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STUDIES ON MECHANICAL AND TRIBOLOGICAL PROPERTIES OF ALUMINUM BASED METAL MATRIX COMPOSITES – A REVIEW

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Abstract —*Two phases namely a matrix and a reinforcement phase constitute composite materials. Most of studies shows that the material used for components should posses better mechanical and tribological properties. Aluminium alloys are used in many engineering applications due to their light weight and high strength characteristics. However, low hardness and consequently low wear resistance limit their use in some applications. Aluminium based metal matrix composites (Al-MMCs) with reinforcements are considered as the promising solution for imparting better wear resistance to aluminium alloys. Aluminium matrix is getting strengthened when it is reinforced with the hard ceramic particles like Silicon carbide, Aluminium oxide and Boron carbide etc. Hence, in this work, it is planned to study the mechanical and tribological properties of aluminium based hybrid metal matrix composites.*

Keywords- *Metal matrix composite, Reinforcement, Mechanical properties, Tribological properties*

I. INTRODUCTION

MMCs are advanced materials formed by combining a ductile metal/metallic alloy with one or two hard phases, called reinforcements, to exploit the advantages of both. Alumina, boron, Silicon Carbide, etc are the most commonly used non-metallic reinforcements, combined with Al alloys to obtain Al matrix composites. It provide unique combination of properties such as high strength-to-weight ratio, stiffness, hardness, wear resistance, thermal /electrical conductivity, fatigue resistance etc. Aluminium is a silvery white metal and it is a light metal, with a density about a third that of steel or brass.Aluminium is a very good conductor of electricity. On a weight-for-weight basis aluminium is a better conductor than copper. Aluminium has a higher resistance to corrosion than many other metals, owing to the protection conferred by the thin but tenacious film of oxide which forms on its surface. Aluminium is a good conductor of heat. Aluminium is very ductile. Aluminium is non-magnetic. Melting point of pure aluminium is about 650°C and the fusion range of most of the aluminium alloys varies between 520 and 650°C. Although pure aluminium is not particularly strong, it forms high strength alloys in conjunction with other metals such as Cu, Cr, Ni, Fe, Zn, Mn, Si and Mg.Some of these aluminium alloys are more than 4 times as strong as the same weight of mild steel. They are malleable and ductile. They exhibit toughness and become stronger at temperatures below the ordinary atmospheric range. They do not work well at temperatures of the order of 300 to 400°C. Aluminium and its alloys can be cast, forged, welded, extruded, rolled, etc.

Ceramics are compounds of metallic and non metallic elements. The name ceramics was derived from the Greek words keramos meaning potter's clay and keramikos meaning clay products. Thus the term ceramics refers both to the material and to the ceramic product itself. Because of the large number of possible combination of elements, a great variety of ceramics is now available for a wide range of consumer and industrial applications. The desirable properties of ceramic materials include high temperature Strength; hardness; inertness to chemicals, food and environment; resistance to wear and corrosion; and low electrical and thermal conductivity. They are generally hard brittle materials that withstand compression very well but do not hold up well under tension compared to the metals. They are abrasive resistant, heat resistant and can sustain large compressive loads even at high temperatures. Many ceramics are chemically inert even at high temperatures, as is shown by their good oxidation and reduction resistance at these temperatures. The nature of the chemical bond in ceramics is generally ionic in character, and the anions play an important role in the determination of the properties of the material. Typical anions that are important constituents of ceramics are carbides, borides, nitrides and oxides. The earliest use of ceramics was in pottery and bricks. Ceramics have been used for many years in automotive spark plugs, as an electrical insulator and for high temperature strength. They have become increasingly important in tool and die materials, in heat engines and in automotive components such as exhaust port liners, coated pistons and cylinder liners. Ceramics can be divided in to two general categories they are traditional and industrial ceramics. Traditional ceramics are white ware, tiles, brick, pottery and abrasive wheels. Industrial ceramics are also called engineering, high technological or fine ceramics used for turbine, automotive, aerospace components, heat exchangers, semiconductors and cutting tools. Based on the potential benefits of MMC, in this work an attempt has been made to examine the various factors like effect of various reinforcement, mechanical behaviour and tribological behaviour were discussed.

