Mechanics and Mechanical Engineering
Vol. 21, No. 1 (2017) 85–93

Effect of Temperature, Load and Sliding Velocity on the Wear Behavior of AA7075–SIC Composites

P. Shanmughasundaram
Department of Automobile Engineering
Karpagam University
Coimbatore-641021, India
sunramlec@rediffmail.com

Received (13 October 2016)
Revised (19 November 2016)
Accepted (25 December 2016)

Dry sliding wear behavior of a aluminum matrix reinforced with SiC composite was investigated under three different temperatures (30^{o}C, 60°C, 90^{o}C), three different load and sliding velocities against a EN 32 carbon steel counter face. Results showed that load and temperature have significant effect on the wear loss. Wear resistance of the composites decrease with temperature, load and sliding velocity within the observed range. Taguchi method was used to find the significance of the parameters. Analysis of variance (ANOVA) was used to investigate the influence of parameters on the wear resistance. It was found that the load was the most dominant factor influencing the wear followed by temperature and sliding velocity.

Keywords: dry sliding wear, temperature, load, sliding velocity, Taguchi, ANOVA.

1. Introduction

A large number of aluminium metal matrix ceramic reinforced composites are being developed for high performance materials in engineering applications particularly in automotive and aerospace industries. The tribological behavior of Al alloy reinforced with SiC composites has been extensively investigated by various researchers. Wear is a removal of material from the surface of the component during relative motion with the other component. The tribological properties can be varied substantially through changes in the microstructure, the morphology, volume fraction and mechanical properties of the reinforcing phase, and the nature of the interface between matrix and reinforcement [1]. Singh and Alpas [2] investigated the dry-sliding wear behavior of a particulate–reinforced aluminum matrix composite 6061 Al-20% $A1_2O_3$ and an unreinforced 6061 Al alloy in the temperature range 25°C to 500°C against a SAE 52100 bearing steel counter face. They reported that in the mild wear regime, the wear rate and the coefficient of friction of the unreinforced 6061 Al decreased slightly with temperature, but the temperature had almost no effect on the wear rate and the coefficient of friction of the 6061 Al-20% Al_2O_3 in the same regime. Faranak Farhadinia and Arman Sedghi [3] investigated the effect of sliding distance, hybrid reinforcement content and temperature on the dry sliding wear behaviour of $Al/(Al_2O_3 + ZrB_2 + TiB_2)$ hybrid composite. They reported that the hybrid composites have higher wear resistance than pure aluminium and Al/Al_2O_3 composites at room temperature and 300°C. Michael Rajan et al [4] investigated aluminum alloy AA7075 reinforced TiB_2particulate composites which were prepared by the in situ reaction of K2TiF6 and KBF4 to molten aluminum. The sliding wear behavior of the AMCs was evaluated using a pin-on-disc wear apparatus. The effect of TiB_2 particulate content (0, 3, 6 and 9 wt %) and temperature (30, 60, 90, 120, 150, 180, 210 and 240°C) on wear rate was studied. The results indicated that TiB_2 particles were effective to enhance the wear resistance of the AMCs at all test temperatures. The wear rate of the AMCs increased when the applied temperature was increased. Hui et al [5] investigated the high temperature friction and wear properties of the composites at a constant sliding velocity of 1.57 m/s and load of 50 N as well as a sliding distance of 942 m. The results showed that the hybrid composites reinforced with Al_2O_3 and carbon fibres attained superior wear resistance over the entire range of