Mechanical and Tribological Aspects of Aluminium Alloy Composites for Gear Application—A Review

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Abstract This chapter highlights the mechanical and tribological aspects of aluminium alloy composites that may act as a better substitute as a Gear material. It elaborately discusses the impact of mechanical properties (like hardness, impact strength, fracture toughness, etc.), material selection factors (like particulate reinforcement type, proportion, size, geometry, etc.), and tribological factors (like sliding velocity, sliding distance, load, etc.) of such aluminium alloy composites on the sliding performance of Gear. The specific results indicate that selection of particulate reinforcement type, proportion, size, and geometry leads to improvement of the mechanical characteristics of aluminium alloy matrix, which further enhances their sliding wear tribological performance, thereby, justifying their suitability for Gear application. The scholars have to investigate the appropriate mix design specific to certain Gear applications. A carefully designed and tested aluminium alloy composite could be a better alternative for a higher benefit-to-cost ratio.

Keywords Mechanical properties · Sliding wear · Tribology · Aluminum alloy · Alloy composites · Gears

1 Introduction

In our automotive dependent world, where fossil-fuel resources are depleting, cost and fuel economy are significant concerns of consumers when buying a car. Friction is a major concern to vehicle efficiency because it absorbs nearly 10% of the input energy. It has investigated that the use of metal alloy composite for bevel gear, and the life strip of bevel gear is analyzed through stress [1]. This matrix is used in

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aerospace and automobile industries and improved characteristics, i.e. modulus of elasticity, microhardness, tensile strength, and wear resistance of particulate filled aluminum alloy composite [2–5]. Moreover, Savaskan et al. [6] had investigated the effects of nickel reinforcement on the small scale structure of a material, mechanical, and wear behavior of zinc aluminium alloy composite. They reported that the friction of composites slowly decreases after the increase in addition of nickel filler content in metal matrix composite. Further, Qua et al. [7] have studied the tribological characteristics of aluminum 6061 alloy, and found that they were improved using the surface compositing techniques with sub-micro-size ceramic particles and friction stir processing. The surface composting technique was used in an alloy of wrought aluminum (6061-T651) with various sub-micro-sized particles. Thakur et al. [8] who had investigated the influence of varying amount of Ti reinforcement on mechanical properties and microstructure of aluminium alloy composite where Ti particulates were produced by the disintegrated melt deposition (DMD) processing technique followed by hot extrusion. The authors found that the mechanical properties such as elastic modulus, ultimate tensile strength, and yield strength increased, but ductility decreased with the addition of Ti particulates in the Al matrix.

Further, Jiméneza et al. [9] studied the behavior of dry wear of $NiAl_3$-reinforced mechanically alloyed aluminium with different microstructure. They compared the wear resistance of both nickel-containing materials (MA Al–NiS and MA Al–Ni S_2), under variable situations with that of the nickel-free mechanically alloyed aluminum obtained by a traditional sintering cycle. Zhou et al. [10] found that properties and microstructure of in situ created $MgAl_2O_4$ spinel whisker reinforced aluminum matrix composite. $MgAl_2O_4$ spinel whisker reinforced composite was fabricated in situ by a powder metallurgy technique in an Al matrix. The hot extruded $MgAl_2O_4$/Al composite rods were obtained with high relative density. Both Hardness and softening temperature of composites are also increased with increasing content of $MgAl_2O_4$ whisker. The hardness was measured through Vickers microhardness tests, and the mechanism of the reinforcement effect of in situ generated $MgAl_2O_4$ spinel whisker was deduced. Further, Mobasherpour et al. [11] had investigated the influence of nano-sized Al_2O_3 filler on the behavior of mechanically synthesized 7075 aluminum alloy composite. The nano-composite powders were characterized by scanning electron microscope (SEM), transmission electron microscope (TEM), and X-ray diffraction (XRD). They found that the role of nano-sized alumina particles is to increase the crystallite size, lattice strain, density and the hardness, ultimate tensile strength of 7075 aluminum alloy with increasing nano-Al_2O_3 weight percentage at the expense of tensile ductility.

Wang et al. [12] had studied the microstructure and mechanical properties of (Al, $Cr)_3Ti$ based alloy with various Al additions, where this mechanically alloyed composite was fabricated by hot isostatic pressing (HIP). The manufacturing processes are as given: (i) cubic L12 ordered structure with $Al_{67}Ti_{25}Cr_8$ powders was formed by mechanical alloying and annealing process, (ii) X% Al–$Al_{67}Ti_{25}Cr_8$ composites were produced by HIP, where X changes from 5 to 20 in steps of 5. Then, the mechanical properties and microstructure of (Al, $Cr)_3Ti$ based alloy were determined. Sabatini et al. [13] applied plasma electrolytic oxidation (PEO) technique for the surface treatment of wrought AA7075 aluminium alloy and A356 cast alloy to improve wear resistance under sliding and abrasive wear conditions. The performances of the two alloys were compared and the wear behavior of the PEO coatings on these two substrates was determined under condition of micro-scale abrasion (with both SiC and Al_2O3 particles) and dry sliding conditions. Further, Venkataraman and Sundararajan [14] had investigated the wear behavior and sliding friction of aluminum (Al), aluminum alloy 7075 (Al 7075) and SiC_p reinforced aluminum matrix composites (Al-SiC), where they used dry sliding wear conditions, and the characterization was performed using Electron probe micro analysis (EPMA), Energy dispersive X-ray analysis (EDS), and SEM techniques. They concluded that the presence of thin and hard mechanically mixed layer (MML) provides the best wear resistance even though the coefficient of friction will stay high. The disadvantage of providing aluminum-metal matrix composites (AMC's) usually the relatively high cost of manufacturing of the reinforcement materials. These composites were synthesized by cost effective techniques that can be used for various important applications, and (AMCs) with Particulate reinforcement of their isotropic properties and lower cost are attracting researchers. The stir casting process is a liquid state process for manufacturing AMCs at industrial scale, and this method is easier than other techniques.

Metal aluminum gears have been replaced by plastic gears because of their functionality and cost advantages. The use of plastics and composites raises sustainability issues because of the depletion of non-renewable petroleum resources and the pollution that is generated. The limitations of composite aluminum alloy gears relative to conventional gears are that aluminum alloy composite gears are cheaper relative to conventional gear. Composites of aluminum alloy are light in weight relative to metal counterpart. Composite gear can be designed for its strength, hardness, and stiffness. Composites may be brittle hence less efficient under the influence of working environment.

Therefore, the present chapter summarizes the mechanical and tribological characteristics that were observed, and accordingly, different the ories showed the effect of this parameter on tribological state. Moreover, the wear behavior of aluminum alloy metal matrix composite may be realized by analyzing the effect of all these factors on tribological mechanisms encountered by morphology of worn surface composites.

2 Mechanical Characteristics of Metal Alloy Composites

The effect of refractory alloying conditions on mechanical properties of Ni–Al had been investigated by Liu, and Horton [15], where the authors used the fabrication techniques; melting, drop forging, and hot extrusion. Moreover, Subramanian et al. [16] studied the effect of adding aluminum to titanium nitride (TiN) matrix on corrosion resistance and properties of titanium aluminum nitride films coated on AISI 316 stainless steel, silicon wafer, and low carbon steel by reactive dc magnetron sputtering. The XRD, transmission electron microscope-selected area electron diffraction (TEM-SAED) patterns and X-ray Photoelectron Spectroscopy (XPS) analyses were used to determine the AlNi film microstructure. Mechanical properties like hardness and yield strength have increased with adding the Al reinforcement in the composite matrix.

