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

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Abstract

Composite materials are used for variety of industrial application owing to their improved mechanical properties over the conventional alloy and materials. The present work is describes to effect of temperature on sliding wear of AZ alloy. The pin-on-disc (by pin heating) test machine is used to study effect of wear parameters like Silicon carbide percentage, disc rpm,temperature and applied load of on the wear of the alloy have been investigated. Taguchi technique is used to conduct the experiment for acquiring the data in controlled way. An orthogonal array and the analysis of variance are employed to investigate the influence of process parameters on the wear of alloy. The objective of experimentation is to establish correlation between dry sliding wear of alloy and wear parameters. This correlation is obtained by regressions and confirmation tests. This test is conducted to verify the experimental results from the mentioned correlations. It is observed that there is a transition from severe wear to mild wear after a time of sliding that decreases at 300°c and 2Kg (low) load. This is due to the generation and retention of oxide and partially-oxidized metal debris particles on the contacting load-bearing surfaces; these are compacted and agglomerated by the sliding action, giving protective layers on such surfaces. It is also observed that increase in temperature is related to the increase in frictional heat caused by load hence wear weight loss is increased.

***Keywords**:AZ alloy; wear; pin heating; orthogonal array; Analysis of variance; Taguchi method.*

1. INTRODUCTION

The need for new wear resistant materials for high performance tribological applications has been one of the major incentives for the technological development of ceramic particulate reinforced Zinc aluminum alloys during the last several years. Several investigators have reported that the incorporation of hard particles such Sic in cast Zinc aluminium alloys improve the sliding, abrasive wear resistance of these alloys [11]. Zinc Aluminum metal matrix composites are among the most promising materials for wear and structural applications due to low density, high wear and seizure resistance, high stiffness, high strength, controlled thermal tribological properties such as expansion coefficient and damping capacity, low cost and ease of fabrication of composites [12]. 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 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, where in the dendrite size and inter dendritic spacing depend on the casting parameters. We can overcome these problems to a great extent by replacing zincwith aluminum.[13]

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. For sliding contact of materials under condition when the temperature of operation is high, oxidation of the materials plays a significant role, causing change of overall wear rate. The importance of oxidation during wear of metallic materials was first identified by Fink [14]. Archard and Hirst[15] proposed Measurement of contact resistance, wear debris analysis and microscopic examination. The role of oxide scale was discussed extensively by Quinn [16] and Lim and Ashby [17] for ambient temperature wear. Subsequently a large volume of work was done on the elevated temperature wear of metallic materials. Most of the studies indicate the formation of glazed layers on the substrate under certain conditions of load, temperature and sliding speed.[18]

2. TAGUCHI TECHNIQUE

The Taguchi's method is a powerful method for designing high quality systems based on orthogonal array (OA) experiments that provide much reduced performance for the experiments with an optimum setting for process control parameters. This method achieves the integration of design of experiments (DOE) [17] with the parametric optimization of the process yielding the desired results. 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. 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 conditions. 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.

3. EXPERIMENTAL PROCEDURE

3.1 Preparation of Alloy

The alloy is prepared from commercially pure aluminum (99.7%), high purity zinc (99.9%) and electrolytic copper (99.9%). The liquid metallurgy technique is used to prepare composite specimens, because it is most economical to fabricate composites. In this process, matrix alloy is firstly superheated over its melting temperature and then temperature was lowered gradually below the liquidus temperature to keep the matrix alloy in the semi-solidstate at this temperature, the preheated SiC particles are introduced into the slurry and mixed. The composite slurry temperature is increased to fully the classification of mild and severe wear based on liquid state and automatic stirring is continued for 5 min at an average stirring speed of 300~350 r/min. Alloyis melted in an electrical furnace and poured at a temperature of 750^{0}C in to a steel mould at room temperature. The melt is 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	SiC (wt.%)	Rpm	Temperature (°C))	Load (Kg)
-1	6	200	100	2
0	9	400	200	4
1	12	600	300	6

3.2 Material and chemical composition for pin

Table 2: Material for pin

A	Al-25% Zn-2.5% Cu-6% Sic
B	Al-25% Zn-2.5% Cu-9% Sic
C	Al-25% Zn-2.5% Cu-12% Sic

The test material is turned in the form of pin with diameter of 10mm and length 25mm.A320 emery paper is used to clean surface of pin before starting of each experiment.