test temperatures. The dominant wear mechanisms shifted to severe adhesion at test temperatures above the critical transition temperature. Natarajan et al [6] investigated the dry sliding wear behaviour of the prepared composite by using a Pin -on -Disc test rig at different applied loads of 9.8, 19.6 and 29.4 N for various temperatures (100, 200 and 300°C). The study at room temperature was also carried out for comparison purpose. The results indicated that the wear rate decreases with the increase in the weight percentage of TiB_2, while it increases with the increase in the applied load. The dry sliding wear test at higher temperature showed that the wear resistance of TiB_2 reinforced composite was higher than those for the unreinforced matrix alloy at all test temperatures. Mahdiar Valefi et al [7] conducted the wear tests using an alumina ball sliding against 5wt% copper oxide doped tetragonal zirconia polycrystalline (CuO-TZP) ceramics as a function of temperature up to 700°C. They reported that the specific wear rate and friction coefficient are strongly dependent on temperature. Kumar et al [8] investigated the effect of temperature and load on the wear behavior of Al–4Cu alloy and Al–4Cu–TiB_2 in situ composites. The wear resistance of the Al–4Cu alloy increased with increase in wt. % of reinforcement TiB_2 particles at all temperatures and loads. It was observed that at elevated temperature the predominant wear mechanisms for the Al–4Cu alloys are adhesion and metal flow, whereas for Al–4Cu–TiB_2 composites oxidation, delamination and metal flow are the most dominant wear mechanisms. Hernandez et al [9] studied the high temperature friction and wear mechanism map for tool steel and boron steel tribopair. They reported that the friction coefficient decreases as both temperature and load are increased as a result of the formation of a protective layer. The formation of stable wear protective layers on the tool steel surface was noticed at temperatures above 200°C. Mousavi Abarghouie and Seyed Reihani [10] investigated the friction and wear behaviors of 2024 Al and 2024 Al/SiCp composite at elevated temperatures range of 20–250°C. Dry sliding wear tests were conducted at a constant sliding velocity of 0.5 m/s, an applied load of 20 N, and a sliding distance of 2500 m using a pin-on-disc apparatus. The SiC particles led to an increase in the critical transition temperature and in the severe wear regime, they caused a considerable improvement in the wear resistance. Gómez-del Río et al [11] analyzed the temperature and velocity transitions in dry sliding wear of Al–Li/SiC composites. Transition between mild and severe wear has been observed in Al-8090 aluminium alloy and Al-8090–SiC composite. Dheerendra Kumar Dwivedi [12] performed wear and friction tests under dry sliding conditions using pin on disc type of friction. It was found that sliding interface temperature has close relation with wear and friction response of these alloys. Initial rise in interface temperature reduces the wear rate and as soon as a critical temperature (CT) is crossed, wear rate abruptly increases in case of all the compositions used in this investigation. Friction coefficient during the sliding of all aluminium alloys (irrespective of silicon content) first decreases with the rise in interface temperature and then abruptly increases beyond certain critical temperature. Rajaram et al [13] studied high temperature tensile and wear behaviour of aluminum silicon alloy at various temperatures from ambient to 350°C. Al–Si alloy was fabricated by stir casting technique. The increase in wear resistance of Al–Si alloy with increasing temperature was observed from wear tests. The oxidational wear was predominantly occurred during sliding.

