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# Hybrid Aluminium Metal Matrix Composites and Reinforcement Materials: A Review

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**ABSTRACT:** Aluminium metal matrix composites (AMMCs) are potential materials for various applications due to their good physical and mechanical properties. The addition of reinforcements into the metallic matrix improves the stiffness, specific strength, wear, creep and fatigue properties compared to the conventional engineering materials. This paper presents the overview of the different reinforcement materials used in AMMCs and their effects on the mechanical and tribological properties like hardness, compression, tensile strength and wear resistance of the materials.

**KEYWORDS:** AMMCs, Hardness, B<sub>4</sub>C, Wear, Reinforcement

## I INTRODUCTION

Engineering applications require materials that are stronger, lighter and less expensive. A good example is the current interest in the development of materials that have good strength to weight ratio suitable for automobile applications where fuel economy with improved engine performance is becoming more critical. Metal matrix composites (MMCs) have been noted to offer such tailored property combinations required in a wide range of engineering applications [1]. The Metal matrix composites are combination of two or more than two different materials including metal, inter metallic compound or next step dispersed phase of metal matrix. To achieve optimum combination of properties it has produced by controlling the morphology of constituent. The properties of Constituent's phase, its relative amount, dispersed geometry including particle shape and size along with orientation in matrix The aim involved in designing metal matrix composite materials is to combine the desirable attributes of metals and ceramics. The addition of high strength, high modulus refractory particles to a ductile metal matrix produce a material whose mechanical properties are intermediate between the matrix alloy and the ceramic reinforcement. Composite materials consist of matrix and reinforcement. Its main purpose is to transfer and distribute the load to the reinforcement or fibers. This transfer of load depends on the bonding which depends on the type of matrix and reinforcement and the fabrication technique[2]. The matrix can be selected on the basis of oxidation and corrosion resistance or other properties. Generally Al, Ti, Mg, Ni, Cu, Pb, Fe, Ag, Zn, Sn and Si are used as the matrix material, but Al, Ti, Mg are used widely.[3].

## II. REINFORCING MATERIALS IN AMMC'S

The final properties of the hybrid reinforcement depend on individual properties of the reinforcement selected and the matrix alloy. The processes root of manufacturing, shape, size, and chemical affinity with matrix material of reinforcement materials influence their microstructure, physical properties, tribological properties and other desirable properties of the composite. Different ceramic materials that are generally used to reinforce aluminum alloys in MMCs are SiC, TiC, ZrC, TiB<sub>2</sub>, ZrB<sub>2</sub>, AlN, Si<sub>3</sub>N<sub>4</sub>, Al<sub>2</sub>O<sub>3</sub>, B<sub>4</sub>C, SiO<sub>2</sub>, Al<sub>4</sub>Mo, Al<sub>3</sub>Ti and Al<sub>3</sub>Zr [4]. The reinforcement materials are embedded into the matrix in the hybrid composite which is characterized by greater light weight, higher strength,

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higher stiffness, better toughness and desired wear resistance than those of conventional materials. Aluminum, reinforced with TiC, TiB<sub>2</sub>, B<sub>4</sub>C and SiC, was synthesized and their behaviors were compared using powder metallurgy route. It was found that B<sub>4</sub>C possesses better hardness property than the other reinforcements.[5].

Ravichandran M et.al, [6] carried out the research work by fabricating aluminium metal matrix composites through liquid powder metallurgy route. The aluminium matrix composite containing TiO<sub>2</sub> reinforcement particle was produced to study the mechanical properties such as tensile strength and hardness. The characterization studies are also carried out to evident the phase presence in the composite and the results are discussed for the reinforcement addition with the mechanical properties. Results show that, the addition of 5 weight percentage of TiO<sub>2</sub> to the pure aluminium improves the mechanical properties. Baradeswaran et.al, [7]. In his experiment, chose the commercial grade aluminium alloy Al 7075 as the matrix material, with B<sub>4</sub>C particles as their reinforcement. The aluminium composites were manufactured with 5, 10, 15 and 20 vol% B<sub>4</sub>C particles with particle size ranging from 16 μm to 20 μm were used as the reinforcement. The hardness of the Al-B<sub>4</sub>C composites was found to increase on increasing the volume fraction of particulates. The ultimate tensile, compression and flexural strength have also been observed to increase on increasing the B<sub>4</sub>C particle content. The wear resistance of the composites increased on increasing the B<sub>4</sub>C particle content. The wear rate is significantly less for the composites compared to pure matrix material. Varol et.al, [8] In his study artificial neural network (ANN) approach was used for the prediction of effect of physical and mechanical properties of Al2024-B<sub>4</sub>C composites produced by powder metallurgy. Effects of reinforcement size and content (wt.%) on the physical and mechanical properties of composites were determined by measuring the density, hardness and tensile strength values. The tensile strength of composites with reinforced fine B<sub>4</sub>C particles increased by 20% compared to the unreinforced Al2024 alloy for 5 h of milling. The reinforcement properties had considerable effects on the density, hardness and tensile strength, as well as the structural behavior of the composites.

