International Journal of Engineering Science Invention (IJESI)
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org ||Volume 7 Issue 7 Ver II || July 2018 || PP 48-56

Review of aluminium composites and their tribological and mechanical properties

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Abstract:*Aluminium metal matrix composites (MMC's) play a crucial role in various fields like automobile, aerospace, military, aircrafts, sheet metal, construction etc. due to unique combination of their properties. The properties such as high strength to weight ratio, high wear resistance and low cost lead to increase in the demand of aluminium composites. Various fabrication techniques are available to produce such composites. In liquid phase processes, Stir casting is a widely used process to fabricate aluminium composites. This paper reviews the effects of various reinforcements on tribological and mechanical properties of aluminium alloy. Various reinforcements like SiC, Al_2O_3, TiC, MoS_2 etc. are used to produce composites. We can fabricate a composite material with the single reinforcement or the combination of two or more reinforcements depending upon the application. Other than that we can also use coatings of alumina, calcia-stabilized zirconia coatings, plasma electrolyte oxidation layers etc. to get better surface properties of aluminum alloy. These coatings are widely used where continuous rubbing motion is desired between two surfaces.*

Keywords –*AMMC, MMC's, SiC, TiC, Al_2O_3*

Date of Submission: 20-06-2018 Date of acceptance: 06-07-2018

I. INTRODUCTION

Composite materials or metal matrix composites (MMC's) are fabricated from two or more different materials to get desirable characteristics. Composite materials are widely used due to their superior properties such as increased stiffness and strength, improved dimensional stability, toughness, impact strength, reduce cost, less thermal expansion, reduced weight, increased chemical wear and corrosion resistance. Recently Aluminium based composite materials are widely used for internal and external applications. These find their application in automobiles, sheet metal, aircrafts, military, aerospace etc. Aluminium is classified into various grades depending upon the major alloying element. Various grades of aluminium are 1xxx (pure aluminium alloys), 2xxx (aluminum-copper alloys), 3xxx (aluminium-manganese alloys), 4xxx (aluminium-silicon alloys), 5xxx (aluminium-magnesium alloys), 6xxx (aluminium- magnesium-silicon alloys), 7xxx (aluminium-zinc alloys), 8xxx (aluminium-lithium alloys) [1]. Composites materials have two phases, one is continuous phase and other is non- continuous phase. Continuous phase is called as matrix (base material) and non-continuous phase is called as reinforcement (reinforced material). Depending upon the properties of material, the reinforcement composites are classify into three categories: a) dispersion strengthened, in which we have uniform distribution of particles in composite, b) fiber reinforced, in which we have continuous fibres throughout the composite, c) Particle reinforced, in which we have particles having size greater than 1µm present in composite material. We can use various processes like casting, extrusion, spraying, forging etc. to produce aluminium composites. We can also produce aluminium composites with the help of powder metallurgy (PM) [3,5] technique. Stir casting [4,8] is proved to be one of the widely used liquid phase processes to produce aluminium MMC's (metal matrix composites). In aluminium composites we generally use MoS_2, SiC, SiO_2, Al_2O_3, TiC, B_4C etc. as a reinforcement material to improve wear resistance, corrosion resistance and other mechanical properties of composites. We can also do heat treatment processes after fabrication of composite material to improve their properties. Before heat treatment composites have good formability and can be easily shaped into various shapes. After fabrication, we provide heat treatment to improve the tribological and mechanical properties of material. Many researchers have also examined the effects of thermal ageing on the mechanical and tribological properties of material [2-4].

II. FABRICATION PROCESSES

We use various fabrication processes to produce a composite material from two or more materials. Process selection is done on the basis of uniform distribution of reinforced material in base material. We classify fabrication process into three types: solid phase fabrication processes, liquid phase fabrication processes and semi-solid method. In solid phase process, we can use powder metallurgy or diffusion bonding process to fabricate a composite material. In liquid phase processes, Stir casting process is widely used for fabrication. In semi solid or two-phase processes, spray [6,9,10], compo casting and rheo casting [11] are used for composite material.

