Dry Sliding Wear behaviour of Aluminium-Red mud-Tungsten Carbide Hybrid metal matrix composites

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Abstract. Red mud is an industrial waste obtained during the processing of alumina by Bayer's process. An attempt has been made to utilize the solid waste by using it as the reinforcement material in metal matrix composites. Red mud received from NALCO has been subjected for sieve analysis and milled to 42 nanometers using high energy ball mill. Red mud is used as a reinforcement material in Pure Aluminium matrix composite at 2%, 4%, and 6% weight at 100 microns level as well as 42 nano meters along with 4%Tungsten carbide by weight. Micro and Nano structured red mud powders, Tungsten carbide powder and Aluminium is mixed in a V-Blender, compacted at a pressure of 40 bar and samples are prepared by conventional sintering with vacuum as medium. In this current work, dry sliding wear characteristics at normal and heat treatment conditions are investigated with optimal combination of Aluminium, Tungsten carbide and different weight fractions of micro and nano structured red mud powder.

Keywords: Sintering, Aluminium, Red mud, Tungsten Carbide, Composites

1. Introduction

Red mud is the caustic insoluble waste residue in the extraction of alumina from its bauxite ore. It is estimated that two tons of alumina used to produce one ton of Aluminium and 58% of alumina and 42% of red mud come out from one ton of bauxite approximately, under normal conditions. In terms of metal production the ratio of aluminium to red mud is 1:2. This waste material has been accumulating at an increasing rate throughout the world. The Bauxite residue which is known as Red mud is mixed with other metals mainly to aluminium to form metal matrix composites which exhibit more advanced mechanical properties and applications [1, 2]. Powder compaction is the process of compacting metal powder in a die through the application of high pressures. The powder is compacted into a shape using the punch tool held in vertical orientation and then ejected from the die cavity. Due to the grave problems of climate change and energy, focus has shifted away from landfill waste, but this is a serious problem. Hazardous industrial, electronic, and bio medical wastes lead to burden on the earth [3, 4, 5]. Hence waste treatment is one of the top most problems of the world. Red mud has been used in the removal of sulphur compounds from kerosene oil [6, 7], in the heap leaching of gold ores as a pH modifier [8, 9], in the anthracene hydrogenation [10, 11] and as a pigment in marine paints as anticorrosive [12].

In China, approximately 10% of Red mud produced, is recycled for further metal extraction or utilized as a raw material for brick production [13]. In India, it is reported that 2.5 million tons are absorbed by the cement industry. Residual Bauxite is introduced as a raw material along with other raw materials such as lime, clay, silica etc. The tests confirmed that residue added cement, as well as mortar and concrete made from this cement, meet the Japanese Industrial Standards [14, 15]. In the current work, the objective is to investigate the heat treatment effect on micro and nano red mud and tungsten carbide reinforced aluminium metal matrix hybrid composites. The best weight fraction of red mud and tungsten carbide as reinforcing materials required in the aluminium metal matrix hybrid composites can be evaluated for optimum properties.

2. Experimental Set Up

2.1. *Sieve analysis* Sieve analysis (or gradation test) is a procedure used to assess the particle size distribution of a granular material. This analysis is used to assess the particle size of the given granular material and distribute it according to range of size in microns. It is also called as particle sizing technique. A typical sieve analysis involves a nested column of sieves with wire mesh cloth (screen). A round pan, called the receiver which is arranged at the bottom of the sieve. The red mud used for the present investigation is collected from the National Aluminum Company Limited (NALCO) Damanjodi, Odisha, India of 100 microns in size. The Chemical composition of Pure Aluminium of 99.72% purity, red mud and tungsten carbide are shown in Table 1, 2 and 3 respectively.

Table 1: Chemical composition of Pure Aluminium

Element	Fe	Si	Mg	Mn	Cu	Zn	Others
Wt%	0.17	0.07	0.001	0.0008	0.005	0.003	Balance

Table 2: Chemical composition of Red mud

Element	Fe_2O_3	Al_2O_3	TiO_2	SiO_2	Na_2O	CaO	V_2O_5	Others
Wt%	53.8	14.3	3.9	8.34	4.3	2.5	0.38	Balance

Table 3: Chemical composition of Tungsten Carbide

Element	Cr	W	Si	B	C	Others
Wt%	3.52	8.5	2.0	1.8	0.5	Balance

2.2. *Ball Milling* Nanoparticles are formed in a mechanical device, generically referred to as a high energy ball mill. The popular mill for conducting mechanical attrition experiments is the planetary ball mill (referred to as Pulverisette).The planetary ball mill owes its name to the planet-like movement of its vials. These are arranged on a rotating support disk, and a special drive mechanism causes them to rotate around their own axes.

