Aluminium LM 25 Red Mud Metal Matrix Composite: Tribological Analysis

Ajay J. Puri[1]

[1] *Assistant Professor, Mechanical Engineering, SSBT's COET, Bambhori Jalgaon,*

[1]ajaypuri19@gmail.com

Abstract

Aluminium is widely known for its low density and mechanical properties. Aluminium is having number of application in aircraft industry as well as in number of automobile components. Aluminium has excellent ductile properties which makes it one of the most widely used materials in the field of automobile sector. In certain situations it becomes difficult to use aluminium because of physical, mechanical and tribological properties. To overcome the drawback of properties these aluminium base metals are widely combined with different reinforcements to from metal matrix composites.

This paper deals with the preparation of aluminium metal matrix composite using stir-casting method and analysis of it tribological properties. Composite consists of aluminium LM25 as a matrix material and Red mud as reinforcement. Taguchi based L9 array was used to design sliding wear experiments. The wear test was carries out on pin on disc apparatus by considering load, RPM, sliding distance and temperature as influencing parameters. Analysis of Variance was used to find out influence of each parameter on sliding wear.

Key words: Aluminium, LM25, Red mud, Taguchi, Dry sliding wear.

1. Introduction

Aluminium alloys have number of engineering applications due its mechanical, thermal properties. One of the major properties which limit the use of aluminium for some of the applications is its wear property. Many of the researchers have worked to improve the wear properties of aluminium and its alloys. It has been found that the wear resistance of aluminium and its alloys can be increased by forming its composite with different reinforcements. Composite consists of two or more different materials. These materials are insoluble in each other and possess different properties. Composites are prepared to get the superior properties than base materials.

Composites material is mechanical mixture of two or more materials. Out of the materials forming composite, one material is known as matrix and other as reinforcement. The volume of matrix material is more as compared to the volume of reinforcement. Matrix material may of any kind out of metal, polymer or ceramic. Studies have shown that the metal matrix composite possess superior damping properties, mechanical strength and wear resistance than base matrix alloy [2,3]. The reinforcements like Al_2O_3, SiC, glass, Zinc etc are widely used. The reinforcements can be used in form of particle and fibres. These fibres and particles possess different orientation and shape as shown in figure 1. The size and shape and orientation of reinforcement influences wear properties of composite material as well as its mechanical properties.

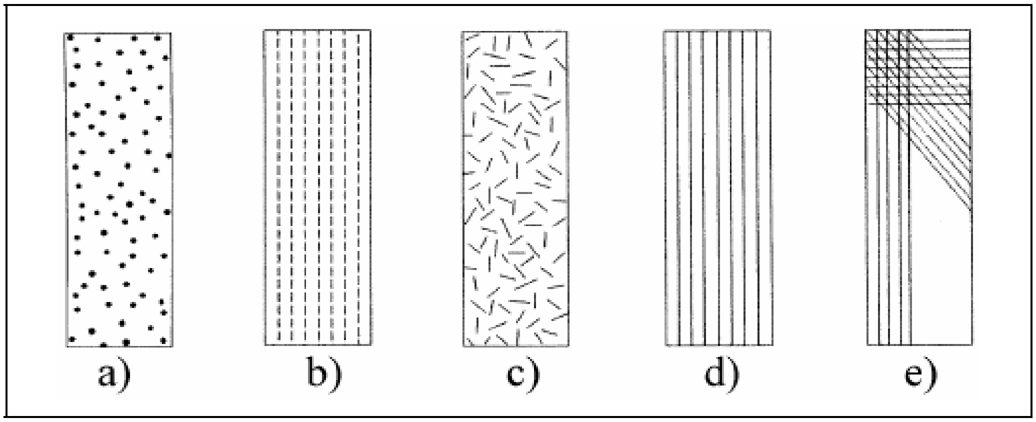

Figure1. Orientation and shape reinforcement in composite materials [1].

Particulate reinforcements possess excellent isotropic properties during the fabrication of composite materials and therefore are widely used as reinforcement [2].

2. Literature Review

The studies of Sannio et al. reports that reinforcement in the form of particles has higher benefits than other type of reinforcements [4]. The cost associated with the preparation of composite using particulate reinforcement can be reduced to greater extent. The researches were made on wear rate of composite material using the number of pin on disc machine parameters such as normal load, sliding distance, sliding velocity of pin, ambient temperature, temperature of pin etc.

