© Applied Science Innovations Pvt. Ltd., India Carbon – Sci. Tech. 9/1 (2017) 7-16

Carbon – Science and Technology

ISSN 0974 – 0546

http://www.applied-science-innovations.com

RESEARCH ARTICLE Received: 03/11/2016, Accepted: 13/02/2017

Effect of particle size, load and speed on the dry sliding wear behavior of Aluminium 8011 - SiC composites

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Abstract: In this paper, effect of load, sliding speed, and particle size on the wear behavior of the Al alloy 8011 –SiC composites was evaluated by pin-on –disc wear test rig. Three different particle sizes of SiC (150, 180, 220 mesh) with weight fraction of 6 % reinforced with Aluminium alloy 8011 were fabricated using the stir casting method. Dry sliding wear test was conducted for 10 minutes, three different loads (10, 20, and 30 N) and three different sliding speeds (200, 300, and 400 rpm) to find the wear loss of the composites. Taguchi and ANOVA techniques were used to analyze the contribution of factors on the wear of the composites. From the results it was seen that with the increase in load and sliding speed the wear loss increases. Wear loss is observed more in the Al 8011-SiC composites reinforced with fine particles than the coarse particles. Load is the most prevailing factor followed by sliding speed, and particle size inducing the wear loss of composites.

Keywords: Load, Sliding speed, Particle size, Taguchi, ANOVA

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1 Introduction: Aluminium matrix composites are widely used in industries especially automobile and aerospace, where the tribology is applied. SiC reinforced aluminium matrix composites are mainly applied into the production of engine blocks, brakes, pistons, cylinders, and power transmission elements in automobile. Wear can be defined as deformation and removal of material on a surface as a result of mechanical action between the surfaces. Wear resistance of the composites is influenced not only by load and sliding speed but shape, size, weight fraction of reinforcement particles and properties of matrix. Aluminium alloy 8011 is the main material for the production of heat exchanger. The wear test was conducted on the T6 Al alloy aged for 2 hrs, 6 hrs and T6 Al alloy. Load was the most dominant factor for the wear resistance followed by heat treatment and sliding speed [1]. The effect of addition of SiC on the wear behavior of aluminium matrix composites was analyzed by Rao and Das. When the SiC content increases, the wear rate and coefficient of friction decreases [2]. Dry sliding wear behavior of SiC and SiC-Gr-reinforced Al 6061 composites was investigated by Mahdavi et al. They concluded that coarse SiC particles reduce the coefficient of friction of the composites [3]. The wear behavior of Al2024 with the reinforcement of different particle sizes of SiC (3.5, 10, 20 μm) was analyzed. The results reveal that wear resistance of the composite decreases for the decrease in particle size [4]. Dry sliding wear test was performed on the Al composite reinforced with fly ash of different particle sizes fabricated by stir casting technique. The reinforcement of larger particle exhibits greater wear resistance than the smaller particles [5]. The effect of particle size and amount of alumina on the mechanical properties and microstructure of Al matrix composites was investigated by Mehdi Rahimian et al. Their result showed that mechanical properties like hardness, yield strength, compressive strength, and ductility increases for the reinforcement of smaller particle size of alumina with Al matrix composites, but the wear loss increases for the composites [6]. Tribological behaviour of Al 7075-Al_2O_3 composites for the reinforcement of three different particle sizes of alumina (63,103,165 μm) for three different sliding velocities (0.837, 1.674, 2.512 m/s) and load was conducted by Shanmughasundaram. He concluded that Composites reinforced with coarse alumina particles exhibit maximum wear resistance. Load is the most dominant factor on wear loss and coefficient of friction of composites followed by sliding velocity and particle size [7]. Wear test was performed on Al6061 reinforced with Al2O3, B4C.Ti3Al and B2Ti in varying volume fraction from 5 % to 15 %. Mechanically mixed layer is formed in all the composites but not in the unreinforced alloy [8]. Composites exhibit higher wear resistance at lower load than the higher load [9]. Wear resistance of Al6061- Al_2O_3 composites increases due to the strong bonding between alumina reinforcement particles and Al 6061 matrix [10]. Fly ash particle size and its volume fraction significantly affect the wear and friction properties of composites [11]. Wear test on Al 2024-alumina composites was conducted by Hosking et al. Their result shows that as the particle size of alumina increases the wear loss decreases, the same was obtained with the increase in volume fraction of alumina [12]. Dry sliding wear behavior of Al composites was conducted by Qin et al. They concluded that wear rate of the composite increases with increase of load and the sliding speed [13]. Wear behaviour of hybrid composites with the addition of SiC of two different sizes was analyzed and reported that wear rate decreases for the composite with the addition of larger particle size of SiC at low speed. At higher speed there was not much change in wear resistance because of the particle size [14]. Mechanical properties of AA 6061-MICRAL-20™ (alumina and mullite) composites were investigated by Park et al. [15]. The effect of particle size of rice husk ash on the tribological behavior of rice husk ash - reinforced aluminum alloy (AlSi 10 mg) matrix composites was conducted and reported that the reinforcement of coarse husk particles exhibit superior wear resistance than the fine husk particles [16]. Experiment on the mechanical properties of Copper/Copper Coated Silicon Carbide Composites by ball milling method was performed and reported that higher hardness and higher compressive yield strength, lower coefficient of thermal expansion, higher thermal conductivity, and lower porosity were obtained for the silicon carbide coated composites [17]. The effect of addition of SiC particle in the Al-Zn-Mg-Cu alloy was analyzed by Rupa Dasgupta et al. They proved that there is improvement in mechanical property and wear resistance as a result of heat treatment and forming composites by the addition of 15 % of SiC [18]. Mechanical properties of Al7075-SiC Composites was performed and reported that tensile strength increases as a result of addition of SiC particles [19]. The results of the experiment on the tribological behavior of Al7075 T6-SiC, Al 6061 T6-Al_2O_3 composites, shows that composite exhibit superior wear resistance than the unreinforced alloy [20]. The effect of matrix particle size, reinforcement particle size and volume fraction on the wear behavior of Al-SiC C composites was analyzed by Ege Anil Dier et al. [21].

