Property Enhancement of Aluminium Based MMCs with Various Reinforcements

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Abstract: Aluminium Matrix Composites are used in a wide variety of fields like Aerospace, Marine, Automotive industries, structural applications, etc. This review paper is concerned with the different Aluminium alloys with various reinforcements and studies the properties like strength, stiffness, hardness, wear rate and porosity. It mainly aimed at the evolution of Aluminium Matrix composites in the Aviation sector. The need for better performance, low cost and quite quality materials are upgraded by the latest MMCs and novel manufacturing processes. With the reinforcements like Silicon Carbide, Boron Carbide, Titanium Oxide, etc. improved the mechanical and tribological properties of MMCs. Likewise, the Fabrication Techniques such as Powder Metallurgy as well as stir casting improved the performance of MMCs.

Keywords: Metal Matrix Composites, Al based MMCs, Reinforcements, Fabrication Techniques, Mechanical Properties

I. INTRODUCTION

Aviation industry has a great challenge for researchers to sustain the atmospheric pressure, temperature, weight, etc. whereas composite materials overcome such difficulties in a high environment. Metals are one among the hardest materials that exist abundantly in nature, which could exhibit good mechanical and physical properties. Even then most of the metals are not used in their purest form, as they are brittle in nature. They are mixed with some other materials to form alloys. Alloys are a result of atomic bonding between the metals and other constituents of it. Alloying of metals increases its strength, melting point, hardness, ductility and other desired properties. However, alloys are too heavy so that it is overcome by Metal Matrix Composites (MMC). MMC's have high strength to weight ratio when compared to alloys and also exhibits better load bearing capacity. Metals gives excellent specific strength and stiffness, isotropic properties, ease of manufacturing to near net shape, and excellent thermal and electrical properties, and affordability, producing discontinuous MMCs suitable for a massive range of aerospace applications and also it provide high structural efficiency and isotropic properties of discontinuous MMCs with the required multi-axial loading when high loads are encountered.

II. REINFORCEMENTS AND ITS CHANGE IN PROPERTIES

Various Reinforcements of Aluminium like silicon carbide, alumina, graphite, fly ash, ZrO_2 etc. are easily added and found to be cheap in an increasing requirement of aerospace applications. Al matrix composites reinforced with three reinforcement fibres namely SiC fibres, optical fibres and shape memory alloy wires are fabricated through ultrasonic consolidation process which induce a plastic flow between two Al foils being bonded. The result discussed that this kind of fabrication need cold process for fibre embedding [1]. The Al matrix alloy (A384) reinforced with SiC of 10% prepared by stir casting with high stirring time and speed (500, 600 and 700 rpm) resulted in even distribution of reinforcement material. The composites formed have better hardness when compared to MMC's formed at low stirring speed and time. By increasing the stirring speed and stirring time of the composite better hardness is achieved. (i.e) stirring speed of 600 rpm and stirring for 10 mins that reaches the maximum Brinell hardness value of about 107 BHN [2]. AMC (Aluminium Matrix Composites) fabricated using stir casting with SiC (3 to 9 wt%) and Cu (0.5 to 1.0 wt%) as reinforcements, under inert atmosphere to neglect the oxidation process that showed fine grain size with increase in reinforcement percentage [3]. Al-TiB_2 composites fabricated via exothermic reaction with two different salts such as K_2TiF_6 and KBF_4 salts used for producing TiB_2 particles of various percentage 5, 10, 15 and 30 wt%. The exothermic reaction improved the wettability of the reinforced particles [4]. Aluminium is reinforced with various percentage of AlN (Aluminium nanoparticles) of 0, 2.5, 5 and 10 wt% were fabricated through high- energy ball milling and sintering technique. The size of the crystal is reduced by sintering for 20-60 minutes at 650^0C under Nitrogen gas. This reduces the size of the crystal and improves the reinforcement content where the densification of compact increases through degassed powders [5]. Al- 7093 alloy reinforced with 10 vol% of B_4C particles fabricated using Boralyn technique which involves blending, cold isostatic pressing (CIP), vacuum sintering and extrusion process. This cost-effective process provides uniform distribution of reinforcement particles on MMC [6].

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III. MECHANICAL PROPERTIES

Aluminium (Al6061) based MMCs prepared by adding various weight percentage of MoS_2 (1%, 2%, 3%, 4%, 5%) using stir casting technique which provides homogenous distribution. It produces better pitting corrosion resistance for 4 wt% MoS_2. AA6061 showed better hardness on heat treatment. The mechanical performance of the composite with 4% of MoS_2 on heat treatment has the highest value while compared with various Weight amounts of MoS_2. Thus the heat treated composites showed better properties than others as well as least pit density **[7].** Al (99% purity) based MMCs are prepared by the addition of two different types of abrasives Al_2O_3 and SiC particles separately in various percentage using stir casting and powder metallurgy technique. The result revealed that the specimen prepared by casting exhibits 1.5 – 2 times better mechanical and tribological properties than those fabricated by PM techniques [8]. Al6061 with heat treated T6 composites manufactured by modified stir casting with the addition of various weight percentages of B_4C particles, along with K_2TiF_6 flux into the molten matrix to improve wettability. The composite thus prepared has a very good micro and macro hardness value than other techniques and strength (tensile) of Al matrix composites increased to 215 MPa. The increase in reinforcement increases the surface area and reduces the grain size. Thus the plastic deformation gets reduced and improves the hardness value of the composite. Thus the addition of reinforcement improves the strength and the thermal mismatch increases the load bearing nature of the composite [9].

