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Evaluation of Properties of LM 25-Alumina–Boron Carbide MMC with Different Ratios of Compositions

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Abstract

In the present day scenario metal matrix composites (MMC's) are showing their vital importance in the fields of aerospace and automotives. The major problem associated with the manufacturability of these MMC's in non-uniform distribution of various particles due to their density difference. The random orientation of the particulates will show tremendous impact on their mechanical behavior; thus it is essential to determine the mechanical properties along with the particulate distribution in MMC.

The present work is focused on fabrication and investigation of Mechanical properties of aluminum alloy, alumina (Al_2O_3) and boron carbide MMC. These materials are identified in the process of investigation due to their high strength, better wear resistance and hardness of alumina and fracture toughness and excellent hardness property of boron carbide.

Stir casting process is employed for the fabrication of MMC's and Mechanical properties of Aluminum alloy-Alumina-Boron carbide metal matrix Composites are experimentally determined. The composition of MMC in varied for alumina (1%, 4%,) and Boron carbide (4%, 1%) by keeping 95% by aluminum alloy.

The fabricated samples are also micro examined for their internal structure and random orientation of particulates using images, developed by scanning electron microscope.

Key Words: LM-25; Boron carbide; Alumina; Stir casting; Mechanical properties, Microscopic Images, MMC.

INTRODUCTION

Now-a-days, Metal Matrix Composites (MMCs) are under serious consideration for a large number of structural applications such as those in the aeronautical/aero-space, transportation, defense and sports industries because of their superior properties. The excellent mechanical properties and the comparatively less cost make them as an attractive option [David L. et. al 1,2 (1985)]. A large number of fabrication techniques are currently used to manufacture the MMC materials according to the type of reinforcement used like stir casting. It has been observed a rapid increasing utilization of aluminum alloys, particularly in the automobile industries, due to low weight, density, coefficient of thermal expansion, high strength, and wear resistance[Vengatesh.D et. al.].

Dinesh Kumar et. al. [4] fabricated aluminum 6063 based metal matrix composites, one reinforced with silicon carbide, graphite and second reinforced with silicon carbide, boron carbide by stir casting technique. Various mechanical tests like tensile test, flexural test, hardness test, and compared results. And concluded that there is an increase in the value of tensile strength, hardness value and flexural strength of a composite Sic and B4c, particulates in comparison to the Sic, graphite reinforced composite. N Subramani et. al. Fabricated aluminum 2024 metal matrix composite reinforced with boron carbide, graphite by stir casting technique and their mechanical properties are evaluated.

S. Ramarao and G. Padmanabhan (2012) Fabricated aluminum alloy boron carbide composites using liquid metallurgy techniques with particulates weight fraction of 2.5, 5 and 7.5 %. SEM images are developed and observed a uniform distribution of boron carbide particulates in aluminum matrix. Madeva Nagaral et. al. (2013) have studied the mechanical behavior Al6061/Al2O/Graphite reinforced MMC liquid metallurgy route. The hardness and tensile properties are evaluated and observed that addition of graphite influence the tensile strength of composite.

T. Raviteja et. al. (2014) have fabricated and evaluated the mechanical properties of Al-Sil2Cu/B_4c composite by varying the weight of B_4c particulates with 2, 4, 6, 8 and 10%. The result integrated that increasing the weight % of reinforcement particulates in the matrix have improved the hardness value by 6.97%, and tensile strength by 33%, when compare to base alloy. N.G. Siddesh kumar et. al. (2014) Have developedAl2219reinforced with B_4C & MoS_2 using stir casting technique and conducted experiment to evaluated microstructure, density, micro hardness, tensile dry sliding wear test.P.B. Pawar et. al. (2014) Have developed a composite by adding silicon carbide in aluminum metal by mass ratio 2.5%, 5%, 7.5% and 10%. Mechanical tests such as hardness test, microstructure test are conducted and that the hardness and material toughness where enhance with the addition of silicon.

