Evaluation of Mechanical Properties of Aluminum Alloy-Alumina-Boron Carbide Metal Matrix Composites

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The importance of composites as engineering materials is considered by the fact that out of over 1600 engineering materials available in the market today consists of 200 composites. These composites initially are Cast Iron and Bronze alloys but owing to their poor wear and seizure resistance, they were subjected to many experiments and the wear behavior of these composites were traversed to a maximum extent and were reported by number of research scholars for the past 25 years. In the present study based on the literature review, the effect of Boron Carbide on Stir Cast Aluminum Metal Matrix Composites is discussed. aluminum hybrid composites are a new generation of metal matrix composites that have the potentials of satisfying the demands of advanced engineering applications such as in aerospace, automobile, space, underwater and transportation applications. This is mainly due to upgraded mechanical and tribological properties like stiff, strong, abrasion and impact resistant and is not easily corroded. This paper attempts to review the different combination and configuration of reinforcing materials used in processing of hybrid aluminum matrix composites and how it effects the mechanical, corrosion and wear performance of the materials.

Keywords: Aluminum alloy, Alumina, Boron Carbide, Metal Matrix Composites, Stir Casting.

INTRODUCTION

A metal matrix composite (MMC) is a composite in which two or more reinforced materials are added to the metal matrix in order to enhance the properties of the composite. A hybrid metal matrix composite (HMMC) consists of three or more composites composed with metals or materials. Composites are the most promising material of recent industrial applications.

In the modern applied sciences, the concept of mixing two or more dissimilar materials has gained much attention. The composite industry has begun to recognize the commercial application of composites which promises to offer much larger business opportunities in aerospace, automotive and industrial sectors (Ramnath et al. 2014). The most commonly used metal matrix is Aluminum, Titanium, Magnesium and their alloys. Aluminum metal matrix composites (AMMC) are the composites in which aluminum is used as the matrix and several material reinforcements are embedded into the matrix. Some of the reinforced materials are Boron Carbide, Alumina, Silicon Carbide, Fly ash, red mud, cow dung, rice husk etc... (Harish et al. 2018).

Boron Carbide (B₄C) is boron-carbon ceramic and is an extremely hard reinforcement material with excellent hardness, corrosion resistance and mechanical properties which makes it a suitable material for a number of engineering applications. Alumina is mostly used as reinforcement material because of its very good electrical insulation, very high compressive strength, high hardness, good gliding properties etc... (Das et al. 2014).

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AMMC are in demand due to their properties like low density, high specific strength, high damping capacity, high specific modulus, high thermal conductivity and high abrasion and wear resistance and also accompanied with good mechanical properties, low thermal coefficient of expansion, better corrosion resistance, high strength to weight ratio and high temperature resistance etc… (Gopal Krishna et al. 2013).

Aluminum metal matrix composite provides lesser wear resistance when compared to steel, hence it is widely used as a metal matrix. The AMMC can be manufactured by various manufacturing techniques such as Stir Casting, Powder Metallurgy, Pressure Infiltration, Squeeze Casting, Vapor Deposition etc… Amongst all the process, Stir Casting is the most common technique used by the researchers.

**MATERIAL SELECTION**

In this paper, materials selected for fabrication of metal matrix composite are Aluminum alloy, Alumina, Boron Carbide. Their properties were discussed briefly in this paper.

**Aluminum Alloy LM25**

The greatest benefit of selecting LM25 is the strength that can be achieved in the heat-treated condition, but heat treatment cannot normally be used on high pressure die castings, it means that LM25 is the most commonly used for gravity or sand casting. It has good machining properties and can be used in marine applications because of its sea water corrosion resistance property and can also be used in industrial applications.

**Alumina or Aluminum Oxide (Al₂O₃)**

Alumina is one of the most cost effective and most used material used material in the family of engineering ceramics. Alumina possess strong ionic interatomic bonding giving rise to its desirable material characteristics. It can be existed in several crystalline phases which all return to most stable hexagonal alpha phase at elevated temperatures. Alpha phase Al₂O₃ is the strongest and stiffest of the oxide ceramics. It has high hardness, refractoriness, excellent dielectric properties and good thermal properties making it to use for wide range of applications.

