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Effect of Silicon Carbide Content on Tribological Properties of Aluminium Zinc Alloy Composite

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***Abstract*-** **Aluminium Zinc alloys are occupying attention of both researches and industries as a promising material for tribological applications. These are light weight having good malleability, formability, high corrosion resistance and high electrical and thermal conductivity. The present work is an attempt to study dry sliding wear of AZ alloy and wear parameters. The pin-on-disc test machine is used to study effect of wear parameters like applied load, rpm, sliding distance and percentage of Silicon carbide on the dry sliding wear of the alloy have been investigated. Techniques of Taguchi were used to conduct the experiment for acquiring the data in controlled way. An orthogonal array and the analysis of variance were employed to investigate the influence of process parameters on the wear of alloy. The objective of experimentation is to establish a correlation between dry sliding wear of alloy and wear parameters. These correlations were obtained by regressions and confirmation tests. These tests were conducted to verify the experimental results from the mentioned correlations.**

***Key words*-AZ alloy; wear; orthogonal array; Analysis of variance; Taguchi method**

1. INTRODUCTION

Aluminium and Zinc alloys have huge industrial applications because of their physical, mechanical and tribological properties such as high wear and seizure resistance, high stiffness, high strength, controlled thermal expansion coefficient and damping capacity. All these properties can be obtained through alloying elements, cold working and heat treatment. These alloying elements are selected based on their effects and suitability. The Zn-Al alloy have been tested for the tribological performance and applied in various engineering applications. These alloys were found superior than traditional bearing materials like bronze, steel, plastics, cast iron etc. These alloys possess low density, low coefficient of friction, low cost. At high stress conditions, this alloy has limited applications due to its lower creep resistance, as compared to traditional aluminium alloys and other structural materials, especially at temperatures above 100^0C. Due to this reason there is a major loss of market potential for this alloy; otherwise it is an excellent material. Dimensional instability was another problem, which is caused by the presence of metastable phases. It was found that, ZA alloys have the typical dendrite structure in the real casting conditions, wherein the dendrite size and interdendritic spacing depend on the casting parameters. We can overcome these problems to a great extent by replacing zinc with aluminium.

The alloying elements may be classified as major and minor elements, microstructure modifiers or impurities; however the impurity elements in some alloys could be major elements in others. Also it has been shown that this problem could be reduced through alloying with different elements such as Cu, Si, SiC, Ni, Mn, and Mg etc [3]. SiC is most effective alloy addition towards improving mechanical and tribological properties of AZ alloys. However, the effects of SiC content on wear properties of these alloys have not been fully studied. On this background the aim of this experimentation work is to investigate the effect of SiC on the wear properties of AZ alloys and to decide the optimum SiC content for above properties.

2. TAGUCHI TECHNIQUE

The Taguchi method, which is effective to deal with responses, was influenced by multi-variables. This method drastically reduces the number of experiments that are required to model the response function compared with the full factorial design of experiments. The major advantage of this technique is to find out the possible interaction between the parameters. The Taguchi technique is devised for process optimization and identification of optimal combination of the factors for a given response. This technique is divided into three main phases, which encompasses all experimentation approaches. The three phases are (1) the planning phase (2) the conducting phase and (3) the analysis phase. Planning phase is the most important phase of the experiment. This technique creates a standard orthogonal array to accommodate the effect of several factors on the target value and defines the plan of experiments. The experimental results are analyzed using analysis of means and variance to study the influence of factors [7].

3. EXPERIMENTAL PROCEDURE

3.1 *Preparation of Alloy*

The alloys were prepared from commercially pure aluminum (99.7%), high purity zinc (99.9%) and electrolytic copper (99.9%). The liquid metallurgy technique was used to prepare composite specimens, because it is most economical to fabricate composites. In this process, matrix alloy was firstly superheated over its melting temperature and then temperature was lowered gradually below the liquidus temperature to keep the matrix alloy in the semi-solid state at this temperature, the preheated SiC particles were introduced into the slurry and mixed. The composite slurry temperature was increased to fully liquid state and automatic stirring was continued for 5 min at an average stirring speed of 300~350 r/min. Alloys were melted in an electrical furnace and poured at a temperature of 750^{0}C in to a steel mould at room temperature. The melt was then superheated above liquidus temperature and finally poured into the cast iron permanent mould of 15 mm in diameter and 150 mm in height [4, 7].

