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Optimization of wear parameters of a Hybrid MMC using Design of Experiments

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Abstract: - Aluminum metal matrix composites (MMC) are finding broad applications in aerospace, automobile and general engineering industries owing to their improved mechanical and wear behavior. Aluminium alloy Al-6Mg, graphite and flyash composites were obtained by stir casting technique. Four different weight percent (2, 4, 6& 8) of particulate reinforcement materials were added to the base alloy. The wear tests were conducted with a constant track radius of 50mm, constant speed of 500rpm, Loads varying from 10N to 40N, sliding distance varying from 0.5km to 2Km.The matrix alloy undergoes severe specific wear rate beyond 1.5 Km of sliding distance migrating toward seizure with the applied load beyond 20N. However, the MMCs maintains almost a linear trend with the sliding distance up to 2000 m with the applied load of 10 N. Similar trend is noticed for all the samples of MMCs even with applied loads of 30 N to 40 N with a little deviation in some of the composite specimens. The optimum values are Load=30N, 2% flyash and 6% graphite and 1.5 Km sliding distance. From the analysis of variance & S/N ratio, it is inferred that the sliding distance has the highest contribution on wear rate followed by load & reinforcement percentage.

Key Words:— *Al6-Mg, Fly ash, Graphite ,Stir Casting, MMC, Wear and DOE.*

I. INTRODUCTION

There are many MMC available in the market, and this figure is rapidly increasing. Advanced materials are being developed to an increasing extent [1]. Among these materials one finds prominently used composite. The development of composites as a new engineering material has been one of the major innovations in the field of materials in the past couple of decades [2]. This outstanding benefit of composite materials is that they can be tailored to produce various combinations of stiffness and strength [3,4].

It is possible to develop new material with a unique combination of properties previously unattainable with conventional materials. This ability to engineer materials with specific properties for specific applications represents a great potential advantage of composites. It is also possible to selectively reinforce the particular areas of components, thus providing development of materials properties only in area, which is truly necessary [5].

A composite as being composed of a matrix material to which one or more reinforcement or filler material is added. A more appropriate definition was being formulated in respect of microstructural form. MMCs materials have microstructure which are synthesized from the component phases (example metal matrix alloy and ceramic reinforcement) whereas conventional metal alloys have microstructure which are achieved via the control of naturally occurring phase transformations during solidification or thermo-mechanical processing [6,7].

The stir casting and extrusion of ZC71/12%SiC composites has been detailed by Badini et al.8] This process, utilized by Magnesium Eletron Ltd, produced a composite with good reinforcement distribution. Al–fly ash particle composites have shown various mechanical properties and dry sliding wear [9]. In recent years, considerable work has been carried out on Al-graphite particle composites. This class of composites is attractive because of their superior properties such as low friction improved wear rate and excellent antiseizing properties. Al-graphite composites were developed for self-lubricating tribological applications [10].

In this research paper discussion on development and wear characterization of aluminium alloy (Al-6Mg) as matrix material and graphite, fly ash as reinforcement material, metal matrix composite is done.

II. MATERIALS AND METHODS

The raw materials used in this research work were Al-6Mg alloy which has a broad application in the field of automobile industry, Graphite and Flyash. The Al-6Mg billets were used as matrix metal of composites. Graphite and Flyash powder particle of size 44μm were used as reinforcement phase. Fine particulate composites exhibit better strength & wear resistance in comparison to coarse particulate composites.

In the present investigation large billets of matrix material were cut into small pieces for accommodating into the crucible. Composites were produced by Stir casting process as shown Fig.1. Stir Casting is a method of composite materials fabrication via liquid state in which dispersed phase of Graphite and Flyash particles were mixed with the molten Al356 alloy by means of mechanical stirring inside a graphite crucible kept inside an electric resistance furnace. The molten composite material is then cast by pouring in to the pre heated metal mould. The stirrer speed is adjusted for getting the vertex formation of molten metal and which is positioned such as 60% of melt is above the stirrer for enhancing good reinforcement dispersion. The processing temperature maintained between 730-7400C and the reinforcing agents were preheated for 4000C to avoid the oxide layer formation over the particles, the particle feed rate to the molten matrix is fixed as 20 grams per minute. Scum powder and Hexo-chloroethane were used as slag removing and degassing agents.

