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A Study on Mechanical Characteristics of Hybrid Metal Matrix Composite

(Aluminum, Graphite, Silicon Carbide, Boron Carbide)

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***Abstract*--Aluminum based matrix composites remain the most explored metal matrix material for the development of MMCs. In the present study, the effect of Silicon carbide, Boron carbide on Stir cast Aluminum Metal Matrix Composites is discussed. Graphite is used as a lubricant. Aluminum Metal Matrix Composites with Silicon carbide and Boron carbide particle reinforcements are finding increased applications in aerospace, automobile, space, underwater, and transportation applications. The hybrid metal matrix composite which consists of aluminum and other constituents such as graphite, silicon carbide and boron carbide are to be casted in three different compositions varying the boron carbide and silicon carbide content and are further employed to different testing such as hardness test, compression test, tensile test, impact test, micro hardness and micro structural analysis. Conventional stir casting process has been employed for producing discontinuous particle reinforced metal matrix composites.**

Keywords— Metal Matrix Composites, Aluminum, Silicon Carbide, Boron Carbide, Stir casting.

I. INTRODDUCTION

Many of our modern technologies require materials with unusual combinations of properties that cannot be met by the conventional metal alloys, ceramics, and polymeric materials.

This is especially true for materials that are needed for aerospace, underwater, and transportation applications. Aluminum based matrix composites remain the most explored metal matrix material for the development of MMCs (Surappa *et al*, 2003). In AMCs one of the constituent is aluminum alloy, is termed as matrix phase. The other constituent is embedded in this aluminum/aluminum alloy matrix and serves as reinforcement, which is usually non-metallic and commonly ceramic such as silicon carbide and boron carbide. When these composites reinforced with silicon carbide particles there is an improvement in yield strength, lower coefficient of thermal expansion, higher modulus of elasticity and more wear resistance than the corresponding non-reinforced matrix alloy systems, Boron Carbide particulate reinforced aluminum composites possess a unique combination of high specific strength. Hence here the two ceramics namely boron carbide and silicon carbide both are reinforced as a particulate in aluminum matrix with a graphite as lubricant.

II. SELECTION OF MATERIALS:

A. Aluminum:

Aluminum is remarkable for the metal's low density and for its ability to resist corrosion due to the phenomenon of passivation. Commercially pure aluminum has a tensile strength of approximately 90 MPa and can be improved 180 MPa by cold working. The heat treatable grades can develop a tensile strength of around 570 MPa and even higher in some alloys. The wear of MMCs depends on the particular wear conditions, but there are many circumstances where Al based composites have excellent wear resistance. The coefficient of thermal expansion of aluminum alloys is affected by the nature of their constituents: example the presence of silicon and copper reduces expansion while magnesium increases it.

B. Silicon Carbide:

Silicon carbide can be used as reinforcement in the form of particulates, whiskers or fibers to improve the properties of the composite. They possess extremely high thermal, chemical, and mechanical stability. Silicon carbide ceramics with little or no grain boundary impurities maintain their strength to very high temperatures, approaching 1600°C with no strength loss. When embedded in metal matrix composites SiC certainly improves the overall strength of the composite along with corrosion and wear resistance. Aluminum MMCs reinforced with SiC particles have up to 20% improvement in yield strength, lower coefficient of thermal expansion, higher modulus of elasticity and more wear resistance than the corresponding un-reinforced matrix alloy systems.

C. Boron Carbide:

Boron Carbide particulate reinforced aluminum composites possess a unique combination of high specific strength, high elastic modulus, good wear resistance and good thermal stability than the corresponding non-reinforced matrix alloy system. A limited research work has been reported on AMCs reinforced with B4C due to higher raw material cost and poor wetting. B4C is a robust material having excellent chemical and thermal stability, high hardness and low density (2.52 g/cm^3) and it is used for manufacturing bullet proof vests, armor tank, etc. Hence, B4C reinforced aluminum matrix composite has gained more attraction with low cost casting route (Kerti and Toptan, 2008; and Toptan *et al.*, 2010).

D. Graphite:

Graphite is an excellent conductor of heat and electricity. It has a good lubricating property. It is stable over a wide range of temperatures. In graphite, the carbon atoms are arranged in flat planes of hexagonal rings stacked on one another. Each carbon atom is attached to three others on the same plane. Thus, only three out of four valence electrons are used in carbon-carbon bonding. The fourth valence electron remains loosely between the planes. This free electron accounts for the electrical conductivity of graphite. The lack of carbon-carbon bonding between adjacent planes enables them to slide over each other making graphite soft, slippery and useful as a lubricant.