A. Micro-structural analysis/porosity

A356 (Al-7Si-0.35Mg) matrix composite with fly ash particles of 13 µm size as reinforcement is fabricated by using three different stir casting technique such as 1) compo casting (semi solid processing), 2) modified compo casting and 3) modified compo casting followed by squeeze casting technique. The result showed that the modified compo casting with surface treatment along with squeeze casting has the best particles than Al356 matrix composite fabricated through liquid metal stir casting (18%) [10]. AMC prepared by adding micro sized and nano sized Al_2O_3 particles using stir casting process followed by a novel 3-step mixing method. This involves heat treatment, injecting the particles which are heat treated into molten alloy under inert gas atmosphere. The stirring process can be carried out at various speeds. The result shows that Al- 10% Al_2O_3 (20 µm) at 300 rpm has a hardness value of 77.1 (HBN) which is the highest value when compared to A356 alloy of hardness 53.1 HBN. Al- 3% Al_2O_3 (50 nm) at 300 rpm exhibits a hardness value of 76.3 HBN with minimum amount of reinforcement. Before pouring the particle into the melt, the particle is heat treated. This improves the wettability and minimizes the agglomeration. Also, by increasing the stirring speed to the limit of 450 rpm, the reinforcement particles distributed evenly and above the speed the alumina particles get wasted and the porosity percentage gets increased [11]. Al alloy (A206) is reinforced with two different reinforcements such as Al_2O_3 particles and milled particulates of alumina with Al and Mg powders by ball milling followed by stir casting process. Presence of Mg improves the wettability which leads to the porosity reduction and this property again gets reduced by stirring turbulence. By reducing the size of alumina particles from micro to nano scale dimensions by ball milling the tensile property gets increased. [12]. Light metal matrix composites like Aluminium or Magnesium alloy composites reinforced with MWCNT produced by squeeze casting method whereas the wettability is measured by sessile drop method. With reinforcement of 25 vol%, Al or Mg alloy which obtained is free from porosity [13]. Al 356 alloy matrix composites processed by two ways, stir casting and compocasting with the addition of 5% of SiC particle sizes of 8µm and 3µm. The compo-casting process improves the distribution of particles and the wettability of the material. The result showed that the porosity reduced to 68% and the hardness improved by 10 % to ~66 BH because of increase in reinforcement particles [14].

B. Hardness test

Al6061 based composites fabricated with the reinforcement of SiC particles of 10 wt% using Mechanical Alloying (MA) succeeded by mechanical pressing, sintering and hot extrusion. Among them composites processed by MA and hot extrusion have best mechanical properties in its increase in milling time. After 9 hours of milling, the crystal size of SiC reduced to 36 nm which is of extreme refined dimensions. As the milling time increases the hardness gets increased, after 9 hours of milling the highest value of hardness ~81 HRB is achieved [15]. Al matrix produced by the reinforcement of 5 and 10 wt% Cu powder (105µm) using stir casting process showed less wear volume loss as well as high hardness. The COF value is less for 5 wt% of Al-alloy matrix when compared to 10 wt% of Al matrix MMC. Al-based Cu matrix alloy with 5wt% Cu revealed better hardness when compared to other composites [16]. AMC reinforced with Iron-aluminide as well as alumina of 10-50 vol% fabricated through in-situ exothermic reaction of nano sized Fe_2O_3 under mechanical milling followed by hot pressing. The greatest hardness of about ~510 VHN is obtained with the reinforcement of 50 vol% of reinforcement [17]. Aluminum alloy (A356.1) based Metal Matrix Composites are generated through stir casting with the addition of 0.5 to 5 vol% of MgO nano particles at different temperatures such as 800°C, 850°C and 950°C. The test results revealed that the MMC has better hardness value of approximately 72 BHN at 2.5 vol% of reinforcements prepared at temperature of 950°C. Also the compressive strength of the composite is high for 1.5 volume percentage at 850°C of fabrication [18]. Aluminum based MMC prepared by succeeded process like wet mixing, cold pressing and sintering with the reinforcement of nano Al_2O_3 particles (50 nm) of various volume fraction ranging from (1-7 vol%) in pure ethanol slurry similarly Al composite with 10 vol% SiC_p (13µm) was prepared using the same procedure to compare the results. The results revealed that the hardness value lead to decrease after 4 vol% Al_2O_3 (i.e.) 66.6

HRF (hardness measured in Rockwell indenter) when compared to 7 vol% Al_2O_3 of hardness 68.4 HRF. Also, it is evident that 4 vol% Al_2O_3/Al composites with a hardness value of 48.6 HRF [19]. There showed a uniform distribution of particle reinforcement under various percentage of graphite particles from 0 to 12 wt% of Al6082 matrix using stir casting process that decreases in its hardness but the tribological properties tend to increase with increase in reinforcement. The hardness gets reduced from 49.5 VHN (cast Al) to 44 VHN (Al-12% Gr) [20]. Fabrication of two different MMCs including Aluminium-Cu powder with the reinforcement of SiC_p and Aluminium- copper powder reinforced with B_4C_p is fabricated through hot pressing method of SiC and B_4C particles of 10, 20 and 30 vol%. The result showed that Al with 30 vol% of B_4C composites produce the highest hardness of 190 HB whereas the hardness value for Al-30 vol% of SiC is approximately 135 HB. Also the increase in reinforcement content decreases the wear rate for Al/Cu–SiC_p and Al/Cu–B_4C_p composites [21]. Aluminium alloys AA6061 and AA707 fabricated using liquid casting technique with the reinforcement of B_4C (10 wt%) and graphite (5 wt%) and compared among them. The hardness increased due to graphite and B_4C where AA7075 hybrid composite showed the highest hardness value of ~120 HB. The wear rate shows the lowest for AA7075 hybrid composite which is less than ~ 0.02 mg/m. The tensile property gets improved due to the presence of B_4C content which enlighten the impregnability of matrix material (AA7075 ~225 MPa). The reinforcement particles B_4C and graphite reduces the wear rate which builds the wear resistance of the MMCs [22]. Al (99.85%) pure is reinforced with MWCNTs that are created through Spark Plasma Sintering (SPS) along hot extrusion process. These methods provide uniform distribution and orientation of CNT which enables the mechanical characteristics of the composite material. The hardness of Al-CNT increases of about 52 HV than pure Al which is of about 22 HV. The tensile strength of Al-CNT increases twice that of pure Al (194 MPa) [23]. Al6061 alloy fabricated with the various weight percentage of reinforcement particles of TiO_2 (0, 4, 8, 10 and 12 wt%) through low and high ball milling technique which gives a very fine nano grain particle. The result revealed as increase in the reinforcement percentage increases the hardness (i.e.) Vickers hardness of Al6061-12% TiO_2 nano composite (1126 MPa) increased 3 to 4 times than micro composites (280.48 MPa) [24]. Al based MMC (Al7075) reinforced with SiC of 4, 8 and 16 vol% of SiC fabricated using FSP which improve the composite layer bonding. The composite comprised of 4 vol% of SiC that has a hardness value ranging from 130 HV to 171 HV on the other hand with 8 vol% the hardness rate increases from 145 HV to 177 HV. However, the relative density percentage of Al7075-SiC composite is reduced to 81.5% (16 vol% SiC) and increased to 87.5% (4 vol% SiC) [25].

