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Sliding Wear Behavior of Particulate Reinforced Aluminium Metal Matrix Composites

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Abstract**—*****Thisreview article summaries the characterization of sliding wear behavior of different ceramic particulate reinforced Aluminium Metal Matrix Composites (AMMC) investigated by various researchers in last few decades. The effect of various parameters i.e. sliding distance, applied load, testing time, testing media, rotational speed, weight fraction of reinforcements, particle size of reinforcements etc. are consideredfor characterization of various tribological properties i.e. frictional force, coefficient of friction (COF), wear rate etc. of the particulate reinforced AMMCs. For the characterization of these tribological properties, the tests were carried out on the pin-on-disc tribometer as per ASTM G99. AMMCs are demanded materials for this modern age, because they work as functionally graded materials for various industries like automobile, sports, aircraft, marine etc.***

Keywords**—*****AMMC,composite, frictional force, hardness,wear.***

I. INTRODUCTION

Metal Matrix Composite (MMC) plays a role of an engineering material for this modern science age and is developed by the macroscopic composition of two phase namely reinforcement phase and metal as a matrix phase. Mostly ceramic materials i.e. alumina (Al_2O_3), silicon carbide (SiC), boron carbide (B_4C) etc. are used as a reinforcement phase in MMC to improve the mechanical as well as tribological properties of the used metal matrix. MMCs hold very good combination of mechanical, tribological, and excellent corrosive resistance properties as compared to conventional materials [1]–[4]. MMCs are need for this present era because individual conventional material is failed to fulfil the requirement of specific properties of the components or parts of automobiles, aircrafts etc. AMMCs are lightweight which have high strength to weight ratio and therefore they are used for aerospace, automobiles, marine etc. AMMCs can also be reduced the power required to take-off of various jet enginesdue to its lightweight with high stiffness properties [5]–[11]. By the uses of AMMCs for well-designed of mufflers and silencers we can reduce the noise and vibration of engines [12]. AMMCs are isotropic in nature if the particles are uniformly distributed of the Al matrix.Rolling, forging, extrusion forming process can also be applicable on AMMCs[7], [13], [14]. Particulate reinforced AMMCs give good combination of mechanical, tribological and corrosion resistance properties at low cost and they are also recyclable these outstanding properties make them more attractive than the conventional materials [15]–[18]. Stir casting, friction stir processing, ultrasonic assist stir casting, squeeze casting, in-situ method, powder metallurgy etc. techniques are used to fabricate the AMMCs. Out of these techniques, stir casting technique is low cost processing route [15].

