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A Review on the Mechanical Properties of Aluminum Based Metal Matrix Composites (MMCs)

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Abstract: *Aluminium Metal Matrix Composites (AMMCs) are a range of advanced engineering materials that can be used for a wide range of applications within the aerospace, automotive, biotechnology, electronic and sporting goods industries. AMMCs consist of a non-metallic reinforcement (SiC, B_4C, Si_3N_4, AlN, TiC, TiB_2, TiO_2) incorporated into Aluminium matrix which provides advantageous properties over base metal (Aluminium) alloys. These include improved abrasion resistance, creep resistance, dimensional stability, exceptionally good stiffness-to-weight and strength-to-weight ratios and better high temperature performance. Fabrication of these advanced engineering materials through liquid state and solid state routes are considered in this paper. This paper attempts to review the different combination of reinforcing materials used in the processing of Aluminium Metal Matrix Composites (AMMCs) and how it affects the mechanical properties of the materials. The major techniques for fabricating these materials are briefly discussed and research areas for further improvement on aluminium composites are suggested.*

Keywords: *Aluminum , Metal Matrix Composites, Mechanical Properties, Reinforcement.*

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I. Introduction

Aluminium is the world‘s most abundant metal and is the third most common element, comprising 8% of the earth’s crust. The versatility of aluminium makes it the most widely used metal after steel. After iron, aluminium is now the second most widely used metal in the world. This is because aluminium has a unique combination of attractive properties. Low weight, high strength, superior malleability, easy machining, excellent corrosion resistance and good thermal and electrical conductivity are amongst aluminum’s most important properties [1]. Aluminium is also very easy to recycle. A unique combination of properties makes aluminium and its alloys one of the most versatile engineering and construction material available today [2, 3]. The metal matrix composites (MMCs), like all other composites consist of at least two chemically and physically distinct phases, suitably distributed to provide properties not obtainable with either of the individual phases. For many researches the term MMCs is often equated with the term light metal matrix composites. Substantial progress in the development of light metal matrix composites has been achieved in recent decades, so that they could be introduced into the most important applications. Aluminum matrix composites (AMCs) are the competent material in the industrial world. Due to its excellent mechanical properties, it is widely used in aerospace, automobiles, marine etc. [4].

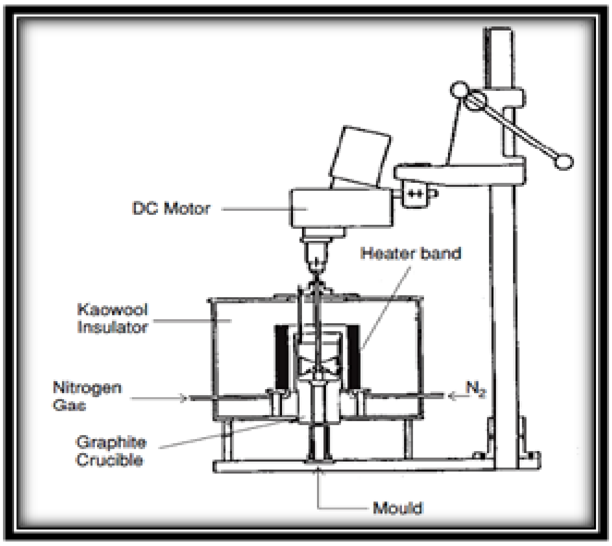
Addition of hard and stiff ceramic phase in metal matrix composites has been established to improve the modulus behaviour and strength properties of the metallic matrices. An important consideration in MMC manufacture is the nature of the interface between the matrix and the reinforcement. This often depends on the processing route and since composite formation occurs at an elevated temperature, it is more chemical than mechanical. Among the problems associated with such chemical interactions is the possible formation of deleterious products on the interface, which can act as damage nucleation sites when the bulk MMC is subjected to stress. In view of the internal stress field therefore, the finer the reinforcement particle is the better the mechanical property of composite. However, it is difficult to produce premium composites reinforced with fine particles of sizes less than 10μm using conventional liquid or semisolid stir-casting method [5].