TABLE - I: Vickers (micro hardness) Hardness value of Al based MMC with various reinforcements

S. No	MMCs	Fabrication Techniques	Hardnes s (HV)
1.	Al/SiC, Cu	Stir casting	90
2.	Al6061/AlNp	Modified stir casting	91
3.	Al6061/Ti3Alp	Stir casting	120
4.	Al-Ti-Cr/SiC, B4C	Stir die casting along with Chillcasting	355.96 (SiC) 217.07 (B4C)
5.	Al6061/ MoS2	Stir casting	106
6.	Al-Cu alloy/Cu powder	Stir casting	~370
7.	Al6061-T6/ B4C	Modified stir casting	80.8
8.	Al6082/Graphite	Stir casting	44
9.	A359/SiC, B4C	Double stir casting	~159 (SiC) ~153 (B4C)
10.	Al6061/ TiB2	High energy stir casting	73.93
11.	Al6061/TiB2 & Graphite	High energy stir casting	91.4
12.	Al6061/ Cu plated carbon fibre rods	Convention al casting	76.34
13.	Al6061/ Al2O3	Stir casting	180
14.	Al1100/ B4C	Ball milling & sintering	550
15.	Al/ AlNp	High energy ball milling & sintering	149
16.	Al/ MWCNT	SPS followed byhot extrusion	52
17.	Al/ MWCNT	Ball milling &hot extrusion	~430
18.	Al7075/ SiC	FSP	177
19.	Al5059/SiC, B4C, Al2O3	FSP	170
20.	Al6061/ SiC	Pressure sintering & hot extrusion	~160
21.	Al5052/ SiC	FSP	116
22.	Al/ Fe2O3	Mechanical milling & hot pressing	~510
23.	Al6061/ TiO2	Low energy & high energy ball milling	~350
24.	Al/ Al2O3	Hot forward extrusion	~93
25.	Al / SiCp	Mechanical alloying	85
26.	Al/ ZrB2	In situ fabrication	64

TABLE - II: Brinell hardness (Macro hardness) value of Al based MMC with various reinforcements

S. No.	MMCs	Fabrication Techniques	Hardn ess (BHN)
1.	Al alloys-ZL109 ZA27/ SiC, Si3N4, B4C, Al2O3& graphite flakes	i)Centrifugal casting ii)Squeeze casting	135(ZA 27) 116(ZL 109)
2.	A384/ SiC	Stir casting	107
3.	Al6061/ AlNp	Modifiedstir casting	79
4.	A356/ Al2O3	i)Stir casting ii)Compo casting	77

5.	Al6061-T6/ B_4C	Modified stir casting	58.6
6.	Al/Aloe Vera	Stir casting	33.8
7.	Al-356-1/ MgO	Stir casting	72
8.	Al356/ SiC	i)Stir casting ii)Compo casting	66
9.	Al/ Al_2O_3 & SiC	i) Stir casting ii) Powder metallurgy	Cast- 70 (Al_2O_3) 68 (SiC)
10.	Al7075/ Al_2O_3& Graphite particles	Stir casting	~134
11.	Al/Al_2O_3 (Micro &nano particles)	Three step novel mixing process followed by stir casting	77.1
12.	Al6061/ B_4C & graphite	Liquid casting	~120
13.	Al6061/ Cu plated carbon fibre rods	Conventional casting	61
14.	Al-Cu/ SiC_p & B_4C	Hot pressing	190 (B_4C) 135(SiC_p)

