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TRIBOLOGICAL ANALYSIS OF AL ALLOY BASED MMC REINFORCED WITH WASTE MATERIALS BY USING TAGUCHI ORTHOGONAL ARRAY METHOD

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Abstract-In near years composites reinforced with waste materials have shown considerable interest for their incomparable good mechanical, tribological properties and low cost. In this analysis we attempt to provide a complete description on the overall performance of rice husk ash and fly ash reinforced composites. Literatures in each category are checked and studied according to the key factors mentioned. Design of experiments was implemented for the analysis of the influence of sliding parameters such as sliding speed, sliding time and load on the Wear properties. The results of the experiments were used to characterize the main factors affecting the wear and coefficient of friction by the Analysis of Variance (ANOVA) method. The Load was found to be the most significant parameter influencing the wear in the sliding process followed by sliding time and a minor effect of sliding speed. Similarly Load was found to be the most significant parameter influencing the coefficient of friction in the sliding process followed by sliding speed and a minor effect of sliding time.

Key Words-Rice husk ash, MMC, Fly Ash, Al-Si Alloy, ANOVA, and Tribological properties.

I. INTRODUCTION

Metal matrix composites have potential applications in different areas due to their unique property combinations [Modi et al., Zhang et al.]. These materials are developed to respond to the demand for materials with high specific strength, stiffness, and wear resistance [Toptan et al.] . Aluminum alloys are an important engineering materials for tribological and mechanical applications due to their low density, high thermal conductivity and improved machinability for automobile, aerospace, marine and mineral processing industries. Choice of a suitable combination of matrix with reinforcement materials has become an interesting area for manufacturing science in MMCs [Ashby et al.]. Aluminium - silicon alloys present a great industrial potential in many applications and are most important amongst the various foundry alloys contributing 80% of the aluminium castings. It is due to its good castability. Al-Si alloys are of particular importance to many engineering applications because of its outstanding characteristics and properties such as low specific density, good corrosion resistance, good castabitity, and low hot tearing tendency [Limmaneevichitr et al.]. It is no wonder why these alloys have found applications in different industrial sectors such as Marine, Automobile, Aerospace industries. One of the main drawbacks of this material system is that they exhibit poor tribological properties. Hence it is desired by the engineering community to develop a new material with greater wear resistance and better tribological properties, without much compromising on the strength to weight ratio. This has led to the development of Al-Si based MMCs.[R.L. Deuis et al.].

For certain applications, the use of composites rather than metals has resulted in savings of both cost and weight. Some examples are cascades for engines, curved fairing and fillets, replacements for welded metallic parts, cylinders, tubes, ducts, blade containment bands etc. Metal matrix composites which are having high specific strength and stiffness can be used where weight is an important factor. So this type of MMCs can be used in robotics, high speed machinery and high speed rotating shafts for land vehicles and ships. For the use of MMCs in automotive engines and brake parts good wear resistance and high specific strengths should be required. For giving a better application in case of precision machinery and electronic packaging tailor able coefficient of thermal expansion and thermal conductivity is an important criteria.

Aluminium is the 3rd most abundant element and the most abundant metal in the earth's crust. Aluminium is a chemical element in the boron group with symbol Al and atomic number 13. It is a silvery white, soft, nonmagnetic, ductile metal and has low density as well as has the power to resist corrosion due to the phenomenon of passivation. Silicon is a chemical element with symbol Si and atomic number 14. The most important properties of silicon is that it's a semiconductor i.e. ability to conduct electricity. It is better than an insulator (like sulphur). Every MMCs process have higher specific weight, specific strength, better thermal stability, fatigue properties and wear resistance over the base metal .

Fly ash is an inexpensive industrial solid waste which is having low density and results as a by-product during combustion of coal in thermal power plants. Fly ash generally consists of fine, powdery particles that are predominantly spherical in shape, either solid or hollow, and mostly glassy (amorphous) in nature. Fly ash is a complex material having wide range of chemical, physical and mineralogical composition. The chemistry of fly ash depends on the type of coal burnt in boiler furnace, temperature of furnace, degree of pulverization of coal, efficiency of ESP etc.

