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A REVIEW OF WEAR CHARACTERIZATION AND FABRICATION OF ALUMINIUM MATRIX COMPOSITES

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Abstract*— Aluminium (Al) is second most abundant metallic element on earth. It has properties such as soft, ductile and resistant to corrosion and it has found wide applications in foil and conductor cables but in order to use aluminium for industrial applications, it is necessary to alloying aluminium with other elements to provide the elevated strength needed for other applications. Owing to very good characteristics shown by aluminium, it has a wide range of applications which make aluminium a very high in demand material. It is required to produce aluminium metal matrix composite and investigate various properties exhibited by these newly formed composites. The composites have shown a tendency to exhibit properties which are much better as compared to aluminium alloy. Aluminium metal matrix composites on comparison with base aluminium alloy have exhibited good combinations of mechanical and tribological properties. These have found wide applications in our daily life. There are some advantages in using particles reinforced aluminium metal matrix composites materials than unreinforced materials such as increased strength, enhanced stiffness, lowered thermal expansion coefficient, light in weight, raised thermal conductivity and improved wear resistance. The usual reinforcements used in aluminium metal matrix composites are alumina (Al_2O_3), boron carbide (B_4C), graphite etc.

***Keywords*— Aluminium, Stir Casting, MMC, Hardness and Wear**

I. INTRODUCTION

Metal matrix composites (MMCs) comprise of minimum two phases which are chemically and physically distinct, effectively distributed to present the properties which cannot be attained with either of the individual phases. The metal matrix composites have many advantages as compared to other materials and composites. The advantages of aluminium matrix composites involved are light weight, increased strength, enhanced stiffness, lowered thermal expansion coefficient, improved wear resistance. On comparing with polymer matrix composites, the metal matrix composites show higher electrical conductivity, higher thermal conductivity, higher strength and stiffness etc. There are many techniques available in the market which can be used for fabrication of composites. These techniques include powder metallurgy, stir casting, liquid metallurgy and pressure infiltration method. There are many factors which need to be considered while choosing a suitable fabrication method for manufacturing the composites. These factors include the homogenous distribution of reinforcement particles in the matrix, cost, and simplicity of the method. Metal matrix composites reinforced with particles are most preferred engineering materials. Integration of soft matrix alloy and hard ceramic phase enhances the strength, wear resistance and creep performance. Stir Casting is the most preferred method for fabrication of aluminium matrix composites due to its simplicity and cost effectiveness. It also provides homogenous orientation of reinforced particles in the matrix.

Aluminium Alloys and their Applications

The elements which are alloyed with aluminium are copper, magnesium, silicon, zinc, lithium and manganese. Small amount of chromium, titanium, zirconium, lead, bismuth and nickel can also be added and very small quantity of iron is also present. Aluminum alloys exhibit low density, excellent strength, enhanced toughness and resists corrosion. They have found wide applications in the automobile and aerospace fields. The aluminium alloys find wide application in industry. The applications of Aluminium Alloy 6061 include:

1) Automobile components
2) Aerospace components
3) Mineral processing components
4) Marine fitting, transport, bicycle frame, camera lenses, drive shafts, electrical fitting and connectors, brake components, valves and couplings.

Wear

Wear is the loss of material when two surfaces rub against each other. Wear testing is done on different apparatus. The most widely used apparatus is the pin-on-disc apparatus. The wear testing can be done in dry conditions or lubricating conditions. The main input parameters for wear testing are applied load, sliding speed and sliding distance.

