Effect of Reinforcement on Abrasive wear of Different Aluminium based Metal Matrix Composite-A Review

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***Abstract*— Aluminium alloys are the most widely used nonferrous materials in engineering applications owing to their attractive properties such as high strength to weight ratio, good ductility, excellent corrosion resistance, availability and low cost. However, their applications have often been restricted because conventional aluminium alloys are soft and notorious for their poor wear resistance. This problem was overcome by reinforcing different particulates in aluminium and its alloys to produce a reinforced metal matrix composite which possesses nearly isotropic properties. After reinforcement, Aluminum Metal Matrix Composites (MMCs) have enhanced properties such as elastic modulus, hardness, tensile strength at room and elevated temperatures and significant weight savings over unreinforced alloys. Owing to their excellent improved properties, Aluminium Metal Matrix Composites (MMCs) are sought over other conventional materials in the field of aerospace, automotive and marine applications. Inspite of many improvements in the tribological behaviour of the material matrix, some problems still persist. Abrasive wear is one of those serious problems which is very vital in industries and needs further meticulous solutions.**

In this paper an attempt has been made to accumulate some of the aspects of mechanical and abrasive wear behaviour of Aluminium alloys on treating it with various reinforcements like silicon, magnesium, fibres and fly ash.

***Keywords*— Aluminium alloys, MMC, Abrasive wear, fly ash.**

I. INTRODUCTION

Aluminum is the most abundant metal and the third most abundant chemical element in the earth's crust, comprising over 8% of its weight. Aluminum alloys are broadly used as a main matrix element in Composite materials. Aluminum alloys for its light weight, has been in the net of researchers for enhancing the technology. The broad use of aluminum alloys is dictated by a very desirable combination of properties, combined with the ease with which they may be produced in a great variety of forms and shapes. Discontinuously reinforced aluminum matrix composites are fast emerging as engineering materials and competing with common metals and alloys. They are gaining significant acceptance because of higher specific strength, specific modulus and good wear resistance as compared to ordinary unreinforced alloys. Reinforcing particles used in this study are silicon carbide and fly ash particles which are added externally One of the main drawbacks of this material system is that they exhibit poor tribological properties. Hence the desire in the engineering community to develop a new material with greater wear resistance and better tribological properties, without much compromising on the strength to weight ratio led to the development of metal matrix composites. Aluminium is one of the most commonly used metal matrixes for production of MMCs. The reinforcements being used are fibers, whiskers and particulates. The advantages of particulate-reinforced composites over others are their formability with cost advantage. Further, they are inherent with heat and wear resistant properties. For MMCs SiC, $Al_2O_3$and Gr is widely used particulate reinforcements.

Silicon carbide ceramics with little or no grain boundary impurities maintain their strength to very high temperatures, approaching 1600°C with no strength loss. It is an excellent abrasive and has been produced and made into grinding wheels and other abrasive products for over one hundred years.

The ceramic particulate reinforced composites exhibit improved abrasion resistance. They find applications as cylinder blocks, pistons, piston insert rings, brake disks and callipers. The strength of these composites is proportional to the percentage volume and fineness of the reinforced particles. These ceramic particulate reinforced Al-alloy composites led to a new generation engineering materials with improved specific properties. The structure and the properties of these composites are controlled by the type and size of the reinforcement and also the nature of bonding Apart from ceramics, fly ash is also one of the reinforcements to increase the abrasive wear resistance. Flyash is one of the residues generated in the combustion of coal. It is an industrial by-product recovered from the flue gas of coal burning electric power plants. Fly ash includes substantial amounts of silica (silicon dioxide, SiO2) and lime (calcium oxide, CaO). In general, fly ash consists of SiO_2, Al_2O_3, and Fe_2O_3 as major constituents and oxides of Mg, Ca, Na, K etc. as minor constituent. Fly ash particles are mostly spherical in shape and range from less than 1 µm to 150 µm with a specific surface area, typically between 250 and 600 m2/kg. The specific gravity of fly ash varies in the range of 0.6-2.8 gm/cc. It is one of the most inexpensive and low density reinforcement available in large quantities as solid waste by-product during combustion of coal in thermal power plants.The utilization of fly ash instead of dumping it as a waste material can be an advantage both on economic and environmental grounds. The reinforcing of fly ash significantly improves the tribological properties of aluminum and its alloy system. The thinking behind the development of hybrid metal matrix composites is to combine the desirable properties of aluminum, silicon carbide and fly ash. Aluminum have useful properties such as high strength, ductility, high thermal and electrical conductivity but have low stiffness whereas silicon carbide and fly ash are stiffer and stronger and have excellent high temperature resistance but they are brittle in nature. When Aluminum Composites are treated with fly ash particulates they exhibit an improved mechanical and wear properties.