II. EFFECT OF DIFFERENT CERAMIC PARTICULATE REINFORCEMENTS ON THE TRIBOLOGICAL PROPERTIES OF AMMC

A. Boron Carbide Reinforced AMMC

The effect of particles size on the abrasive wear of B_4C particulate reinforced AMMCs are evaluated by Nieto et al. [19]. They used three different particle size of B_4C particulates i.e. micrometric B_4C-p (μB_4C), submicron B_4C-p ($s\mu B_4C$) and nano-metric B_4C-p (nB_4C) to reinforce the AA5083. They found larger B_4C-p reinforcements impart higher hardness because they are prone to particle pull-out. The AA5083+nB_4C composite has superior wear resistance because it has high hardness and greater interfacial area, which hindered pull-out of nB_4C particles. It enhances hardness by 56% and abrasive wear resistance by 7% as compared to AA5083. The effect of nano and micro particle size of B_4C-p on mechanical properties of Al-B_4C (0-10 wt. % of B_4C particulates) MMCs are analysed by Harichandran and Selvakumar[20]. In this analysis composites were fabricated by stir and ultrasonic cavitation-assisted casting process. They analysed the tensile strength, impact energy, wear resistance and ductility of nano B_4C-p reinforced composite are greater than the micro B_4C-p reinforced composite. They noted that the ductility and the strength of nano particulate MMCs are decrease beyond the 6 wt. % due to agglomeration of particles and porosity in the composite.Abrasive wear behavior AA5052/B_4C MMCs are characterized by Patel et al. [14]. They fabricate the composites by stir casting processing route and investigated the effect of applied loads (5N-15N) on the weight loss, COF, frictional force and abrasive wear rate. They found weight loss, COF, frictional force and abrasive wear rate of AA5052 alloy are higher than the AA5052/B_4C AMMC at all applied loads. They also observed that weight loss, frictional force and abrasive wear rate increase with increase in applied loads. The effect of volume fraction and particle size of B_4C on the abrasive wear behavior of AMMCs is analysed by Canakci and Arslan[21]. They observed small particle size B_4C particulates are agglomerate on the Al2024 matrix and large particle size of B_4C-p give uniform distribution in the Al2024 matrix. The density of the composites decreases with increase in the B_4C-p content and decrease in the particle size of B_4C-p.They investigate volume loss and specific wear rate of the Al2024/B_4C-p MMCs are decrease with increase in the volume fraction as well as particle size of the B_4C-p. Specific wear rate of the developed AMMCs is also decrease with increase in sliding time. B_4C-p reinforced A356 MMCs are fabricated by Raja and Raja [22] and the effect of different parameters like applied load and sliding distance percentage of B_4C-p were taken for the analysis of wear behavior. They noted that the wear rate of the developed AMMCs is increase with increase in applied loads and sliding distance.Patidar and Rana [23] published a survey article on the effect of B_4C particle reinforcement on the various properties of AMMCs. According to their survey the wear rate and volume loss are found increasing by increase in applied loads, sliding velocity and by decrease in weight percentage of B_4C-p.

B. Fly-Ash Reinforced AMMC

Bharathi et al. [24] have investigated the influence of fly ash content in AMMC on the scratching abrasion resistance. They found that the abrasive wear resistance of composite has increased with increase in fly ash content due to the stiffness, hardness and strength of the reinforced fly ash particle. Wear rate has increased with increase in load and speed due to improved friction at the contact surfaces and due to the breakage of bonds between the reinforcement particle and the matrix material. The wear behaviour of fly ash particulate reinforced AMMCs were also studied by Sharma et al. [25]. Composites were fabricated with 2, 4 and 6 wt. % of fly ash contents in aluminium by using stir casting route. They also observed the wear resistance increases with increasing the fly ash contents in the fabricated composites. The high fly ash contents (6 wt.%) composites have 13.6% less wear as compared to low fly ash content (2 wt.%) composites. Ramachandra and Radhakrishna[26] have investigated the effect of fly ash reinforcement on sliding, slurry erosive wear and corrosive behaviour of AMMCs. They noted that when increases the fly ash content then increase in sliding wear resistance, reduction in coefficient of friction (COF), increase in slurry erosive wear resistance by formation of protective layer against the impact of slurry and decrease in corrosion resistance of the composites. If the rotational speed or normal load increases then wear resistance of the composites decrease. Frictional force increases with increase in sliding velocity. COF decreases with increase in normal load.Kumar et al. [27] have investigated the high temperature sliding wear behavior of press-extruded AA6061/fly-ash MMCs. They analysed AA6061–fly ash composites in T6 condition have exhibited better wear behavior compared to the matrix alloy at room and high temperatures.Uthayakumar et al. [28] have studied on the dry sliding friction and wear behavior of fly-ash reinforced AA-6351metal.They used 5, 10 and 15 wt.% of the fly-ash as a reinforcement and prepared the composites by stir casting method. They observed the wear resistance increase with increase in the fly-ash content. According to their researchin wear behavior the contribution of applied load and sliding speed are 49.71% and 30.43%, respectively.

