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TRIBOLOGICAL BEHAVIOUR OF AL6061-NANO RED MUD PARTICULATE METAL MATRIX COMPOSITE BY TAGUCHI'S TECHNIQUES

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ABSTRACT

An attempt has been made to evaluate the properties of biodiesel-Hydrogen Peroxide blends in various proportions. Jatropha, Surahonne, Pongomia and Neem are the biodiesel oils whose blends with diesel and H2O2 are evaluated. Density, Viscosity, Flash and fire point and calorific value are the values evaluated. These properties play a vital role in deciding the atomization of fuel, flow through the manifolds, combustion, energy release etc of the fuel blends.

Keywords: *MMCs, Stir casting, Taguchi's techniques, wear behaviour*

INTRODUCTION

In the last two decades, research has shifted from monolithic materials to composite materials to meet the global demand for light weight, high performance, environmental friendly, wear and corrosion resistant materials. Metal Matrix Composites (MMCs) are suitable for applications requiring combined strength, thermal conductivity, damping properties and low coefficient of thermal expansion with lower density. These properties of MMCs enhance their usage in automotive and tribological applications [1]. A composite material is basically composed of at least elements to produce material properties that are having different to the properties of those elements on their own. In practice, the composite consists of a matrix as a bulk material and a reinforcement of some kind, in order to increase the strength and stiffness of the matrix.Most of the materials in its fibrous forms exhibits good strength property, but in order to achieve these properties the fibres should be bonded by a suitable matrix. The fibres are isolated from one another to prevent the abrasion and formation of new surface flaws and acts a mediator to hold the fibres in place a good matrix should have the ability to deform under the applied load, and transfer that onto the fibres and should distribute the stress concentration evenly. A metal matrix composite consists of some attractive properties when they are compared with organic matrices. They include strength retention at increased temperatures, higher transverse strength, good electrical conductivity, better thermal conductivity, excellent erosion resistance etc. One of the major disadvantages of the metal matrix composites is their higher densities and lower mechanical properties compared to polymer matrix composites. One more difficulty is the high-energy requirement for fabrication of such composites. In aerospace industries, the interest has been concentrated on fibre reinforced aluminium and titanium. A variety of methods has been employed to reinforce aluminium alloys with boron. Even though the bonding between them may be poor, better elastic properties can be achieved by the unidirectional incorporation of fibres in the metal even though the bonding between them may be poor. In the field of automobile, MMCs are used for pistons, brake drum and cylinder block because of better corrosion resistance and wear resistance [2,3]. Fabrication of MMCs has several challenges like porosity formation, poor wettability and improper distribution of reinforcement. Achieving uniform distribution of reinforcement is the foremost important work. A new technique of fabricating cast Aluminium matrix composite has been proposed to improve the wettability between alloy and reinforcement. In this, all the materials are placed in graphite crucible and heated in an inert atmosphere until the matrix alloy is melted and followed by two step stirring action to obtain uniform distribution of reinforcement [4]. The fabrication techniques of MMCs play a major role in the improvement of mechanical and tribological properties. The performance characteristics of Al alloy reinforced with 5% volume fraction of SiC fabricated through stir casting and found that the stir casting specimen have higher strength compared to powder metallurgy specimen. The size and type of reinforcement also has a significant role in determining the mechanical and tribological properties of the composites. The effect of type of reinforcements such as SiC whisker, alumina fiber and SiC particle fabricated by Powder Metallurgy on the properties of MMCs has been investigated. It was found that

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there existed a strong dependence on the kind of reinforcement and its volume fraction. The results revealed that particulate reinforcement is most beneficial for improving the wear resistance of MMCs. As reported earlier the fabrication methods for MMC's vary depending upon the choice of matrix materials and the type of reinforcements. Tjong S C et. al. studied the wear behavior of aluminum silicon alloy reinforced with the low volume fraction of Silicon carbide particles prepared by the Compo Casting technique. The wear behavior of unreinforcedAl-12 % SiC alloy and the metal matrix composites was investigated by them using block on ring test at the room temperature in dry conditions. Their result show that the addition of low volume fractions of Silicon carbide particles about 2% to 8% is very effective way of increasing the wear resistance of composites. Yoshiro Iwai et. al. studied the wear properties of Silicon carbide whiskers reinforced 2024 aluminium alloy with the volume fraction of whiskers ranging from 0-16%produced by the Powder Metallurgy technique (PM).

