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HIGH STRESS ABRASIVE WEAR BEHAVIOUR OF ALUMINIUM ALLOY AND COMPOSITE: A REVIEW

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ABSTRACT

Aluminium alloys and its composites have of wide application in the automobile, aerospace, defence and other engineering sectors especially where abrasive wear plays major role. This review article aims to investigate experimental procedures and effects of parameter like sliding distance, abrasive medium, reinforcement, abrasive grit size and load on the wear rate. Many researchers have mostly used aluminium alloys which are LM2, LM6, LM13, LM25 and of other series Al-1100, 2011, 2014, 2024, 2124, 6061 and 7075 on high stress abrasive wear (HSAW). Apart from these, in the series of aluminium alloys very limited work has been done on HSAW.

Keywords: MMCs, aluminium alloys, HSAW, pin on disc apparatus, abrasion tester.

INTRODUCTION

Metal matrix composites (MMCs) play a vital role in applications of automobile, aerospace, and engineering components because of their properties like high specific strength, wear and seizure resistance, stiffness, thermal stability, and high thermal conductivity [1-3]. MMCs are made by mixing of a strengthening phase to the matrix, by applying any of the following techniques: powder metallurgy processing [4]; spray atomization and co-deposition [5-6]; plasma spraying [7-8]; stir casting (compo-casting) [9-10] and squeeze casting [11].

Aluminium alloys because of their light weight and ease of processing have wide range of applications like automobile, aerospace, and other engineering sectors. Amalgamation of hard dispersoid like SiC, Al_2O_3, B_4C, etc. in Al-alloys increases strength and stiffness but decrease ductility. The synthesis and characterization of aluminium matrix composites (AMCs) requires significant attention among MMC_s and poor machinability is one of major drawback of AMCs [12-16]. This mainly happens due to the hard dispersoid causing great damage to the machining tools.

A lot of research has already been done to obtain high efficient machining of AMCs by applying special tools such as polycrystalline diamond (PCD) tools and carbide tools with various machining speed and feed rate [12-16]. It has been analysed that improvement in machining of AMCs is possible at relatively slower machining speed and higher feed rate with aforesaid tools but using these tools is comparatively costlier in machining materials.

Various ceramic materials like silicon carbide, alumina, zircon etc. have already been used as dispersoid for synthesis composites [17-40]. Literature survey reveals that little research has been made to natural minerals like granite, sillimanite, corundum etc. for making aluminium alloy composite, though these natural minerals have great capacity for using as reinforcement [41-47]. Because of excellent wear resistance as well as higher stiffness, this type of composites has various major applications in automobile components like brake drum, piston, cylinder liners, etc. [17, 48].

Research has also been done to decrease the machining operation of AMCs by creating near to net shape components either by precision casting or by secondary processing techniques. AMC components have been formed by squeeze casting [49], squeeze infiltration [50-52], and powder metallurgy routes [53-55]. Various attempts have also been made to observe the practicability of super plastic forming; in the temperature range of 450 $^{\circ}C$ to 525 $^{\circ}C$, with the aim of evaluating the secondary processing of AMCs for fabrication of near-net-shape parts [56-59].

Wear is defined as the continuous loss of matter from the surfaces as an effect of relative motion [60]. Since the world's attention is increasing towards reducing loss of resources of material and energy so analysis on wear is being done globally. It is understood that complete knowledge of wear mechanism will ultimately result in better specification including composition and better properties [61].

Basic mechanisms for different characteristic modes of wear are
[62-63]:

- Mild wear: Delamination and oxidation.
- Severe: Adhesive, diffusive and abrasive.
- Scuffing: Adhesive and diffusive.
- Scoring: Abrasive.
- Pitting: Fatigue and external attack.

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Types of wear

Types of wear based on nature of movement

On the basis of the nature of movement or the medium involved in contact between mating surfaces beneath an external load, the subsequent types of wear may be defined. Wear surfaces produced as a result of different types of wear are shown in Figure-1(a)-(d) [63].

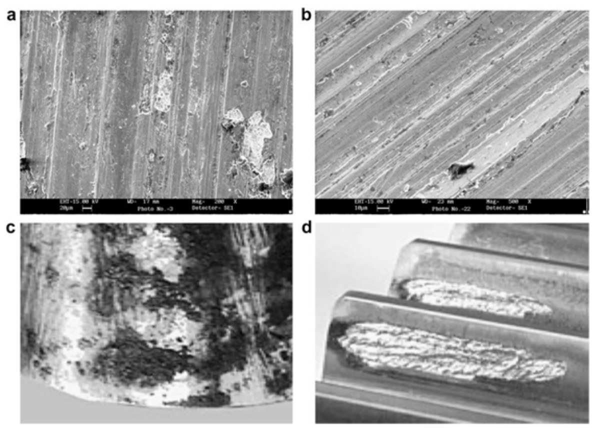

Figure-1. Micrographs showing typical morphologies of different types of wear: (a) adhesive wear, (b) abrasive wear, (c) corrosive wear and (d) surface fatigue wear [63].