Metal Matrix Composites are being increasingly used in aerospace and automobile industries owing to their enhanced properties such as elastic modulus, hardness, tensile strength at room and elevated temperatures, wear resistance combined with significant weight savings over unreinforced alloys. Aluminium alloy (LM6) is used in marine, automobile, aerospace industries .MMCs possess superior wear resistance and are hence potential candidate materials for a number of tribological applications. These include pistons and cylinder liners in automotive engines, brake discs/drums in railway vehicles and in automobiles. However, cost still remains a major barrier in designing aluminium composite components for wider applications in automotive industries along with the wear problems.

Wear is related to interactions between surfaces and more specifically the removal and deformation of material on a surface as a result of mechanical action of the opposite surface. The need for relative motion between two surfaces and initial mechanical contact between asperities is an important distinction between mechanical wear compared to other processes with similar outcomes. Wear can also be defined as a process where interaction between two surfaces or bounding faces of solids within the working environment results in dimensional loss of one solid, with or without any actual decoupling and loss of material.

Abrasive wear particles are most commonly the result of dust or dirt in the oil. The dirt particles become wedged between two moving parts, embed in the softer surface, and cut into the harder one. The wear debris from this process appears to be miniature shavings from a machining operation. Abrasive wear particles can be several hundred microns long. Hard metals tend to form smaller abrasive particles that may have a needle like appearance. Abrasive wear occurs when a hard rough surface slides across a softer surface. ASTM International (formerly American Society for Testing and Materials) defines it as the loss of material due to hard particles or hard protuberances that are forced against and move along a solid surface. Abrasive wear is commonly classified according to the type of contact and the contact environment. The type of contact determines the mode of abrasive wear. The two modes of abrasive wear are known as two-body and three-body abrasive wear. Two-body wear occurs when the grits or hard particles remove material from the opposite surface. Three-body wear occurs when the particles are not constrained, and are free to roll and slide down a surface. There are a number of factors which influence abrasive wear and hence the manner of material removal. Several different mechanisms have been proposed to describe the manner in which the material is removed. Three commonly identified mechanisms of abrasive wear are plowing, cutting and fragmentation. Plowing occurs when material is displaced to the side, away from the wear particles, resulting in the formation of grooves that do not involve direct material removal. The displaced material forms ridges adjacent to grooves, which may be removed by subsequent passage of abrasive particles. Cutting occurs when material is separated from the surface in the form of primary debris, or microchips, with little or no material displaced to the sides of the grooves. This mechanism closely resembles conventional machining. Fragmentation occurs when material is separated from a surface by a cutting process and the indenting abrasive causes localized fracture of the wear material. These cracks then freely propagate locally around the wear groove, resulting in additional material removal by spelling. Abrasive wear can be measured as loss of mass by the Taber Abrasion Test according to ISO 9352 or ASTM D 1044.

II. LITERATURE REVIEW

Adel Mahamood Hassan et al. [9] conducted wear test using a pin-on-disk wear testing machine and found that the wear properties of the Al–Mg–Cu alloys were considerably improved by the addition of SiC particles; however, wear resistance of the composites was much higher than that of the unreinforced aluminium alloys. The wear volume loss of alloys increased linearly with increasing sliding distance. But the rate of volume loss for the composites was much smaller than that of the matrix. They also found that the wear resistance of Al–4 wt% Mg alloy increased considerably with copper addition up to 5 wt%, but the coefficient of friction values increased insignificantly.

Hayrettin Ahlatci et al. [17] observed abrasive wear behaviours of the aluminium matrix hybrid composites produced by pressure infiltration. The composites were reinforced with 37 vol% Al2O3 and 25 vol% SiC particles and contained up to 8 wt% Mg in their matrixes. It was found thatmetal–metal and metal–abrasive wear resistance increased with increasing Mg content of the matrix and abrasive resistance decreased with increasing test temperature, especially above 200^{o}C.