Studies of H. B. Bhaskar and Abdul sharif [5] of Aluminium beryl particulate composite shows that sliding distance and normal load are directly related with wear rate of matrix material and composite material. The weight percentage of reinforcement is inversely related with the wear rate.

Studies of Huda et al [6] shows that the manufacturing process of metal matrix composite is function of reinforcement material. It has been reported that in the view of blending ability particulate reinforcements are much ahead than other type of reinforcements.

Reddapa H. N. et al. [7] conducted the experiments with the process parameters 1) Load (5 to 15N), 2) sliding distance (1 to 6km) and weight percentage of beryl (0 to 12%). The composite used was made up of Al6061 as a matrix material and Beryl particle

(Be_3Al_2 $(SiO_3)_6$) as reinforcement. Stir casting method was used to prepare composite. Sliding wear test was conducted using pin on disc machine with constant sliding velocity 1.66m/s and counter-face material EN32 steel disc. Wear was measured as loss of pin height by LVDT transducer of accuracy of 1μm. From the scanning electron microscope analysis it was observed that there is uniform distribution of beryl particles in composite with 10% beryl. Results of experiment revealed that there is significant increase in wear with increase in load.

Bharat Admile et al [8] carried out dry sliding wear test on metal matrix composite of aluminium LM25 with fly ash as a reinforcement with different weight percentages. The 4, 8 & 12weight percentage of fly ash was reinforced using stir casting technique. The wear test was carried out with ASTM G99 standard on pin on disc machine using specimen of 5mm diameter × 30mm length. The experiments were designed using Taguchi L9 orthogonal array with load, sliding speed, sliding distance and weight percentage of fly ash as control factors. It was found from the results that when compared with sliding distance and weight percentage of fly ash, load and sliding speed have more influence on wear rate of composite material.

Yogesh kumar singla et al. [9] carried out wear test on Aluminium 6061 alloy and compared its results with composite of aluminium 6061. The composite of Al 6061 alloy was prepared by having reinforcement one at a time out of Silicon carbide, Red Mud and Alumina. The result of wear test lead to conclusion that wear rate of aluminium 6061 is more as compared to its any of its composite with reinforcement of SiC, RM and A_2O_3. Out of the Reinforcement SiC, RM and A_2O_3 wear rate of composite is minimum with 10% reinforcement of SiC.

V. Damiel Jebin et al. [10] conducted wear test on metal matrix composite of Aluminium 6063 and particles of Al_2O_3. The reinforcement with weight % 4 and 8were used to prepare composite material. The cylindrical pins of diameter 8mm× length 50mm of composite materials were prepared and used for test. The sliding velocity was considered as a influencing parameter and normal load kept constant to study the influence of velocity on wear rate of composite material. The four levels of sliding velocity i.e. 2.5, 3, 3.5 and 4m/s with a constant normal load 9.81 were considered for test. The increase in sliding velocity results high wear rate of composite with 2 and 4% Al_2O_3 than the composite material with 8% reinforcement of Al_2O_3.

L. Liu, W. Li, Y. Tang, B. Shen, and W. Hu [11] found from experiments that the wear rate of aluminium composite reinforced with short carbon was inversely related with weight percentage of reinforcement and directly related with applied normal load.

Y. Iwai et al. [12] prepared metal matrix composites of Al 2024 and ADC12 alloy reinforced with different percentages of Silicon carbide particles, whiskers and aluminium oxide fibres. The dry sliding wear test was carried out at a constant load and velocity to find out the influence of volume fraction of reinforcement and its type. The improved sliding wear rate was observed in relation with reinforcement type and its volume. The volume fraction of 2% of silicon carbide particle, 10% of aluminium oxide fibres and 29% of silicon carbide whiskers in metal matrix composite was resulted in steady state wear rate.

F. H. Stott [13] studied change in wear rate of metal matrix composites and metals by considering ambient temperature as a parameter. The experiments lead to conclusion that the wear rate changes from high to low at 20-800˚C ambient temperature. At higher temperature the micro particles produced due to sliding of surfaces forms layer on mating surfaces. Hard oxide glaze surface is formed at high temperature due to oxidation, compaction and sintering on these layers. These oxides are formed by the oxidation of metal asperities. The oxide formed on sliding surface depends on nature of metal, temperature developed and duration of contact.

