Evaluation of the Mechanical Characteristics of Boron Carbide and Aluminium Oxide Reinforced Hybrid Aluminium Composites for the automobile, aerospace application in future

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Abstract

In this century we are in a position to think about alternate material for all the application. Based on this ideology, we started to work on the Aluminum metal matrix composites because of its many good and essential characteristics. Aluminum metal matrix composites are widely favored in aerospace, automotive, and marine industries due to their exceptional properties, including a high strength-to-weight ratio and excellent wear resistance. Furthermore, the incorporation of nano-sized particles is gaining momentum as it enhances the strength of the metal matrix composites while preserving the ductility of the matrix alloy. This study focuses on the fabrication and assessment of the mechanical properties of an aluminum matrix composite reinforced with micro-sized boron carbide and nano-sized aluminum oxide using the stir casting technique.

Keywords: Metal matrix composites, Boron carbide, Nano Aluminum oxide, Stir casting, Mechanical properties

1. Introduction

1.1. Composites

Composite materials are precisely defined as materials crafted by combining two or more constituent materials, each possessing significantly different physical or chemical properties. When these materials are melded together, they create a composite with characteristics that diverge from those of its individual components. Importantly, the individual constituents retain their separate and distinct identities within the final composite structure. The allure of composite materials lies in their ability to offer advantages in terms of strength, weight, or cost-effectiveness when juxtaposed with traditional materials.

Composite materials find a wide array of applications, including in the construction of buildings, bridges, and various structures. They are commonly used in crafting boat hulls, swimming pool panels, race car bodies, shower stalls, bathtubs, storage tanks, as well as imitation granite and cultured marble sinks and countertops. Remarkably, the most cutting-edge composite materials even find routine use in spacecraft, enduring the rigors of demanding environments in outer space. There are many different types of composite materials, in that we focusing on the Metal matrix composites (MMC).

1.2. METAL MATRIX COMPOSITES

A metal matrix composite (MMC) is composite material with at least two constituent parts, one being metal. The other material may be a different metal or another material, such as a ceramic or organic compound. When at least three materials are present, it is called as a hybrid composite.

Metal matrix composites (MMCs) find wide-ranging applications thanks to their remarkable characteristics, including exceptional strength, lightweight nature, and high stiffness. Among the various materials used as matrices in MMCs, aluminum stands out as the top choice due to its low density, ease of fabrication, and strong engineering properties. Recently, particle-reinforced aluminum matrix composites have gained prominence in the automotive industry, finding applications in critical components such as engine pistons, cylinder liners, brake discs, and more.

A large variety of metal matrix composite materials exist. The reinforcing phase can be fibrous, plate like, or equiaxed (having equal dimensions in all directions) and its size can also vary widely from about 0.1 to more than 100 micrometers. Matrices based on most engineering metals have been explored, including aluminum, magnesium, zinc, copper, titanium, nickel, cobalt, iron, and various aluminides. This wide variety of systems has led to an equally wide spectrum of properties for these materials and of processing methods used for their fabrication.

The advantages of MMCs metals are,

- Higher strength-to-density ratios
- Higher stiffness-to-density ratios
- Better fatigue resistance
- Better elevated temperature properties: higher strength, lower creep rate
- Lower coefficient of thermal expansion
- Better wear resistance

The commonly used reinforcing materials in MMCs are as follows,

- Carbon fibers
- Silicon carbide fibers
- Alumina or aluminium oxide

- Silicon carbide
- Graphite
- Titanium boride
- Boron carbide
- Titanium carbide
- Molybdenum disulfide
- Fly ash, Rice husk ash and so on

2. Material Selection

2.1. A study on material selection

Abhishekkumar et al investigated the best possible predicted results and carried out the experimental setup of electromagnetic stir casting process in composite materials. The authors also showed significant effect of the mechanical properties such as hardness and tensile strength of A359/Al2O3. They reinforced A359 with 2, 4, 6, 8 weight percentage(%) of Al2O3 particles having average size of 30μm. The processing temperature had been kept at 7500C and the stirring speed is 300rpm. The researchers concluded that the hardness and tensile strength of the cast composites increases on increasing the weight fraction of Al2O3 particles and the microstructural observation assured that there is a good particulate matrix interface bonding.

