MECHANICAL AND TRIBOLOGICAL PROPERTIES OF FLY ASH REINFORCED ALUMINIUM 6061 COMPOSITE- A REVIEW

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Abstract—There is an increasing interest in using composites made from low density and low cost reinforcements. Among various discontinuous reinforcements used, fly ash is most promising, inexpensive and low density reinforcement available in large quantities. It is a solid waste by-product obtained from thermal power plants. Fly ash has been used as filler in aluminium, polyester, epoxy, polyurethane and various rubbers. This development is due to advantages of fly ash such as low density, strong filling ability, excellent fluidity and good processibility of the filled materials. Further, as a waste by-product, its usage decreases overall cost of composites and pollution impact on the environment. Hence, composites reinforced with fly ash are likely to be used for ‘weight critical’ applications in automotive and small engine components as well as friction materials. This paper attempts to review the recent publications made in this field.

Keywords—Al6061, Fly ash, Mechanical properties, Wear

I. INTRODUCTION

Aluminium based metal matrix composites (MMCs) are potential engineering materials having combination of useful properties such as high specific strength, high specific stiffness and better hardness. During sliding against metals and abrasives, these exhibit better wear resistance than unreinforced alloys. These materials are used in various structural applications such as helicopter parts (parts of the body, support for rotor plates, drive shafts), rotor vanes in compressors and in aero-engines [1].

Al6061 is the widely used matrix material because of unique combination of its low density, high strength, good mechanical properties, highcorrosion resistance, low electrical resistance and better machinability properties. However, poor wear resistance has limited its use in certain tribological applications. In recent years, both fiber and particulate reinforced Al6061 composites have shown considerable improvement in tribological properties as well [1].

It is seen that higher cost of manufacturing of continuous fiber reinforced MMCs has led to use of particle reinforced and whisker reinforced MMCs [2]. Particles such as mica, alumina (Al₂O₃), graphite, boron and silicon carbide (SiC) have been used as fillers with aluminium alloys. Although these composites have high specific strength and high specific modulus, emphasis is to make them cost effective. In this regard, filler with lower density and cost like fly ash has emerged as potential reinforcement for making AMMCs. Fly ash generated from thermal power plants in India pose threat to environment causing health hazards. It is estimated that, of 90mega tons (Mt) of coal combustion by-products generated annually, only 25% is currently used, much of it is in the form of extenders in cement and in polymers; the remainder is ending up in landfilling. It is anticipated that fly ash particles as reinforcement in aluminium alloys would promote yet another use of this by-product [3]. Tribological properties of components used in aircraft fittings, valves, pistons rings, brake drums,
Since light metal alloys normally have poor wear resistance, they need surface treatments like coating with oxides or nitrides.

II. MECHANICAL PROPERTIES

Charles and Arunachalam[4] conducted property analysis and mathematical modeling on machining properties of aluminium alloy hybrid (Al-alloy/SiC/fly ash) composites produced by liquid metallurgy and powder metallurgy techniques containing aluminium with disperoids of silicon carbide added in varying proportions (10, 15 and 20 vol.% and fly ash maintained at 10 vol. %). They found that, addition of disperoids particles resulted in an increase in hardness and wear resistance.

Mares [5] reported that mechanical properties were dependent on particulate nature and content for some aluminium matrix composites. They made composites by vortex casting with either single-phase or two-phase (hybrid) reinforcement. The reinforcing particles were graphite and silicon carbide, in volume fractions up to 10%. Hardness measurement and tensile tests were carried out at room temperature. Mechanical properties and wear properties, in different conditions of heat treatments were evaluated. They concluded that heat treatment had potential to produce a desired combination of properties in aluminium graphitic composites by varying the parameters such as temperature and duration.

Basavarajappa et al. [6] studied mechanical properties of as cast aluminium alloy composite reinforced with SiCp and graphite particles. Their results revealed that as reinforcement content increased, ultimate tensile strength, yield strength, hardness and compressive strength increased predominantly but the density of the composite decreased. The increased strength of aluminium 2024/SiCp-Graphite composite was attributed to synergistic influence of dislocation density generated due to differences in coefficients of thermal expansion between constituents of the composite.