S. Rajesh, et al. [14] designed experiments using Taguchi L_9 orthogonal array to study wear behaviour of aluminium red mud metal matrix composite. They investigated to find out the optimum combination of influencing parameters. Use Multi Objective Optimization based on Ratio Analysis (MOORA) revealed optimum combination of load, sliding velocity, percentage of reinforcement and hardness of counter-face material as 20N, 3m/s, 20% and 58 HRC respectively.

T. M. Duarte and J. M. L. Reis [15] experimentally investigated heat conduction in red mud/epoxy and red mud/ polyester composites. The weight percentage of red used as reinforcement was 5, 10, 15, 20 and 25%. Polymers are promising materials for a broad variety of applications, but low thermal conductivity limits their use. Most polymers have an effective thermal conductivity between 0.1W/mK and 0.6W/mK. Epoxy resin used was MD131 from epoxy fiber. The effective thermal-conductivity experiments were performed using a direct measuring device of thermal conductivity manufactured by Laser Comp, Fox-50, which is capable of measuring samples from −10 ◦C to 110◦C. The measurable thermal-conductivity range is from 0.1W/mK to 10W/mK. The effective thermal conductivity of red mud waste composites, both epoxy and unsaturated polyester, increases with red mud waste content.

Rugada Vaikunta Rao and Dr. N.V.S.Raju [16] studied wear characteristics of aluminium red mud composite. Aluminium IE 07 grade was used as matrix material and red mud as a reinforcement. The size of red mud particles was 150 microns. The composite was prepared with 20% and 30% red mud reinforcement using stir casting method. The results of experiment revealed that the wear decreases with the increase in percentage of red mud particles.

Naresh Prasad et.al [17] found out wear behaviour of aluminium red mud metal matrix composite. Matrix material used was aluminium IE-07 with 10, 15, 20 and 30 weight percent of Red Mud reinforcement. The dry sliding wear properties were studied by setting different sliding velocities and normal loads on pin on disc machine. The results of experiment lead to conclusion that red mud fillers improve the wear resistance of aluminium. The strength of matrix increases due to increased interfacial area between aluminium matrix and red mud particle.

R. Surendran et.al [18] studied tribological behavior of aluminium LM25 alloy reinforced with nano aluminium oxide. Composite was prepared using pressure die casting. The wear test was carried out using pin on disc tripmeter. The tests were carried out in dry conditions of sliding using pin of 8mm diameter. Reinforcement was added in the percentage of 1, 1.5, 2.5 and 5% of aluminium alloy. The results of experiment revealed that wear rate of the composite decreases with increase in weight percentage of the reinforcement. The composite with 5% of alumina are superior in wear properties than the composite with lower weight percent of alumina.

S. A. Kori and M. S. Prabhudev [19] studied the change in wear rate of A356 alloy with added copper at constant temperature of 300°C. The pin on disc apparatus was used to carry out wear test by considering four influencing parameters viz. sliding speed, alloy composition, normal pressure and sliding distance. The studies revealed that wear rate of Al356 alloy is direct function of pressure, sliding distance and sliding speed and is inverse function of Cu addition level. The high temperature leads to strengthening of material through precipitation hardening.

N. Matarajan et. al used brake shoe lining material to prepare pins for sliding wear test to be carried out on A356 alloy with 25% Silicon carbide particles. The counter-face material used was grey cast iron and aluminium A356 SiC composite. The composite was prepared by mixing 25% SiC particles in melt of A356 aluminium alloy. The casted component was then subjected to machine. It has been found from the dry sliding wear tests that normal load and sliding velocity is directly related with wear rate of grey cast iron. Stable friction coefficient is achieved through formation of film at contact places.

When the sliding results of brake shoe lining material was compared in view of both the counter-face materials, it was observed that A356 alloy composite leads to severe wear than grey cast iron.

