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Experimental Analysis of Wear Characteristics of MMC – Industrial Waste As Reinforcement

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Abstract

Composites are most valuable materials in recent times as it has low density and low cost reinforcement. Among all reinforcement used, red mud waste reinforcement is the most inexpensive and low density reinforcement available in the large amount as the solid waste by- product. Metal matrix composites have been most promising materials in recent times as it has got significant properties when compared to unreinforced alloys. In this investigation, Stir casting method was used to prepare the aluminium – red mud composites. For structural characterization studies and phase identification, X-ray diffraction test was conducted. Micro-structure analysis was conducted for uniform distribution of red mud with aluminium matrix and there was a good bonding between aluminium matrix and red mud. Dispersion of red mud particles in aluminium matrix improves the hardness of the matrix material and also the wear behaviour of the composite. The effect is the increase in interfacial area between aluminium matrix and red mud particles leading to the increase in strength appreciably. Co-efficient of friction decreases as the load increases. At higher load and higher speed specific wear rate decreases with increases in Red mud content.

Keywords: Metal Matrix Composite, Industrial Waste, Wear.

Introduction

Wear of metals is probably the most important yet at least understood aspects of tribology. It is certainly the youngest of the tri of topics, friction, lubrication and wear, to attract scientific attention, although its practical significance has been recognizes throughout the ages. The findings of Guillaume Amontons in 1699 [1] establishing scientific studies of friction are almost of 300 years ago, while Petrov [2], Tower [3] and Reynolds [4] brought enlightenment to the subject of lubrication a century ago in the hectic 1880s. Substantial Studies of wear can be associated only with the five decades that have elapsed since R.Holm [5] explored the fundamental aspects of surface interactions encountered in electrical contacts.

One third of our global energy consumption is consumed wastefully in friction. In addition to this primary saving of energy, very significant additional economics can be made by the reduction of the cost involved in the manufacture and replacement of prematurely worn out components. The dissipation of energy by wear impairs strongly the national economy and the life style of most of people. So, the effective decrease and control of wear of metals are always desired [6].

Wear causes an enormous annual expenditure by industry and consumers. Most of this is replacing or repairing equipment that has worn to the extent that it no longer performs a useful function. For many machine components this occurs after a very small percentage of the total volume has been worn away. For some industries, such as agriculture, as many as 40% of the components replaced on equipment have failed by abrasive wear. Other major sources of expenditure are losses production consequential upon lower efficiency and plant shutdown, the need to invest more frequently in capital equipment and increased energy consumption as equipment wears. Estimates of direct cost of abrasive wear to industrial nations vary from 1 to 4 % of gross national product and Rigney [7] has estimated that about 10% of all energy generated by man is dissipated in various friction processes.

Wear is not an intrinsic material property but characteristics of the engineering system which depend on load, speed, temperature, hardness, presence of foreign material and the environmental condition [8]. Widely varied wearing conditions causes wear of materials. It may be due to surface damage or removal of material from one or both of two solid surfaces in a sliding, rolling or impact motion relative to one another. In most cases wear occurs through surface interactions at asperities. During relative motion, material on contacting surface may be removed from a surface, may result in the transfer to the mating surface, or may break loose as a wear particle. The wear resistance of materials is related to its microstructure may take place during the wear process and hence, it seems that in wear research emphasis is placed on microstructure [9]. Wear of metals depends on many variables, so wear research programs must be planned systematically. Therefore researchers have normalized some of the data to make them more useful. The wear map proposed by Lim and Ashby [8] is very much useful in this regard to understand the wear mechanism in sliding wear, with or without lubrication.

Theory of Wear:

Wear occurs as a natural consequence when two surfaces with a relative motion interact with each other. Wear may be defined as the progressive loss of material from contacting surfaces in relative motion. Scientists have developed various wear theories in which the Physico-Mechanical characteristics of the materials and the physical conditions (e.g. the resistance of the rubbing body and the stress state at the contact area) are taken in to consideration. In 1940 Holm [5] starting from the atomic mechanism of wear, calculated the volume of substance worn over unit sliding path. Barwell and Strang [10] in 1952: Archard [11] in 1953 and Archard and Hirst [12] in 1956 developed the adhesion theory of wear and proposed a theoretical equation identical in structure with Holm's equation. In 1957, Kragelski developed the fatigue theory of wear. Because of the Asperities in real bodies their interactions on sliding is discrete and contact occurs at individual locations, when taken together, form the real contact area. Under normal force the asperities penetrate into each other or are flattened out and in the region of real contact points corresponding stress and strain rise. In sliding, a fixed volume of material is subjected to the many times repeated action, which weakens the material and leads finally to rupture.