Auradi et al produced a 11wt.% B4C particulate reinforced with 6061 Al matrix composites by conventional melt stirring method. The process carried out at a temperature of 750 0 C involving two stage additions. The authors introduced the preheated B4C particles, having average size of 88μm, along with the K2TiF6 halide salt (with ratio of 0.3) in steps of two rather than adding all at once. The average stirring speed is 250rpm. The authors characterized the prepared composites by SEM and XRD studies by which they assured that the uniform distribution of B4C particulates without clustering in 6061 Al matrix. The researchers also added that the addition of B 4 C particulates to 6061 Al matrix has resulted in improvements in mechanical properties of the base alloy.

Bharath et al prepared a 6061Al-Al2O3 metal matrix composite by stir casting technique and evaluated its mechanical and wear properties. The authors varied the addition level of reinforcement from 6 to 12wt% in steps of 3wt%. They preheated the reinforcement particles to a temperature of 2000C and then dispersed those reinforcement particles in steps of three into the vortex of molten Al6061 alloy to improve the wettability and distribution. The researchers revealed that the hardness and tensile properties were higher in case of composites when compared to unreinforced 6061Al matrix; also increasing the addition level of reinforcement has resulted in further increase in both hardness and tensile strength.

Dinesh Kumar Koli et al reviewed on properties, behavior and processing methods for aluminium alloy and nano Al2O3 particulate reinforced metal matrix composites. The researchers assured that the addition of nano Al2O3 particles will give greater tensile strength, high modulus of elasticity and reduced weight for the same performance. Also they added that it will give improved fracture toughness of the metal matrix composite.

Himanshukala et al reviewed the mechanical and tribological behaviors of stir cast aluminium matrix composites. The researchers reported that the addition of Al2O3, SiC, B4C particles in Al matrix improves the hardness, tensile and yield strengths while ductility is decreased. Also they added that the addition of graphite in Al matrix increases the tensile strength and elastic modulus while hardness is decreased.

Siddesh Kumar et al attempted to develop the Al 2219 reinforced with B4C and MoS2 for hybrid composites by using stir casting technique. The authors added the preheated B4C (3 wt.% constant) and MoS2 particles of 3, 4, 5 wt.% into the semi liquid molten aluminium alloy, which is heated at 7500C, in steps and mixed together with an average stirrer speed of 400-450rpm for about 5mins. The researchers reported that the density and micro hardness of the MMCs increases by increasing the wt.% of the reinforcement particle B4C whereas tensile and yield strengths decreases by increasing the secondary reinforcement MoS2.

2.2 About Aluminum Matrix composites

2.2.1 ALUMINIUM ALLOY (LM25)

Aluminium and its alloys have attracted the most attention as matrix material in metal matrix composites. Among various aluminium alloys, LM25 is a common purpose alloy of aluminium which is used where good mechanical properties are needed. It has a good resistance to corrosion and has a high strength. It responds well to heat treatment and is available in four different conditions.

The uses of aluminium alloy of grade LM25 are increased by its availability in as-cast and partially heat treated conditions as well. The nominal chemical composition of LM25 aluminium alloy is presented in the table [11]. From the chemical composition of the LM25 alloy, it is clear that aluminium content occupies the major amount of the LM25 alloy followed by silicon content.

Elements	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Sn	Ti	Pb	Ca	Al
Percentage (%)	6.731	0.391	0.043	0.043	0.504	0.009	0.015	0.001	0.002	0.007	0.004	0.005	Bal

Table 2.1. Chemical compositions of Aluminium alloy LM25

LM25 alloy finds application in the food, chemical, marine, electrical and many other industries and above all in road transport vehicles where it is used for cylinder blocks and heads, and other engine and body castings. Also they are of high resistance to corrosive attack by sea water and marine atmospheres.