Puri A. J. and S. A. Sonawane [21] experimentally investigated to find most influencing parameter of dry sliding wear rate of composite material made up of aluminium and red mud. The composite was prepared from aluminium and red mud. Red mud was obtained in the quantity of 17.5% of mass of matrix material. Total four influencing parameters were considered in this study out of which normal load found to have higher influence than other parameters under consideration on wear rate of this composite material. The other parameters respectively RPM, sliding distance and temperature influenced wear rate in descending order.

3. Experimental Procedure

A) Materials

Matrix material used here was aluminium alloy LM25. The reinforcement material in the form of particles used was red mud. The aluminium is widely known for its low density and thermal properties. It finds number of applications where heat dissipation is primary concern. Aluminium is also used to prepare cylinder heads of internal combustion engines. The aluminium reinforced with silicon carbide is used to prepare piston of internal combustion engine.

Table 1. Chemical Composition of LM25

Element	Si	Mg	Fe	Cu	Ni	Others	Al
Wt %	7.10	0.53	0.14	0.19	0.06	0.36	Balance

Table 2. Chemical Composition of Red Mud

Element	Al_2O_3	Fe_2O_3	TiO_2	SiO_2	CaO	MnO	V_2O_5	Others
Wt %	45	25	2	1.6	1.8	0.16	0.067	Balance

Aluminium LM25 matrix is reinforced with reinforcement to improve its properties. Table 1 and Table 2 show the chemical composition of matrix material and reinforcement material. The red mud particles were obtained from NALCO India. The particle size was in the ranging from 110 μm to 150 μm. The aluminium alloy was melted in furnace. The mass of aluminium was measured before melting and red mud quantity of 22.5% this mass was taken. The red mud was preheated and maintained at this temperature to avoid segregation of particles in the slurry of aluminium. As soon as the melting is completed, slurry of Aluminium melt was formed by lowering temperature of melt upto 650°C to uniformly mix Red Mud particles in it. Mechanical stirrer was used to avoid the segregation of red mud particles in slurry. Magnesium is added in slurry to improve wetting characteristic of slurry. Magnesium has lower surface tension and also acts as a scavenger of oxygen. Good wetting is required during casting to form satisfactory bond between solid and liquid. The slurry of aluminium LM25 mixed with 22.5% of red mud particles was then poured in moulds. The cylindrically casted MMC specimens were subjected to turning for reduce its size to 12mm diameter and 25mm length.

B) Microstructure of MMC

Microstructure of metal matrix composite was studied using scanning electron microscope. The images with the magnification ranging from ×100 to ×2500 were developed on SEM at VNIT Nagpur. Figure 2(a) shows the images of aluminium metal matrix composite with 22.5% red mud at a magnification of ×1500 and 2(b) at a magnification of ×2500. It can be clearly observed from the SEM images that red mud particles are uniformly mixed in aluminium LM25 matrix material.