From the above results, it was noted that load, sliding velocity and particle size plays a major role on the wear loss of the composites. Hence, a methodical study has to be done to analyze the influence of load, sliding speed and particle size on the wear behavior of the composites. In this present research, dry sliding wear test on Al8011-SiC composites with the reinforcement of three different particle sizes of SiC (150, 180, 220 mesh) with three different load (10, 20, 30 N) and sliding speeds (200, 300, 400 rpm) was conducted using pin-on disc wear testing rig. Composites were fabricated using stir casting method. Taguchi and ANOVA techniques were used to analyze the wear behavior of composites.

2. Materials and Methods

2.1 Stir Casting method: Al 8011 was used as the matrix material and SiC particle of three different sizes 150 mesh (coarse), 180 mesh (intermediate) and 220 mesh (fine) were used as reinforcement to produce composites by stir casting method (Figure 1).

Composites were produced with 6 % weight fraction of SiC. Composition of Al 8011 is Al = 97.14 %, Si = 0.53 %, Fe = 0.99 %, Cu = 0.27 %, Mn = 0.21 %, Mg = 0.25 %, Cr = 0.049 %, Zn = 0.19 %, Ti = 0.028 %, Pb = 0.10 %, Ca = 0.008 %, Ni = 0.045 %. Aluminium alloy was obtained from the supplier in as – cast condition. SiC particles were preheated to remove the moisture content. Hexachloroethane tablets were used for degassing and argon gas was used to prevent oxidation during melting. AL alloy was charged in to the crucible and the furnace temperature was raised up to liquidus temperature in order to melt the Al scraps completely. Stirring was started and preheated SiC particles were added.1.5 wt. % magnesium was added into the molten Al to promote the wetting action between Al and SiC particles. Finally melt was poured into the mould for solidification.

Figure (1): Stir casting method.