Zheng et al. [17] had investigated the mechanical properties and microstructure of magnesium matrix composites reinforced with aluminum borate whiskers. They investigated the compatibility of the aluminium alloy composite whisker with molten magnesium alloys, and developed more cost effective magnesium matrix composites fabricated by squeeze casting technique. When the volume fraction was more constant than hardness, elastic modulus and tensile strength of the composites are increased. When the volume fractions was constant, elongationwas decreased. Magnesium matrix composites are widely used for aerospace fields, and defense industry. Yu et al. [18] investigated the effect of coating Al_2O_3 reinforcing particles on the interface, and mechanical properties of 6061 alloy aluminum matrix composites. This study was performed to enhance the interfacial properties of the squeeze casting Al_2O_3 powder reinforced 6061Al composites. The comparison of the mechanical properties of coated Al_2O_3/6061Al composite with those of uncoated particles showed that the mechanical properties of coated Al_2O_3/6061Al composite are better. The elongation, ultimate tensile strength, and yield strength are increased as a result of coating Al_2O_3 reinforcing particles. Safavi et al. [19] had investigated that the influence of Al content on the mechanical properties and cold workability of Fe-33Ni-15Co alloy. They found that ductility and toughness decrease with increasing Al content reinforcement in the matrix composite. Thakur et al. [20] studied the effect of varying amounts of Ti reinforcement on the mechanical properties and microstructure of Al based composite, which was fabricated by the disintegrated melt deposition (DMD) processing technique followed by hot extrusion. They found that the mechanical properties such as ultimate tensile strength, yield strength, and elastic modulus increased, but ductility decreased with adding Ti particulates in the Al matrix.

Bhingole et al. [21] had studied the processing, microstructure, and behavior of ultrasonically processed in situ $MgO–Al_2O_3–MgAl_2O_4$ distributed magnesium alloy composites. Microstructure of the composites was characterized for the uniformity in the distribution of reinforcement particles. Further, it was found that the mechanical properties such as hardness, yield strength, and strain-hardening exponent grow with the mixing of filler contents in matrix composite and related to mechanical properties. The dry sliding wear behavior was also evaluated over a range of loads, and the operating wear mechanisms are analyzed. Mordyuk et al. [22] studied the evaluation of the wear resistance of Al–6Mg alloy plates after reinforcement of sub-surface layers with QC $Al_{63}Cu_{25}Fe_{12}$ particles by the ultrasonic impact treatment (UIT). XRD and SEM represented that the layers of 40–50 μm thickness were produced by process which contain homogeneously dispersed fine (0.5–3 μm) or coarse (15 μm) particles, with the values of volume fractions 9% and 22%, respectively. It was also found that microhardness is affected by grain/crystallite size of the matrix alloy composite.

Stein et al. [23] studied first the effect of the multi-walled carbon nanotubes (MWCNT) concentration on the mechanical properties of carbon nanotubes (CNT)/AA5083 composites and compared their results with analytical models. Second they studied the reinforcement with MWCNT and single-walled carbon nanotubes (SWCNT). They determined the optimal content of CNT in order to achieve enhanced mechanical properties of AA5083 aluminium alloy matrix composites. Merhy et al. [24] investigated the Crack growth of A356-T7 aluminum alloy under thermo-mechanical fatigue loading. The important variables generating the fatigue crack propagation and relative contributions were calculated. He et al. [25] reported that the Al_2O_3-CeO_2/Ni-base alloy composite coatings prepared on aluminum alloy 7005 which were prepared by plasma spray. They investigated the mechanical performance, wear properties, and microstructure of the composite coatings, and improved the wear resistance of Ni-base alloy coatings. Akbari et al. [26] had studied the fracture behavior and mechanical properties of nanometric Al_2O_3 particle-reinforced aluminium alloy (A356) composite, and focused on the parameters of vortex method. Nano-Al_2O_3 particles were milled separately with the powders of copper and aluminum then incorporated into aluminum alloy and used to fabricate A356/1.5 vol. % nano-Al_2O_3 composites.

Lee et al. [27] investigated the high temperature impact properties and microstructural evolution of 6061-T_6 aluminum alloy. The deformation behavior of 6061-T6 alloy was determined at strain rates in the range 1×10^3–5×10^3 s^{-1}, and temperatures range 100–350 °C using a compressive split-Hopkinson pressure bar (SHPB). Karakulak et al. [28] studied the influence of nickel content on the hardness and microstructure of the Al–Cu–SiC composite alloys. They found that the wear properties of Al–Cu–SiC–xNi composite alloys which were determined under dry sliding conditions were affected. The hardness increased with the increase of nickel content, but the wear resistance reached a maximum with Ni addition at 1 wt.%Ni. The corrosion behavior of Al–Cu–SiC–xNi composite alloys was investigated using potentiodynamic polarization, impedance spectroscopy, and chronoamperometric methods, and corrosion resistance was improved with the increase of Ni content. Zhao et al. [29] investigated the development of silicon carbide (SiC) nano-particulate reinforced AlON composites through the change of SiC content. And it was determined that with increasing addition of SiC particles up to 8 wt.%, the relative density, hardness, Young's modulus, flexural strength, and fracture toughness all increased moderately, but when the addition of SiC nano-particles reached 12 wt.% all of these mechanical properties decreased. Skan et al. [30] studied the influence of silicon content on the tribological and mechanical properties of monotectoid-based zinc–aluminum–silicon alloys. The tensile strength and hardness of the alloys were found to increase with the addition of filler silicon content in the matrix. They found that friction coefficient and wear rate of the alloys decrease with the increase in silicon content up to 2 wt. % Si. It was also found that the wear behavior of the Zn–Al–Si alloys correlates strongly with their hardness, tensile strength, and friction coefficient. Jiméneza et al.

[31] studied the dry wear of $NiAl_3$-reinforced mechanically alloyed aluminum with different microstructure. They compared the tribological resistance of both nickel-containing materials (MA Al–NiS and MA Al–Ni S_2), under variable conditions, where the nickel-free mechanically alloyed aluminum, MA Al S, was obtained using a traditional sintering cycle and used as a reference.

Savaşkan et al. [6] investigated the influence of nickel addition on the mechanical properties and microstructure, lubricated friction, and wear behavior of Al–40Zn–3Cu alloy, and determined the most suitable alloy composition (with nickel addition) for their tribological applications. They also found that the wear volume of the alloys exhibited a gradual decrease following an initial increase with increasing percentage of nickel. Qu et al. [32] improved the tribological properties of aluminum 6061 alloy using surface compositing with sub-micro-size ceramic particles through friction stir processing. They applied the surface composting technique in a wrought aluminum alloy (6061-T651) with two different sub-micro-size ceramic particles and characterized of the processed composite surface. Chen et al. [33] investigated the room temperature mechanical properties of Al–8.5Fe–1.3V–1.7Si/15 vol. % SiC_P composite sheet (where the subscript p refers to particulates) produced using a spray deposition (SD)-rolling process. They determined the micro-structures, density, and rigidity. Joel Hemanth [34] studied the influence of presence of nano particulates ZrO_2 particulates in Al matrix, and the effect of its increasing amount on the mechanical response and microstructure of standard LM 13 Al alloy. They found that the presence of nano-ZrO_2 particles in the Al matrix significantly improves hardness, strength, and fracture toughness, but slightly reduces the ductility. Also they observed that the thermal and electrical tests developed on the composite indicate that both electrical resistance and thermal conductivity decreased with increasing the reinforcement content.