C. Strength properties

Al7075 based MMC prepared by stir casting reinforced with 5wt % of graphite particles and Al_2O_3 particles of (2, 4.6 and 8 wt. %). Al_2O_3 is added to Al707 alloy, inorder to improve the hardness which gets reduced by the intervention of graphite particles that retard the hardness rate and by the addition of Al_2O_3, the mechanical properties such as hardness, flexural strength, tensile strength and ultimate compressive strength get increased.(refer graph for values) Flexural strength increased 23% when compared to Al7075. Wear rate gets reduced due to the presence of Al_2O_3 upto 36% less of 2 wt% Al_2O_3 and 5wt% of graphite (minimum wear rate occurs at this stage). Because of graphite content, COF decreases and also the graphite gives a lubricating property [26]. Aluminium 1100 alloy reinforced with various percentage of B_4C (0, 6, 10, 15 and 25 wt %) fabricated using ball milling and sintering. The density and electrical conductivity decrease with increase in B_4C content. The flexural strength decreases due to the formation of B_4C derivative on the grain boundaries which can be reduced by heat treatment and brittle nature of MMC. Thus B_4C is used in nuclear and friction applications [27]. Al- Mg-Si based MMC reinforced with various percentage of SiC particles (20, 30 and 40 vol %) that are fabricated by freeze casting and pressure less infiltration techniques. The compressive strength increases with increases in reinforcement content which shows maximum compressive strength twice that of matrix alloy with 30% vol % of SiC along longitudinal direction. The highest value of elastic modulus is 163 GPa with40 vol% of reinforcement. The result states that with increase in reinforcement percentage of SiC particles the strong interfacial bonding is occurred [28]. Al based MMC reinforced with 7 wt% of SiC particles that are fabricated using compo-casting along with squeeze casting. The result showed that wear resistance, yield strength and compressive strength increases with increase in reinforcement content. The MMC showed higher wear resistance with 20 vol % of SiC. The compressive strength increased by 45% than matrix alloy with 15 vol% [29]. Al based metal matrix composites prepared by stir casting with the reinforcement of fly ash as well as Aloe Vera powder individually to study the mechanical and tribological properties. The hardness values of AMC-FA and AMC-AV obtained from Brinell hardness number (BHN) are 28.2 and 33.8. The addition of Aloe Vera powder with Al matrix increases the ultimate tensile strength which proves that AMC-AV is best suitable for high strength applications. Aloe Vera composite provides homogenous distribution and better hardness and tensile strength in its characteristics which is helpful in aerospace, automotive and marine applications [30]. Aluminium alloy (ZL109) matrix composites prepared by the reinforcement of sub-micron TiB_2 particles developed by in situ reaction of K_2TiF_6 and KBF_4 salts, using stir casting with a small addition of Na_3AlF_6 as reactive assistant. The results revealed that 8.3 wt% TiB_2 /ZL109 composite (271 MPa) has an increase in UTS value by 105 MPa than ZL109 matrix composite (166 MPa) at 260°C. when subjected to high temperature, the mechanical properties of composite was evaluated by contribution ratio that characterize the particles effect at varying temperature which improved the peak values for 9.1TiB_2 /ZL109 as 44.6% and for 8.3TiB_2 /ZL109 as 63.3% at 260 °C and above the temperature the contribution gets decreased [31]. Aluminum 6061 composite reinforced with 1 wt% of graphene fabricated by semi-solid sintering whereas mechanical milling is used for the dispersion of graphene which influence the mechanical properties. By varying the time for ball milling from 10 min to 90 min, the flexural strength of Al6061-1% graphene composite gets varied 9 (i.e.) when milling for 60 min, the strength increased to 47% and for 90 min, the strength increased to 34% when compared with AL6061. Further milling can help to improve the graphene distribution and degrade the number of stacked layers. This says that the graphene dispersion affects the strength of the composite [32]. Al matrix composite reinforced with nano sized (35 nm) and submicron (0.3 µm) sized alumina particles fabricated by wet attrition milling succeeded by hot forward extrusion process. The result showed that by increasing the amount of nanoparticle, the strength as well as hardness get increased first and then decreased which says that above 4 wt% of alumina nanoparticles the strength gets reduced **[33].** Fabricating Aluminium along 4.5 wt% of Cu reinforced with 10 vol% of SiC particulate composites through mechanical alloying (MA) technique. SiC_p increases by increasing the duration of MA and hence the mechanical properties have been improved which exhibits the hardness value of MMC 85 HV whereas MMC without MA is of about 74 HV. Mechanically alloyed for 6 hours improved the yield strength from 252±7 MPa (without MA) to 393±9 MPa (MA). Likewise, MA for 6 hours increases UTS from 338±8 to 463±8 MPa [34]. Aluminium with 5 wt% of Cu reinforced with 13.3 or 27.2 vol% of SiC_p (10µm) that are fabricated through conventional hot-pressing method under nitrogen in inert gas atmosphere. The result showed that the yield strength as well as tensile strength is more in Al-5Cu-30%SiC composite (174±8 MPa and 241±9.5 MPa). The elongation of Al-5Cu-30% SiC matrix alloy is reduced below 2% when the reinforcement of 27.2 vol% of SiC particles is added which was before above 20% [35].

Al based MMC fabricated using hot pressing and hot extrusion where pure Al reinforced with zirconium based glassy particles ($Zr_{57}Ti_8Nb2.5Cu13.9Ni_{11.1}Al_{75}$) that are prepared by mechanical alloying. The result discussed that for 40 vol% glass reinforcement, the compressive strength is 155 MPa whereas for pure it is 200 MPa. For 60 vol% of glassy reinforcement, the compressive strength increases to 250 MPa [36].