Adhesive wear

Adhesive wear is due to application of load between two metallic components which are sliding with each other in absence of abrasives. Mild wear or oxidative wear happens in stainless steel due to thin oxide layer on the surface results in the creation of metallic bond between the asperities. Wear rates are large on large high load application on the surfaces. This type of wear is normally happens in sliding components in a valve, conveyor belts, fasteners, etc. Analysis shows very good wear resistance in martensitic steels for a minimum hardness of 53 HRC. In austenitic stainless steels, the alloy additions increase the stability of oxide film and also work hardness [64].

Figure-2. Schematic representations of (a) adhesive wear, (b) oxidative wear [64].

Abrasive wear

In abrasive wear there is ploughing of localized surface contacts by a harder material [64]. Abrasive wear may occur in both metallic and non-metallic particles but most likely non-metallic particles suffer wear by abrasion. Harder particles than material have probability of serious scratching or abrasion (Figure-3b). Abrasive wear is further subdivided into three types namely high stress, low stress and gouging. High stress abrasion occurs due to high stress which results in additional work hardening. Some examples of abrasion caused are in rolling-contact bearings, gears, pivots and cams. Low stress abrasion has light rubbing activity of abrasive particles along with the metal surface which are the reasons of scratches and there is no work hardening. Gouging abrasion is due to high stress that creates grooves or gouges on the affected surface. Few examples where it may be seen are impact hammers in pulverisers, parts of crusher liners, etc. Major factors which affect the resistance from abrasion are hardness, microstructure and carbon content (for steel).

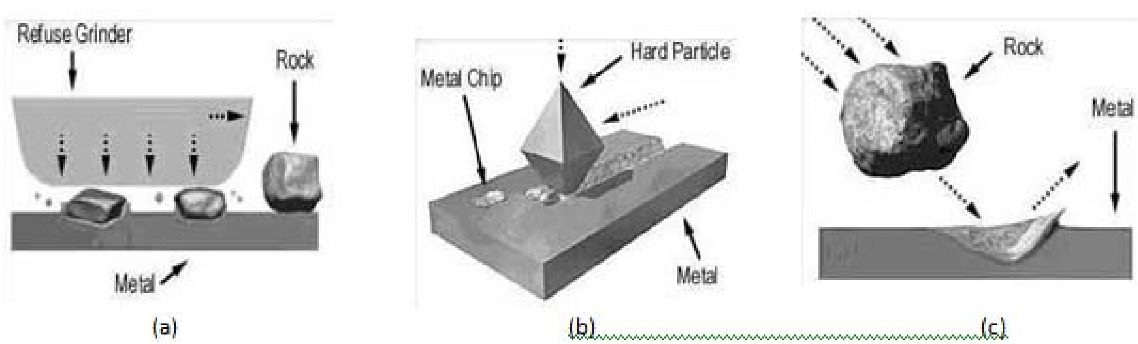

Figure-3. (a) Low stress abrasive wear, (b) HSAW, (c) gouging [64].

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Corrosive wear

This type of wear occurs due to effect of corrosive reagent [64]. Electrochemical elimination of material happens together with the removal of material through physical interaction of the two surfaces that are in contact to each other. Both these two occurrence increase the overall elimination of material. Wear is continuous by removal of the oxide film which exposes new surfaces of the metal to surrounding, dissolution of the metal surface which is exposed, interaction among asperities in contact with the surroundings and interaction among the surroundings and plastically affected areas. The materials which normally oppose the development of oxides may be used in corrosive wear surroundings.

Surface fatigue wear

Cyclically stressed surface of materials face this kind of wear. The ball bearings, gears, etc generally have the surface fatigue wear. The degree of fatigue wear is determined by the factors like residual stress, surface finish, microstructure and hardness. Resistance to fatigue wear may be enhanced by surface healing like carburizing, nitriding and shot peening because they improve surface hardness and increase residual stress distribution [64].

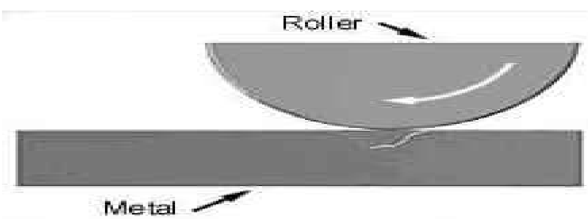

Figure-4. Schematic representation of contact fatigue [64].

Erosive wear

Impingement action of the erodent particles carried by a fluid medium is responsible for the material removal from the surface in this type of wear (air / liquid) [65]. Erosive wear is primarily by cutting and deformation processes. Deformation occurs at high angle of particle impact and cutting action is dominated at a low angle of particle impact in metals [66]. The deformation created by pointed particles impinging an object is closely equivalent to that created by abrasion. The major distinction is that in erosion the surface irregularity formed can become comparatively greater, for the reason that an impinging particle may easily remove material from a low point on the surface.