Harichandran et.al, [9] investigated the effect of the addition of micro- and nano-boron carbide particles to aluminium on the mechanical properties of the composites. The micro and nanocomposites containing different weight % of B<sub>4</sub>C particles were fabricated using stir- and ultrasonic cavitations assisted casting processes. The nano composites were stronger and more ductile than the aluminium composites reinforced with micro-sized B<sub>4</sub>C particles. Increasing the amount of B<sub>4</sub>C particles increased the ultimate tensile strength and decreased the ductility. The study also indicated that the ductility and impact energy of the nanocomposites were better than the micro B<sub>4</sub>C particle-reinforced composites. The wear resistance of the nanocomposite significantly increased when the B<sub>4</sub>C content was increased up to 8% of addition, and this increase was more pronounced than that resulting from micro B<sub>4</sub>C particle-reinforced composites.

Manoj Singla et.al, [10] developed aluminium based silicon carbide particulate metal matrix composite. Aluminium (98.41% C.P) and SiC (320-grit) chosen for the study. Reinforcement of SiC weight fraction was 5%, 10%, 15%, 20%, 25%, and 30%, by keeping all other parameters constant. Authors observed that uniform dispersion of SiC particles in the aluminium matrix through the two step stir casting method, maximum hardness and maximum impact strength obtained at 25% weight fraction of 320 grit size SiC particles. Bhushan et.al,[11] fabricated and investigated the behavior of 7075 Al alloy which is reinforced with SiC particles of 10 and 15 weight % and of size 20-40 μm by stir casting process. Microstructure of 7075 Al alloy, AA7075-10 wt. % SiC particles (20-40 μm) and AA7075-15 wt. % SiC particles (20-40 μm) composites are found. There are no unfavorable chemical reactions; hence, these composites are suitable for automobile, aircraft, and space applications.

### III. HYBRID AMMC'S: PRODUCTION, MECHANICAL AND TRIBOLOGICAL PROPERTIES

Aluminium hybrid composites are a new generation of metal matrix composites that have the potentials of satisfying the recent demands of advanced engineering applications. These demands are met due to improved mechanical properties, amenability to conventional processing technique and possibility of reducing production cost of aluminium hybrid composites. The performance of these materials is mostly dependent on selecting the right combination of reinforcing materials since some of the processing parameters are associated with the reinforcing particulates[22]. The fabrication of the AMMC's includes liquid state processes: stir casting, compo casting, squeeze casting, spray casting and in situ (reactive) processing, ultrasonic assisted casting. Solid state processes: Solid state

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process includes powder metallurgy (PM route), high energy ball milling, friction stir process, diffusion bonding and vapor deposition techniques. Stir casting method of fabrication of MMC's. Liquid state fabrication of Metal Matrix Composites involves incorporation of dispersed phase into a molten matrix metal, followed by its Solidification. In order to provide high level of mechanical properties of the composite, good interfacial bonding (wetting) between the dispersed phase and the liquid matrix should be obtained. Wetting improvement may be achieved by coating the dispersed phase particles (fibers). Powder metallurgy is the process of blending fine powdered materials, pressing them into a desired shape or form (compacting), and then heating the compressed material in a controlled atmosphere to bond the material (sintering). The powder metallurgy process generally consists of four basic steps: powder manufacture, powder blending, compacting, and sintering [24].