II. LITERATURE REVIEW

2.1 Mechanical properties

Muruganandan et al. (2015) used Aluminium 7075 as a matrix material with fly ash and titanium carbide as reinforcement materials. A comparison has been made between the reinforced and unreinforced alloys such as Al6061, Al7075 and concluded that the tensile strength and hardness of the proposed composite is increased by increasing the weight percentage of fly ash and titanium carbide. Chennakesava (2010) studied mechanical properties for different metal matrix composites produced from Al6061, Al6063 and Al7072 matrix alloys reinforced with silicon carbide particulates. Their investigation shoed that the yield strength, ultimate strength and ductility of Al/SiC metal matrix composites are in the descending order of Al 6061, Al6063 and Al 7072 matrix alloys. Sachin Malhotra et al.(2013) investigated the effect of reinforcement of Zirconia and Fly Ash on mechanical properties of Al 6061 aluminium alloy composites samples, processed by stir casting method. Two sets of composites were prepared with fixed percentage of fly ash (10%) and varying percentage of Zirconia (5% and 10%) by weight fraction. The author has revealed that increase in percentage increases the properties such as tensile strength and hardness. Sreenivasa Reddy et al.(2012) investigated on formation of a hybrid composite by using industrial waste fly ash and E glass short fibers by dispersing them into Al7075 alloy by Stir casting method. The MMC was obtained for the different compositions of E-glass and Fly ash particulates. The specimens were tested for tensile test at different loads by using Universal Test Machine. The results are plotted and it is concluded that the MMC obtained has got better tensile strength compared to Al7075 alloy alone. Further, tensile strength slightly increased with 1 hour aging heat treatment. For 3 hour and 5 hour aging tensile strength decreases.

Jebeen Moses et al.(2014) investigated the effect of Al6061 reinforced with various amounts (0, 5, 10 and 15 wt. %) of SiC. The microstructures of the AMCs were studied using optical and scanning electron microscopy. It was observed that the distribution of SiC particles in the matrix was uniform and SiC particle clusters were also seen in a few places. SiC particles were properly bonded to the aluminum matrix. Microhardness and ultimate tensile strength was tested and it was found that reinforcement of SiC particles improved the microhardness and ultimate tensile strength (UTS) of the AMCs. Pradeep et al. (2014) studied the effect of reinforcement of red mud and silicon carbide with Al7075 aluminium metal matrix composite under different working conditions. The samples are fabricated using stir casting technique. The samples are heat treated to enhance the mechanical properties. They found that the combination of a matrix material with SiC and red mud particles improves mechanical properties like tensile strength, compressive strength, hardness and yield strength. Also microstructure studies indicated the presence of fine inter metallic particles SiC and Red mud reinforced in between Aluminium dendrite structure. Jenix Rino et al. (2013) compared the properties of Al6063 MMC reinforced with Zircon Sand and Alumina with four different volume fractions of Zircon sand andAlumina with varying volume fractions of (0+8)%, (2+6)%, (4+4)%, (6+2)%and (8+0)%. The hardness and the tensile strength of the composites are higher for (4+4) %. In this combination, the particle dispersion is uniform and the pores are less where inter-metallic particles are formed. Dora siva Prasad et al. (2014) investigated the effect of Al356.2 with up to 8% rice husk ash and sic particles. The uniform distribution of rice husk ash and sic was observed in the matrix. The porosity and hardness increases with the increase in percentage of the reinforcement whereas the density of hybrid composites decreases, The yield strength and ultimate tensile strength increase with the increase in RHA and sic content. Suresha and Sridhara (2012) observed that the Brinell hardness of LM 25-SiC-Gr hybrid composites increased up to 2.5% of combined equal percentage of reinforcement and then decreased. The increase was due to the addition of SiC particulates, overriding the effect of Gr particulates, and the decrease was due to the overriding effect of Gr particulates, the addition of which reduced hardness as a consequence of the increase of porosity.

