STATISTICAL ANALYSIS ON TRIBOLOGICAL BEHAVIOUR OF AN AL ALLOY 7075 – AL_2O_3 COMPOSITES

P. Shanmughasundaram Palanisamy[1)]
[1)] *Department of Automobile Engineering, Karpagam University, Coimbatore, India*

Received: 05.02.2016
Accepted: 03.03.2016

[*]Corresponding author: *Tel.: 91 9842461672*, *sunramlec@rediffmail.com, Department of Automobile Engineering, Karpagam University, Coimbatore-641021,Tamilnadu,India*

Abstract
Al alloy 7075 reinforced with Al_2O_3 particles of three different sizes (63,102, and 165 μm) were fabricated through the stir casting method. Dry sliding wear tests were conducted to evaluate the influence of load, sliding velocity and particle size on the wear loss and coefficient of friction of the composites using a pin-on-disc wear testing rig. Tests were conducted according to L9 Taguchi orthogonal array for three different loads (10, 30, and 50 N) at three different velocities (0.837, 1.674, and 2.512 m/s) for a constant time period of 30 minutes. The results showed that the wear increased with increasing load and sliding velocity whereas the coefficient of friction increased with increasing sliding velocity. On the contrary, the coefficient of friction decreased with increasing load. Composites reinforced with coarse Al_2O_3 particles exhibit superior wear resistance. It was found that the load was the most dominant factor influencing the wear loss and coefficient of friction followed by sliding velocity and particle size. A Scanning Electron Microscope (SEM) was used to study the morphology of the worn surfaces of the pins.

Keywords: stir casting, Al alloy 7075 - Al_2O_3 composite, dry sliding wear, coefficient of friction, Taguchi

1 Introduction

Usage of metal matrix composites in automotive, aerospace or any other tribological applications could provide the weight reduction and energy consumption significantly. Wear can be described as a process of removal of material from one or both of two solid surfaces caused by relative motion between them. Tribological behaviour of metal matrix composite is strongly influenced by the properties of matrix and reinforcement materials, shape, size, volume or weight fraction and distribution of reinforcement particles. Aluminium alloy 7075 which has zinc as the primary alloying element is widely employed in aircraft and aerospace industry due to its high strength-to-weight ratio, fatigue strength and machinability. Wernick et al [1] studied the dry sliding wear behavior of different pretreated conditions of 7075 Al alloy. Babic et al [2] investigated the tribological behaviour of Zinc-Aluminium alloys and they reported that the heat-treated alloys enhance the tribological for all the loads of sliding conditions. Sajjadi et al [3] studied the comparison of microstructure and mechanical properties of A356 aluminium alloy/Al_2O_3 composites fabricated by stir and compo-casting processes. They reported that the addition of alumina (micro and nano) led to the improvement in yield strength, ultimate tensile strength, compression strength and hardness.

Park et al [4] examined the effect of particulate volume fraction on the mechanical properties of AA 6061 - MICRAL-20™ (alumina and mullite) composites. Venkata Siva et al [5] studied the