The pouring temperature was controlled to be around 720°C. Finally, the super-heated melt was poured into the pre heated metal mould. The preheating temperature 350°C for moulds was maintained for slower cooling. Thus composites containing reinforcement particles of 0 to 20% were obtained in the form of cylinders of diameters 22mm and length 210mm.The processing variables such as Speed of stirrer, Processing temperature, pouring speed, Mould temperature, reinforcement feed rate, incubation time have to be considered for developing a good composite casting.

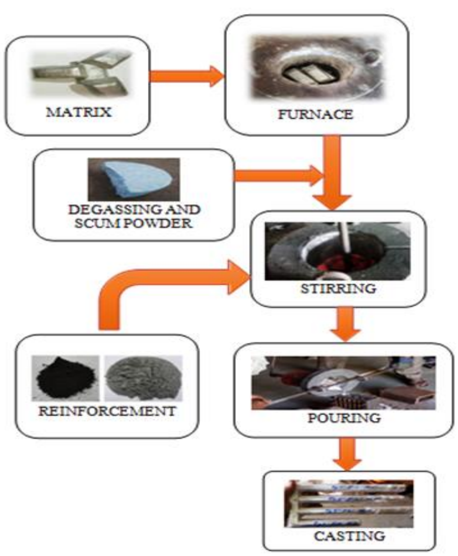

Fig.1. Stir casting process

A. Wear Test

The term wear most often refers to the abrasive wear arising from the rubbing of abrasive particles on a surface. Wear is defined as a progressive loss of substance resulting from mechanical interaction between two contracting surfaces. Cylindrical wear specimens of diameter 6 mm and length 15 mm were cut. Ground and polished to the required size before testing. The wear tests were carried out on pin-on-disc as shown in Fig.2 wear testing machine in accordance with ASTM G99 standards. The test samples were clamped in the holder and held against the rotating wheel (made of EN24 steel of hardness Rc57) at a distance of 60 mm from the center. In the present investigation, normal loads of 20N, 30N, 40N, 50N and 60N respectively were applied on the specimen and the speed of the rotating wheel was varied from 200 to 500 rpm in steps of 100 rpm. Before each test, the disc was cleaned with acetone to remove traces of grease and other surface contaminants. A standard test procedure was employed for each specimen as follows.

- The specimen is first weighted in an electronic balance to an accuracy level of 0.01 mg to determine the initial weight.
- The specimen is then mounted in the wear-testing machine and tested for different loads and speeds for duration of 15 minutes.
- The specimen is re-weighed after the tests to determine the respective weight loss through wear.
- Each result is obtained from an average of at least three relations.

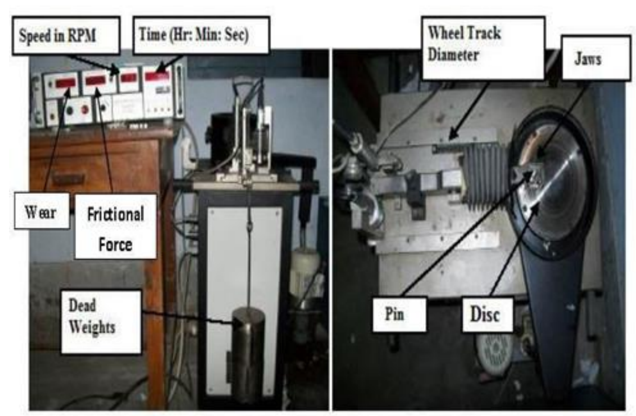

Fig.2. Wear Test Machine

III. DESIGN OF EXPERIMENTS

A. Taguchi Method

The Taguchi method is a powerful tool for designing high quality systems based on Orthogonal Array (OA) experiments that provide much reduced variance for the experiments with an optimum setting of process control parameters. It introduces an integrated approach that is simple and efficient to find the best range of designs for quality, performance and computational cost. This method achieves the integration of designs of experiments (DOE) with the parametric optimization of the process of yielding the desired results. The traditional experiment design procedures focus on the average process performance characteristics. But the Taguchi method concentrates on the effect of variation on the process quality characteristics rather than on its averages. That is, Taguchi approach makes the process performance incentive (robust) to variation in uncontrolled or noise factors. Taguchi recommends that this can be done by the proper design of parameters during the "parameter design" phase of off-line quality control. He designed certain standard OAs by which simultaneous and independent valuation of two or more parameters for their ability to affect the variability of a particular product or process characteristics can be done in minimum number tests. Using OA, the Taguchi method explores the entire design space through a small number of experiments in order to determine all of the parameter effects and several of the intersections. These data are then used to predict the optimum combination of the design parameters that will minimize the objective function and satisfy all the constraints. In addition to locating a near optimum objective function, the Taguchi method provides information on parameter trends and noise sensitivities thereby enabling a robust design.