Cavitation

Bubbles may form if the portion of liquid is under tensile stresses. Bubbles may collapse abruptly, will create a mechanical shock on the specimen surface. A close by solid surface can be damaged due to this shock, which will result in removal of material.

Fretting wear

A small oscillatory motion at interface results in wear of materials in fretting wear. The coefficient of wear in this case relies upon the amplitude of oscillation, when the relative displacement at the interface is lower than the critical value. At high amplitudes of oscillation, the fretting coefficient of wear move towards that of unidirectional sliding wear [67].

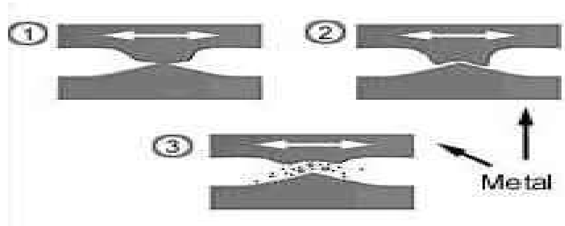

Figure-5. Schematic representations of fretting wear [67].

Types of wear based on the wearing contacts

Single-phase wear

Solid moving relative to a sliding surface is responsible for removal of material from the surface in single phase wear. The relative motion can be sliding or rolling for wear occurrence [68].

Multi-phase wear

Solid, liquid or gas all acts as a carrier for a second phase that actually creates the wear in this type of wear [68].

EXPERIMENTAL REVIEW

After extensive literature study, it was observed that maximum researchers adopt Pin on Disc apparatus or Abrasion tester for HSAW test. The following parameters have been adopted by numerous researchers for the above apparatus:

Pin on disc

Murato˘glu *et al.* [27] performed the abrasive wear tests which were of the pin-on-disc type by using a polishing machine. Preparation of the wear test specimens were in the form of cylindrical shape having 6mm diameter and 50mm length. Abrasive wear tests were conducted under dry conditions under an applied load of 10N on a grade 80 mesh abrasive paper attached to the grinding disc. Diameter of 160mm was employed in all tests, and duration of abrading was 50 s at fixed track.

Sahin *et al.* [32] investigated the pin-on-disc type of apparatus to determine the wear characteristics of MMCs. For abrasive medium the emery paper was fixed to a 12 mm thick, and 160 mm diameter steel wheel was used. The wear pin specimens made from the MMCs were just about 5 mm in length. The track radius was used 90 mm in length and the width of the wear track was 6.5 mm. In the experimentation, normal load on the pin was

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changeable at a constant sliding speed of 0.8 ms^{-1} and the sliding distance was 48m. All the tests were conducted of loads vary from 8 N to 32 N.

Kok [36] carried out a pin-on-disc with emery paper apparatus to assess the wear characteristics of composites and aluminium matrix alloy. three sizes of 20 (600 grit), 46 (320 grit) and 60 mm (240 grit) attached on a rotating 115 mm diameter and 12 mm thick aluminium disc with the help of a double sided tape with SiC papers were employed as abrasive mediums. Test specimens shaped in the form of cylinder 8 mm in diameter and 30 mm in length. The parameters used were: normal load on the pin, 2 N, equivalent to nominal normal stress of 0.04 MPa, sliding velocity of 2 ms^{-1} and total sliding distance was 450 m.

Shah *et al*. [69] conducted tests to evaluate the two body abrasive wear behaviour of aluminium alloys against 320 grades SiC polishing papers mounted on steel disc on Pin on Disc type wear. Wear tests were done at different loads (5, 10 N) at a constant sliding speed of 1 m/s. Diameter of wear track was 80 mm Yilmaz [72] performed the abrasive wear tests using a Pin on Disc type apparatus in which abrasive wear tests were conducted under the loads of 10–120N on a grade 80 abrasive paper stuck to the grinding disk, which rotated at 320 rev min^{-1}. A fixed track diameter of 160mm was employed in all tests, and the duration of abrading was 60 s. Wear specimen were machined to cylinders 0.03m in length and 0.01m in diameter.

Meric *et al*. [70] studied wear behavior of the specimens on a pin-on-disk model wear test apparatus. Electric motor with a constant speed of 100 rpm was used to drive the disk of 200 mm in diameter. Specimens prepared from AlMgSi1 alloys and four different particle sizes (30, 18, 11, and 5 µm) of abrasive SiC papers were employed .Different loads (6.45, 9, 9.3, and 11 N), and sliding speeds (0.078, 0.156, 0.208, and 0.338 ms^{-1}) were imparted.

Ramesh *et al*. [71] conducted abrasive wear tests on a Pin on Disc type machine by changing the steel disc with abrasive wheels of various grit sizes (60, 80 and 120). 8mm diameter and 25mm length of polished cylindrical samples of was employed. Constant speed of 50rpm while load was varied from 5N to 25N in intervals of 5N parameters at which the tests were performed with experimentation duration of 15 min and sliding distance of 2.36m was chosen for all the tests.