The present study involves determination of the dry sliding wear in the Al-Si alloy based MMC prepared by reinforcing fly ash and rice husk. The experiments are conducted on pin-on-disc machine. An attempt is also made to quantify the effect of process parameters such as applied load, sliding speed, and sliding time on the dry sliding wear behavior of the Al-Si based MMCs prepared with waste materials fly ash and rice husk by using Taguchi design of experiment. The quantitative effect of process parameters on responses is brought out by applying statistical design of experiment.

II. A DETAILED LITERATURE REVIEW ON WASTE MATERIAL AS REIFORCEMENT

Suresha et al. (2012) [1] investigated statistically the dry sliding friction behaviour of hybrid aluminium matrix composite reinforced with combined SiC and Graphite particles. The authors concluded that load in the most important factor affecting the friction coefficient of the hybrid composite followed by sliding speed. The coefficient of friction increased with increase in load and sliding distance. The author also revealed that the average friction coefficient of the hybrid composite is quite low compared to pure alloy.

Pramila Bai et al. (1992) [2] studied the dry sliding wear behaviour of A356-Al-SiCp composite and have revealed that the wear resistance of the composite increases with increasing weight percentage of SiC particle from 15 to 25.

Das et al (2007) [3] conducted a comparative study on the abrasive wear behaviour of aluminium alloy based composite reinforced with alumina and zircon sand. The authors observed an increase in wear resistance for both the composites with decrease in particle size of the reinforcement. The author also revealed that wear resistance of zircon sand reinforced composite was better than Al2O3 reinforced composite. It shows that wear rate is constant with increase in sliding distance.

Alaneme et al. (2003) [4] incorporated rice husk ash (RHA) and alumina particles into Al-Mg-Si alloy matrix and studied its corrosion and wear behaviour. The author concluded that corrosion resistance and wear rate of the hybrid composite increase in wt% of RHA in alloy matrix.

Ramachandra et al. (2007) [5] investigated the wear and friction characteristics of Al (12% SiC) matrix composite reinforced with fly ash particles. The authors observed that wear resistance of the composite increased with increase in weight percent of fly ash while it decreased with increase in normal load and sliding velocity. With increase in fly ash content the slurry erosive wear resistance of the composite increased and the corrosion resistance decreased.

Deuis et al. [6] showed that aluminium–silicon alloys and aluminium-based metal–matrix composites (MMCs) containing hard particles offer superior operating performance and resistance to wear and in industrial processes where abrasive slurries are transported by rotating paddles or impellers, elements fabricated from MMC materials provide higher abrasive resistance and therefore a longer service life compared to those made from iron or nickel-based alloys. They also showed that composites characterized by a hardness greater than the abrasive particles and a reinforcement phase of high fracture toughness and low mean free path, compared to the abrasive grit dimension, exhibit high abrasive wear resistance. Studies related to abrasive wear of Al–Si alloys and aluminium-based MMCs that contain discontinuous reinforcement phases were reviewed.

Ohatgi et al. [7] reported that a low-pressure infiltration casting technique was used to produce Al–50 vol% graphite particle composites. The tribological behavior of the composites worn surfaces was investigated. They found that the wear rate for the composites was lower than the base alloy. They noticed that the reduced wear rates of the composites in comparison to the base alloy are due to the formation of a solid at the surface.

In a study by de Mello [8] the three-body abrasion of aluminium matrix composites reinforced with silicon carbide particles SiC has been investigated. The metal matrix composites MMCs were fabricated by a powder metallurgy route involving a final hot extrusion step, with Al 1100 matrix and a-SiC reinforcement with mean sizes of 10, 27 and 43 mm, in the proportions of 5, 10 and 20 vol.%. Using a wet monolayer tester, three-body abrasive wear tests were conducted under a constant load against silicon carbide and alumina abrasives with four different grits of 320, 400, 600 and 1000. The microstructural characterizations were performed using light microscopy. The dominant wear mechanisms were identified using scanning electron microscopy. The influence of type of the abrasive particles on wear rate and dominating wear mechanism is reported. Relationships between size and volume fraction of the Si reinforcement and wear rate is discussed. It is shown that Si reinforcement increases the abrasion resistance against all the abrasives used. This increase is generally higher against alumina than silicon carbide abrasives.