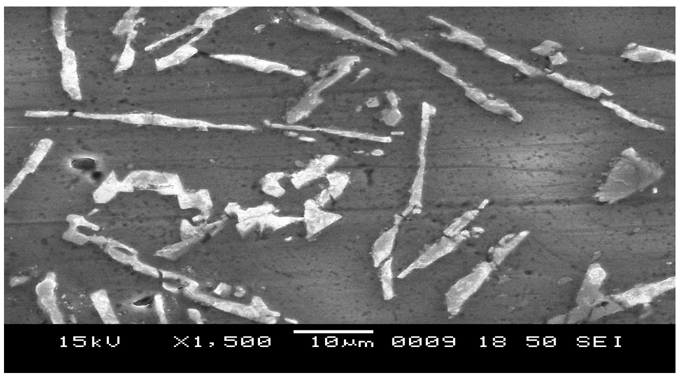

Figure 2(a). Al LM25 with22.5% RM at 1500X

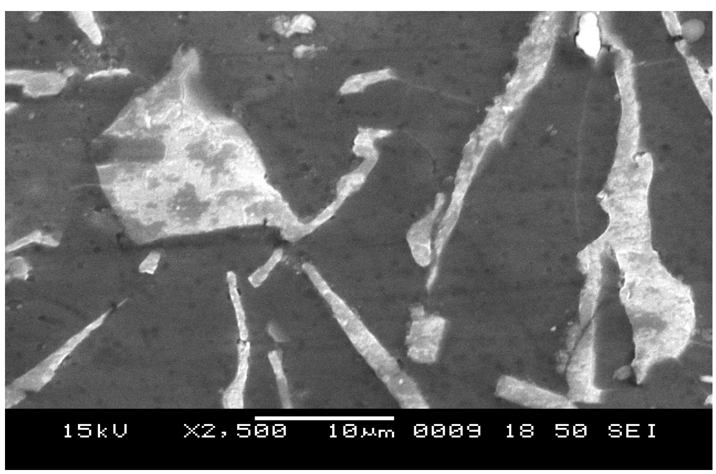

Figure 2(b). Al LM25 with 22.5% RM at 2500X

C) Wear Analysis

The wear test was carried out using computerized pin on disc machine. The wear rate of LM25 red mud metal matrix composited was estimated by finding out the mass loss during wear test. The weighing machine of 0.0001gm accuracy was used to weigh test specimen before and after test. The standard used for test was ASTM G99-95. The complete experimental setup of pin on disc machine is shown in figure 2. The machine was installed with disc of En31 steel with the hardness of 60HRC. The disc was having surface roughness of 1.6Ra. The disc surface and specimen were cleaned using polish paper before and after each experimental run. Load, RPM, Sliding distance and Pin temperature were studied as wear influencing parameters.

Figure 3. Complete Arrangement of pin on disc.

These four parameters with their three levels are considered to carry out the wear test on LM 25 red mud metal matrix composite. The parameters and their levels are selected from literature review and one variable at a time analysis. The three levels of load was from 10N to 20N with a step of 5N. The levels of RPM were from 300 to 500 with a step of 100. The sliding distance was varied from 1000m to 1500m with a step of 250m. The temperature was varied from 100 to 150 ˚C with step of 25˚C. The wear rate is ratio of mass loss to sliding distance. The wear rate of composite material was found out using this relation between mass losses and sliding distance.

D) Design of Experiments using Taguchi Technique

Taguchi technique of design of experiments is one of the widely used design experiments technique. The number wear behaviour studies of metal matrix composites were carried out by using Taguchi technique. The control factors i.e. parameters and levels of it which influence wear rate has to be selected carefully while using Taguchi design of experiments technique. The MINITAB 17 software was used for analysis and design of experiments. The control factors and their levels are used to define orthogonal array and find influence of these factors on wear rate. The combination of control factors lead to formulation of L_9 orthogonal array to carry out wear experiments. A linear regression model was formulated to study the change in wear rate with respect to influencing parameters.

Table 3. Experimental runs and result

Exp. No.	Sliding Distance m	Temperature ˚C	RPM	Load N	Wear rate×10^-7 N/m
1	1000	100	300	10	0.0600
2	1250	125	400	10	0.1520
3	1500	150	500	10	0.1460
4	1250	150	300	15	0.0746
5	1500	100	400	15	0.1150
6	1000	125	500	15	0.1500
7	1500	125	300	20	0.1900
8	1000	150	400	20	0.1560
9	1250	100	500	20	0.1360

4. Experimental Results

A regression analysis formulates equation between wear rate and the influencing parameters. MINITAB17 software is widely used tool to design experiments, perform regression analysis and ANOVA. The results of analysis carried out in MINITAB17 are shown with main effects plot showing wear rate performance characteristics. From main effects plots in figure 4 optimum levels of control factors for minimum wear rate can be found out easily.

Analysis of Variance (ANOVA) for wear rate:

ANOVA helps to find out the percentage influence of parameters on wear rate of composite material. The parameter having minimum value of p indicates more influence on wear rate. It can be observed from table 4 that temperature of pin is having minimum value of p and it affects wear rate greatly. The percentage contribution of temperature of pin on wear rate from table is 43.30%. The other p values in ascending order are for load, RPM and sliding distance i.e. the percentage contribution of sliding distance is minimum out of these three.

