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Effect of B_4C Particulate Reinforcement on Mechanical Behaviour of Al7010 Alloy

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***Abstract*— In the present work, the study is done about composite material constituting of B_4C particulate reinforced into Al7010 matrix with different weight fractions of 3wt%, 6wt%, which is fabricated using conventional melt stirring (stir casting) method. Characterization of the prepared composites is studied in detail using optical microscope. The uniform distribution of B_4C particulates in matrix was clearly evident from microstructure studies. To study the Mechanical behavior the Brinell hardness test, tensile test and compression test were done for both Al7010 matrix material and its composite containing B_4C reinforcement. Outcome reveals that, addition of hard B_4C particulates into matrix increased its hardness, yield and ultimate strength.**

***Index Terms*- reinforcement, microstructure, stir casting, particulates**

I. INTRODUCTION

Aluminum alloys which are having good combination of physical, mechanical and tribological properties, is gaining huge importance in industries day to day. Aluminum matrix composites (AMCs) are the competent material in the industrial world. Due to its excellent mechanical properties, AMCs is widely used in aerospace, automobiles, marine etc. Researchers, especially in the defense application, are continuously striving hard to find the materials that suit their specific requirements. Improvement in production methods and finding the alternate materials are a few options to meet the above requirement.
Aluminum alloy-base metal-matrix composite (MMC) materials are used in the design of ground transportation vehicles and aircraft. Compared with conventional unreinforced alloys, composite materials usually exhibit higher strength, both at ambient and elevated temperatures.The demand for ceramic to metal bonding is growing. The unique properties of ceramics and metals make them highly desirable assembly components across many applications and industries. Among metal matrices, aluminum based matrices play very demanding role in production of MMCs, because of its unique properties and less processing cost [2].

Aluminum alloys is the material used widely in aerospace, automobile and many other industries due to their unique properties like low density and good mechanical properties, wear resistant, low coefficient of thermal expansion as compared to the conventional metals and there alloys. Along with excellent mechanical properties, the most important factor that adds is its low production cost [1].

In case of aluminum as matrix, the reinforcing ceramic particles like SiC, Al_2O_3 and B_4C, are used to achieve the strength. Proper selection of the variables has to be done in order to optimize the properties of composites etc. [3].

The reinforcing particles used to produce the composites have a varying density. The particle density is one of the important factor which determines the distribution of the particles in molten metal. If the particles have higher density than molten metal, then the particles settle down at the bottom of the molten slowly and particles those particles having lower density may segregate at the top. Hence both case results with un-uniform distribution of reinforcement. The reinforcement particles addition in to the melt provides more substrate, which helps in solidification and thereby increasing the nucleation rate and decreasing the grain size. The presence of hard surface area of reinforcing particles will offers more resistance to plastic deformation, finally which leads to rise in the hardness of composites [1-5].

II. EXPERIMENTAL DETAILS

a. Materials Used

Reinforcement: Boron carbide (B_4C)

Among the refractory carbides, next to carbides of tungsten, titanium and silicon carbide, boron carbide (B_4C) has of late assumed great significance as a strategic material

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because of its high hardness, low density, and high cross section for neutronabsorption, chemical inertness, and etc. The main applications of this material seen in industries like Military, nuclear, automobile etc.

Boron carbide is the third hardest material next to diamond and cubic boron nitride with its low density 2.52 g/cm3[2]. Boron carbide is one of the most promising ceramic materials due to its attractive properties, including high strength, low density, extremely high hardness (the third hardest material after diamond and carbide)It has toughness similar to diamond.

Table 1: Properties of Boron carbide (B_4C)

Density (g/cm^3)	2.52
Melting point (^{o}C)	2445
Young's Modulus (GPa)	450-470
Hardness (Knoop 100kg) (kg/mm^2)	2900-3580
Thermal Conductivity at 25^{o}C (W/mK)	30-42

Matrix: Aluminum 7010 Alloy

Aluminum and its alloys are well known for their good combination of mechanical and physical properties. They are sensitive at temperatures above 250°C, and may lose their strength above that temperature. However, the desired strength of the aluminum alloys can be achieved below zero temperatures, thus making them perfect low-temperature alloys. Alloy 7010 is considered as high strength and stress corrosion cracking resistant aluminum alloy. Around 87.8-90.6 % of aluminum is present with rest amount been alloyed by different materials. Zinc is the main content of this alloy, hence it is also called as Al-Zn alloy.

