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ALUMINIUM METAL MATRIX COMPOSITES - A REVIEW

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Abstract. Aluminium matrix composites (AMCs) 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 effect of addition on different reinforcements in aluminium alloy highlighting their merits and demerits. Major issues like agglomerating phenomenon, fiber-matrix bonding and the problems related to distribution of particles are discussed in this paper. Effect of different reinforcement on AMCs on the mechanical properties like tensile strength, strain, hardness, wear and fatigue is also discussed in detail. Major applications of different AMCs are also highlighted in this work.

1. INTRODUCTION

MMC (Metal matrix composites) are metals reinforced with other metal, ceramic or organic compounds. They are made by dispersing the reinforcements in the metal matrix. Reinforcements are usually done to improve the properties of the base metal like strength, stiffness, conductivity, etc. Aluminium and its alloys have attracted most attention as base metal in metal matrix composites [1]. Aluminium MMCs are widely used in aircraft, aerospace, automobiles and various other fields [2]. The reinforcements should be stable in the given working temperature and non-reactive too. The most commonly used reinforcements are Silicon Carbide (SiC) and Aluminium Oxide (Al_2O_3). SiC reinforcement increases the tensile strength, hardness, density and wear resistance of Al and its alloys [3]. The particle distribution plays a very vital role in the properties of the Al MMC and is improved by intensive shearing. Al_2O_3 reinforcement has good compressive strength and wear resistance. Boron Carbide is one of hardest known elements. It has high elastic modulus and fracture toughness. The addition of Boron Carbide (B_4C) in Al matrix increases the hardness, but does not improve the wear resistance significantly [4]. Fibers are the important class of reinforcements, as they satisfy the desired conditions and transfer strength to the matrix constituent influencing and enhancing their properties as desired. Zircon is usually used as a hybrid reinforcement. It increases the wear resistance significantly [5]. In the last decade, the use of fly ash reinforcements has been increased due to their low cost and availability as waste by-product in thermal power plants. It increases the electromagnetic shielding effect of the Al MMC. Based on the stated potential benefits of MMC this paper examine the various factors like (a) effect of various reinforcement (b) mechanical behaviour like strength, wear ,fatigue behaviour, etc. (c) processing methodology and its effects.(d) application of the speciality AMC were discussed.

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2. SILICON CARBIDE REINFORCED AMC