The parameter design phase of the Taguchi method generally includes the following steps:

- Identify the objective of the experiment.
- Identify the quality characteristics (performance measure) and its measurement systems.
- Identify the factors that may influence the quality characteristics, their levels and possible intersections.
- Select appropriate OA and assign the factors at their levels to the OA.
- Conduct the test described by the trials in the OA.
- Analysis of the experiment data using the signal-to-noise (S/N) ratio, factor effects and the analysis of variance.

IV. Results And Discussions

The wear rate of the composites reduced with the increase in reinforcement content. The reduction in wear rate by as much as 20 to 25% as the content of Flyash (2-8%) and Graphite (2-8%) varied. The improvement in wear resistance of composites at low loads is attributed due to the presence of reinforcement, which forms a thin film at the contact surface between the composites and the counter face. At low loads the composites derive their wear resistance from the reinforcement. At high loads however, due to fracture composites lose their ability to support the load. As a result, the counter face comes in direct contact with the matrix alloy in which high strains are developed causing removal of the surface layers by delimitation.

It is very interesting to note that irrespective of the material (alloy or composites) beyond the transitional load the materials experience severe wear and gets seized-off, which is termed as 'seizer'. The load at which the material experiences severe wear, all of a sudden is termed as transition load. The transition load for the matrix alloy almost starts at 20 N of applied load where as for MMCs, the transitional load starts beyond 40N.In the case of developed Hybrid MMCs, significant increase in the transition load can be attributed to the presence and uniformly dispersion of hard Flyash and Graphite particulates in the matrix material.

The matrix alloy undergoes severe specific wear rate beyond 1.5 Km of sliding distance migrating toward seizure with the applied load beyond 20N. However, the MMCs maintains almost a linear trend with the sliding distance up to 2000 m with the applied load of 10 N. Similar trend is noticed for all the samples of MMCs even with applied loads of 30 N to 40 N with a little deviation in some of the composite specimens.

A. *Plan of Experiments*

The Pin-on disc wear test was performed with three parameters: applied load, reinforcement percentage and sliding distance and varying them for four levels. According to the rule that DOF for an OA should be greater than or equal to the sum of those wear parameters, a L16 OA which has 16 rows and 3 columns was selected as shown below:

- Taguchi Array = L16 (4^3)
- Factors = 3
- Runs = 16
- Level of Design = 4
- Level Values

For column 1 = 1, 2, 3, 4

For column 2 = 1, 2, 3, 4

For column 3 = 1, 2, 3, 4

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Table 1: Orthogonal Array L16 of Taguchi

Experiment No.	Column 1	Column 2	Column 3
1	1	1	1
2	1	2	2
3	1	3	3
4	1	4	4
5	2	1	2
6	2	2	1
7	2	3	4
8	2	4	3
9	3	1	3
10	3	2	4
11	3	3	1
12	3	4	2
13	4	1	4
14	4	2	3
15	4	3	2
16	4	4	1

The selection of OA depends on three items in order of priority, viz., the number of factors and their interactions, number of levels of the factors and the desired experimental resolution or cost limitations. A total of 16 experiments were performed based on the run order generated by the Taguchi model. The response of the model is wear rate and COF. In OA, the first column is assigned to applied loads, second column is assigned to sliding distance and third column is assigned to reinforcement percentage and the remaining columns are assigned to their interactions. The objective of the model is to minimize the wear rate and COF. The Signal to Noise (S/N) ratio, which condenses the multiple data points within a trial, depends on the type of characteristic being evaluated. In this study, “smaller the better” characteristic was chosen to analyze the dry sliding wear resistance. The response table for signal to noise ratios show the average of selected characteristics of each level of the factor. This table includes the ranks based on the delta statistics, which compares the relative value of the effects. S/N ratio is a response which consolidates repetitions and the effect of noise levels into one data point. The main effects are shown in below.