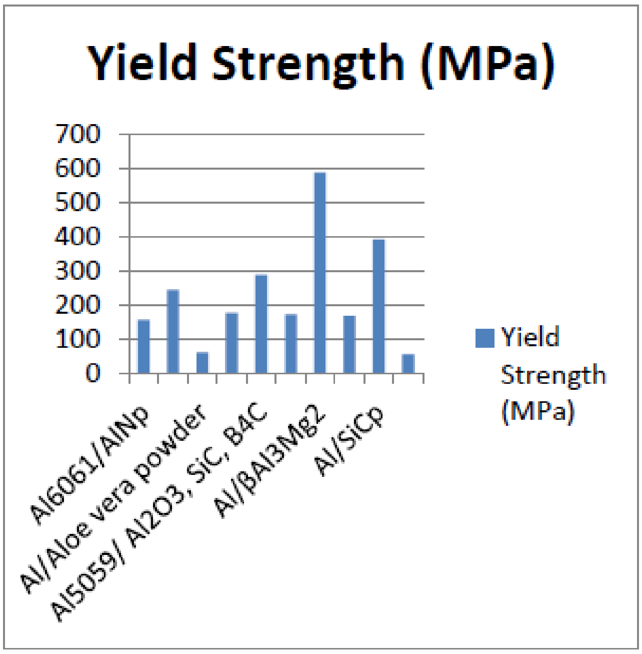

Fig. 1. Yield strength of MMCs with reinforcements

Al based MMC reinforced with 20 and 40 vol% of β– Al_3Mg_2 fabricated using hot extrusion which neglect the unwanted interfacial reaction among matrix and reinforcement. The result exhibited that the density gets reduced to 2.4 g/cm^3 by an increasing amount of reinforcement which is greater than pure Al (2.7 g/cm^3). For 60 vol% of β– Al_3Mg_2, the compressive strength is of about 575 MPa and for 80 vol% of reinforcement it is increased to 630 MPa. Also the specific strength of 20 vol% of β–Al_3Mg_2 increases to 180 KNm/Kg than pure Al of 55 KNm/Kg. yield strength of MMC with reinforcement is higher for 80 vol% reinforcement (589±20 MPa) than 60 vol% reinforcement (448±20 MPa) **[37].** Aluminium matrix composites manufactured using flake powder metallurgy by adding graphene sheets heighten the tensile strength of Al composite to 249MPa with the addition of 0.3 wt% which is 62% improvement over aluminium matrix **[38].** Al based MMC (A356) fabricated by ball milling followed by a new method called non-contact ultrasonic vibration method with the reinforcement of SiC nanoparticles that are encapsulated by graphene nanosheets. The result showed that the tensile ductility increased to 84% and the yield strength increased to 45% than matrix alloy which also enhances high thermal conductivity. The maximum yield strength of 58 MPa is attained for onion like encapsulating graphene sheets coated MMC **[39].** Al5059 reinforced with different reinforcement particles such as Al_2O_3 (130 nm), B_4C (35 nm) and SiC (250 nm) that are fabricated by FSP. Due to the reinforcement of B_4C the hardness value reaches the highest of 170 HV when compared to other reinforcements and the percentage of elongation reduced to 2.5% for B_4C content. The yield strength of Al5059-B_4C matrix composite is increased to 290 MPa than Al5059 (210 MPa). The UTS value of Al- Al_2O_3 increased to 375 MPa and for B_4C it is 350 MPa **[40].**

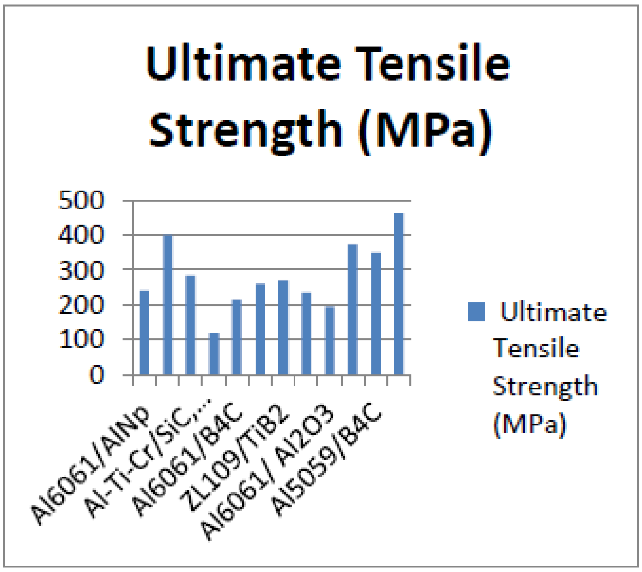

Fig. 2. Ultimate tensile strength of MMCs with reinforcements

D. Thermal conductivity

Al matrix composites with diamond powder as reinforcement prepared by two different mixing process such as mechanical mixing (MM) and mechanical alloying (MA) followed by SPS showed a dense, uniform and good thermal conduction properties. By comparing the thermal properties of mechanically mixed and mechanically alloyed composites, the highest thermal conductivity was shown by MM for 2 hours as 325 Wm^{-1}K^{-1} whereas the diamond particles gets damaged in MA initially. MM along with SPS provides the composites of high thermal conductivity and increase in relative density [41]. Al based matrix alloy ($AlSi_7Mg_{0.3}$) reinforced with silicon and graphite flakes prepared by pressure infiltration process which are infiltered for 60s at the temperature of 760 °C under 100 MPa. Here Si particles are used instead of SiC because of its low density and to avoid reactivity with Al melt which SiC does. Thermal conductivity after reinforcement increased to 526 W/mK and the Coefficient of Thermal Expansion reduces to 7.3 ppm/K. This kind of MMC with Graphite flakes is used in low- cost thermal applications [42].

E. Wear test

Al-6Cu-Mn based MMCs reinforced with 13 vol% of SiC particulates by a novel method called spray deposition technique. For sprayed MMC the pores are stable at low loads and as the load increases the porosity level gets high which leads to crack formation and high wear rate [43]. AMC reinforced with various percentage of TiB_{2p} (5, 10 and 15 wt%) fabricated through mechanical alloying (2, 4 and 8 hours) followed by cold pressing and pressureless sintering.