Table 2: Chemical Composition of Al7010 alloy

Element	Content(%)	Element	Content(%)
Zn	5.7-6.7	Si	0.12
Mg	2.1-2.6	Mn	0.10
Cu	1.5-2.0	Ti	0.06
Fe	0.15	Cr	0.05
Zr	0.1-.16	Ni	0.05

Table 3: Properties of Al7010 allloy

Density (g/cm^3)	2.82
Young's Modulus (GPa)	71.5
Thermal conductivity at 20°C (Wm/m^2°C)	154
Ultimate tensile strength (MPa)	552
Melting point (^{o}C)	650-660

Aluminum metal matrix composites (AMCs) are tremendously used potential materials in various applications because of their better combination of mechanical and physical properties. To improve the stiffness, specific strength, wear, creep and fatigue properties compared to the conventional engineering materials, the metal matrix is added with different reinforcements. Major applications of different AMCs are increasing day to day. Fabrication of Aluminum based MMCs is done using economical stir casting process. This method is under practice from decades. The problem of this process is in obtaining sufficient wetting of reinforced particle by liquid metal and to uniform dispersion of the particles. Hence to achieve this fabrication was done by considering different processing parameters [9-10].

b. Fabrication Procedure

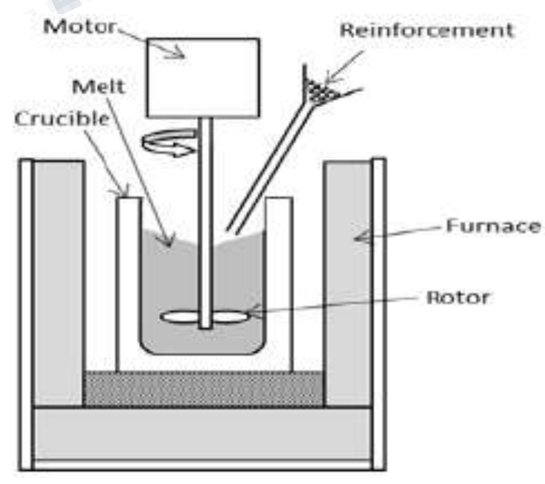

Figure 1: Stir casting setup

Stir casting is a primary process of composite production in which continuous stirring of molten base metal is done by introduction of reinforcements. The resulting mixture is poured into the die and allowed to solidify. The advantage of stir casting is lower cost of process. In this work, stir-casting method is used for preparing aluminum metal–matrix composite. This whirlpool technique provides high strength and homogeneous set of aluminum composite materials. Al-B_4C composites were produced by casting route at 850°C and titanium-containing flux (K_2TiF_6) was used to overcome the wetting problem between B4C and liquid aluminum metal [4]. Addition of K_2TiF_6 flux forms a reaction layer containing TiC and TiB_2 at the interface to increase wettability and interface bonding. Before addition of reinforcement and K_2TiF_6 the degassing agent hexachloroethe is added to remove the dissolved gasses during production on aluminum.

c. Hardness Test

The Brinell scale characterizes the indentation hardness of materials through the scale of penetration of an indenter, loaded on a material test-piece. The value of the Brinell Hardness Number (BHN) is calculated using the below formula:

$$BH = 2P/[\ \pi\ D\{D-\sqrt{}(D2-d2)\}]$$

Where P = Load applied, D = Diameter of indenter, d =Diameter of indentation.

Macro hardness test is performed on alloy with different weight fractions of reinforcement by using the Brinell hardness tester. Before subjecting to test the specimens are grinded and polished using emery sheets to obtain clear uniform surface. The tester with hardened steel ball of diameter 10mm is used for producing indentation on the specimen surface. The specimen is placed on the test platform and the indenter is allowed to touch the specimen surface. A minor load of 10 kgf is applied on the specimen surface. Then the major load of 1000 kgf is applied on the point located for 30 seconds. Then the load is released and the specimen is removed. The hardness test is repeated at four different places on the surface of all the composite specimens and using microscopic screw gauge the diameter of the indentation is measured. The Brinell Hardness Number (BHN) is calculated and the average value is taken as the hardness value of the specimen.