III. METHODOLOGY:

A. Composition for Fabrication:

The fabrication is done with different composition of B_4C, Sic and Graphite in our studies. In this project we choose the pure aluminum as a parent material and B_4C, Sic and Graphite as a host material. The pure aluminum is mixed with different compositions of B_4C, Sic, and Graphite weight ratios shown in the below table.

Table 1: Different Composition of B_4C, Sic and Graphite

SI. No	Aluminum	Graphite	Silicon carbide	Boron carbide
1	90%	2%	2%	6%
2	90%	2%	4%	4%
3	90%	2%	6%	2%

B. Reinforcement:

Reinforcement agent used in this work is boron carbide (2-6%), Silicon Carbide (2-6%) and Graphite (2%). Boron carbide has low wettability property, hence it cannot be readily mix with Aluminum melt. In order to improve the wettability and remove moisture content it is preheated to 480°C for 2 hour in a muffle furnace so as to remove the moisture content and to improve wettability by preheating the reinforcement materials.

C. Preparation of Composition by Stir Casting Method:

Stir casting is the best and economical method for producing the aluminum metal matrix composite and mixing of ceramics materials effectively.

Table 2: Process parameters

Parameter	Unit	Value
Spindle speed	Rpm	450
Stirring time	Minutes	5
Stirring temperature	°C	800
Preheated temperature of B_4C	°C	480
Preheating time	Minutes	120

The aluminum is heated up to 800º C for producing cast material. The melting point of pure aluminum is about around 723º C. In that temperature the aluminum in a solid state after that only it can melts. The complete melt of aluminum is obtained at round 730º C. But during the casting preparation there is heat loss. To prevent this heat loss the material is heated up to 800º C.

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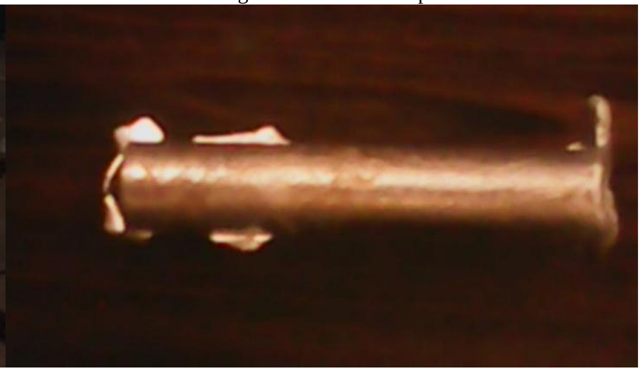
Fig. 1: Preparation of Composite

Fig. 2: Fabricated Composite



IV. EXPERIMENTAL SET-UP:

A. Tensile Test:

ASTM (American standards for testing of Materials) specification gives the drawing of the specimen to be prepared for conducting the test with tolerances. The prepared tensile specimen were inspected after machining and loaded in the tensile testing machine or universal testing machine and the tensile force is given. A tensile specimen is a standardized sample cross-section. It has two shoulders and a gauge (section) in between. The shoulders are large so they can be readily gripped, whereas the gauge section has a smaller cross-section so that the deformation and failure can occur in this area. The tensile specimen for testing is shown.

Fig. 3 Specimen for Tensile test

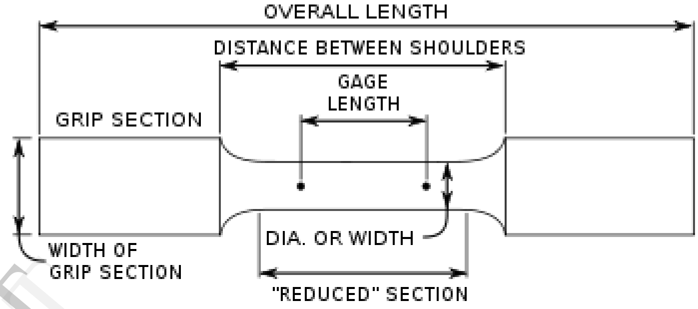


Table 3: Dimensions of Tensile Test Specimens

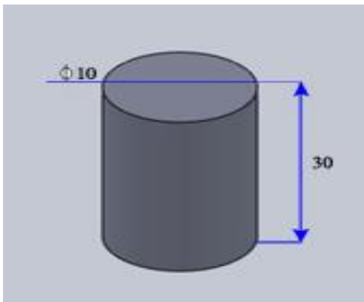
Specification	Dimensions (mm)
Diameter	6
Distance between shoulders	60
Overall length	90
Diameter of grip section	14
Length of the grip section	15