For the concerns of production related problems D. Siva Prasad, Dr. A. Rama Krishna [9] in the year 2011 studied Production and Mechanical Properties Of A356.2 /RHA composites and concluded that to improve the precision, this liquid should have a high density. It must also be chemically stable, have a low vapour pressure and a low well-defined surface tension. It was observed that the density decreases with the increase in weight % of the reinforcement.

To get the low cost for MMC's, in the year 2013 S.D.Saravanan, M.Senthil Kumar [10] studied effect of mechanical properties on rice husk ash reinforced aluminum alloy (Al-Si10mg) matrix composites and concluded that there was good dispersibility of RHA particles in aluminium matrix which improves the hardness of the matrix material and also the tensile behavior of the composite. The effect is increase in interfacial area between the matrix material and the RHA particles leading to increase in strength appreciably. Ductility of the composite decreases with the increase in weight fraction of the rice husk Ash. This is due to the increase in hardness of the rice husk ash particles or clustering of the particles.

R. S. Rana et al (2013) [11] studied tribological behaviour of AA 5083/micron and nano SiC composites fabricated by ultrasonic assisted stir casting process and found aluminium matrix micron 10 wt. % and nano (1, 2, 3 and 4 wt. %) SiCp composites have been successfully fabricated by ultrasonic assisted stir casting process and wear rate of Al-SiCp composites increases with increase in sliding distance. This indicates that fracturing tendency of the surface is more predominant than strain hardening of the surface during sliding wear tests.

III. EXPERIMENTAL PROCEDURE

3.1 Matrix material:

Al-Si master alloy is used as the matrix material with the composition of 12.2491% of Si, 0.0174% of Co, 0.4353% of Fe, 0.08% of Cu, 0.1601% of Mn, 0.0672% of Ti, 0.0944% of Zn, 0.0264% of Ni, 0.0632% of Sn, 0.0199% of Cr, 0.0082% of Ca, 0.0146% of V, 86.7654% of Al.

3.2 Reinforcement Material:

Rice Husk contains about 20% ash, 22% lignin, 38% cellulose, 18% pentosans, 2% moisture. But once the husk is carburized in Nitrogen atmosphere it forms Rice Husk ash. This ash contains 95% silica (SiO_2), 1% K_2O, P_2O_5 & Na2O3, Fe_2O_3 & MgO.

Fly Ash, also known as "Pulverized Fuel Ash" is one of the Coal Combustion Products and is composed of the fine particles. Even a pure form of Fly Ash contains 20%-60% SiO_2, 5%-35% of Al_2O_3, 10%-40% of Fe_2O_3, 1%-12% of CaO, 0%-15% of LOI.

3.3 Preparation of MMC by Stir Casting:

After cleaning Al-Si ingot, it is cut to proper sizes, weighed in requisite quantities and are charged into a vertically aligned pit type bottom poured melting furnace (Fig.1). Fly ashes are preheated to $650^oC\pm5^oC$ before pouring in to the melt of Al-Si Alloy.

Fig 1*:* Bottom pouring Furnace

This is done to facilitate removal of any residual moisture as well as to improve wetability. The molten metal is stirred with a BN coated stainless steel rotor at speed of 600-650 rpm. A vortex is created in the melt because of stirring where preheated fly ash is poured centrally in to the vortex. The rotor is moved down slowly, from top to bottom by maintaining a clearance of 12mm from the bottom. The rotor is then pushed back slowly to its initial position. The pouring temperature of the liquid is kept around 700^0C. Casting is made in rectangular metal mould (250x20x45 mm3). For comparison purpose two composites are prepared, one with fly ash and the other with rice husk.