2.2. Experimentation

Dry Sliding Wear Test: Pin-on-disc apparatus which is shown in Figure (2) was used to conduct dry sliding wear test. Test specimens were made cylindrical with 10 mm diameter and 25 mm height and surfaces of the pin were polished using emery sheet. The rotating disc was made up of EN 32 steel with 100 mm track diameter, 8 mm thick and with hardness of 65 HRC.

Figure (2): Pin-on-disc apparatus.

The wear loss was measured in terms of microns using the LVDT (Linear Variable Differential Transformer). The wear test was conducted for 10 minutes. The average of the three test readings were taken into consideration. The room temperature was 29 ºC and 60 % relative humidity. Three parameters such as mesh size (A), Load (B) and sliding speed (C) were chosen. Three levels were selected for each parameters, Mesh size (150, 180, 220), load (10, 20, 30) and sliding speed (200, 300 and 400 rpm).

2.3. Statistical analysis: Taguchi method: Taguchi method is a systematic method to find the performance of the process parameters which will give the desired output. In this study, "smaller is better" S/N ratio was taken to find the best parameter which causes wear loss. The wear loss was considered to be minimum. Mathematical equation of the S/N ratio for smaller is better is represented by the equation (1)

$$\frac{S}{N} = -10 Log\left(\frac{1}{n}\sum_{i}\frac{1}{Y_i^2}\right) \quad (1)$$

where, Y is the observed data and n is the number of observations, L27 Orthogonal array was used and wear test was carried according to the array 27 tests were conducted and each test was repeated thrice and mean was taken to reduce errors. The corresponding wear loss and S/N ratios are shown in Table (1).

3. Results and discussion: It can be observed from the from the response diagram of S/N ratio (Figure. 3), that the optimum level of parameters were 150 mesh size, load (10 N) and sliding speed (200 rpm). ANOVA was performed with the help of the MINITAB15 software package. ANOVA analysis is presented in Table (2). The p-value is used to test the significance of each parameter. When the value of p-value is less than 0.05 it indicates that the parameter is highly significant at 95 % confidence level. The last column of the Table (2) shows the percentage contribution of controlling parameters on the wear loss. It was observed that the load (44.49 %) was the major contributing factor followed by Sliding speed (32.32 %) and mesh size (14.05 %) influencing wear loss. From the Figure (4) it is observed that wear loss increases when the load increases .The wear loss increased to 70 µm from 45 µm for constant sliding speed of 400 rpm when the load was increased from 10 to 20 N. Wear loss was found to be increased by 55 %.

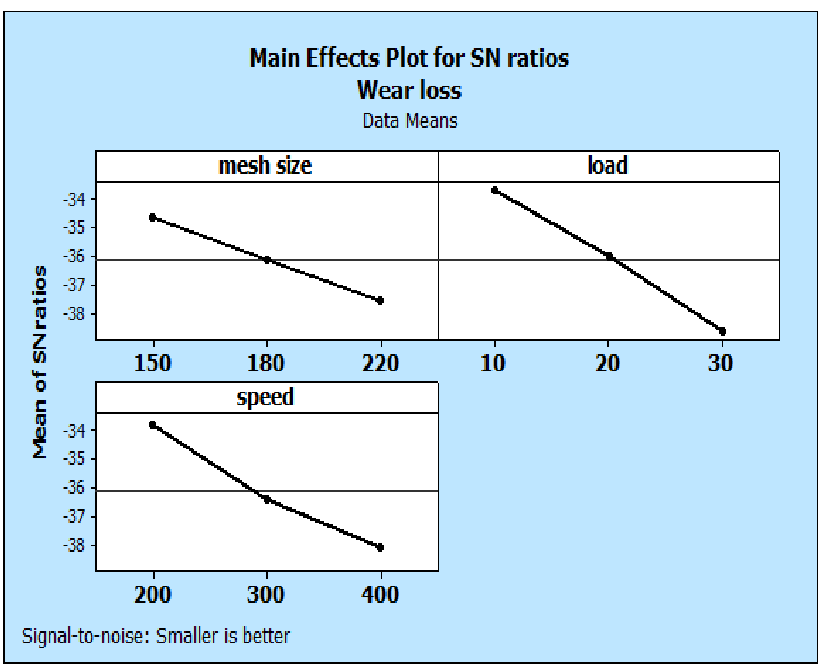

Figure (3): Response diagram for signal to noise (S/Ns) ratios.