3.3 Material for disc

The counter face (disc) is fabricated using EN 31 steel. Having chemical composition 1.30% c, 1.40% Cr, 0.3% Ni, 0.50% Mn, .0025% S .0024% P30%Si and reminder Fe and hardness is 180 BHN.

3.4 SEM microstructure and XRD test

In order to get micro structural details of the prepared samples, they are 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.

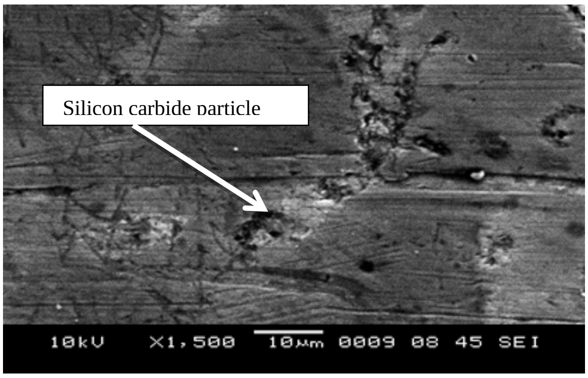


Fig. 1: SEM photograph of Al – 25% Zn-2.5% Cu- 6 % SiC

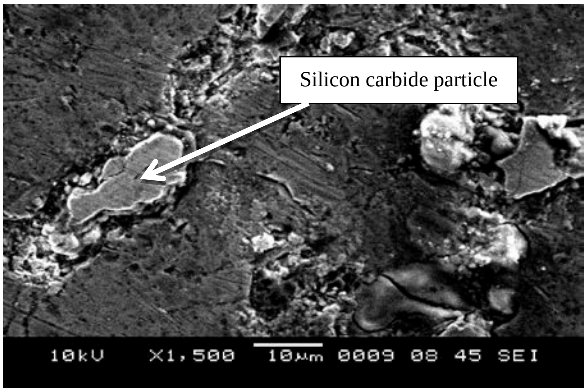


Fig. 2: SEM photograph of Al – 25% Zn-2.5% Cu- 9 % SiC

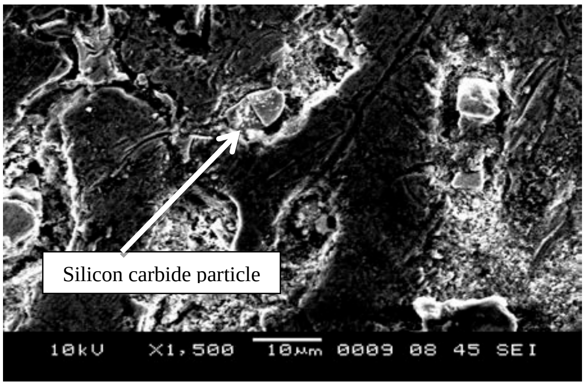


Fig. 3: SEM photograph of Al – 25% Zn-2.5% Cu- 12 % SiC

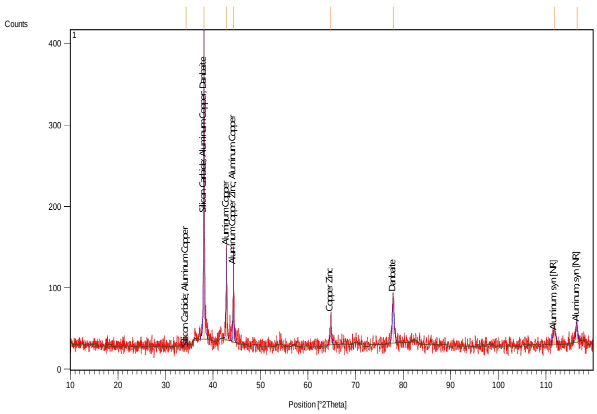


Fig. 4: XRD of Al - 25 Zn-2.5 Cu- 6 % SiC

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

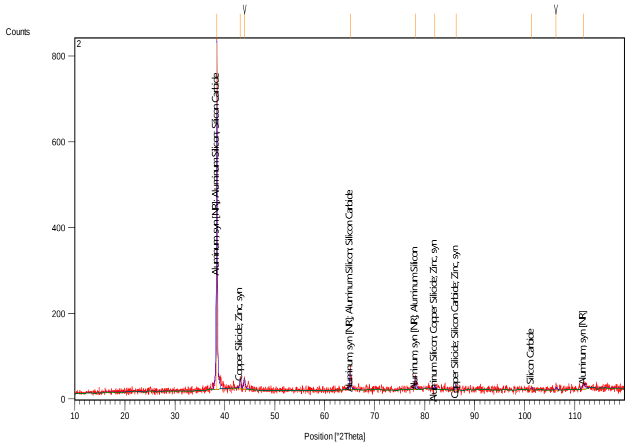


Fig. 5: XRD of Al - 25 Zn-2.5 Cu- 9 % SiC

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

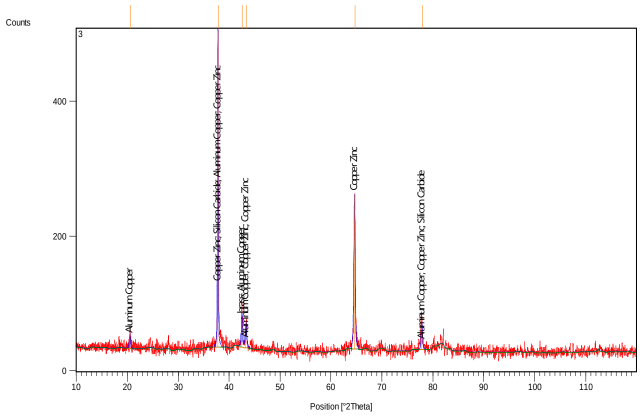


Fig 6: XRD of Al - 25 Zn-2.5 Cu- 12 % SiC

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

3.5 Wear test experimental setup and procedure

The experiment is conducted on pin on disc apparatus tribo tester is used to carry out sliding wear characteristics of the composite as per ASTM G99-95 standards at elevated temperature (by pin heating) for duration of 20 minutes.

Wear specimen (pin) is selected which is size 10 mm diameter and 25 mm length is cut from as cast samples machined and then polished metallographically.A single pan electronic weighing machine with least count of 0.0001 g is used to measure the initial and final weight of the specimen. The cylindrical pin flat ended specimens of size 10 mm diameter and 25 mm length is tested against EN31 steel disc by applying the