Abrasive wear tester

Das *et al*. [21] investigated high stress (two-body) abrasion tests of Al alloy and Al composites which were carried out on 40mm×35mm×5mm rectangular specimens by using a Suga made abrasion tester. The experiments were carried out at various loads (*i.e*., 1, 4, and 7 N) and at a fixed abrasive size of 80 mm and up to a sliding distance of 104 m.

Das *et al*. [29] have done high stress (two-body) abrasive wear tests of Al alloy and Al alloy–SiC composites which were carried out on 40mm×35mm×5mm rectangular specimens using Suga made Abrasion Tester. The experiments were conducted at different loads (i.e., 1N, 3N, 5N and 7N) and at different abrasive sizes (40µm, 60µm and 80µm) up to a sliding distance of 108 m.

Mondal *et al*. [34] shown high stress (two body) abrasion tests on 40mm×35mm×5mm rectangular specimens using Suga Abrasion Tester. Emery paper embedded with SiC particle (size: 30 µm to 80 µm) was employed as the abrasive medium. Weight loss of the specimen was calculated after each 400 stroke (corresponding sliding distance: 26 m). The tests were done at various applied loads, i.e., at 1 N, 4 N and 7 N and at various size of abrasive paper (30 µm to 80 µm).

Das [39] investigated two-body abrasive wear tests using a Suga abrasion tester. A wear specimen in the form of a rectangular piece (length 35 mm, breadth 30 mm, thickness 4 mm) was placed against a 50 mm diameter wheel wrapped in SiC abrasive paper of grit size 400.

Singh *et al.* [47] conducted high stress dry abrasion tests using a Suga Abrasion Test Machine. Rectangular specimens of size 40mm ×35mm ×5mm were formed for doing the abrasion tests. The abrasive sizes employed in the wear analysis were 25 and 200 µm and the loads applied were ranging from 1, 3, 5 and 7 N. The sliding speed was at 0.04 m.

Gupta *et al.* [72] performed high stress abrasion tests on 35mm×40mm×3mm rectangular specimens using an abrasion tester. The experiments were done at the applied loads of 3 and 7N while the abrasive used was 180grit SiC emery paper. Traversal distances taken were 400, 800 and 1200 cycles corresponding to linear distances of 26, 52 and 78 m, respectively.

Mondal *et al.* [73] carried out two body abrasive wear test samples have the dimension of 35mm×40mm×5mm. The tests were done in a Suga-made two-body abrasion tester at various applied loads (between 1 and 7N at an increment of 2N) and abrasive sizes (60, 120 and 180 µm) up to a total sliding distance of 108m having an interval of 27m sliding distance.

Furthermore parameters adopted during analysis by various investigators are reported in Table-1and is given below.

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Table-1. Wear parameters for testing on the pin on disc and abrasion tester.

Matrix	Reinforcement			Abrasive media	Apparatus	Load (N)	References
	Material	µm	Wt. or Vol.%	Material			
Al-Cu (2014) alloy	SiC_p	60-100	10 wt.%	SiC abrasive papers	Suga made abrasion tester	145,275,402,530,595, 610 & 720 grams	17
Al-Cu alloy	SiC_p	63-100	20 wt.%	30, 60 & 110µm SiC abrasive papers	Suga abrasion tester	1-7	18
Al 1100	α -SiC_p	10, 27 & 43	5, 10 and 20 vol.%.	SiC & Al2O3(20,38,46 & 60µm)	pin-on-disc	5.5	19
Al–Si (LM13) alloy	SiC_p	n.a.	10 and 15 wt.%	180 and 400 grit size SiC abrasive papers	Suga made abrasion tester	1, 3, 5 & 7	20
Al-Si alloy (A 332.1)	SiC_p	50to 80	10 wt.%	SiC paper(80 µm)	Suga made abrasion tester	1,4 &7	21
Pure aluminium	SiC_p	13 and 37µm mean diameters	60 vol.%	85, 105, 125, 180 and 250 µm of Al_2O_3 abrasive belts	abrasive wear tester	28	22
Al–Cu based alloy (Al- 2011 alloy)	SiC_p	32 and 64 µm	5 and 10 wt.%	36, 17 and 9 µm SiC V/s Al2O3 paper	pin on disc	10, 15, 20 & 25	23
LM13 alloy	SiC_p	50–80	15Wt.%	SiC paper(80 µm)	Suga made abrasion tester	1-7	24
Al and Al/1–8 wt.% Si	α -SiC_p	12–40	60 vol.%	Al2O3 paper (85–250 µm)	abrasive wear tester	28	25
ADC-12	SiC_p	25–50 and 50–80	5 to 15 wt%.	SiC paper(15to 180 µm)	Suga made abrasion tester	1-7	26
Al -2124 alloy	SiCp	n.a.	25 vol.%	80 gradeof SiC paper	pin on disc	10	27
Al–Cu based alloy	SiC_p	32, 64 and 142	10 and 15 Wt.%	18, 45&110 µm SiC paper	pin-on-disc	2, 3 and 7, 8	28
Al–Si (LM13) alloy	SiCp	50- 80	10 and 15 wt%	40 µm, 60 µm and 80µm SiC papers	Suga made Abrasion Tester	1,3, 5 and 7	29
Al-2014 alloy	SiC_p	9, 14 & 33	15wt%	140,70 & 20µm SiC paper	pin-on-disc	10,20 & 30	30
AA7075 alloy	SiC_p	40–150mm	5 to25 vol.%	25to 110 µm SiC paper	pin-on-roller	40-80	31
Al -2014 alloy	SiCp	50	20 wt.%	180 grits of SiC paper	pin on disc	8 to 32	32