The test process involves placing the test specimen in the testing machine and applying tension to it until it fractures. During the application of tension, the elongation of the gauge section is recorded against the applied force. The data is manipulated so that it is not specific to the geometry of the test sample. The elongation measurement is used to calculate the engineering strain, ε.

B. Compression test:

The compressive strength is the capacity of a material or structure to withstand loads tending to reduce size. It can be measured by plotting applied force against deformation in a testing machine. Some material fracture at their compressive strength limit; others deform irreversibly, so a given amount of deformation may be considered as the limit for compressive load. Compressive strength is a key value for design of structures. Compressive strength is often measured on a universal testing machine. Measurements of compressive strength are affected by the specific test method and conditions of measurement. Compressive strengths are usually reported in relationship to a specific technical standard. The test specimen is made as cylinder rod as diameter 10mm and 30mm length. The test specimens are machined as per the ASTM standard. The test specimen after machining can be shown in the below diagram.

Fig. 4: Specimen for Compressive Test

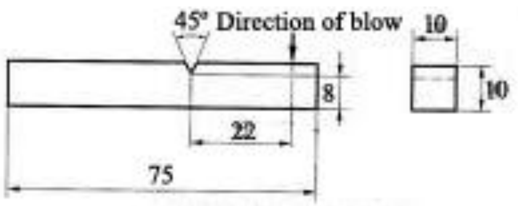


The material is subjected to the compressive load on both side of the specimen. The specimen under the compressive load tends to buckling and reducing the length of the work piece with increase in diameter of the rod. The diameter of test specimen before testing is 10mm.

C. Impact test:

The izod impact test, also known as the izod V-notch test, is a standardized high strain-rate test which determines the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of a given material's notch toughness and acts as a tool to study temperature - dependent ductile-brittle transition. It is widely applied in industry, since it is easy to prepare and conduct and results can be obtained quickly and cheaply. The test specimens for izod impact test are ASTM E23 standard. The ASTM E23 describes impact testing of notched-bar metallic specimens. The standard covers both Charpy and Izod style testing and outlines test methods for measuring the energy absorbed by the broken specimen. The specimen machined for impact test is shown below.

Fig. 5: Specimen for Impact Test



The test specimens are machined as per the ASTM E23. The notch is cut as per the dimensions. The notch 2mm is cut from 22 mm from the end of the specimens. The test specimen is placed perpendicular in the vice. The load is acted perpendicular to length of the test specimen.

D. Hardness Test:

The Vickers test is often easier to use than other hardness tests since the required calculations are independent of the size of the indenter, and the indenter can be used for all materials irrespective of hardness. The basic principle, as with all common measures of hardness, is to observe the questioned material's ability to resist plastic deformation from a standard source. The Vickers test can be used for all metals and has one of the widest scales among hardness tests. The unit of hardness given by the test is known as the Vickers Pyramid Number (HV) or Diamond Pyramid Hardness (DPH). The hardness number is determined by the load over the surface area of the indentation.

Table 4: Specifications of Hardness Equipment

Parameters	**Specifications**
Major load	15 N
Minor load	3 N
Indenter ball diameter	1/16”

The Vickers hardness is more effective then birnell hardness test the diamond ball indenter is used in the setup. The surface is machined and the testing can be done in various placing and take a mean value gives the hardness of the test specimens.