II.1 SOLID PHASE PROCESSES

In solid phase processes composites are fabricated by mutual diffusion bonding of the metal matrix and reinforced material at high temperature and pressure in solid state. Powder metallurgy is proved to be one of the widely used processes for the fabrication of various composites. In this process, we mix the materials in powder form to get a homogeneous mixture of base material and reinforcement. After that we compress the mixture with high pressure and sintering is done on the samples for 3-4 hours at defined temperature. In 2011, J.Corrochano fabricated Al-Mg-Si-alloy-$MoSi_2$ composite by using powder metallurgy process. C.S. Shin investigated effects of specimen orientation, tempering and temperature on the mechanical behaviour of aluminium composites fabricated by powder metallurgy (2010). Air atomized aluminium and silicon carbide particles were used to fabricate AMMC (Aluminium metal matrix composite).

II.2 LIQUID PHASE PROCESSES

In liquid phase processes, the reinforcing phase are introduced into liquid metal, followed by its solidification. For example, stir casting, infiltration, gas pressure infiltration etc. Stir casting route process is one of the simple and economical liquid phase processes for producing metal matrix composites (MMC's). In this process reinforced material is mixed with liquid base metal with the help of stirrer. Due to molten state of base material, it also traps impurities like slag, oxides formed on the surface of melt. A. El-Sabbagh introduce SiC fine particles in Al 6061 and Al 6082 alloys with the help of stir casting (2012). In similar way DevarajuAruri also use stir-casting technique to produce aluminium composites with the reinforcement of SiC, Gr, and Al_2O_3 (2013).

II.2 SEMI SOLID OR TWO PHASE PROCESSES

Semi solid casting was proposed by De Ciccoet. al. In semi solid processes like rheo casting, we have less thermochemical degradation due to low temperature practice. During this process preheated particles are added in semi solid slurry to get uniform distribution of the particles. S. Ji. et.al. also used twin-screw rheomoulding process for the processing of engineering alloys (2001).

III. MECHANICAL CHARACTERIZATION

Mechanical characterization term refers to the identification of mechanical behaviour of composite materials, which are considered as a base for the prevention of material failure during service. Mechanical properties of composite materials largely depend upon the type of reinforcement, shape and size of particles, quantity (weight %) of reinforced material etc. From past few years, number of investigations have been done for the improvement of the mechanical properties of aluminium composites by incorporating various reinforcement like SiC, TiC, Al_2O_3, MoS_2 etc. N. Krishnamurthy et.al.[6] (2012) developed Al_2O_3 and calcia-stabilized zirconia coating on Aluminium 6061 with the help of spraying method. By comparing the properties of both coatings, density of calcia-stabilized zirconia coatings was found to be denser than alumina coatings, which lead to less erosion of calcia-stabilized zirconia coating under erosion test. By comparing hardness, alumina coating is harder than calcia-stabilized zirconia coating. Strength, young modulus and strain hardening rate shows increment with the increase in reinforcement. They also observed decrease in percentage elongation with reinforcement. C.S. Shin et. al.[3] (2014) evaluated the effects of temper, specimen orientation and temperature on mechanical properties of Al 6061/SiC composites. The author observed that strength and stiffness was improved with the reinforcement but cannot be proved beneficial at 300^0C. Fracture toughness decreases with SiC reinforcement. Figure 1. shows stress strain response of aluminium/SiC composites at various temperatures.

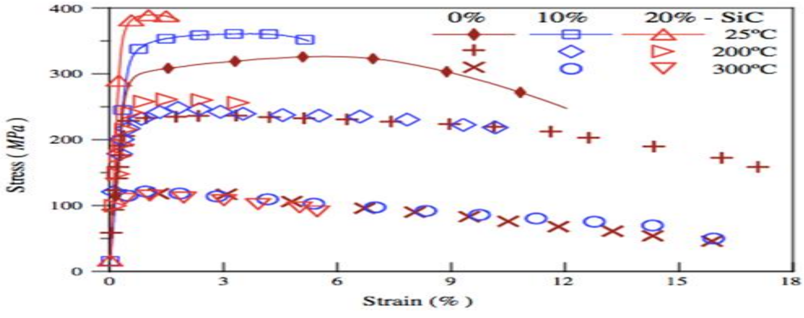


Fig.1. Stress-strain behaviour of Al/SiC Composites at various temperatures (C.S. Shin et. al.[3] (2014))