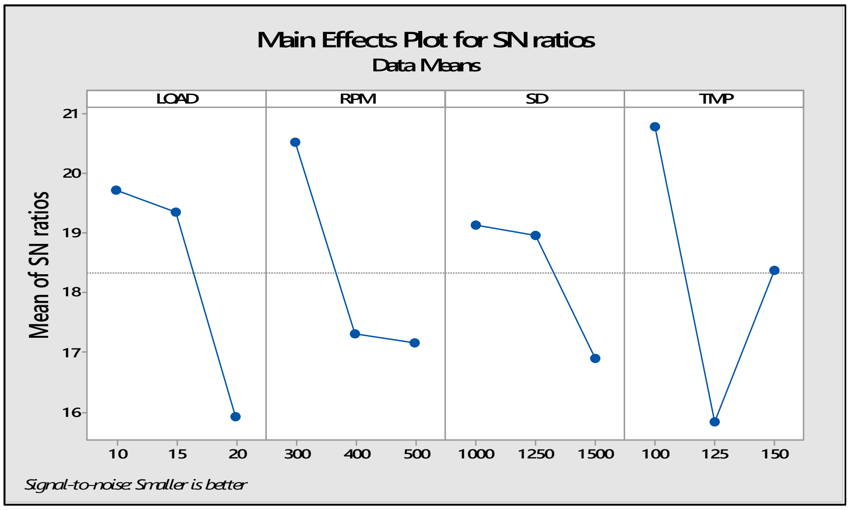

Figure 4. Main effect plot for SN ratios wear rate

From figure 4 optimum level of influencing parameters viz. load, RPM, slididng distance and Temperature are 10N, 300RPM, 1000m and 100˚C for minimum wear rate of MMC.

Table 4. ANOVA Results

Source	DF	Sum of Square	Mean Square	F Value	P Value	% Contribution
Load	2	0.009982	0.004991	64.77	0.000045	32.77
RPM	2	0.003459	0.001729	22.44	0.003100	11.35
Sliding distance	2	0.003131	0.001565	20.31	0.004600	10.28
Temperature	2	0.013187	0.006594	85.56	0.000014	43.30
Error	9	0.000694	0.000077			2.2
Total	17	0.030453				100

Table 5. ANOVA Model summary

S Value	R-square	R-square(adjusted)	R-square(predicted)
0.0087886	97.719%	95.713%	90.898%

2) Regression equation for wear rate:

Wear Rate = (0.00495 Normal Load + 0.000149 RPM + 0.000049 Sliding Distance + 0.000589 Temperature of pin - 0.1394)

ANOVA helps to find significant parameters out the considered by breaking total variations into accountable sources. The obtained R square value is 97.72%.

5. Confirmation Experiment

To test the efficiency of the model the confirmation tests were performed by selecting optimum parameter values obtained from main effects plots. Table 6 shows the comparison of wear rate obtained from the mathematical model developed in the present work, with values obtained experimentally respectively. By comparing the results of values obtained from wear rate equation and results of confirmation test, we have concluded that the confirmation test holds the equation for the values which are not included in the orthogonal array. It can be observed from table 6 that the calculated error is less than 5% for wear rate. Therefore the multiple regression equation derived above correlate the evaluation of wear rate in the composite with the degree of approximation.

Table 6. Result of confirmation experiment

Parameter	Model value	Experimental value	Error %
Wear rate	0.0627	0.0600	4.5

6. Conclusions

To optimize the dry sliding wear parameters viz, Load, Sliding distance, RPM and Temperature of pin using Taguchi orthogonal array and analysis of variance used in this paper.

1. Metal matrix composite with aluminium as matrix and red mud as reinforcement was stir casted successfully and its wear rate was found using computerized pin on disc machine.
2. The microstructure Aluminium LM25 red mud composite is observed by Scanning electron microscope (SEM). The images of the microstructures of these samples up to a resolution of 2500X were obtained and the presence of red mud was identified.
3. The equation for the wear rate is obtained by multiple regression analysis and it is found that the equation correlate the evaluation of wear rate in the composite.
4. From the results of ANOVA it can be concluded that temperature of pin influence wear rate significantly.