Tamer Ozbenet al. [6] investigated the mechanical and machinability properties of SiC particle reinforced Al-MMC. With the increase in reinforcement ratio, tensile strength, hardness and density of Al MMC material increased, but impact toughness decreased. Sedat Ozdenet al. [7] investigated the impact behaviour of Al and SiC particle reinforced with AMC under different temperature conditions. The impact behaviour of composites was affected by clustering of particles, particle cracking and weak matrix-reinforcement bonding. The effects of the test temperature on the impact behaviour of all materials were not very significant. Srivatsan et al. [8] conducted a study of the high cycle fatigue and investigated the fracture behaviour of 7034/SiC/15p-UA and 7034/SiC/15p-PA metal matrix composites. The modulus, strength and the ductility of the two composite microstructures decreased with an increase in temperature. The degradation in cyclic fatigue life was more pronounced for the under-aged microstructure than the peak-aged microstructure Also, for a given ageing condition, increasing the load ratio resulted in higher fatigue strength. Maik Thunemann et al. [9] studied the properties of AMMC's based on preceramic-polymer-bonded SiC performs. Polymethylsiloxane (PMS) was used as a binder. A polymer content of 1.25 wt.% conferred sufficient stability to the preforms to enable composite processing. It is thus shown that the PMS-derived binder confers the desired strength to the SiC preforms without impairing the mechanical properties of the resulting Al/SiC composites. Sujan et al. [10] studied the performance of stir cast Al_2O_3 and SiC reinforced metal matrix composite material. The result showed that the composite materials exhibit improved physical and mechanical properties, such as low coefficient of thermal expansion as low as $4.6x10^{-6}$/°C, high ultimate tensile strength up to 23.68%, high impact strength and hardness. The composite materials can be applied as potential lightweight materials in automobile components. Experimentally it is found that with addition of Al-SiC reinforcement particles, the composite exhibited lower wear rate compared to Al-Al_2O_3 composites. Zhang Peng et al. [11] studied the Effects of Particle Clustering on the flow behaviour of SiC particle reinforced Al MMCs. The results revealed that during the tensile deformation, the particle clustering has greater effects on the mechanical response of the matrix than the elastic response and also the plastic deformation is affected very much. The particle clustering microstructure will experience higher percentage of particle fracture than particle random distribution. Balasivanandha Prabhuet et al. [12] analysed the influence of stirring speed and stirring time on distribution of particles in SiC AMC. The study was about high silicon content aluminium alloy–silicon carbide metal matrix composite material, with 10% SiC synthesized using different stirring speeds and stirring times. The analysis revealed that at lower stirring speed and time, the particle clustering was more at some places, by increasing them the distribution resulted better and also it had its effect on hardness of the composite. Uniform hardness values were achieved at 600 rpm with 10 min stirring. Tzamtzis et al. [13] suggested processing Al/SiC particulate MMCs under intensive shearing by novel Rheo-process. The current processing methods such as conventional stir casting technique often produce agglomerated particles in the ductile matrix and as a result these composites exhibit extremely low ductility. Whereas the Rheo-process significantly improved the distribution of the reinforcement in the matrix by allowing the application of sufficient shear stress (s) on particulate clusters embedded in liquid metal to overcome the average cohesive force or the tensile strength of the cluster. Valencia Garcia et al. [14] suggested an alternate technique of compo forging of Al-Si Metal Matrix Composites reinforced with SiC. This method of preparation increased the mechanical resistance to elongation .This method proves to be more economical as it reduces production stages, as well as time and energy consumption. Narayana Murty et al. [3] studied the hot working characteristics of 6061A – SiC and 6061 – Al_2O_3 particulate reinforced metal matrix composites. They proposed from productivity viewpoint that a high strain rate region in which high values of mass and efficiency are present should be selected for bulk working operations and the lower strain rate regions for secondary metal working operations. Palanikumar and Karthikeyan [15] and Kýlýçkap et al. [16] assessed the factors influencing surface roughness on the machining of Al/SiC particulate composites. The parameters like feed rate, cutting speed, % volume fraction of SiC were optimized to attain minimum surface roughness using response graph, response table, normal probability plot, interaction graphs and analysis of variance (ANOVA) technique. Feed rate is the factor, which has greater influence on surface roughness, followed by cutting speed and % volume fraction of SiC. The recommended machining conditions are low cutting speed with high feed rate and depth of cut for rough and medium turning process. Using coated carbide cutting tool, high cutting speed and low feed rate produces better surface finish. Natarajan [17] has compared the wear behaviour of A356/25SiC MMC with the conventional grey Cast iron sliding against automobile friction material. It has been found that the wear resistance of the composite is higher than the conventional grey cast iron and it is a very suitable material for brake drum. However, it cannot be used for lining material because of the presence of hard SiC particles. Quan Yanming and Zhou Zehua [18] investigated about the tool wear and its mechanism for cutting SiC particle-reinforced AMMC's. The results of experiments shows that the major damage mechanism is abrasive wear on tool flank edge for conventional tools and brittle failure for high hardness tools in the cutting the composites. The major factors affecting tool life are volume fraction of SiC and its size in the composite.

3. ALUMINIUM OXIDE REINFORCED AMC

Park et al. [19] investigated the effect of Al_2O_3 in Aluminium for volume fractions varying from 5-30% and found that the increase in volume fraction of Al_2O_3 decreased the fracture toughness of the MMC. This is due to decrease in inter-particle spacing between nucleated micro voids. Park et al. [20] investigated the high cycle fatigue behaviour of 6061 Al-Mg-Si alloy reinforced Al_2O_3 microspheres with the varying volume fraction ranging between 5% and 30%. They found that the fatigue strength of the powder metallurgy processed composite was higher than that of the unreinforced alloy and liquid metallurgy processed composite. Tjong et al. [21] compared the properties of two aluminium metal matrix composites, Al–B_2O_3–TiO_2 system and Al–B–TiO_2 system. It was found that the reactive hot pressing of the composites resulted in the formation of ceramic Al_2O_3 and TiB_2 particulates as well as coarse intermetallic Al_3Ti blocks. Al–B–TiO_2 had higher Al_3Ti content and showed high tensile strength, but low tensile ductility. Al–B_2O_3–TiO_2 had more fatigue strength than Al–B–TiO_2. Kok [22] fabricated the Al_2O_3 particle reinforced 2024 Al alloy composites by vortex method and studied their mechanical properties and found the optimum conditions of the production process with a pouring temperature of 700 °C, preheated mould temperature of 550 °C, stirring speed of 900 rev/min, particle addition rate of 5 g/min, stirring time of min and with a applied pressure of 6 MPa. The wettability and the bonding between Al alloy/Al_2O_3 particles were improved by applied pressure but porosity will be decreased by this pressure. Abhishek Kumar et al. [23] experimentally investigated the characterization of A359/Al_2O_3 MMC using electromagnetic stir casting method. They found that the hardness and tensile strength of MMC increases and electromagnetic stirring action produces MMC with smaller grain size and good particulate matrix interface bonding. Abouelmagd [24] studied the hot deformation and wear resistance of powder metallurgy aluminium metal matrix composites. It was found that the addition of Al_2O_3 and Al_4C_3 increases the hardness and compressive strength. The addition of Al_4C_3 improved the wear resistance of the MMC. Kannan and Kishawy [25] conducted orthogonal cutting tests to study the effect of cutting parameters and particulate properties on the micro-hardness variations on the machined Al_2O_3 particulate reinforced AMC. They found that the micro-hardness is higher near the machined surface layer. Micro-hardness variations were higher for low volume fraction and coarse particles.