C. Alumina Reinforced AMMC

The tribological properties of aluminium-clay composites for brake disc rotor applications have investigated by Agbeleye et al. [29]. The AA6063-clay composites with 5, 10, 15, 20, 25 and 30 wt. % of clay particles of grain size of 250 μm were developed through stir casting route. With the 15-25 wt. % clay addition in AA6063 composites were similar to conventional semi-metallic brake pad in terms of wear and friction properties. They found that the mechanical properties, wear resistance and COF of the AA6063 improved with the addition of clay particles. El-Aziz et al. [30] have investigated the wear and corrosion behaviour of alumina reinforced (upto 0-25 wt.%) Al-Si alloy MMCs fabricated by stir casting route. They observed that the distribution of the alumina particles in Al alloy matrix is uniform and wear resistance of the composite is increases with increasing the wt. % of alumina particulates. They found that the composite with 10 wt.% alumina particulate have high corrosion resistance as compared to as cast alloy and other composites. Heat treatment of these as cast alloy and composites enhanced both the corrosion resistance and the wear resistance property of them.Fang et al. [31] have investigated the synergistic effects of wear and corrosion for Al_2O_3 particulate reinforced AA6061 MMCs. They used 0, 10, 15 and 20 vol. fraction of Al_2O_3. Their studies involved to investigate the effects of applied load, rotational speed, and environments (dry air and 3.5% NaCl solution) on the wear rates of MMCs. They noted that the wear rate in 3.5 wt. % NaCl aqueous solution is larger than that in laboratory air at every applied load and rotational speed due to degradation of passive film. They observed the wear rate decreases with increase in rotational speed and increases with increase in applied loads in both aqueous and air media. Yilmaz and Buytoz[32] have investigated the abrasive wear of Al_2O_3 reinforced aluminium-based MMCs. They used different grade of abrasive papers, different Al_2O_3 particle size,and 5, 10 and 15 vol. % of Al_2O_3 to investigate the wear rate. They analysed at same vol.% of Al_2O_3, wear rate decreases with increase in the particle size. Wear rate of the developed AMMCs is increases with increase in applied loads, decrease in particle size, decrease in grade of abrasive paper.

D. Basalt Reinforced AMMC

The dry sliding wear behaviour and micro hardness of basalt particulate (0, 2.5, 5, 7.5, and 10 wt.%) reinforced AA7075 composites synthesis by stir casting are analysed by Raja et al. [33]. They observed that when increase in wt.% of basalt then hardness, wear resistance and COF of the composites increases. When increase in applied load then COF decreases and volumetric wear loss increases. When sliding velocity increases then COF slightly increase and volumetric wear loss marginally decreases. The formation of the oxide layer over the surface of these composites increases the wear resistance property. The reduced mean size of wear debris obtained for the increase in basalt wt. %. The effect of basalt short fibre content, load, sliding distance and sliding velocity on dry sliding behaviour 0, 2.5, 5, 7.5, and 10% basalt short fiber reinforced AA7075 MMCs are reported by Vannan and Vizhian[34]. They noted that wear rate decreases with increase in basalt short fibre content and increases in sliding distance due to hardness and self-lubrication property of basalt short fibre respectively. Wear rate increases with increase in sliding velocity or increase in load. The mechanical property of these composite have also investigated by them and observed the young modulus, ultimate tensile strength, compressive strength and hardness increase but ductility decreases with increase in content of hard basalt fibre in 7075 Al alloy [35].