**Boron Carbide (B₄C)**

Boron Carbide is one of the hardest materials known, ranking third behind diamond and cubic boron nitride. It was originally discovered from the by-products of metal borides. It is difficult to sinter to high relative densities without the use of sintering aids. It has good chemical resistance, good nuclear properties. It can be used in various applications such as nuclear, ballistic amour etc…

**LIQUID STATE FABRICATION OF MMC**

Amongst the various fabrication techniques, liquid state fabrication is chosen to fabricate the metal matrix composite for this project. Liquid state fabrication of metal matrix composites involves incorporation of dispersed phase into molten matrix metal, followed by its solidification. To attain good mechanical properties of composite, good interfacial bonding between dispersed phase and molten matrix metal should be obtained.

Liquid state fabrication methods are attractive as they are relatively simple, cost effective and are potentially scalable to industrial level. These methods include Stir Casting, Compo Casting, Squeeze Casting, Vapor deposition method etc…

**Stir Casting**

In Stir Casting, the dispersed phase (ceramic particles, short fibers) is mixed with a molten metal matrix by means of mechanical stirring. In recent development, stir casting is a two-step mixing process. The matrix metal is heated above its melting temperature so that the metal is totally melted. The molten metal is the cooled down to temperature between the liquids and solidus points and kept in semi solid state. At this stage, the preheated particles (ceramics, short fibers) are added and mixed. The slurry is again heated until it turns to liquid state and mixed thoroughly. The effectiveness of this two-step processing method is mainly assigned to its ability to break the gas layer around the particle surface.

**Compo Casting**

Compo Casting is a liquid state process in which reinforcement particles are added to a solidifying melt while being vigorously agitation. It is shown that the primary solid particles already formed in the semisolid slurry can mechanically entrap the reinforcing particles, prevent their gravity partition and reduce their agglomeration. These will achieve better distribution of the reinforcement particles. The lower porosity observed in the castings has been allocated to the better wettability between the matrix and the reinforcement particles as well as the lower volume shrinkage of the metal matrix alloy.
Squeeze Casting

Squeeze Casting infiltration or Pressure Die Infiltration is a forced infiltration method of liquid phase fabrication of metal matrix composites, using a movable part (ram) for applying pressure on the molten metal and force it to penetrate into a discharged dispersed phase, placed in the lower fixed mold part.

Spray Deposition

This technique typically consists of winding fibers onto a foil-coated drum spraying molten metal on them to form a mono tape. The source of molten metal may be wire feedstock or powder which is melted in a flame, arc or plasma torch.

METHODOLOGY

The fabrication procedure of composites with detailed steps is explained below.

1. AL-LM 25 alloy
2. Melted at 800°C
3. Add degasser 5g
4. Remove impurities
5. Mix AL-LM 25 + Al₂O₃+B₄C
6. Stir the mixture for 10min at 500rpm
7. Pour the molten metal into die
8. AL-LM 25/ Al₂O₃+B₄C composites

Figure 2: Squeeze Casting, Ramanathan et.al (2014).

Figure 3: Spray Deposition, Cava RD et. Al (2014).
LITERATURE REVIEW

Auradi et al. (2014) produced 11wt% B4C particulate reinforced with 6061 Al matrix composites by conventional melt stirring method. They observed that the improved mechanical properties (hardness, yield stress, UTS) of composite when explicit to the matrix alone whereas ductility decreases. And they obtained extent of improvements in yield strength and ultimate tensile strength were 44.35% and 42.6% respectively.

Baradeswaran et al. (2013) studied the influence of B4C on the tribological and mechanical properties of Al7075- B4C composites. The authors revealed that the hardness of composite increased when compared with base alloy because of addition of B4C particular’s and wear rate of composite decreased when compared with base alloy.