4. BORON CARBIDE REINFORCED AMC

Bo Yao et al. [26] investigated the trimodal aluminium metal matrix composites and the factors affecting its strength. The test result shows that the attributes like nano-scale dispersoids of Al_2O_3, crystalline and amorphous AlN and Al_4C_3, high dislocation densities in both NC-Al and CG-Al domains, interfaces between different constituents, and nitrogen concentration and distribution leads to increase in strength. Vogt et al. [27] studied the cryomilled aluminium alloy and boron carbide nano-composite plates made in three methods, (1) hot isostatic pressing (HIP) followed by high strain rate forging (HSRF), (2) HIP followed by two-step quasi-isostatic forging (QIF), and (3) three-step QIF. The test results showed that the HIP/HSRF plate exhibited higher strength with less ductility than the QIF plates, which had similar mechanical properties. The increased strength and reduced ductility of the HIP/HSRF plate is attributed to the inhibition of dynamic recrystallization during the high strain rate forging procedure. Mahesh Babu et al. [28] investigated the characteristics of surface quality on machining hybrid aluminium-B_4C-SiC metal matrix composites using taguchi method. It was found that feed rate was the most important parameter followed by the cutting speed. Moreover it was concluded that the feed rate does not have a significant effect on surface quality. Barbara Previtali et al. [4] investigated the effect of application of traditional investment casting process in aluminium metal matrix composites. Aluminium alloy reinforced with SiC and B_4C were compared and the experiments showed the the wear resistance of SiC reinforced MMC is higher than that of B_4C reinforced MMC.

5. FIBER REINFORCED AMC

Sayman et al. [29] studied the elasto plastic stress analysis of aluminium and stainless steel fiber and found that under 30 MPa pressure and at a temperature of 600 °C, good bonding between matrix and fiber was observed, moreover increase in the load carrying capacity of the laminated plate was also visualised. Onur Sayman [30] analysed the elastic-plastic thermal stress on steel fiber reinforced Aluminium metal-matrix composite beams and found that the intensity of the residual stress and the equivalent plastic strain are greatest at 0° orientation angle and concluded that the higher the orientation angle the lower the temperature that causes plastic yielding. Cesim Atas and Onur Sayman [31] reported that for steel fiber reinforced Al MMC plates, yielding begin at the edge of the laminated plates. They found that the yielding does not occur at the corner of the plate. Ding et al. [32] investigated the low cycle fatigue behaviour of the pure Al reinforced with 20% Al_2O_3 fiber in total strain controlled mode. They found that the predicted fatigue lives coincide with the observed fatigue lives over a wide range of strain amplitudes for a wide range of test temperatures. However, the predicted fatigue live coincide best with the observed fatigue lives only at the large levels of cyclic plastic strain and total strain. Ding et al. [33] investigated the behaviour of the unreinforced 6061 aluminium alloy and short fiber reinforced 6061 Al alloy MMC. They found that the addition of high-strength Al_2O_3 fibres in the 6061 aluminium alloy matrix will not only strengthen the microstructure of the 6061 aluminium alloy, but also channel deformation at the tip of a crack into the matrix regions between the fibres and therefore constrain the plastic deformation in the matrix which leads in reduction of fatigue ductility. Woei-Shyan Lee et al. [34] studied the effects of strain rate on the properties and fracture behaviour of laminated Carbon fiber reinforced 7075-T6 Aluminium alloy and found that the flow stress increases with strain rate, but decreases with temperature. Work hardening rate decreases with increase n strain and temperature. A greater density of Al debris and fiber fracture was found at high strain rate for all temperature. Gudena and Hall [35] studied the high strain rate compressive deformation behaviour of a continuous Al_2O_3 fiber reinforced Al MMC tested in the longitudinal and transverse direction and found that in transverse direction, the composite exhibit strain rate similar to that of monolithic alloy. Rams et al. [36] studied the electroless nickel coated fiber reinforced Aluminium matrix composites and found that the wettabiliy of the composite increases. This wettability enhancement and reduced damage on the fiber is due to Ni-Al-P transient intermetallic layer that is formed due to heating. Shi et al. [37] studied the morphology and interfacial characteristics of aluminium matrix composites reinforced with the diamond fiber. The composite exhibit high thermal conductivity and low thermal expansion coefficient. Pressure-less metal infiltration process results in good bonding between the diamond fibers and the aluminium-matrix. Hui-Hui Fu et al. [38] investigated the wear properties of three AMC namely Saffil/Al, Saffil/Al_2O_3/Al and Saffil/SiC/Al on a pin-on-disk friction and wear tester. Under dry sliding condition, Saffil/SiC/Al showed the best wear resistance under high temperature and high load while the wear resistance of Saffil/Al and Saffil/ Al_2O_3/Al was similar. The investigation indicated that under lubricated condition, with the lubricant of liquid paraffin, Saffil/Al shows the best wear resistance and the wear resistance of Saffil/ Al_2O_3/Al is better than that of Saffil/SiC/Al under room temperature, but under high temperature, its vice-versa.