Table 1: Measured values and S/N ratios for wear.

Exp.No	Parameters			Values	
	Mesh Size (A)	Load, N (B)	Sliding Speed, rpm (C)	Wear (μm)	Signal/ Noise Ratio
1	150	10	200	35	-30.8814
2	150	10	300	40	-32.0412
3	150	10	400	45	-33.0643
4	150	20	200	40	-32.0412
5	150	20	300	60	-35.563
6	150	20	400	70	-36.902
7	150	30	200	49	-33.8039
8	150	30	300	80	-38.0073
9	150	30	400	96	-39.6454
10	180	10	200	40	-32.0412
11	180	10	300	52	-34.3201
12	180	10	400	60	-35.563
13	180	20	200	49	-33.7148
14	180	20	300	66	-36.3909
15	180	20	400	76	-37.6163
16	180	30	200	62	-35.8478
17	180	30	300	86	-38.69
18	180	30	400	110	-40.8279
19	220	10	200	44	-32.8691
20	220	10	300	58	-35.2686
21	220	10	400	72	-37.1466
22	220	20	200	60	-35.563
23	220	20	300	72	-37.1466
24	220	20	400	90	-39.0849
25	220	30	200	76	-37.6163
26	220	30	300	102	-40.172
27	220	30	400	142	-43.0458

Table (2): ANOVA analysis for wear.

Factor	DoF	SS	F-Value	P-Value	Percentage,%
Wear					
Mesh Size(A)	2	2271.80	84.74	0.000	14.05
Load, N (B)	2	7189.80	268.17	0.000	44.49
Sliding Speed, rpm (C)	2	5223.46	194.83	0.000	32.32
Mesh Size*Load (A * B)	4	242.31	4.52	0.033	1.49
Mesh Size*Speed (A * C)	4	182.31	3.40	0.066	1.12
Load*Speed (B * C)	4	941.65	17.56	0.001	5.82
Error	8	107.24			0.66
Total	26	16158.57			100

DOF- Degrees of Freedom; Seq. SS- Sequential sums of squares;