II. CURRENT STATUS OF RESEARCH

Sharma et.al **[1]** conducted the study to examine the influence of silicon nitride particulates on sliding wear performance of Al 6082 matrix composite under dry conditions. The composite is synthesized by stir casting method and analysis is done utilizing Response Surface Methodology (RSM). The variation in reinforcement percentage is kept from 0 to 12%. It is observed from the results that the sliding distance becomes most significant parameter whereas percentage reinforcement becomes least influential parameter. Rahman and Rashed **[2]** investigated microstructures, mechanical behaviour and wear performance of aluminium matrix composites using silicon carbide as reinforcement. The process of stir casting prepares the composite. The variation in the SiC content is 0,5,10 and 20 wt. %. It was clear from the results that by incorporating SiC reinforcements in aluminium matrix, tensile strength as well as hardness are increased. The composite containing 20 wt. % SiC as reinforcement exhibited the highest hardness and tensile strength. The wear tests were done using pin-on-disc machine. Results revealed that reinforcing SiC particulate into aluminium matrix led to increase in its wear resistance. Jin et.al **[3]** analysed the tribological characteristics of 6061 Al alloy composite incorporating $Mg_2B_2O_5$ reinforced whiskers. It is manufactured by utilizing power ultrasonic stir casting route. The experiments to find the unlubricated sliding wear performed on ball-on-disk machine opposite counter face of GCr45 steel. The outcomes show that the rate of wear of the aluminium matrix composites using ZnO coated $Mg_2B_2O_5$ whiskers is the least amongst other materials available. As there is increase in load applied and sliding speed, transformation in wear behaviour of the composites from a mild wear into a severe wear takes place. While testing the tribological performance of whisker reinforced composite it was seen that the coefficients of friction tend to be smaller under dry conditions and the rate of wear rises with rise in the value of load or sliding velocity. Sarada et.al **[4]** manufactured a low cost aluminium metal matrix composite incorporating ash of bamboo leaf and silicon carbide using the double step stir casting method. The observations revealed ultimate tensile strength, hardness as well as percent elongation get lowered as there is rise in bamboo leaf ash content. The important process variables for manufacturing the hybrid composite by stir casting process are design of stirrer, stirring speed and pouring temperature of alloy, type of mould and type of reinforcement particle. Light Optical Microscope (LOM) is used to examine wear out surfaces and wear debris. The direction of abrasive action and the sliding direction are the same but the wear debris is more fine and smooth for hybrid composites as compared to conventional composites.

Alaneme and Olubambi **[5]** examined the wear performance and corrosion behaviour of the Al–Mg–Si alloy hybrid composites manufactured by introducing rice husk ash plus Al_2O_3 as reinforcements. Double stir casting employed in manufacturing composite with 2, 3 and 4 wt. % rice husk ash mixed with alumina. It was revealed that Al–Mg–Si/10 wt. % Al_2O_3 single reinforcement composite exhibited much better resistance to corrosion in comparison with hybrid matrix composites in NaCl solution of 3.5%, rates of corrosion rises as there is rise in wt. % of rice husk ash (RHA). Wear rate and friction coefficient of composites show an increasing trend with increasing RHA wt. %. Sahin **[6]** investigated wear behaviour of the Al hybrid matrix with 15 wt. % SiC particulate reinforcement. The fabrication method used is the Powder Metallurgy method. Pin-on-disc wear tester used and utilizing Taguchi's approach wear behaviour is examined. Analysis of variance (ANOVA) analysed affect of process variables on wear of composite. It is clear from the results that particle grain size has maximum influence over abrasive wear. Hardness comes after particle grain size in influencing the hardness. This can be attributed to the fabrication method of powder metallurgy, size of the particles and conditions of testing. Kok **[7]** investigated wear performance of different size particulate and particles weight fraction up till 30 wt. % particulate alumina integrated into AA 2024 matrix composite. The composites were manufactured utilizing vortex method. The worn out surface observed with scanning electron microscope investigate wear performance. It is seen in results that Al_2O_3 particulate reinforcements enhanced abrasion resistance in opposition to all other abrasives used, and there is a reduction in the abrasive wear resistance with growing size of abrasives and rising sliding distance. Rao and Das **[8]** evaluated the wear performance of aluminium alloy (Al–Zn–Mg–Cu) composite under dry sliding conditions and was analysed for different applied pressures and different sliding speed. Pin-on-disc apparatus against heat-treated steel counter surface was utilized to investigate the wear behavior. The composite has considerably lower wear coefficient as compared to alloy and it is more lowered by the incorporation of reinforcement particles in the form of particles of silicon carbide. Rao and Das **[9]** evaluated the influence of sliding distance on the wear performance of alloy composite obtained after casting and heat-treated particulate Al–SiCp composite. The input parameters are sliding distance (0– 5000 m), pressure (0.2, 0.6, 1.0 and 1.4 MPa) along with sliding speed maintained at 3.35 m/s. The composite shows homogenous arrangement of silicon carbide particles as reinforcement. It was revealed that the composite after undergoing heat treatment exhibit good wear properties in comparison to original alloy, whereas reverse trend was shown by the coefficient of friction. The composite wear rate rises with the rise in the value of applied pressure.