2.2.2.ALUMINIUM OXIDE (Al_2O_3)

Aluminium oxide or alumina is a chemical compound of aluminium and oxygen. It is an electrical insulator but has a relatively high thermal conductivity (30 Wm-1K-1) like ceramic material. Its hardness makes it suitable for use as an abrasive and also as a cutting tool. The nano aluminium oxide particle which is used in this study is shown below.

Figure 2.1 Nano Aluminium oxide particles

In this study, Al 2 O 3 particles having 20-30nm average size has been used as a reinforcement material. Rajmohan et al (2014) said that the use of nano particles can improve the strength of the MMCs.

2.2.3. BORON CARBIDE (B_4C)

Boron carbide is one of the most promising ceramic materials due to its attractive properties, including high strength, low density, extremely high hardness, good chemical stability and neutron absorption capability

Figure 2.2: Boron carbide particles

It is produced by reacting carbon with B_2O_3 in an electric arc furnace. For commercial use, the boron carbide powders are milled and then purified to remove the metallic materials

The wettability of boron carbide is poor. Zhiwei Liu (2014) and Suresh (2012) et al said that the addition of Ti and TiB_2 can improve the interfacial bonding. So In order to improve the wettability between boron carbide and molten aluminium alloy a halide salt namely Potassium hexafluorotitanate (K_2TiF_6) is used [4, 5, 12] and it is shown below.

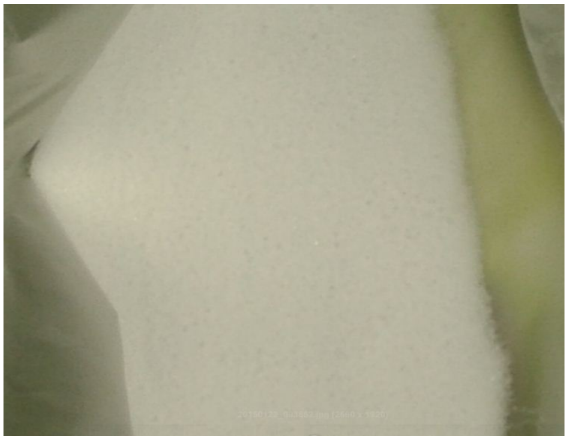

Figure 2.3: Potassium hexa fluorotitanate salt

2.2.4. PROPERTIES OF THE MATERIALS

The mechanical properties of the selected materials such as Aluminium alloy of grade LM25, Boron carbide particles (B_4C) and Aluminium oxide particles (Al_2O_3) are shown in table

Material	Tensile strength (MPa)	Density (g/cm^3)	Coefficient of thermal expansion ($10^{-6}/ {}^0C$)	Modulus of elasticity (GPa)
Al alloy LM 25	190 – 250	2.68	2.2	71
B_4C	261	2.3 – 2.55	3.2	362
Al_2O_3	255.2	3.98	7.4	380

Table2.2: Properties of the selected materials

3. FABRICATION AND TESTING PROCEDURE

The experimental setup to fabricate the MMCs comprises of crucible and a stirrer; crucible and stirrer are made up of cast iron and mild steel respectively. In the fabricating procedure, preheating is the first process, so that the void crucible was preheated up to 450 to 5500C, whereas the die which is used to solidify the melt was preheated up to 2000C. The reinforcement particles such as nano aluminium oxide particles and the mixture of micro B4C particles and the equal amount of K2TiF6 flux were separately preheated up to 400 to 5500C. The base metal, aluminium alloy LM25 was melted in the crucible at the temperature around 8000C. To remove all the entrapped gases from the mixture in the crucible, a degasser agent was used. Then the reinforcement particles were added singly and mixed by means of mechanical stirring into the matrix alloy weighing 1000 g. Here the reinforcement particles were added into the molten Al alloy in two steps rather than adding all at once; it gives the advantage of avoiding agglomeration. So that the nano Al2O3 particles were divided into two equal amounts and added on the individual basis with the molten alloy.