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Pure Aluminium and Al-11.8 Si eutectic alloy	γ-Al_2O_3	100	3 to 5 wt%	80 grit alumina abrasive sheet	apparatus consists of a friction drum, spindle and rotating shaft	5 & 10	33
Al-Si alloy(ADC 12)	Al_2O_3	50 to 90	10Wt.%	SiC paper(30 µm to 80 µm)	Suga made abrasion tester	1, 4 & 7	34
AA2014 alloy	Al_2O_3	75–150	10 vol.%	SiC paper (20–100µm)	Suga made abrasion tester	1-7	35
Al-2024 alloy	Al_2O_3 particles	n.a.	10, 20 and 30 wt%	20 ,46 and 60 µm SiC papers	pin on disc	2	36
Al-4.5 wt%Cu alloy	Al_2O_3 & Zircon	44–74 & 74–105	15 vol.%	220 grit SiC paper	abrasive wear tester	15	37
2024 aluminium alloy	Al_2O_3 particles	16 and 32	10, 20 and 30 wt.%	20, 46 and 60 µm SiC paper	pin-on-disc	2 and 5	38
LM13 alloy	zircon particle	50-90	30 wt%	SiC paper(400 grit))	Suga made abrasion tester	1,3,&7	39
Al metal matrix composite	zircon	20	2.5, 5, 7.5, 10, 12.5, 15 vol %	n.a.	pin-on-disc	20 &25	40
LM6 alloy	granite particles	50–150	10 wt.%	SiC paper(25 & 200 µm)	Suga made abrasion tester	1,3,5 &7	48
Al–(4%,12%, 20%)Si–0.3% Mg alloy	influence of silicon	n.a.	4,12&20%wt %	320 grade of SiC	pin on disc	5 and 10	69
Al–(4–20%)Si–0.3%Mg alloy	Influence of silicon	n.a.	4,8,12,16 & 20 wt.%	100, 320 and 600 grade SiC papers	pin on disc	3	71
Al-6061 alloy	silicon nitride particles	n.a.	6 to 10 wt.%	n.a.	pin on disc	5 to 25	74
Al–Si alloys	influence of silicon	n.a.	23,26,28 &31wt %	1000 grit SiC abrasive papers	pin on disc	3 to 31	75

EFFECT OF PARAMETER OF ALUMINUM ALLOY AND ITS COMPOSITE

Effect of sliding distance on wear rate

Das [39] studied the abrasive wear rates against sliding distances of Al-Si alloy and Al-Si-zircon particle composites in the as-cast and heat treated conditions, at applied loads of 1, 3 and 7 N are shown in Figure-6. Wear rate is not directly proportional to the sliding distance while wear rate increases with increased sliding distances can be observed from above studies. A transition from mild to severe wear was observed at various loads. wear rate of as-cast LM13 alloy was increased from 1.1 $\times 10^{-10}$ m^3 /min to 1.94 $\times 10^{-10}$ m^3 /min when the sliding distance was increased from 54 to 108 m at an applied load of 1.00 N. ahead of this sliding distance (108 m), a drastic enhancement in wear rate from 1.94 $\times 10^{-10}$ m^3 /min to 4.10 $\times 10^{-10}$ m^3 /min was observed. Though, in the case of LM13-zircon

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composite, in the heat treated condition, the transition from mild to severe wear took place only after a sliding distance of 162 m. An analogous tendency was observed at higher loads, i.e. at 4.0 and 7.00 N.

Effect of abrasive medium on wear rate

Sharma *et al.* [71] carried out high stress abrasive wear behaviour of Al–Si–Mg alloys in cast and heat treated condition as a function of silicon content adjacent to 100, 320 and 600 grade abrasive medium is shown in Figure-7. It is analyzed that wear rate of Al–Si–Mg alloys decreases with increase in silicon wt. % in as cast (Figure-7a) and heat treated condition (Figure-7b and c) as well. Precipitation hardening of the Al–Si–Mg alloys under investigation decreases the wear rate. However, Al–Si–Mg alloys precipitation hardened at 170 ºC (Figure-7b) were subjected to higher wear rate as compared with the alloys precipitation hardened at 210 ºC(Figure-7c).