Zhiqiang and Guobin **[10]** evaluated the wear performance of the aluminium matrix composite using SiC as the reinforcement under the dry sliding conditions. The loss of wear of the silicon particle-reinforced composites is less than the original alloy. There is more loss of material of composites and also of the original alloy when there is a rise in the load applied and sliding speed. At low loads, very less abrasion and scratch was shown by the composite material whereas abrasion and delaminating wear were more dominating in case of high loads. The wear behavior of the composite changes under varying loads as there is weak interface bond the matrix and reinforcement particles. Baradeswaran and Perumal **[11]** have conducted the study to investigate the wear and mechanical behaviour of Al 7075/graphite composites under dry sliding

conditions. The fabrication technique used is liquid stir casting. The wt.% of reinforcements selected is 5, 10, 15 and 20 wt. % of graphite. The experimentation was done on the pin on disc machine revealed that wear rate went down with the introduction of graphite content and at 5 wt. % graphite content exhibited its lowest value. The average friction coefficient gets lowered with the incorporation of graphite and was observed to be least at 5 wt. % graphite. The mechanical properties show decreasing trend as the graphite content gets increased as compared to base alloy. Higher wear property relative to base alloy is shown by composite due to 5 wt. % graphite present in it. Wu et.al **[12]** examined the effect of the parameters of Plasma activated sintering (PAS) process on the mechanical properties and microstructure of aluminium metal matrix composites (AMMCs). The holding time as well as temperature have an influence on the densifying performance of B_4C reinforced Al 7075 composite. To analyse the effect of residual porosity on the composite, bending strength, compressive strength and Vicker's hardness are measured. High mechanical properties with the value of Vickers hardness to be 181.6 HV,1100.3 MPa is bending strength, compression yield strength is high at 878 MPa and fracture strength obtained is 469.3 MPa for the reinforced Al 7075/B_4C matrix composite and governed by a thick microstructure. These values are obtained because matrix and reinforced material have strong interface between them. Barati et.al **[13]** used Plasma Electrolytic Oxidation (PEO) to form Alumina- Zirconia nanostructure coatings on 7075 Al alloy. The machine was operated in a Direct Current potential static mode. On analysing the tribological behaviour of the dry sliding wear behaviour it was revealed that the coated samples have shown significant improvement in the tribological properties. 15.2 – 24.2 µm is the range of coating thickness whereas 0.68 – 2.35 µm is the range of roughness. There was uniform arrangement of aluminium, zirconium and oxide in the coatings. The level of porosity gets increased as there is rise in the PEO voltage and the high temperature tetragonal zirconium phase (t-ZrO_2) is formed. Substantial rise in the wear characteristics of coated samples was attained as the composite was subjected to PEO treatment at 500 V for a time span of 200 s. Wear rate for the coating is 2.62 ×10-6 mm^3 N^{-1} m^{-1} and 0.22 is the value of friction coefficient. These values are around 120 and three times lesser than the values obtained for substrate.

Gopalakannan and Sentthivelan **[14]** synthesized the 7075 aluminium nanocomposite consisting of 1.5 wt. % SiC nano-sized reinforcements, by a new technique of ultra cavitation. The scanning electron microscopy (SEM) and field emission scanning electron microscopy (FESEM) revealed that there is a homogenous arrangement and good dispersion of the silicon carbide nano sized particles within the aluminium metal matrix. During the Electric Discharge Machining of the new nanocomposite it was revealed with the help of response surface methodology that the pulse current is the most significant factor. It has influenced material removal rate (MRR), electrode wear rate (EWR) as well as surface roughness (SR). The optimum set of values identified for MMNC were voltage 50 V, 8 A of pulse current, 8 µs Pulse on time and 9 µs of Pulse off time. Finally the optimization of parameters was done for minimizing EWR, SR and maximizing MRR using desirability function approach. Basavarajappa et.al **[15]** used the liquid metallurgy route to manufacture aluminium matrix composites using particulate SiC and graphite (Gr) as reinforcements. The testing of dry sliding wear behaviour of the composite was done and compared with Al/SiCp composite. There is an increase in the wear resistance of the composite due to the addition of graphite particles in it. There is a reduction in the volume of wear loss owing to the creation of a defensive layer between pin and counter face as well as due to the smearing of the graphite. The wear factor having the maximum on the wear behaviour of both the composites is sliding distance. In SiCp-Gr reinforced composite the most influential factor is the sliding distance then applied load and at last is the speed. Sharma et.al **[16]** used pin on disc apparatus to study the wear behaviour of aluminium and mild steel discs. The results reveal that there is a variation in depth of penetration of each metal (aluminium and mild steel) with respect to varied applied load. Dry testing and wet testing conducted on the metal disc help to find the effect of lubricant (HP racer 2 stroke engine oil) on the wear pattern. Lubricant forms a thin layer of film between two metals and reduces the rate of wear between the two metals. Metal can be prevented from damage using thick layer of lubrication on it and depth of penetration can be reduced. Kapsiz et.al **[17]** conducted the experimentation to understand the of wear pattern of cylinder liner / piston ring pair. It was revealed using ANOVA that the input variable exerting the highest influence is the sliding velocity. The weight loss of piston ring is considerably affected by the interaction between sliding velocity and the type of oil.