6. ZIRCON REINFORCED AMC

Jenix Rina et al. [39] compared the properties of Al6063 MMC reinforced with Zircon Sand and Alumina with four different volume fractions of Zircon sand and Alumina with varying volume fractions of (0+8)%, (2+6)%, (4+4)%, (6+2)% and (8+0)%. The hardness and the tensile strength of the composites are higher for (4+4)%. In this combination, the particle dispersion is uniform and the pores are less where inter-metallic particles are formed. Sanjeev Das et al. [5] comparatively studied the abrasive wear of Al-Cu alloy with alumina and Zircon sand particles and found that wear resistance of the alloy increases significantly after the addition of alumina and zircon particles. However, zircon reinforced composites showed better wear resistance than that of alumina reinforced composite due to its superior particle matrix bonding. Scudino et al. [40] investigated the mechanical properties of Al-based metal matrix composites reinforced with Zircon-based glassy particles produced by powder metallurgy. The test results showed that the compressive strength of pure Al increases by 30% with 40% volume of glass reinforcement. While the volume fraction of the glassy phase increasing to 60%, the compressive strength further increases by about 25%.

7. FLY ASH REINFORCED AMC

Fly ash particles are potential discontinuous dispersoids used in metal matrix composites due to their low cost and low density reinforcement which are available in large quantities as a waste by product in thermal power plants. The major constituents of flyash are SiO_2, Al_2O_3, Fe_2O_3, and CaO. Rajan et al. [41] compared the effect of the three different stir casting methods on the properties of fly ash particles reinforced Al-7Si-0.35Mg alloy. The three stir casting methods are liquid metal stir casting, compocasting, modified compocasting followed by squeeze casting. The compression strength of the composite processed by modified compocasting cum squeeze casting is improved compared to the matrix alloy. However, the tensile strength was found to be reduced. The modified compocasting cum squeeze casting process has resulted in a well dispersed and porosity free fly ash particle dispersed composite. Zuoyong Dou et al. [42] studied the electromagnetic interference shielding effectiveness properties of the 2024 Al alloy – fly ash composites. The composite have effective shielding property in the frequency range of 30.0 KHz – 1.5GHz. But the addition of fly ash particulate decreases the tensile strength of the composites. Ramachandra and Radhakrishna [43] experimentally found that the wear resistance of Al MMC increases with the increase in flyash content, but decreases with increase in normal load and sliding velocity, and also observed that the corrosion resistance decreases with the increase in fly ash content.

8. SUMMARY

Several confronts must be surmounted in order to strengthen the engineering usage of AMCs such as processing methodology, influence of reinforcement, effect of reinforcement on the mechanical properties and its corresponding applications. The major conclusions derived from the prior works carried out can be summarised as below:

- SiC reinforced Al MMCs have higher wear resistance than Al_2O_3 reinforced MMCs.
- SiC reinforced Al MMCs are suitable materials for brake drums as they have high wear resistance but cannot be used in brake linings as it will damage the brake drum.
- It has been found that the increase in volume fraction of Al_2O_3 decreases the fracture toughness of the Al MMC.
- The optimum conditions for fabricating Al_2O_3 reinforced Al MMC as pouring temperature-700 °C, preheated mould temperature-550 °C, the stirring speed-900 rev/min, particle addition rate-5g/min, the stirring time - 5 min and the applied pressure was 6 MPa.
- The wear resistance of SiC reinforced Al MMC is higher than B_4C reinforced MMC.
- Al MMCs reinforced with diamond fiber exhibit high thermal conductivity and a low thermal expansion co-efficient.
- The wear resistance and compressive strength of Al MMCs increase with the addition of Zircon sand reinforcement.
- The addition of flyash reinforcement in Al increases the wear resistance but decreases the corrosion resistance.

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