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Dry Sliding Wear Test Conducted On Pin-On-Disk Testing Setup For Al6061-Sic Metal Matrix Composites Fabricated By Powder Metallurgy

Ramesh B. T.[1], Dr. Arun Kumar M. B.[2], Dr. R. P. Swamy[3]

[1] Department of Mechanical Engineering, S. T. J. Institute of Technology, Ranebennur, Karnataka 581 115, India
[2] Department of Mechanical Engineering, G.E.C, Haveri, Karnataka, India
[3] Department of Mechanical Engineering, U. B. D. T. College of Engineering, Davanagere, Karnataka, India

Abstract

The composite material plays vital role in modern technology. There are varieties of composites. Metal matrix Composites (MMCs) are a relatively new family of composite materials which are becoming more and more common place by the development of new production techniques and processing equipment.

Al6061-SiC composites containing three different weight percentages 5%, 10%, and 15% of SiC have been fabricated by powder metallurgy method. Hardness and wear characteristics of Al6061-SiC composites have been investigated and compared with each other. Rockwell hardness testing machine used to investigate the hardness number of different composition of Al6061- SiC composite and dry sliding wear tests have been carried out using pin-on-disk wear test rate normal loads of 20, 40 and 60N and at different sliding velocity. Weight loss of samples was measured and the variation of cumulative wear loss with sliding distance has been found to be linear for Al6061–SiC of different compositions of the composite. It was also observed that the wear rate varies linearly with normal load but lower in composites as compared to that in base material. The wear mechanism appears to be oxidative for composites under the given conditions of load and sliding velocity as indicated by scanning electron microscope (SEM) of the worn surfaces. Further, it was found from the experimentation that the wear rate decreases linearly with increasing weight fraction of silicon carbide and average coefficient of friction decreases linearly with increasing normal load and weight fraction of SiC. The best results have been obtained at 15% weight fraction SiC particles for minimum wear.

In view of the above said facts, a project work which is entitled as **"Dry sliding wear test conducted on pin-on-disk testing setup for Al6061-SiC metal matrix composites fabricated by powder metallurgy"** is undertaken by the student of post graduate. The objective of the project work is to study the mechanical characteristics Al6061-SiC composite.

Key Words: *Metal Matrix Composites MMC's, Silicon Carbide SiC*

1. Introduction

Composite materials are important engineering materials due to their outstanding mechanical properties. Composites are materials in which the desirable properties of separate materials are combined by mechanically or metallurgical binding them together. Each of the components retains its structure and characteristic, but the composite generally possesses better properties. Composite materials offer superior properties to conventional alloys for various applications as they have high stiffness, strength and wear resistance.

Modern composite materials constitute a significant proportion of the engineered materials market ranging from everyday products to sophisticated niche applications. While composites have already proven their worth as weight-saving materials, the current challenge is to make them cost effective. The efforts to produce economically attractive composite components have resulted in several innovative manufacturing techniques currently being used in the composites industry. It is obvious, especially for composites, that the improvement in manufacturing technology alone is not enough to overcome the cost hurdle. It is essential that there be an integrated effort in design, material, process, tooling, quality assurance, manufacturing, and even program management for composites to become competitive with metals. Conventional monolithic materials have limitations in achieving good combination of strength, stiffness, toughness, and density. To overcome these short comings and to meet the ever increasing demand of modern day technology, composites are most promising materials of recent interest. Metal matrix composites (MMCs) possess significantly improved properties including high specific strength; specific modulus, damping capacity and good wear resistance compared to unreinforced alloys. There has been an increasing interest in composites containing low density and low cost reinforcements.

The purpose of this chapter is to provide a review of past research efforts related to composites, the reinforcement particle, the matrix element, and the process used in this study. A review of other relevant research studies is also provided. Substantial literature has been studied on metal matrix composite, silicon carbide, aluminum and powder metallurgy methods. The review is organized chronologically to offer sight to how past research efforts have laid the groundwork for subsequent studies, including the present research effort. The review is detailed so that the present research effort tailored to the present body of literature as well as to justly the scope and direction of the present research effort.

There have been tremendous strides in engineering materials since 1950s. Several super alloys and heat resistance materials have been developed for various industrial applications, especially aerospace/aircraft and defense. Automotive, medical and sport equipment industries pushed advances in materials particularly having low density and very light weight with high strength, hardness and stiffness. One of these important advanced materials is composite.