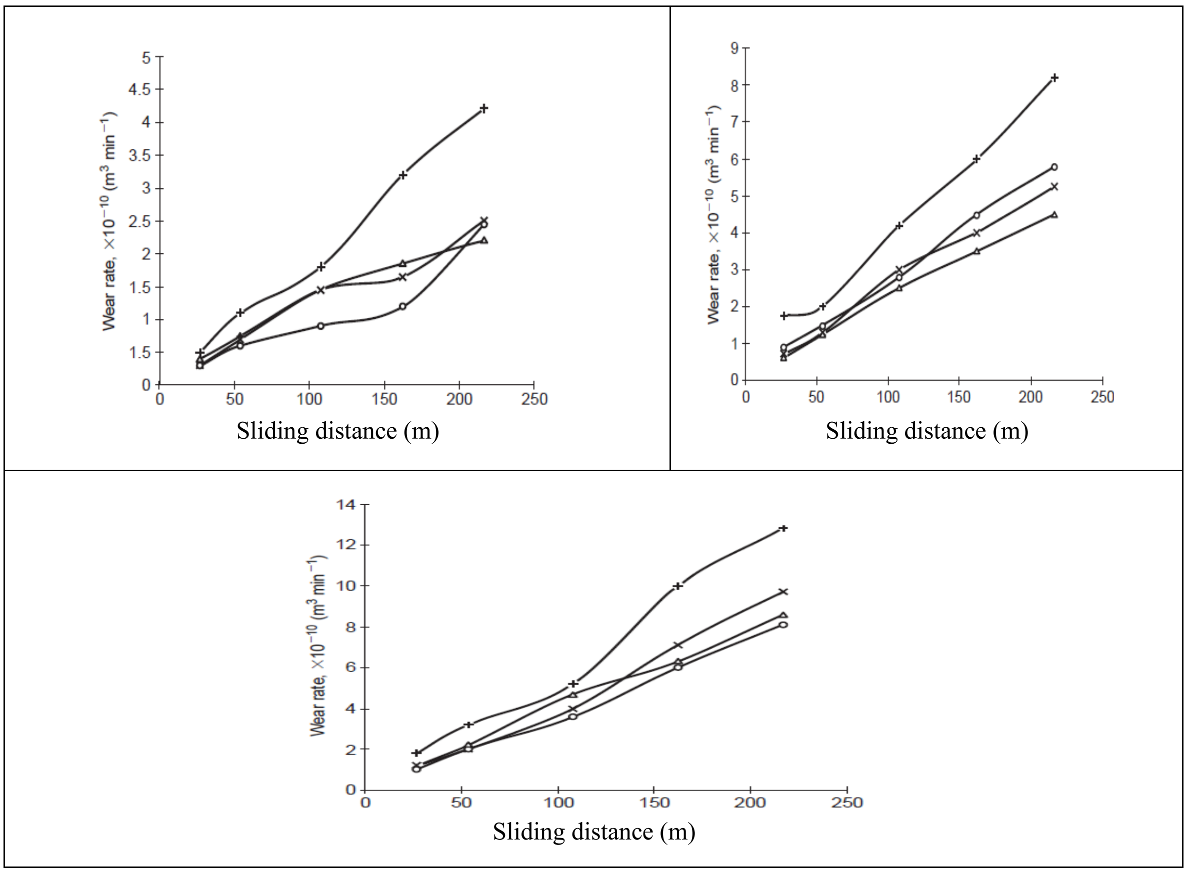

Figure-6. Wear rate as a function of sliding distance of Al-Si alloy and Al-Si-zircon composite in as-cast and heat treated conditions at applied loads of (a) 1.0, (b) 3.0 and (c) 7.0 N. (+), LM13; (Δ), LM13, heat treated; (X), LM13-zircon; (O), LM13 - zircon, heat treated [39].

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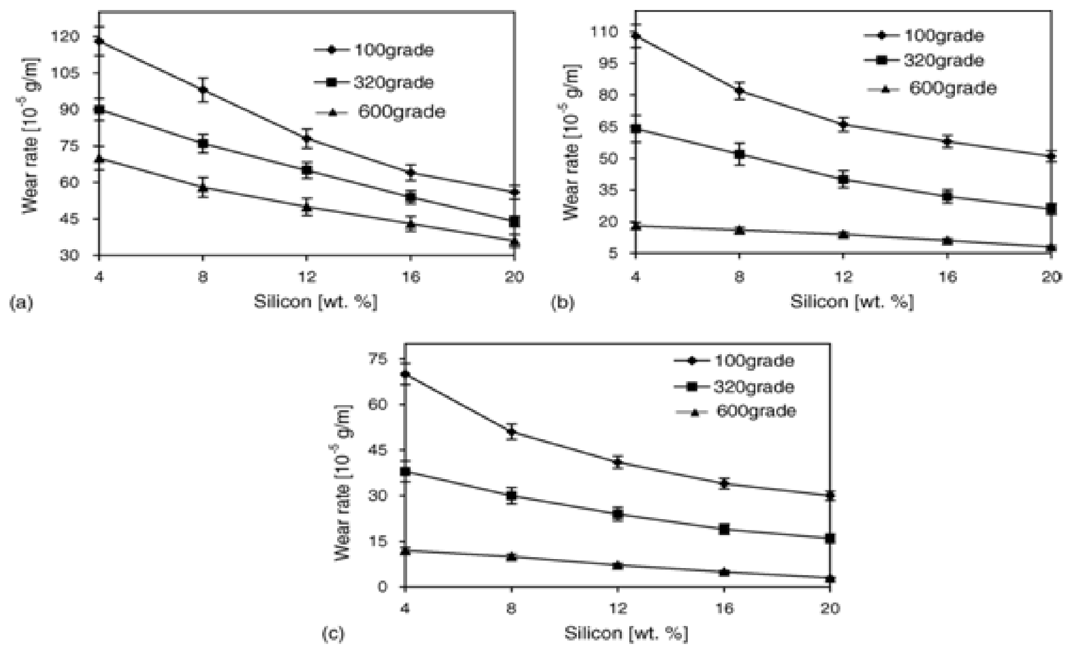