References

1. Biljana Bobic, Slobodan Mitrovic, Miroslav Babic, and Ilija Bobic "*Corrosion of Metal-Matrix Composites with Aluminium Alloy Substrate" Tribology in industry*, Volume 32, 2010.
2. Aleksandar et.al, "Tribological Behavior of Al-Based MMC and their Application in Automotive Industry" Tribology in industry, 2004 Volume 26.
3. G. Chandramohan et al., "Application of Taguchi techniques to study dry sliding wear behaviour of metal matrix composites," *Materials and Design*, 2007, Volume 28.
4. A. P. Sannino et al., "Dry Sliding Wear of Discontinuously Reinforced Aluminum Composites: Review and Discussion," *Wear*, 1995, volume 189, Pages 1–19.
5. H.B. Bhaskar and A. sharief, "Tribological Properties of Aluminium 2024 Alloy Beryl Particulate MMC" International Journal of Industrial Engineering and Management Science, December 2012, Vol. 2.
6. D. Huda et al., "Compaction behaviour of metal matrix composite," *Emerging Metals*, 1993 volume 86, pages 85–92.
7. Reddappa H.N, Suresh K.R, Niranjan H B and Satyanarayana K.G "Dry sliding friction and wear behavior of Aluminum/Beryl composites", international journal of applied engineering research, dindigul, 2011Volume 2.
8. Bharat Admile, S. A. Sonawane and G. Kulkarni, "Application of Taguchi Method for Optimization of Process Parameters for Wear loss of LM25 Fly ash Composite", IJIET-International Journal of Innovations in Engineering and Technology, December 2014, Volume 4.
9. Y. Singla, R. Chhibber, H. Bansal and A. Kalra, "Wear behavior of Aluminum Alloy 6061 Composites Reinforced with SiC, Al2O3, and Red Mud: A Comparative Study", The Minerals, Metals & Materials Society 2015.
10. V. Daniel Jebin, D. Shivalingappa and J. Jenix Rino, "Wear behavior of AL 6063 Alumina Metal Matrix Composite" IJSR- International Journal of Science and Research, India, March 2013, volume 2,ISSN 2319-7064.
11. L. Liu, W. Li, W. Hu, Y. Tang and B. Shen, "Friction and Wear properties of Short Carbon Fiber Reinforced Aluminum Matrix Composites," Wear, 2009, volume 266, pages 733–738.

12. Y. Iwai et al., "Sliding Wear Behaviour of SiC Whisker Reinforced Aluminium Composite," *Wear*, 1995, volume 181-183, pages 594-602.
13. F. H. Stott, "High Temperature Sliding Wear of Metals", Tribology International, 2002, Volume 35, pages 489-495.
14. S. Rajesh et al., "MOORA Based Tribological Studies on Red Mud Reinforced Aluminium Metal Matrix Composites" The Scientific World Journal, 2013 Volume, 8 pages.
15. T. M. Duarte and J. M. L, "Experimental Investigation of Heat Conduction in Red Mud/Epoxy and Red Mud/Polyester Composites". International Journal of Thermophys, 2014, Volume 35, pages 1590-1600.
16. Rugada Vaikunta Rao and Dr. N.V.S.Raju, "Determination of wear characteristics of Aluminum based Silicon Carbide refractory bricks reinforced with Red mud extracts for Torpedo Type of Ladle Refractory Lining". *International Journal of Engineering Science Invention ISSN (Online): 2319 – 6734, ISSN (Print),* pages 2319 - 6726.
17. Naresh Prasad et al., "Dry Sliding Wear Behavior of Aluminium Matrix Composite Using Red Mud an Industrial Waste". International Research Journal of Pure & Applied Chemistry, 2013, Volume 3, pages 59-74.
18. R. Surendran, Dr. A. Kumaravel and S. Vignesh, "Tribological Behaviour of Lm25 Aluminium Alloy Reinforced With Nano Aluminium Oxide". *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE),* May-June 2014, Volume 11, pages 01-07.
19. S.A. Kori et al., "Sliding wear characteristics of Al-7 Si-0.3 Magnesium alloy with minor additions of copper at elevated temperature" Wear, 2011, Volume 271, pages 680 - 688.
20. N. Natarajan et al., "Wear Behaviour of A356 25SiC_p Aluminium Matrix Composites Sliding against Automobile Friction Material". Wear, 2006,Volume 261, pages 812-822.
21. Puri A. J. and Dr. S. A. Sonawane, "Experimental Investigation of Wear Properties of Aluminium LM25 Red Mud Metal Matrix Composite". *IJSRD - International Journal of Scientific research and Development*, 2015, volume 3, Issue 10, pages 691-695.