Though all the theories are based on different mechanisms of wear, the basic consideration is the frictional work. Hence friction is the prime consideration. In the last two decades numerous studies of wear properties of Aluminium based Metal Matrix Composites with different type of reinforcements has been studied. Kirit J. Bhansali and Robert Mehrabian [13] have studied the abrasive wear resistance of aluminum matrix composites containing Al2O3 and SiC using a dry sand/rubber wheel abrasion tester. Their results show that composites containing Al2O3 were found to be superior to those containing SiC. G.Wang, & I.M. Huttching [14] reported the investigations of the response of alumina fiber- aluminum metal matrix composites systems to wear by two-body abrasion. Their results show that wear resistance of the composites was found to range from almost two to six times that of the unreinforced matrix alloy. A.T. Alpas and J.Zhang [15] studied the dry sliding wear of aluminum matrix composites and determined how the micro structural parameters such as volume fraction of particulate and particulate size affect the wear resistance of these materials. V.Constantin et. al. [16] investigated the sliding wear behaviour of Aluminum Silicon Carbide metal matrix composites reinforced with different volume fraction of particulate against a stainless steel slider. Their results show that addition of reinforced particles increases the resistance of the composites to sliding wear under dry conditions, even for small volume fraction of particles. Rohatgi.P.K et. al. [17] in their work report test examination of abrasive wear resistance of Aluminum alloy (A356) containing fly-ash particles. Their results show that the wear resistance of specimen containing fly ash was comparable to that of alumina fiber-reinforced alloy and superior to that of base A356 alloy.T.Miyajima & Y.Iwai [18] studied the effect of reinforcements on sliding wear behaviour of aluminum matrix composites. Their results show that the degree of improvement of wear resistance of metal matrix composites (MMC) is strongly dependent on the kind of reinforcement as well as its volume fraction. Aluminum metal matrix composites are emerging as promising friction materials. One of the important applications that are being considered for MMCs is as rotor (disc/drum) material in automotive brake system. K.M.Shorowordi et. al. [19] studied the effect of velocity on the wear, friction and tribochemistry of aluminum MMC sliding against phenolic brake pad. Their results show that higher sliding velocity leads to lower wear rate and lower friction coefficient for Al-B4C and Al-SiC metal matrix composites.

Hutching I.M [20] studied the "Tribological properties of Metal Matrix Composites" and has the opinion that under certain conditions MMCs show high wear resistance but this is not the case always and is some time depended on the wear mechanism. Axen et. al. [21] studied the friction and wear behaviour of an Al-Si, Mg-Mn aluminum alloy reinforced with 10%, 15%, and 30% volume of alumina fibers.

Their results shows that fiber reinforcement increases the wear resistance in milder abrasion situations and the coefficient of friction decreases with increasing fiber content and matrix hardness of composites. Zongy Ma Jing et. al. [22] studied the abrasive wear of discontinuous SiC reinforced aluminum alloy composites. Their result shows that the composites exhibits excellent abrasive resistance compared with the unreinforced matrix alloy. A.Alahelisten et. al. [23] studied the effect of fiber reinforcement of aluminum magnesium and Mg-9 Al-1 Zn on the wear properties. Their results shows that tribological behaviour of MMCs depends much on type of MMC and the type of contact situation i.e. tribosystem. L. Cao et. al. [24] studied the wear behaviour of SiC whisker reinforced aluminum composite. Their results show that the SiC whisker–Al composite exhibits a fairly good wear resistance especially for higher sliding velocities and / or higher loads. Liang.Y.N et.al. [25] studied the effect of particle size on the wear behaviour of SiC particulate reinforced 2024 Al composites investigated using three tests, sliding wear test, impact abrasion test, and erosion test. Their results show that the wear behaviour of particulate reinforced aluminum composite is significantly affected by particle size.