E. Silicon Carbide Reinforced AMMC

Karamis et al. [36] have analysed the failure and tribological behaviour of the AA5083 and AA6063 composites reinforced by SiC-p under ballistic impact. The wear behaviour of AA5083 and AA6063 reinforced by 15, 30 and 45 vol.% SiC-p (250-500μm) composites fabricated by squeeze casting are investigated under condition of high-velocity (710m/s) impact by firing 7.62mm armour piercing rounds into these MMCs specimens of disc-shaped with a diameter of 140mm and a thickness of 20mm. By the use of scanning electron microscopy (SEM) and optical microscopy wear and failure mechanisms of projectile tips and hole surfaces produced by high-velocity impact are evaluated. Terminal ballistic tests performed and find depth of the projectile penetration reduced if the friction between the projectile and MMC armour is increases due to the projectile comes into contact with more reinforcement particles or if the particles are brittle then sometimes broken up into smaller pieces and buried into the frictional surfaces. When projectile impacts on the MMC armour then projectile nose is plastically deformed, because of swelling and the presence of SiC particles in the matrix. The predominant wear mechanisms are three or two-body abrasion as a result of the frictional conditions and melt wear generated from higher friction and then re-solidified over the sliding (frictional) surfaces when cooled down. The cracks observed on hole surfaces caused by rapid plastic deformation and solidification but these cracks do not propagate to the subsurface. In the matrix, compacted zone is observed near the surface which is highly deformed due to impact of projectile. The hardness distribution is different in compacted zone from the matrix. Abrasive wear behavior AA5052/SiC MMCs are characterized by Patel et al.[4]. They fabricate the composites by using stir casting processing route with sand mould and investigated the effect of applied loads (5N-15N) on the weight loss, COF, frictional force and abrasive wear rate. They found weight loss, COF, frictional force and abrasive wear rate of AA5052 alloy are higher than the AA5052/SiC AMMC at all applied loads. They also observed that weight loss, frictional force and abrasive wear rate increase with increase in applied loads.Uzkut[37] has investigated the abrasive wear behaviour of AA2011 reinforced with SiC-p (avg. particle size 64μm) volume fractions of 7, 14 and 21%. Composites were fabricated by vortex method. He observed the wear resistance of the AA2011 composites was higher than the unreinforced AA2011. The increase in sliding distance, wear volume loss of the AA2011 increased. When increase in SiC-p content, the wear resistance of the AA2011 composites increased but decreased with the increasing abrasive grit size of the emery used. Idrisi and Mourad[38] have studied on the fabrication and wear analysis of AMMCs reinforced by SiC micro and nano particles. AA5083 matrix composites reinforced with micro (5 and 10 wt. %) and nano (1 and 2 wt. %) SiC-p have been fabricated by use of stir casting process. For performing wear analysis, these composites are used for manufacturing of gears through milling operation. Wear test of gears were performed at different loads (10N, 20N, and 30N) and time (30mins, 60mins, 90mins and 120mins) and found that wear increase with increase in load and time. AA5083 reinforced with 2 wt. % nano SiC-p composite gear shows the highest wear resistance among the all tested composition. At 10N, AA5083 with 10 wt. % of micro SiC-p demonstrated more wear resistance as compared to AA5083 with 1 wt. % nanoSiC. On the other hand, AA5083 with 1 wt. % nano SiC shows more wear resistance as compared to AA5083 with 10 wt. % of micro SiC at 30N. At 20N both composite shows comparatively same wear resistance. Manivannan et al. [39] have also studied about the tribological and surface behaviour of SiC-p reinforced aluminium matrix nano composite in which AA6061 matrix reinforced with 1.2% nano SiC-p (average particle size of 50nm) by using ultrasonic cavitation assisted stir casting. They noted that the hardness of the AA6061- 1.2 wt. % nano SiC-p composite is 73% increase as compare to AA6061. The AA6061-1.2 wt. %nano SiC-p composite have superior wear resistance at the higher applied load. At all applied load, the COF of nanocomposite were lower than those of the unreinforced alloy. Erturk et al. [40] have analysed the tribological behaviour of SiC particulate reinforced