Cocen et al. [2] discussed the effect of hot extrusion on strength and ductility of SiCp reinforced Al-Si alloy. The material used in their work was Al-5%Si with 9, 13, 17, 22 and 26 vol.% SiCp manufactured by melt stirring technique. Cast ingots of matrix alloy and composites were extruded at 500°C at an extrusion ratio of 10:1. It was found that with the application of extrusion, clusters of SiCp disappeared and porosity content was substantially reduced to very low levels. The yield strength and tensile strength increased with increase in content of SiCp up to 17 vol.% and then decreased with further additions of reinforcement. The yield and tensile strength values improved approximately by 40% with the application of extrusion.

Massardier et al. [7] investigated the mechanical properties of aluminium based composite reinforced with preforms elaborated by Elf-Atochem. These preforms consisted randomly oriented hexagonal and monocrysalline-alumina platelets. The volume fraction of platelets in a preform was varied between 15 and 35%. Two aluminium matrices (either A9 pure aluminium matrix (99.9% Al) or a 6061 aluminium alloy (1% Magnesium, 0.6% Silicon)) were used to prepare composites by squeeze-casting technique. The influence of variable parameters of the material on the tensile properties was studied. They concluded that there was an increase in Young’s modulus, 0.2% proof stress, flow stress and ultimate tensile strength compared to unreinforced metal. These improvements were obtained at the expense of tensile ductility.

Mahagundappa et al. [8] studied the influence of reinforcement and thermal aging on mechanical properties of Al6061 hybrid composites and their study concluded that tensile strength, compression strength, Young’s modulus and hardness increased with the increase in reinforcement content but the ductility decreased substantially. Also, all these properties increased with increase in aging
duration with marginal improvement in ductility. This result may be due to formation of precipitate in the matrix alloy.

Kok [9] examined the effect of Al2O3 particle content (10, 20, 30 wt.%) and size (16, 32, 66 µm) in Al 2024 alloy on hardness and tensile strength. In processing of MMC by stir casting, Al2O3 particles were heated to 400°C for 10 minutes and then air cooled to room temperature before incorporation. The clearance of the impeller from bottom of the crucible was approximately 10 mm with the melt depth being 90 mm. Mixing of particles was carried out for 5 minutes before the melt was poured into preheated mold by tipping the furnace. Scanning electron microscope (SEM) pictures showed that coarser particles dispersed more uniformly while finer particles led to agglomeration and segregation of particles and porosity. The tensile strength and hardness of MMC increased but the elongation decreased with decreasing particle size and increasing wt.% of particles.

Sudarshan and Surappa[10]fabricated A356 Al–fly ash particle composites using stir-cast technique and hot extrusion. Composites containing 6 and 12 vol.% fly ash particles were processed. Narrow size range (53–106 µm) and wide size range (0.5–400 µm) fly ash particles were used. They found that bulk hardness, matrix microhardness, 0.2% proof stress of A356 Al-fly ash composites were higher compared to those of unreinforced alloy. Addition of fly ash led to increase in hardness, elastic modulus and 0.2% proof stress. Composites reinforced with narrow size range particles exhibited superior mechanical properties compared to those with wide size range particles. A356 Al–fly ash MMCs exhibited improved damping capacityas compared to unreinforced alloy at ambient temperature.

Ozbennet al. [11] studied the mechanical properties of 5, 10 and 15 wt. % of SiCp reinforced AlSi7Mg2 MMCs. The impact toughness was found to be varying between 0.4-0.6 J., which was due to brittle fracture of the reinforcement material and extremely rigid inter metallic compound formation between reinforcement and matrix material.

Mahendra and Radhakrishna[12] fabricated an Al–4.5%Cu alloy with fly ash particles by stir casting technique and evaluated density, hardness, wear, tensile and compression strength of the composite. The hardness increased, whereas the density decreased, with the increase in fly ash content. The tensile, impact and compression strength increased with increase in the content of fly ash. SEM observations showed that there was uniform distribution of particles throughout the matrix. These materials exhibited better mechanical and tribological properties required for some automotive components.

Veeresh Kumaret al. [13] studied the mechanical and tribological properties of Al7075 reinforced with Al2O3 particulate composites prepared by liquid metallurgy route. 2-6 wt.% of Al2O3 was dispersed in two steps to obtain castings. They concluded that micro hardnessand tensile strength of the composites increased with the increase in Al2O3 content. The percentage elongation decreased as the reinforcement content increased.