Yar et al. [35] studied the mechanical properties and microstructure of aluminum alloy matrix composite with nano-particle MgO as the reinforcement, where reinforced A356.1 alloy was fabricated by stir casting method. Nano-particle MgO, wrapped in aluminum foil, was incorporated into the molten metal, at various temperatures. Simultaneous stirring of molten metal at constant stirring rate was also employed. Reinforcement content and optimum casting temperature were found by investigating mechanical properties and microstructure. Onat [36] investigated the mechanical properties, micro structural features, and dry sliding wear properties of Al–4.5Cu–3 Mg/15 vol. % SiC_p matrix composites, synthesized by squeeze casting technique. The improvement of dry sliding wear characteristics of Al–4.5Cu–3 Mg matrix composites reinforced with SiC particles at different loads and speeds has been investigated. Tang [37] studied the mechanical/thermal stress intensification for mode II crack tip: Fracture initiation behavior of steel, titanium, and aluminum alloys. Also, how the thermal stress affects the fracture behavior, and in what cases the heat flow enhances or retards the crack propagation are analyzed and discussed.

Panagopoulos et al. [38] studied the surface mechanical behavior of Ni–P–fly ash coatings containing various amounts of Fe, and deposited by electroless deposition technique on zincate coated 5083 wrought aluminium alloy substrates. They found that these coatings higher hardness and roughness compared to Ni–P/zincate coatings, and the frictional coefficient of Ni–P–fly ash/zincate coating/stainless steel is less than that of 5083 aluminium alloy/stainless steel. Abdizadeh etal. [39] have investigated that the effects of sintering temperature and content of zircon on some mechanical and physical properties, such as microstructure, morphology, yield strength, compression strength, elongation, and density of an aluminium/zircon silicon oxide ($Al/ZrSiO_4$) composite produced by powder metallurgy techniques.

Sajjadi et al. [40] have investigated the behavior of mechanical aluminum alloys reinforced by micro and nano hard particles such as aluminium oxide and silicon carbide. The nano and micro composites were synthesized by two techniques; stir-casting and compo-casting. The structure was determined by optical (OP) microscope and scanning electron microscope (SEM). Further, they also studied the mechanical properties like yield, compression, and ultimate tensile strength of the composite and found that they increase with increasing aluminium oxide percentage because of the increasing load stress. Further, Liu et al. [41] had studied the aluminum matrix composites reinforced with various percentages of multi-walled carbon nanotubes produced by friction stir processing (FSP) technique. The microstructure was determined by the optical microscope (OM), transmission electron microscope (TEM), and SEM. It was found that the microhardness and tensile strength of MWCNTs/Al composites gradually increase with increasing MWCNT content, but the elongation decreases. Zhou et al. [10] had studied the properties and microstructure of in situ produced magnesium aluminates ($MgAl_2O_4$) spinel whisker reinforced aluminum matrix composites, which were produced using the powder metallurgy technique. The as-prepared composites were hot extruded and magnesium aluminates/aluminum composite rods with more relative density were obtained. Hardness and softening temperature of the composites were increased with increasing the content of magnesium aluminates whisker. The hardness, thermal behaviors are determined by Vickers microhardness test and coefficient of thermal expansion (CTE) measurements respectively, while wear resistance was determined by abrasive wear tests. The mechanism of the reinforcement effect of in situ generated $MgAl_2O_4$ spinel whisker was determined too.

Pengting et al. [42] had studied a new Al–3Ti–1B–0.2C master alloy which was prepared by the melt reaction method. They investigated the grain refining performance of the master alloy on the A356 alloy. The mechanical properties of aluminium alloy A356 including the ultimate tensile strength, yield strength, and elongation had been improved with the addition of the master alloy. The master alloy showed high grain refining efficiency and stability. It could be used for industrial application such as cast aluminum alloys. Further, Selvam et al. [43] had studied the effect of fly ash content on the mechanical properties and microstructure of AA6061/fly ash aluminum metal matrix composites (AMCs). Aluminum alloy AA6061 filled with fly ash particles was fabricated by the combocasting method. The microstructures of the (AMCs) were analyzed using SEM. The microhardness and tensile strength of the AMCs increased with the addition of fly ash particles in metal matrix composite, and higher ultimate tensile strength (UTS) was obtained compared to unreinforced AA6061 alloy. Mobasherpour et al. [11] studied the effect of nano-size aluminium oxide filler on the mechanical behavior of synthesis 7075 aluminum alloy composites by mechanical alloying. The nano-composite powders were characterized by SEM, TEM, and XRD. They investigated the role of alumina hard nano-sized particle reinforcement on the crystallite size, lattice strain, density, hardness, and mechanical properties, and found that the ultimate tensile strength and hardness of the Al 7075 nano-Al_2O_3 tend to increase with increasing nano aluminium oxide volume content at the expense of tensile ductility.

Hamid et al. [44] had studied the surface mechanical properties and microstructure of electrodeposited Ni coating on aluminium alloy composite Al 2014. The authors modified the surface of Al 2014 using electrochemical deposition of Ni, and concluded that electrochemical deposition combined with heat treatment can be used to enhance the surface mechanical properties of aluminium alloys. They also determined the electrochemical conditions and the heat treatment method under which compact, uniform, and adherent Ni coatings can be obtained on aluminium alloy Al 2014. Moreover, Zhang et al. [45] had investigated the mechanical properties and microstructure of multiphase coating deposited by plasma nitriding GB-5083 aluminum alloy coated by Ti. The authors developed this method to manufacture multiphase coatings containing both nitride and intermetallic on GB-5083 aluminium alloy to harden its surface properties. Their method consists of two steps, i.e. producing pure Ti film on the GB-5083 aluminium substrate, and post plasma nitriding the Ti coated substrate. Furthermore, Arik [46] had studied the influence of the process of mechanical alloying on mechanical properties of aluminum-based composite materials reinforced with α- silicon nitride (α-Si_3N_4). The mixture of Al and α-Si_3N_4 powders was prepared using two different methods, namely; mechanical alloying, and conventional mixing. The effect of some variables, such as sintering temperatures, the amount of silicon nitride, and the preparation of the starting powders on the mechanical properties of the produced Al matrix composite materials were observed and investigated.

Further, Wang et al. [47] had studied the mechanical properties and microstructure of $(Al,Cr)_3Ti$ based alloy with various Al additions. The composites were manufactured by hot isostatic pressing (HIP). The manufacturing technique used by these authors to fabricate $(Al,Cr)_3Ti$ based alloys by additions of Al was (mechanical alloying (MA) + hot isostatic pressing (HIP)). The followed processes are given as (i) cubic L12 ordered structure $(Al,Cr)_3Ti$. which was made by mechanical alloying and annealing process, (ii) Al–$(Al, Cr)_3Ti$ composites which were fabricated by HIP. The mechanical properties and microstructure of $(Al,Cr)_3Ti$ based alloy were determined. Panagopoulos et al. [48] investigated the mechanical behavior of Zn–Fe alloy coated mild steel samples. The ultimate tensile strength of Zn–Fe coated mild steel was less than that of the bare mild steel. The ductility of Zn–Fe coated mild steel was found to decrease significantly with increasing Fe content in the coating.