load. After experimentation the specimens is 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 gives the sliding wear of the composite specimen and then the weight loss was calculated [7]. The sliding wear of the composite is studied as a function of the weight percentage of the sic composite, the rpm the temperature, the applied load.

3.6 Plan of experiments

Standard orthogonal array is used to conduct the experiments. The selection of the orthogonal array is 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 is chosen for the present experiments, which has 27 rows and 6 columns. The wear parameters chosen for the experiments were (1) weight percentage of SiC, (2) rpm, (3) temperature, (4) load. The experiment consists of 27 tests (each row in the L_{27} orthogonal array) and the columns are assigned with parameters. 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 is conducted with the aim of relating the influence of percentage of Sic, rpm, temperature and Load by pin heating at elevated temperature. On conducting the experiments as per orthogonal array, the wear results for various combinations of parameters are obtained and ANOVA results are shown in the Table 3.

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 3 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) Weight Percentage of Sic, (2) disc rpm, (3) temperature (4) Load has the influence on the wear of the composite. The last column in Table 3 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 Sic composition (2.324%), rpm (8.720%), temperature (17.775%), and Load (66.025%) have great influence on the wear. The Sic composition is influencing comparatively less (2.324%), which indicates that there is no appreciable increase in wear by increasing the SiC content from 6 to 12 weight percent.