B. Vijaya Ramnath et. al (2014) have fabricated had investigated are mechanical properties and inner structure of aluminum ally, alumina (Al_2O_3), and boron carbide metal matrix composite. Gurwinder singh et. al. (2014) developed a hybrid composite of aluminum with Sic, Al_2O_3 and C particles using squeeze casting technique. Hardness test, impact test are performed on samples and concluded that the squeeze performed from Al reinforced with Sic/Al_2O_3/C is clearly superior to base Al comparison of impact strength and hardness.

Bhargavi rebba et. al. (2014) did experimental investigates are molybdenum disulphide powders reinforced in Al 2024. The comparison ratios 1, 2, 3, 4, 5-weight % of MoS2 powders of approximately 40µm using stir casting technique hardness and tensile strength of the specimen are evaluated and observed that the hardness and tensile strength increased with the increasing Wt % of reinforcement particles up to 4% and further there are decreasing. Jhony james et. al. [14] prepared hybrid aluminum metal matrix composite reinforced with Sic and TiB_2. With varying weight % of reinforcement .K.R. Padmavathi et. al. (2014) have studied the wear and friction behavior of Al-6061 with various percentages volumes of multiwall carbon nano tube and silicon carbide reinforcement through stir casting and then die casting. Siddique et. Al (2015) Siddique Ahmed Ghias and Vijaya Ramnath [2015] investigated the tensile property of Aluminum SiC Metal Matrix composite and found that hybrid composite has good strength. B.N.Saradaa et. al(2015)Particle distribution strongly influences the physical and mechanical properties of the composites.

EXPERIMENTAL DETAILS

Materials

In this work for preparing metal–matrix composite, aluminum alloy (LM 25) is used as base material; alumina and boron carbide in powder form are used as the reinforcements. Boron carbide having 220 mesh size, aluminum oxide and aluminum alloy ingot are required for the preparation. Aluminum alloy ingot is cut into small pieces of 10mm x10mmx 30mm, so that it can be easily placed in graphite crucible for melting.

Aluminum alloy (LM 25)

The tensile properties of aluminum alloy (LM 25) at elevated temperatures are influenced by the condition (heat treatment) of the castings and the duration at the elevated temperatures. The heat-treated alloy has good machining properties. They are of high resistance to corrosive attack by sea-water and marine atmospheres

Aluminum oxide or alumina

Aluminum oxide (Al_2O_3) is a chemical compound of aluminum and oxygen. It is commonly called alumina. Al_2O_3 is an electrical insulator but has a relatively high thermal conductivity (30 W m $^{-1}$ K $^{-1}$) like ceramic material. Its hardness makes it suitable for use as an abrasive and as a cutting tool.

Boron carbide

Boron carbide is one of the mainly hopeful ceramic materials due to its attractive properties, including high strength, low density, exceptionally high hardness (the third hardest material after diamond and boron nitride), good chemical stability and neutron combination capability .Boron carbide has stability to ionizing radiation. Its hardness is almost equal to diamond. The properties of aluminum alloy (LM 25), alumina and boron carbide are shown in Table 1.

Table 1: Properties of Materials used

Material	Tensile strength (Mpa)	Density (g/cm^3)	Coefficient of thermal expansion (10^{-6}/^{o}C)	Modulus of Elasticity (Gpa)
Al-alloy LM25 grade	145.9	2.68	2.2	71
Al_2O_3	255.2	3.98	7.4	380
B_4C	261	2.55	3.2	368

STIR CASTING METHOD

The schematic diagram of stir casting for production of MMC is shown in Fig. 1. Stir casting is a primary process of composite production in which continuous stirring of molten base metal is done followed by introduction of reinforcements. The resulting mixture is poured into the die and allowed to solidify. In stir-casting, the particles often tend to form agglomerates, which can be only dissolved by vigorous stirring at high temperature. The various advantages of stir casting are simplicity, flexibility, applicability to large quantity, near net shaping, lower cost of processing and easier control of matrix structure. 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.

Fabrication Procedure

The experimental arrangement consists of the main furnace and components along with four mild steel stirrer blades. The first process in the experiment is preheating. Here, the empty crucible and the reinforcement powders, namely boron carbide and alumina powders are heated separately to a temperature close to that of the main process temperature. The melting of the aluminum alloy (95%) ingot is carried out in the graphite crucible inside the furnace. Initially, the ingot was preheated for 3–4 hours at 550°c. At the same time boron carbide and alumina powders are also preheated to 400°C in the respective containers. Then, the crucible with aluminum alloy is heated to 830°C while the preheated powders are mechanically mixed with each other below their melting points.