DevrajuAruri et.al. [8] (2013) fabricated surface hybrid composites of aluminium alloy with reinforcement of SiC, Gr, Al_2O_3. They observed increase in micro hardness with the reinforcement of SiC and Al_2O_3 particles due to their pining effect. Tensile strength decreases with the reinforcement of Al_2O_3 and SiC particles. S. Gopalakrishnan et.al.[14](2012) investigated effects of reinforcement of Titanium carbide (TiC) particles in aluminium alloy 6061. The author found that specific strength of composites increases with the increasing percentage of TiC particles. Fig. 2 (a) & 2 (b). Shows the deviation in tensile strength and elongation of Al 6061/TiC composites with the TiC reinforcement.

Fig. 2(a) UTS with varying % of TiC (S. Gopalakrishnan et.al.[14](2012))

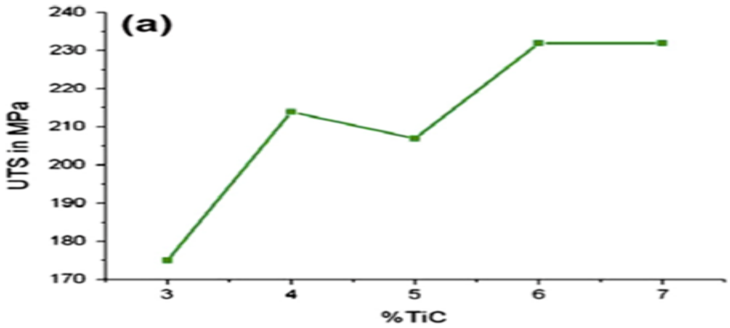
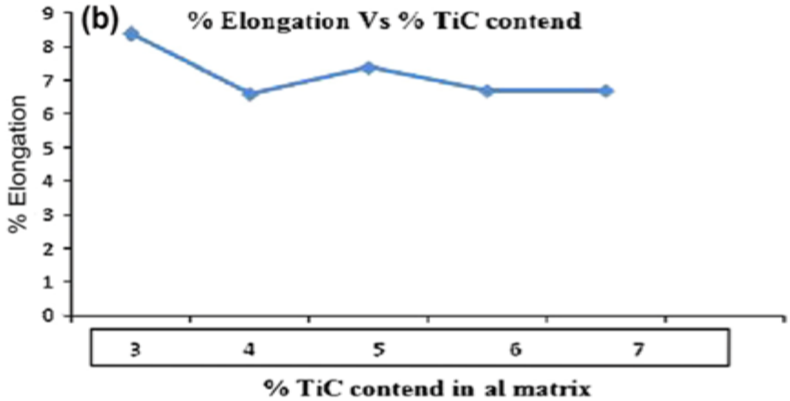


Fig. 2(b) % Elongation with the varying % of TiC (S. Gopalakrishnan et.al.[14](2012))



Paras Mittal et.al.[15] (2018) Investigated the mechanical properties of aluminium 7075 with reinforcement of SiC, Red mud and Al_2O_3. The author revealed that hardness of composites having reinforcement of Al_2O_3 and red mud is more than the SiC reinforced composites and also increases with the percentage of reinforcement. Ismail Ozdemiret. al.[16] (2000) evaluated the properties of Al/SiC metal matrix composites and revealed that tensile and yield strength increases with the % of SiC upto 17% and decline with further increment in percentage. The elastic modulus increases with % of SiC while ductility of composite decreases. B.Bhav Singh et.al. [17](2009) fabricated composite material of aluminium alloy as base matrix and carbon fibre as reinforcement. They found that UTS (Ultimate tensile strength) and yield strength increases up to 4wt% of carbon fibre. Hardness of composites initially shows an increment with carbon fibre and then decreases with further addition of carbon fibre. M.karbalaeiAkbari et.al.[18](2013) investigated the effects of reinforcement of Nano-sized aluminium oxide and copper in A356 alloy. They observed superior compressive strength and hardness of composites than base metal alloy. It increases with the addition of Al_2O_3 and have maximum hardness and compressive strength with the reinforcement of Al_2O_3-Cu. Hardness changes over the length of components (cylinder) due to difference in Nano particles and porosity contents, however compressive strength remain constant. Qiang Zhang et.al.[19] (2003) evaluated the mechanical properties of SiCp/Al composites and revealed that the brinell hardness and modulus of composite increases with the volume fraction of SiC but no trend was observed for bending strength. A. Baradeswaranet.al[20].(2013) investigated the behaviour of Al 7075-B_4C composites with 5, 10, 15, 20 vol% of B_4C. They observed that strength and hardness of composites shows an increment with the vol% of B_4C due to increase in the ceramic phase of matrix. Hardness and tensile strength are shown in figure. 3 (a) and 3 (b).