AA5754 matrix composite under dry and lubricated conditions. AA5754 matrix reinforced 10 wt. % SiC-p (particles size of 44μm) composite fabricated by squeeze casting technique and their tribological behaviour investigated by using a pin on disc tribometer. They observed the wear properties of the AA5754 were considerably improved by the addition of SiC-p into it. The weight losses of tested materials are linearly increased with increase in sliding distance. To study the wear assessment using optical methods, the material surfaces before and after the wear tests were examined and found that adhesive and abrasive forms of wear were present. Pradhan et al. [41] have also investigated the tribological behaviour of Al-SiC particulate metal matrix composite under dry, aqueous and alkaline medium. In this study aluminium alloy LM6 reinforced with 7.5 wt. % of SiC particles (400 mesh size = 37μ m) by using the liquid stir casting process. They found that wear increases with increase in applied load and sliding speed under all conditions (dry, aqueous and alkaline environments) but wear is maximum in alkaline environment followed by aqueous medium and dry sliding. COF decreases with increase in applied normal load. The COF remains low in alkaline solution compared to the other environments due to the lubrication effect of the alkaline solution. Pradhan et al. [42] have investigated the effect of SiC-p wt. % on tribological properties of Al-SiC particulate MMCs under acid environment. In this analysis Al LM6 reinforced with different weight percentages of SiC-p (5 wt. %, 7.5 wt. % and 10 wt. %) composites are fabricated through the liquid stir casting method. They found that wear increases with increase in applied load and sliding speed but the COF decreases with increase in load and increase in wt. % SiC-p and slightly fluctuates with variation of sliding speed. From microstructure analysis of the worn surfaces they found adhesive, abrasive and corrosive wear mechanisms are present for removal of material from the Al-SiC-p MMCs. Wear resistance of the composites are increased with the increase in wt. % of SiC particles in Al. For engineering applications; Das [43] has developed AMMCs by using stir-casting technique in which Al-Si (BS: LM13) reinforced with 10 and 15 wt.% SiC-p of size 50-80 μm. He found that the erosive-corrosive wear rate of the composite is less than that of the alloy. In all tribo-conditions aluminium composite provides higher wear resistance than those of the base alloys. Composite exhibits more or less wear rate to that of base alloy beyond a critical load and abrasive size, wear rate with the applied load increases almost linearly. As compared to the alloy, frictional heating and COF are considerably less in composite. Under both dry and lubricated sliding wear composites exhibit improved wear resistance and seizure pressure as compared to the alloy. Kumar et al. [44] have analysed influence of corrosion-erosion wear in slurry (made up of alumina of size 90-150μ m and proportion of 10, 20 and 30 wt.%, while normality of H_2SO_4 is 0.01N, 0.1N and 1N was added to create the corrosive conditions) on AA6061/SiC AMMCs by using Taguchi technique. In corrosive-erosive wear test the weight % of abrasive particles in slurry is the major factor which influence on the wear rate (57.52%) followed normality of H_2SO_4 in slurry (31.46%) and reinforcement (3.04%). Around the dispersoid / matrix interfacial region cracking tendency of the composites is observed. Ramachandra and Radhakrishna[45] have investigated the sliding, slurry erosive and corrosive wear of aluminium alloy (Si-7.2%) LM25 reinforced with SiC particulates (0, 5, 10, 15 wt. %) by conventional vortex casting technique. They were found that with the addition of SiC particles, the sliding and slurry erosive wear resistance improved considerably. The formation of a passive layer in slurry erosive wear retarded the wear of the material. Corrosion resistance decreased with the addition of SiC particles as compare to the alloy matrix. They observed that pitting corrosion was the dominant mechanism. By examinations of micrographs of wear debris, worn surfaces and subsurface they found that the LM25 alloy wears primarily due to micro-cutting and MMCs wear due to micro-cutting, plastic deformation, oxidation, and thermal softening. The bulk hardness increases with increase in the wt. % of SiC-p in Al alloy matrix. The density of MMCs was not much change as compared to the base metal.