Devaraju et al. [49] found that the effect of filler particles and rotational speed on the mechanical properties and wear of aluminum alloy 6061-T6/(SiC + Al_2O_3) surface hybrid composites. These hybrid composites were synthesized by the use of friction stir processing (FSP), and Taguchi method was used to obtain the optimum rotational speed and volume percentage of filler particles for improving the mechanical properties and wear of the surface hybrid composites. The filler particles (i.e. SiC and Al_2O_3) decreased in size (~5 μm) than the as received particles size, and the wear resistance at optimum condition improved. The mechanical properties and wear were found to be correlated with microstructures and worn micrographs [50]. Further, Zheng et al. [51] had studied that mechanical properties and microstructure of aluminum alloy matrix composites reinforced with Fe-based metallic glass particles. This composite was synthesized by the powder metallurgy method.

Zadeh et al. [52] had investigated the structural and mechanical characterization of aluminium based composite which was reinforced with heat treated aluminium oxide particles. The aluminium oxide particles were heated at 1000 °C, and x-ray diffraction (XRD) was used to characterize the structure of Al_2O_3 during heat treatment. Scanning electron microscope (SEM) was used to determine the size and shape of the Al_2O_3 grains. The compression strength of the aluminum with 1 wt.% aluminum oxide was found to increase while adding Al_2O_3 heat treated particles to A356 metal matrix.

Taleghani et al. [53] had investigated the mechanical and microstructural characterization of 7075 aluminum alloy consolidated from a premixed powder using cold compaction and hot extrusion. To avoid the effects of microstructural differences between various parts of the extrudates, all of the samples were cut from the center of each extruded rod [54]. The extruded samples were characterized using SEM and XRD techniques. Ozdemir et al. [55] had investigated the effect of forging on the properties of particulate-silicon carbide reinforced aluminum-alloy composites. The mechanical properties of these composites reinforced with particulate SiC were investigated under foundry conditions. The effects on the mechanical properties after forging were found to increase with yield strength, and improvement of tensile strength, but ductility decreased with the addition of the particulate reinforced SiC in the metal matrix composites up to an optimum reinforcement volume fraction.

Chou et al. [56] had investigated the effects of the composition on the homogenized analysis and physical properties. In addition, the microstructure and uniform properties analysis of the composites are observed. The aluminum alloy composites A356, 6061, and 1050 are infiltrated into the porous aluminum oxide (Al_2O_3) performs which were formed by sintering, by squeeze casting to make Al_2O_3/A356, Al_2O_3/6061, and Al_2O_3/1050 composites.

Figure 1a, b and Table 1 show a summary of the mechanical properties and the effects of various fillers on mechanical properties of aluminium composites from literature. It is found that the 12 wt.% SiC/AlON tensile strength is higher than other fillers of composite. The 5 wt.% B_4C flexural and compressive strength is maximum compared to other particulate fillers. Hardness of composites increases with increasing various filler contents. Hardness of composite is higher at 6 wt.%Al_2O_3 compared to other reinforcements. Similar results were reported by various materialists [6, 22, 36]. Therefore, this chapter shows that the mechanical properties of metal matrix composite were improved by reinforcements.

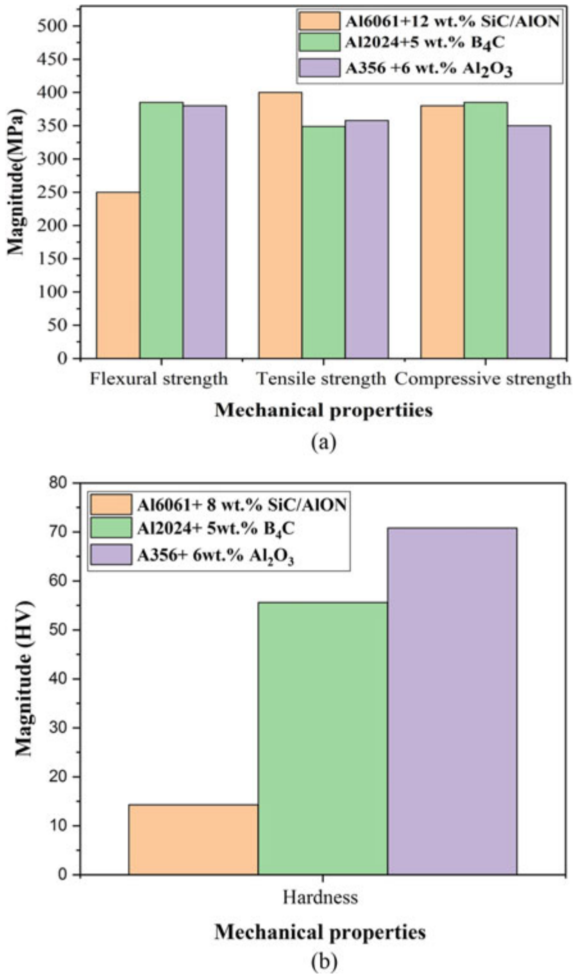

Fig. 1 Comparative studies of mechanical properties of aluminum alloy composite. **a** Flexiral, tensile, and compressive strengths. **b** Hardness [19, 29, 33]

3 Tribological Behavior

3.1 Effect of Wear Parameters

3.1.1 Normal Load

Zhiqiang et al. [57] had discovered that wear loss of both the aluminium alloy matrix as well as composite samples increase with increasing the applied load. The authors had found that the frictional coefficient of the composite specimen is less than that of the aluminium alloy matrix upto a load of 65 N and vice versa. At a load of 50 N, the transition of the tribological conditions of aluminium alloy matrix takes place,

Table 1 Comparative studies on mechanical properties of aluminum alloy composite [19, 29, 33]

Composition	Hardness (HV)	Flexural strength (MPa)	Tensile strength (MPa)	Compressive strength (MPa)
Al6061 + 0% Sic/AlON	13.5	300	325	225
Al6061 + 4% SiC/AlON	13.8	330	350	300
Al6061 + 8% SiC/AlON	14.3	400	375	337
Al6061 + 12% SiC/AlON	10.5	250	400	380
Al2024 + 0%B_4C	20.4	400	250	270
Al2024 + 1%B_4C	28.7	430	270	290
Al2024 + 2%B_4C	35.8	456	290	310
Al2024 + 3%B_4C	46.9	500	330	350
Al2024 + 5% B_4C	55.6	525	349	385
A356 + 0% Al_2O_3	25.7	275	350	290
A356 + 2% Al_2O_3	29.4	325	340	310
A356 + 4% Al_2O_3	38.9	360	356	320
A356 + 6% Al_2O_3	70.8	380	358	350

while wear resistance of the composite specimen was improved in comparison to that of the alloy specimens. At this condition, the wear loss rises suddenly for the metal alloy matrix composite. Therefore, the AMCs reinforced with 9 wt.% SiC possess greater wear resistance than the matrix alloy [58]. These results were also found by Rajeev et al. [59] who had investigated the wear of aluminium composites reinforced with 15 wt.% silicon carbide contents and found that specific wear rate increases as the normal load increases in the range 60 N–120 N. During the manufacturing of composite specimens, aluminum alloy gets in SiC particles and coefficient of friction decreased with the increase in the applied load value of up to 98 N and this condition was assigned to the presence of trio layers within a specific normal load.