Tuti Y. Alias and M.M. Haque [1] studied wear behaviours of both the as-cast and the heat-treated aluminium-silicon eutectic alloy. Wear experiments on heat-treated specimens were conducted with a pin-on-disk type wear testing apparatus. In general, the increase in wear with an increase in input weight, rotational speed and sliding distance was observed for both the as-cast and heat-treated specimens of aluminium-silicon eutectic alloy.The wear was more pronounced in the as-cast samples compared to the heat-treated ones due to some inherent characteristics obtained during different heat treatment cycles.

M.Ramachandra and K. Radhakrishna [3] studied the abrasive wear behaviour of al-si (12%)-sic metal matrix composite synthesised using vortex method. Wear behaviour was studied by using computerized pin on disc wear testing machine and was found that the abrasive wear resistance of MMC increased with increase in SiC content. But wear increased with increase in sliding velocity and normal load.

M. I˙zciler Et al. [8] studied the wear behaviour of 25 vol. % SiC reinforced 2124 Al alloy composite produced by powder metallurgy method in RWAT system. SiC and Al2O3 abrasive particles were used as the abrasive medium. Wear tests were performed under the loads of 30, 60 and 90 N at the room temperature. It was found that the wear rate of the composites increased with increasing the load. Wear rate of the composites abraded by SiC abrasive particles showed higher value than that of the composites abraded by Al2O3 abrasive particles.

Yusuf Sahin etal. (2010) [18] prepared Aluminium alloy matrix reinforced with 15wt% SiC particles by powder metallurgy (PM) method. Wear behaviour of the composite was in terms of the Taguchi approach, on a pin-on-disc machine. The chemical composition of the alloy (wt %) is Si 0.75, Fe 0.26, Cu 4.9, Mg 0.58, Zn 0.68 and balance Al. In order to produce MMCs, SiC particles with various sizes were used as the reinforcement materials in addition to Al 2014 alloy. This experiment specifies four principle wear testing conditions including the abrasive size (A), applied load (B), sliding distance (C) and type of tested materials or hardness of tested samples (D) as the process parameters. It was found that that the abrasive grain size exerted the greatest effect on the wear.

G.B. Veeresh Kumar et al. (2012) [17] Conducted Dry-sliding wear test using a computer aided pin-on-disc wear-testing machine at constant sliding velocity (V = 2.62 m/s) and load on the pin was varied from 10 to 60 N while the sliding distance of 6 km was maintained and tests were conducted at room temperature in accordance with ASTM – G99 standard (diameter of the pin was 10 mm and 25 mm in length). It was found that the volumetric wear loss of the composites decreases with increased contents of SiC reinforcement in the matrix alloy.

Manoj Singla et al. (2009) [13] conducted on a study of Wear Properties of Al-SiC Composites. Al–SiC composites containing four different weight percentages 5%, 10%, 20% and 25% of SiC have been fabricated by liquid metallurgy method and a dry sliding wear tests have been carried out using pin-on-disk wear test rate normal loads of 5, 7, 9 and 11 Kgf and at constant sliding velocity of 1.0m/s. It was found that wear rate decreases linearly with increasing weight fraction of silicon Carbide and average coefficient of friction decreases linearly with increasing normal load and Weight fraction of sic. The best results have been obtained at 20% weight fraction of 320 grit size sic particles for minimum wear.

Sudarshan and M.K.Surappa (2008,)[5] had studied the dry sliding wear of flyash particle reinforced A356composites containing 6 and 12 vol. % of fly ash particles and studied dry sliding wear behaviour of unreinforced alloy and composites using Pin-On-Disc machine at a load of 10, 20, 50, 65 and 80N at a constant sliding velocity of 1 m/s.Fly ash particles having wide size range(0.5–400microns) and sieved fly ash particles having narrow size range (53–106microns) were used as reinforcement. Particle size analysis was done using a computerized particle size analyzer, Malvern made laser light particle size analyzer (Mastersizer).