Their results shows that the SiC whiskers reinforcement may improve the wear resistances of aluminum alloy for both the severe and mild wears. D Huda et. al. reported that a particular fabrication technique depend on type of proper matrix and the reinforcement materials to form the MMC.

THE REINFORCEMENT OF RED MUD

Into Aluminium Matrix

To achieve the Optimum performance from composite materials, there is an advantage of selecting the shape and the size of reinforcement material to fit in the application. It is known that different material types and the shapes will have advantages in different type of matrices. For an instance, silicon carbide whiskers have been effective in toughening Al_2O_3 and also Si_3N_4 . Both silicon carbide whiskers and the silicon carbide grit have been particularly effective in increasing the modulus of aluminium alloys. It is however understood from the literature that particulates offer greater flexibility in altering the properties of interest. Thus the researchers has worked out separately to reinforce Silicon carbide, Aluminium oxide, TiB_2, Boron and Graphite into the aluminium matrix to achieve the different properties and are much expensive. The increasing demand for low cost reinforcement leads to show the interest towards production and utilization of red mud which is an industrial waste from Bayer's process, containing major elements like Al_2O_3,TiO_2, Fe_2O_3 and Na_2O for the preparation of a metal matrix composites for wear resistant applications.

DESIGN OF EXPERIMENTS (DOE)

Design of Experiment is one of the important and powerful statistical techniques to study the effect of multiple variables simultaneously and involves a series of steps which must follow a certain sequence for the experiment to yield an improved understanding of process performance [5]. All designed experiments require a certain number of combinations of factors and levels be tested in order to observe the results of those test conditions. Taguchi approach relies on the assignment of factors in specific orthogonal arrays to determine those test combinations. The DOE process is made up of three main phases: the planning phase, the conducting phase, and the analysis phase. A major step in the DOE process is the determination of the combination of factors and levels which will provide the desired information [6]. Analysis of the experimental results uses a signal to noise ratio to aid in the determination of the best process designs. This technique has been successfully used by researchers in the study of dry sliding wear behaviour of composites. These methods focus on improving the design of manufacturing processes. In the present work, a plan order for performing the experiments was generated by Taguchi method using orthogonal arrays [7]. This method yields the rank of various parameters with the level of significance of influence of a factor or the interaction of factors on a particular output response.

MATERIAL SELECTION

Aluminium alloy 6061 was used as matrix in the synthesis of composite. Aluminium alloy was taken from Hindalco Industries Limited, in the form of plates and then cut into smaller pieces with the help of power hacksaw in order to keep the alloy inside the crucible properly. Composition of matrix was analyzed and the chemical composition of the matrix alloy is given in Table 1

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Table 1: Chemical Composition of Al6061 alloy

Element	Si	Fe	Mn	Mg	Cu	Zn	Ti	Cr	Al
Wt %	0.76	0.14	0.29	0.84	0.33	0.004	0.02	0.006	97.61

Red Mud is used as reinforcement material. Initially red mud is received as a solid form like small stones, then these solid particles were crushed and grinded in the mixture grinder in order to obtain the size of the particle needed or intended to be i.e., the size of particles ranging between 30-40 nm. This is achieved with the help of a Ball Milling machine.

PREPARATION OF COMPOSITES

For the preparation of the composite, liquid metallurgy route was adopted as described in earlier works including the authors' work [8, 9 and 10]. Briefly, Al6061 alloy was first melted in graphite coated crucible, and then degassed. Vortex was created using a ceramic-coated steel impeller for about 10 minutes with a stirring speed of 400rpm. Preheated nano red mud particles were then introduced into this vortex, which was maintained at 720°C. The nano red mud particles of 5%, 10%, 15% and 20% was separately added and stirring was continued. Then, molten composite slurry is poured into coated cylindrical steel molds. Using these cast Al6061- nano red mud particulate composites specimens for wear test were prepared by machining the cylindrical bar castings.