This metal–matrix is then kept into the furnace at the same temperature. The furnace completely melts the pieces of aluminum alloy and the powders of alumina and boron carbide. The stirring mechanism is lowered into the crucible inside the furnace and set at the required depth. The various automatic stirring of the material takes place for 10 min with 550 rpm of stirring rate, there-by uniformly dispersing the additive powders in the aluminum alloy matrix. The temperature rate of the furnace should be controlled at $830^0 \pm 10^0$ C in final mixing process. The degasser removes all the trapped gases from the mixture in the crucible and ensures that the temperature of the mixture in the crucible does not get transferred easily to the atmosphere. This experiment is repeatedly done by varying the compositions of the composite powder. For each composition, a total of 0.75 kg (750 gm) material mix is used for preparing the samples. Apart from the above compositions, the aluminum alloy [LM 25] alone is melted and solidified in dies.

Sample 1 contains aluminum alloy—95%, alumina—1% and boron carbide—4%, sample 2 contains aluminum alloy—95%, alumina—1% and boron carbide—4% and sample 3 contains aluminum alloy only.Fig.1 shows Stir casting apparatus employed in the current work. Fig.2. shows the fabricated samples removed from stir casting setup.

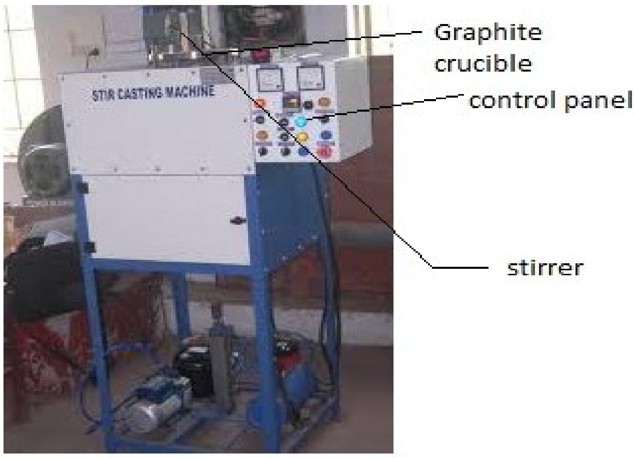

Figure 1. Stir casting Apparatus.

Figure 2. Casted Composition Samples

TESTING

The following tests are conducted on the fabricated specimens to know their mechanical properties.

Tensile test

The ability of a material to withstand a static load can be determined by testing the sample in tension or compression. Mechanical testing plays an important role in evaluating the fundamental properties of engineering materials as well as in developing new composite materials and to control the quality of materials used in design and construction. Tensile test is carried out using a universal testing machine. The specimen is prepared and tested as per ASTM: E8 standards.

Flexural test

The use of flexural test is to determine the flexural property of composite. This test measures the behavior of materials subjected to simple three point bending. The specimen is prepared as per ASTM: E290 standard.

Hardness test

The hardness test measures the resistance of a solid to permanent shape change when a force is applied. Brinell hardness test is carried out to find out the deformation of the composite under constant compressive load.

RESULTS AND DISCUSSION

The results of the test are discussed in this section.

Tensile test

The tensile test is done using universal testing machine and the specimens are cut as per the ASTM: E8 standard. The results obtained are furnished in Table 2. The tensile test specimen is shown in Fig. 4.

Comparison of tensile properties for different composites

Fig. 5shows the comparison of Force Vs Stroke for the three samples. It can be noted that sample 2 has the highest value of force for the same values of stroke followed by sample 1 and sample 3.

Fig.6 shows the comparison of break load, maximum displacement and percentage elongation for three samples. Sample 3 has the maximum values of break load, maximum displacement and percentage elongation. The sample 2 has greater break load, greater displacement and percentage elongation than sample 1. Since sample 3 contains aluminum alloy only the tensile strength of that sample is higher than other two samples.