F. Hybrid AMMC

The Al-Cu-(fly ash + SiC) hybrid metal matrix composites (HMMCs) are characterized by Mahendra and Radhakrishna[46]. Al-4.5Cu alloy with 5, 10 and 15 wt. % of equal proportion of fly ash & SiC as particulates (avg. particle size 10μm) has been successfully synthesized by using stir casting method. Fluidity, density, tensile strength, compressive strength, impact strength (by Izod and Charpy test), dry sliding wear, slurry erosive wear, and fog corrosion behaviour of the HMMCs are reported. They noted that with increase in percentage of particulates (fly ash + SiC); the hardness, tensile strength, compression strength, impact strength, sliding wear resistance and erosive wear resistance increases, but fluidity, density and corrosion resistance property of HMMCs decreases. The wear is more in case of basic media as compare to acidic and neutral media. Corrosion of composite is more than the base alloy and increases with temperature. Gaitonde et al. [47] have studied on wear and corrosion properties of AA5083/Al_2O_3/Graphite hybrid composites. Investigate the hardness, slurry erosive wear and corrosion (immersion, salt spray and polarization) behaviour of AA5083, AA5083-3%Al_2O_3-3%Gr, AA5083-6%Al_2O_3-3%Gr and AA5083-3%Al_2O_3-6%Gr hybrid composites. Particles are added in wt.% with size of alumina and graphite is 20-60µm. They noted that micro-hardness of hybrid composites are higher than the alloy matrix. An increased content of hard reinforcement (Al_2O_3) in the hybrid composites enhance in micro-hardness of hybrid composites. The slurry erosive wear resistance of hybrid composites is higher than the unreinforced matrix alloy. 3%Al_2O_3+6%Gr shows higher wear resistance as compare to its alloy matrix and other composites. If the solid particle size in slurry increases, the wear rate of composites also increases. The mass loss during immersion test decreased when content of reinforcement in the matrix alloy increases. Sample in which having 6% Gr content shows much resistance to corrosion. Ravindranath et al. [48] have investigated the dry sliding wear behaviour of AA2219, AA2219 + 8% B_4C and hybrid composite (AA2219 + 8% B_4C + 3% Gr) by use of pin on disc wear test machine. The composites are prepared by stir casting process. They noted that the wear rate increase with increase in applied load and sliding distance. Hybrid composite has high wear resistance as compared to mono composite material. Senthilkumar et al. [49] have characterized the mechanical and tribological behaviour of Al+2Gr+2.5B_4C, Al+2Gr+5B_4C and Al+2Gr+7.5B_4C stir cast composite. They noted that the composite with 7.5 % B_4C has higher wear resistance and higher hardness value as compared to other two composites. They observed compressive strength is higher for 5% B_4C composite. Kumar et al. [50] have evaluated the mechanical and wear properties of aluminium AA430.0 reinforced with SiC and MgO. AA443.0 and SiC+MgO (2.5%, 5% and 7.5% by weight with 150µm particles size) have been chosen as matrix and reinforcement material respectively and composites are fabricated by stir casting process. They observed that when increase in wt.% of the reinforcement then hardness, tensile strength, COF and wear resistance of the composites are increases but ductility or percentage elongation of the composites are decreased. COF is low at higher applied load and decreased with increase in sliding speed. Wear rate of the composites are increases with increase in applied load and sliding speed. Hariprasad et al. [51] have reported the wear characteristics of AA5083 and AA5083+5% Al_2O_3+3 or 5 or 7% B_4C stir cast hybrid composites. The wear rate of AA5083+5% Al_2O_3+3% B_4C was approximately 10% lower than the other two composites.Patel et al. [18] have fabricatedAl5Mg5SiC/3WO_3 HMMC by replacing the Zn content in Al5Mg5Zn/3WO_3 AMMC and evaluate the hardness, toughness and sliding wear resistance properties. They observed wear resistance and hardness of the Al5Mg5SiC/3WO_3 HMMC are higher than the Al5Mg5Zn/3WO_3 AMMC.