By stir casting method, aluminum matrix was reinforced with B4C particulates of size 105 μm size with different wt% of B4C. The microstructure and mechanical properties of the fabricated AMCs was analyzed, which found that the hardness of composite is maximum for the 12wt% of reinforcement. The hard surface area of particles gives more resistance to plastic deformation which leads to rise in the hardness of composites. The tensile strength was maximum at 8% and decreased for further addition of reinforcement [3].

Study about fabrication and mechanical properties of Al-Si12Cu/B4C Metal Matrix Composites. The composites were fabricated by reinforcing B4C particles with varying wt%, using stir casting process. The performance of the composites was studied and compared with the base alloy to know the improvement in properties that has been contributed by the reinforcement particles. Using optical microscope the microstructure was examined on the composite specimens which confirmed the uniform dispersion of reinforcement particles in the matrix. Mechanical properties were tested by using Brinell hardness tester and computerized UTM. The test results showed that, by increasing wt % of reinforcement in the matrix, hardness and tensile strength of the composites was improved to 6.97 % and 33 % respectively when compared to base matrix alloy [11].

d. Tensile Test

The tensile test is carried for casted composite material which were machined as per ASTM (E8) standard. The test is conducted by fixing the specimen in between the jaws of the computerized Universal Testing Machine (UTM). Input data like specimen length, gauge length and diameter of the specimens is fed. Gradual load is applied on the two ends of the specimen. For ultimate load the specimen gets broken, which is later removed from the machine. The test results, ultimate load, yield load, break load, % elongation and the graphical form related to the applied load will be recorded. The specimen before and after tensile test is shown in Figure 2: (a) and (b).

a) Specimens after test

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b) Specimen before test

Figure 2: Tensile test specimens before and after test.

Fabrication of Al- B4C was successful and much easier by the stir casting method, with uniform distribution of reinforcement. The increase in addition of B4C into aluminum matrix tend to the increase the micro and macro hardness of the AMCs. The tensile strength of the composite was found to be increasing with increasing wt% percentage of B4C [4].

The mechanical properties of Al6010 matrix alloy has improved after addition of B4C particulates. It can be stated that B4C particles as reinforcement are very effective in improving the tensile strength of the composite. A distribution of reinforced B_4C particles throughout the matrix was uniform. Addition of degassing agent K_2TiF_6 helped in avoiding defects such as voids, air gaps, pores and cracks. Mechanical properties like ultimate tensile strength and yield strength of Al2024/ B4C composites increased significantly in comparison with base alloy [5-6].

e. Compression Test

To obtain light-weight, strong materials in the emerging industrial applications, study about fabrication of Al/B_4C composites is must. The composite was prepared with addition of different weight fraction of B_4C reinforcement. After subjecting the specimens to various tests it revealed that, with the increase of weight fraction of B_4C, the density of the composites decreased whereas the hardness and ultimate compressive strength of the composites was increased [7].

Aluminum-based hybrid MMCs reinforced with three different reinforcement Graphite/SiC/B_4C, which was fabricated economically using the stir casting process. After tests, it resulted with high tensile strength, compressive strength and high hardness with less increase in brittleness[8].

a) Specimens after test

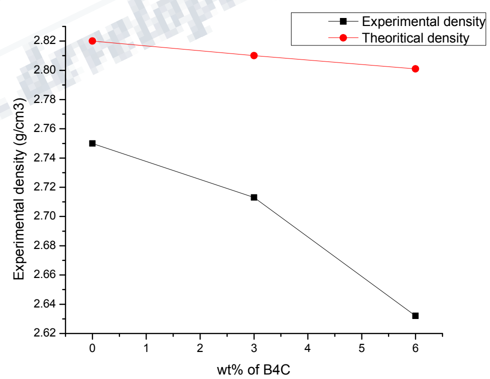
b) Specimens before test

Figure 3: Compression test specimens before and after test.

III. RESULTS AND DISCUSSION

3.1 *Density Calulation*

Graph 1: Theoretical and experiment density for different weight fraction of B_4C



From above graph it is clear that as the reinforcement increases the density decrease, which behaves same as the theoretical value.

