 |
| 3 | Al7030 Alloy + 6 wt. % $B_4C$ | 668.72 | 723 |
| 4 | Al7030 Alloy + 9 wt. % $B_4C$ | 688.4 | 785 |

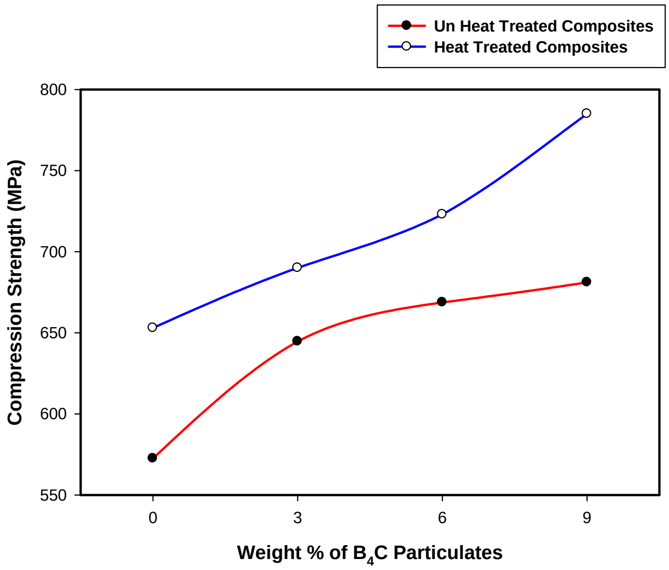



Figure 5: Compression strength of AA7030-$B_4C$ composites with and without heat treatment

Figure 5 and table 2 shows the compression strength of AA7030 alloy and various wt. % of $B_4C$ composites. From the graph as weight percentage of $B_4C$ reinforcement increases from 3 to 9 wt. %, there is increase in compression strength. This increase compression strength is mainly due to high compression strength of ceramic particulates. The compression strength of AA7030 alloy increased from 573 MPa to 688 MPa by adding 9 wt. % of $B_4C$ particulates in the matrix.

Further, AA7030-$B_4C$ composites with heat treatment exhibited the superior properties as compared to un heat treated composites.

## Fatigue Strength

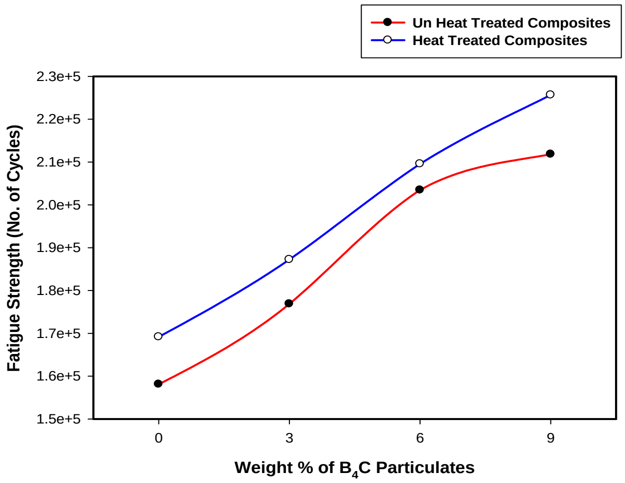



Figure 6: Fatigue strength of AA7030-$B_4C$ composites with and without heat treatment

Figure 6 shows the fatigue strength of AA7030 alloy and various wt. % of $B_4C$ composites. From the graph as weight percentage of $B_4C$ reinforcement increases from 3 to 9 wt. %, there is increase in fatigue strength. Further, AA7030-$B_4C$ composites with heat treatment exhibited the superior properties as compared to un heat treated composites.

**CONCLUSIONS**

The results of the study of microscopic structure and mechanical properties of the AA7030-3, 6 and 9 wt. % of $B_4C$ composites materials produced by stir casting are remarked as below:

- The liquid metallurgy technique was successfully adopted in the preparation of AA7030-3, 6 and 9 wt. % $B_4C$ composites.
- The microstructural studies revealed the uniform distribution of the $B_4C$ particulates in the AA7030 alloy matrix.
- The ultimate tensile strength and yield strength properties of the composites found to be higher than that of base matrix. The improvements in UTS and YS by adding 9 wt. % of $B_4C$ was increased by 26% and 18% respectively.
- Further, heat treated composites are exhibited more UTS and YS as compared to the unheat treated.
- Compression and fatigue strength of heat treated AA7030-$B_4C$ composites are more than that of unheat treated composites.

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