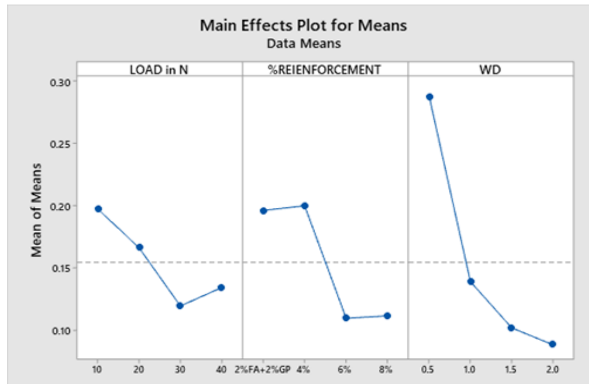

Fig.3. Main effects Plot for wear loss

It can be seen that the wear loss decreased with increase in load up to 30N and increased at 40N. Lower wear rates are observed at 30N load, Al-6Mg 2% Flyash-6% Graphite. At 2.0km the wear was minimum. At higher loads, the amount of heat generation increased and plastic deformation takes place at the pin surface which resulted into more material removal rate and adversely affected the wear performance. The formation of lots of pits, dislodgement of SiC particles and non-uniform tribolayer was observed at higher load (40 N) which resulted in higher wear. While at lower load due to low contact pressure the contact area was less and few points of the pin surface would be in contact with the disc, which resulted in less material removal rate. The combined effect of weir debris and thin tribolayer leads to the formation of mechanically mixed layer which reduced the material removal rate from the specimen surface and enhanced the wear performance of the composite at 2Km Wear distance/Sliding Distance.

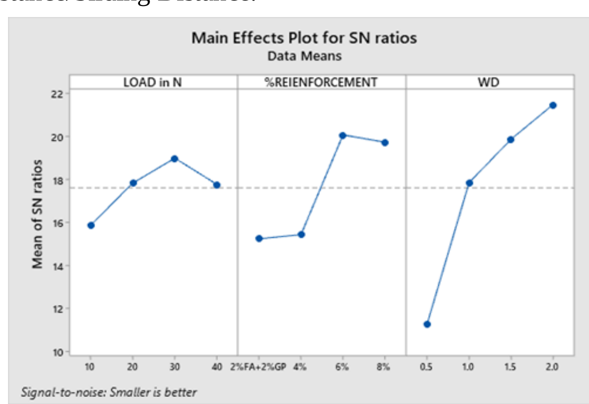

Fig.4. Main effects plot for SN ratios – wear rate

From the fig we can confirm that the optimum values are Load=30N, 2% flyash and 6% graphite and 1.5 Km sliding distance.

V. Conclusion

Sliding wear test results of 2%,4%,6% and 8% reinforced composites show that wear rate of composites increased with increasing applied load and decreased with increasing reinforcement particle wt.%. The addition of reinforcement to the matrix alloy greatly decreased the wear rate of resulting composites. 8% reinforced composite exhibited delamination wear under 40 N and mild adhesive wear under 20 N.

The mechanically mixed layer forms in the worn surface of matrix and composite and it is served as a protective layer and a solid lubricant. The matrix alloy showed a transition from mild to severe wear at the loads of 30 N.

The effect of the reinforcement wt% on wear resistance of composite is minimum under low load, while it is remarkable under high loads. The composite specimens exhibited abrasion wear at low loads, while at high loads delamination wear was dominant.

The weak interface bond between reinforcements and Aluminum matrix is the main reason of composite wear property change under different applied load.

The matrix alloy undergoes severe specific wear rate beyond 1.5 Km of sliding distance migrating toward seizure with the applied load beyond 20N. However, the MMCs maintains almost a linear trend with the sliding distance up to 2000 m with the applied load of 10 N. Similar trend is noticed for all the samples of MMCs even with applied loads of 30 N to 40 N with a little deviation in some of the composite specimens.

The optimum values are Load=30N, 2% fly ash and 6% graphite and 1.5 Km sliding distance. From the analysis of variance & S/N ratio, it is inferred that the sliding distance has the highest contribution on wear rate followed by load & reinforcement percentage.

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