Composites contain large particles exhibited excellent wear under sliding wear conditions with steady applied load. Wang and Rack [26] studied on the comparative assessment of the effect of different types of reinforcement. Their results show that in the case of 20% vol. SiC particles Vs 20% Volume SiC-whisker (perpendicular or parallel), the steady state wear rates of the composites were generally independent of the reinforcement geometry (Particulate or whisker) and orientation (perpendicular Vs Parallel). A.Ravikiran, M. K. Surappa [27], studied the effect of sliding speed on wear behaviour of Al-30 wt % SiC MMC, concluded that the wear rate of pin material (MMC) decreases with increasing speed, and also the wear rate of the composite decreases with increasing area fraction of SiC particles. Manish Narayan et. al. [28] have done an experimental study on dry sliding wear behaviour of Al alloy 2024 Al2O3 particle metal matrix composites and have shown that the Al 2014, 15 vol% Al2O3 composite shows better seizure resistance than does the unreinforced alloy in the peak aged condition and also in the as-extruded condition the wear resistance of the unreinforced alloy is better than that of composite. As reported earlier the fabrication techniques for MMCs vary depending upon choice of matrix material and the type of reinforcement. Tjong. S.C et. al. [29] studied the wear behaviour of aluminum silicon alloy reinforced with low volume fraction of SiC particles prepared by Compo Casting process. The wear behaviour of unreinforced Al-12 % SiC alloy and metal matrix composites was investigated by them using a block– on-ring test at room temperature under dry conditions. Their result shows that the addition of low volume fraction of SiC particles (2 to 8%) is a very effective way of increasing wear resistance of composite. Yoshiro.Iwai et. al. [30] studied the wear properties of SiC whisker reinforced 2024 Al alloy with volume fraction of whiskers ranging from 0 to 16% produced by Powder Metallurgy technique. Their results show that SiC whisker reinforcement can improve the wear resistance of aluminum alloy for both severe and mild wear. D. Huda et. al. [31, 32] reported that a particular fabrication technique depends on the type of the proper matrix and reinforcement materials to form the MMC. Sannino and Rack [33] however showed that the effect of the shape of reinforcement depends on the sliding velocity. It is difficult to deduce the effects of reinforcement from the literature because in the reported studies experimental conditions such as contact load and sliding velocity spread over very wide ranges and these studies employ different kinds of test apparatus. The effects of sliding velocity on the frictional and wear behavior of aluminum MMC sliding against ferrous counter body have been studied by a number of researchers [34 & 35]. Their studies revealed that the frictional and wear characteristics of aluminum MMC depend on the sliding speed in a complicated way. Depending upon the sliding velocity range, both increase and decrease in wear rate with sliding velocity were reported.

It is clear from the above discussions that the wear properties are improved remarkable by introducing a hard inter metallic compound into the aluminum matrix [36]. It has also been demonstrated that because the bonding strength between intermetallic and matrix is very strong, pulling out is prevented even at high loads [37]. The Wear of aluminum based metal matrix composites (MMCs) depends on several factors such as volume fraction, morphology, and size of reinforcing phase as well as the strength of the interface. Work published in the literature is mainly concerned with SiC, Al2O3 particles. There are also relatively few discussions on the wear behavior of aluminum MMCs reinforced with alumna fibers [38] and also with natural minerals [39]. But till now as per the information of the investigator no work has been done with red mud as reinforcement. Therefore the present investigation is aimed at preparation of a Metal Matrix Composite using red mud as reinforcing material and to study its friction and wear behaviour.

Methods & Materials

Experiments have been conducted in the Pin-on-disc type Friction and Wear monitor with data acquisition system, (Fig. 1) which was used to evaluate the wear behaviour of the composite, against hardened ground steel disc having hardness 65 HRC and surface roughness (Ra) 0.5 µm. It is versatile equipment designed to study wear under sliding condition only. Sliding generally occurs between a stationary Pin and a rotating disc. The disc rotates with the help of a D.C. motor; having speed range 0-2000 rev/min with wear track diameter 50 mm-180 mm, which could yield sliding speed 0 to 10 m/sec. Load is to be applied on pin by dead weight through pulley string arrangement. The system has a maximum loading capacity of 200N.

Figure 1: Pin-On-Disc Type Friction and Wear Monitor With Data Acquisition System

Aluminium:
Commercially pure aluminium from Madras Aluminium Company's (MALCO), Tamilnadu was collected and was used for experimental purpose. The composition analysis along with test results such as hardness, density, & tensile strength are presented in tables 1 & 2.