Composites were fabricated using stir-cast technique. Composites having different particle sizes and volume fraction of fly ash are designated as follows: composites with 6 vol. % fly ash particle (sieved), (C6S), composites with 12 vol. % fly ash particle (sieved), (C12S) and composites with 12 vol. % fly ash particle. Fly ash from Raichur thermal power plant (India) was used in their study sliding wear tests were conducted in air at ambient temperature using a Pin-on-Disc Machine, (DUCOM's Wear Friction Monitor, and Model-TR 20). Results show that the dry sliding wear resistance of Al-fly ash composite is almost similar to that of Al2O3 and Sic reinforced Al-alloy. Composites exhibit better wear resistance compared to unreinforced alloy up to a load of 80 N. Fly ash particle size and its volume fraction significantly affect the wear and friction properties of composites. Microscopic examination of the worn surfaces, subsurface sand debris has been done. At high loads (>50 N), where fly ash particles act as load bearing constituents, the wear resistance of A356 Al alloy reinforced with narrow size range (53–106 microns) fly ash particles were superior to that of the composite having the same volume fraction of particles in the wide size range (0.5–400microns).Wear is dominant in unreinforced alloy, whereas abrasive wear is predominant in composites. At higher load, subsurface delaminating is the main mechanism in both the alloy as well in composites.

M. Ramachandra and K. Radhakrishna (2007), [6] prepared metal matrix composite by using stir casting method for study. Al–12% Si alloy in the form of ingots were used for the trials. Two body sliding wear tests were carried out on prepared composite specimens. Computerized pin-on-disc wear test machine was used for these tests. The tangential friction force and wear in microns were monitored with the help of electronic sensors. These two parameters were measured as a function of load, sliding velocity and % fly ash. For each type of material, tests were conducted at three different normal loads (4.9, 9.8 and 14.7 N) keeping the sliding speed fixed at

95 m/min. Flyash was added in weight percentage of 5, 10, and 15% in Al metallic matrix using vortex method. The optical micro -graph of 10 and 5% fly ash reinforced MMCs.

It was observed that the MMCs exhibited better wear resistance (20–30% improvement) due to its superior load bearing capacity. Four different wear mechanisms were found to operate under the test conditions of variation in normal load, % fly ash content and sliding velocity. They are abrasion, oxidation, delimitation, thermal softening and adhesion. Corrosion resistance of reinforced samples has decreased with increase in fly ash content. The results indicate that the wear resistance of the fly ash reinforced material increased with increase in fly ash content, but decreases with increase in normal load, and track velocity. The microscopic examination of the worn surfaces, wear debris and subsurface shows that the base alloy wears primarily because of micro cutting .Corrosion has increased with increase in fly ash content.

Kenneth Kanayo Alaneme et. al.(2013),[12],conducted study on the corrosion and wear behaviour of Al–Mg–Si alloy matrix hybrid composites developed with the use of rice husk ash (RHA) and silicon carbide (SiC) particulates as reinforcements were investigated. RHA and SiC mixed in weight ratios 0:1, 1:3, 1:1, 3:1, and 1:0 were utilized to prepare 5, 7.5 and 10 wt% of the reinforcing phase with Al Mg Si alloy as matrix using double stir casting process. Open circuit corrosion potential (OCP) and potentiodynamic polarization measurements were used to study the corrosion behaviour while coefficient of friction was used to assess the wear behaviour of the composites. The corrosion and wear mechanisms were established with the aid of scanning electron microscopy. The results showed that the effect of RHA/SiC weight ratio on the corrosion behaviour of the composites in 3.5%.NaCl solution was not consistent for the different weight percent of reinforcement (5,7.5, and 10 wt%) used in developing the Al–Mg–Si based composites. It was evident that foremost cases the use of hybrid reinforcement of RHA and SiC resulted in improved corrosion resistance of the composites in 3.5% NaCl solution. Preferential dissolution of the more anodic Al–Mg–Si alloy matrix around the Al–Mg–Si matrix/RHA/SiC particle interfaces was identified as the primary corrosion mechanism. The coefficient of friction and consequently the wear resistance of the hybrid composites were comparable to that of the Al–Mg–Si alloy matrix reinforced with only SiC.