Flexural test

The flexural test is done using three point flexural testing machine and the specimen was cut using ASTM: E290 standard. Tested specimen is shown in Fig. 7and flexural properties are furnished in Table 3.

Comparison of flexural properties for different composites

Fig. 8shows Force Vs Stroke graph for three samples of flexural test. It can be noted that sample 1 has the highest value of force for the same values of stroke followed by sample 2 and sample 3.

Fig. 9shows the values of break load and maximum deflection for three samples. From Fig. 9 it can be seen that sample 1 has the highest break load and flexural strength. Sample 1 has a higher break load than sample 2.

Brinell hardness test

The Brinell hardness test is carried out on the three samples and the results are furnished in Table 4. The ball shaped indenter made of hardened tungsten is used for this test. The diameter of ball shaped indenter is 10 mm and the load applied is 250 Kef. Brinell hardness test specimen in shown in fig 2.

Fig. 10shows the hardness value of three samples. It can be noted that sample 2 has the maximum hardness followed by sample 1 and sample 3 in all the trials.

Figure 3: Hardness test specimen

Figure 4: Tensile test specimen

Table 2: Tensile Properties of Composite Materials

Sample	Composition of composite specimen	Break load (kN)	Maximum displacement (mm)	Tensile strength (MPa)	Elongation (%)	Tensile modulus (N/mm²)
1	Aluminum alloy—95% Alumina—4% Boron carbide—1%	7.68	4.79	129.1	13.6	949.5
2	Aluminum alloy—95% Alumina—1% Boron carbide—4%	8.5	5.23	139.3	14.9	932.9
3	Aluminum alloy	8.9	5.79	145.9	16.5	915.3

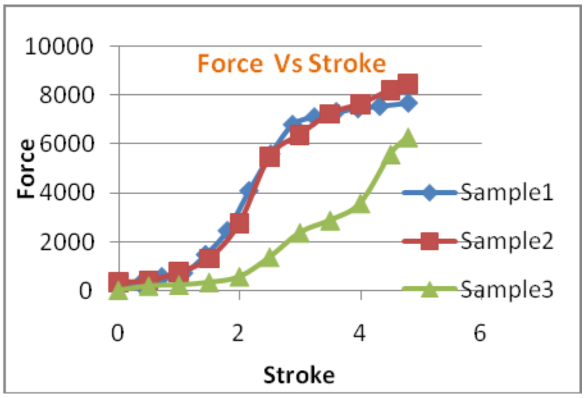

Figure 5: Force Vs Stroke graph for tensile test

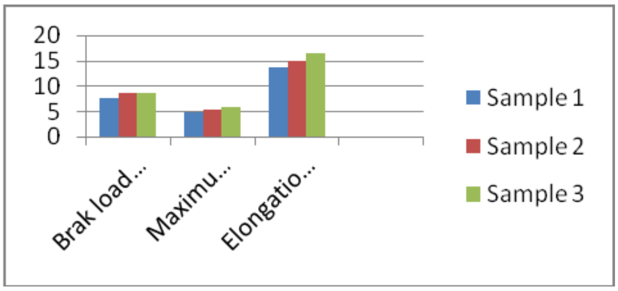

Figure 6: Break load, maximum displacement and percentage elongation (tensile test).

Table 3: Flexural properties of composites

Sample	Composition of composite specimen	Break load (kN)	Maximum deflection (mm)	Flexural strength (N/mm²)
1	Aluminum alloy—95% Alumina—4% Boron carbide—1%	9.5	3.6	192.80
2	Aluminum alloy—95% Alumina—1% Boron carbide—4%	7.35	2.6	145.84
3	Aluminum alloy LM25	4.5	1.85	54.39