The as-received red mud is subjected for sieve analysis using mechanical sieve shaker and the particles of uniform size are collected. The reduction in particle size of red mud from micron level to the nano level is carried out using a high-energy planetary ball mill in a stainless steel chamber using tungsten carbide and zirconia balls of 10 mm Φ and 3 mm Φ ball sizes respectively. The milling is

carried for 30 hours by maintaining the rotation speed of the planet carrier at 200 rpm. The ball mill is loaded with ball to powder weight ratio (BPR) of 10:1. Toluene is used as the medium with an anionic surface active agent to avoid agglomeration. The milled sample powder is taken out at after 6hrs, 24 hours and 30 hours of milling and dried with mechanical drier.

In Figure 1, the XRD Pattern for 30 hours milled Red mud is shown. The crystallite size is reduced from 400nm to 42 nm during 30 hours of ball milling. The fresh Red mud powder particles were mostly angular in shape. The shape of the 30h milled particles is irregular and the surface morphology is rough. The relative lattice strain is increasing with increasing the duration of milling time. This lattice strain is increased from 0.12 to 0.28 for as received at 30 h milled Red mud. The intensity of the peaks in the XRD pattern got reduced and the peak broadening increased as the duration of milling increases.
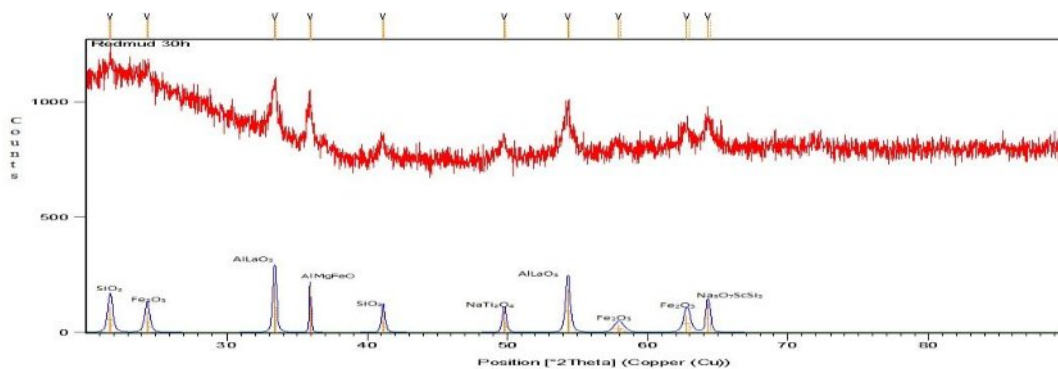

Figure 1.XRD Pattern for 30 hours milled red mud

2.3 Mixing and Compacting The samples after continuous ball milling are brought and allowed for mixing for proper interaction of particles with each other. The obtained samples are compacted in a hydraulic press of 100 ton load capacity (7.5 H.P). During compacting pressure applied is 40 bar and compact pressing time was 4 sec.

2.4 Sintering It is a thermal treatment, below the melting temperature of the main constituent material, which transforms a metallic or ceramic powder (or a powder compact) into a bulk material containing, in most cases, residual porosity. Vacuum maintained during sintering was 250 Pa(using a compressor of 1.5 H.P).Raising the temperature to 300°C in 30 min. Soaking at 300°C for 30 min. Raising the temp to 620°C(time taken is 35min) and again soaking at 620°C for 30 min. Then cooling is done to room temperature (time taken is about 3hrs). Hence the total sintering cycle time was 5hr 5min. The Figure 2 shows the Aluminium, red mud and tungsten carbide compacted samples in Sintering Machine.