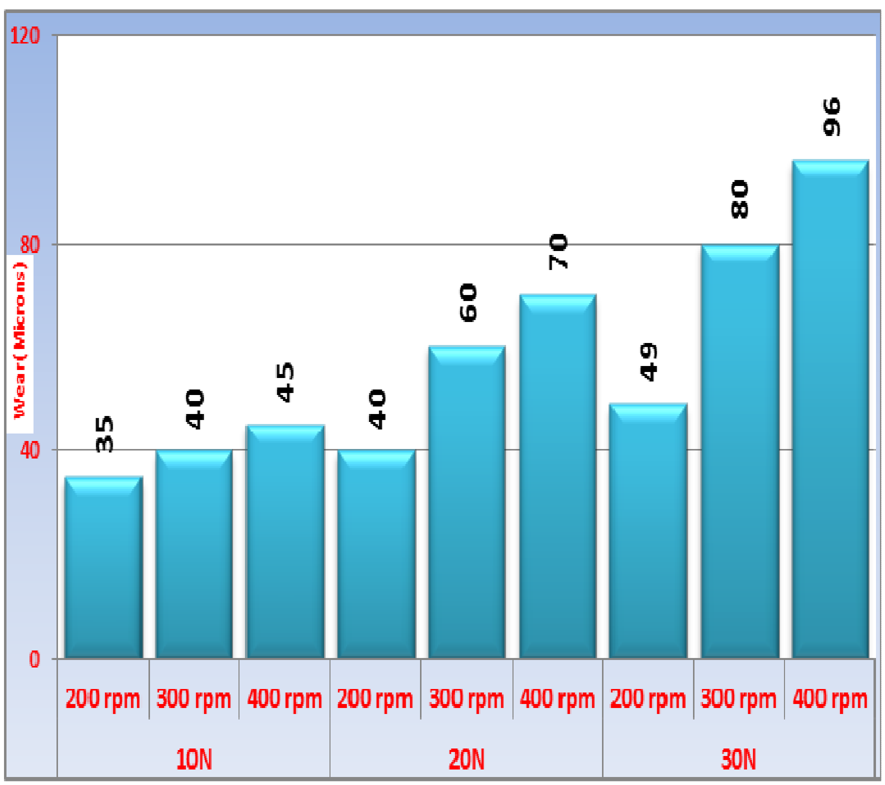

Figure (4): Effect of load and sliding speed and 150 mesh particle size on the wear loss of Al8011-SiC composites.

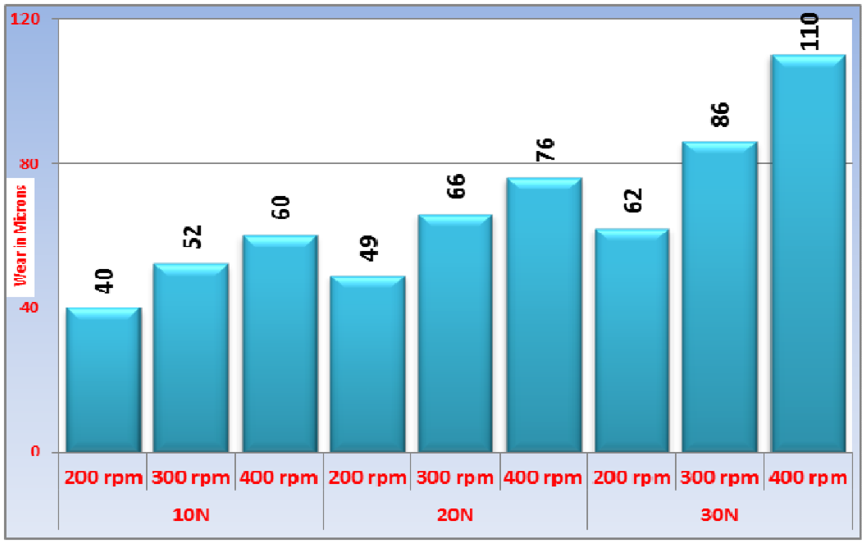

Figure (5): Effect of load and sliding speed and 180 mesh particle size on the wear loss of Al8011-SiC composites.