Aluminium metal matrix composites (AMMC) are the composites in which aluminium is used as the matrix and several reinforced materials are embedded into the matrix. Some of the reinforced materials are silicon carbide, graphite, fly ash, particulate alumina, red mud, cow dung, rice husk etc. AMMC are in demand due to their properties like low density, high specific strength, high damping capacity, high thermal conductivity, high specific modulus, and high abrasion and wear resistance [6], low density, good mechanical properties, low thermal coefficient of expansion, better corrosion resistance [7], high strength to weight ratio and high temperature resistance [8] etc. Aluminium metal matrix composite provides lesser wear resistance when compared to steel and hence it is widely used as a matrix metal. The AMMC can be manufactured by various manufacturing techniques such as stir casting, powder metallurgy, pressure infiltration, squeeze casting [9], chemical vapor deposition etc. Amongst all the processes, stir casting is the most common method used by the researchers [10].

II. Modified Stir Casting Of Mmcs

In a normal practice of stir casting of MMC, it involves adding ceramic particles into the melt in the crucible which is kept inside the furnace. Stirring is carried out vigorously to form a vortex where the reinforcing particles are introduced through the side of the vortex. The melt is transferred to permanent mold after stirring. Modified stir casting involves directly transferring the melt into a permanent mold with a bottom pouring arrangement attached to the furnace.

Hashim et al. [11] used a modified stir casting method to produce an Al/SiCp MMC. A specially designed rig with bottom pouring mechanism shown in Figure 1 was used to fabricate the composite. All substance (Al as matrix, SiC as particulates and Mg as wetting agent) were placed in a graphite crucible and heated in an inert atmosphere until the matrix alloy is melted and then followed by a two-step stirring action before pouring into a mold. The stirring action of the slurry produces cast MMC with smaller grain sizes which strengthen the alloy matrix.



Shoujiang et al. [12] fabricated pure aluminum matrix composites reinforced with 20% vol. SiC particles by modified squeeze casting technique followed by hot extrusion. The mechanical properties of as cast composite were compared with that of extruded composite. Gopalakrishnan and Murugan [13] produced the different weight % of TiCp reinforced Al matrix composite using a modified stir casting method and a considerable increase in MMCs strength were obtained. The AA6061-AlNp composites were fabricated using modified stir casting method and obtained UTS of the AA6061-20% AlNp composite was 46.95% greater than that of the corresponding monolithic alloy [14].

An improvement in conventional stir casting is a double stir casting method or two-step casting process. In the first stage, the matrix material is heated to above its liquidus temperature and then cooled down to a temperature to keep in a semi-solid state. At this stage, the preheated reinforcement materials are added and mixed with a mechanical stirrer. Again the slurry is heated to a liquidus state and mixed thoroughly. Nowadays, this two-step mixing process has used in the fabrication of aluminium because of more uniform microstructure as compared of conventional stirring [15]. A recent development in stir casting is three step stir casting for the fabrication of nanoparticle reinforced composite. In this method, first, the Al particles and reinforcement are mixed using ball milling process to break down the initial clustering of nanoparticles. Then the composite powder is mixed with melt by mechanical stirring [16].The present study deals with the stir cast Aluminium Matrix Composite (AMC) regarding their mechanical properties enhanced.

III. Mechanical Properties

The aluminium metal matrix composites have various effects on the mechanical properties that impart many modern-day applications. Investigation on mechanical properties tends to make the study of composites in depth.