Figure 2. Sintering Machine

2.5 Pin-on-Disc Wear Testing Machine All the wear tests are carried out on the pin-on-disc wear testing machine as per ASTM G-99 standard under unlubricated condition in a normal laboratory atmosphere at 50-60% relative humidity and a temperature of 28-32ºC. 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 so that the specimens under test are continuously cleaned with woolen cloth to avoid the entrapment of wear debris and to achieve uniformity in experimental procedure. The test pieces are cleaned with tetra-chloro-ethylene solution prior and after each test.

3.Results and Discussions

3.1 Dry sliding wear behaviour After conducting the wear tests on the pin-on-disc wear testing machine, the plot between wear rate, % weight fraction of red mud with aluminium and tungsten carbide is shown in Figure 3.
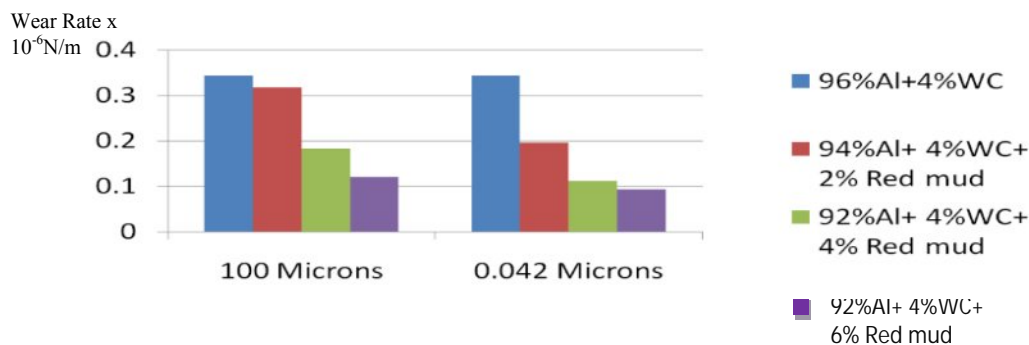

Figure 3.Variation of wear rate with Aluminium, Red mud and Tungsten Carbide

The plot between wear rate, % weight fraction of red mud and temperature of 100 μm particle size with pure aluminium and 4% tungsten carbide at 10N and 20N loads are shown in Figure 4 and 5 respectively.
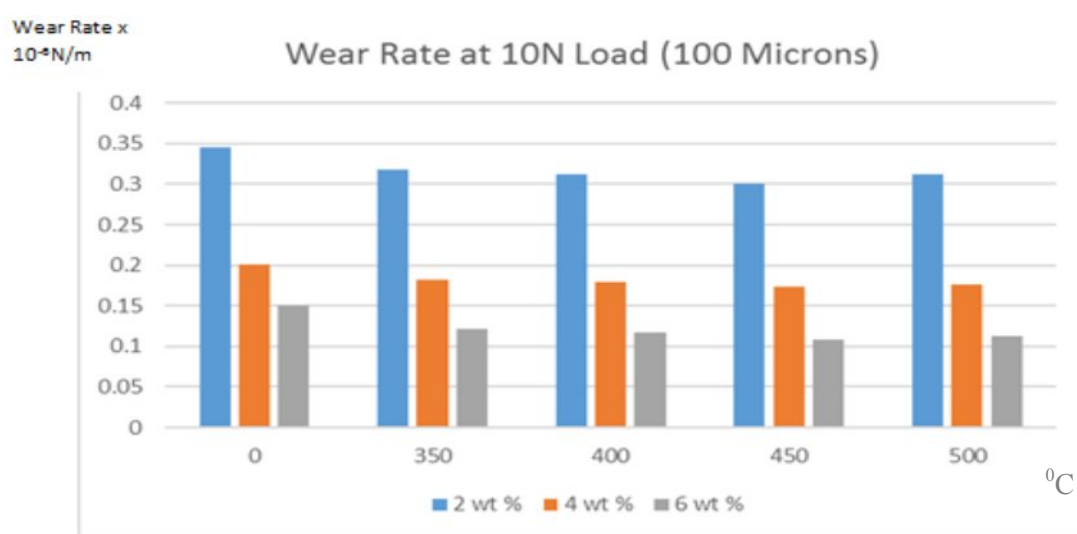