Table3: show ANOVA results

Source	DF	SeqSS	Adj MS	F	P	% Contribution	Significant/Not Significant
SIC COMPOSITION	2	0.013441	0.006720	4.06	0.035	2.324	Significant
RPM	2	0.050419	0.025209	15.23	0.000	8.720	Significant
TEMPERATURE	2	0.102775	0.051387	31.04	0.000	17.775	Significant
LOAD	2	0.381740	0.190870	115.29	0.000	66.025	Significant
Error	18	0.029799	0.001656				
Total	26	0.578174					

4.2 Main effect plot

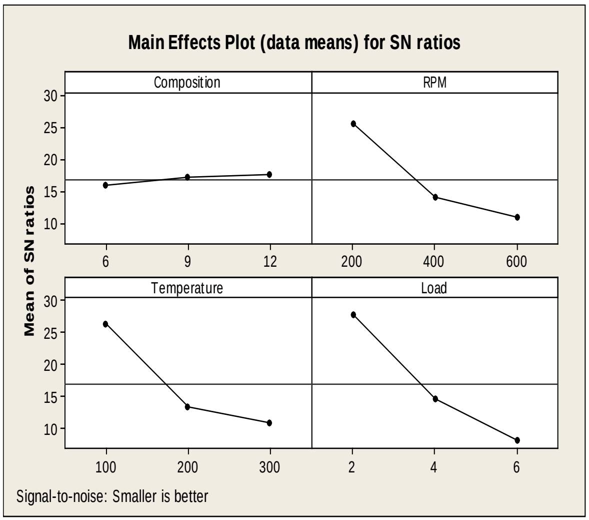


Fig. 7.1 Main effect plot for SN rations

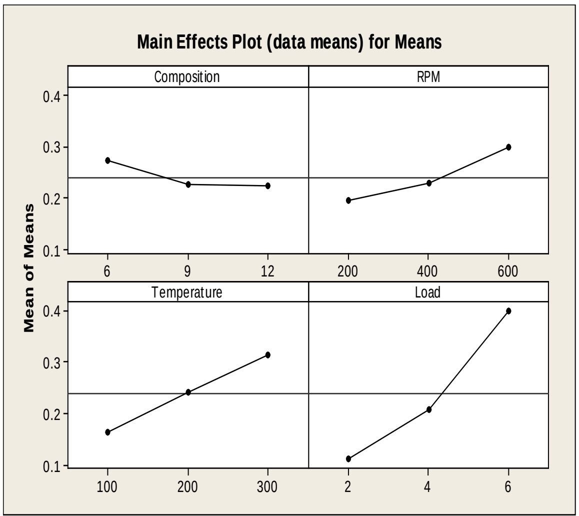


Fig.7.2Main effect plot for Means

The graph shows the Main Effect plot for S/N ratio. The level for a factor with the highest S/N ratio is the optimum level for response measured. From the plot, it is observed that the minimum wear is at the higher S/N values in the response graph. The optimal wear parameters are 12 % of Sic content (level 3),200 rpm (level 1), 100 °C temperature (level 1)and 2 Kg Load (level 1) From S/N ratio graph, it is observed that for sliding wear, the Load and temperature has the greatest influence on the wear. Fig. 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.

4.3 Multiple Linear Regression Models

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

Wear = -0.227-0.00820composition + 0.000259RPM +0.000756 Temperature + 0.0715 Load (1)

Substituting the recorded values of the variables for the above equation (1) the sliding wear of the material is 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 is the more effect on wear of the composites, which is followed by temperature, disc rpmand weight percentage of SiC for the tested range of variables. The important factor affecting the sliding wear is the load and coefficient associated with it is positive. 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 temperature is positive which predicts that increase in wear weight loss with increasing temperature. The coefficient of Sic content is negative which predicts that Sliding wear of composite decreases with increasing Sic content. The coefficient of rpm is positive which indicates that Sliding wear increases with increasing rpm for the tested range.

4.4The Effect of rpm on wear for load of 2Kg, 4Kg, 6Kg

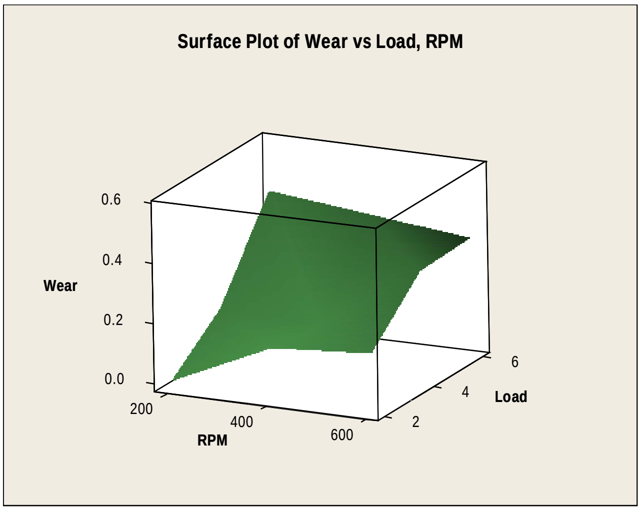


Fig.8The relationship between rpm versus wear for load of 2 Kg, 4 Kg, and 6 Kg.