Similar findings were reported by Baradeswarm et al. and Ravindran et al. [60, 61]. The increase in the wear rate with increasing load may be related to the more plastic deformation of wear surface under highest load. Kumar and Dhiman [62] had observed different wear mechanism during the analysis of hybrid composite and unreinforced alloy under condition of sliding wear (for a load range of 20–60 N). The transitional load was also reported by the researchers for all the specimens. They have also found that the hybrid composites showed higher wear resistance than those of the alloy matrix over the complete range of the applied load. Rajmohan et al. [63] and Radhika et al. [64] had found that the wear rate improved with a growing applied load value for all of the composite samples. The wear performance of hybrid composite has been analyzed by the analysis of variance technique, and it shows the effect of very important controllable parameters. In these investigations the load has been observed as a significant contributor in wear behavior of composites. It was found that the wear mechanism of the particulate reinforced hybrid composite is different from the adhesion to pure abrasion with the improvement of the normal load value. Furthermore, Umanath et al. [65] found that wear rate of the composite increases with increasing load from 40 to 60 N. The authors found that the decrease of the load decreases the force of friction, and increasing the load, reduces the hardness and increases the wear rate.

Further, Murakami et al. [66] investigated the wear properties and friction when sliding against aluminum alloy 5052 pin samples during unlubricated conditions at 823 K in air. Si_3N_4–8 mass % Al_2O_3–6 mass% Y_2O_3, AISI 52,100 steel, ZrO_2–3 mol.% Y_2O_3, WC-6 mass% Co were chosen as disk materials, because they were used as sliding materials. Moreover, the worn surfaces of the disk and pin samples were observed by scanning electron microscopy (SEM). Howell and Ball [67] had studied the sliding wears of alloys with particulate-reinforced against friction materials. They reported that the effect of contact pressure, and sliding velocity on the friction and wear mechanisms occurs at the sliding interface. Rao et al. [68] studied the influence of heat treatment on the sliding wear of aluminum alloy (Al–Zn–Mg) hard particle composite. They reported that during varying applied load and sliding speed, where the authors emphasized on variables like wear rate, temperature rise, coefficient of friction, and seizure pressure. The sliding wear of 7009 alloy, especially compared to 7009 alloy with silicon carbide composite was missing even though it has good strength for use as airplane structural sheets, and armor materials. Daoud and Khair [69] studied the influence of speed and load on the wear and frictional behavior of brake rotor fabricated from alloy A359 with 20 Vol. % SiC particle composites sliding against the automobile friction material. The dry wear behavior and sliding friction were determined in a pin-on-disc apparatus. The composite was prepared by the use of the stir casting technique. The wear debris and worn surfaces were checked for their chemical characterization and morphology using SEM provided with energy dispersive X-ray (EDX) analyzer. Ramesh et al. [70] had investigated wear behavior and friction of nickel phosphorus (Ni–P) coated silicon nitride (Si_3N_4) reinforced Al6061 alloy composites. Dry sliding friction and wear tests were examined using pin-on-disk apparatus. Al6061–Ni–P–Si_3N_4 composites exhibited reduced wear rate and coefficient of friction compared to the matrix alloy, but increased wear resistance.

Jha et al. [71] had studied the sliding wear behavior of aluminum syntactic foam (ASF), where they made a comparison with the wear behavior of 10 wt.% silicon carbide (SiC) particle-reinforced aluminum matrix composite (AMC). The experiment was performed under dry and lubrication conditions using the pin-on-disc

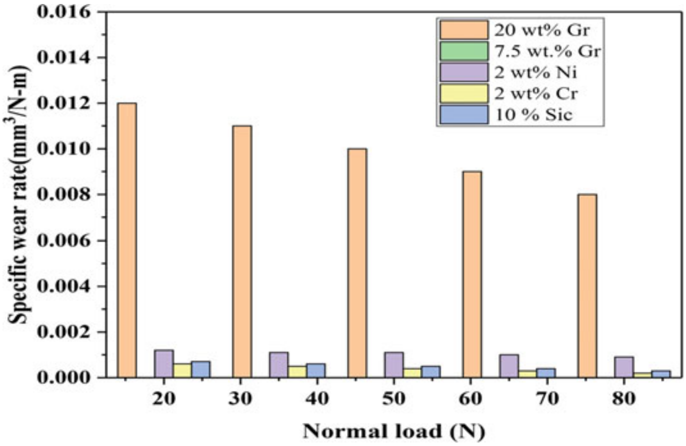

Fig. 2 Comparative studies of influence of normal load and reinforcement type on specific wear rate [57–65]

machine. And tribological properties such as wear rate, the frictional coefficient, and the frictional heating were determined and discussed. It was reported that wear rate, friction coefficient, and temperature rise of (ASF) were smaller than those of (AMC) in both dry and lubricated conditions. Moreover, Zhu et al. [72] had studied the dry sliding friction and wear characteristics of in situe composites (Al_3Zr + α-Al_2O_3)/Al at high temperature, using of the pin-on-disc machine. The wear resistance of the composites was found to be increasing by the increase of the reinforcement volume fraction. Figure 2 shows the influence of load on specific wear rate of aluminum alloy composite, and it was found that various reinforcements show different specific wear rates with load. It was found that 20 wt.% Gr specific wear rate is good compared to the other fillers. Summarizing the effect of applied normal load on the tribological behavior of aluminum alloy composites, it could be said that wear mechanism of composites acts by different load dependent zones. This area was further investigated to be based upon the interaction of applied normal load with several other variables [48–72]. Further, normal load has been found by almost all the researchers, giving details about the safe loading conditions and working areas for an individual composite.

3.1.2 Sliding Velocity

Zhiqiang et al. [57] investigated the effects of sliding velocity on weight loss and frictional coefficient of silicon particles reinforced aluminum matrix composites and noted increasing trend with increasing the sliding speed. Ravindran et al. [61] also found that the wear loss of powder metallurgy based Al 2024/5 wt. % SiC/x wt.% Gr (x = 0, 5, 10) composites was decreasing with increasing sliding velocity (up to a transition velocity of 5 m/s). Therefore, the Al 2024/5 wt.% SiC/5 wt.% Gr composite showed smallest wear loss among all specimens of the composite. The authors [61] made analysis of variance (ANOVA) table to determine the order of significant factors and their interactions and found that the sliding speed effect on the wear behavior was 12.43%, and the effect of sliding speed on frictional coefficient was 8.86%. The reduction in wear of the composites may be related to the presence of solid lubricant (graphite) particles in the composites, which form a tribo-layer on the wear contact surfaces. Kumar and Dhiman [62] had also found that the specific wear rate of unreinforced alloy (Al 7075) and composite (Al 7075/7 wt.% SiC/3 wt.% Gr) reduced with increasing the sliding speed (up to 4 m/s) for few normal load conditions (20–40 N). Therefore, the specific wear rate of both materials was changed, i.e. the weight loss increased with sliding speed. But, under more loads (40–60 N), the unreinforced alloy seized at a speed of 6 m/s due to the combination of abrasion and delaminating wear, when severe wear was reported on the composite (without a seizure). However, the transitional speed of 4 m/s was reported, beyond which the wear raised rapidly for all specimens.