Table 1 Process with their values at three level parameters

Level	rpm	Load (Kg)	Sliding distance (Km)	SiC (wt. %)
-1	200	2	2	6
0	400	4	4	9
1	600	6	6	12

3.2 *SEM microstructure and XRD test*

In order to get micro structural details of the prepared samples, they were taken for SEM & XRD tests. The images of the microstructures of these samples up to a resolution of 1500X were obtained and different phases were identified as shown in the fig 1, 2, 3. Also XRD GRAPHS of these sample show presence of these phases at various peaks as shown in fig 4, 5, 6.

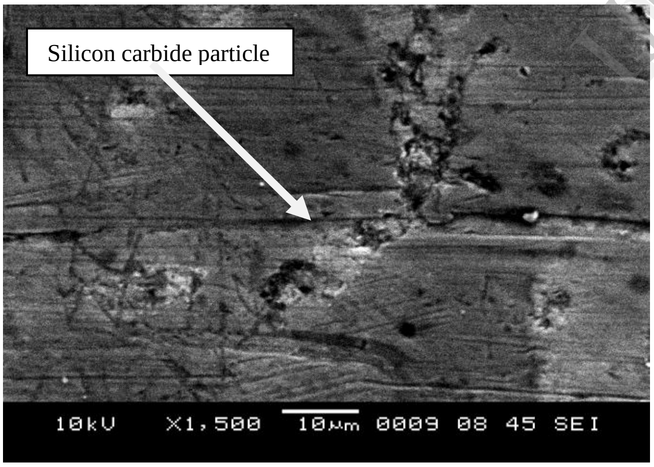

Fig. 1: SEM photograph of Al – 25% Zn-2.5% Cu- 6 % SiC

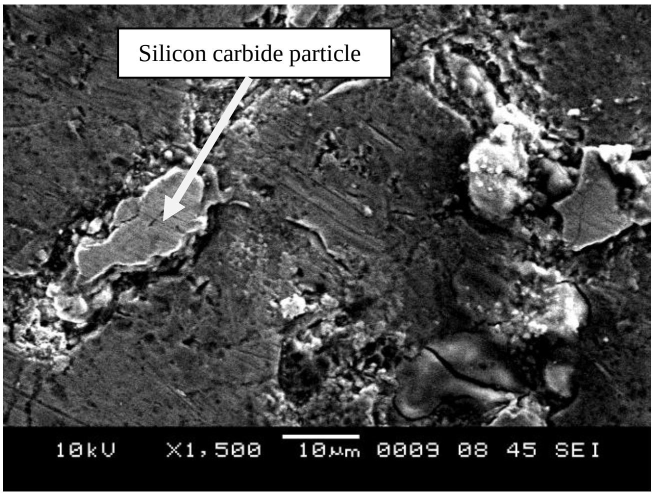

Fig. 2: SEM photograph of Al – 25% Zn-2.5% Cu- 9 % SiC

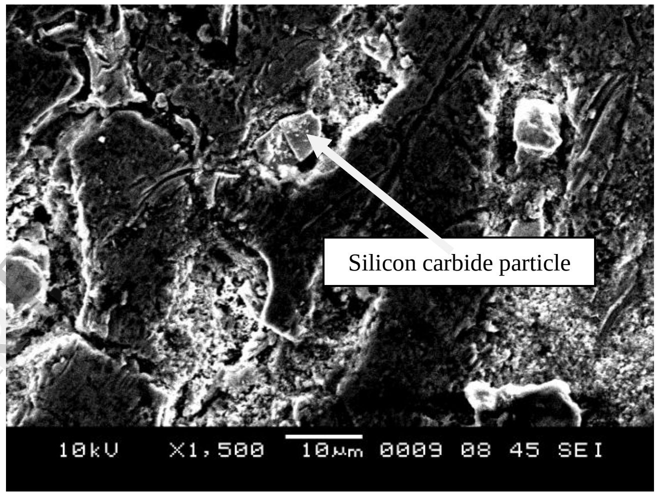

Fig. 3: SEM photograph of Al – 25% Zn-2.5% Cu- 12 % SiC

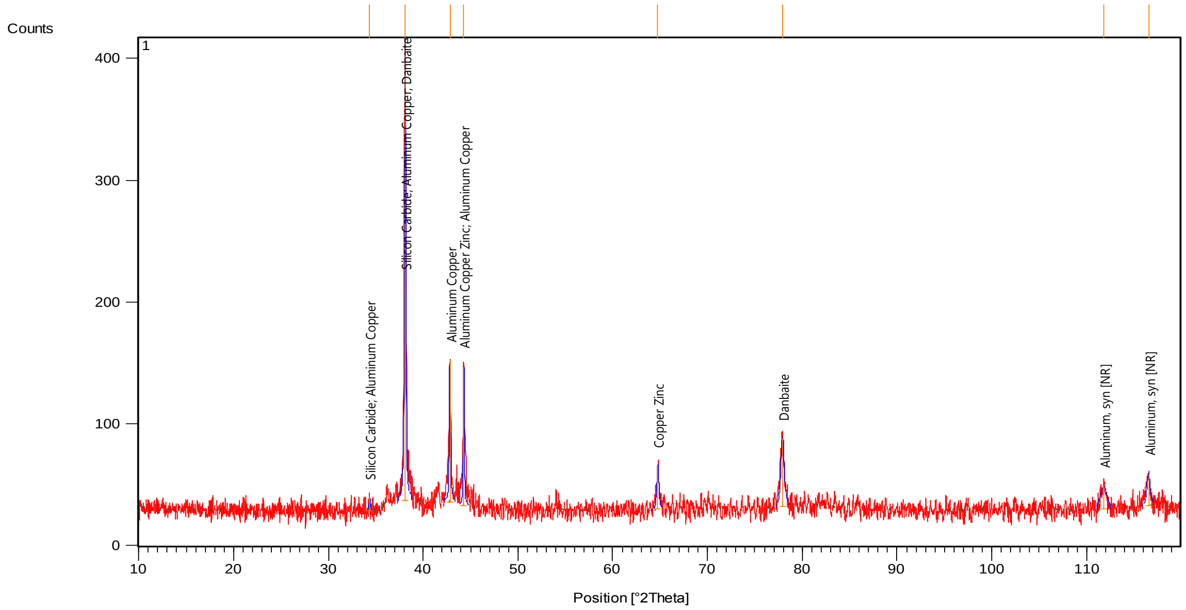

Fig. 4: XRD of Al - 25 Zn-2.5 Cu- 6 % SiC

The above fig show X-ray diffraction results of sample A in which SiC peaks were seen at 34^{O} and 38^{O}.And other peaks of phases Al, Cu, Zn and their mixtures are also as shown in the figure.