Table 1: Compositional analysis of aluminium

Sl. No	Si	Fe	Ti	V	Cu	Mn	Al
1	0.08	0.15	0.001	0.007	0.001	0.003	99.76

Table 2: Density, Hardness & Tensile Strength of Aluminium

Density	2.7 gm/cc
Hardness	40.8 VHN
Tensile Strength	67 Mpa

2.2 Red Mud: The red mud used for the present investigation was brought from Madras Aluminium Company's (MALCO), Tamilnadu. Dust was prepared manually. The size of the dust was measured by using a sieve. As per this analysis the average size of the dust was 150 micron. Red mud dust was subjected to XRD, and chemical analysis. The presence of different elements as confirmed by chemical analysis is presented in table3.

Table 3: Chemical (dry) Analysis of Red Mud

Constituents	% (wt)	Constituents	% (wt)
Al_2O_3	15.0	Fe_2O_3	54.8
TiO_2	3.7	SiO_2	8.44
Na_2O	4.8	CaO	2.5
P_2O_5	0.67	V_2O_5	0.38
Ga_2O_3	0.096	Mn	1.1
Zn	0.018	Mg	0.056
Organic C	0.88	L.O.I	Balance

2.3 XRD Analysis: This was done to detect the presence of different elements in the red mud. XRD work was carried out on a Philips X-ray diffract meter. The X-ray diffract grams are taken using Cu Kα radiation at scan speed of 3°/ min. Fig.2a shows the XRD analysis of red mud particles. The large peak found are of Al2O3 particles, where as small peaks indicates the presence of Fe2O3 in red mud. The noisy peaks indicate the presence of other trace elements like SiO2, Al3Fe etc.

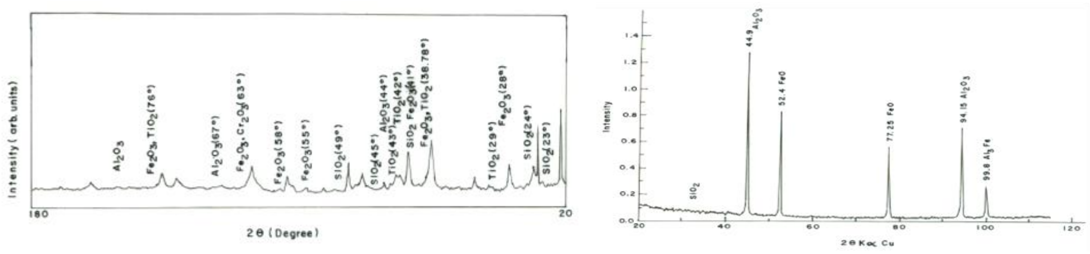

Figure 2: (A & B) XRD Pattern of MALCO Red Mud

The selected 20% red mud added sample has been analyzed by x-ray diffraction analysis. The composites were produced under different conditions to identify the different phases in it; the study was made on the analysis chart, which is shown in the diffract gram Fig.2b. The large peaks found are of Al2O3 particles, where as small peaks indicate the presence of FeO, and Al3Fe in MMC. The noisy peaks indicate the presence of other trace elements like SiO2 in the diagram and confirm the presence of red mud particles in the composites.

Preparation For The Test Specimens:

The cut pieces from ingot were pickled in 10% sodium hydroxide solution at 95-100°C for 10 minutes. The sinut formed was removed by immersion for one minute in a mixture of one part nitric acid and one part water followed by washing in methanol. Immediately after drying in air, the weighted quantity of pickled aluminium was melted in a crucible.

The required quantities of red mud (10, 15, 20 and 30 percent by weight) were taken in powder containers. The red mud was preheated in a furnace up to 400°C and maintained at that temperature before mixing with Aluminum melt. The weighted quantity of pickled aluminium were melted to desired superheating temperature of 800°C in graphite crucible 3 phase electrical resistance furnace with temperature controlling device was used for melting. After melting was over, the required quantity of red mud particulates, preheated to around 400°C were then added to the molten metal and stirred continuously by using mechanical stirrer. The stirring time was maintained between 60-80sec at an impeller speed of 550 rpm.