The Various Mechanical Properties That Are Considered In The Present Study Are As Follows:

Gopal Krishna U.B et al. [17] investigated the Effect of boron carbide reinforcement on aluminium matrix composites. The authors produced Al- B_4C by stir casting route with different particle size (Viz 37µ,44µ,63µ,105µ,250µ) of reinforcement and observed that the micro Vickers hardness of AMC's was to be maximum for the particle size of 250µ and for 12 wt% in case of varying wt% of the reinforcement of 105µ size. And the tensile strength of AMC's was found to be maximum for the particle size of 105µ and found maximum for 8 wt% in case of varying wt% of the reinforcement of 105µ size . Baradeswaran et al. [18] studied the influence of B_4C on the tribological and mechanical properties of Al7075- B_4C composites. The authors has revealed that the hardness of composite increased when compared with base alloy because of addition of B_4C particular's and wear rate of composite decreased when compared with base alloy[18]. Kok [19] fabricated AA2024/10, 20, 30, vol. % Al_2O_3 composites with particle sizes of 16 µm, 32 µm, and 66 µm by a vortex method. The density of the composites increased with increasing wt. % and size of particles, whereas the porosity of composites increased with decreasing particle size and increasing wt. % of particles.Poddar et al [20] used the stir cast vortex method to fabricate Mg-alloy/15 vol. % SiC and resulted in increased hardness as well as elastic modulus of composite compared to monolithic alloys.

Cambronero et al. [21] investigated the mechanical characterization of AA7015 aluminum alloy reinforced with ceramics and concluded that hardness increased by ceramic addition due to this the plastic deformation of composite is decreased and better wear behavior achieved. Jinkwan jung and shinhoo kang et al. [22] 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 an 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). Ibrahim et al. [23] investigated mechanical properties and fracture of Al-15vol%B_4C based Metal matrix composites. The authors observed that the ductility of the composite material decreases with increased vol% B4C and the fracture of B_4C reinforcements occurs by a cleavage mechanism .Kalaiselvan et al. [24] fabricated Al6061-B_4C composite by stir casting route. They observed that the micro and macro hardness of composite linearly increased from 51.3HV to 80.8HV and 34.48BHN to 58.6 BHN with addition of B_4C particles (wt%) and also tensile strength increased from 185Mpa to 215MPa.

Saheb [25] had developed aluminium matrix composites with particulates of silicon carbide and graphite in order to obtain a homogeneous dispersion. The experiments had been conducted with varying weight% of silicon carbide and graphite which resulted in the increase in hardness with the increase in weight%. The best results were obtained at 4% and 25% weight fraction of graphite and silicon carbide respectively. Bansal and Saini [26] had investigated the metal matrix composite of Al_359 reinforced with silicon carbide and graphite. Graphite is a solid lubricant and it softens the composite. Hence, the hardness of Al_359-silicon carbide was much better than that of Al_359-graphite. Good bonding between SiC/Gr helps the material to be able to withstand higher loads. Basavaraju et al. [27] prepared a hybrid metal matrix composite of aluminium LM25 with the reinforcement of silicon carbide, graphite and fly ash and found that the Brinell hardness increased till 4% reinforcement and then decreased. Improvement in tensile strength was also observed by Kumar et al. [28] during the evaluation of Al6061 with fly ash. Three sets of fly ash were reinforced with the weight fraction of 10%, 15%, and 20%. The increase in tensile strength was because of filler fly ash, as it possesses high strength but at the same time, there was a decrease in tensile strength beyond 15% due to poor wettability. It was found that the ultimate tensile strength increased to 192.74 MPa. Shyu et al. [29] produced in-situ reacted titanium carbide reinforced aluminium alloys composite. A carbonaceous gas reacts with titanium in liquid melt to form TiC. It was found that tensile and yield strength increased up to 18 % after the formation of TiC in aluminium matrix.

IV. Conclusion

From literature review related to the Aluminium alloy- B_4C Composite material have been concluded that,

- Composite materials have better properties than monolithic metals and their alloys.
- The stir casting technique for aluminium matrix composite is better than other technique because it provides ease of operation, higher performance and better quality.
- The percentage increase of reinforcement increases the hardness of the composite.
- Improved tensile strength, and yield strength impact are obtained on adding the different reinforcement.

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