Further, Ramachand and Radhakrishna [73] had studied the effect of fly ash reinforcement on corrosive behavior, sliding wear, and slurry erosive wear of aluminum matrix composite and the aluminum alloy composites which were synthesized by the use of the liquid metallurgy route. However, the sliding wear of the metal matrix composite were obtained by various parameters like normal load, percentage fly ash, and track velocity, and sliding wear behavior was investigated using pin-on-disc wear testing machine. The worn surfaces are observed using scanning electron microscope and it was observed that wear resistance of fly ash reinforced material increased with increasing fly ash content, but decreases with increasing the normal load, track velocity. Corrosion wear had increased with the addition of particulate reinforced fly ash of the composite. Also it was observed that the magnitudes of wear and frictional force increase with increasing the normal load and sliding velocity. These findings are consistent with the those obtained by Lee et al. [74] had investigated dry sliding wear of the micro-arc oxidation (MAO) coating applied on aluminum matrix composites A356/20 vol.% SiC_p composites with and without surface coating. The samples were tested using pin-on-disc wear test apparatus in the temperature range 25–180 °C with different sliding velocities, and applied load. The authors studied the feasibility of more improvement of wear behavior for alloy composites by MAO coating technique. The variation of wear rate with the applied load and sliding speed for uncoated and MAO-coated specimens were tested at room temperature for constant sliding distance of 1500 m. It was observed that the wear rate increases with increasing applied load and sliding speedy regardless coating thickness.

Figure 3 shows the influence of sliding velocity on specific wear rate of aluminum alloy composite with various types and quantities of reinforcements. It is reported that the 15 wt.% SiC of specific has the best wear rate than other fillers, and the lowest wear rate is that of the 2 wt.% Co filler. Similar studies are reported by various researchers in above literature [57–62].

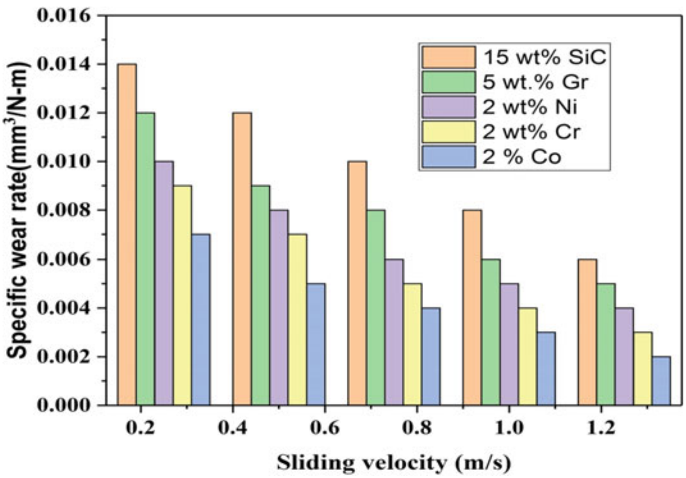

Fig. 3 Comparative studies of the effect of sliding velocity on specific wear rate for different types and quantities of fillers [57–62]

It has been uncovered from the literature review that the kind of counterpart and load variation may outcome in conflicting outcomes [57, 59, 63, 64]. From these investigates, it is not possible to get a general relationship between the wear of composites and sliding velocity (0–5 m/s). In general, one can say that as the surface of wear track comes in contact with the counter face during initial run-in-period, the wear rate of aluminium alloy composite has also increased. Yet, the wear rate obeys decreasing pattern with enhanced velocity. It may be related to temperature increase and tribo-layer formation (based on interaction with other variables) up to the transition limit. Moreover, the tribo-layers are divided and metal-to-metal contact begins. At larger sliding speed, more frictional heat was generated which causes localized melt and more plastic deformations. These factors contribute to remove materials from the wear surface, and the wear tracks have been clearly noticed in some of the examinations [63, 64].

3.1.3 Sliding Distance

The weight loss was approximately linearly related with the sliding distance, which is the repeated trend followed by wear type characterized by tribo-chemical reaction, mainly when oxidation of the matrix occurs. The wear resistance increases with increasing the sliding distance owing to shear force, and micro-cutting by the hard asperities of the counter face material, then the matrix alloy will deform and when the sliding distance increases, frictional heat between pin and disk surface also increases. The wear rate increases with increasing the sliding distance because of the increase of temperature and cracking of the composite specimen [57–60].

Ravindran et al. [61] have investigated the wear loss and frictional coefficient of Al 2024–5 wt.% SiC-x wt.% Gr (x = 0, 5, 10) composites increase with increasing sliding distance. By using ANOVA they found that sliding distance had the largest influence on wear loss, with percent of significance (p = 57.12%).

Further, Kumar and Dhiman [62] had investigated sliding wear behaviors of the hybrid composite and 7075 aluminium alloy at small speed (2–6 m/s) and small load (20–60 N) combinations. They reported that for combination of small speed (2–4 m/s), and small loads (20–40 N), the specific wear rate follows a reducing trend with increasing the sliding distance in the range 2000–4000 m. According to them this may be related to initial association between the two surfaces through large number of sharp asperities and the contact between the two surfaces was made by these points.

Toptan et al. [75] had reported the effects of B_4C volume fraction, sliding velocity, sliding distance, and applied load on dry sliding wear behavior of aluminium alloy matrix composites reinforced with 15 and 19 vol.% B_4C_p which were fabricated by squeeze casting route at 850 °C under low vacuum. In their study, they used a general full factorial experimental design. The authors determined the effects of the mentioned factors and interactions on the average frictional coefficient values, and value of wear rate combine in composite specimens and counter materials. Regarding the sliding distance, they reported that the frictional coefficient and wear rates increased with increasing the value of sliding distance. Moreover, they reported that the values of frictional coefficient were almost linearly increasing during sliding distance. Further, Sarmadi et al. [76] had also studied the influence of graphite content on the value of frictional coefficient, and wear loss for metal composites and Copper–graphite composites, which were synthesized by the use of friction stir processing technique. The friction and wear behavior of the composites were tested by a pin-on-disc tribometer. In Fig. 13 of Ref. [76] the wear weight loss was plotted versus sliding distance in the range 0–1000 m for specimens of different graphite content, and the figure shows that wear weight loss increases with the increase in sliding distance.

Basavarajappa et al. [77] had studied the influence of sliding speed, sliding distance, and normal load on dry sliding wear behavior of the Al/SiC_p and Al/SiC_p–Gr composites, which were fabricated by liquid metallurgy route, where the Taguchi experiments were used for collecting data. An orthogonal array and analysis of variance were utilized to get the percentage of influence of various parameters on dry sliding wear of the composites and the alloy composites with particulate SiC and graphite (Gr) particles [78]. It was observed that graphite particles were effective factors in increasing dry sliding wear resistance of Al/SiC_p composite. Baskaran et al. [79] had investigated the sliding wears behavior of in situe casted aluminium alloy AA7075 reinforced with 4 wt.% and 8 wt.% tin carbide TiC fabricated by the use of reactive in situ casting technique, where Taguchi technique was used. The wear behavior was obtained using a pin-on-disc tribometer machine, and they examined the significance of the effect of filler percentage, sliding velocity, sliding distance, and load on the sliding wear behavior of the fabricated composites using ANOVA analysis. They found that load and sliding velocity with percentage contributions of

50.09% and 31.26% respectively are the most effective, on sliding wear behavior, while sliding distance is insignificant with very small percentage contributions.

Also Kiran et al. [80] had investigated the parameters that influence the wear behavior of heat treated zinc alloy (ZA-27), and zinc alloy/silicon carbide-germanium (ZA-27/9SiC–3Gr) by Taguchi technique. Zinc based alloy and composite particulate with SiC_p (9 wt. %) and Gr (3 wt. %) were manufactured by stir casting method, and wear behavior was analyzed using a pin-on-disc apparatus. The influence of various parameters likes, sliding speed, load, and sliding distance on wear behavior were determined using analysis of variance (ANOVA), and wear mechanism of the worn surface was analyzed using scanning electron microscopy. They found that load is the most important parameter in causing wear in the case of the alloy followed by sliding distance, then sliding speed. Similarly for composites the most significant is the load, followed by sliding speed, and sliding distance.