Theoretical calculation:

ρc = (Vm*ρm) +(Vr*ρr)
Vr = (Wr/ρr)/{(Wr/ρr) +(Wm/ρm)}
Vm = (Wm/ρm)/{(Wr/ρr) +(Wm/ρm)}

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where, V-Volume fraction, W- weight fraction, ρ-Density, m-matrix, r- reinforcement.

Experimental density:

Vernier caliper scale is used to measure the length and diameter of the standard specimen for accurate dimensions, later the mass is weighed using digital weighing machine. Using the data collected the density is calculated.

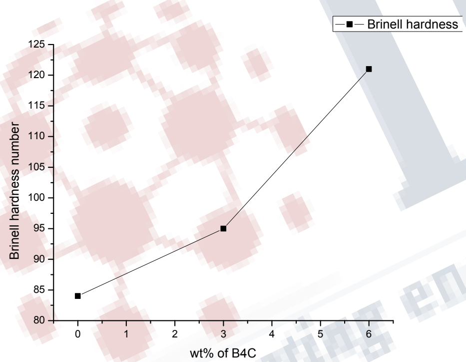
$\rho = m/V$, $V=\Pi/4\ d^2 * l$

Where, ρ-density (g/cm^3), m-mass(g), V-Volume (cm^3), d-diameter (mm), l-length (mm)

3.2 Hardness

The Brinell hardness test is conducted for polished specimen having even surface. On same surface few trials are done find the hardness value, finally the mean of all the values is considered as approximate hardness of the specimen. The test is repeated with all other specimens with different weight fractions of B4C.

Graph 2: Brinell hardness v/s wt% of B_4C

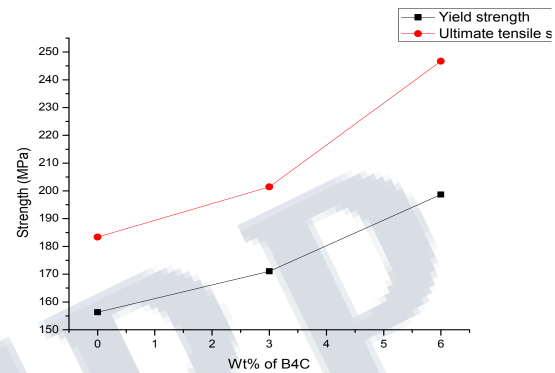


From above graph 2 it is clear that the addition of B4C increases the hardness of the Al7010 base alloy. This is because of the hard material B4C which restrict the plastic deformation.

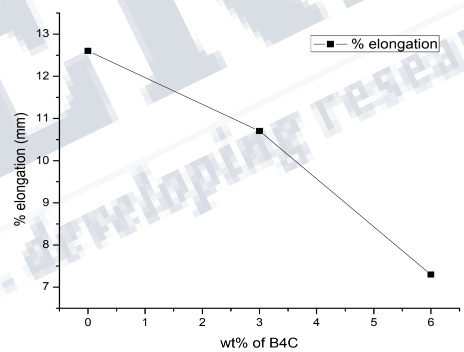
3.3 Tensile Test

The tensile test specimens are machined according to ASTM E8 Standard. Later the specimens are tested using computer controlle universal testing machine. The test is carried out with load rate of 5mm/min. The input data like, gauge length, diameter, overall length is fed before. Finally when the specimens fail the ultimate tensile strength, yield strength, % elongation can be obtained.

Graph 3: Yield/Ultimate strength v/s wt% of B_4C



Graph 4: %Elongation v/s wt% of B4C



From the above graph 2 and 3 it is evident that as the weight fraction of B4C increase both the ultimate and yield strength increases, but the percentage elongation decreases. For 6% addition of B_4C reinforcement the sudden variation of the result can be seen in both graphs.