A composite material is a non uniform solid consisting of two or more different materials that are mechanically or metallurgically bonded together. Each of the various composites retains its identity in the composite and maintains its characteristic properties such as stiffness, strength, weight, high temperature, corrosion resistance, hardness, and conductivity, which are not possible with the individual components by themselves (Black, 2007). Example of the traditional composite is brick which consists of clay that mix up with grass and concrete that have mixture of cement and sand. In this example, clay and cement are matrix component while grass and sand are the reinforcement (Hashim J. 2003).

More or less, the strength of a composite is a function of the strength of its interface between the matrix and the reinforcement. The failure of a functional composite is essentially a result of the failure of the interface. Hence the strengthening mechanism is the most dominant parameter in successful fabrication of a high strength composite [10].

Composites differ by their matrix type, reinforcement type, size and form, composition, temper state, etc. With such a big window available for fabricating a composite from different constituent materials, it is not uncommon to experiment with materials with vividly different properties. There are three broadly classified groups of composites: Polymer Matrix Composite, Metal Matrix Composite, and Ceramic Matrix Composite.

2. Materials Selection

2.1 Materials Used

The matrix material for present study is Al6061.Table 2.1 gives the chemical composition of Al6061. Table 2.2 gives the details of the physical and mechanical properties of Al6061. The reinforcing material selected was SiC of particle size 125 µm. Table 2.3 gives the details of the physical and mechanical properties of Silicon Carbide.

2.1.1 Aluminium Alloy 6061

Aluminium alloy 6061 is one of the most extensively used of the 6000 series aluminium alloys. It is a versatile heat treatable extruded alloy with medium to high strength capabilities.

2.1.1.1 Composition

Table 2.1: Typical composition of aluminium alloy 6061

Component	Magnesium	Silicon	Iron	Copper	Zinc	Titanium	Manganese	Chromium	Others	Aluminium
Amount (wt. %)	0.8-1.2	0.4-0.8	0.7	0.15-0.40	0.25	0.15	0.15	0.04-0.35	0.05	Balance

2.1.1.2 Physical and Mechanical Properties of Al6061 Alloy

Table 2.2: Physical and Mechanical Properties of Al6061 Alloy

Matrix	Elastic Modulus (GPa)	Density (g/cc)	Poisson's Ratio	Hardness (HB500)	Tensile Strength (MPa)
Al6061	70-80	2.7	0.33	30	115

2.1.2.1 Mechanical Properties of Silicon Carbide Particulates

Table 2.3: Physical and Mechanical Properties of Silicon Carbide Particulates [26]

Reinforcement	Elastic Modulus (GPa)	Density (g/cc)	Poisson's Ratio	Hardness (HB500)
SiC	410	3.10	0.14	2800

3. Fabrication and Experimental Work

This chapter describes the experimental procedure as adopted in the present project work. The equipment / instruments used for the various experiments in this work are listed in a tabular form depicting their specific contextual uses, their specification, and particulars.

Details of each procedural step adopted for the fabrication of the test specimen, their heat treatment profile, and the methods of mechanical testing carried out, the generation of the micrographs through Scanning Electron Microscopy (SEM) has been furnished. For the sake of clarity and brevity, photographs of equipments / instruments that have been used in this work are also inserted.

3.1 Equipments / Instruments Used

Table 3.1: Equipments used in the work

SI. NO.	Instrument / Equipment	Specification
1	Universal Testing Machine	Model – TUN 400
2	Muffle Furnace	Make: Wild Barfield Model: HT 25 Max. Temp.: 1150^{0}C
3	Scanning Electron Microscope	Make : JEOL Type: JSM-6480LV
4	Rockwell Hardness Machine	Model: MRB-250
5	Wear Testing Machine	Disc Diameter – 16mm

3.2 Compaction of the Powder Mix

About 5.6 grams of the powder mix was taken adopting a method of coning and quartering for compaction in a universal testing machine in a metallic die-punch arrangement.

3.3 Sintering of the Green Pellets

Green pellets obtained after pressing were subjected to sintering in a temperature about 550^0 C muffle furnaces. Sintering was done in the solid state only. Sintering temperature and the time of holding were constant. Furnace for the entire duration of sintering to prevent oxidation of Aluminium and heating rate was maintained at 5^0 C/minute.

3.4 Testing Properties

In order to evaluate the properties of the Al-SiC composites the hardness, porosity, density, compressive strength, indirect tensile strength, and microstructure were determined.

