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Chapter

A Short Review on Al MMC with Reinforcement Addition Effect on Their Mechanical and Wear Behaviour

Vikas Verma and Alexandra Khvan

Abstract

Advanced mechanical and wear properties and applications of composites with bases of light weight metals have led to the need of aluminium (Al) metal matrix composites (MMCs). In today's time aluminium (Al) metal matrix composites (MMCs) are considered the most potential material for structural and functional applications. Composite materials with aluminium matrices are used in defence, aerospace, automotive and aviation, thermal management areas. Beneficial properties with reduced prices have enlarged their applications. To obtain desired physical and mechanical properties like high hardness, high strength, high stiffness, high wear, abrasion and corrosion resistance Al is reinforced with different metallic, non-metallic and ceramic elements. Al MMCs are used to make piston, connecting rod, engine cylinders, disc and drum brakes where wear has a great role in the functioning of these components as excessive wear of the mating components sometimes leads to catastrophic failures. Improvement of mechanical, especially tribological properties of hybrid composites were provided by the use of certain reinforce materials such as SiC, Al_2O_3 and graphite. Hence the present chapter presents a review on aluminium metal matrix composites (MMCs) reinforced with different particulate, whisker, fibres reinforcements highlighting their effect on physical, mechanical and wear behaviour of Al MMCs.

Keywords: aluminium (Al), metal matrix composite (MMC), stir casting, reinforcement, wear

1. Introduction

Aluminium (Al) amongst several metals is attractive due to its ductility, malleability, good conductivity, light weight, good strength and availability in abundance (8% of earth crust is aluminium). It combines with hard materials like ceramic and offer promising metal matrix composites (MMCs) with improved properties and hence finding wide range of industrial and structural applications including aerospace, automotive, marine and military [1–5]. For developing aluminium-based metal matrix composites various methods are applied by various researchers in liquid metallurgy routes for mass production. Reinforcement in aluminium metal matrix composites can be in particulate, whisker, continuous or discontinuous fibres.

Their addition to the base metal may vary in percentage resulting in improved properties. Composites having aluminium as base metal gives the following advantages: higher strength, improved stiffness, reduced density, survival at high temperature, high wear and corrosion resistance, improved damping capabilities [2].

For developing aluminium-based metal matrix composites various methods like powder metallurgy, spray decomposition, liquid metal infiltration, squeeze casting, mechanical alloying and compo casting are applied by various researchers in liquid metallurgy routes for mass production. Most common method use for processing of aluminium MMCs by powder metallurgy (PM). Via PM route aluminium MMCs can be prepared either by direct metal oxidation (DIMOX) or by reinforcements of particles in the matrix so as to achieve high density, high hardness and strength. In MMCs generally matrix component is more in quantity and reinforcement is a contrasting phase distributed in the matrix in order to reinforce it. The reinforcement rather than making a solid solution with the base matrix, it gets distributed all around it. When three constituents are present, it is called a hybrid composite. The aim of the reinforcement particles is to give high strength and stiffness to the composite and the aim of the matrix is to bind the reinforced particles together by virtue of its adhesive and cohesive nature and to transfer the load to and between reinforcements. In case of particle reinforced composites significant improvement is obtained in the mechanical properties in terms of strength, hardness and stiffness [6–8]. As a continuous phase, the matrix controls the interlaminar strength, elevated-temperature strength and transverse properties of the composite. The matrix holds reinforcing particles in the proper orientation and position so that they can carry the intended loads and distributes the loads evenly among the reinforcements so in a way matrix allows the strength of the reinforcements to be used to their full potential. The matrix also provides a vital inelastic response so that stress concentration are reduced and internal stresses are redistributed from broken reinforcements, reinforcements increase strength, decrease the coefficient of thermal expansion, and improve the wear resistance at a cost of a reduction in ductility and in fracture toughness [9]. Amongst the various methods employed to synthesize metal matrix composites, stir casting method is preferred and used for bulk production. The particular advantages of this process lie in its simplicity, cost effectiveness, flexibility and applicability to larger size components and mass production [10]. Selection of optimum parameters of stirring speed, stirring time, uniform feed rate of particles preheating temperature of the mould results in homogenous mixing and wetting of reinforced particles with base metal. It is seen that the cost of manufacturing of composite materials using a conventional casting method is about one third to half as that of competitive methods and, for high volume production, this cost is expected to reach the level of one-tenth [11]. In MMC's processing there are limitations with the conventional methods as conventionally produced composites are thermodynamically unstable when used at high temperature for longer time [12].