Ravesh and Garg (2012) reported that the hardness of fly ash-SiC-reinforced hybrid aluminium composites increased with increasing volume fraction reinforcements. The Rockwell hardness on the C scale was observed to be 61, 70, 81 and 93 for 2.5%, 5%, 7.5% and 10% of SiC, respectively, with a constant 5% fly ash-reinforced hybrid Al 6061-T6-treated hybrid matrix composites. Mahagundappa et al. (2006) have studied the influence of reinforcement and thermal aging on the mechanical properties of Al 6061 based hybrid composites, and concluded that the ultimate tensile strength, compression strength, young's modulus and hardness increases with increasing the reinforcement content but the ductility decreases substantially. And all these things also increase with increase in the aging duration with the marginal improvement in the ductility which may be due to the formation of precipitate in matrix alloy. Ghanashyam Shenoy et al. (2012) evaluated the effect of Al-Si-Mg Based Hybrid Composite at different aging conditions. They concluded that hardness of the hybrid composite material increases with wt% of Mica and E-glass content as compared to parent metal. This is because of addition of reinforcement makes the ductile Al6061 alloy into more brittle and hard as silica content increases. Zhu and Iizuka (2003) fabricated porous ceramics with a framework of aluminium borate whiskers by in situ firing ceramic powder compacts, and incorporated within an Al alloy matrix by squeeze casting. They found that the microstructures of the porous aluminium borate and the composites were isotropic and independent of the compaction and the casting direction. The hardness and the tensile strength of the Al alloy matrix composite increased with increasing volume fraction of porous aluminium borate with decreasing diameter of aluminium borate whiskers. The tensile strengths of the composite were higher than those of un-reinforced Al alloy.

2.2 Tribological Properties

Deepak Singla et al. (2013) analyzed that sliding speed and effect of load on the friction coefficient and wear properties of Al 7075-Fly Ash composite material on pin on disc apparatus. Result shows that the coefficient of friction increases as the fly ash content increases and improves the ability to resist the wear. This is due to the favorable effect of fly ash particles which increases the hardness of composite material up to some range. However the addition of 30gm fly ash particles in the Al 7075 was very effective to improve its ability to resist the material loss. Vinitha et al. (2014) investigated the tensile strength, impact strength and wear resistance of Al 7075 Alloy reinforced with Fly ash, SiC and Redmud. They observed that the tensile and impact strength was higher in Al7075-SiC-Redmud composite than Al7075-SiC-Flyash. The wear resistance of the composite Al7075-SiC-Flyash, was higher by maintaining the constant weight percentages of SiC and Fly ash while it decreases by increasing the weight percentage of Fly ash. In Al7075-SiC-Redmud, wear resistance increases with increase in Red mud content. Sucitharan et al. (2013) studied the wear behaviour of Al6063 Aluminium alloy with Zircon sand composite produced by the stir casting technique by controlling various casting parameters. The combination for studying wear behavior of composites investigated is 0, 2, 4, 6, 8 wt% of $ZrSiO_4$ with the matrix and it was found that the increase in reinforcement increase the wear resistant property. Leng Jinfeng et al. (2009), studied that with the addition of graphite, the friction coefficient of SiC/Al composites decreases and the wear resistance is significantly increased by 170 to 340 times. Moreover, the wear loss of counter face steel is decreased by a factor of about 2/3. The wear resistance of SiC/Grp/Al composites increases with the increase of the graphite particle size.

Veeresh kumar et al.(2010) studied the hardness, tensile strength and wear resistance properties of Al6061-SiC and Al7075-Al_2O_3 composites. The composites are prepared using the liquid metallurgy technique, in which 2-6 wt. % of reinforcement were added in the base matrix. The SiC and Al_2O_3 improved the hardness and density of their respective composites. Further, the increased percentage of these reinforcements contributed in increased hardness and density of the composites. The microphotographs showed the uniform distribution of the particles in the matrix system. The dispersed SiC in Al6061 alloy and Al_2O_3 in Al7075 alloy contributed in enhancing the tensile strength of the composites. Dhanasekaran et al. (2015) investigated the tensile and wear behavior of Titanium Carbide reinforced with Aluminium Alloy 6063 Metal Matrix Composite fabricated by stir casting technique. Titanium carbide particulates were added in varying proportions of 2wt% 4wt% and 6wt%. The addition of TiC refines the grain structure which increase of the strength of the composite. But at higher percentage of TiC, there is a decrease in the mechanical properties. The ductility of the composite was decreased with increasing particle reinforcement. The hardness increases up to 4wt% TiC addition but it decreases when reinforcement composition is increased to 6wt%. Rajesh et al.(2014) studied the wear properties of Al6061 aluminium metal matrix composite reinforced with boron carbide processed using stir casting at lower temperature of 775 ^oC using halide salt K_2TiF_6 with ratio $0.05Ti/B_4C_p$. They observed improved wettability of B_4C due to the addition of Ti compound in the form of K_2TiF_6 halide salt and uniform distribution of reinforcement from SEM micrographs. They also found that the porosity of the increased with increased volume fraction of B_4C and the wear rate was minimum for Al6061+6%B_4C compared to Al6061+4%B_4C at a sliding velocity of 6.67m/s, load of 49.05N with a sliding distance of 565.4m.