3.4.1 Hardness

Rockwell hardness was measured on the polished surfaces of the Al-SiC composite samples using B scale on Rockwell hardness tester. A 1/16" Ball indenter with fixed indentation load of 100 kg was used for all tests. Five readings were taken for the samples of each composition and the average hardness was determined.

3.4.2 Wear Test

A pin-on-disc is used to perform the wear experiment. The wear track, alloy and composite specimens are cleaned thoroughly with acetone prior to test. Each specimen is then weighed using a digital balance having an accuracy of ±0.001 gm. After that the specimen is mounted on the pin holder of the tribometer ready for wear test. Specimens of size 12 mm diameters and 15mm length were cut from the cast samples, machined, and then polished. During the test, the sample is held pressed against a rotating EN32 steel disc (hardness of 65HRC) by applying load that acts as counter weight and balances the pin.

The track diameter was chosen as 80mm and the parameters such as the load, sliding speed and sliding distance were varied in the range given. Once the surface in contact wears out, the load pushes the arm to remain in contact with the disc. This movement of the arm generates a signal which is used to determine the maximum wear. Weight loss of each specimen was obtained by weighing the specimen before and after the experiment by a single pan electronic weighing machine with an accuracy of .001g after thorough cleaning with acetone solution.

Dry sliding wear rate test was performed with three parameters: applied load, sliding speed, and sliding distance and varying them for three levels. 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 as 27 rows and 13 columns was selected a total of 27 experiments were performed based on the run order generated by Taguchi model. The response for model is wear rate. In Orthogonal array, first column is assigned to sliding speed, second column is assigned to load, fifth column is assigned to sliding distance and ninth column is assigned to material composition. The objective of model is to minimize the wear rate.

3.4.3 Scanning Electron Microscopy

The fractured test pieces were examined with the help of a Scanning Electron Microscope (JSM-6480LV) (Fig. 4.5). The fractured surfaces were studied for modes of fracture, the failure of the Interface, failure of the matrix, failure of the reinforcement, etc.

Fig.4.5: JEOL JSM-6480LV scanning electron microscope

4. Results and Discussion

In this chapter presents the mechanical properties of the Al6061-SiC composites prepared for this present investigation. Details of processing of these composites and the tests conducted on them have been described in the previous chapter. The results of various characterization tests are reported here. This includes evaluation of hardness, wear and SEM analysis has been studied and discussed. The interpretation of the results and the comparison among various composite samples are also presented.

4.1. Mechanical Characteristics of Composites

The characterization of the composites reveals that the % of Sic is having significant effect on the mechanical properties of composites. The properties of the composites with different Sic % under this investigation are presented below.

4.1.1. Effect of SiC % on Hardness

The measured hardness values of all the three composites are presented in Figure 4.1. It can be seen that the hardness value of 15% of SiC composites is more as compared to 5 and 10 % of SiC composites. Among three types of composites 5% SiC composite showing less hardness value.

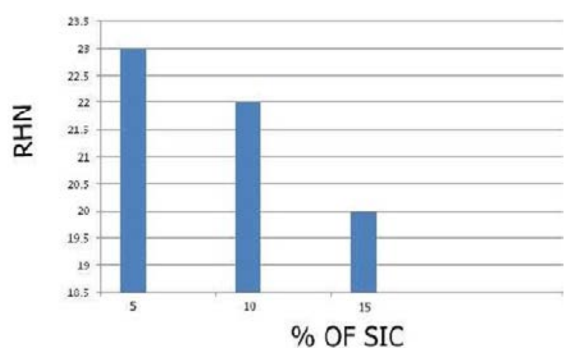

Fig. 4.1: Effect of SIC % on Rockwell hardness of the composites

4.1.2. Effect of Sic % on Wear Rate

The experiments were conducted as per orthogonal array and the wear rate results obtained for various combinations of parameters are shown in Table 4.1. The experimental values were transformed into S/N ratios for measuring the quality characteristics using MINITAB 15. The S/N ratio obtained from all the experiments are shown in Table 4.1.