Baradresar et al. (2008) reported the effect of application of traditional investment casting process in AMMC. Aluminum alloy reinforced with SiC and B4C were compared and the experiments showed the wear resistance of SiC reinforced MMC is greater than that of B4C reinforced MMC.

Basithrahman et al. (2016) studied on wear behavior of Aluminum hybrid metal matrix composites. Hybrid Aluminum metal matrix composites were fabricated by stir casting method. Aluminum is used as a matrix material & Al2O3, B4C & SiC are used as reinforcement particles. The weight fraction of & Al2O3 is varied, B4C & SiC are kept constant. The fabricated composites are machined for wear test according to ASTM standard. Wear test was done by varying load of 9.81N, 19.62N, 29.43N & 39.24N. The morphological study of worn specimens was done using Scanned Electron Microscope (SEM), which revealed the uniform distribution of reinforcement particles with base metal.

Blaza et al. (2015) studied in hybrid Aluminum metal matrix composites application in automotive industries for the production of engines, car shaft, piston rings & sockets are studied. The use of hybrid Aluminum metal matrix composites instead of metal matrix composites or monolithic results in reduction of weight which improves the decrease in fuel consumption of automobile vehicles.

Cambronero et al. (2003) observed the mechanical properties of A7015 aluminum alloy reinforced with ceramics and reported that hardness increased by ceramic addition due to this the plastic deformation of composite is decreased and better wear behavior achieved.

Chandra Mohan et al. (2014) conducted investigations on the fabrication of Al/Graphite/Boron Carbide Hybrid metal matrix composite was done by stir casting process and studied the properties of the fabricated composite. The study revealed the tensile strength of composite material compared to the as cast Al LM25 alloy, increased significantly by 60-70%. From the microstructure analysis it is evident that the composites fabricated have fairly even distribution of reinforcements in the composite material.

Chuangdongwu et al. (2014) examined the effect of plasma activated sintering parameters on microstructure and mechanical properties of Al-7075/ B4C composite. They observed that the high mechanical properties including Vickers hardness 181.6 HV, bending strength1100.3 MPa, high compression yield strength 878.0 MPa and fracture strength 469.3 MPa of the consolidated Al-7075/B4C composite sintered at 530°C for 3 min were achieved and attributed to a fully dense microstructure and a strong interphase interface between matrix and reinforcement.

Clara Hofmeister et al. (2010) investigated the trimodal Aluminum metal matrix composites and the factors effecting its strength. The test result shows that the attributes like nano-scale dispersoids of Al2O3, crystalline and amorphous Al4C3 and AlN, and also high dislocation densities in both NC-Al and CG-Al domains, which results in interfaces between different constituents, and nitrogen concentration and distribution leads to increase in strength.

David Raja et al. (2013) reported that among different reinforcements used, fly ash is one of the cheapest available reinforcement and its advantage includes low density which makes the path for development of cost-effective AMCs.

Deaquino et al. (2011) stated that the effect of the addition of Al2O3 and graphite on the hardness of the hybrid composites was increased. It was observed that the properties were improved with increasing Al2O3 ceramic particulate content. The hardness of the hybrid composites is directly proportional with the content of Al2O3 exceeding that of the base alloy in all of the compositions. The addition of Al2O3 particles increases the tensile strength and the flexural and compression strength of the hybrid composites is greater than that of the base alloy.

Dinaharan et al. (2012) casted Aluminum matrix using various ceramic particles, such as SiC, Al2O3, TiC, B4C and WC. Test such as the microstructure through SEM, micro hardness and tensile strength were carried on casted material. SiC, TiC, B4C and WC reinforced particles had fragmentation during Friction Stir Processing because of plastic deformation and contact with the rotating tool. The fragmented particles are mixed well with Aluminum. All types of reinforcements increased the UTS of Aluminum.