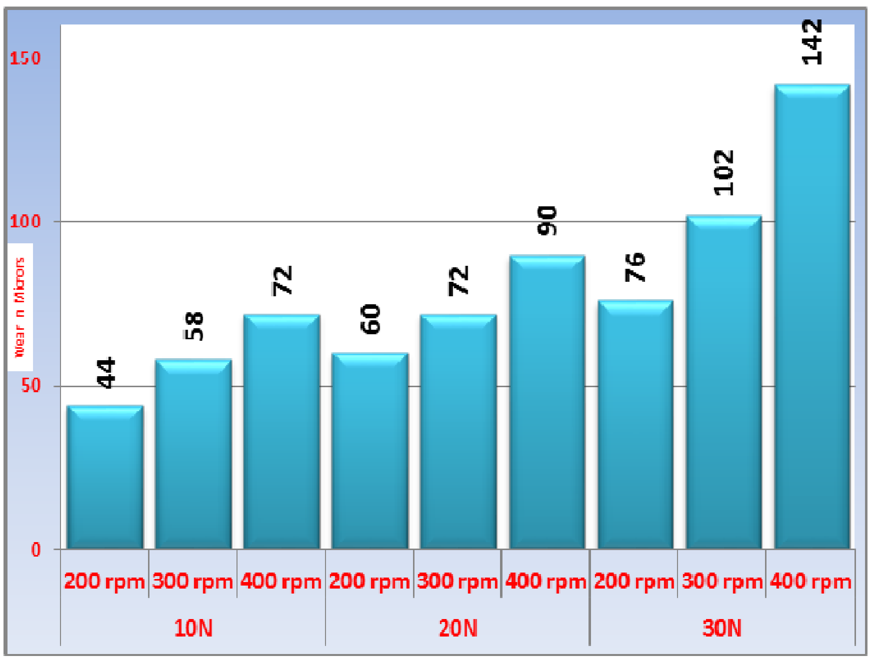

Figure (6): Effect of load and sliding speed and 220 mesh particle size on the wear loss of Al8011-SiC composites.

From Figure (4 and 5), It is clear that as the mesh size increases the wear loss increases. Composites fabricated with coarse particles (150 mesh) have less wear loss when compared to intermediate particles (180 mesh). The wear loss increased from 96 µm to 110 µm for the constant speed (400 rpm) and constant load (30 N). When the mesh size was increased from 150 to 180, it can be noted approximately 15 % increase in wear loss. Similar condition was observed from the Figure (6), the wear loss increased for the increase in sliding speed and increase in the applied load .For the constant load 10 N the wear increases to 44 µm from 72 µm when the sliding speed increases from 200 to 400 rpm. Wear loss was found to be increased by 64 %. The increase in sliding velocity causes increase in temperature due to this adhesion increases at the sliding contact.

When the load increases the wear loss increases, regardless of the sliding speed and mesh size of the SiC particles. It was also noted from the results that composites fabricated with 150 mesh size (coarse SiC) particles offer higher wear resistance than the 180 mesh size (intermediate SiC) particles and 220 mesh size (fine SiC) particles. The effect of load and sliding speed on the wear loss of the composites was different for smaller and larger particles. The larger particles have higher wear resistance due to their resistance against penetration of pin over the surface. Because of their good bonding with the matrix they bear most of the applied load. Result indicates that particle size is one of the major parameter which affects the wear resistance. Coarse reinforcement particles in the aluminium metal matrix composites exhibit lower wear loss. These results are in line with work done by Mahdavi and Akhlaghi **[3]**. The load is the most important controlling factor affecting the wear loss followed by sliding speed then followed by the particle size was concluded by Shanmughasundaram **[1]**.

3.1 Multiple linear regression model: Multiple linear regression equations were used to find the correlation concerning the factors and response. The value of regression coefficient, R^2 (0.993) is in good agreement with the adjusted R^2 (0.978) for wear loss of the Al8011-SiC composites. It can be observed that the values of regression coefficient R^2 and adjusted R^2 are close to each other.

The regression equation developed for wear loss of Al8011-SiC composite is given by

$$Wear = -81.5 + 0.320\ mesh\ size + 1.98\ load + 0.170\ speed. \qquad (2)$$

It was observed from the Equation (2) that the coefficients associated with load and sliding speed are positive. It indicates that the wear loss of the composites decreases with decreasing applied load and sliding speed. Wear resistance increases with decrease in mesh size of the SiC particle (150 mesh).

3.2 Confirmation test: Parameters used in the confirmation experiments is given in the Table.3 and results are displayed in the Table (4). Result curves of wear loss of Al8011-SiC composites obtained from the dry sliding wear test rig for duration of 10 minutes are shown in Figure (7 and 8). The experimental values of the wear loss of the composites and calculated values obtained from the regression equation are almost the same with least error (± 5 %). It is confirmed that the wear loss of the composite can be predicted from the resulting equations.