Ahlatci et al. [14] investigated the effect of Si addition up to 8% on abrasive wear and mechanical properties of Al–Si/60 vol.%SiC composites produced by pressure infiltration technique. They concluded that amount of porosity present in the microstructure of Al/60 vol.%SiC composites decreased with increasing Si content. The hardness increased with increasing Si content due to precipitation of eutectic Si. As the amount of Si increased up to 1%, the strength increased without significant loss in toughness after which the strength showed a decline with further increase in Si content. The impact resistance continuously decreased with increasing Si content. Al–1% Si alloy sample exhibited maximum resistance to abrasion. For Si contents greater than 1%, abrasion resistance decreased, which may be attributed to reduction in strength and toughness.
Aigbodion and Hassan [15] worked on Al-Si-Fe alloy with silicon carbide (5-25 wt.%) additions using stir casting method. The results revealed that addition of SiC increased the hardness, yield strength and tensile strength values up to maximum values of 67.0 HRB, 79.98 N/mm², 106.12 N/mm² respectively at 20 wt.%SiC. However, it was accompanied by reduction in impact energy and density. The work recommended that SiC addition should be between 15 and 20 wt % only to develop necessary properties.

Selvaraj et al. [16] presented a study of Al6061-Al2O3 and Al7075-SiC composites in terms of hardness and tensile strength. The composites were processed by liquid metallurgy route, 2-10 wt.% of particulates of Al2O3/SiC were dispersed in Al6061/Al7075 respectively in 2 steps to obtain the composites. The microstructures revealed uniform distribution of particles in the matrix alloy. Brinell hardness increased with increase in filler content. The dispersion of Al2O3 in Al6061 and SiC in Al7075 confirmed the enhancement of mechanical properties. The composites exhibited improved hardness. The tensile strength values increased with filler content in the respective matrices. Further, Al6061-10% Al2O3 composite exhibited 15% increase in tensile strength, while Al7075-10% SiC, showed 21% increase in tensile strength. Percentage elongation decreased with increase in filler content.

Seah et al. [17] investigated the mechanical properties of ZA-27 zinc-aluminium alloy/graphite particulate composites containing graphite particles of size 100-150 µm ranging from 0 to 5 wt.%. The ‘vortex method’ was used in which the graphite particles were poured into vortex created by stirring the molten metal by means of mechanical agitator. The results revealed that as graphite composition was increased, there were significant monotonic increase in ductility, tensile strength, compressive strength and Young’s modulus while there was a significant monotonic decrease in hardness of the material.

Singla et al. [18] conducted experiments on pure aluminium reinforced with SiC of volume fractions from 5 to 30 at 5 percent varying range manufactured by stir casting method. In cast composites, dendrites were found to be equiaxed and in the regions with clusters of SiC particles, primary α-Al seemed to be finer. The results showed an increase in hardness, impact strength with increase in SiC content. The best results were obtained at 25 wt.% of SiC addition. The hardness, impact strength values were 45.5 BHN and 36 N-m respectively.

Seah et al. [19] studied the mechanical properties of cast lead-antimony alloy composites containing SiC particles of size 90-150 µm and of contents ranging from 0 to 5 wt.%. The vortex method was employed in which the SiC particles were poured into the vortex created by stirring the molten metal at 400°C by means of a mechanical agitator. The results of this study revealed that as SiC composition was increased, there was significant increase in the UTS, hardness, torsional strength and impact strength of the composite, accompanied by a reduction in its ductility.

Sakthivel et al. [20] worked on Al2618 alloy reinforced with two different sizes (7 and 33µm) and weight fractions (0.5, 10 %) of silicon carbide produced by stir casting at a stirrer speed of 700 rpm and position of impeller was 1/10 of the melt depth from bottom of the crucible. Increase in porosity content was observed with increase in weight percent of the particle. Hardness of the composite increased with weight percent and decrease in particle size whereas impact strength decreased with increase in weight percent and decrease in particle size.

Pathak et al. [21] produced SiCp reinforced Al-Si alloy MMC by stir casting. The materials considered in their study were matrix alloy (Pure Al, Al-4.6%Si,Al-11.8%Si,Al-14.4%Si) and reinforcement was SiC particles of 50µm size with 0.6,1.5,2.2 wt.%. From the metallographic study, entrapments of SiC particles were identified in grain boundaries associated with silicon particles and
fragmented dendrites. Highest hardness value of 96.3 BHN was observed with Al-14.4%Si-2.2%SiC. The tensile yield stress, UTS and hardness increased with incorporation of SiC. But there was some decrease in percentage elongation with SiC content. Wear resistance under dry sliding conditions increased with SiC content.