Hardness rate increases with increase in reinforcement content, with 15 wt% TiB_2 particles for 8h of MA showed the microhardness value of 2.43±0.23 GPa whereas the relative density slightly decreases of about 89.66%.highest wear rate is achieved for Al-5TiB_2 is 8.32 $\times 10^{-3}$ mm^3/Nm and the highest wear resistance is of 7.17(Al-15%TiB_2) [44]. Al based MMC with SiC particulates are fabricated by Direct Metal Laser Sintering (DMLS) whereas the reinforcement SiC particles is of different volume percentage (10%-30%) that reduces the surface wear and also avoid the plastic formation of material. The specific wear rate is reduced by the addition of reinforcement upto 20 vol% of SiC particles and above that there is a very mild decrement of specific wear rate. (At 30 vol% spec. wear rate is ~ 0.65×10^-4 mm^3/Nm) **[45].** A359 alloy (Al9Si0.7Mg) MMC fabricated by stir casting method which is of low-cost reinforced with SiC (~5 µm) particles with the volume percentage of 20% for the application of automotive friction materials. From the result the wear rate esteemed of A359-20 vol% of SiC_p gets decreased at the sliding speed range of 3 m/s and 6 m/s when applying the load from 30N to 50N and above the load the wear rate gets increased. From the consideration it is clear that when sliding speed increases, the rate wear gets reduced. (At 50 N the spec. wear rate is ~ 2×10^-3 mm^3/m for both sliding speeds). The COF (Coefficient of Friction) ranges of about 0.2 – 0.65 at the same sliding speeds. Thus A359-SiC is used as brake rotor applications which provide better wear resistance [46]. Aluminium alloy A359 with 1% Mg is reinforced with 20 vol% of SiC and 7.5 vol% of B_4C separately fabricated through double stir casting process. The wettability of the composite is improved by double stirring. The result exhibited that the micro hardness value for Al-20% of SiC is higher than other Particulate reinforced- MMC which is given as for Al 7.5 vol% B_4C(155$HV_{0.5}$) and for A359 + 1% Mg (102 $HV_{0.5}$). The wear rate of Al-20% SiC is more than Al 7.5% B_4C and A359 + 1%Mg alloy due to SiC particle present in high volume percentage [47]. Aluminium alloy (Al6061) reinforced with copper plated carbon fiber rods prepared by conventional casting route. The result exposed that an increase in density of matrix composite by 11% compared to cast alloy (Al6061). The micro hardness and bulk hardness of Al6061 – Cu plated carbon fiber is 76.34 VHN and 61 BHN (25 vol% of carbon fibers) there is also a reduction in grain size by 36. %, COF and wear rate by 14.2% and 54% when compared with other. Thus AL6061 reinforced composite showed excellent properties which improve the wear resistance at high velocity that are used in automobile brake drum applications [48].

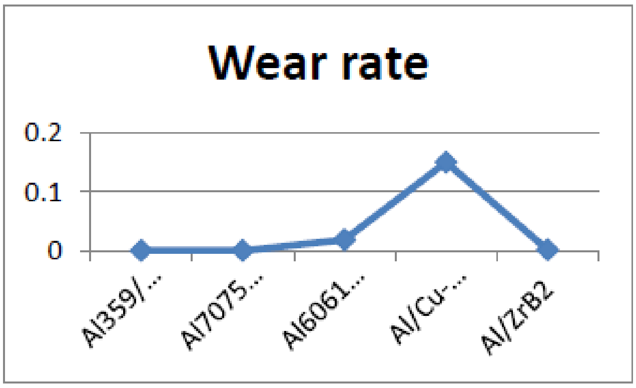

Fig. 3. Wear rate of MMCs with reinforcements

IV. SUMMARY

This paper represents MMCs with various reinforcements and its properties including tribological and mechanical properties have been reviewed. The Metal Matrix Composites have major properties like excellent hardness, better wear resistance, and high thermal and electrical conductivity, etc. Aluminium matrix composites with hybrid reinforcement showed better isotropic properties than others through powder metallurgy or other casting techniques. The wear rate and the hardness increases by increasing the reinforcement content. Beyond the limit of reinforcement either in weight wise or percentage wise the properties tends to decreases due to high friction rate and agglomeration of particle with increase in reinforcement. The comparisons of MMCs with different reinforcements are made. Aluminium matrix composites are commonly fabricated through stir casting and powder metallurgy but in recent research such fabrication techniques are overcome by Additive manufacturing. This technique has some future scope due to its cost- effectiveness and material saving feature.

REFERENCES

1. C.Y. Kong, R.C. Soar, "Fabrication of metal–matrix composites and adaptive composites using ultrasonic consolidation process," Materials Science and Engineering vol. 412, 2005, pp.12–18.
2. S. Balasivanandha Prabu, L. Karunamoorthy, S. Kathiresan,B. Mohan, "Influence of stirring speed and stirring time on distribution of particles in cast metal matrix composite," Journal of Materials Processing Technology vol. 171, 2006, pp. 268–273.
3. Ajitanshu Vedrtnam, Anuj Kumar, "Fabrication and wear characterization of silicon carbide and copper reinforced aluminium matrix composite," Materials Discovery, vol 9, 2017, pp. 6-22.
4. S. Lakshmi, L. Lu, M. Gupta, "In situ preparation of TiB2 reinforced Al based composites," Journal of Materials Processing Technology, vol. 73,1998, pp. 160–166.
5. Hamid Abdolia, Hamed Asgharzadeha, Esmail Salahib, "Sintering behavior of Al–AlN-nanostructured composite powder synthesized by high-energy ball milling," Journal of Alloys and Compounds, vol. 473, 2009, pp. 116–122.
6. H.M. Hu, E.J. Lavernia, W.C. Harrigan, J. Kajuch, S.R. Nutt, "Microstructural investigation on B4C: Al-7093 composite," Materials Science and Engineering, vol. 297, 2001, pp. 94–104.
7. E. Subba Rao, N.Ramanaiah, "Influence of Heat Treatment on Mechanical and Corrosion Properties of Aluminium Metal Matrix composites (AA 6061 reinforced with MoS2)," Materials Today: Proceedings, vol. 4, 2017, pp. 11270–11278.
8. Bekir Sadık Unlu, "Investigation of tribological and mechanical properties Al2O3–SiC reinforced Al composites manufactured by casting or P/M

method," Materials and Design, vol. 29, 2008, pp. 2002–2008.