Sahin **[18]** used molten metal mixing method to synthesize the SiCp-reinforced aluminium composite and investigated the wear behaviour with the help of pin-on-disc type wear testing machine. Observations show that the wear rate shows an increasing trend as there is increase in the values of applied load, abrasive size and sliding distance. When the Al_2O_3 emery paper is used, the wear rate shows a decreasing trend as the sliding distance is increased. The rate of wear increases with increasing the abrasive size and applied load. Abrasive size found to be more effective for both matrix alloy and its composite followed by applied load due to higher probability of fracturing and fragmenting of hard dispersed particles in the composite. Sundarrajan et.al **[19]** investigated the mechanical and wear properties of Al alloy-cotton shell ash composite and compared those with properties of other Al alloy composites. For that purpose al alloy-cotton shell ash composites of three different volume fractions (2%, 4% and 6% cotton shell ash) have been fabricated by stir casting route. On the addition of the particular ash in the Al alloy, hardness and impact strength were improved. From the result the impact strength and the hardness values of the composite material having 6% ash are very high when comparing the remaining two types of composite materials. The friction coefficients and wear rates showed significant decrease with the increase of cotton shell ash in aluminium alloy. The mass fraction of the ash particles up to 4 to 5 % in the Al alloy cotton shell ash composite materials is having the good wear properties. Mindivan et.al **[20]** used the squeeze casting technique to manufacture different

aluminium composite reinforced with 50 wt. % SiC particles using different aluminium alloys (2618, 6082, 7012 and 7075) . Then the wear testing was done using reciprocating wear tester. Two mediums of air and water were taken and the alumina ball of 10 mm diameter was rubbed on the surface of composite. The tests carried out in air discovered that at high loads, 7012 along with 7075 aluminium matrix composites exhibit increased wear behaviour in comparion with 2618 and 6082 aluminium matrix composites. In water, the rate of wear and the friction coefficient have significantly lesser values. The wear rate and coefficient of friction showed decreasing trend at more hardness of the matrix. For the newly synthesized composites, progression of wear mechanism was in two diverse manner which are mild wear and then the severe wear varying according to testing conditions. Deaquino-Lara et.al **[21]** used mechanical alloying (MA) along with hot extrusion for manufacturing the Al 7075-graphite composite. The pin-on-disc tester was used to test the wear performance of composite. 20 N and 40 N are the loads applied along with sliding velocity kept at 0.367 m/s. The effects of graphite concentration (0–1.5wt. %) and that of time for milling (0–10 hr) on wear resistance and hardness of the AMC were examined. The results showed substantial enhancement in wear resistance as well as hardness of aluminium matrix composite by adding Graphite with 1.5 wt. % and milling time of 10 hr. The composite also exhibited uniform distribution of the reinforcement particles in the aluminium matrix composite. The utilization of scanning electron microscopy was done to understand the wear behavior. It was also revealed that abrasive wear is more dominant in all extruded composites, whereas for Al 7075 composites, combination of adhesive and delaminating wear is the dominating mechanism.