III. TRIBOLOGICAL PROPERTIES

Following paragraphs narrate the work done so far to improve tribological properties of aluminium alloys.

Unlu[22] studied the mechanical and tribological properties of pure Al (99% purity), Al based (3% Al2O3 and SiC, and 6% Al2O3 and SiC) particle reinforced composites prepared by casting and PM methods. Tribological properties were investigated by wearing with 10 N load and 50 rpm on pin-on-disc machine at dry sliding conditions. Mechanical properties were investigated. He found that wear loss of particle reinforced Al specimens decreased about 1.5–2 times. Optical and scanning electron microscopy micrographs revealed that surfaces of pure Al specimens were rougher than those of particle reinforced Al specimens. Abrasive and adhesive wear tracks decreased for particle reinforced ones due to particle addition and better wear resistance property. In addition, tribological and mechanical properties of cast specimens were about 1.5–2 times better than those of PM specimens.

Ravikiran and Surappa [23] studied the dry sliding wear behavior of A356 Al-30 wt.%SiCpMMCs against steel disc at an applied pressure of 2 MPa, in the speed range of 0.5 to 10.0 m/s. At low speeds, frictional force exhibited a periodic oscillation with time which vanished at higher speeds. Wear rate continuously decreased with increasing speed. These phenomena were explained in terms of transferred material from steel disc onto the pin surface at low speeds, increased area fraction of SiCp on the pin surface and protrusion of SiCp in the matrix decreased the matrix damage and increased speeds.

Basavrajappa et al. [24] investigated the dry sliding wear behavior of Al2219 alloy and Al2219/SiCp/Gr hybrid composites. The composites were fabricated using the liquid metallurgy technique. The dry sliding wear test was carried out for sliding speeds up to 6 m/s and for normal loads up to 60 N by using a pin on disc apparatus. It was found that the addition of SiCp and graphite reinforcements increased the wear resistance of the composites. The wear rate decreased with the increase in SiCp content. As speed increased, the wear rate decreased initially and then increased. The wear rate increased with the increase in load. Scanning electron microscopy micrographs of the worn surface were used to predict the nature of the wear mechanism. Abrasion was the principal wear mechanism for the composites at low sliding speeds and loads. At higher loads, the wear mechanism changed to delamination.

Zhang et al. [25] investigated particle effects on friction and wear of 6061 aluminium reinforced with SiC and alumina (Al2O3) particles by means of Vickers microhardness measurements and scratch tests. Unreinforced 6061 Al matrix alloy was also studied for comparison. To explore the effect of heat treatment, materials were subjected to three different heat treatment conditions, i.e. under-aged, over-aged and T6. Multiplescratch tests using a diamond and a steel indenter were carried out to simulate real abrasive wear processes. Vickers microhardness measurements indicated that T6 heat treated composites showed the highest hardness. The peak-aged composites exhibited the best wear resistance. The wear rate of fine particle-reinforced composites was mainly affected by hardness. However, the wear rate of large particle-reinforced composites was influenced by both the hardness and fracture of the particles.

Singla et al. [26] fabricated Al–SiC composites containing 5%, 10%, 20% and 25% of SiC by liquid metallurgy method. They investigated friction and wear characteristics of Al–SiC composites under
dry sliding conditions and compared with those observed in pure aluminium. Dry sliding wear tests were conducted by using pin-on-disc wear test at normal loads of 5, 7, 9 and 11 kgf and at constant sliding velocity of 1.0 m/s. Weight loss of samples was measured and the variation of cumulative wear loss with sliding distance was found to be linear for both pure aluminium and the composites. It was observed that the wear rate varies linearly with normal load but lower in composites as compared to that in base material. The wear mechanism appears to be oxidative for both pure aluminium and composites under the given conditions of load and sliding velocity as indicated by SEM micrographs of the worn surfaces. Further, it was found that the wear rate decreased linearly with increasing weight fraction of silicon carbide and average coefficient of friction decreased linearly with increasing normal load and weight fraction of SiC. The minimum wear was obtained at 20\% weight fraction of 320 grit size SiC particles.

This article attempts a reasonably comprehensive review of representative journal publications covering improvements in mechanical and tribological properties of Al6061 fly ash reinforced composite used for structural applications. Most of the articles have appeared since 2000.

REFERENCES