9. K. Kalaiselvan, N. Murugan, Siva Parameswaran, "Production and characterization of AA6061–B4C stir cast composite," Materials and Design, vol. 32, 2011, pp. 4004–4009.
10. T.P.D. Rajan, R.M. Pillai, B.C. Pai, K.G. Satyanarayana, P.K. Rohatgi, "Fabrication and characterisation of Al–7Si– 0.35Mg/fly ash metal matrix composites processed by different stir casting routes," Composites Science and Technology, vol. 67, 2007, pp. 3369–3377.
11. S.A. Sajjadi, H.R. Ezatpour, H. Beygi, "Microstructure and mechanical properties of Al–Al2O3 micro and nanocomposites fabricated by stir casting," Materials Science and Engineering A, vol. 528, 2011, pp. 8765– 8771.
12. S. Tahamtan, A.Halvaee, M.Emamy, M.S.Zabihi, "Fabrication of Al/A206–Al2O3 nano/micro composite by combining ball milling and stir casting technology," Materials and Design, vol. 49, 2013, pp. 347–359.
13. Hisao Uozumi, Kenta Kobayashi, Kota Nakanishi, Tadashi Matsunaga, Kenji Shinozaki, Hiroki Sakamoto, Takayuki Tsukada, Chitoshi Masud, Makoto Yoshida, "Fabrication process of carbon nanotube/light metal matrix composites by squeeze casting," Materials Science and Engineering A, vol. 495, 2008, pp. 282–287.
14. S. Amirkhanlou, B. Niroumand, "Synthesis and characterization of 356-SiCp composites by stir casting and compocasting methods," Trans. Nonferrous Met. Soc. China 20, 2010, pp. 788-793.
15. N. Parvina, R. Assadifard, P. Safarzadeh, S. Sheibani, P. Marashi, "Preparation and mechanical properties of SiC- reinforced Al6061 composite by mechanical alloying," Materials Science and Engineering A, vol. 492, 2008, pp. 134–140.
16. P. Vijaya Kumar Raju, S. Rajesh, J. Babu Rao, N.R.M.R. Bhargava, " Tribological behavior of Al-Cu alloys and innovative Al-Cu metal matrix composite fabricated using stir- casting technique," Materials Today: Proceedings, vol. 5, 2018, pp. 885– 896.
17. D. Roy, S. Ghosh, A. Basumallick, B. Basu, "Preparation of Fe-aluminide reinforced in situ metal matrix composites by reactive hot pressing," Materials Science and Engineering A, vol. 415, 2006, pp. 202–206.
18. A. Ansary Yar, M. Montazerian, H. Abdizadeh, H.R. Baharvandi, "Microstructure and mechanical properties of aluminum alloy matrix composite reinforced with nano-particle MgO," Journal of Alloys and Compounds, vol. 484, 2009, pp. 400–404.
19. Yung-Chang Kang, Sammy Lap-Ip Chan, "Tensile properties of nanometric Al2O3 particulate-reinforced aluminum matrix composites," Materials Chemistry and Physics, vol. 85, 2004, pp. 438–443.
20. Sharma, Satpal Sharma, Dinesh Khanduja, "A study on microstructure of aluminium matrix composites," Journal of Asian Ceramic Societies, vol. 3, 2015, pp. 240–244.
21. Fevzi Bedir, "Characteristic properties of Al–Cu–SiCp and Al–Cu–B4Cp composites produced by hot pressing method under nitrogen atmosphere," Materials and Design, vol. 28, 2007, pp. 1238–1244.
22. A. Baradeswaran, S.C. Vettivel, A. Elaya Perumal, N. Selvakumar, R. Franklin Issac, "Experimental investigation on mechanical behaviour, modelling and optimization of wear parameters of B4C and graphite reinforced aluminium hybrid composites," Materials and Design, vol. 63, 2014, pp. 620–632.
23. Hansang Kwon, Mehdi Estili, Kenta Takagi, Takamichi Miyazaki, Akira Kawasaki, "Combination of hot extrusion and spark plasma sintering for producing carbon nanotube reinforced aluminium matrix composites," Carbon, vol. 4 7, 2 0 0 9, pp. 5 70–5 7 7.
24. S. Sivasankaran, K. Sivaprasad, R. Narayanasamy, Vijay Kumar Iyer, "Synthesis, structure and sinterability of 6061 AA100−x–x wt.% TiO2 composites prepared by high-energy ball milling," Journal of Alloys and Compounds, vol. 491, 2010, pp. 712–721.
25. H. Izadi A., Nolting C., Munro D.P., Bishop K.P., Plucknett A.P., Gerlich, "Friction stir processing of Al/SiC composites fabricated by powder metallurgy," Journal of Materials Processing Technology, vol.213, 2013, pp. 1900-1907.
26. A. Baradeswaran, A. Elaya Perumal, "Study on mechanical and wear properties of Al 7075/Al2O3/graphite hybrid composites," Composites: Part B, vol. 56, 2014, pp. 464–471.
27. R.M. Mohanty, K. Balasubramanian, S.K. Seshadri, "Boron carbide-reinforced alumnium 1100 matrix composites: Fabrication and properties," Materials Science and Engineering A, vol. 498, 2008, pp. 42–52.
28. Alateng Shaga, Ping Shen, Chang Sun, Qichuan Jiang, "Lamellar-interpenetrated Al–Si–Mg/SiC composites fabricated by freeze casting and pressureless infiltration," Materials Science Engineering A, vol. 630, 2015, pp.78–84.
29. C. Milliere, M. Suery, "Fabrication and properties of metal matrix composites based on SiC fibre reinforced aluminium alloys," Materials Science and Technology, vol. 4, 1988, 41-51.