Fig. 3.(a) Hardness with vol% B_4C (A. Baradeswaran et.al.[20] (2013))

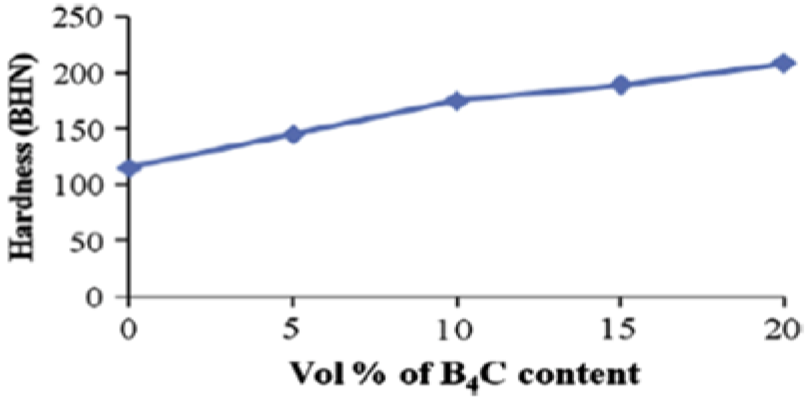
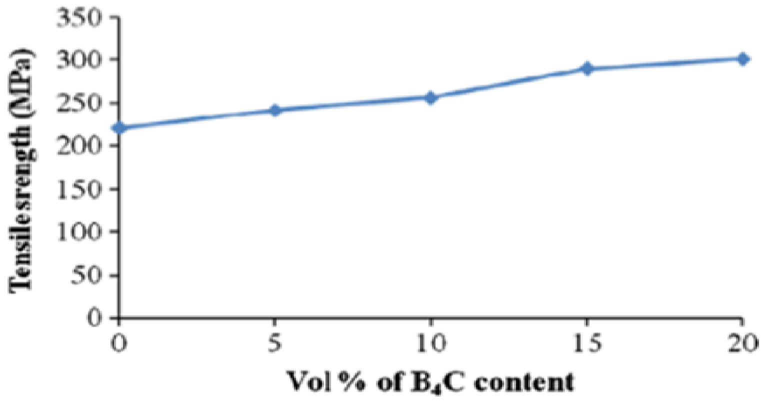


Fig. 3(b) Tensile strength with vol%B_4C (A. Baradeswaran et.al.[20] (2013))