Further, Jin et al. [81] had investigated the friction and wear characteristics of $Mg_2B_2O_5$ whisker reinforced aluminium 6061Al matrix composite produced by power ultrasonic-stir casting process. The ball-on-disk wear testing machine was used under dry sliding conditions. It was reported that the wear rate of the $Mg_2B_2O_5$ whiskers coated with ZnO reinforced aluminum matrix composites was the smallest among the materials. They reported that the frictional coefficients of the matrix and composites were gradually decreasing and remained stable with the increase in the sliding distance and sliding time. Jiang et al. [82] had studied the friction and wear properties of in situe synthesized aluminium oxide reinforced alloy composites. These composites were manufactured by powder metallurgy and in situ reactive synthesis method. The influence of various parameters sliding speed, load, and long-time continuous friction on friction and wear properties of $Al-5\%\ Si-Al_2O_3$ composites were studied. The authors found that the frictional coefficient and wear loss increased with the increase of the sliding distance. Alidokhta et al. [83] had investigated the microstructure and wear behavior of friction stir processed cast aluminum alloy (A356), where the composites were synthesized using friction stir process, and dry sliding wear tests were performed on a pin-on-disc apparatus. They observed that the wear mass loss increases with increasing sliding distance, and the extent of wear is significantly lower in friction stir processed A356 when compared with the as-cast A356. The wear rate was found to decrease with sliding distance, but it is larger in the case of as-cast A356.

Baradeswaran and Elaya Perumal [84] had investigated the influence of graphite on the tribological and mechanical behavior of Al 7075 composites under dry sliding conditions. The composites were synthesized using liquid casting method. They evaluated the optimum amount of graphite added in Al 7075 for the minimum wear rate. In addition to other results they reported that the wear mass loss decreases with the increase in sliding distance, while wear rate increases with increasing sliding distance. Thangarasu et al. [85] have reported the effect of TiC particles of various volume fractions on dry sliding wear behavior and microstructure of AMCs. TiC were used as reinforcement to make AMCs due to its hardness and its elastic modulus. These composites were produced by the use of friction stir processing (FSP) method. The microstructure of AA6082/TiC AMCs was examined by the optical spectroscopy and the scanning electron microscope (SEM), and sliding wear behavior was performed by using a pin-on-disk apparatus. Their data in Fig. 5a shows that the weight loss approximately increases with the increase of sliding distance but in two stages (before 500 m, and after 500 m), while Fig. 5b in their work shows that the rate of wear fluctuates and shows maxima and minima with sliding distance.

On the other side, Radhika et al. [64] had reported a reduction in the wear rate as well as the frictional coefficient within selected values of sliding distance, which may be related to the presence of hard alumina particles, which produce abrasion resistance. The researchers had reported various regions while considering the effect of sliding distance on wear behavior of the composite.

Figure 4 shows a comparative plot of sliding distance and several particulates on the specific wear rate of aluminum alloy composite. It was found that the specific wear rate decreases with the increasing the sliding distance. The SiC_p reinforcement wear rate is higher than those of the other reinforcing particulates. These results are also dependent on the interaction of sliding distance with other parameters. As the numerical values of another variable change, wear performance of the composites changes too. The abrasion was the normal mechanism which had been reported for the composites with an increasing distance. The research [64] also disclosed that sliding distance is the most influential variable with contribution of 46.8%, and the contribution of sliding distance to the friction coefficient is (50%). As far as the influence of sliding distance on the tribological behavior of aluminum alloy composite is concerned, some of the investigators had found initial-run-in period during the wear investigations [61, 62]. However, some had found the initial-run-in stage for the AMCs [57, 59, 64]. However, the contradiction in outcomes may be a remark to the interaction of sliding distance with other variables.

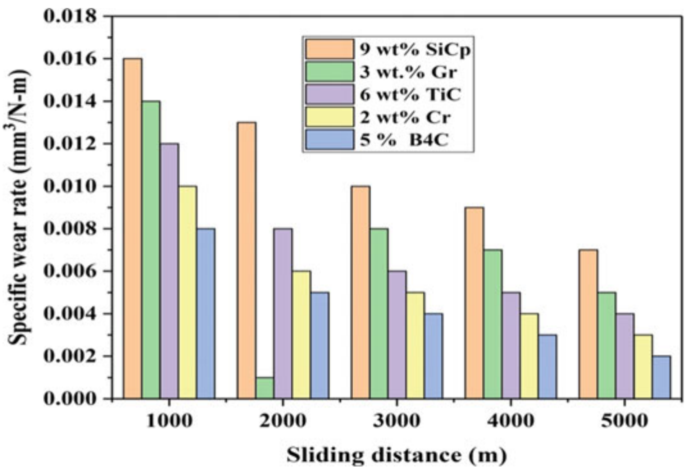

Fig. 4 Comparative studies of influence of sliding distance, and different reinforcements on specific wear rate of aluminum alloy composite [75–94]

3.2 Influence of Material Factors of Metal Alloy Composite

3.2.1 Influence of Reinforcement Type of Metal Alloy Composite

Aluminium composites reinforced with ceramic phases like Al_2O_3 or SiC have performed well tribological properties [57, 59]. Some investigators [95, 96] had reported that a critical load survives during dry sliding conditions above which a ceramic dependent composite offers small change in wear resistance differentiate to a nun-filled sample, while others [96, 97] had reported that hard ceramics can actually increase the wear rate of mating counterface due to their abrasive action, and therefore can decrease the overall wear resistance of the tribo-system. In this respect, the discovery of Al-composite reinforced with smooth phases were also of great interest. These authors [97, 98] had also reported that the intermetallic fillers such as Ni–Al and Ni_3Al enhance the wear resistance of Al-alloys (similar as that of SiC reinforced composite). Furthermore, it also helps in decreasing the wear of counterface simultaneously. Walker et al. [99] had prepared aluminium alloy matrix composites reinforced with 15 vol.% Ni_3Al intermetallic particles which gave superior wear resistance to the monoliths at loads 42 and 91 N.

Pan et al. [100] showed that Al 2124 + SiC exhibits more wear resistances than the Al 2124. The flow of alloy matrix around the fillers had been noticed by Wang et al. [98] too.