Figure-7. Abrasive wear rate as a function of silicon at against different abrasive mediums for alloys in (a) as cast, (b) aged at 170 ºC and (c) aged at 210 ºC [71].

Effect of reinforcement on wear rate

Ramesh [74] *et al*. investigated variation of wear rate of selected matrix. Figure-8 representing the change of wear rate of as cast and hot forged matrix alloy with reinforcement. It is shown that with increase in percentage of silicon nitride in the matrix alloy, there is a decrease of abrasive wear rate for both as cast and hot forged composites. However, in all identical test conditions, the abrasive wear resistance of hot forged alloy and its composites were higher.

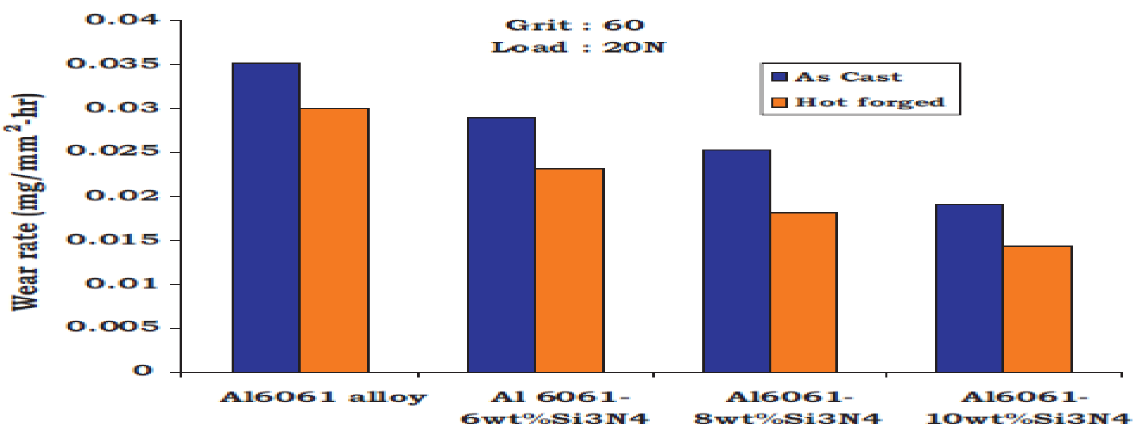

Figure-8. Variation of wear rate of as cast and hot forged Al6061 alloy with reinforcement [74].

Effect of abrasive grit size on wear rate

Ramesh [74] *et al*. found change of abrasive wear rate of as cast and hot forged Al6061 alloy and its composites with abrasive grit size as shown in Figure-9. It is shown that with decrease in the abrasive grit size (or with increase in abrasive particle size) both as cast and hot forged alloy and their composites shows increased wear rate. However, in all the cases observed that when compared with as cast alloy and its composites, hot forged alloy and its composites possessed reduced wear rate.

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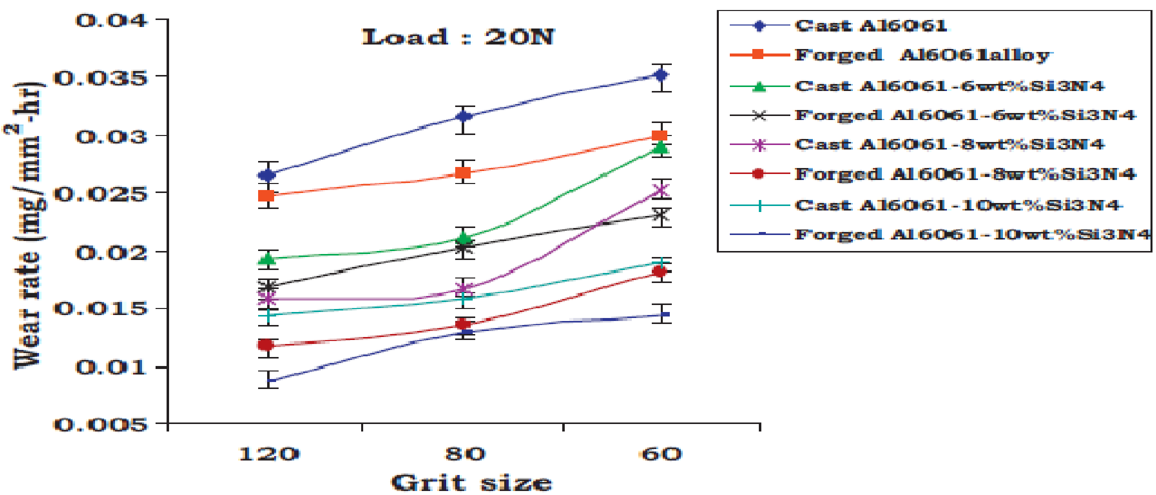