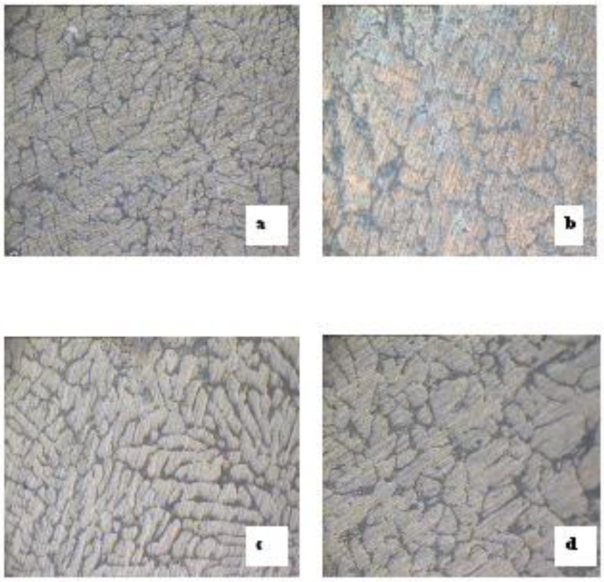

Figure 3: Micrographs showing red mud distribution of different volume fractions (a) 10% (b) 15% (c) 20% & (d) 30% at (200X).

During stirring to enhance the wettability small quantities of Magnesium was added to the melt [40]. The melt with the reinforced particulates were then poured to a prepared cylindrical mould by bottom pouring method. After pouring is over the melt was allowed to cool and solidify in the mould. For the purpose of comparison, the matrix material was also cast under similar processing conditions. After solidification the casting were taken out from the mould and were cut to require shape and sizes for wear testing. To ascertain the distribution of reinforcement particulates cut pieces of the samples were polished and were inspected under optical microscope. The distribution with different volume fraction of red mud particles in the matrix are shown in Fig.3. It is clear from these figures that the reinforcing particles were distributed uniformly in the aluminium matrix.

Testings

Hardness test - The hardness of the heat treated samples was measured using Vicker hardness measuring machine with a load of 0.4903 N. The load was applied for 30 seconds. In order to eliminate possible segregation effect a minimum of three hardness readings were taken for each specimen at different locations of the test samples. The hardness is presented in table - 4.

Table 4: Hardness of Samples

Specimen	**Yield Stress (MPa)**	**Yield Stress (MPa)**	**Elasticity Modulus (GPa)**	**Percentage Elongation**	**Impact Strength ($Kg.m/cm^2$)**	**Hardness (VHN)**
Pure Al	24.5	67	73	25	6.3	40.8
90%Al+ 10%RM	23.47	6.75	34.98	9.23	7.44	52.78
85%Al+ 15%RM	31.77	7.68	47.53	11.51	8.98	53.6
80%Al+ 20%RM	25.83	5.83	42.1	14.18	8.34	55.8
70%Al+ 30%RM	31.96	7.1	57.1	16.15	10.66	54.82

Tensile test - The tensile behaviour of all the prepared samples were determined to examine the possibility of correlations between wear and tensile properties. Circular cross section specimen with a specific gauge length of 60 mm, grip distance of 100 mm and a gauge diameter of 8 mm were used for the tensile tests. These tests were carried out at a constant crosshead speed of 5 mm/min and full scale load range of 20 kN corresponding to an initial sample rate 9.103 pts/sec in a tensile testing machine of 100 kN capacities. The results of the tensile tests for different composites are presented in table-4.

Impact test - The size of the specimen for the impact test was 10 mm x 10 mm x 50 mm with a rectangle notch size of 2 mm. The tests were carried out at room temperature using an impact-testing machine of Charpy type. The tests was carried out with an initial energy of hammer 30 Kg.m and with a striking velocity of 5.6 m/s. Impact test result for different test specimen are presented in table–4.

Wear Test - Before conducting the test, the pin and the disc surfaces were polished with emery papers, so that the contact will be a smooth one. All the wear tests were carried out as per ASTM G-99 standard under unlubricated condition in a normal laboratory atmosphere at 50-60% relative humidity and a temperature of 28-32°C. Each test was carried out for 6 hrs run. The mass loss in the specimen after each test was estimated by measuring the weight of the specimen before and after each test using an electronic weighing machine having accuracy up to 0.01mg. Care has been taken that the specimens under test are continuously cleaned with woolen cloth to avoid the entrapment of wear debris and to achieve uniformly in experiential procedure. The test pieces are cleaned with tetra-chloro-ethylene solution prior and after each test. The tests have been carried out under the following conditions;

- The specimens under tests were fixed to the collect (Fig.1). The collect along with the specimen (Pin) is positioned at a particular track diameter. This track diameter is to be changed after each test i.e. a fresh track is to be selected for each specimen. During experiment the specimens remains fixed and disc rotates.