The fig.8 shows the relationship between rpm versus wear for load of 2 Kg, 4 Kg, and 6 Kg. It is observed that, the wear is low for load of 2 Kg as compared to load of 4 Kg and 6 Kg. It is also observed that, wear increases as the rpm increases from low to high speeds for load of 2 Kg, 4 Kg, and 6 Kg. As the disc speed was increased, the material removal ability of disc material will increase and it will remove the material from the pin surface. It observed from the graph that wear volume of the alloy increased with increasing sliding speed (rpm). The increase in the values of these properties may be related to the production rate of the wear particles and centrifugal force acting on them. As the sliding speed increases the production rate of the wear particles would be expected to increase. Since there is no lubricating oil to act as coolant the wear particles may get oxidized very quickly and act as abrasives. It is also known that less smearing occurs on both sample and disc surfaces during dry running compared to the case in the lubricated sliding. These indicate that as the sliding speed increases the number of abrasive wear particles pass through the contacting surfaces increases. It is also known that as the rotational speed (rpm) increases the centrifugal force acting on the wear particles increases. As the centrifugal force increases the amount of loose wear particles scattered from the surface of the rotating disc is expected to increase. This may reduce the amount of smeared material on the surface of the wear samples giving rise to higher wear.

4.5 The Effect of material composition on wear for temperature of 100°c, 200°c and 300°c.

The fig. 9 shows the relationship between material composition versus wear for temperature of 100°c, 200°c and 300°c.

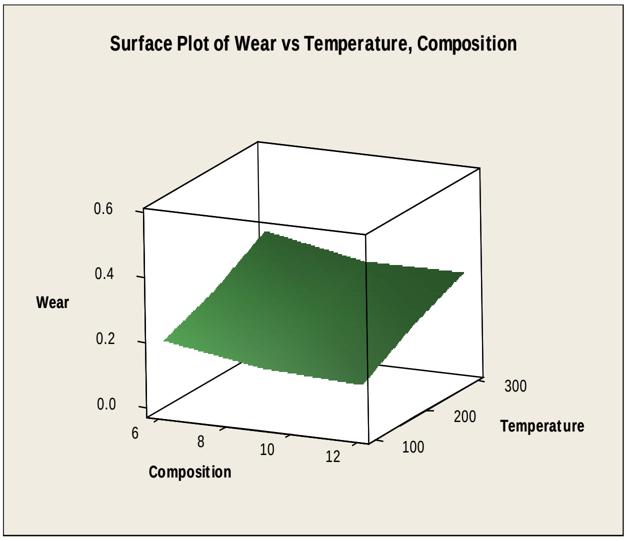


Fig.9 The relationship between material composition versus wear for temperature of 100°c, 200°c and 300°c.

It is observed that, the wear is low for temperature of 100°c as compared to temperature of 200°c and 300°c. It is also observed that, wear decreases as the material composition increases from 6% SiC to 12 % of SiC for temperature of 100°c, 200°c and 300°c. The slidingwear of composite decreases with increasing reinforcement content. This is attributed to the hard SiC particles, which acts as a major load-bearing element for a multi component system. The load bearing capacity is the major reason of decreasing wear weight loss.

4.6 The Effect of temperature on wear for load of 2Kg, 4Kg, 6Kg

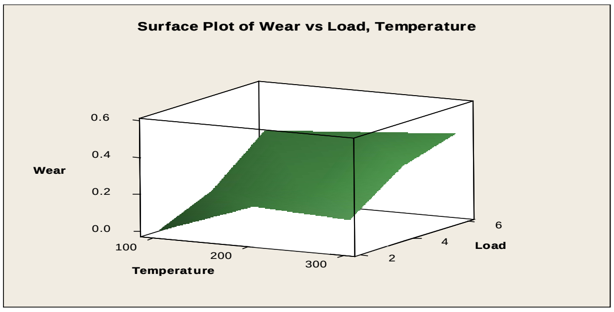
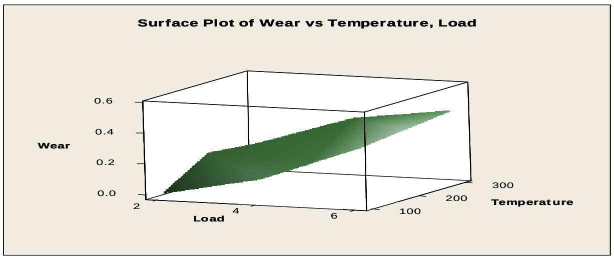