3.4 Wear test

Wear tests are carried out on a pin-on-disc type machine (TR201LE) (Fig.2) under atmospheric condition. The test samples having the dimensions of 8 mm diameter and 40 m length

Fig 2: Ducomo Machine

(Fig.3) are slide against the low alloy steel disc (material EN-31-HRS 60 W 61 equal to 4340) of dia 215 mm, and Hardness R_c 62. Weight loss is measured with electric sensor weighing machine. Coefficient of friction and wear are measured continuously with an electric sensor attached to the machine and are recorded. The worn out samples are cleaned with acetone and are weighed in the balance. Each test is performed thrice for making the statistical analysis. We have three parameters and three levels for each parameter. The three levels of each parameter have two degrees of freedom (DOF), and thus total DOF is calculated as eight. The total DOF of a selected orthogonal array should be greater than the total DOF required for the experiment. Therefore, the L9 Taguchi orthogonal array design is selected as the experimental layout.

IV. Result and discussion

4.1 Fabrication of MMC

Matrix used: Eutectic Al–Si (LM6) alloy.

Reinforcement used: As received fly ash and rice husk

The Al-Si alloy based metal matrix composites is then made by using fly ash and rice husk. In the present investigation, it is anticipated that both the composites i.e MMC (FA) and MMC (RHA) will have the same vol% of the dispersed phases. However, within the experimental

TRIBOLOGICAL VARIABLES			Al-Si ALLOY		MMC(RHA)		MMC(FLY ASH)	
LOAD	SPEED	TIME	COF	WEAR	COF	WEAR	COF	WEAR
10	1 m/s	1000sec	0.265	78	0.232	64	0.212	47
10	2 m/s	2000sec	0.340	143	0.327	136	0.298	120
10	3 m/s	3000sec	0.367	183	0.342	165	0.310	158
30	1 m/s	1000sec	0.218	282	0.207	230	0.187	224
30	2 m/s	2000sec	0.238	344	0.219	317	0.198	280
30	3 m/s	3000sec	0.295	246	0.243	231	0.212	209
50	1 m/s	1000sec	0.159	694	0.137	623	0.114	560
50	2 m/s	2000sec	0.165	422	0.142	415	0.125	403
50	3 m/s	3000sec	0.229	606	0.203	564	0.157	528

limitation, it was possible to have 9.2 and 9.8 vol% of particulates in the MMC (FA) and MMC (RHA) composites