- Load is applied through a dead weight loading system to press the pin against the disc.
- Frictional force arises at the contact can be read out from the controller.
- The speed of the disc or motor rpm can be varied through the controller.
- For a particular type of composite 27 sets of test pieces were tested.
- Each set of test was carried out for a period of 6 hrs run. After each one hour run the test pieces were removed from the machine and weighted accurately to determine the loss in weight.

Calculation

Wear rate was estimated by measuring the mass loss in the specimen after each test and mass loss, Δm in the specimen was obtained. Cares have been taken after each test to avoid entrapment of wear debris in the specimen. Wear rate which relates to the mass loss to sliding distance (L) was calculated using the expression,

$$Wr = \Delta m/L \qquad (1)$$

The volumetric wear rate Wv of the composite is relate to density (ρ) and the abrading time (t), was calculated using the expression,

$$Wv = \Delta m / \rho t \qquad (2)$$

The friction force was measured for each pass and then averaged over the total number of passes for each wear test. The average value of co-efficient of friction, μ of composite was calculated from the expression,

$$\mu = Ff / Fn \qquad (3)$$

Where Ff is the average friction force and Fn is the applied load.

For characterization of the abrasive wear behaviour of the composite, the specific wear rate is employed. This is defined as the volume loss of the composite per unit sliding distance and per unit applied normal load. Often the inverse of specific wear rate expresses in terms of the volumetric wear rate as

$$Ws = Wv / Vs\, Fn \qquad (4)$$

where Vs is the sliding velocity.

Experimental results of the wear test of different test pieces (10, 15, 20, and 30 % by weight of red mud) at different test conditions (first and last readings) are tabulated and presented in table 5(a & b).

Table 5 (a) & 5(b): Wear test result of test pieces (First Reading & Last Reading)

Aluminium Load - 10N $\rho = 2.62 \times 10^3 Kg/m^3$
RPM = 200 $V_s = 1.257$ m/sec

m_1 (gm)	m_2 (gm)	Δm (gm)	t (sec)	F^f (Kg^f)	μ	R.D x 10^3 (m)	W_r x 10^{-6} (N/m)	W_v x 10^{-12} (m^2/sec)	Ws x 10^{-13} (m^3/N-m)
8.25	8.18	0.07	3600	0.33	0.33	4.53	0.15175	7.4215	6.018
8.25	8.12	0.13	7200	0.33	0.33	9.06	0.14091	6.8914	5.5886
8.25	8.04	0.21	10800	0.29	0.29	13.59	0.15175	7.4215	6.0185
8.25	7.97	0.28	14400	0.33	0.33	18.12	0.15175	7.4215	6.0185
8.25	7.92	0.33	18000	0.30	0.30	22.65	0.14308	6.997	5.674
8.25	7.87	0.38	21600	0.33	0.33	27.18	0.1373	6.714	5.444

Al+30%RM Load - 30N $\rho = 2.55 \times 10^3$ Kg/m^3
RPM = 400 Vs = 3.141 m/sec

m_1 (gm)	m_2 (gm)	Δm (gm)	t (sec)	F^f (Kg^f)	μ	R.D x 10^3 (m)	Wr x 10^{-6} (N/m)	Wv x 10^{-12} (m^2/sec)	Ws x 10^{-13} (m^3/N-m)
8.23	7.72	0.51	3600	0.84	0.28	11.309	0.4424	55.55	6.01
8.23	7.28	0.95	7200	0.87	0.29	22.618	0.4120	51.742	5.597
8.23	6.82	1.41	10800	1.05	0.35	33.927	0.4077	51.198	5.538
8.23	6.29	1.94	14400	0.90	0.30	45.236	0.4207	52.832	5.715
8.23	5.85	2.38	18000	0.99	0.33	56.545	0.4129	51.851	5.609
8.23	5.50	2.73	21600	0.93	0.31	67.854	0.3947	49.544	5.341

Results and Discussion

Based on the tabulated results, various graphs are plotted and presented in Figs. 4 to 8 for different percentage of reinforcement under different test conditions.