PLAN OF EXPERIMENTS

Dry sliding wear test was performed with three parameters: applied load, sliding speed, and sliding distance and varying them for three levels as shown in Table 2. In the current work, studies have been carried out to assess friction and the wear behavior of aluminium red mud composite under the controlled laboratory conditions. A comprehensive picture of the wear under various working conditions has been presented by conducting laboratory tests in a pure sliding mode by using a pin-on-disc machine and then studying them under optical microscope to know the wear mechanisms. According to the rule that degree of freedom for an orthogonal array should be greater than or equal to sum of those wear parameters, a L27 Orthogonal array which has 9 rows and 3 columns was selected and obtained results are been as shown in Table 3

Table 2 Process parameters and levels

Level	Load (Kg)	Sliding Speed, S (m/s)	Sliding distance, D (m)
1	0.5	0.5	1000
2	1.0	1.0	2000
3	1.5	1.5	3000

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Table 3: Wear and Frictional Force under dry sliding condition

Sl No	Wt %	Sliding Distance m	Load Kg	Velocity m/s	Time min	Speed rpm	Wear microns
1	5	1000	0.5	0.5	33.33	95.48	32
2	5	1000	1	1	17.06	190.96	30
3	5	1000	1.5	1.5	11.11	286.44	31
4	5	2000	0.5	1	33.33	190.96	48
5	5	2000	1	1.5	22.22	286.44	96
6	5	2000	1.5	0.5	67.06	95.48	106
7	5	3000	0.5	1.5	33.33	286.44	49
8	5	3000	1	0.5	100	95.48	163
9	5	3000	1.5	1	50	190.96	176
10	10	1000	0.5	0.5	33.33	95.48	43
11	10	1000	1	1	17.06	190.96	47
12	10	1000	1.5	1.5	11.11	286.44	48
13	10	2000	0.5	1	33.33	190.96	43
14	10	2000	1	1.5	22.22	286.44	88
15	10	2000	1.5	0.5	67.06	95.48	102
16	10	3000	0.5	1.5	33.33	286.44	70
17	10	3000	1	0.5	100	95.48	172
18	10	3000	1.5	1	50	190.96	188
19	15	1000	0.5	0.5	33.33	95.48	63
20	15	1000	1	1	17.06	190.96	60
21	15	1000	1.5	1.5	11.11	286.44	68
22	15	2000	0.5	1	33.33	190.96	62
23	15	2000	1	1.5	22.22	286.44	76
24	15	2000	1.5	0.5	67.06	95.48	93
25	15	3000	0.5	1.5	33.33	286.44	105
26	15	3000	1	0.5	100	95.48	144
27	15	3000	1.5	1	50	190.96	161

THE TEST PROCEDURE

Pin surface was made flat initially such that it will take load over its entire cross sectional area called as first stage. This is achieved by pin sample surfaces to be ground prior to test by using the emery paper of80 grit size. Run in wear is performed in the later stage to avoid initial turbulent period associated with friction and wear curves. The last stage is the actual testing called the steady state wear. In this stage there is transfer of material from pin onto disc and formation of wear debris and their subsequent removal. Before each test, both pin and the disc were cleaned up with acetone soaked cotton. Prior to each test, precautionary measures were taken to make sure that the load applied was in normal direction. Figure 1 represents the pin-on-disc apparatus.

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Fig 1: Pin-on-disc apparatus

RESULTS AND DISCUSSIONS

Wear Rate

Wear occurs as natural consequences when two surfaces with relative motion interacts with each other. Wear may be defined as the progressive loss of the material from contacting surfaces in relative motion. Scientists has developed various wear theories, in which the Physico Mechanical characteristics of materials and the physical conditions, e.g. the resistances of the rubbing body and the stress state at the contact area are taken in to considerations. In 1940, Holm starting from the atomic mechanism of wear calculated the volume of substance worn out over unit sliding path.