As it is known that today aluminium metal matrix composites are considered the most potential material for structural and functional applications and are finding versatile application in industries due to their price including defence, aerospace, automotive and thermal management areas, as well as in sports and recreation because of their unique isotropic properties of high strength, high stiffness, reduced density (weight), high wear, abrasion and corrosion resistance and improved high temperature properties. These properties are limited in conventional alloys [1–5]. Some of the applications of Al MMCs are shown in **Figure 1** [13]. It is reported that in aluminium-based metal matrix composites fabrication aluminium is reinforced with different reinforcing material like MgO, SiC, MnO, Al_2O_3 which give high mechanical properties to these composites like hardness, fracture toughness and reduced density (weight). Al MMCs consist of hard particles like SiC, WC,

Figure 1.
(a) Piston, (b) engine with cylinder barrel, (c) piston connecting rod, (d) brake system made of aluminium (Al) metal matrix composites (MMCs) [13].

Al_2O_3, etc. and these particles make the aluminium matrix plastically constrained which improves its high temperature properties and they give superior mechanical and wear resistant properties [14].

2. Physical and mechanical properties of aluminium-based metal matrix composites

Researchers have reinforced Al matrix with different metallic, non-metallic and ceramic elements to have desired physical and mechanical properties. Stir casting given by Ray [15] is the best liquid state fabrication technique through which metal matrix composites can be successfully processed. In this method reinforcements are dispersed in molten metal matrix by mechanical stirring as shown in **Figure 2**. Al-Al_2O_3 (MnO_2) hybrid MMCs were processed *via* stir casting technique by adding varying wt.% of Al_2O_3 and MnO_2 particles to the Al melt at high temperature and stirred for uniform distribution of the particles in the melt. At high temperature MnO_2 particles react with molten aluminium and get reduced to metallic manganese, and retain in the matrix of molten aluminium [15, 16] Al-Al_2O_3 composite were developed by direct metal oxidation (DIMOX) and hybrid composite by using both ex situ and *in situ* approaches together by a dispersing powder mixture of Al_2O_3 and MnO_2 in a ratio of 1:1, through stir casting route in aluminium matrix [17]. Al-Al_2O_3 composites were synthesized successfully under ambient conditions and it was found that the particles increased as the holding time and the number of stirrings was increased resulting in improved mechanical properties. Hence, oxidation, which is known as a major problem in composite preparation by liquid metallurgy route, can be used for preparation of