From the literature review, it was understood that there is no clear understanding in the literature regarding the contribution of temperature, load and sliding velocity on the wear resistance of the composites. Hence this work aims to find the influence of the parameters on the wear resistance under three different temperatures (30°C, 60°C, 90°C), three different load and sliding velocities against a EN 32 carbon steel counter face using Taguchi and Analysis of Variance (ANOVA).

2. Materials and fabrication of Composites

Composites are fabricated using stir casting furnace which is shown in Fig.1.

Figure 1 Stir casting furnace

Figure 2 Pin on disc wear test rig

AA 7075 was used as the matrix material and SiC particles with an average size of 120 μm were used as the reinforcement material. AA 7075 was charged into the crucible and the melt temperature was raised to liquidus temperature of aluminium alloy. Preheated SiC (10wt.%) particles were incorporated into the molten aluminium gradually and stirring was carried out at 200 rpm for 3 minutes. Then, the melt temperature was dropped till the slurry reaches the semi solid state. Stirring was done for 3 minutes in semi solid state in order to enhance the homogeneous distribution of the SiC particles in the Al matrix. Finally the melt temperature was raised to liquids temperature and composite melt was poured into the mould.

3. Dry sliding wear test

Dry sliding wear test specimens (6mm diameter and 25 mm height) were prepared and specimens were polished prior to testing. Wear tests were carried out on a pin–on–disc wear test rig according to ASTM G99 standard. A schematic wear test rig setup is shown in Fig. 2. The wear tests were performed for the three different normal loads (30 N, 60 N and 90 N), three different sliding velocities (1 m/s ,2 m/s and 3 m/s) at three different temperatures (30°C, 60°C and 90°C) for a constant duration of 10 minutes. Relative humidity of air is 55%. The wear track diameter was fixed as 70 mm and the speed of the disc was maintained for attaining desired sliding velocities. Prior to the tests, surface temperature of the specimen was maintained to the desired temperature. The wear loss (μm) which is the height loss of the pin during sliding, coefficient of friction and frictional force experienced by the pin was measured continuously. The data is received, displayed and stored on the computer using "Magnum Data Acquisition Software".

4. Results and discussion

Fig. 3 shows the effect of temperature; load and sliding velocity on the wear resistance of AA 7075 SiC – composites. When the load was increased from 20 N to 40 N at a sliding velocity of 3.142 m/s and temperature of 30°C, wear increased by 59% i.e., 49 μm to 120 μm. It can also be inferred from the Figure 3 that the wear of composites decreases with increase in sliding velocity. It can also be noted that the wear increased considerably (17%) when increasing the sliding velocity from 1.571

m/s to 3.142 m/s at a constant load of 40N and temperature 90°C. The wear loss increases almost linearly with the applied load, irrespective of the sliding velocity at constant pin temperature. The results showed that the wear resistance tends to decrease with an increase in load, sliding velocity and temperature of the materials.

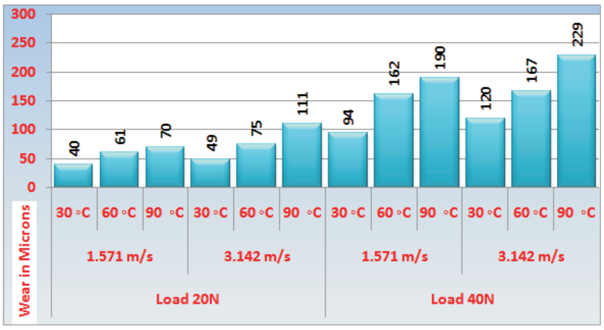

Figure 3 Effect of temperature, load and sliding velocity on wear of AA 7075 – SiC composite

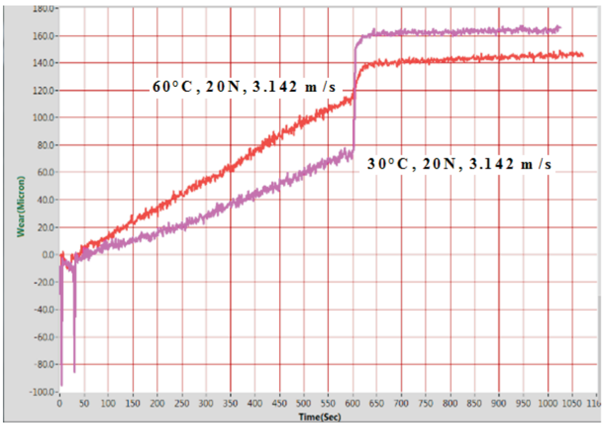

Figure 4 Effect of temperature on wear of AA 7075 – SiC composite

Fig. 4 shows the effect of temperature on wear of AA 7075 – SiC composite. It can be seen that wear loss was observed to be higher when the temperature of the pin was increased from 30°C to 90°C irrespective of load and velocity conditions. It can be noted from the Fig. 4 that when the temperature was increased from 60°C to 90°C at a sliding velocity of 3.142 m/s and load of 20 N, wear increased from 75 μm to 111 μm. As the temperatures of the pin increases, the material becomes softer and hence wear resistance tend to decrease thereby more material is removed from the wear surface.

5. Taguchi technique

Design of Experiment is a structured, organized technique to describe the relationship between parameters that affect a process and its responses. The Taguchi technique was chosen for this study as it involves reducing the variation in a process through robust design of experiments. In this work, L9 orthogonal array design matrix was used to study the influence of parameters on the outcome of the process. In this investigation, the wear parameters namely, temperature, applied load and the sliding velocity each at three levels are considered. Parameters and levels are given in Table.1. In this study, "smaller is better" S/N ratio is used to predict the optimum parameters because lower wear loss was desirable. Hence, the optimal level of the process parameters would be the level of the highest S/N ratio. In addition, the testing results were analyzed using analysis of variance (ANOVA) to study the influence of the parameters on the performance. Measured values and S/N ratio are presented in Tab. 2.