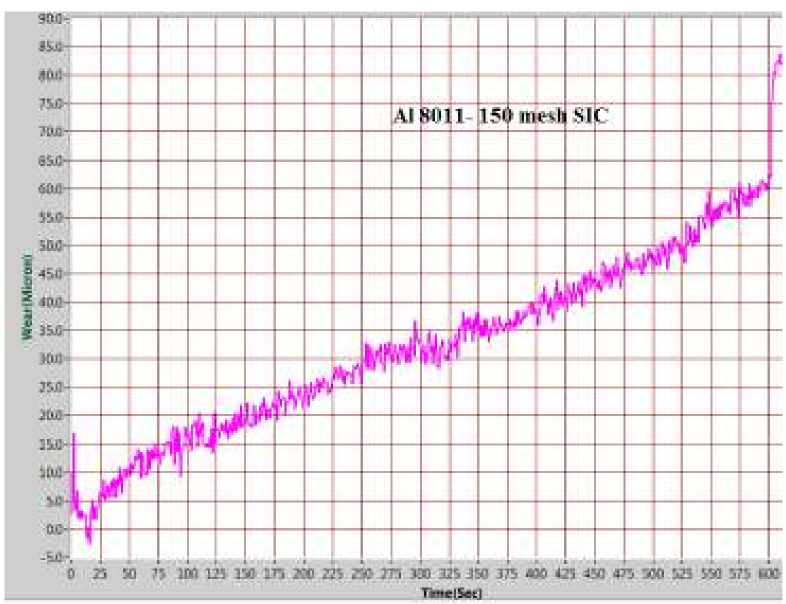

Figure (7): Typical wear curve of Al 8011-150 mesh SiC at a speed of 300 rpm, 25 N.

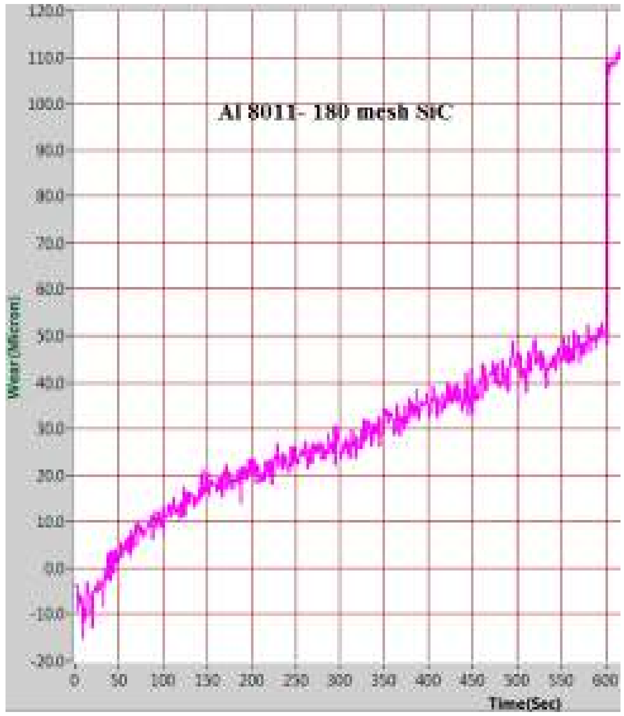

Figure (8): Typical wear curve of Al 8011-180 mesh SiC at a speed of 250 rpm, 15 N.

Table (3): Parameters used in the confirmation test.

Level	Mesh Size (A)	Load, N (B)	Sliding Speed, rpm (C)
I	150	25	300
II	180	15	250

Table (4): Results of confirmation tests.

Test I			Test II		
Wear Loss					
Model equation	Expt.	Error %	Model equation	Expt.	Error %
67	64	4.47	48.3	50	-3.51

4. Conclusion: Optimal conditions for attaining minimum wear loss were obtained using Taguchi S/N ratio analysis. It was observed that as the load and sliding speed increases the wear loss increases. Taguchi method result shows that the optimum parameters were load (10 N), sliding speed (200 rpm) and mesh size (150) in minimizing the wear loss of the composites. The ANOVA result indicates that applied load was the major dominant factor on the wear loss of the composites followed by sliding speed and particle size. The wear loss of the composites was mainly influenced by the applied load which accounts for (44.49 %), followed by sliding speed (32.32 %), the particle size (14.05 %) of the total effect. From the result, it was observed that composites reinforced with coarse SiC particles carry greater portion of the applied load than the fine and intermediate SiC particles.

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