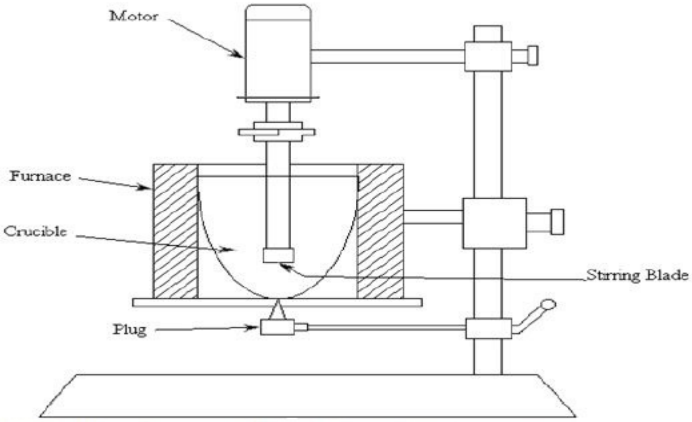

Figure 3.1: Stir casting-line diagram

After adding the each amount of particles into the liquid aluminium alloy, that mixture was mechanically stirred at the speed of 200rpm for 2 min and the temperature was maintained at 7500C. The mixture of micro B4C particles and K2TiF6 flux also adopts the same adding and mixing procedure of nano Al2O3 particles.

Figure 3.2: Pouring of melt

Eventually, the melt was poured into the preheated die at 7000C and allowed to solidify at the atmospheric temperature. This experiment was repeatedly executed by keeping the weight % of B_4C particles as constant and varying the weight % of nano Al2O3. Besides the base alloy LM25 alone was melted and solidified in the die. After the fabrication, the specimens were prepared for tensile, hardness and impact tests to evaluate the mechanical properties of the composites.

The ability of a material to withstand a static load can be determined by testing the material in tension or compression. In this study, tensile tests were carried as per ASTM E8M standard on the samples, with the aid of ultimate tensile testing machine at room temperature 28 ± 50C.

The resistance of a solid to permanent shape change when a force is applied can be measured by hardness test. In this work, Brinell hardness tests were conducted to determine the deformation of the metal matrix composite under constant compressive load from a sharp object.

Impact test of a specimen implies abrupt and dynamic application of the load on the composite specimen. In this study, charpy test was carried out to determine the amount of energy absorbed by the composite specimen for the given load in joules. For this, the specimen was prepared as per ASTM E23 standard.

4. EVALUATION OF MECHANICAL PROPERTIES OF AMCs

In this investigation, to evaluate the mechanical properties of the Al matrix composites the following tests are carried out: Tensile, Impact, Hardness tests and SEM analysis.

4.1. Tensile test

The tensile test is made out by using the universal testing machine and the specimens for this test were prepared as per ASTM E8M standard. Fig 4.1. displays the comparison of Load vs. Cross head displacement for all the samples. It can be noticed that the tensile strength is increased on increasing the wt. % of the reinforcement particles and also it is significantly higher than that of the base alloy