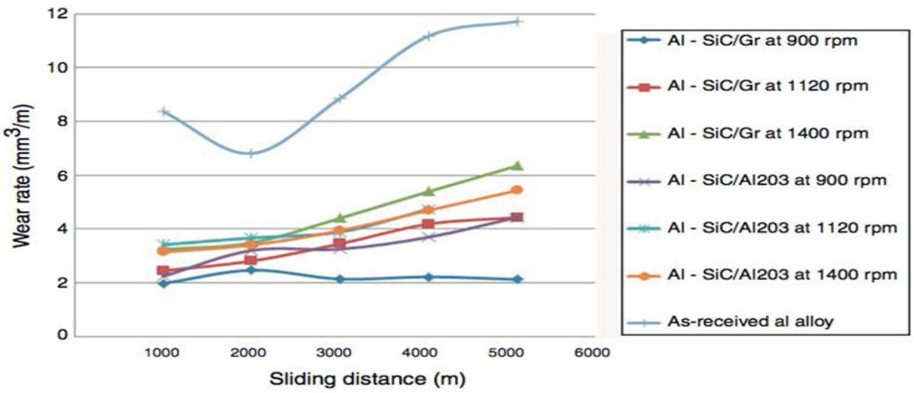
Zhenyang Yu et.al.[21](2012) studied the effects of reinforcement of $MgAl_2O_4$ whiskers in aluminium matrix. They revealed that the mechanical properties like hardness and tensile strength of composites increases up to three times of pure aluminium with the reinforced material. Essam R.I Mahmoud et.al. [22](2010) added a surface hybrid MMCs layer on aluminium plate and observed that average hardness of composite at 100% SiC increased to 60HV. They also found that hardness decreases with increasing the relative ratio of alumina (Al_2O_3). A. Baradeswaran et.al.[23](2014) fabricated Aluminium 7075/Al_2O_3/graphite hybrid composites and investigated its mechanical properties and revealed that the tensile strength, compressive strength, hardness and flexural strength of composite materials increases with the increased volume percentage of reinforcement. Addition of Al_2O_3 particles increases the compressive, tensile and flexural strength of composite and on the other hand graphite decreases the hardness, tensile, compressive and flexural strength of composite material. G.B.Veereshkumar et.al.[24] (2012) investigated the effects of reinforcement of Silicon carbide in Al 6061. The authors observed that the hardness and tensile strength of composites increases with the increment in % of SiC. Ductility of material reduces with the reinforcement of SiC.H.Y Yue et.al. [25] (2017) fabricated composite of Al 6061 reinforced with aluminum borate whiskers and investigated its mechanical properties. They observed superior mechanical properties of composites and increases with the reinforcement.

Shuai Ma et.al.[26] (2018) Investigated the performance of aluminium/sintered carbon composites. They observed that Al/SC composites bear excellent mechanical properties and can attain compressive strength up to 304.28 Mpa. T.S.A. Suryakumari et.al.[27] (2018) studied the effects of reinforcement of SiC and Al_2O_3 in aluminium matrix and observed that composite with 5% SiC and 2.5% Al_2O_3 have high micro hardness and impact strength. K. Ravikumar et.al.[28] (2017) Investigated the effects of reinforcement on the mechanical behaviour of aluminium metal matrix composites. Stir casting route was used for the fabrication of composites with different wt.% of TiC. They observed that impact strength along with density and elongation of composites decreases with the addition of reinforcement. Tensile strength of composites improves initially and then starts decreasing with TiC. Authors also observed that hardness of MMC's increases with the addition of reinforcement (TiC). T.Rajmohan et.al.[29] (2013) fabricated hybrid aluminium matrix composites reinforced with the particles of Mica and SiC in Al356 with the help of stir casting. They observed better hardness and strength with Al/10SiC-3mica composites. Xiong Cao et.al.[30] (2018) investigated the mechanical behaviour of carbon fiber/aluminum composites and observed that as compared to base metal the hardness of composites increases by 46.8%. They also got 18.6% increment in ultimate tensile strength and 13% improvement in elongation of composites fabricated at 100 rpm and at a speed of 75 mm/min. Ch. HimaGireesh et. al. [31] (2018) investigated mechanical behaviour of aluminium composite reinforced with aloe vera powder and achieved better tensile strength, impact strength and hardness than base material.

IV. WEAR CHARACTERIZATION

Wear or Tribological properties of aluminium composites also vary with the reinforcement. Many researchers have investigated wear properties of aluminium composites due to its wide range of application. J.corrochano et.al. [5] (2011) investigated wear behaviour of Al-Mg-Si alloy-MoS_2 under dry sliding conditions and observed that composite bears higher wear resistance than monolithic alloys. They also reported improved wear resistance of composites with the decrease in particle size of reinforced material. MahagundappaM.Benal et.al. [2] (2007) studied the wear properties of Aluminium 6061 composites with the reinforcement and ageing durations. Pin on Disc machine is used to carry out wear tests. Researchers observed that heat treated specimens have high hardness and improved wear properties. Wear rate of hybrid composites also decreases with increase in wt.% of reinforced material. Devarajuaruri et.al.[8] (2013) fabricated aluminium 6061-T6 surface hybrid composites with the help of stir casting and investigated the impact of tool rotational speed on wear properties of composites. They reported superior wear properties of Al-SiC/Gr composites due to the presence of Gr (solid lubricant) and SiC (load bearing element). Wear rate of aluminium composites with sliding distance is shown in Figure 4