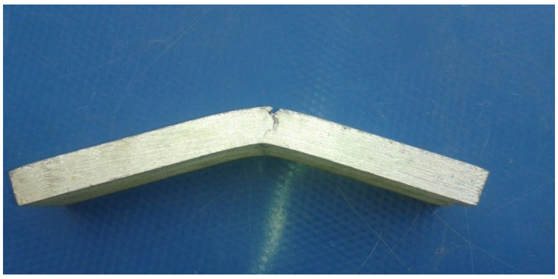

Figure 7: Flexural test specimen

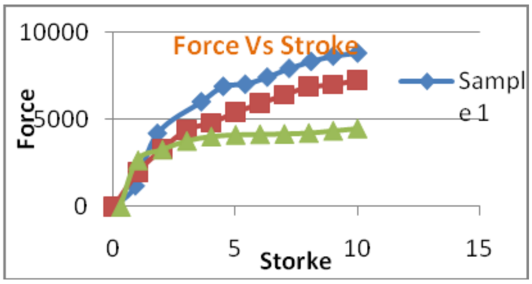

Figure 8: Force Vs Stroke graph for flexural test.

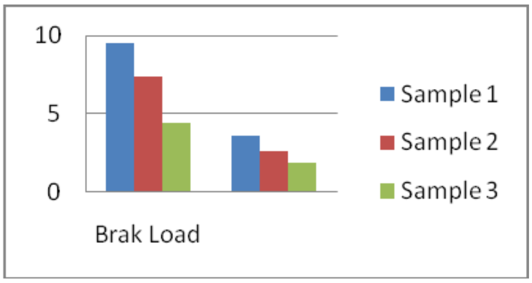

Figure 9: Break load and maximum flexural strength for flexural test.

Table 4: Hardness values of composites [in BHN]

Sample	**Composition of composite specimen**	**Trail 1 (BHN)**	**Trail 2 (BHN)**	**Trail 3 (BHN)**	**Average**
1	Aluminum alloy—95% Alumina—4% Boron carbide—1%	56.5	58.1	54.8	56.46
2	Aluminum alloy—95% Alumina—1% Boron carbide—4%	65.2	62.4	63.6	63.73
3	Aluminum alloy LM-25	40.05	42.7	42.6	41.78

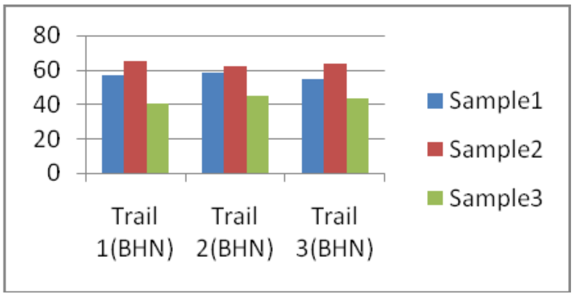

Figure 10: Brinell hardness number (hardness test).

MICROSTRUCTURE

To ensure the distribution of the reinforcement in the matrix, microstructure characterization was investigated experimentally by using inverted metallurgical microscope. The specimens were cut from the central portion of the composites, and then polished on the belt grinding machine for 3 minutes, and next polished on a disc polishing machine with different grades of emery papers for 4 min each, and then etched with Keller's reagent to remove the burrs and foreign particles. And then, the specimen was placed on the viewing stage of the inverted metallurgical microscope and then examined the microstructure with the monochromatic light source and photograph of microstructure was captured at magnification of 100 X and 500 X.

Microstructures of samples

Fig.10shows the microstructure of sample 1 at 100x magnification. The general arrangement of aluminum molecules and reinforcements of the aluminum alloy are faintly visible in the image. The darker particles are boron carbide and the lighter ones are aluminum. The aluminum particles in the matrix are more clearly visible at a magnification of 500x as shown in Fig. 12.The composite particulates are well distributed due to stirring effect.

Fig. 14shows the microstructure of sample 2 with a magnification of 500. However, only a few deboning particles are observed compared to sample 1.

Fig. 15shows the microstructure of sample 3 which consist of aluminum alloy [LM 25]. The picture shows the inner surface of sample 3 which consist of aluminum and other components like copper, silicon, magnesium, etc. It consists of tighter packing than the other composites, which explain the better tensile properties of the sample 3 compared to 1 and 2 samples.

From Fig. 16, the images of sample 3 can be clearly distinguished from those of samples 1 and 2 as these images lack the molecules of the reinforcements, which are visible in the cases of samples 1 and 2.