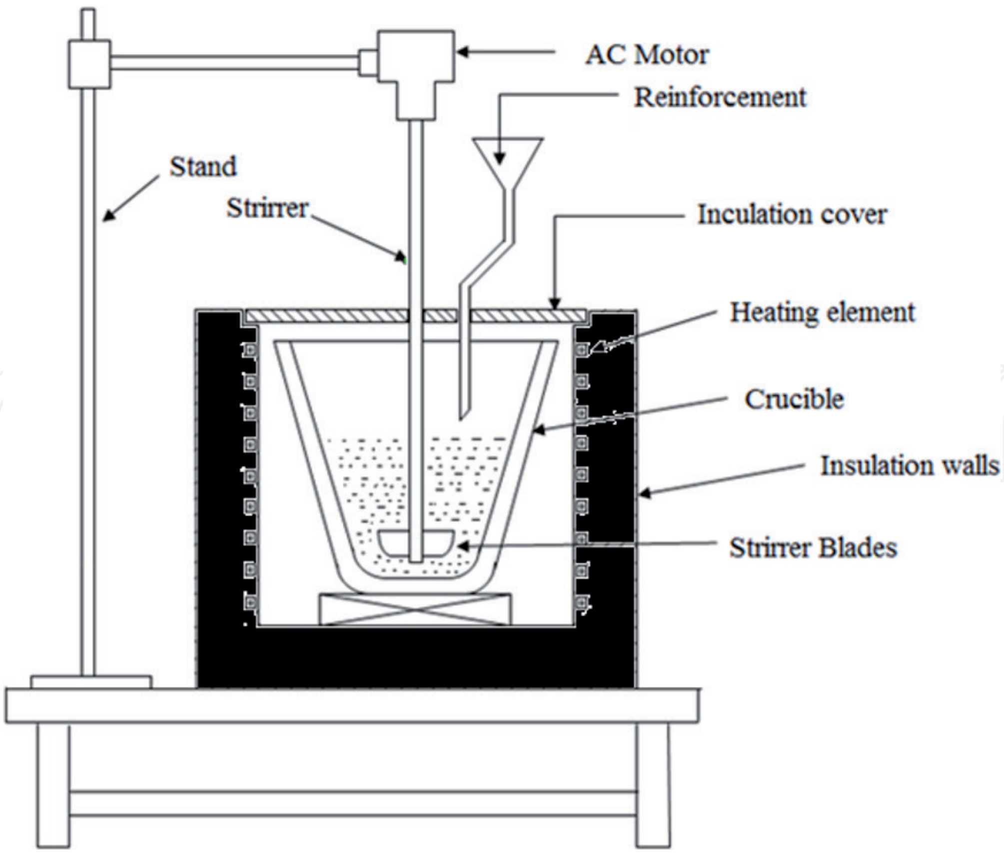

Figure 2.
Stir casting set up schematic diagram.

composites and for improving the properties. In hybrid composites the mechanical properties as well as particle distribution improved as Al_2O_3 + MnO_2 were introduced and also with their increasing wt.%. It is reported that reinforcing with 60 vol% Al reinforcement elastic modulus of pure aluminium increase from 70 to 240 GPa and leads to decrease to the coefficient of expansion from 24 to 7 ppm/°C [18]. Jokhio et al. [19] found that the addition of 2.77 wt.% Mg contents in Al matrix increases wettability, reduces porosity and develops high bonding with Al_2O_3. Wahab et al. [20] in their work found an increase in hardness value (from 44 to 94 HV at 100 g load) of Al-Si alloy when reinforced with 0–10 increasing wt.% of AlN. Tzamtzis et al. [21] found that the addition of 1 wt.% of Mg in A356/SiCp composites increases wettability and its further increases results in agglomeration of particles which increases viscosity resulting in non-uniform distribution of particles in the matrix. Saheb [22] found that the addition of varying weight fraction of silicon carbide, graphite and alumina in Al matrix, the hardness value of Al MMCs increases, maximum hardness of 45.5 and 74 BHN have been obtained with addition of 25% weight fraction of SiC and at 4% weight fraction of graphite respectively. It is observed in mechanical and microstructural behaviour of Al-7075/B_4C composites with constant weight of B_4C processed at varying temperatures (450–540°C) that due to the formation of MgO at higher sintering temperature above 530°C led to decrease in hardness and bending strength [23]. Increase of 81 and 37% in yield strength and ultimate tensile strength is observed in nano-Al_2O_3/2024 composites fabricated by solid-liquid mixed casting combined with ultrasonic treatment [24]. The effect of graphite particle on Al6082 metal matrix composite is investigated by Sharma et al. [25]. Agglomerations of graphite particles at some points were found with presence of large impurities due to non-uniform distribution. Hardness is reduced to 11.1% with 12 wt.% Graphite due to brittle nature of Gr reinforcement particles. Summarising, addition of different reinforcement have resulted in different microstructural features leading to distinct physical and mechanical properties in aluminium-based metal matrix composites (Al MMCs).