Fig.4 Aluminium composites wear rate with sliding distance.(Devarajuaruri et.al.[8] (2013))



S. Gopalakrishnan et.al. [14] (2012) investigated the wear behaviour of AA6061 matrix reinforced with titanium carbide (TiC) particulates. They revealed that wear resistance increases with the increase in TiC particles and decreases with the normal load. Variation in wear rate with load and reinforcement is shown in Figure 5(a) and Figure 5(b) respectively.

Fig. 5.(a) wear rate with %TiC (S. Gopalakrishnan et.al. [14] (2012))

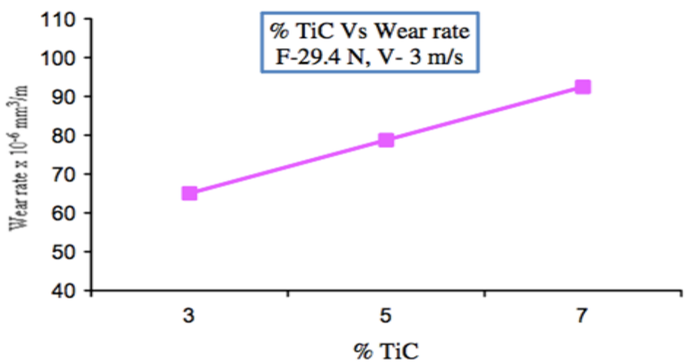
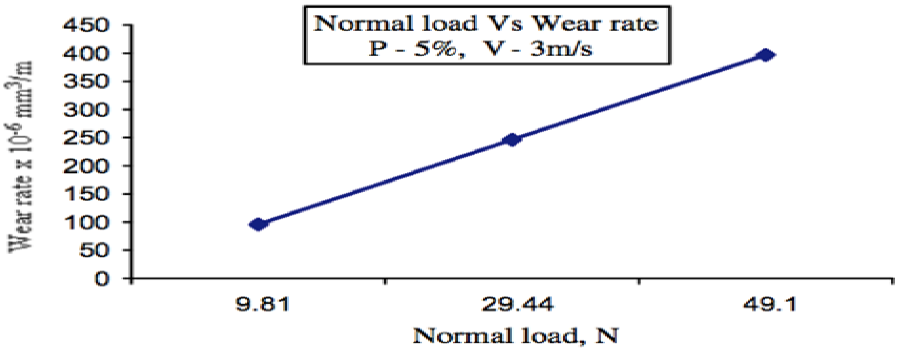


Fig. 5.(b) wear rate with normal load (S. Gopalakrishnan et.al. [14] (2012))



A.Baradeswaran et.al. [32] (2013) analyzed the wear behaviour of aluminium metal matrix composites reinforced with aluminium oxide (Al_2O_3) by Taguchi technique. They observed improved wear properties with the addition of Al_2O_3 particles. They also noticed that wear rate at 6 wt.% Al_2O_3 of composites reduces to $1/10^{th}$ as compared to the base metal. From Taguchi analysis they got minimum mass loss due to wear at combination of load at 10N, sliding distance of 400m and 6 wt.% of Al_2O_3. They observed decrease in sliding friction with Al_2O_3 and obtained minimum value of coefficient of friction (0.44) at 6 wt.% Al_2O_3 composites. Wear rate increases with increase in normal load due to increase in working temperature. Paras Mittal et.al. [15] (2018) studied the wear behaviour of aluminium composites fabricated with different reinforcement. They use SiC, Red mud and Al_2O_3 as a reinforcing material and observe superior wear properties of composites with reinforcement as compare to pure metal. A.Baradeswaran et.al. [20] (2013) investigated the wear behaviour of composites fabricated by introducing B_4C particles in Al 7075 alloy matrix. The result showed increase in the wear resistance of composites. Wear rate decreases as compare to metal matrix and found only 11% of pure metal at 10vol% B_4C reinforcement. Abdulhaqq A. Hamid et.al. [33] (2006) investigated the effects of porosity and dispersion of MnO_2 particles on the wear behaviour of Al(Mn)- $Al_2O_3(MnO_2)$ composite. They observed decrease in volume loss and improved wear properties of in cast in situ composites as compare to Al-Mn base alloy and commercial aluminium at high load conditions. Wear resistance increases with increase in volume fraction of porosity in situ composites.