Elzayady et al. (2005) concluded that Aluminum-Alumina composites have good mechanical and tribological properties and are used for crank bearings and motor block in order to improve the wear resistance. The soft structure of Aluminum has very poor wear resistance, which makes it inadvisable to use in machine parts therefore using hard phases like Al2O3 could impart hardness and wear resistance in Aluminum or its alloy.
Gomes et al. (2013) investigated that, among ceramic materials, SiC and Al₂O₃ are widely used, due to their favorable combination of hardness, density and cost effectiveness. When these reinforcements are composed with Al-MMCs, the resulting material exhibits significant increase in its hardness, strength, elastic modulus and wear resistance.

Gopal Krishna U.B et al. (1999) found the effect of reinforcement of Boron Carbide on Aluminum matrix composites. The authors produced Al-B₄C by stir casting method with different particle size (viz 37µ, 44µ, 63µ, 105µ, 250µ) of reinforcement and noticed that the micro Vickers Hardness of AMC was to be effectively high for the particle size of 250µ and 12 wt%. In case of varying wt%, with the reinforcement of 105µ size particles the tensile strength of AMC’s was found to be maximum for 8 wt%.

Hashim et al. (2014) studied the resulting microstructure has been found to be more uniform than that processed with conventional stirring. The other problem is if the reinforcement particles are distributed uniformly in molten matrix, they tend to float or sink in the molten metal due to density differences between the reinforcement particles and the matrix alloy melt. If the dispersion of the reinforced particles is not uniform, then they have high tendency to agglomeration and clustering. By injecting the particles with an insert gas into the melt is useful in improving the distribution of the reinforcement particles.

Ibrahim et al. (2013) observed mechanical characterization and fracture of Al-15vol%B₄C based Metal matrix composites. The authors observed that the ductility of the composite material decreases with increased vol% of B₄C and the fracture of B₄C reinforcements occurs by a cleavage mechanism.

Jha P.K et al. (2004) examined this category of hybrid AMCs is developed basically for optimization of performance with less focus on the production cost. Silicon carbide (SiC), alumina (Al₂O₃), boron carbide (B₄C), tungsten carbide (WC), graphite (Gr), carbon nanotubes (CNT)and silica (SiO₂) are some of the synthetic ceramic particulate that has been studied but silicon carbide and alumina are mostly utilized compared to other synthetic reinforcing particulates.

Jinkwanjung and shinhookang et al. (2011) Advances in manufacturing boron-carbide aluminum composites. The authors revealed that with addition of titanium metal to aluminum born carbide composite reduces 100-200°C sintering temperature of composite and Heat treatment of boron carbide skeleton in the temperature range of 1000-1400°C before infiltration has optimum effect on the infiltration of liquid aluminum on boron carbide. Bimodal distribution of powder mixture increases the green density of the skeleton and mechanical properties (toughness, hardness).

Kalaiselvan et al. (2017) stated fabrication and properties of AA6061-B₄C stir casting composite. Authors concluded that the addition of 4 to 12 wt% of B₄C particles the micro and macro hardness of the composite were changed from 51.3HV to 80.8HV and 34.4BHN to 58.6BHN respectively.

RESULTS AND DISCUSSION

Different combinations of reinforcements are used to fabricate hybrid metal matrix composite and varying the proportions of the reinforcements, 3 different samples are fabricated and tested to evaluate the mechanical properties. The 3 different sample compositions are shown in the table below.

<p>| Table 1: Variation of proportions of reinforcements in the Composite. Vijaya et.al (2014). |</p>
<table>
<thead>
<tr>
<th>Sample</th>
<th>Composition of Composite Specimen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample-1</td>
<td>Aluminum alloy-95%</td>
</tr>
<tr>
<td>Sample-2</td>
<td>Aluminum alloy-95%</td>
</tr>
<tr>
<td>Sample-3</td>
<td>Aluminum alloy-100%</td>
</tr>
</tbody>
</table>

**Tensile Test**

The tensile test is conducted by using Universal Testing Machine and the samples are cut as per the ASTM: B-557M standard. The three samples were compared to evaluate the mechanical properties.