Figure-9. Variation of wear rate of as cast and hot forged Al6061 alloy and its composites with abrasive grit size [74].

Effect of load on wear rate

Xu [75] *et al*. investigated the wear rates as shown in Figure-10 that indicates the Al-Si alloys increase with the increasing load. Furthermore, it can be clearly observed that the wear rates of the modified and heat-treated Al–Si alloys are lower than those of the unmodified and non-heat-treated Al-Si alloys under loads of 3-31 N, respectively. Therefore, it can be concluded that both the modification and the heat-treatment are beneficial to improve the wear resistance of the hypereutectic-Si alloys.

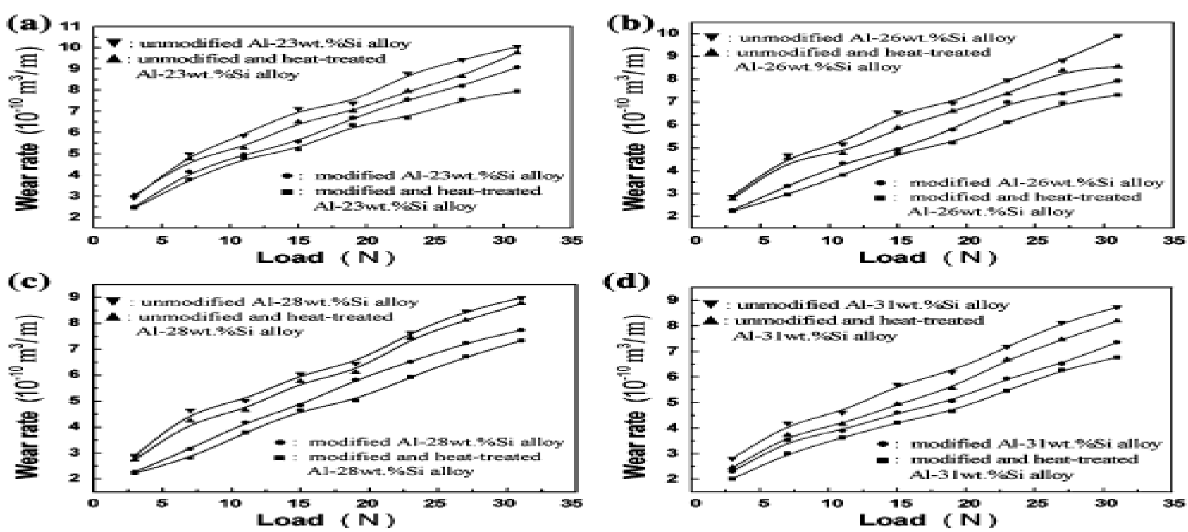

Figure-10. Wear rate as a function of applied load: (a) differently processed Al–23 wt. % Si alloys, (b) differently processed Al- 26 wt. %Si alloys, (c) differently processed Al–28 wt.% Si alloys and (d) differently processed Al–31 wt. %Si alloys [75].

CONCLUSIONS

The purpose of this review paper was to highlight the current research focus involving HSAW of Aluminium Alloy and its composites. A significant body of experimental data has been reported in the area of HSAW displayed in Table-1. The two most common Abrasive wear test apparatus are pin on disc and abrasion tester. However, Comparison of experimental data is difficult due to the wide range of wear parameters and counter face materials used.

Many researchers have investigated influence of load, reinforcement size, volume fraction, type and size of abrasive paper on wear behaviour. Presently, a number of works have been conducted in HSAW on LM2, LM6,

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LM13, LM25 and other series Al-1100, 2011, 2014, 2024, 2124, 6061 and 7075. Apart from these series of aluminium alloys very limited work has been done on HSAW. So, future research requires investigating the wear behavior of other Aluminium alloys and its composites in the field of HSAW. An attempt has been done to outline the wear parameters for testing on the Pin on Disc and Abrasion tester and effect of parameters.

Thus, the information reviewed in this paper has direct relevance to the effect of parameters in wear behaviour of Al alloy and it's composite.

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