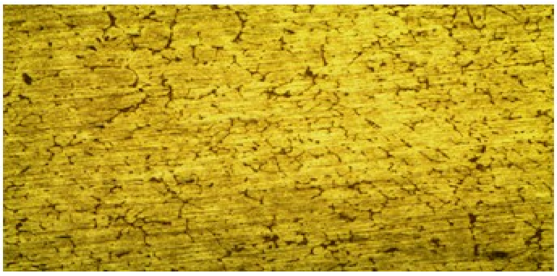

Figure 11: Sample 1 at 100X

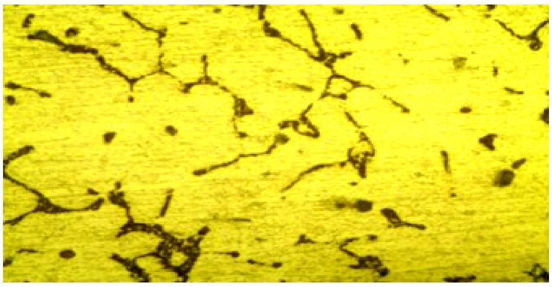

Figure 12: Sample 1 at 500 X

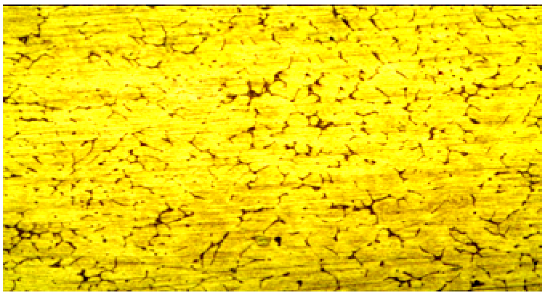

Figure 13: Sample 2 at 100X

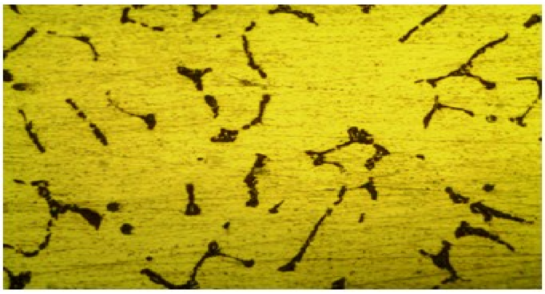

Figure 14: Sample 2 at 500X

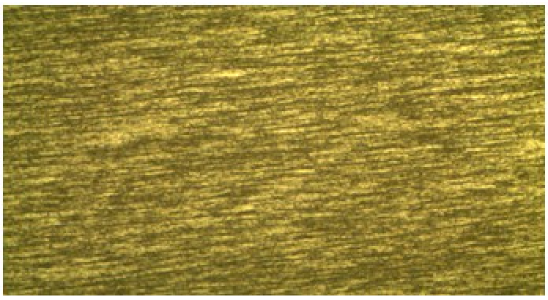

Figure 15: Sample 3 at 100X

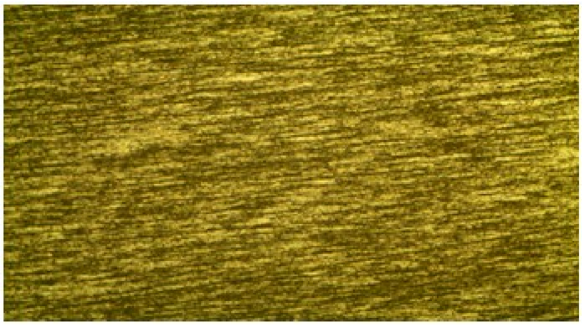

Figure 16: Sample 3 at 500X

CONCLUSIONS

In this work, three different samples are fabricated and the following inferences are made;

(1) It has been inferred that the tensile strength of sample 3 is marginally higher than other two samples because of its aluminum content. But, the sample 2 has higher tensile strength (139.38 MPa) than sample 1 (129.14 MPa).

(2) It has been noted that the flexural strength of sample 1 is(192.80 N/mm^2) higher than other two samples.

(3) The Brinell hardness of sample 1 (56.46 BHN) is marginally lower than that of sample 2 (63.73 BHN) but higher than that of sample 3 (42.83 BHN).

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