It is very clear from the above discussions that the wear properties are improved remarkably by introducing harder inter metallic compound into aluminum matrix. It has also been demonstrated, because the bonding strengths between intermetallic and the matrix is very strong, pulling out is even prevented at high loads. The Wear of aluminum based metal matrix composites (MMC's) depends on many factors such as the volume fraction, morphology, and the size of reinforcing phase as well as the strength of interface. Work published in literature is mainly concerned with Silicon carbide and Al2O3particles. There are also few discussions on the wear behavior of aluminum MMC's reinforced with the alumna fibers and also with natural minerals. But till now as per the information of the investigators, no work has been done with the red mud as reinforcement. Therefore the current investigation is aimed at preparations of a Metal Matrix Composite using red mud as the reinforcing material and to study its frictional and wear behavior. The wear experiment is performed by the use of Pin-on-disc tribometer. The composite specimens wear track, and alloy are cleaned thoroughly with acetone prior to each test. After that, the specimen is then mounted on the pin holder, and to ensure for the specimen to be in fully contact with the track, a trial run is made. For all the experiments, speed, load and total time is calculated under room temperature. The detail Taguchi calculations are as shown in Table 4. The Response for Signal to Noise Ratios based on the Smaller is better condition is considered and the obtained Regression Equation ia as shown in Eq. (1). Anova (Analysis of Variance) tables are shown in Table 5 for wear rate. From the below table, analysis of varience for wear model shows the maximum of significant level in considered parameters. The values of probability less than 0.05 imply that models are significant. The mean effect plot for the obtained results is as shown in the Figure 2.

Table 4: Response Table for Means

Level	Wt.%	Sliding Distance	Load	Velocity
1	81.22	46.89	57.22	102.00
2	89.00	79.33	97.33	90.56
3	92.44	136.44	108.11	70.11
Delta	11.22	89.56	50.89	31.89
Rank	4	1	2	3

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Table 5: Analysis of Variance table

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Remarks
Regression	4	52887.2	52887.2	13221.8	28.9449	0.000000	
Wt.%	1	566.7	566.7	566.7	1.2407	0.277367	Insignificant
Sliding Distance	1	36090.9	36090.9	36090.9	79.0093	0.000000	Significant
Load	1	11653.6	11653.6	11653.6	25.5117	0.000047	Significant
Velocity	1	4576.1	4576.1	4576.1	10.0178	0.004486	Significant
Error	22	10049.4	10049.4	456.8			
Total	26	62936.7					

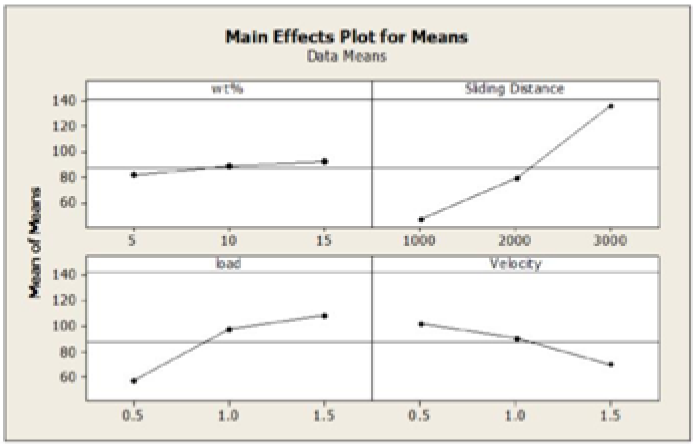

Fig 2: Main Effects Plot for Means

CONCLUSION

The conclusions drawn from the present work are as follows:

- Red mud, the waste generated from the alumina plant can be successfully used as a reinforcing material to produce a Metal Matrix Composite (MMC) component in aluminium matrix to be used in wear environments. It can also be intensive material, and there by a savings of about 15% matrix material could be achieved.
- There is a good dispersibility of red mud particles in aluminium matrix, which improves the wear behavior of the composite. The effect is to increase in interfacial area between the matrix material and red mud particles leads to the increase in strength appreciably.
- The specific wear rate of the composite decreases with the addition of filler volume fractions, and after attaining a minimum value it again increases. Thus there exists an optimum filler volume fraction which gives maximum wear resistance to the MMC.
- Many parameters such as sliding velocity, sliding distance and the load are responsible for wear. However it is much more appropriate to express the sliding wear results in terms of the wear co-efficient (K), extracted from the Archard's law. Wear Co-efficient is a Co-relation factor between several variables of the sliding wear experiment results.

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