V. MICROSTRUCTURE STUDY:

The microstructure study is very useful for the analysis of properties and proportion of mixing in the aluminum matrix. In that the microstructure reveals the strength of materials. A carefully prepared specimen and magnification are needed for microscopic examination. Proper preparation of the specimen and the material’s surface requires that a rigid step-by-step process be followed. The first step is carefully selecting a small sample of the material to undergo microstructure analysis with consideration given to location and orientation. This step is followed by sectioning, mounting, grinding, polishing and etching to reveal accurate microstructure and content

Inference:

The image of the matrix shows the microstructure of the metal matrix composite in pure aluminum. The matrix shows fine grained Al_2Si particles of eutectics evenly precipitated in aluminum solid solution. The matrix also shows the composite particles as agglomerated and isolated locations

dispersed in the matrix. The dark red particles are the B_4C particles. The eutectic grains are non-dendrite and divided and uniformly dispersed. No undissolved Gr-Al_2 eutectic particles observed. The eutectic particles of Al-Si are not sharp angled or script like and they are far apart. The matrix on scanning does not show any abnormal casting defect. The below figure shows the microstructure of the three different compositions.

Fig. 6: Microstructure of Three Compositions

90% of aluminum, 2% of graphite, 2% of silicon carbide and 6% of boron carbide

90% of aluminum, 2% of graphite, 4% of silicon carbide and 4% of boron carbide

90% of aluminum, 2% of graphite, 6% of silicon carbide and 2% of boron carbide

VI. Results and Discussions:

A. Tensile Test:

The tensile test can do in the tensile testing equipment. The maximum load in the machine is 5 ton. The test can be done until the component can broke. The tested specimen can be shown in the below diagram.

Fig. 9: Specimen Subjected to Tensile Test

The testing results can be shown in the stress strain graph. By using the formula we calculating the tensile strength. The formula is mentioned below.

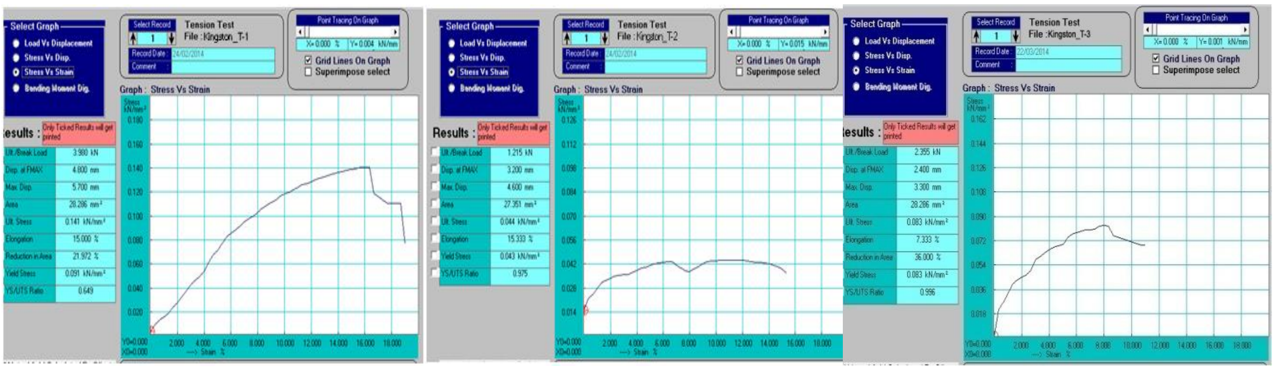
$$\textit{Tensile Strength} = \frac{\textit{Breaking Load}}{\textit{Area of the Specimen}}$$

Where

P= load at which the specimen can broke.

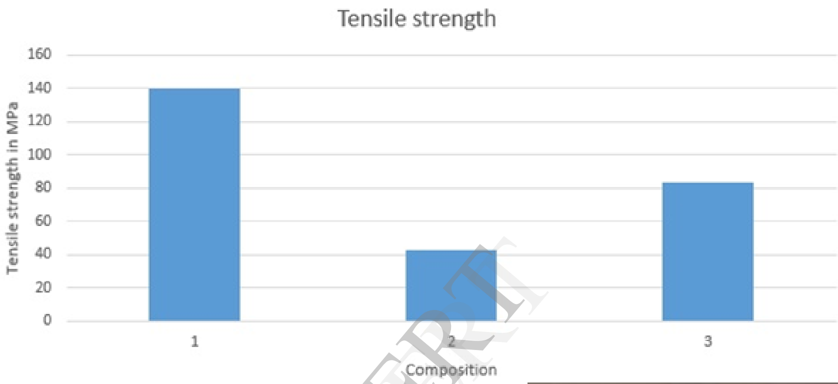
A = Area of the specimen (πr^2)

Graph 1: Stress - Strain Graph for Three Compositions



a. Sample 1 b. Sample 2 c. Sample 3

Graph 2: Tensile Strength Vs Composition



From that we plot a chart showing the tensile strength of our three different compositions can be shown. As per our testing results the more ductile material among our three compositions is the 1st composition. The composition consists of Graphite (2%), silicon carbide (2%) and boron carbide (6%) is better than others.