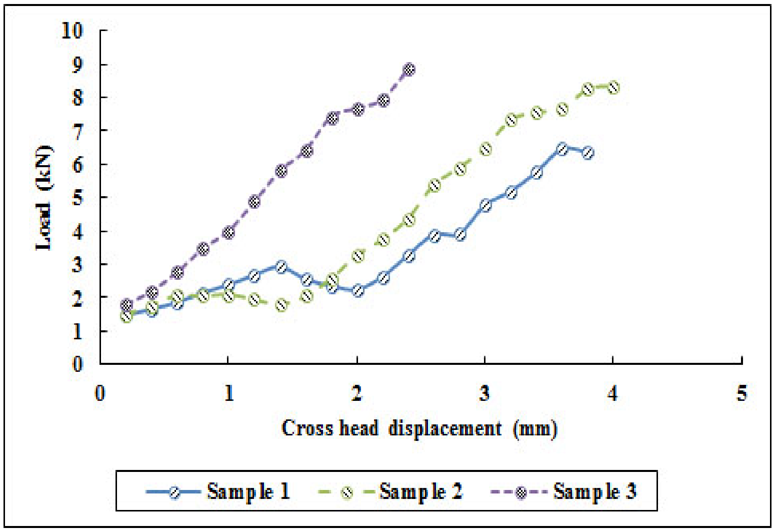

Figure 4.1. Load vs. Cross head displacement

The betterment in the tensile strength noticed with the addition of reinforcement particles, could be due to the incorporation of higher strength to matrix material, by providing more resistance to the tensile stresses. This is for the reason of reassigning the load from the matrix material to the reinforcement particles increased the tensile strength of the composite specimens. This increase in tensile strength is due to the higher strength of the reinforcement particles such as boron carbide and aluminium oxide.

Generally, the particles in nano scale level will get more dispersed in the matrix material than the particles in micro scale level; so only the tensile strength of the sample 2 is lesser than the sample 3 and higher than the sample 1.

Fig 2. depicts the comparison of break load, maximum displacement and the elongation percentage for all the samples.

From Fig 2. Sample 1 attained the maximum value of break load than the sample 2 whereas sample 2 has the greater break load value than the sample 3. But sample 1 has the lower value of displacement than other samples; this is due to whenever the wt.% of reinforcement particles were increased, the tensile stress applied to the composite specimen undergone more resistance due to motion dislocation.

Higher strength of the composites is due to the addition of B4C and nano Al_2O_3 particles acts as the obstacles to the motion of dislocation and also due to very good bonding between matrix material and the reinforcement particles.

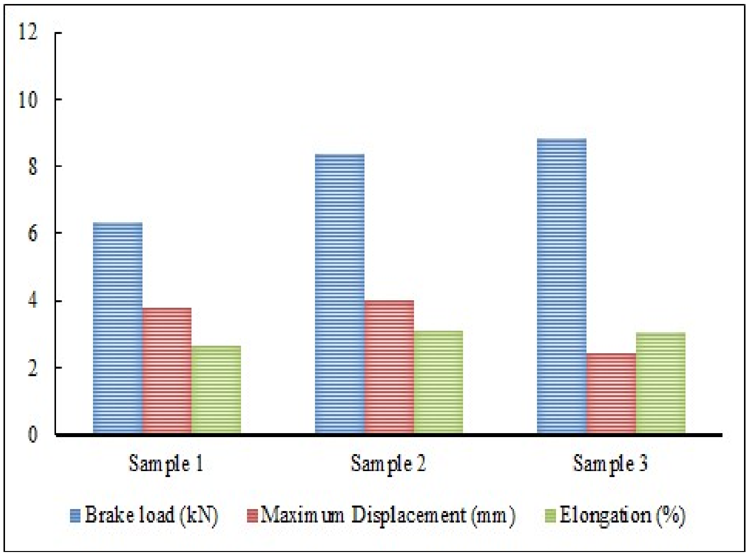

Figure 4.2. Comparison of Break load, Maximum displacement, Elongation (%) for three samples.

3.2 Hardness test

The Brinell hardness test is executed on all the composite samples. The ball shaped intender having diameter of 2.5 mm and made up of tungsten is used for this test. The load employed is 62.5 Kgf.

The Fig 4.3. shows the hardness value of all the three composite samples. It can be noted that the average hardness value of the sample 3 is maximum followed by the sample 2 and sample 3.