3. Wear behaviour of aluminium-based metal matrix composites

Now a days, aluminium-based metal matrix composites (Al MMCs) are used in making of piston, connecting rod, contactors, where sliding is an important factor [26]. Excessive wear of the mating components sometimes leads to catastrophic failures [27]. So study of wear properties of Al MMCs has become the need of time. Wear tests are generally conducted on ball/pin wear tester, schematic diagram as represented in **Figure 3**. Wear properties of many MMCs having continuous and discontinuous reinforcements like Al_2O_3, MnO_2, SiC, graphite, mica, glass, graphite and others have been reported [28–30].

There has been increasing interest in composites and many researchers contributing their work in the area of wear analysis of aluminium composites, cermets, ceramics [30–40]. Umanath et al. [30], examined the effect of SiC and Al_2O_3 on dry sliding wear behaviour of Al6061 hybrid composites prepared by stir casting method, results showed that with increase in the volume content, wear decreases due to the presence of hard oxide particles. Suresh et al. [39] investigated the wear behaviour of Al6061 reinforced with Al_2O_3 and graphite by keeping 2 wt.% graphite constant and Al_2O_3 content is varied 2–8 wt.%. The reinforcement of Al_2O_3 and graphite improved the tribological behaviour and caused reduction in the wear of Al6061 composites. The wear decreased with the increase of speed and aluminium oxide percentage. Basavarajappa and Chandramohan [40], worked on the dry sliding wear behaviour of Al2219 reinforced with SiC (0–15 wt.%). Results shows that 15% SiC reinforced composites have better wear resistance then other composites. Raghavendra and Ramamurthy [41], examined the influence of particle size and volume fraction on wear behaviour of Al7075 alloy reinforced with Al_2O_3 particles, size is varied 100–200 microns and the volume fraction is varied 3–12 wt.%. Results showed that hardness

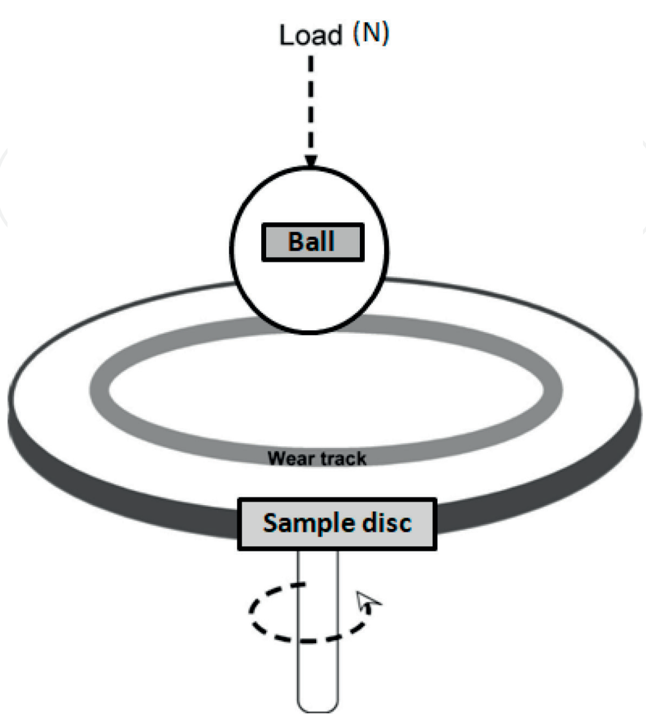

Figure 3.
Schematic diagram for sliding wear ball on disc tests.