Ravindra Singh Rana et al.(2014) studied the dry sliding wear performance of Al5083 with 10 weight percentage of SiC composites fabricated by Ultrasonic assisted stir casting process. They found that applied load has the highest influence on wear rate followed by sliding distance and sliding speed for Al-5083/10% SiC composites. Anasyida et al. (2010) studied the dry sliding wear behaviour of Al–12Si4Mg alloy with cerium addition and reported that increasing cerium content up to 2 wt% improved both wear resistance and micro hardness. Addition of more than 2 wt% cerium, however, led to a decrease in micro hardness, resulting in lower wear resistance of the alloys. Mazahery et al. (2009) produced stir cast A356 alloy matrix composite reinforced with nano-Al_2O_3 particles. The author has revealed that the values of the yield strength, ultimate tensile strength and ductility of the composite increased with the increase in volume percentage of the nano particles. Also the hardness of the composite improved compared to pure alloy. Lakshmipathy et al. (2014) studied the wear behaviour comparison of Al7075 with SiC and Al6061 with Al_2O_3 composites. Results showed that wear rate decreases with increase in reinforcement percentage. The experimental results showed that hardness of composites increases with increase in SiC and Al_2O_3 particle and the impact strength decreases with increase in SiC and Al_2O_3 content. Veeresh kumar et al. (2014) investigated the wear behavior of Al7075 aluminium matrix composites reinforced with SiC particulates. The wear properties of the composites containing SiC were better than that of the matrix material and further, the composite containing 6 wt% SiC content exhibited superior wear resistance. An Artificial neural network model was developed to predict the tribological properties of the Al7075-SiC composites. The predicted values of tribological properties using a well trained ANN were found in good agreement with measured values.

Pei-peng Jin et al. (Ref 18) investigated that friction and wear properties of $Mg_2B_2O_5$ whisker reinforced 6061Al matrix composite fabricated via power ultrasonic-stir casting process were investigated using a ball-on-disk wear-testing machine against a GCr45 steel counter face under dry sliding conditions. From the investigation, it was found that the applied load and sliding speed steadily increase the coefficients of friction and wear rates of the as-received matrix alloy and the fabricated composites decrease. As the applied load and sliding speed increase, the wear mechanisms of the composites shift from a mild to a severe regime. Ted Guo et al. (2000) investigated the tribological behavior of self-lubricating aluminium/SiC/graphite hybrid composites. They found that hardness decreases with the amount of the graphite addition fracture energy decreases monotonously with the addition of graphite. Also, the co-efficient of friction decreases with the addition of graphite. Amount of graphite released on the wear surface increases as the percentage of graphite addition increases. Graphite released from the composites did bond on the wear surfaces on the counter parts however the amount bonded is small, and there is no significant difference in the amount bonded for different Graphite additions. Shanmughasundaram et al. (2013) investigated the dry sliding wear behavior of eutectic Al-Si alloy-graphite composites. They found that the wear and friction coefficients decreased linearly with increasing weight percentage of graphite particles. Wear resistance of the composite increased considerably with increasing sliding velocity at constant load

III. CONCLUSION

The above review for the aluminium based metal matrix composite leads to the following conclusions:

- Among the different fabrication procedure, Stir casting method is an effective casting method to develop the metal matrix composites, to obtain uniform distribution of the reinforcement and homogeneous properties of the casting. It is also widely acceptable method due to its low cost and easy portability.
- The addition of alumina, SiC, B_4C, fly ash, TiC etc. particles in aluminium improves the hardness, yield strength, tensile strength and ductility.
- Aluminium and its alloys reinforced with ceramics particles have shown an improvement in mechanical properties and tribological properties.
- The addition of graphite increases the wear resistance and decreases the hardness and coefficient of friction.

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