Table 4.1: Wear rate and S/N ration obtained as per Taguchi's L27 Orthogonal Array

SI. NO.	Load, N (L)	Speed, m/s (S)	SiC, wt% (F)	Wear Rate kg/m × 10^{-5}	S/N Ratio
1	20	1.05	5	0.304	-10.3425
2	20	1.05	10	0.102	-19.8280
3	20	1.05	15	0.087	-21.2096
4	20	1.83	5	2.148	-6.6407
5	20	1.83	10	1.294	-2.2387
6	20	1.83	15	1.002	-0.0174
7	20	2.62	5	2.602	-8.3061
8	20	2.62	10	1.516	-3.6140
9	20	2.62	15	1.096	-0.7962
10	20	1.05	5	2.963	-9.4346
11	40	1.05	10	1.784	-5.0279
12	40	1.05	15	0.428	-7.3711
13	40	1.83	5	4.008	-12.0586
14	40	1.83	10	3.030	-9.6289
15	40	1.83	15	1.974	-5.9069
16	40	2.62	5	5.094	-14.1412
17	40	2.62	10	3.794	-11.5819
18	40	2.62	15	2.756	-8.8056
19	60	1.05	5	4.836	-13.6897
20	60	1.05	10	3.290	-10.3439
21	60	1.05	15	2.878	-9.1818
22	60	1.83	5	6.050	-15.6351
23	60	1.83	10	5.572	-14.9202
24	60	1.83	15	4.210	-12.4856
25	60	2.62	5	6.238	-15.9009
26	60	2.62	10	5.970	-15.5195
27	60	2.62	15	4.494	-13.0527

4.1.2.1. S-N Ratio Analysis

The influence of control parameters such as load, sliding speed and SiC content on wear rate has been evaluated using S/N ratio response analysis. The control parameter with the strongest influence was determined by the difference between the maximum and minimum value of the mean of S/N ratios. Higher the difference between the mean of S/N ratios, the more influential was the control parameter

The S/N ratio response analysis, presented in Table 4.2 shows that among all the factors, load was the most influential and significant parameter followed by sliding speed and SiC content. Figure 4.2 (a) shows the mean of wear rate graphically and Figure 4.2 (b) depicts the main effects plot for means of S/N ratio for wear rate. From the analysis of these results, it can be inferred that parameter combination of L = 20 N, S = 1.05 m/s and F = 9% gave the minimum wear rate for the range of parameters tested.

Table 4.2: Response table for S/N ratios - smaller is better (wear rate)

Level	Load	Speed	SiC
1	3.307	1.23	9.496
2	7.69	8.837	5.894
3	13.414	10.191	2.407
Delta	16.722	11.421	7.089
Rank	1	2	3

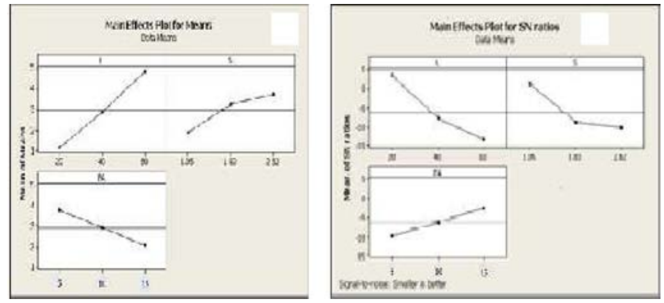

Fig.4.2: (a) Means of Wear Rate, (b) Means of S/N Ratios

4.1.2.2. Anova and Effects of Parameters Rate on Wear

Analysis of Variance (ANOVA) was used to determine the design parameters significantly influencing the wear rate (response). The table shows the results of ANOVA for wear rate. This analysis was evaluated for a confidence level of 95%, that is for significance level of α=0.05. The last column of Table 4.3 shows the percentage of contribution (P %) of each parameter in the response, indicating the degree of influence on the result.

Table 4.3: ANOVA Results for Wear Rate

Source	DF	Seq SS	Adj SS	Adj MS	F	P	P (%)
Load, N (L)	2	62.0034	62.0034	31.0017	262.410	0.000	65.05
Speed, m/s (S)	2	17.1340	17.1340	8.5670	72.520	0.000	17.98
SiC, wt% (F)	2	13.0396	13.0396	605198	55.190	0.000	13.68
LXS	4	0.4796	0.4796	0.1199	1.010	0.454	0.50
LXF	4	1.5645	1.5645	0.3911	3.310	0.070	1.64
SXF	4	0.1481	0.1481	0.0370	0.310	0.861	0.16
Residual Error	8	0.9451	0.9451	0.1181			0.99
Total	26	95.3144					100.00

Notes: DF, Degrees of freedom; Seq SS, Sequential sum of squares; Adj SS, Adjusted sum of squares; Adj MS, Adjusted mean squares; P, Percentage of contribution.