increased with decrease in particle size and the wear rate was reduced with reduction in particle size. Increase in volume fraction reduced the wear and coefficient of friction. Vivekanandan et al. [42], investigated the wear resistance by varying load on the fly ash reinforced composites. Fly ash was added to the aluminium alloy and fabricated by stir casting method. At varying load it was noticed that wear rate of composites was less than the pure alloy at all loads. Kumar et al. [43], worked on the mechanical and wear behaviour of aluminium-fly ash composites formed by stir casting method. It was found that the hardness of composites increased with increase in addition of fly ash. Addition of fly ash shows improvement in the strength of composites. Strengthening of composites is due to dispersion and reinforcement. Both the wear rate and frictional force decreased with the adding of fly ash in Al6063 alloy. The aforementioned literatures show that various researchers have attempted to improve the properties of Al alloy by adding different alloying elements.

Al_2O_3 alloy when reinforced with 20 wt.% of alumina gives better wear resistance properties [44]. Al6061-alumina fibre composites abrasive wear rate is reported to be very less than the matrix alloy and is reported to have better wear resistance almost six times the matrix alloy [44]. The reason attributes to it is due to the addition of hard ceramic particles. Wear rate of Al7091 alloy and Al7091-SiC composites have almost same wear rate at 1.2 m/s sliding velocity whereas at increasing sliding velocity composites show less wear than un reinforced matrix [45–47]. TiO_2 as reinforcement in Al alloys give high mechanical properties as hardness and superior corrosion resistance [11]. Al6061 is considered as candidate material to prepare MMCs owing to its better formability characteristics and option of modification of the strength of composites by adopting optimal heat treatment [26]. Dinaharan et al. [48] fabricated aluminium alloy Al6061 reinforced with ZrB_2 particles (10 wt.%) and found ZrB_2 particles into the aluminium matrix improved tensile strength and wear resistance but reduced ductility and corrosion resistance. The wear resistance was measured using a pin-on-disc wear apparatus at room temperature according to ASTM G99-04 standard under dry sliding conditions. The polished surface of the pin of 6 × 6 × 50 mm was slide on a hardened chromium steel disc. The test was carried out at a sliding velocity of 15 m/s, normal force of 25 N and sliding distance of 2500 m. Wear resistance for Al6061 and Al6061/10 ZrB_2 is found to be 182.48 and 377.51 m/mm^3. The pitting corrosion rate was measured using potentiodynamic anodic polarisation technique as per ASTM G5 (ACM Gill-5500) at room temperature and found that 0.0230 and 0.1746 mm/year corrosion rate for Al6061 and Al6061/10 ZrB_2. Lus et al. [49] investigated the wear properties of *in situ* A380-Mg_2Si alloy squeeze cast composites. Wear tests were carried out on pin-on-drum type equipment where a rotating disk (34 rev min^{-1}) with 120 grid sand paper. Samples were placed vertically with loads such as 20, 25, 30, 35 and 40 N. The travel distances were selected to be 20, 40, 60 and 80 m [49]. Wear tests were basically carried out in two folds. The conditions of the first set of experiments were constant load of 20 N with changing travel distances of 20, 40, 60 and 80 m. As seen in the volumetric loss was linear where the samples cast in die without any pressure had the lowest loss of 0.0565 cm^3 and the casting with the highest pressure (i.e., 40 MPa) had the highest weight loss of 0.127 cm^3 at 80 m sliding distance. In the second set of experiments, the travel distance was kept constant at 20 m and the load was increased from 20 to 40 N by 5 N increments. This time, the volumetric loss was exponential the parts cast under 40 MPa had the highest volumetric loss of 0.26 cm^3 [49]. Volumetric loss and wear rate of *in situ* Mg_2Si-A380 composite increases exponentially when the load is increased. The hardness measurements were carried out on the matrix of the samples by using Micro hardness tester (HV10) and the hardness values were 138, 108, 87 HV10 for 0, 30, and 40 MPa squeeze pressures, respectively [49].