Figure 4.Plot between wear rate, % weight fraction of red mud (100 μm) with aluminium and tungsten carbide and temperature at 10N load
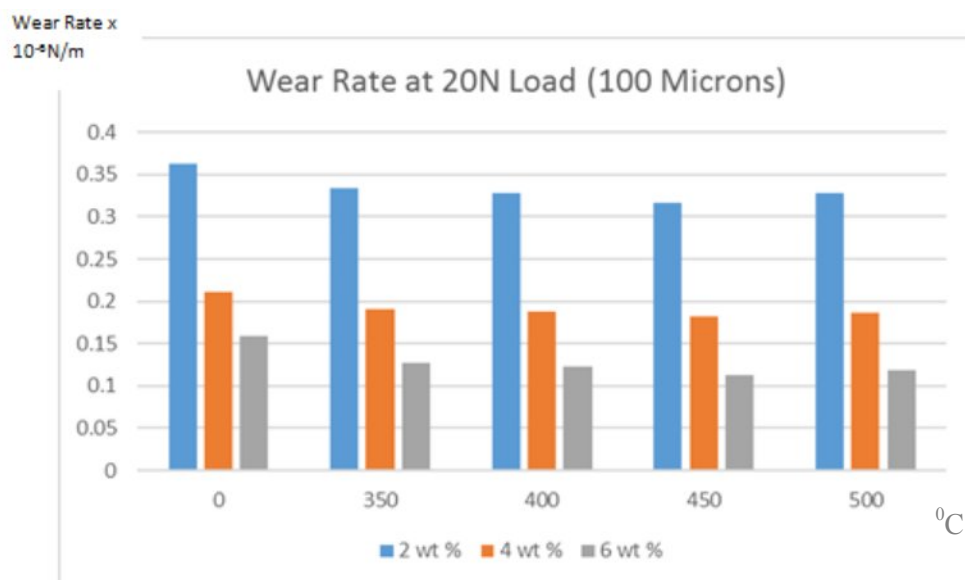
Figure 5.Plot between wear rate and % weight fraction of red mud (100 µm) with aluminium and tungsten carbide and temperature at 20N load

The plot between wear rate, % weight fraction of red mud and temperature of 0.042 µm particle size with pure aluminium and 4% tungsten carbide at 10N and 20N loads are shown in Figure 6 and 7 respectively.
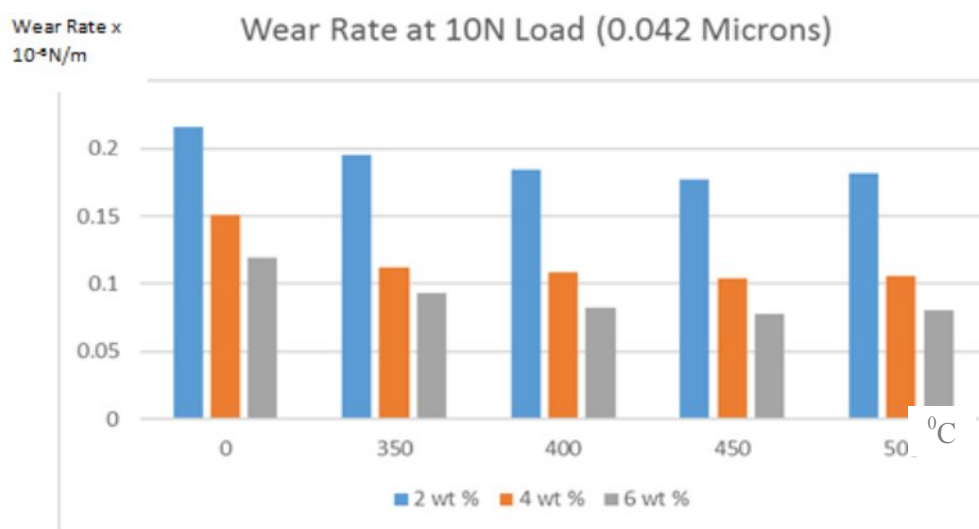

Figure 6.Plot between wear rate, % weight fraction of red mud (0.042 µm) with aluminium and tungsten carbide and temperature at 10N load

Figure 7.Plot between wear rate and % weight fraction of red mud (0.042 µm) with aluminium and tungsten carbide and temperature at 20N load

3.2. Mathematical Modelling A mathematical model is developed for aluminium, red mud and tungsten carbide at normal condition and the overall equation is obtained using Regression analysis which is shown in equation 1.