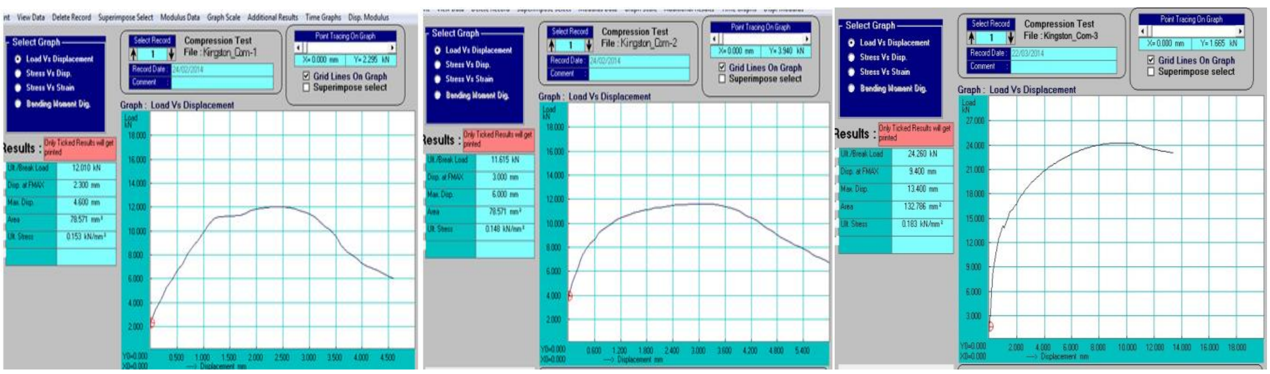
B. Compressive Test:

The compressive test can be done in the same machine. The compressive load can be acting on the both side of the test specimens. The specimens after testing are shown below.

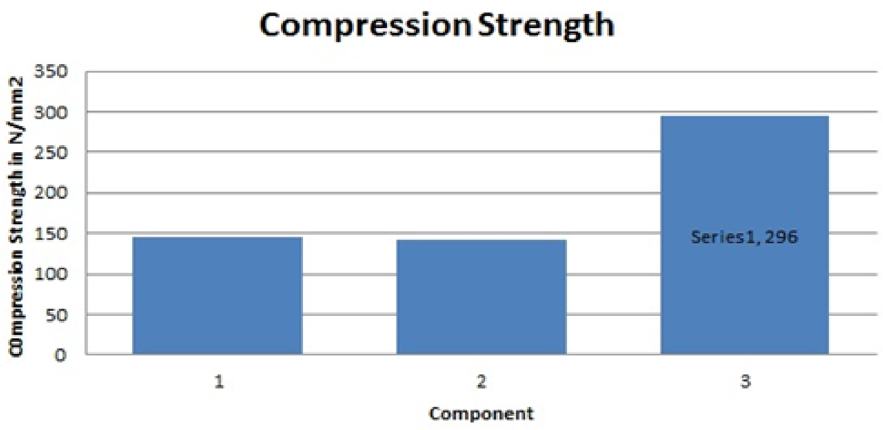
Fig. 10: Specimen Subjected to Compressive Test

The testing results can be shown in the load - displacement graph given below.