3.4 Compression Test

The compressive strength of material is its capacity to withstand loads tending to the reduction of specimen size. It can be measured by plotting applied force against deformation in a testing machine. Material fractures at their compressive strength limit. Compressive strength is a key value for design of structures which is measured on a UTM. The test specimen is machined in cylindrical form as per

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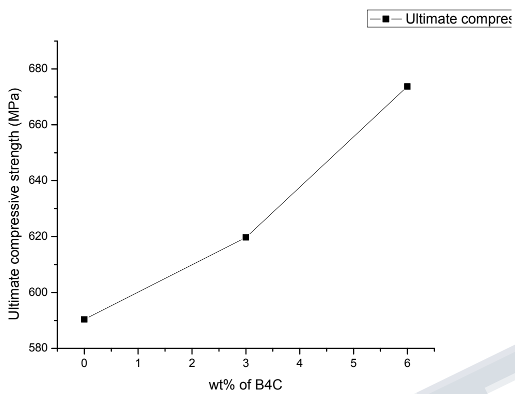
ASTM standard dimension with length/diameter ratio equal 1.5. The material is subjected to the compressive load on both side of the specimen. The specimen under the compressive load tends to reduce the length of the work piece with increase in diameter of the rod [10].

Graph 5: Ultimate compressive strength v/s wt% of B4C

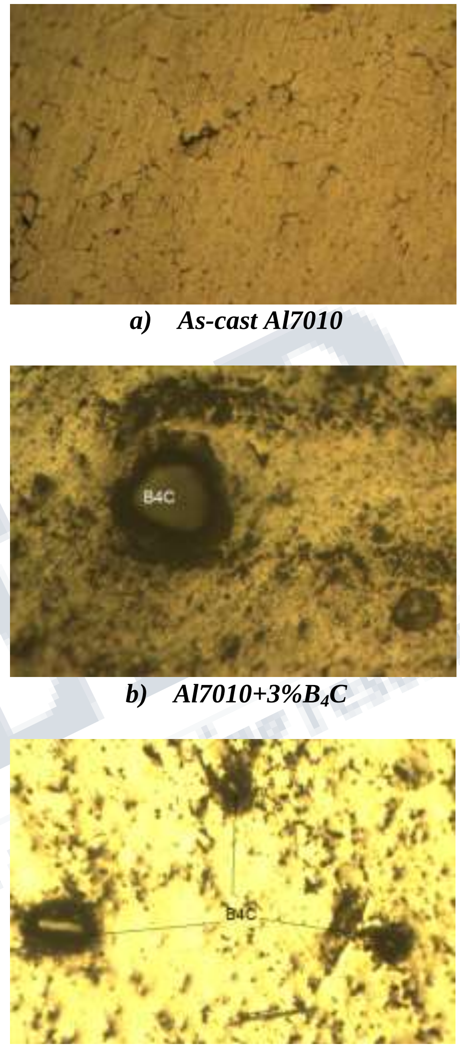


From above graph 4 it is clear that as reinforcement increases the compression strength goes on increasing, for 6% of reinforcement the strength increases suddenly.

3.5 Microstructure

The specimens were polished using emery papers, followed by disc polishing to obtain the mirror surface. These specimens are viewed under optical microscope to know the uniform distribution of B_4C in the base matrix alloy. Using the advanced microscopes like Scanning electron microscope, XRD helps in obtaining highly magnified view which helps in studying the inter molecular bound between the matrix and reinforcement.The precipitation, oxide layers, defects like voids, cracks can be studied using the microstructure study.

The polished composite specimens with different weight fractions of B_4C is viewed under optical microscope to conform the homogeneous distribution of reinforcement.



a) As-cast Al7010

b) Al7010+3%B_4C

c) Al7010+6%B_4C

Figure 4: Optical microstructure images of different weight fraction of B4C

From above optical images it can be clearly seen that the B_4C particles are uniformly distributed. The density of B_4C is increased from 3% to 6%, where more particles can be seen in case of 6% as shown in above figures 'b' and 'c'.

IV. CONCLUSION

The composite specimens are fabricated using conventional stir casting method.

- After microstructure study using optical microscope it was evident that B_4C particulates were uniformly distributed in the Al7010 base alloy.
- Density was calculated both experimentally and theoretically, the experimental results showed that the density of base alloy decreases with addition of B_4C.
- Brinell hardness test showed the increment of hardness value with B_4C addition.
- Tensile test results showed that both the yield and ultimate strength increased with addition of B_4C. When compared to base alloy (183.36Mpa) the 3% of B_4C addition increased the ultimate tensile strength by 9.38% and 6% addition showed 29.46%
- Compressive strength increased with B_4C addition to base alloy (590.36MPa), the 3% addition of B_4C increased the strength by 4.85% and 6% of addition increased the strength by 13.187%

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