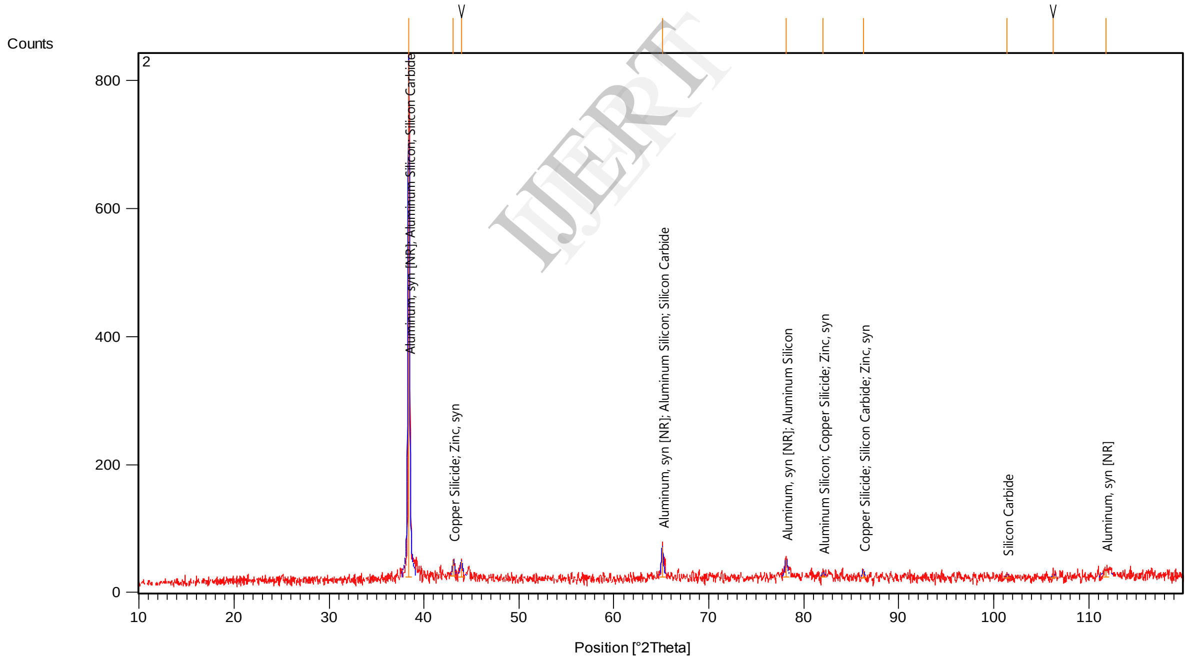

Fig. 5: XRD of Al - 25 Zn-2.5 Cu- 9 % SiC

The above fig show X-ray diffraction results of sample B in which SiC peaks were seen at 38^{O}, 65^{O}, 86^{O} and 101^{O} .And other peaks of phases Al, Cu, Zn and their mixtures are also as shown in the figure.

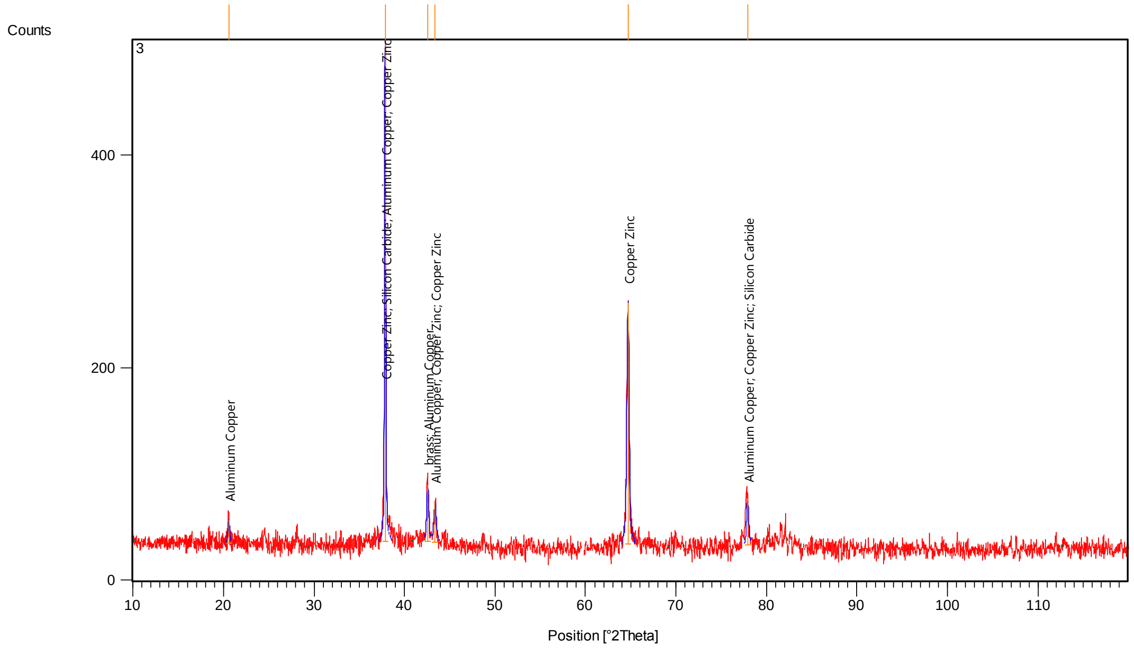

Fig 6: XRD of Al - 25 Zn-2.5 Cu- 12 % SiC

The above fig show X-ray diffraction results of sample C in which SiC peaks were seen at 38^{O} and 78^{O} .And other peaks of phases Al, Cu, Zn and their mixtures are also as shown in the figure.