Graph 3: Load - Displacement Graph for Three Compositions



Graph 4: Compressive Strength Vs Composition



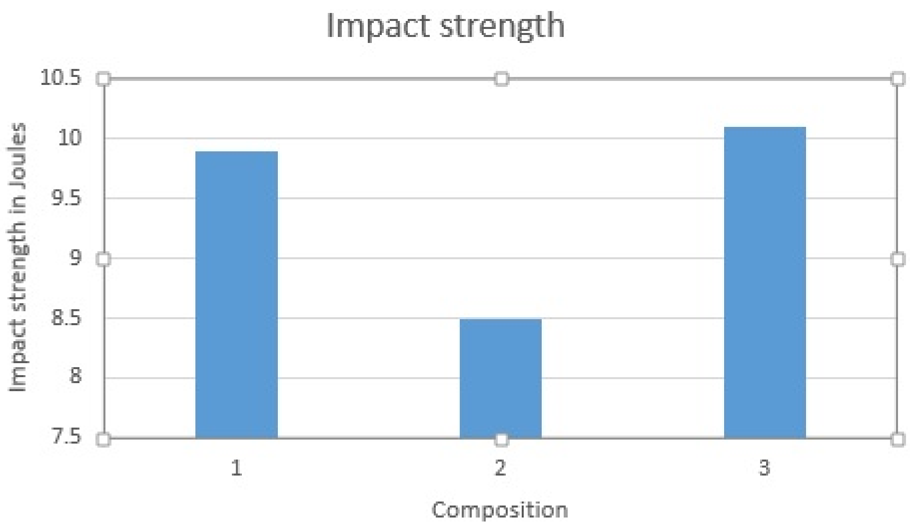
From the various results from the stress strain curve. The compressive strength is calculated in N/mm^2. The graph shows the compressive strength for different composition shown below. From the graph, it is concluded that the composition consisting of Graphite (2%), silicon carbide (6%) and boron carbide (2%) has more compressive strength.

C. *Impact Test:*

Impact test can be carried out in the Izod impact equipment. The Notch can be cut as per the ASTM E23 standard. The result shows the high hardness can possess high energy to break. The tested specimen can be shown in the below diagram.

Figure No: 8.3 Impact Tested Specimen

Graph 5: Impact strength Vs Composition



The can be plotted with composition as x-axis and Impact strength in joules is shown in the below diagram.

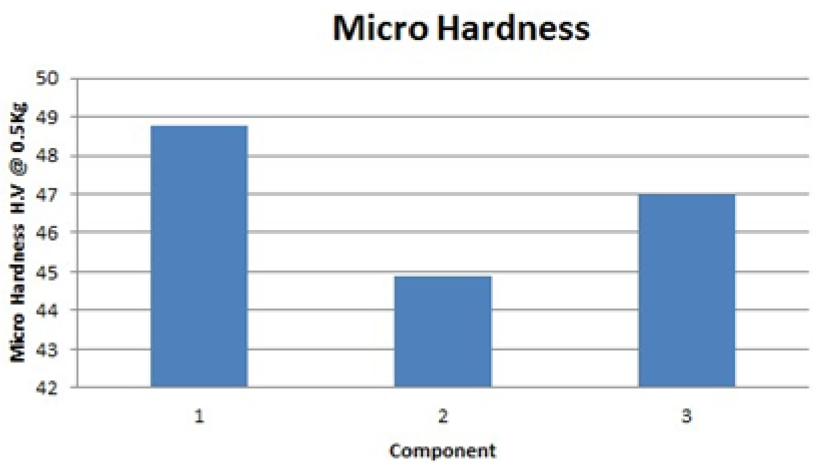
The results shows that the high strength has required more energy to break it have more ductile. The brittle material has requires less energy to break. Sample 1 and 3 has high impact strength, hence they are more ductile.

D. *Hardness:*

Hardness is the main property for various applications. The material as both hardness and strength is aluminum. Thus the hardness of our metal matrix composite has reasonable hardness. The increase in hardness leads to changing material into brittle one. Aluminum is a ductile material and our reinforcement increase hardness with little increase in brittleness. But the strength is increased. The various composition from our project was evaluated.

The graph is plotted between the micro hardness Vs composition. The results shows the sample 1 (Graphite (2%), silicon carbide (2%) and boron carbide (6%)) has more hardness compared to other two compositions.

Graph 6: Hardness Vs Composition



Thus the mechanical properties can be determined and evaluated that the properties such as tensile strength, compressive strength, impact strength and hardness of casted component.

VII. CONCLUSION:

The aluminum-based MMCs reinforced with Graphite/SiC/B_4C particles were fabricated using the stir casting process and the microstructure and the hardness of the fabricated MMCs according to the working conditions were also evaluated. As results of experiments for fabricating the MMCs, it was seen that the contents of the Gaphite, SiC and the B_4C for making a good achievement is the hybrid composite which consists of 90% Aluminum, 2% of Graphite, 2% of Silicon Carbide and 6% of Boron Carbide. Since it has high tensile strength, that reveals it ductility, it has good compressive strength and too has high hardness with less increase in brittleness.

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