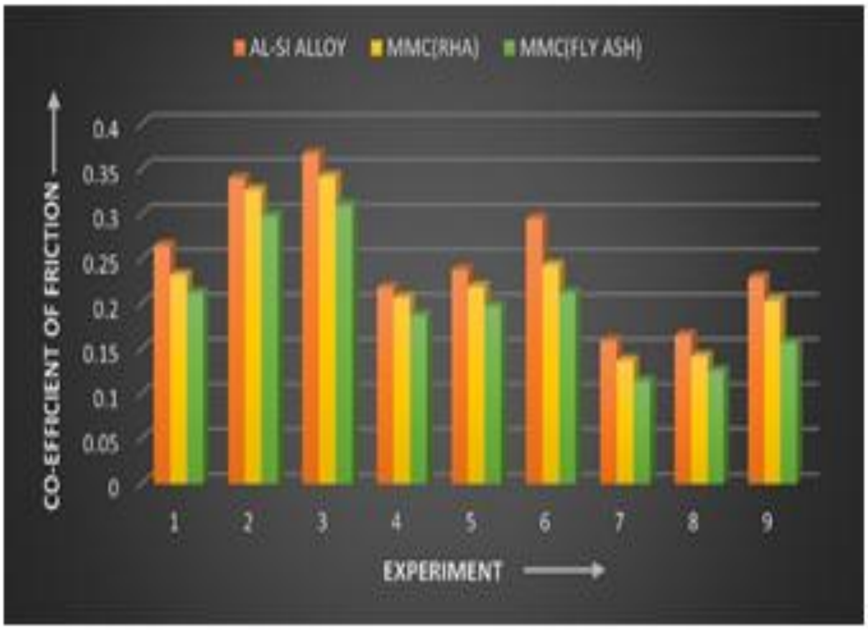

Chart 1: Co-efficient of Friction

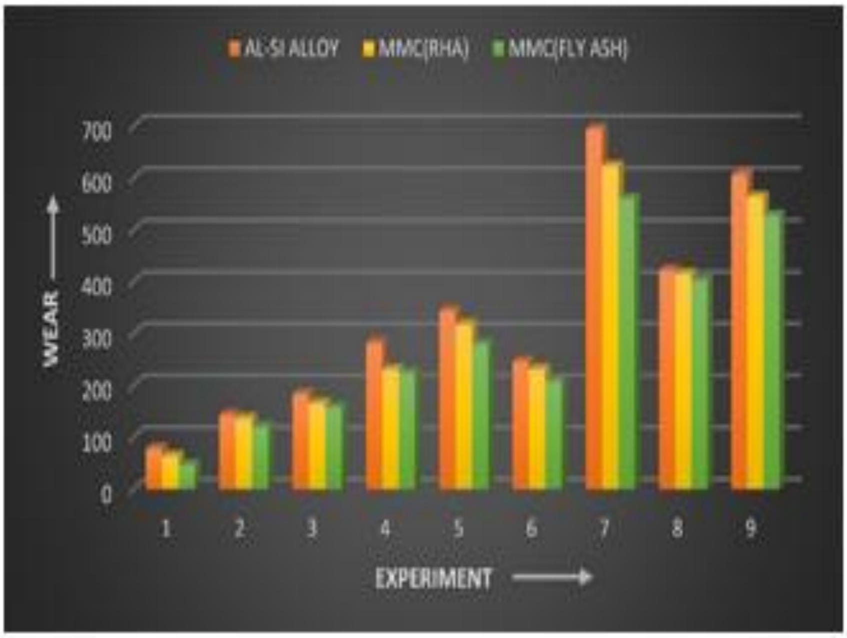

Chart 2: Wear

Chart 1 and 2 has shown the comparison between co-efficient of friction (COF) and Wear (W) according to the planned experimental numbers for Al-Si alloy, MMC prepared with rice husk ash [MMC (RHA)] and fly ash [MMC (FA)].

So based upon the above experimental result MMC is better than Alloy for the comparison of Wear and Co-efficient of Friction. The wear rate decreases with Fly ash reinforcement and more over Fly Ash is much better than Rice Husk Ash. This is because the content of Al_2O_3 and CO is more in Fly Ash which helps to improve various properties. Further Carbon is slippery and helps to reduce the Wear and Co-efficient of Friction. So for further experiment we are only considering tribological analysis of MMC(FA) for our experiment by using Taguchi method.

4.3 Analyzing and evaluating results of the experiments using the Taguchi method

The Taguchi method uses the quality characteristics of signal-to-noise (S/N) ratio to determine the optimal combinations for process response. Mainly, there are three S/N ratios that are used for calculations based on the objective function for the response: the lower the better, the nominal the better and the larger the better. For the present study, the lower wear and coefficient of friction values indicate the better performance. Therefore, the lower the better was used for the S/N ratio values. These two S/N ratios are calculated using the following equations below.

Smaller the better characteristic

$$\frac{S}{N} = -10\log\frac{1}{n}\left(\Sigma\, y^2\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where, y is the observed data and n is the number of observations. These S/N ratios are expressed on a decibel scale (dB). S/N ratios and level values are calculated by using Eq. (1), “the smaller the better” in the MINITAB 17 program. S/N ratios obtained from this equation are given in Table-2.

Table-2: Tribological result for MMC (FA)

LOAD (N)	SPEED(m/s)	TIME(sec)	COF	WEAR	S/N RATIO OF COF	S/N RATIO OF WEAR
10	1	1000	0.212	47	13.4733	-33.4420
10	2	2000	0.298	120	10.5157	-41.5836
10	3	3000	0.310	158	10.1728	-43.9731
30	1	2000	0.187	224	14.5632	-47.0050
30	2	3000	0.198	280	14.0667	-48.9432
30	3	1000	0.212	209	13.4733	-46.4029
50	1	3000	0.114	560	18.8619	-54.9638
50	2	1000	0.125	403	18.0618	-52.1061
50	3	2000	0.157	528	16.0820	-54.4527

Since the experimental design is orthogonal, it is then possible to disintegrate at different levels the effect of each process parameter. For example, the mean S/N ratio for the load at levels 1, 2 and 3 can be calculated by averaging the S/N ratios for the experiments 1–3, 4–6, and 7–9 respectively. The mean S/N ratio for each level of the other process parameters can be found out in the similar manner. The mean S/N ratio for each level of the process parameters is summarized and called the mean S/N response table for coefficient of friction (Table 3). The mean S/N graph for COF is shown in Chart 3. The larger S/N ratio yields the optimal parametric combination for COF. Therefore, based on the S/N analysis, the optimal process parameters for COF are as follows:

Load at level 3, Speed at level 1 and Time at level 3 i.e. L_3-S_1-T_3. In the response table for coefficient of friction, it is clearly shown that rank of load is 1 whereas for speed and time is 2 and 3 respectively. It indicates that the load is the most significant process parameter for coefficient of friction followed by speed and time.

Table-3: Response Table of Signal to Noise Ratios for Co-Efficient of friction

LEVEL	LOAD	SPEED	TIME
1	11.39	15.63	15.00
2	14.03	14.21	13.72
3	17.67	13.24	14.37
DELTA	6.28	2.39	1.28
RANK	1	2	3

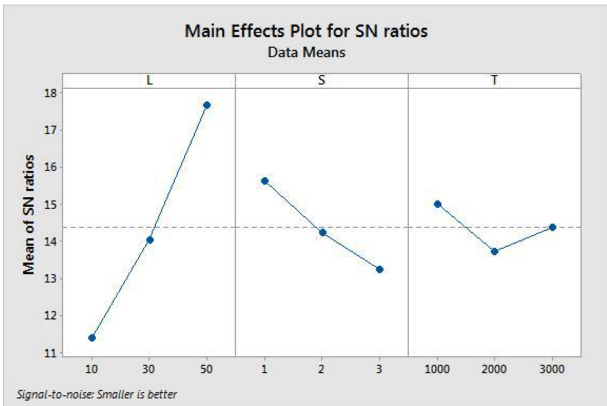

Chart-3: S/N ratios graph for COF

Table-4: Results of analysis of variance for Co-efficient of friction (MMC reinforced Fly Ash)

SOURCE	DF	Seq SS	Adj MS	F	P	CONTRIBUTION
LOAD	2	59.6698	29.8349	420.59	0.002	84.1%
SPEED	2	8.6683	4.3342	61.10	0.016	12.21%
TIME	2	2.4673	1.2336	17.39	0.054	3.47%
ERROR	2	0.1419	0.0709			0.2%
TOTAL	8	70.9473				100%

Analysis of variance (ANOVA) is used to find and check the statistical significance of the parameters at 95% confidence level and to find the contribution in percentage of the parameters to the process response. The significance of each parameter is tested using probability values (P value). When the P-value in the ANOVA table for S/N ratios is less than 0.05 (95% confidence level), it is considered that the parameters are statistically significant. The results of data analysis of S/N ratio for COF values, which are calculated by Taguchi method, are shown in Table 3. Thus, it is seen in

Chart 3 and Table 3 that the third level of A factor (Load), the first level of B factor (Speed) and the third level of C factor (Time) are higher. Consequently, the optimum wear conditions determined under the same conditions for the experiments to be conducted will be 50N for the Load, 1m/s for the speed and 3000sec for the sliding time. In addition, the percentage contribution expresses the importance of the parameters for the response. According to the ANOVA table for COF, the significance and importance of the parameters are expressed by the p-value and percentage contribution, respectively. The p-value in Table 4 shows that, except for the Load, the other two parameters are statistically insignificant at a 95% confidence level, implying that the parameters have insignificant impact on the COF value. This table also shows that the Load (L), Speed(S) and Sliding Time (T) affect the COF value of MMC (FA) by 84.1 %, 12.21 % and 3.47 % respectively.

4.4 FOR WEAR

The wear behavior of the MMC(FA) has been studied using the Taguchi method. In the present study, lower the better characteristic used for analysis of wear in Al-Si MMC. In the analysis, higher value of S/N ratio yields optimum wear conditions. The optimum wear conditions, which are the applying load of 10N, the speed of 1m/s and the sliding time of 1000 sec (1 1 1 orthogonal array) are obtained for the best abrasive wear values. Level values of the factors obtained for abrasive wear, according to the Taguchi design, are given in Table 5. Chart 4 shows the main effect plot for S/N ratio of wear. The average S/N ratio for every level of experiment is calculated based on the recorded value as shown in Table 5. The different values of S/N ratio between maximum and minimum are (main effect) also shown in Table 5. The load and the time are two factors that have the highest difference between values, 14.17 and 3.14 respectively. Based on the Taguchi prediction that the larger different between value of S/N ratio will have a more significant effect on abrasive wear. Thus, it can be concluded that wear and time will increase significantly when load is increased.