M. Uthaya Kumar et al.(2013)[14] in their study described the multifactor-based experiments that were applied to research and investigation on dry sliding wear system of stir-cast aluminium alloy 6351 with 5, 10, and 15 wt.% fly ash reinforced metal matrix composites (MMCs). The effects of parameters such as load, sliding speed, and percentage of fly ash on the sliding wear, specific wear rate, and friction coefficient were analyzed using Grey relational analysis on a pin-on-disc machine. Analysis of variance (ANOVA) was also employed to investigate which design parameters significantly affect the wear behaviour of the composite.

The experimental results show that the composites retain the wear resistance properties at lower loads with increase in fly ash percentage. Mild wear was also observed in the composites as the sliding speed increases. For all the trials it is observed that mild-to-severe wear exists, and it is witnessed by the microscopic results. The applied load and sliding speed are the most influencing factors, and it is observed that their contributions to wear behaviour are 49.71% and 30.43%, respectively.Theresults showed that the applied load exerted the greatest effect on the dry sliding wear followed by the sliding velocity. The confirmation experiment is conducted with the level A2B3C1 to verify the optimal design parameter, and it exhibits better wear performance.

GrigoriosItskos et al. (2011), [7]in their study used highly calcareous fly ash particles for the fabrication of Al and Al based metal matrix composite by means of powder metallurgy. After compacting and sintering Al/Si and Al powders containing 10, 15, 20% fly ash particle the homogenous microstructure of the produced composite was tested using Scanning Electron Microscope (SEM).The composites were tested using Pin on disc machine against spheres of Alumina .The worn surface was then examined using EDS and SEM machines. Addition of high Ca and high silicon fly ash significantly enhances the tribo-performance of Aluminium. Al/Si is having better characteristics then Al/Si fly ash. But addition of fly ash up to 15% of weight results in a rather restricted deterioration of wear strength of products.

Sathyabalan et al. (2009) [10]Worked on hybrid LM6 Aluminium alloy metal matrix composites (MMC) with fly ash and Si-C. The effect of the four parameters, size and weight of the reinforcements on the wear loss has been studied. Artificial neural networks, from the artificial intelligence family, are a type of information processing system, based on modelling the neural system of human brain. The effect of the parameters was investigated using ANN. Central composite rotatable method of design of experiments was used to arrive at the combination and the number of specimens. The value of the Fly Ash varied by 5% & 15% keeping SiC constant by 5%. By this process three sets of specimens were prepared for each test. The specimens were prepared using the liquid metallurgy route and tested. Pin-on-disc apparatus was used for determining wear. The data from the experiments were used for training and testing the network.

Results showed that the accuracy in ANN prediction was appreciable with the error estimated for wear loss being less than 2%.The ANN prediction is quick and economical way of estimating the properties.

Dr.G.K.Purohit et al (2013),[15] work deals with fabricating or producing aluminium based metal matrix composite and then studying its microstructure and wear behavior of produced test specimen. A modest attempt has been made to develop aluminium based MMCs with reinforcing material, with an objective to develop a conventional low cast method of producing MMCs and to obtain homogeneous dispersion of reinforced material. To achieve this objective stir casting technique has been adopted. Aluminium Alloy (LM6) and SiC, Fly Ash was chosen as matrix and reinforcing material respectively. Experiment was conducted by varying weight fraction of Fly Ash (5% and 15%) while keeping SiC constant (5%).

The result showed that the increase in addition of Fly Ash increases the Wear Resistance of the specimen and. It was also found that the wear resistance tends to increase with increase in addition of Fly Ash in LM6/SiC Hybrid composite. From their study they concluded that we can use Fly Ash for the production of composites and can turn industrial waste into industrial wealth. This can also solve the problem of storage of Fly.

P.K. Rohatgi and R.Q. Guo(1997)[19],had introduced Fly ash into Al-Si hypoeutectic alloy (A356) to make low-cost composites with decreased density and improved hardness and abrasive wear behaviour. The mechanisms of abrasive wear of stir-castA356^5 volume % fly ash composite were discussed based on the results of wear tests of composites and the A356 base alloy. They used Precipitator fly ash from Wisconsin Electric in their study. Most of these fly ash particles were less than 50 micron size. Scanning electron microscopy was used to investigate the morphology of the worn surfaces, wear debris for both composite and A356 base alloy. The subsurface of the worn samples was also observed. These morphology observations provide a method to understand the abrasive wear and friction mechanism of the composites showing that the base alloy wears primarily by microcutting but the compo-site wears by microcutting and delaminating caused by crack propagation below the rubbing surface through interfaces of fly ash and silicon particles with the matrix. The abrasion wear resistance of the containing Aluminium-cu alloy A356 with 5 vol % fly ash is superior to that of the base A356 alloy below a load of 8N at sliding velocities of 1m/s.