The comparison of break load, maximum displacement and percentage elongation were carried out and observes as, the sample 3 (pure Al alloy) has maximum break load values, maximum displacement and maximum percentage elongation. Whereas sample 1 has greater break load than sample 2 and sample 1 has maximum percentage elongation which is equal to sample 3, and sample 1 has less displacement when compared with sample 2 because variation in mechanical properties of three samples changes with the variation in the proportions of reinforcements added to melted metal.

**Figure 4:** Break load, maximum displacement and percentage elongation (tensile test). Vijaya et.al (2014).
**Flexural Test**

The flexural test is conducted by three-point flexural testing machine and the specimens was cut as per the standards of ASTM: A370. Three samples were compared to evaluate flexural properties.

Comparison of break load and maximum deflection of three samples were carried out and observed that sample 3 has superior values of both break load and deflection. Sample 1 has greater break load than sample 2, whereas sample 2 has greater deflection than sample 1.

![Figure 5: Break load and maximum deflection (flexural test). Vijaya et al. (2014).](image)

**Impact Strength**

The Charry Impact test is performed by preparing the samples as per IS 1757 standard. It was observed that sample 2 observes more energy to resist the impact force when compared to sample 1 and sample 3, because the high content of carbon which makes the sample 2 turn out to be into high strength.

![Figure 6: Energy absorbed in Impact test. Vijaya et al. (2014).](image)

**Brinell Hardness Test**

The Brinell Hardness Test is carried out on the three samples and three trials are conducted. The ball shaped indenter made of hardened tungsten is used for this test. The diameter of ball shaped indenter is 10mm and the load applied is 500kgf. The test resulted as, the value of sample 2 has the maximum hardness followed by sample 1 and sample 3 in all the 3 trials, because of the high carbon content makes the sample 2 more harden.

![Figure 7: Brinell Hardness number (Hardness test). Vijaya et al. (2014).](image)

**Morphological Analysis using Scanning Electron Microscope (SEM)**

The Scanning Electron Microscope (SEM) uses electrons instead of light to attain the image. The main principle of SEM is the bombarding of electrons and with the secondary electrons which are reflected are used to form an image. The main purpose of SEM is microstructure analysis. Three samples microstructures were analyzed and reported that sample 3 consists of tighter packing of metal atoms than the other 2 composites, which explains the reason for better tensile and flexural properties when compared to samples 2 and 3.

![Figure 8: Sample 1 at 500×. Ramnath et al. (2014).](image)
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CONCLUSIONS

This paper presents the different combination of reinforcements used in the synthesis of hybrid AMC’s and how it influences their mechanical properties.

1. It has been observed that the tensile strength of sample 3 is marginally higher than the samples 1,2 because of its Aluminum content, but the sample 1 has higher tensile strength than sample 2. It has been noted that, Flexural strength for sample 3 is higher than the other 2 samples.

2. The impact strength of sample 2 is greater than the other 2 samples, because carbon content makes the sample 2 more strengthen component. Brinell hardness test concludes that, the sample 2 has high hardness value when compared to sample 1 and sample 3.

3. Finally, it is observed that the fabrication of Hybrid Metal Matrix Composites results in advancement of mechanical properties such as low density, mechanical compatibility, high elastic modulus, low thermal expansion, high compression and tensile strength etc...

4. With the advancement in mechanical properties this Al alloy-Al₂O₃-B₄C hybrid composite can be widely used in various areas such as marine applications, automotive industries, space applications etc...

5. It was noticed that hardness of the composite will be increased depending upon the added reinforcement fraction or by reducing the particle size of reinforcement however, the porosity in the composites affects hardness adversely. The hardness of ceramic reinforced composites will be improved by ageing time heat treatment and ageing temperature.

6. yield stress, Young’s modulus, breaking (fracture) stress and ultimate tensile stress of ceramic-reinforced Aluminum matrix composites were higher than monolithic alloys and increased with the reinforcement fraction of ceramic materials however, the ductility of the composites is reduced.

7. It is hard to attain a perfectly homogeneous phase of composites through reinforced particles in the matrix phase, when the Aluminum matrix composites were fabricated through liquid metallurgy or stir casting method.

REFERENCES


Accepted 24 May 2019


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