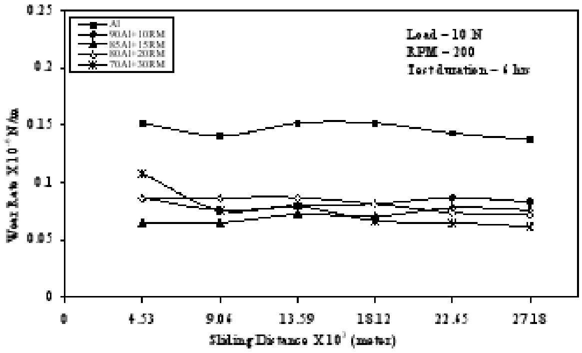

Figure 4: Variation of Wear Sliding Distance

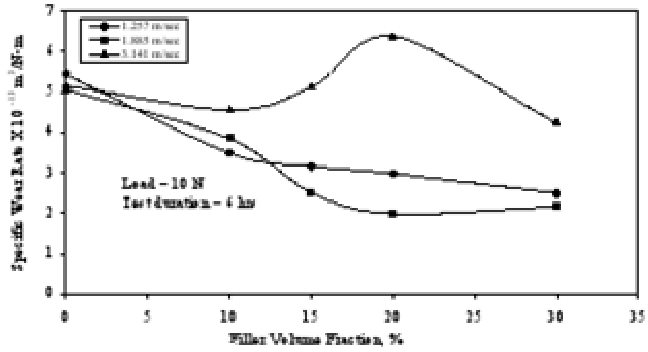

Figure 5: Variation of Specific Wear Rate With Filler Volume Fraction

Figs.4 shows the variation of wear rate with sliding distance for 10N loads at 200 rpm. It is seen from the plots that with addition of red mud particles the wear rate of the composite is decreasing. Also as the sliding distance increases the wear rate first decreases and then almost remains same for the entire test period. Since the trend for 300 and 400 rpm remains same as 200 rpm, it has not been presented here.

Figs. 5 show the variation of specific wear rate with filler volume fraction for 10N loads i.e. red mud. It is clear from the plot that the specific wear rate decreases with increase in filler volume fraction and after attaining a minimum value within 10-20% it again increases. Thus there exists an optimum filler volume fraction, which gives maximum wear resistance to the composite.

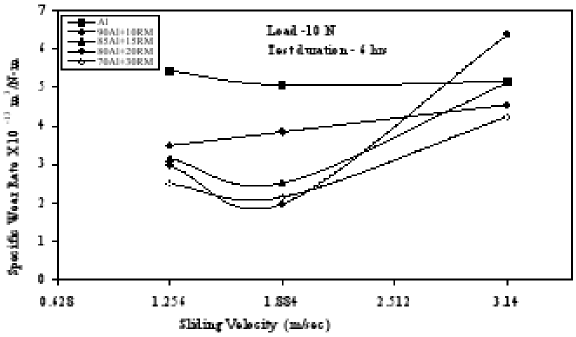

Figure 6: Variation of Specific Wear Rate With Sliding Velocity

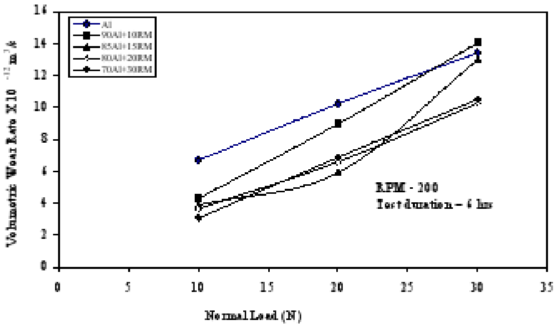

Figure 7: Variation of Volumetric Wear Rate With Load

Figs.6 show variation of specific wear rate with sliding velocity. The plot shows that the specific wear rate of the composite increases with increase in sliding velocity. From the figure it is also clear that rate of increase of wear rate is initially high and decreases as the load increases. For 30% volume of red mud this is somewhat deviating in all cases i.e. the wear rate increases to a very high value in comparison to other. This deviation somewhat relates to the results projected in Figs.5.