S = 0.3437 R-Sq = 99.0% R-Sq (adj) = 96.8%

It can be observed from the results obtained in the Table 4.3, that load was the most significant parameter having the highest statistical influence (65.05%) on the dry sliding wear of composites followed by sliding speed (17.98%) and SiC content (13.68%). When the P-value for this model was less than 0.05, then the parameter or interaction can be considered as statistically significant

This is desirable as it demonstrates that the parameter or interaction in the model has a significant effect on the response. From an analysis of the results obtained in Table 4.2, it is observed that the load (L), sliding speed (S), SiC content (F), the interaction effect of load with SiC content (L*F) is significant model terms influencing wear rate of composites, since they have obtained the P - value < 0.05. Although the interaction effect of load with sliding speed (L*S) exerts some influence on the dry sliding wear, it may be considered

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statistically insignificant for its P-value is greater than 0.05, and hence it is neglected. The coefficient of determination (R^2) is defined as the ratio of the explained variation to the total variation.

It is a measure of the degree of fit. When R^2 approaches unity, a better response model results and it fits the actual data. The value of R^2 calculated for this model was 0.99, i.e., very close to unity, and thus acceptable. It demonstrates that 99.0% of the variability in the data can be explained by this model. Thus, it is confirmed that this model provides reasonably good explanation of the relationship between the independent factors and the response.

4.1.2.3. Multiple Linear Regression Model

A multiple linear regression analysis attempts to model the relationship between two or more predictor variables and a response variable by fitting a linear equation to the observed data. Based on the experimental results, a multiple linear regression model was developed using MINITAB 15. A regression equation thus generated establishes correlation between the significant terms obtained from ANOVA, namely, load, sliding speed, SiC content and their interactions. The regression equation developed for wear rate is:

$$Wear = - 2.14 + 0.115\, L + 1.19\, S - 0.135\, FA - 0.00371\, L * F \quad \text{-------------} \ (2)$$

The above equation can be used to predict the wear rate of the hybrid composites. The constant in the equation is the residue. The regression coefficient (R^2) obtained for the model was 0.959 and this indicates that wear data was not scattered. The coefficient associated with load (L) in the regression equation is positive and it indicates that as the load increases, the wear rate of the composite also increases. The coefficient associated with sliding speed (S) in the regression equation is also positive and this suggests that the wear rate of the composite increases with increasing sliding speed. It can be inferred from the negative value of the coefficient associated with SiC content (F) in the regression equation that as the weight percentage of SiC content increases, wear rate of the composite reduces. SiC metal matrix composites fabricated by powder metallurgy.

The wear resistance of hybrid composite has increased due to the increase in the weight fraction of SiC. The increased area fraction of hard SiC particles, improved the load carrying capacity and the abrasion resistance of composites. 9 wt% SiC reinforced hybrid composite exhibit, the lowest wear rate at all loads and sliding speeds. The other interaction effects indicated in the equation was marginal.

4.1.2.4. The Confirmation Test

In order to validate the regression model, confirmation wear tests were conducted with parameter levels that were different from those used for analysis. The different parameter levels chosen for the confirmation tests are shown in Table 4.4. The results of the confirmation test were obtained and a comparison was made between the experimental wear rate values and the computed values obtained from the regression model (Table 4.5). The error associated with the relationship between the experimental values and the computed values of the regression model for hybrid composites was very less (around +/- 7% error).

Hence, the regression model developed to demonstrate a feasible and effective way to predict the wear rate of the hybrid composites.

Table 4.4: Parameters used for confirmation tests

Test No.	Load, N (L)	Speed, m/s (S)	SiC, wt% (F)
1	20	1.05	5
2	40	1.83	10
3	60	2.62	15

Table 4.5: Confirmation test results

Test No.	Experimental Wear Rate (kg/m × 10-5)	Regression Model Predicted Wear Rate, (kg/m x 10-5)	Error (%)
1	0.2935	0.2787	5.04
2	2.0735	2.2122	-6.69
3	3.8589	3.7005	4.10

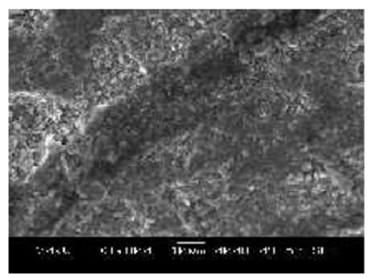
4.1.3. Wear Surface Studies Using SEM

For the wear study following wear test specimens were selected

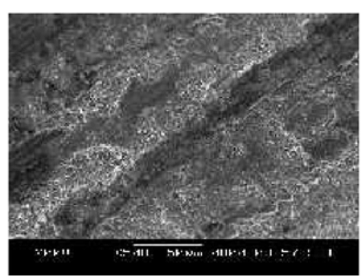
(a) Al-5% SiC composite
(b) Al-10% SiC composite
(c) Al-15% SiC composite

The below figure shows the scanning electron micrograph of worn surfaces of different composition Al6061 – SiC composite. A transfer layer of compacted wear debris along with the wear tracks can be observed over the sliding surface. This layer reaches a critical thickness before being detached resulting eventually in generation of wear debris. The extent of cover provided by this transfer layer is determined by the load, sliding speed and it increases with increasing load because of the increased frictional heating and hence better compaction.