The effect of external ultrasonic treatment during solidification of a casted hypereutectic Al-Si (18% Si) alloy is studied by Unal et al. [50] and found that it has favourably affected the hardness and provided an increase of 15–20%. From the pin on disc wear tests performed under 67 N and with 1250 m sliding distance, it was revealed that the ultrasonic treated and non-treated samples exhibited similar amounts of weight loss [50]. Yamanoglu et al. [51] studied the effect of nickel (1–5 wt.%) on microstructure and pin on disc wear behaviour of pure aluminium against steel and alumina counter faces. The dry sliding wear response of the Al-*x*Ni alloys against steel and alumina counter faces was investigated [51]. The results showed that the hardness of the alloys increases with increasing nickel content; it is 46.2 HV3 at 5% Ni.

Severe wear damage was observed at low and high nickel contents. Maximum wear resistance was obtained with the addition of 3 wt.% nickel to the pure aluminium under both loads and against both counter faces. The wear resistance of the alloys increased with increasing nickel content up to 3 wt.% Ni and tended to decrease >3 wt.% Ni. The wear rate of the Al-*x*Ni alloys increased with increasing applied normal load [51]. One of the disadvantages with Al is that it leads to corrosion. It is preferentially in use in marine applications and to protect it from corrosion anti corrosive coatings are done on it like that of zinc chromate. The harmful effect of zinc chromate is that it is toxic in nature and is hazardous to the environment. Its replacement is done with cerium oxide which is available in nature abundantly and is less toxic. Wear study of Al_2O_3 and B_4C reinforced with Al5083 alloy matrix processed by stir casting method shows that shows that at varying load increasing wt.% of B_4C from 8 to 12% has increased the wear rate also [52]. Iacob et al. [53] observed the wear rate of $Al/Al_2O_3/Gr$ hybrid composites and found low wear rate as Al_2O_3 and Gr acted as load bearing elements and solid lubricant. Also, there is increase in micro hardness due to Al_2O_3 particles. Ganesh et al. [54] studied the mechanical and wear behaviour of Al2219 alloy—SiC composites and found that higher wt.% of SiC (20%) and sintering temperature (600°C) resulted in high hardness and reduced wear at varying wear load and speed. Using Taguchi Technique Al-Al_2O_3 composites wear behaviour is studied and optimised by Baradeswaran et al. [55]. Taguchi analytical and graphical results shows minimum wear loss at 6 wt.% of Al_2O_3 at 10 N load and sliding distance of 400 m as optimum combination. Wear tests were conducted for 10, 20, 30, and 40 N load and sliding distance of 1200 m with regular interval of 200 m at 0.6 m/s sliding speed.

Summarising, literature survey shows that Al base MMCs are of huge need as they are used for various applications as for making different machine components as heavy duty pistons, aircraft generator housings, air cooled cylinder heads, engine crankcases, petrol and oil tanks, oil pans, water cooled cylinder heads, rear axle housings, flywheel housings, automotive transmission cases, oil pans, rear axle housings, brackets, water cooled cylinder blocks, various fittings and pump bodies, air brake castings, gear cases, air cooled cylinder heads, air brake castings, gear cases, air cooled cylinder heads, Internal combustion engine pistons and blocks, cylinder bodies for compressors, pumps and brakes which gets degraded with passage of time due to either wear (abrasive, adhesive) or corrosion so its becomes very essential to study their wear properties [56].

4. Conclusions

Present industrial developments are associated with materials having advantageous physical, mechanical and wear characteristics that can achieve technological needs. Aluminium and its composites are best suited materials as have better properties than unreinforced materials. Beneficial properties with reduced prices have enlarged their applications. Al MMCs are used in defence, aerospace, automotive, aviation, thermal management areas in engine pistons, cylinders barrel, connection rods, elements of vehicles braking systems because of their unique properties of high hardness, high strength, high stiffness, high wear, abrasion and corrosion resistance.

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