Table 1 Parameters and levels

Code	Parameters	Levels		
		I	II	III
A	Temperature [°C]	30^{o}C	60^{o}C	90^{o}C
B	Applied Load [N]	20	30	40
C	Sliding velocity [m/s]	1.571	2.356	3.142

Table 2 Measured values and S/N ratios

Exp. No.	A temperature [°C]	B applied load [N]	C sliding velocity [m/s]	Wear loss	Signal/Noise Ratio
1	30	20	1.571	40	-32.0412
2	30	30	2.356	82	-38.2763
3	30	40	3.142	120	-41.5836
4	60	20	2.356	79	-37.9525
5	60	30	3.142	127	-42.0761
6	60	40	1.571	162	-44.1903
7	90	20	3.142	111	-40.9065
8	90	30	1.571	153	-43.6938
9	90	40	2.356	217	-46.7292

Table 3 Response table for signal to noise ratios

Level	A Temperature [°C]	B Applied Load [N]	C Sliding velocity [m/s]
I	-37.30	-36.97	-39.98
II	-41.41	-41.35	-40.99
III	-43.78	-44.17	-41.52
Delta	6.48	7.20	1.55
Rank	2	1	3

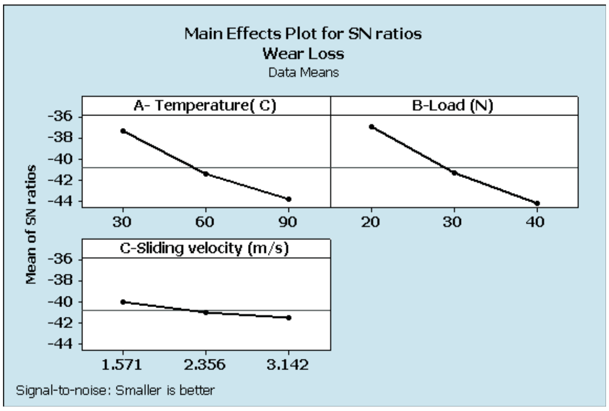

Figure 5 The main effects plot for S/N ratio

The response table for S/N ratio was shown in Tab. 3. Ranking of parameter was computed according to the delta value which is the difference between the maximum and minimum values of S/N ratio. The parameter which has highest value of delta will have the greatest influence on the wear loss. It can be noted that from Tab. 3 that load has the significant impact on wear loss followed by temperature and sliding velocity. The main effects plot for S/N ratio is shown in Fig. 5. It can be inferred that the optimum parameters for minimum wear loss of the composites were applied load (20 N), temperature (30°C) and sliding velocity (1.571 m/s). From the plot, it can be concluded that wear increases with temperature within the observed range. Moreover, the wear resistance decreases with increase in applied load and sliding velocity. ANOVA which is a statistical technique can be employed to identify the significant parameters and to find the percentage contribution of parameters on the performance characteristic. ANOVA was performed by using MINITAB15 software for a level of significance of 5% to study the contribution of the parameters.
It can be observed from the ANOVA analysis which is presented in Tab. 4, P-value value of the applied load and temperature, have less than 0.05, these parameters can be considered as statistically highly significant. The percentage contribution (Pc%) of each variable in the total variation indicating their degree of influence on the wear loss of the composites. The applied load (55.06%) has the major contribution on wear loss followed by temperature (43.50%) and sliding velocity (0.475%).

Table 4 ANOVA analysis

Wear Parameter	Dof	Seq.SS	F value	P value	Pc
A Temperature [°C]	2	9529.6	45.77	0.021	43.507
B Applied Load [N]	2	12061.6	57.93	0.017	55.066
C Sliding velocity [m/s]	2	104.2	0.50	0.666	0.4757
Error	2	208.2			0.9505
Total	8	21903.6			100

Dof: degrees of freedom; Seq.SS: sequential sums of squares; Adj.MS: Adjusted sums of squares; Pc: percentage of contribution.