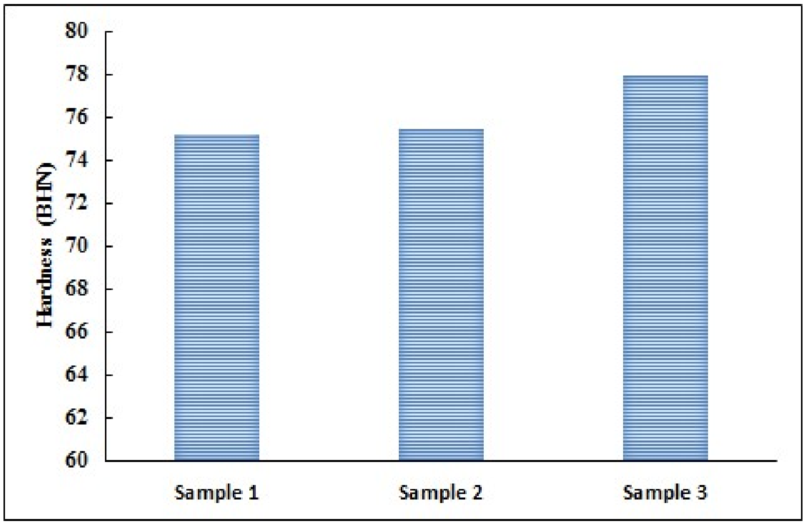

Figure 4.3. Comparison of Hardness values for three samples

But the increase in hardness value of the sample 2 and sample 3 is very minimal than the base material sample 1. This happened may be due to the uneven distribution of reinforcement particles over the specimen.

3.3. Impact test

The Charpy test is carried out by preparing the specimen as per the ASTM E23 standard.

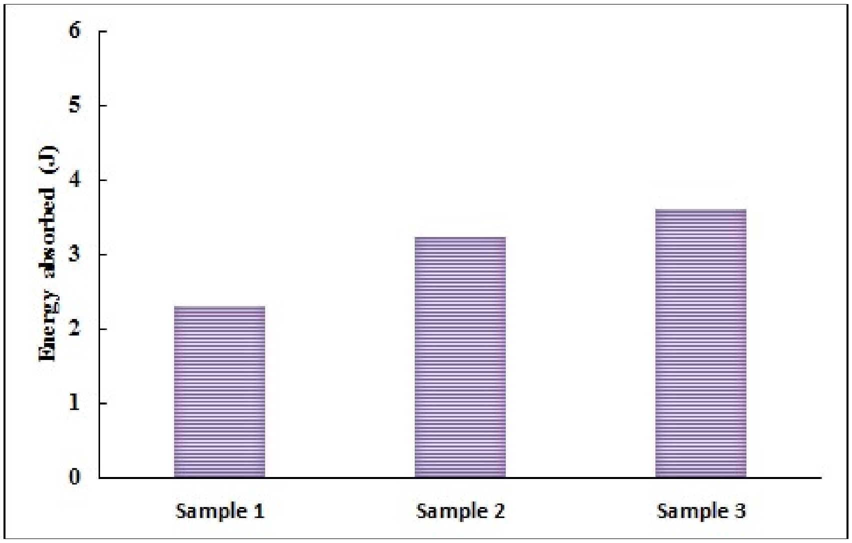

Figure 4.4. Comparison of energy absorbed for three samples

It has been clearly noted that the sample 3 absorbs more energy followed by sample 2 and sample 1. The Fig 4.4. indicates that the energy absorption of the composites increases with the increase in wt. % of the reinforcement particles.

5.CONCLUSION

The aluminium based metal matrix composites were produced through stir casting technique, by keeping the wt.% of the micro B_4C as 3% and varying the wt.% of the nano Al_2O_3 as 4% and 5%. The wettability and the interfacial bonding between the B_4C particles and the molten aluminium alloy was improved by using K_2TiF_6 flux. And then the tensile, hardness and impact tests were carried out to evaluate the mechanical properties of the composites. The following inferences were made after those tests.

- The tensile strengths of the composites were higher than the base alloy. Higher strength of the composites is due to the addition of micro B_4C and nano Al_2O_3 particles acts as the obstacles to the motion of dislocation and also due to very good bonding between matrix material and the reinforcement particles.

- Considering the results of impact test, the energy absorbed by the composites was higher than the energy absorbed by the base alloy.

- After the hardness test, it was found that there was a minimal increase in the hardness value of the composites when compared to the base alloy.

- It is identified that, the mechanical properties of the composites were increased on increasing the wt.% of these reinforcement particles.

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