30. Ch.Hima Gireesh, K.G.Durga Prasad, K.Ramji, P.V.Vinay, "Mechanical characterization of aluminium metal matrix composite reinforced with aloe vera powder," Materials Today: Proceedings, vol. 5, 2018, pp. 3289–3297.
31. Hongzhan Yi, Naiheng Ma, Xianfeng Li, Yijie Zhang, Haowei Wang, " High-temperature mechanics properties of in situ TiB2p reinforced Al–Si alloy composites," Materials Science and Engineering A, vol. 419, 2006, pp. 12–17.
32. Mina Bastwros, Gap-Yong Kim, Can Zhu, Kun Zhang, Shiren Wang, Xiaoduan Tang, Xinwei Wang, "Effect of ball milling on graphene reinforced Al6061 composite fabricated by semi-solid sintering," Composites: Part B, vol. 60, 2014, pp. 111–118.
33. M. Tabandeh Khorshid, S.A. Jenabali Jahromi, M.M. Moshksar, "Mechanical properties of tri-modal Al matrix composites reinforced by nano- and submicron-sized Al2O3 particulates developed by wet attrition milling and hot extrusion," Materials and Design vol. 31, 2010, pp. 3880–3884.
34. L. Lu, M.O. Lai, C.W. Ng, "Enhanced mechanical properties of an Al based metal matrix composite prepared using mechanical alloying," Materials Science and Engineering A, vol. 252, 1998, pp. 203–211.
35. B. Ogel, R. Gurbuz, "Microstructural characterization and tensile properties of hot pressed Al–SiC composites prepared from pure Al and Cu powders," Materials Science and Engineering A, vol. 301, 2001, pp. 213– 220.
36. S. Scudino, G. Liu, K.G. Prashanth, B. Bartusch, K.B. Surreddi, B.S. Murty, J. Eckert, "Mechanical properties of Al- based metal matrix composites reinforced with Zr-based glassy particles produced by powder metallurgy," Acta Materialia, vol. 57, 2009, pp. 2029–2039.
37. S. Scudino, G. Liu, M. Sakaliyska, K.B. Surreddi, J. Eckert, "Powder metallurgy of Al-based metal matrix composites reinforced with b-Al3Mg2 intermetallic particles: Analysis and modeling of mechanical properties," Acta Materialia, vol. 57, 2009, pp. 4529–4538.
38. Jingyue Wang,a Zhiqiang Li, Genlian Fan,a Huanhuan Pan, Zhixin Chen, Di Zhang, "Reinforcement with graphene nanosheets in aluminum matrixcomposites," Scripta Materialia, vol. 66, 2012, pp. 594–597.
39. A. Fadavi Boostani, S. Tahamtan, Z.Y. Jiang, D. Wei, S. Yazdani, R. Azari hosroshahi, R. Taherzadeh Mousavian, J. Xu, X. Zhang, D. Gong, "Enhanced tensile properties of aluminium matrix composites reinforced with graphene encapsulated SiC nanoparticles," Composites: Part A, vol. 4, 2014, pp.41-51.
40. S. Sahraeinejad, H. Izadi, M. Haghshenas, A.P.Gerlich, "Fabrication of metal matrix composites by friction stir processing with different Particles and processing parameters," Materials Science & Engineering A, vol.. 626, pp. 507-513.
41. Chu Ke, Jia Chengchang, Liang Xuebing, Chen Hui, "Effect of powder mixing process on the microstructure and thermal conductivity of Al/diamond composites fabricated by spark plasma sintering,"Rare Metals Vol. 29, 2010, pp. 86-91.
42. Cong Zhou, Gang Ji, Zhe Chen, Mingliang Wang, Ahmed Addad, Dominique Schryvers,Haowei Wang, "Fabrication, interface characterization and modeling of oriented graphite flakes/Si/Al composites for thermal management applications," Materials and Design, vol. 63, 2014, pp. 719–728.
43. Manchang Gui, Suk Bong Kang, Jung Moo Lee, "Influence of porosity on dry sliding wear behavior in spray deposited Al– 6Cu–Mn:SiCp composite," Materials Science and Engineering A, vol. 293, 2000, pp. 146–156.
44. Ozge Balc, Duygu Ag˘aog˘ulları, Hasan Gokce, Ismail Duman, M. Lutfi Ovecog˘lu, "Influence of TiB2 particle size on the microstructure and properties of Al matrix composites prepared via mechanical alloying and pressureless Sintering," Journal of Alloys and Compounds, vol. 586, 2013, pp.78-84 .

45. Subrata Kumar Ghosh, Partha Saha, "Crack and wear behavior of SiC particulate reinforced aluminium based metal matrix composite fabricated by direct metal laser sintering process," Materials and Design, vol. 32, 2011, pp. 139–145.

46. A. Daoud, M.T.AbouEl-khair, "Wear and friction behavior of sand cast brake rotor made of A359-20 vol% SiC particle composites sliding against automobile friction material," Tribology International, vol. 43, 2010, pp. 544–553.

47. Barbara Previtali, Dante Pocci, Cataldo Taccardo, "Application of traditional investment casting process to aluminium matrix composites," Composites: Part A, vol. 39, 2008, pp. 1606–1617.

48. C.S. Ramesh, H. Adarsha, S. Pramod, Zulfiqar Khan,"Tribological characteristics of innovative Al6061–carbon fiber rod metal matrix composites," Materials and Design, vol. 50, 2013, pp. 597–605.

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