Figs.7 show the variation of volumetric wear rate with normal load. It can be observed from the plots that the volumetric wear rate increases with increase in normal load. This is because at higher load, the frictional thrust increases, which results in increased debonding and fracture. A similar effect of normal load on volumetric wear rate has been observed by Cirino et.al. [41] in the case of carbon epoxy composite and Verma et. al. [42] for GRP composite. It is also evident from the plot that at higher speed and high volume fraction, the volumetric wear rate of the composite for a load of 20 N is higher than pure aluminium. This shows the dependence of load and the volume fraction of red mud on the volumetric wear behaviour of the composite over pure aluminium. At 400 rpm (i.e. velocity, vs = 3.141 m/sec) the critical load (the load above which the composite shows higher volumetric wear rate than pure aluminium) was reduced to 20 N. As many parameters e.g. sliding velocity, sliding distance and load are responsible for wear and are expressed in the earlier figures, it is more appropriate to express the sliding wear results in terms of the wear constant, K [43, 44] as extracted from Archard's law. For known values of V (wear volume), H (Vickers hardness of the softer material), S (sliding distance), and L (normal load), the wear coefficient (K) can be determined from the following equations:

$$V = K\ L\ S\ /\ H \text{ ---------------------------} \qquad (5)$$

Rabinowicz interpreted the wear constant K as a co-efficient related to the probability of asperity fracture [45]. Thus the wear constant K is a correlation factor between several variables of the sliding wear experimental results and is related to various microscopic mechanisms. Fig.7 shows the variation of wear co-efficient with particle volume content. It is apparent in this figure that the wear co-efficient tends to decrease with increasing particle volume content. Thus red mud addition is beneficial in reducing the wear of the aluminium red mud composite. Same type of results has been reported by S.C.Tjong et.al. [46] for the wear behaviour of aluminium based MMC composite reinforced with a perform aluminosilicate fiber.

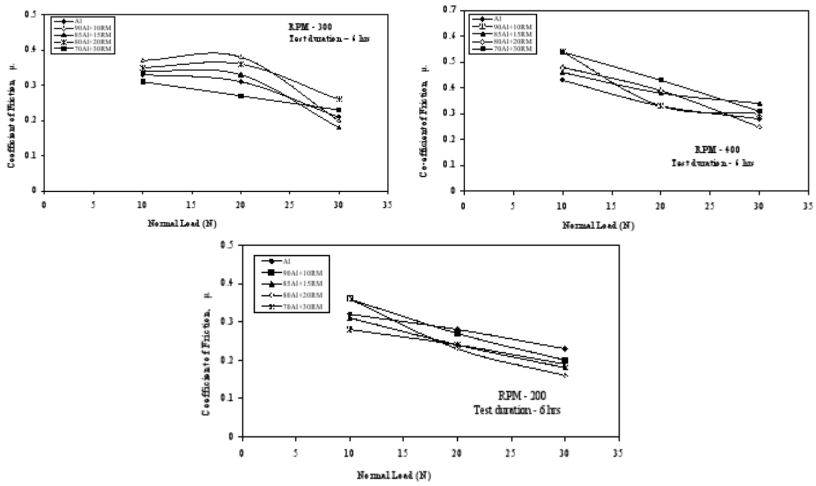

Figure 8: (a, b & c). Variation of coefficient of friction with load at 10

Figs.8 (a, b & c) shows the variation of coefficient of friction with normal load at 200, 300 & 400 RPM. This shows that the coefficient of friction in all cases decreases with the increase of normal load. This decrease in value occurs likely as a result of particulate standing above the surface making contacting area of the specimen smaller.

Conclusions

The following conclusions have been drawn from the above study

- Aluminium matrix composites have been successfully fabricated with fairly uniform distribution of red mud particles.

- Dispersion of red mud particles in aluminium matrix improves the hardness of the matrix material and also the wear behaviour of the composite. The effect is the increase in interfacial area between aluminium matrix and red mud particles leading to the increase in strength appreciably.
- Co-efficient of friction decreases as the load increases.
- At higher load and higher speed specific wear rate decreases with increases in Red mud content.
- Wear co-efficient tends to decrease with increasing particle volume content. It also indicates that red mud addition is beneficial in reducing wear of the aluminium red mud composite.
- Wear resistance of the composite increases due to addition of red mud particles.

However there exists an optimum filler volume friction which gives maximum wear resistance to the composite.

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