Essam R.I. Mahmoud et. al. [22] (2010) studied the wear behaviour of surface-hybrid-metal matrix composites layer produced on aluminium plate (A 1050-H24) with the reinforcement of mixture of SiC and Al_2O_3 particles having average size of 1.25μm. Ball on disc wear tester was used for wear testing of composite material. They observed that wear volume loss of composites depend upon the applied normal load and relative proportion of Al_2O_3 and SiC particles. They found that at 2N load, wear resistance decreases with increase in Al_2O_3 particles and at 5N load composites having 20% Al_2O_3 and 80% SiC have high wear resistance as compare to other combinations of Al_2O_3 and SiC particles. Also the wear resistance became almost independent of relative contents of Al_2O_3 and SiC particles at 10N load. NidhiJha et.al. [34] (2011) compared the tribological behaviour of cenosphere-filled aluminium synthetic foam with aluminium composite reinforced with 10 wt.% SiC particle. Authors observed the wear behaviour at load of 3 kg and at different sliding speed. They concluded that aluminium synthetic foam (ASF) has superior wear performance than the aluminium matrix composite (AMC) under similar conditions. A. Baradeswaran et.al. [23] (2014) investigated the wear behaviour of aluminum composite fabricated with the reinforcement of Al_2O_3 and graphite particles. Liquid metallurgy route was used to fabricate material. They observed less wear due to thin layer of graphite particles on sliding surface and increase in hardness due to Al_2O_3 particles. G.B. Veereshkumar et.al. [24] (2012) studied tribological behaviour of Al6061-SiC composites having 2 to 6 wt% of SiC. They observed high wear resistance of SiC reinforced composites as compare to the base alloy. Volumetric wear loss increases with the increase in load, sliding distance and with the increment in SiC Content. Shuai Ma et.al [26] (2018) investigated the wear behaviour of aluminum/sintered-carbon composites. They observed that at 70N load, coefficient of friction of Al/SC composite having reinforcement of 7.17% vol. fraction reached a minimum value as compare to the other composites. Similarly, under low load condition of 20N, composite having 26.92% vol. fraction Al alloy have low friction coefficient. T.Rajmohan et.al. [29] studied the wear properties of hybrid aluminium matrix composites fabricated by introducing mica and Silicon carbide (SiC) ceramic particles in aluminium (Al 356) alloy matrix with stir casting. The results indicated that the wear loss of composites improves with the increase in content of mica particles. Vipin K. Sharma et.al. [35] (2017) investigated the wear properties of aluminium flyash composites. Stir casting route was used to fabricate composites having 2, 4 and 6 wt.% of flyash content. Author revealed that composites having 6wt.% of flyash shows less wear (0.32g), while low friction coefficient (0.12) was achieved at 4 wt.% of flyash. Wear rate and friction coefficient at various wt% of flyash shown in Fig. 6(a) and 6(b).

Fig. 6(a) Wear with wt.% of flyash (Vipin K. Sharma et.al. [35] (2017))