Several researchers have developed variety of hybrid AMMC'S using various methods and have studied properties like the mechanical and tribological properties ie, tensile strength, hardness, stiffness, wear and creep resistance etc... Some of work done in the recent articles is presented below

Hafeez Ahamed [12,13] has studied the compaction, sintering, micro structural and micro hardness behavior of pre-mixed (elemental) Al6063, Al6063/1.5Al<sub>2</sub>O<sub>3</sub>, and Al6063 / 1.5Y<sub>2</sub>O<sub>3</sub> and Al6063/0.75Al<sub>2</sub>O<sub>3</sub>/0.75Y<sub>2</sub>O<sub>3</sub> powders and has reported that among the different nano composites investigated, the one with combined Al<sub>2</sub>O<sub>3</sub> and Y<sub>2</sub>O<sub>3</sub> particulates was found to be most effective in increasing sinterability and micro hardness properties while the sinterability of the Y<sub>2</sub>O<sub>3</sub> particulates reinforced nanocomposites were found to be more stable under varying sintering time. In his further work the same author has studied the structural evolution associated with grain refinement and superior mechanical properties by the addition of nano-size Al<sub>2</sub>O<sub>3</sub> and Y<sub>2</sub>O<sub>3</sub> particulates into monolithic Al6063 alloy matrix. Synthesis of monolithic Al6063 alloy, Al6063/1.5Al<sub>2</sub>O<sub>3</sub>, Al6063/ 1.5Y<sub>2</sub>O<sub>3</sub> and Al6063/0.75Al<sub>2</sub>O<sub>3</sub>/0.75Y<sub>2</sub>O<sub>3</sub> nano-composite materials containing ceramic particles were successfully fabricated appropriately using P/M technique followed by MM-MA-compaction sintering and hot extrusion. The addition of singular or hybrid (nano-Al<sub>2</sub>O<sub>3</sub> or/and nano-Y<sub>2</sub>O<sub>3</sub>) reinforcements in monolithic Al6063 alloy simultaneously increases 0.2% YS, UTS and micro hardness. The work by P. Sharma, et al., [14,15] focuses on the effect of graphite particles addition on the microstructure of Al6082 metal matrix composites manufactured by conventional stir casting process. The reinforcement content was varied from 0% to 12% in a step of 3. The scanning electron micrograph revealed a reasonably non-uniform distribution of Gr particles in the matrix. The hardness of composites decreased by 11.1% with respect to addition of weight percentage of Gr (0-12%). The main outcome of present investigation is that it would not be beneficial to reinforce Gr particles to Al6082 metal matrix as a non-uniform microstructure and a decrease in hardness at all weight percentages of Gr reinforcement have been observed. In his another work the author has studied the effect of graphite particles on the dry sliding wear behavior of Al6082 alloy shows that the hardness of composite decreased as compared to cast Al6082. The wear resistance of composite has been improved as compared to conventional AA6082 matrix.

Shorowordi et.al,[16] observed the aluminium metal matrix composites containing reinforcing particles of B<sub>4</sub>C, SiC and Al<sub>2</sub>O<sub>3</sub> (0-20 vol.%) were processed. The stir-casting manufacturing route followed by hot extrusion was utilized, being one of the cost-effective industrial methods. A clear interfacial reaction product/layer was found at Al-SiC interface for composites held for a relatively long processing time (>30 minutes). No reaction product was observed at Al- B<sub>4</sub>C and Al-Al<sub>2</sub>O<sub>3</sub> interfaces at the resolution limit of the SEM used. On the other hand, two secondary phases (alumina and another phase containing aluminium, boron and carbon) were found in the aluminium matrix away from the interface in Al- B<sub>4</sub>C composites. From the fracture surface analysis, B<sub>4</sub>C reinforced Al composite seemed to exhibit a better interface bonding compared to the other two composites. Ezatpour.et.al.,[17] investigated the effects of adding nano-alumina particles to Al6061 alloy and extrusion process on the mechanical and microstructure properties of the composites, In extruded state, the higher strength and ductility could be due to lower porosity content, more uniform distribution of Al<sub>2</sub>O<sub>3</sub> in the matrix, and grain refinement. In comparison to unreinforced alloy, Al6061 reinforced with hard particles possesses higher strength, stiffness, and wear and creep resistance.

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Friction stir processing (FSP) was used by Narimani.et.al [23] to produce mono and hybrid surface composite layers of aluminium matrix containing  $B_4C$  and  $TiB_2$  particles Applying FSP on aluminium substrate without the addition of ceramic particles increased the hardness and improved the wear resistance material. Embedment of  $B_4C$  and  $TiB_2$  ceramic particles on the surface increased the hardness and improved the wear behavior of composite layers in comparison with FSPed AA6063. The 100% $TiB_2$  sample exhibited the highest value of hardness with better wear behavior. Vijayanand Dharanikota studied the tribological behavior of aluminium alloy Al-6082 reinforced with silicon carbide particles (0%,5% & 10% Volume percentage of SiC) fabricated by powder metallurgy was investigated . the author has studied the optimization of dry sliding performances on the aluminum hybrid metal matrix composite using grey relational analysis in the Taguchi method. Different loads, sliding speeds, sliding distances and varying percentage of Silicon Carbide are selected as control factors. The multiple responses to evaluate the dry sliding performances are specific wear rate and coefficient of friction. The results indicated that the four test parameters had a significant role in controlling the friction and wear behavior of composites out of which %vol. was identified as most influential parameter followed by load for specific wear rate and load for coefficient of friction.