Wear Rate = 0.3079739 -Wt% Red mud (0.0365) +Particle size (0.00070693)………. (1)

The R square value 0.8757 is obtained. The value of R square is very near to the unity i.e the relation between the weight percentage of red mud and the wear rate is calculated with maximum accuracy.
A mathematical model is developed for aluminium, red mud and tungsten carbide at heat treatment condition and the overall equation is obtained using Regression analysis which is shown in equation 2.

Wear Rate =0.3278566 – [Temperature in ^{0}C x (0.000153666)] + [Micron size x (0.00083451)] – [% weight composition of red mud x (0.034………………… (2)

The R square value 0.8643 is obtained from regression analysis.

Conclusions

- As % weight composition of red mud with pure aluminium and tungsten carbide increases, there is an improvement in wear resistance. The maximum wear resistance is obtained for 42 nm or 0.042 microns level of 6% weight fraction of red mud with pure aluminium and tungsten carbide.
- It is also observed that, for the same weight fraction of red mud compacted with pure aluminium and tungsten carbide, the wear resistance is higher for the nano structured reinforcement than micro structured reinforcement. This is due to the increase in surface area of contact, presence of iron oxide in red mud and higher bond strengths.
- As increase in speed of rotation of the specimen, the wear resistance is increased. The highest wear resistance is observed for the test specimen with 42 nm size and 6% weight fraction of red mud powder at 600 RPM speed.
- A decrease in wear rate is observed with increase in the amount of temperature up to 450^{0}C and then it is started for declining in nature.

References

[1] Ghazali M J Rainforth W M and Jones H 2007 The wear of wrought aluminium alloys under dry sliding conditions *Tribol Int* 40 pp 160–169

[2] Mondal D P Das S and Jha Nidhi 2009 Dry sliding wear behavior of aluminum syntactic foam *Mater Des* vol 30 pp 2563–2568

[3] Qian Y 2004 Technical study of mixed pond for red mud from Bayer process and red mud from sintering process (In Chinese) *Light Met* 10 pp 18–20

[4] Sharma S C 2001 The sliding wear behavior of Al6061–garnet particulate composites *Wear* 249 pp 1036–1045

[5] Liu W Zhang X and Jiang W 2011 Study on particle- size separation pretreatment of Bayer red mud *J Environ Eng* 5 pp 921–924

[6] Han Y Yang Y and Wang X 2011 Research on the basic characteristics and utilization value of the Sintering process and Bayer red mud *Mater Rev* 25 pp 122–126

[7] Deuis R L Subramanian C and Yellup J M 1996 Abrasive wear of aluminum composites—a review *Wear* 201 no 1-2 pp 132–144

[8] Rahimian M Parvin N and Ehsani N 2011 The effect of pro- diction parameters on microstructure and wear resistance of powder metallurgy Al-Al$_2$O$_3$ composite *Materials and Design* 32 no 2 pp 1031–1038

[9] Wilson S and Alpas A T 1997 Wear mechanism maps for metal matrix composites *Wear* 212 pp 41–49

[10] Sharma S C 2001 The sliding wear behavior of Al6061–garnet particulate composites *Wear* 249 pp 1036 – 1045

[11] Rao R N Das S Mondal D P and Dixit G 2009 Dry sliding wear behavior of cast high strength aluminium alloy (Al–Zn–Mg) and hard particle composites *Wear* 267 pp 1688–1695

[12] Paramguru R K Rath P C and Misra V N 2005 Trends in red mud utilization—A review *Miner Process Extr Metall Rev* 26 pp 1–29

[13] Kumar S Kumar R and Bandopadhyay A 2006 Innovative methodologies for the utilization of wastes from metallurgical and allied industries *Retour Conserv Recycl* 48 pp 301–314

[14] Yang Q Zhao L Xiao H and Zhao N 2000 Analysis of Intrinsic stress in diamond films by X-ray Diffraction *International center for diffraction Data Advances in X-ray Analysis* 43 pp 151-156

[15] Yang Y and Li X 2004 Study on bulk aluminium matrix Nano-composite fabricated by ultra-sonic dispersion on Nano sized SiC particles in molten aluminium alloy *Materials Science and Engineering-A* 380 pp 378-383