Table-5: Response Table for Signal to Noise Ratios for Wear

Source	DF	Seq SS	Adj MS	F	P	Contribution (%)
Load	2	302.35	151.175	35.62	0.027	81.4%
Speed	2	16.187	8.093	1.91	0.344	4.35%
Time	2	44.616	22.23	5.24	0.16	12.01%
Error	2	8.0489	4.244			2.166%
Total	8	371.486				100.00%

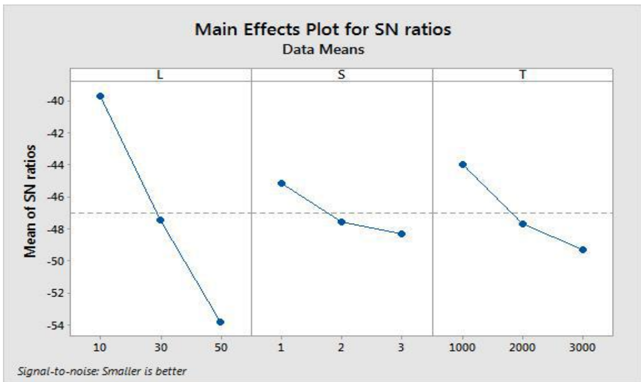

Chart-4: S/N ratios graph for Wear

Table-6: Results of analysis of variance for Wear

Source	DF	Seq SS	Adj MS	F	P	Contribution (%)
Load	2	302.35	151.175	35.62	0.027	81.4%
Speed	2	16.187	8.093	1.91	0.344	4.35%
Time	2	44.616	22.23	5.24	0.16	12.01%
Error	2	8.0489	4.244			2.166%
Total	8	371.486				100.00%

The results of data analysis of S/N ratio for abrasive wear values, which are calculated by Taguchi method, are shown in Table 6 (where DF is degree of freedom, F variance ratio, and P significant factor). Thus, it is seen in Chart 4 and Table 5 that the first level of A factor (Load), the first level of B factor (Speed) and the first level of C factor (Time) are higher. Consequently, the optimum wear conditions determined under the same conditions for the experiments to be conducted will be 10N for the Load, 1m/s for the speed and 1000sec for the sliding time. In addition the percentage contribution expresses the importance of the parameters for the response. According to the ANOVA data for wear given in Table 6, the p-value and percentage contribution expresses the significance and importance of the parameters. The p-value in Table 6 shows that, except for the Load, the other two parameters are statistically insignificant at a 95% confidence level, implies that the parameters have insignificant impact on the wear value. This table also shows that the Load (L), Speed(S) and Sliding Time (T) affect the wear value by 81.4%, 4.35 % and 12.01 % respectively.

V. CONCLUSION

Based upon the experiment we came to a conclusion that MMC is better than Alloy for the comparison of Wear and Co-efficient of Friction. Fly Ash reinforced with MMC shows better properties of tribological behavior than that of Rice husk Ash reinforced with MMC. This happens because the presence of carbon in Fly Ash which is slippery and helps to reduce the Wear and Co-efficient of Friction.Optimization for the tribological testing parameters like, coefficient of friction and wear properties of MMC(FA) has been done by Taguchi method L9 $(3)^3$ orthogonal array. It is seen from the study that the normal load is the most significant factor followed by sliding speed and sliding time at 95% confidence level in case of friction coefficient. However, for wear normal load and sliding time are significant parameters at same confidence level for the three tested materials. The optimum combination of process parameters are found out for minimum friction coefficient and wear from the study. Under dry condition, minimum friction coefficient is found at the highest levels of normal load and speed and the lowest level of sliding time. Minimum wear is found at the lowest levels of normal load and time and at the lowest level of sliding speed.

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