T. S. Senthilkumar [18].has studied 6082 aluminium alloy as the base metal and SiC and Boron glass powder as the reinforcements. Preferred fabrication method is stir casting route. Al 6082 is reinforced with SiC and Boron glass powder composites with various wt. % combinations. The mechanical properties such as tensile, hardness and corrosion tests were evaluated Corrosion rate decreases for Al 6082 hybrid composites with duration of the exposure to the corroding solution. The hybrid composite specimen showed better corrosion resistance than the un-reinforced matrix alloy, also it is seen that corrosion rate increases with increases in normality of solution.The Boron glass powder content in aluminium alloys plays a significant role in the corrosion resistance of the material. Increase in the percentage of addition will be advantageous to reduce the density and increase in the strength of alloy. For both Al 6082 Hybrid composites, corrosion rate decreases monotonically with increase in the reinforcement content. this work shows that various mechanical properties of the Al 6082 alloy which has moderate strength was improved by reinforcing with SiC and boron glass powder.Uthayakumar.et.al, [19]fabricated the Hybrid metal matrix composites consist of a metal or an alloy matrix with strongly embedded multiple hard reinforcements to enhance the wear resistance properties. The study emphasizes on the dry sliding wear behaviour of aluminium reinforced with 5% SiC and 5%  $B_4C$  hybrid composite using a pin on disc tribometer. Wear performance of the hybrid composites was evaluated over a load range of 20-100 N, at the sliding velocities from 1 to 5 m/s. Detailed metallurgical examination and energy dispersive analysis were carried out to assess the effect of SiC and  $B_4C$  particles on the wear mechanisms. The Focused Ion Beam (FIB) technique is used to characterize the Tribo layers that were formed at the worn surfaces of composites. The experimental results show that the hybrid composites retain the wear resistance properties up to 60 N loads and sliding speed ranges 1-4 m/s. The enhancement of wear resistance with small amount of SiC and  $B_4C$  is achieved by the cooperating effect of reinforcement particles.

R. Ipek [20].studied the adhesive wear characteristics of 4147 Al/ $B_4C$ , 10, 15 and 20 wt.%  $B_4C$  particle and Al/SiC metal matrix composites 20 wt.% SiC contain produced by liquid metallurgy was investigated under the dry sliding conditions and their wear behaviors are compared with 4147 Al/SiC-reinforced 20 wt.% SiC. The results showed that the wear resistance of Al/ $B_4C$  matrix increases considerably with increasing wt.%  $B_4C$  particle content in Al alloy matrix .In his study Ravindran.et.al, [21] had developed aluminium (Al)-based graphite (Gr) and silicon carbide (SiC) particle reinforced, self-lubricating hybrid composite materials by powder metallurgy. The tribological and mechanical properties of these composite materials were investigated under dry sliding conditions. The developed composites have exhibited higher wear resistance and higher coefficient of friction when compared with matrix the incorporation of SiC reinforcement to Al2024 alloy increases the wear resistance of the composites. The addition Gr reinforcement in Al2024/SiC composites as a hybrid reinforcement further increased the wear resistance of the composite. Increased content of SiC reinforcement, lead to higher coefficient of friction. The presence of hard ceramic particularly in high content SiC hybrid composites was found to have influence on the wear properties.



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## IV. CONCLUSION

This paper presents the different combination of reinforcements used in the synthesis of hybrid AMMC's and how it influences its performance. AMMC's can be effectively manufactured by use of appropriate fabrication technique depending on choice of reinforcement. Aluminium alloy with reinforcement is always better than base alloy because reinforcement particle's improves the mechanical properties like tensile strength, impact strength, wear resistance, hardness and corrosion resistance etc. It was also found that among the various reinforcement particles like TiC, TiB<sub>2</sub>, B<sub>4</sub>C, SiC, Al<sub>2</sub>O<sub>3</sub>, Gr. etc B<sub>4</sub>C possesses better hardness property than the other reinforcements

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