Fig. 10 The relationship between temperature versus wear for load of 2 Kg, 4 Kg, and 6 Kg.

The fig.10 shows the relationship between temperature versus wear for load of 2 Kg, 4 Kg, and 6 Kg. It is observed that, the wear is low for load of 2 Kg at 100°c temperature. It is also observed that, wear increases as the temperature increases from 100°c to 200°c for load of 2 Kg and 4 Kg .It is also observed that wear is decrease for load of 2Kg at 300°c temperature this phenomena due to a decrease of wear while rise in temperature at reduction on minimum load there is a transition from severe wear to mild wear after a time of sliding that decreases with increase in temperature. This is due to the generation and retention of oxide and partially-oxidized metal debris particles on the contacting load-bearing surfaces; these are compacted and agglomerated by the sliding action, giving protective layers on such surfaces. At low temperatures, the layers generally consist of loosely-compacted SiC particles; at higher temperatures, there is an increase in the rates of generation and retention of particles while compaction, sintering and oxidation of the particles in the layers are facilitated, leading to development of hard, very protective oxide 'glaze' surfaces.

4.7 The Effect of load on wear for temperature of 100°c, 200°c and 300°c.



The fig.11 shows the relationship between load versus wear for temperature of 100°c, 200°c and 300°c. It is

Fig. 11 The relationship between load versus wear for temperature of 100°c, 200°c and 300°c.

observed that, the wear is low for temperature of 100°c as compared to temperature 200°c and. It is also observed that, wear increases as the load increases from low to high value for temperature of 100°c, 200°c and 300°c. Except at 300°c temperature and load 2Kg load wear is decreases. As the load was increased, the penetration ability of fractured particles will increase and it will remove the material from the pin surface. The fractured small particles of silicon carbide between the pin and the counter face from a three body abrasion and remove the material on the surface of the pin. As the load increases the more fractured silicon carbide particles occur, which penetrate in to the pin and flow through it.The increase in temperature may be related to the increase in frictional heat caused by pressure (load). However, the increase in the wear is consistent with one of the adhesive wear laws which state that the wear of material is proportional to the normal load or pressure between the contacting surfaces.

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	SIC %	Rpm	Temperature (°C)	Load (Kg)
1	6	600	200	4
2	9	400	300	6
3	12	600	100	2

Table 5: Show Confirmation test results

Test	Estimated Wear	Experimental Wear	Error %
1	0.3164	0.2986	5.961
2	0.4586	0.4273	7.325
3	0.0486	0.0518	6.584

6. CONCLUSION

Load is the wear factor that has the highest physical properties as well as statistical influence on the wear of the composites (66.025%), temperature (17.775%), the rpm (8.720%), and SiC composition (2.324%) and for sliding wear of Aluminium zinc alloy metal matrix composites, the temperature (17.775%) has moderate influence on the wear. The rpm (8.720%) and SiC composition (2.324%) are the wear factor that has least influence on 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 SEM & XRD test shows the presence of SiC content in all three samples.

This experiments of study presents that that there is a transition from severe wear to mild wear after a time of sliding that decreases with increase in ambient temperature. This is due to the generation and retention of oxide and partially-oxidized metal debris particles on the contacting load-bearing surfaces; these are compacted and agglomerated by the sliding action, giving protective layers on such surfaces at minimum load and at temperature 300°c wear decreases.

It is also observed that wear volume of the alloy increased with increasing sliding speed (rpm). The increase in the values of these properties may be related to the production rate of the wear particles and centrifugal force acting on them.

The increase in temperature may be related to the increase in frictional heat caused by load (pressure), therefore, the wear is increases.

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