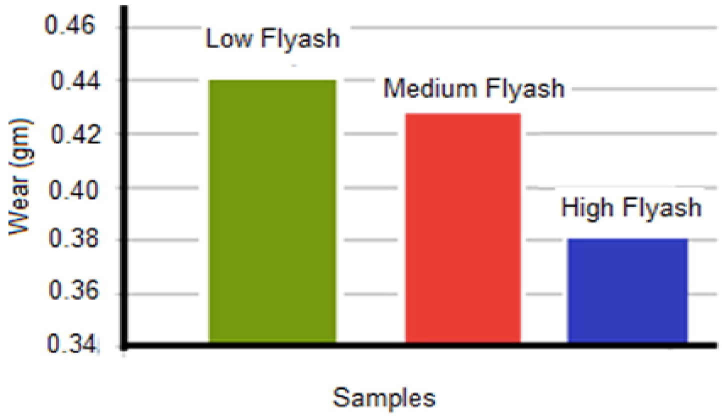
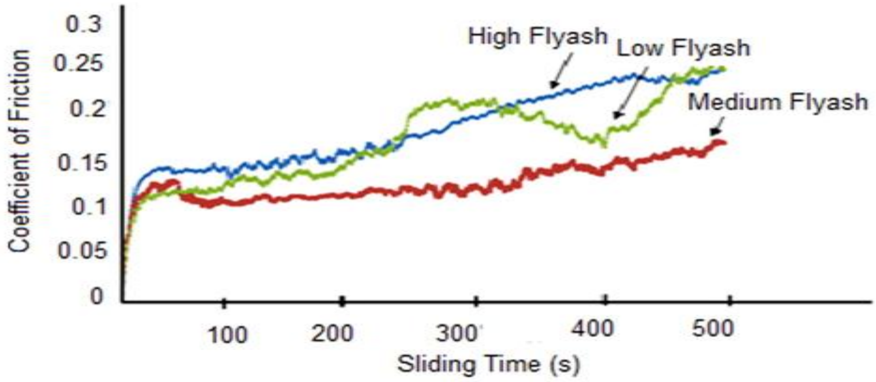


Fig. 6(b) coefficient of friction with wt.% of flyash (Vipin K. Sharma et.al. [35] (2017))



Hui Tan et.al. [36] (2018) investigated the wear properties of Al-20Si-5Fe-2Ni-Graphite composite at 25-500^{0}C. The composites showed improved wear properties or less wear rate than base alloy at all the test temperatures. At low temperature 25^{0}C, abrasive wear is predominant and with the rise in temperature it transforms to abrasive wear and delamination wear at high-test temperatures. Mohamed M. EI-SayedSeleman et.al. [37] (2018) investigated the effects of reinforcement of graphite particles on tribological behaviour of aluminum alloy composites and observed high wear resistance of composite and increases with the reinforcement. Composite having 20wt% of graphite content has superior wear resistance than base metal. Omkararanke et.al. [38] (2018) investigated the wear properties of Al 7075 composites reinforced with Multiwall carbon nanotubes(MWCNT). They observed less wear rate with the increase in percentage of reinforcement. Wear resistance increases up to 0.5 wt.% of MWCNT and remain constant between 0.5-0.75. Under severe testing, wear resistance shows a decline curve as compare to the base material. Jianbin Zhu et.al. [39] (2017) investigated the wear properties of A356/fly-ash-mullite interpenetrating composites. Wear resistance of the composites increase with reinforcement and the wear rate was observed to be less than half of the base metal (A356 alloy). A. Pramanik [40] (2016) studied the effects of reinforcement of Al_2O_3 particles in Al 6061. Author observed that the reinforcement of Al_2O_3 increases the wear resistance of composites and useful to control wear. M.V. Phanibhushana et.al. [41] (2017) studied the wear behaviour of hermatite reinforced aluminium composites. Weight loss of specimens was used to calculate the wear rate of the composites and the result shows improved wear resistance with increase in reinforcement. At reinforcement of 8%, they get 30-40% decrease in wear factor as compare to the base metal.

V. CONCLUSION

In this paper, we studied various reinforced materials used for producing aluminium composites and their effect on mechanical and wear properties of composites. It is clear form above literature review that the properties of the composites largely depend upon the type of reinforcement and vary with the reinforcement content. Stir casting is one of the widely used economic processes to produce aluminium composites. Some researchers also use powder metallurgy for producing aluminium composites. Wear properties of composites improved with the addition of SiC, TiC, Al_2O_3, B_4C, flyash, hermatite and mica particles and vary with the content of reinforcement. The addition of SiC, TiC, Al_2O_3, B_4C, carbon fibre, aloe vera powder improves the strength and hardness of composite materials. The addition of red mud also increases the hardness of composites. Hardness of composites decreases with the addition of graphite particles but improves the tribological behaviour.

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Rinki Yadav "Review of aluminium composites and their tribological and mechanical properties "International Journal of Engineering Science Invention (IJESI), vol. 07, no. 07, 2018, pp 48-56