6. Conclusions

Tribological behaviour of Al 7075 - SiC 10wt % composites has been analyzed using Taguchi and ANOVA techniques, leading to the following conclusions. The wear of the composites increased with increasing temperature irrespective of the load and velocity conditions within the observed range. Wear resistance tend to decrease when the load and velocity increases at constant temperature. It was found that the optimum parameters for minimum wear loss of the composites were applied load (20 N), temperature (30°C) and sliding velocity (1.571 m/s). It was also observed that the applied load (55.06%) was the major contributing factor followed by temperature (43.50%) and finally sliding velocity (0.475%) in influencing the wear resistance of the composites.

References

[1] **Lee, G. Y., Dharan, C. K. H. and Ritchie, R. O.**: A physically–based abrasive wear model for composite materials, *Wear*, 252, 322–331, **2002**.

[2] **Singh, J. and Alpas, A. T.**: High–temperature wear and deformation processes in metal matrix composites, *Metallurgical and Materials Transactions*, A, 27, 3135–3148, **1996**.

[3] **Farhadinia, F. and Sedghi, A.**: Wear behaviour of Al/(Al_2O_3 + ZrB_2 + TiB_2) hybrid composites fabricated by hot pressing, *International Journal of Materials Research*, 106, (2), 160–165, **2015**.

[4] **Rajan, M. H. B., Ramabalan, S., Dinaharan, I. and Vijay, S. J.**: Effect of TiB2 content and temperature on sliding wear behavior of AA7075/TiB2 in situ aluminum cast composite, *Archives of Civil and Mechanical Engineering*, 14, 72–79, **2014**.

[5] **Hui, L. Y., Jun, D., Rong, Y. S. and Wei, W.**: High temperature friction and wear behavior of Al_2O_3 and/or carbon short fibre reinforced Al–12Si alloy composites, *Wear*, 256, 3–4, 275–285, **2004**.

[6] **Natarajan, S., Narayanasamy, R., Kumaresh Babu, S. P., Dinesh, G., Anil Kumar, B. and Sivaprasad, K.**: Sliding wear behaviour of Al6063/TiB2 in situ composites at elevated temperature, *Materials and Design*, 30, 7, 2521–2531,**2009**.

[7] **Valefi, M., de Rooij, M., Schipper, D. J. and Winnubst, L.**: Effect of temperature on friction and wear behaviour of CuO–zirconia composites , *Journal of the European Ceramic Society*, 32, 10, 2235–2242, **2012**.

[8] **Kumar, S., Subramanya Sarma, V. and Murty, B. S.**: High temperature wear behavior of Al–4Cu–TiB_2 in situ composites, *Wear*, 268, 11–12, 1266–1274, **2010**.

[9] **Hernandez, S, Hardell, J, Courbon, C, Winkelmann, H and Prakash, B.**: High temperature friction and wear mechanism map for tool steel and boron steel tribopair, *Tribology (Leeds)*, 8, 2, 74–84, **2014**.

[10] **Mousavi Abarghouie, S.M.R. and Seyed Reihani, S. M.**: Investigation of friction and wear behaviors of 2024 Al/SiCp composite at elevated temperatures, *J. Alloys and Comp.*, 501, 2, 326–332, **2010**.

[11] **Gomez-del Rio, T., Rico, A., Garrido, M. A., Poza, P. and Rodriguez, J.**: Temperature and velocity transitions in dry sliding wear of Al–Li/SiC composites, *Wear*, 268, 5–6, 700–707, **2010**.

[12] **Dwivedi, D. K**:, Sliding temperature and wear behaviour of cast Al–Si–Mg alloys, *Materials Science and Engineering*, A, 382, 328–334, **2004**.

[13] **Rajaram, G., Kumaran, S. and Srinivasa Rao, T.**: High temperature tensile and wear behaviour of aluminum silicon alloy, *Materials Science and Engineering*, A, 528, 247–253, **2010**.