3.3 *Wear test experimental setup and procedure*

A single pin type pin-on-disc test apparatus was used to carry out dry sliding wear characteristics of the composite as per ASTM G99-95 standards. The tests were carried out at the room temperature under dry operating conditions. Wear specimen (pin) of size 10 mm diameter and 25 mm length was cut from as cast samples machined and then polished metallographically. A single pan electronic weighing machine with least count of 0.0001 g was used to measure the initial weight of the specimen. The cylindrical pin flat ended specimens of size 10 mm diameter and 25 mm length were tested against EN31 steel disc by applying the load. After running through a fixed sliding distance, the specimens were removed, cleaned with acetone, dried and weighed to determine the weight loss due to wear. The difference in the weight measured before and after test gave the sliding wear of the composite specimen and then the weight loss was calculated [7]. The sliding wear of the composite was studied as a function of the weight percentage of the sic composite, sliding distance, the applied load and the rpm.

3.4 *Plan of experiments*

Standard orthogonal array was used to conduct the experiments. The selection of the orthogonal array was based on the condition that the degrees of freedom for the orthogonal array should be greater than or equal to sum of those wear parameters. An L_{27} orthogonal array was chosen for the present experiments, which has 27 rows and 6 columns as shown in Table 3. The wear parameters chosen for the experiments were (1) rpm, (2) load, (3) sliding distance, (4) weight percentage of SiC . Table 3 indicates the factors and their level. The experiment consists of 27 tests (each row in the L_{27} orthogonal array) and the columns were assigned with parameters. The first column in table 3 was assigned to rpm; second column was assigned to load; Third column was assigned to sliding distance and fourth column was assigned to weight percentage of SiC and remaining columns were assigned to their interactions. For lower is the better performance objective, the response to be studied. ANOVA is performed to determine significant parameter and at last confirmation test is conducted to verify the optimal process parameter.

4. RESULTS AND DISCUSSION

The tests were conducted with the aim of relating the influence of rpm, Load, Sliding distance and percentage of Sic with dry sliding wear of the composite. On conducting the experiments as per orthogonal array, the wear results for various combinations of parameters were obtained and are shown in Table 3. ANOVA results are shown in the Table 2.

4.1 *Analysis of variance*

The adequacy of the models is tested using the analysis of variance (ANOVA) technique. It is a statistical tool for testing null hypothesis for designed experimentation, where a number of different variables are being studied simultaneously. ANOVA issued to quickly analyze the variances present in the experiment with the help of fisher test (F test). This analysis was carried out for a level of significance of 5%, i.e. the level of confidence 95%. Table 2 shows the result of ANOVA analysis. One can observe from the ANOVA analysis that the value of P is less than 0.05 in all three parametric sources. Therefore it is clear that 1) rpm, (2) Load, (3) Sliding distance; (4)

Weight Percentage of SiC has the influence on the wear of the composite. The last column in Table 4 shows the percentage contribution of each factor on total variation indicating their degree of influence on the result. One can observe from the ANOVA table that the Load (46.52%), Sliding distance (40.27%), rpm (4.76%) and SiC composition (2.63%) has great influence on the wear. The SiC composition is influencing comparatively less (2.63%), which indicates that there is no appreciable increase in wear by increasing the SiC content from 6 to 12 weight percent.