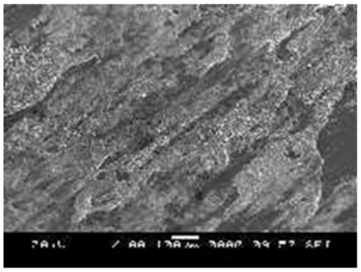
Representative SEM diagrams from the wear surfaces of Al-5% SiC composite are presented in Figure 4.3. The Figure 4.3 (a),(b) & (c) provides overall view of wear pattern at 1000 X, 500 X & 100 X respectively. And similarly Al-10% SiC and Al1-5%SiC composites are presented in Figure 4.4 and 4.5 respectively.



(a)

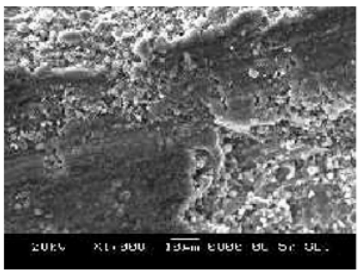


(b)

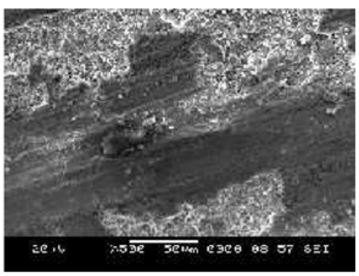


(c)

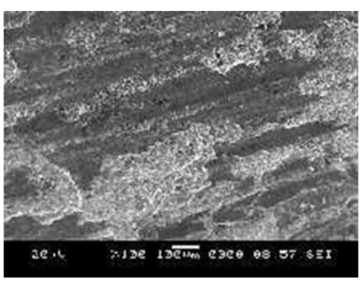
Fig.4.3: Scanning Electron Micrographs of worn surfaces of Al- 5% SiC.



(a)

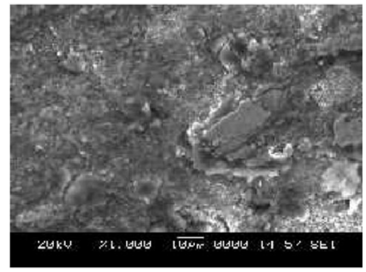


(b)

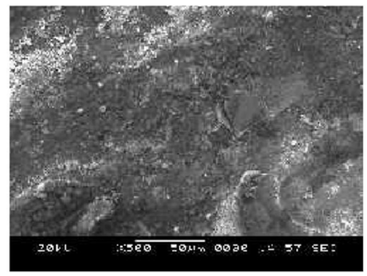


(c)

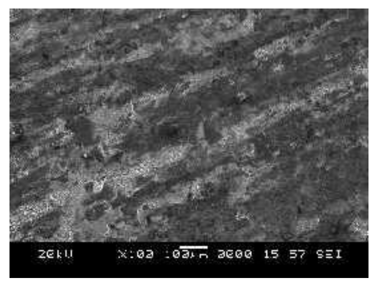
Fig.4.4: Scanning Electron Micrographs of worn surfaces of Al- 10% SiC.15%



(a)



(b)



(c)

Fig.4.5: Scanning Electron Micrographs of worn surfaces of Al- 15% SiC

5. CONCLUSIONS

The experimental study reveals following conclusions

1. The present work shows that successful fabrication of Al6061-SiC composites with different composition is possible by powder metallurgy technique.

2. In this work hardness test has done for different composition of Al6061-SiC composite and the higher Rockwell hardness number of Al6061-5% SiC composite observed is 23.

3. The wear rate increases with the increase in normal load. However, the composites have shown a lower rate of wear (up to 15% SiC) as compared to that observed in 5 and 10% SiC.

4. SEM analysis as done for different composition like 5, 10 & 15% of SiC clearly observed at an 5% of SiC refined grain structure for respective composites.

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