G. Comparative Analysis Between Different Particulate Reinforced AMMCs

Sujan et al. [52] have studied about the physio-mechanical properties of AMMCs reinforced with Al_2O_3 and SiC particles. They fabricate the composites by stir casting technique in which 5, 10 and 15 wt. % Al_2O_3 (particle size of 400µm) and SiC particles used as reinforcement for Al356 matrix. They observed when increase in weight fraction of reinforcement particles then density, hardness, tensile strength and wear resistance of the composite materials are increase but the coefficient of thermal expansion decreases. For 10 wt. % and 15 wt. % particulate reinforced AMMCs, Al-SiC composites exhibit relatively higher hardness, tensile strength and density compared to Al-Al_2O_3 composite materials. For 5 wt. % Al-Al_2O_3 composite has slightly higher density, hardness and tensile strength as compared to the same wt. % of Al-SiC composite. Wear resistance of all Al-SiC composites are higher than the Al-Al_2O_3 composites. When grinding speed is increase then wear rate of both alloy and composites are also increased.Ramnath et al. [53] have given a review on AMMCs and overview of the effect on the mechanical properties like tensile strength, hardness, wear and fatigue due to the addition of different reinforcements in aluminium alloy and highlight their merits, demerits and applications. According to their review, SiC reinforced AMMCs have higher wear resistance than Al_2O_3 reinforced AMMCs and B_4C reinforced AMMCs. It is suitable materials for brake drums due to their high wear resistance but cannot be used in brake linings as it will damage the brake drum. The increase in volume fraction of Al_2O_3 in the Al matrix decreases the fracture toughness of the AMMC. The addition of fly ash reinforcement in AMMCs increases the wear resistance but decreases the corrosion resistance.

III. FORMULAS USED FOR CHARACTERIZATION OF TRIBOLOGICAL PROPERTIES

Various tribological parameters i.e. weight loss during wear test, COF, wear rate, volume loss during the wear test, volumetric wear rate, volumetric wear resistance, wear depth and relative wear depth of the MMCs test samples are calculated by the equation (1), (2), (3), (4), (5), (6), (7) and (8) respectively [18], [54]–[57].

$$\Delta w = w_b - w_a \tag{1}$$

$$\mu = \frac{F}{P} \tag{2}$$

$$Wr = \frac{\Delta w}{S_d} \tag{3}$$

$$\Delta v = \frac{\Delta w}{\rho} \tag{4}$$

$$Wv = \frac{\Delta w}{\rho \times S_d} = \frac{\Delta v}{S_d} \tag{5}$$

$$WR_v{}^{-1} = \frac{S_d}{\Delta v} \tag{6}$$

$$W_d = \frac{\Delta v}{A} \tag{7}$$

$$RW_d = \frac{W_d\,(alloy)}{W_d(composite)} \tag{8}$$

Where: 'Δw' is weight loss of the test sample in g, 'w_b' & 'w_a' is the weight of the test sample before after abrasion test in g respectively, 'μ' is COF, 'F' is frictional force in Newton, 'P' is applied load in Newton, 'Wr' is wear rate in g/m, 'S_d' is the sliding distance in meter, 'Δv' is the volume loss in mm^3, 'ρ' is the measured density in g/mm^3, 'Wv' is the volumetric wear rate in mm^3/m, '$WR_v{}^{-1}$' is the volumetric wear resistance in m/ mm^3, 'W_d' is the wear depth in meter, 'A' is the cross sectional area of the test specimens in m^2 and 'RW_d' is the relative wear depth with no unit.

IV. CONCLUSION

From this survey of wear behavior of particulate reinforced AMMCs the following points are concluded:

- Nano-particle imparts higher wear resistance to AMMCs as compared to the micro and sub-micro size particulate reinforced AMMCs.
- Small particle size reinforcing causes agglomeration of particles in Al matrix, but bigger particle size reinforcing imparts homogeneous distribution of the particles in the matrix.
- Increase in applied loads, sliding distance, sliding velocity increase the wear rate of the particulate reinforced AMMCs.
- Increase in the wt. % of reinforcement decreases the wear rate of the particulate reinforced AMMCs.
- Wear rate of the AMMCs in aqueous solution is higher than the wear rate of AMMCs in air. Wear is more in case of basic media as compare to acidic and neutral media.
- SiC reinforced AMMCs have higher wear resistance than Al_2O_3 reinforced AMMCs and B_4C reinforced AMMCs

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