Meydanoglu et.al **[22]** utilized the dynamic spraying process using cold gas to put coatings of 7075 Al with B_4C or SiC particulate reinforcements over T6 Al 6061 alloy. It was observed that the fine grained coatings without any discontinuity at interface were deposited on composite. It was also seen that the ceramic particles in the matrix composite have a significant role in enhancing wear resistance and hardness of the coatings as compared to original aluminium 7075 coatings. Better wear performance is presented by composites with B_4C coatings in relation to composites with SiC reinforcement coatings. Campos et.al **[23]** used the mechanical milling process to manufacture AA 7075 composites consisting of carbon-coated silver nanoparticles(Ag-CNP). It had been found that Ag-CNP influence in powder refining and crystal size. Increased values of Vickers microhardness (HVN) are obtained as the content of Ag-CNP is increased. Al based nano-composite are manufactured by dispersing Ag-C nanoparticles by mechanical milling. Ag-C nanoparticles have an important effect on particle and crystal size refinement. An increase in microhardness is observed with rise in Ag-CNP content and also with increase in milling time. Higher properties can be obtained by merging the process of mechanical milling with nanoparticles dispersions as compared to properties attained by T6 and T73 treated AA 7075 alloy. Microhardness is affected by concentrations only upto 2 wt. % concentration of reinforcements. Ezatpour et.al **[24]** prepared a nanocomposite when pure argon gas was used to insert the mixture of Al/nano-Al_2O_3 into the molten Al 7075 alloy and then further subjected to high temperature extrusion. Mechanical properties of the aluminium metal matrix nanocomposite (AMMNC) were examined by performing tensile tests, compression tests and measuring their hardness. The nanocomposite prepared shows uniform distribution of nanoparticles inside the matrix as well as fine grain microstructure. The nanocomposites prepared by stir casting exhibit elevated porosity. The nanoparticles distribution in the matrix is poor if manufactured by stir casting. The experimental results confirmed that there is a upgradation of ultimate tensile strength, compression strength and also in hardness due to addition of nano sized alumina particles and extrusion. The help of Preference Selection Index (PSI) materials selection method was taken in order to choose the bet interaction of workability and strength of Al 7075/ Al_2O_3 nano-composites.

Panwar and Chauhan **[25]** fabricated the Al 6061 composite using red mud as the reinforcement as it will reduce the cost. The composite is fabricated by stir casting method using a stirrer to ensure regular distribution of reinforced particulate within matrix. It is revealed that as the value of reinforcement percentage and that of ageing time increases, an increasing trend is presented by micro and macro hardness of composite. It was also found that vice versa happens when particulate reinforcement size is kept high. Wu et.al **[26]** studied the effect of reinforcement particle size on the microstructure and mechanical behaviour of Al metal matrix composites. Al 7075 was reinforced with three different types of particles sizes of B_4C (56.9 mm, 4.2 mm and 2.0 mm) to form the composite. When the value for volume fraction of B_4C is invariant, the composite with coarse reinforcement particles exhibited a relatively there is uniform and distinct arrangement of particulate boron carbide. Panwar et.al **[27]** studied the influence of lubrication on sliding wear of aluminium hybrid composite incorporated with red mud as reinforcement. It was observed that impact energy and tensile strength show an increasing trend whereas elongation exhibits reduction, as the weight fraction is increased and along with it there is reduction in the size of the reinforced particles. It is also noticeable that in wet condition the specific wear rate is less. But it shows a decreasing trend load and sliding speed are reduced and the reinforced particles weight fraction is increased.

III. CONCLUSIONS

- The best suited method for synthesis of aluminium matrix composites is the stir casting as it is simple and cost effective.
- The mostly used apparatus for wear testing is the Pin-on-disc wear testing machine.
- The input parameters for wear testing are applied load, sliding distance and sliding speed.

- The composites show an increase in wear resistance and hardness of composites by the integration of ceramics in the composite.
- The techniques like Taguchi's method, Response Surface Methodology (RSM) can be used to find the impact of different process parameters on the wear behaviour of different aluminium metal matrix composites

IV. FUTURE PROSPECTS OF STUDY

- The new metal matrix composites can be formed by the use of various reinforcements.
- The newly formed MMCs can be tested on various parameters such as hardness, roughness and their non conventional machining such as Electric Discharge Machining.
- The comparison of the properties of various newly formed composites can be carried out in order to find out as to which most suitable composite is.
- The optimization of various process parameters can be done using various analysis techniques like Finite Element Analysis, Artificial Neural Network and Genetic Algorithm etc.

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