Table 2: show ANOVA Results

Source	DF	Seq SS	Adj MS	F	P	% Contribution	Significant/ Not Significant
RPM	2	0.0259	0.01295	7.4	0.005	4.7652	Significant
LOAD	2	0.252865	0.126433	72.2	0	46.523	Significant
SLIDING DISTANCE	2	0.218891	0.109446	62.5	0	40.273	Significant
SIC COMPOSITION	2	0.014341	0.00717	4.09	0.034	2.6385	Significant
Error	18	0.031518	0.001751				
Total	26	0.543516					

Table 3: Show Orthogonal array of Taguchi for wear

Run	rpm	Load(kg)	Sliding distance (km)	Composition %	Wear in g	SN Ratio
1	200	2	2	6	0.097130	20.2529
2	200	4	4	6	0.280170	11.0516
3	200	6	6	6	0.602125	4.4063
4	400	2	4	6	0.225070	12.9536
5	400	4	6	6	0.506685	5.9052
6	400	6	2	6	0.339425	9.3851
7	600	2	6	6	0.434615	7.2379
8	600	4	2	6	0.210205	13.5471
9	600	6	4	6	0.551870	5.1633
10	200	2	2	9	0.096575	20.3027
11	200	4	4	9	0.253050	11.9359
12	200	6	6	9	0.493750	6.1299
13	400	2	4	9	0.181580	14.8186
14	400	4	6	9	0.384080	8.3116
15	400	6	2	9	0.326440	9.7239
16	600	2	6	9	0.291120	10.7186
17	600	4	2	9	0.267870	11.4415
18	600	6	4	9	0.483175	6.3179
19	200	2	2	12	0.074030	22.6118
20	200	4	4	12	0.334410	9.5144
21	200	6	6	12	0.459430	6.7556
22	400	2	4	12	0.198555	14.0424
23	400	4	6	12	0.392490	8.1234
24	400	6	2	12	0.283050	10.9627
25	600	2	6	12	0.342275	9.3125
26	600	4	2	12	0.231735	12.7002
27	600	6	4	12	0.528660	5.5362