P.K. Rohatgi et al [11] worked on the abrasive wear properties of stir-cast A356 aluminium alloy-5 vol % fly ash composite and tested it against hard Sic abrasive paper and compared to those of the A356 base alloy. The results indicate that the abrasive wear resistance of aluminium–fly ash composite is similar to that of aluminium-alumina fibre composite and is superior to that of the matrix alloy for low loads up to 8 N(transition load) on a pin. At loads greater than 8 N, the wear resistance of aluminium–fly ash composite is reduced by deboning and fracture of fly ash particles. Microscopic examination of the worn surfaces, wear debris, and subsurface showed that the base alloy wears primarily by microcutting, but the composite wears by microcutting and delaminating caused by crack propagation below the rubbing surface through interfaces between fly ash and silicon particles and the matrix. The decreasing specific wear rates and friction during abrasion wear with increasing load have been attributed to the accumulation of wear debris in the spaces between the abrading particles, resulting in reduced effective depth of penetration and eventually changing the mechanism from two-body to three-body wear, which is further indicated by the magnitude of wear coefficient.

Gun Y. Lee et al(2001),[4]has presented a simple physically-based model for the abrasive wear of composite materials on the mechanics and mechanisms associated with sliding wear in soft (ductile)- matrix composites containing hard (brittle) reinforcement particles. The model was based on the assumption that any portion of the reinforcement that is removed as wear debris cannot contribute to the wear resistance of the matrix material. The size of this non-contributing portion (NCP) of reinforcement is estimated by modeling three primary wear mechanisms, specifically, plowing, cracking at the matrix/reinforcement interface or in the reinforcement, and particle removal. Critical variables describing the role of the reinforcement, such as relative size, fracture toughness and the nature of the matrix/reinforcement interface, are characterized by a Single contribution coefficient, *C*. Predictions was compared with the results of experimental two-body (pin-on-drum) abrasive wear tests performed on a model aluminum particulate-reinforced epoxy-matrix composite material. Their model provided a reasonable description of the variation in abrasive wear rates with reinforcement volume fraction and provides a justification for the “negative reinforcement” effect.

O. Yılmaz et. al.(2001),[20],had studied the effects of volume fraction, Al2O3 particle size and effects of porosity in the composites on the abrasive wear resistance of compo-casting Al alloy MMCs have for different abrasive conditions. Al2O3 particulates were added to an Al matrix as 5, 10 and 15 vol. %. The microstructure of the composites with Al2O3 reinforcement were investigated and optical micrographs of Al alloy composites with Al2O3 reinforcement the abrasive tests with 80 grade SiC abrasive paper have shown that the increase of Al2O3particulates in the matrix increased wear resistance less than on the wear with 220 grade SiC abrasive paper. The wear rate of Al alloy increased drastically with increasing sintered porosity. However, for composites, The porosity effect is less significant. The wear rates decreased with increase in Al2O3 size for the composites containing the same amount of Al2O3.Their result showed that Aluminum alloy composites reinforced with larger Al2O3 particles are more effective against abrasive wear than those reinforced with smaller Al2O3 particles. At the same time the results show that the beneficial effects of hard Al2O3 particles on wear resistance.

III. CONCLUSION

The exhaustive literature survey presented above reveals that extensive work has been reported to improve wear properties of Aluminium based Metal Matrix Composites. It reveals that when aluminium alloy treated with different reinforcements like silicon, magnesium, fibres, ceramics and fly ash are tested with different wear tests, renders improved wear properties. Apart from that it also resulted in amelioration of other mechanical properties like hardness, compressive and tensile strength and corrosive properties. Finally there is an immense potential, scope and opportunities for the researchers, in the field of prediction of wear and mechanical properties of the aluminium alloys by reinforcing with different ceramics, fibers, etc.

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