3.2.2 Influence of Reinforcement Content of Metal Alloy Composite

It had been recognized that the more volume fraction of hard ceramic filler improves the wear resistance of discontinuously reinforced aluminum (DRA) through abrasion, fretting, and sliding, except under few situations, through the wear rate for reinforced and unreinforced Al-matrices are alike (e.g. for a particular range of applied normal load and sliding velocity) [101]. Further, Rajeev et al. [59] for Al–Si–SiC_p composites found that the tribology loss and frictional coefficient of the composites decrease with increasing SiC_P contents from 6 wt.% to 18 wt.%. Dwivedi [102] found that the increase in Si-contents in cast Al–(4–20%) Si–0.3% Mg composites increases the resistance for thermal softening and also increases the ability to support the oxide film surface. Silicon addition to pure aluminium improves wear and seizure resistance, because silicon is an anti-adhesion agent [103]. Baradeswaran et al. [60] have investigated the composites (AA7075 + Al_2O_3) and found that wear rates and frictional coefficient decrease as the Al_2O_3 reinforcement content increases up to 6 wt.%, after which it begins increasing. The differences of wear rate and frictional coefficient with Al_2O_3 reinforcement contents were analyzed in the range 0–8 wt.% at different load conditions for 1200 m sliding distance. The wear resistance of the composites was increasing with addition of the Al_2O_3 particle content. It may be related to the cause that the particles of Al_2O_3 were much harder and stronger than the aluminium composite. Further, Ravindran et al. [61] had observed the effect of filler contents of solid lubricant particles (for constant contents of SiC grains) in 2024 aluminium alloy with 5 wt.% SiC and x wt.% Gr (x = 0, 5, and 10) composites. They reported that the lowest wear loss, and coefficients of friction are those of the composites with 5 wt.% graphite content, which was due to the self-lubricating effect of graphite. Their results showed that wear of hybrid composites first decrease with increasing Gr content up to 5 wt.%, then it increases for the 10 wt.% Gr content. Gautam et al. [104] found that there was decrease in ductility of Cu–4Cr–4G composites at larger particle content caused by hot forging, which may be related to the ease of fragmentation of metal particles from the matrix, and so contributing in increasing the volume loss. Savas and Bican [105] studied the properties of dry sliding friction and wear of the ternary Al–25Zn–3Cu and quaternary Al–25Zn–3Cu–(1–5)Si alloys. They reported that the steady state values of the frictional coefficient and temperature of the alloys was continuously increasing with increasing the silicon content, while the wear volume of the alloys increased with increasing the silicon content up to 3%, then the trend was reversed.

Wang and Rack [106] have elaborated a statistical wear model depending on the fact that the filler distributions are not perfectly homogeneous. By this model they reported that the wear rate of the unreinforced component varies exponentially with nominal reinforcement volume fraction. The experiments were performed on the SiC_w 2124 Al composite/17–4 PH steel system, and the results confirmed the validity of the theoretical model.

Moreover, Diler and Ipek [107] found that the volume fraction and particle sizes of matrix and reinforcement are effective on the wear behavior of Al–SiC_p composites, where wear loss decreases with the increase in the volume fraction up to a point (17.5 Vol.%), and volume fraction is the most significant factor for wear behavior, then the particle size of reinforcement and matrix, in addition, the interaction between volume fraction when it is high, and particle size of reinforcement has negative effect on the wear resistance. Also, they found that hardness increases with increasing volume fraction, and according to Archard's adhesive wear theory, the improve in wear resistance is related to the increase in hardness of the material. Moreover, wear loss depends on hardness of material according to Archard's theory too. The wear resistance is associated with hardness of material as given in the following formula [108];

$$V = \frac{r \times e \times q}{h} \tag{1}$$

where V is the volume of material, r is the wear coefficient, e is the sliding distance, q is the applied normal load, and h is the bulk hardness of the material.

The effect of the other variables (load, velocity, particle size, etc.) can also be simultaneously investigated to get exact understanding of the wear behavior of AMCs under increasing volume percentage [53].

3.2.3 Influence of Particle Size of Metal Alloy Composite

According to Hutchings et al. [109], and Zum Gahr [110] the removal of ceramic particles is a role of interface property of reinforcement and the matrix alloy as it keeps the ejection of reinforcing particles from the wear surface. As the interface bonding is strong to keep the whole particles in an alloy, while the composite is expected to give more wear resistance even under severe tribological conditions. The authors had investigated the ceramic particle size with regard to the depth/width of tribological groove produced by the counterpart that may be used to predict the possibility of ejection of the reinforcement particles from the wear surface during abrasive action. When the ceramic particle size (reinforcement) is less than the depth/width of the grooves, the reinforcement ceramic particles did not offer any resistance against the abrasive action. In the same context, some authors such as Mondal et al. [111] had investigated the critical abrasive size above which the composite can suffer of smaller wear resistance in comparison with the pure alloy.

Some researchers [112–114] found that AMCs suffer from the greater wear rate compared to the alloy at a load value of 7 N with 80 mm abrasive when the size of the SiC particle was within the range of 50 and 80 mm. The composites wear was found to be based on the contact of abrasives with the matrix. The number of fillers in the nominal region was varying with the size and proportion of the reinforcement. On the other side, Kumar and Balasubramanian [115] had developed a mathematical model to study the influence of reinforcement size and volume fraction on the abrasive wear behavior of AA7075Al/SiC_p P/M composites. They observed that the coarser the SiCp articles the lower the abrasion and vice versa. That is reinforcement SiCp particles of large size are expected to remain embedded in the matrix until it can no longer support them. So, in general for the taken range of particle size (which is about 40–150 μm), and volume fraction (which is 5%–25%), the coarser particle size and large volume fraction give larger abrasive resistance. Therefore, coarser particles give good protection to the matrix below sliding conditions. In the same context, Lee et al. [116] found for powder metallurgy (P/M) aluminium alloy 6061 matrix composites reinforced with silicon carbide particles (SiC_p) that when the composites contain the same amount of SiC_p particles, the wear rates decrease with increasing the size of SiC_p. Hence according to Yılmaz and Buytoz [117] the aluminium alloy composites which were reinforced with larger size of SiC_p particles are more effective against abrasive wear than the ones reinforced with smaller size SiC_p particles. This agrees with the findings of Diler and Ipek [107] who had found that for a particular range of volume fraction (12.5–17.5 vol%), the composites reinforced with fine particles show less better wear resistance as compared to those reinforced with coarse particles. Their idea of their investigations was that the increase in size of reinforcing particulate may be utilized or detrimental according to the operative mechanisms. However, a simple rule respecting the influence of reinforcement particles size on the wear characterization of composite can not be inferred [106–116]. Finally, it can be said that the interactions between various variables (i.e. reinforcement particle size, volume percentage) have considerable effect on the wear resistance of AMCs as well as their main effects.

4 Scope for Future Research Work

The research work thus far in the development of metal powder particulate filled metal fabricated alloy composites has decorated certain areas for future research.

1. Variety of al alloys exists for the commercial application for the gear fabrication. Different grades of aluminium alloy can be used to fabricate gears with the addition of the same filler material used in the existing work.
2. Mechanical alloying can be used to fabricate the gear made up of composite materials. Powder technology is one of the existing methods to enhance the property of the gear.
3. The performance of the gear material can further be enhanced by addition of other filler material.
4. The tribological property of the powder reinforced composite material can be further improved by addition of solid lubricating particles.
5. The failure of gears was majorly caused by various factors like misalignment, over loading, dift and rust, error in manufacturing, and improper material section or fabrication.

5 Conclusions

In this chapter, a literature overview on mechanical and tribological aspects of aluminum alloy composites for gear application is made. The following are the salient observations:

1. Wear mechanism is the prominent wear associated with automobile and aerospace industry and comes out to be a severe problem resulting in gear worn surface damage of components thereby alternating the working performance and bring large economic loss.
2. Parameter like reinforcement size, normal load, sliding velocity, sliding distance and composition, etc., are the factor affecting the specific wear rate.
3. Though much work had been reported on various dry sliding wear and friction characteristics of metals, alloys and homogeneous materials, comparatively less had been reported on the sliding wear and friction performance of metal matrix composite for gear.
4. Reinforcement of MMC can improve wear behavior and friction properties.
5. It was found by number of researchers that the reinforcement with particulates like Al, SiC, ZnO, and Al_2O_3 increases hardness, resistance, and sliding wear characteristics of aluminium composite materials.
6. Theoretical models help in predicting and analyzing sliding wear behavior of metal composites.

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