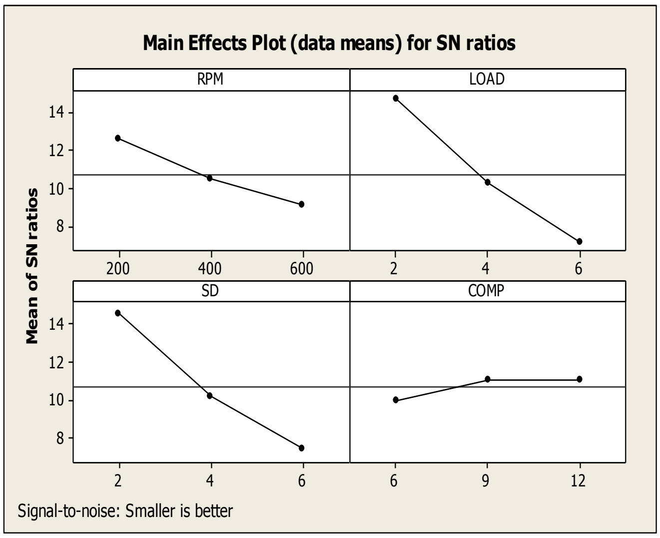

Figure 7.1

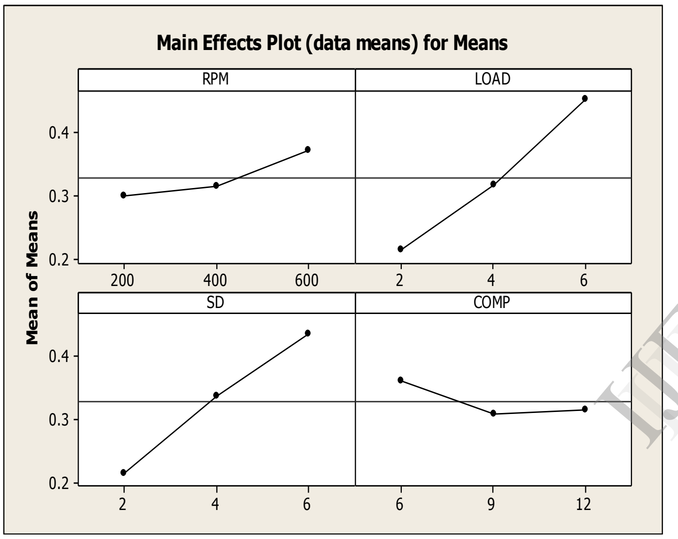

Figure 7.2

The graph shows the Main Effect plot for S/N ratio. The level for a factor with the highest S/N ratio was the optimum level for response measured. From the plot, it is observed that the minimum wear was at the higher S/N values in the response graph. The optimal wear parameters were 200 rpm (level 1), 2 Kg Load (level 1), 2 Km Sliding distance (level 1) and 12 % of Sic content (level 3). From S/N ratio graph, it is observed that for dry sliding wear, the Load and Sliding distance has the greatest influence on the wear. Figures 7.1 and 7.2 show graphically the effect of control factors on wear. Process parameter settings with highest ratio always give the optimum quality with minimum variance. The graph show the change of ratio when setting of the control factor was changed from one level to another.

4.2 Multiple Linear Regression Models

To establish the correlation between the wear parameters (1) rpm, (2) Load, (3), Sliding distance, (4) weight percentage of SiC and the dry sliding wear loss the wear multiple linear regression model was obtained using statistical software “MINITAB R14”.The terms that are statistically significant are included in the model. Final Equation obtained is as follows ,

WEAR = - 0.133 + 0.000181 RPM + 0.0591 LOAD + 0.0550 SD - 0.00746 COMP ……………..(1)

Substituting the recorded values of the variables for the above equation (1) the sliding wear of the material can be calculated. The positive value of the coefficient suggests that the sliding wear of material increases with their associated variables. Whereas the negative value of the coefficient suggest that the sliding wear of the material will decreases with the increase in associated variables. The magnitude of the variables indicates the weightage of each of these factors .It is observed from the Equation (1) that the Load has the more effect on wear of the composites, which is followed by Sliding distance, Weight percentage of SiC and rpm for the tested range of variables. The important factor affecting the sliding wear is the load and coefficient associated with it is positive (0.0591). This suggests that the Load increases the penetration ability of the fractured particles, will increase and remove the material on the pin surface. The coefficient of Sliding distance is positive (0.0550) which indicates that increase in wear weight loss with increasing the Sliding distance. The coefficient of SiC content is negative (-0.00746) which indicates that Sliding wear of composite decreases with increasing Sic content. The coefficient of rpm is positive (0.000181) which indicates that Sliding wear increases with increasing rpm for the tested range.

5. CONFIRMATION TEST

To test the efficiency of the model the confirmation tests were performed by selecting the set of parameters as shown in Table 4. Table 5 shows the comparison of wear results from the mathematical model developed in the present work (Eq.(1)), with values obtained experimentally. It can be observed from table 5 that the calculated error varies from 4% to 8% for wear. Therefore the multiple regression equation derived above correlate the evaluation of wear in the alloy with the degree of approximation.

Table 4: Show Parameters used in the confirmation wear test

Test	Rpm	Load (Kg)	Sliding Distance (km)	SIC %
1	600	4	4	6
2	400	6	6	9
3	600	2	2	12

Table 5: Show Confirmation test results

Test	Estimated Wear	Experimental Wear	Error %
1	0.38724	0.36986	4.6990
2	0.55686	0.60234	7.5505
3	0.11428	0.12120	5.7095

6. CONCLUSION

Load is the wear factor that has the highest physical properties as well as statistical influence on the dry sliding wear of the composites (46.52%), the sliding distance (40.27%), rpm (4.76%) and SiC composition (2.63%) and for dry sliding wear of Aluminium zinc alloy metal matrix composites, the sliding distance (40.27%) has moderate influence on the wear. The rpm (4.76%) and weight percentage of SiC (2.63%) are the wear factor that has least influence on dry sliding wear of the composites.

The highest wear resistance was obtained with 12% SiC composition. Wear resistance of tested alloy increased with increasing SiC content. Hardness of alloy increased with SiC content and 12% of SiC is the harder material than 9 and 6% of SiC. The confirmation tests shows that the error associated with dry sliding wear of the composite varies from 4% to 8%. The SEM & XRD test shows the presence of SiC content in all three samples.

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