DOI 10.12776/ams.v22i1.660 p-ISSN 1335-1532
e-ISSN 1338-1156

effect of hot working on the structure and tribological properties of aluminium reinforced with Al_2O_3 particulates prepared by stir-cast melt technique. It was reported that as-cast and forged Al-Al_2O_3 composites showed higher wear resistance than pure Al. Vencl Aleksandar et al [6] analyzed the tribological properties of heat-treated (T6) samples of A356 Al-Si alloy - Al_2O_3/SiC/ graphite composite fabricated by compo casting process. They reported that wear resistance of composites reinforced with SiC particles was higher and coefficient of friction was lower compared to the composite reinforced with Al_2O_3 particles. Song and Han [7] analyzed the mechanical properties and wear behaviour of Al/Al_2O_3/C hybrid metal matrix composites fabricated by squeeze casting method. Lakshmipathy and Kulendran [8] analyzed the tribological behaviour of Al 7075 T6, Al 6061 T6 alloy – SiC / Al_2O_3 composites using reciprocating wear test method. They reported that composite with Al7075-SiC and Al6061-Al_2O_3reinforcement shows better wear resistance compared to its matrix alloy.
Amro M.AI-Qutub et al [9] studied the dry wear behavior of Al 6061- $A1_2O_3$ particulate composite under different sliding speeds and applied loads using pin-on-disc tribometer at room temperature. It was reported that the wear rate increases with applied load for all the composites regardless of sliding speed. Kathiresan and Sornakumar [10] analyzed the effects of normal load and sliding speed on tribological properties of an Al alloy- Al_2O_3 composite with En 36 steel disc. It was reported that the wear rate increases with normal load and sliding speed. The wear and friction coefficient of the aluminium alloy-aluminium oxide MMC are lower than the plain aluminium alloy. Aigbodion et al [11] analyzed an effect of bagasse ash reinforcement on the wear behaviour of Al-Cu-Mg/ bagasse ash particulate composites. It was reported that composites provided higher friction coefficient compared to unreinforced alloy. Rao and Das [12] studied the effect of SiC content and sliding speed on the wear behaviour of aluminium matrix composites. The results revealed that as the SiC content increases the wear rate decreases, but reverse trend was observed for coefficient of friction.
Kök and Özdin [13] conducted sliding wear tests on Al 2024- Al_2O_3 composites fabricated by a vortex method to investigate the wear properties of the composites. It was found that the wear resistance of the composites was significantly larger than that of the aluminium alloy, and increased with increasing Al_2O_3 particles content and size. The results emphasized that the effect of Al_2O_3 particle size on the wear resistance was more significant than that of the particle content. Liang et al [14] studied the effect of particle size on wear behaviour of SiC particulate-reinforced aluminium alloy composites. They reported that the wear resistance increases rapidly with increasing particle size. Ravikumar et al [15] studied the dry sliding wear behaviour of Aluminium alloy (Al/3.25Cu/8.5Si) composites reinforced with fly ash particles of three different size ranges (53–75,75–103,and103–150 μm) fabricated using a stir-casting technique. They observed that the composites reinforced with coarse fly ash particles exhibit superior wear resistance to those reinforced with fine fly ash particles. Mahdavi and Akhlaghi [16] studied the effect of the SiC particle size (19,93 and 146 μm) on the dry sliding wear behaviour of SiC and SiC–Gr-reinforced Al6061 composites. They reported that the increased SiC particle size reduced the porosity, hardness, volume loss, and coefficient of friction of both types of composites.
Mehdi Rahimian et al [17] investigated the particle size and amount of alumina on microstructure and mechanical properties of Al matrix composite fabricated by powder metallurgy. They reported that as the alumina particle size decreases, hardness, yield strength, compressive strength and elongation increases and factors such as wear resistance, grain size and

DOI 10.12776/ams.v22i1.660 p-ISSN 1335-1532
e-ISSN 1338-1156

distribution homogeneity in matrix decreases.Mitrovic et al [18] investigated the influence of Al_2O_3 particle content on the sliding wear behaviour of ZA-27 Alloy composites.
Sahin and Cetinkaya [19]investigated the microstructure and tribological behaviour of Al_2O_3 particle-reinforced aluminium alloy composite.Saravanan et al [20] studied an effect of particle size on tribological behavior of rice husk ash-reinforced aluminium alloy (AlSi10Mg) matrix composites. They reported that the composite reinforced with the coarse rice husk ash particles exhibits superior wear resistance compared to the fine rice husk ash particles.
From the literature, it was observed that magnitudes of friction coefficient and wear loss of metal matrix composites differs significantly at different normal loads, sliding velocities and particle size. Earlier investigations showed that the tribological behaviour of composites can be improved with increase in particle size. However, a systematic study has to be carried out to explore the contribution of load, sliding velocity and particle size on the tribological behaviour of the composites. In this present work,Taguchi L9 orthogonal array and ANOVA techniques were used to investigate the influence of applied load, sliding velocity and particle size on the tribological behaviour of Al alloy 7075 - 5wt. % Al_2O_3 composites which are fabricated through stir casting method. Scanning Electron Microscope (SEM) was employed to study the morphology of worn surfaces to identify the wear mechanism.

2 Experimentation

2.1 Specimen Preparation

Al alloy 7075 was used as the matrix material and Al_2O_3 particles were used as reinforcement. In this study, composites were fabricated using stir casting method by keeping 5 wt. % Al_2O_3 constant. Composition of Al alloy 7075 is presented in **Table 1**. The three different sizes of Al_2O_3 particles were chosen such as 63 μm (fine), 102 μm (intermediate) and 165 μm (coarse).

Table 1 Composition of Al alloy 7075 alloy

Element	Al	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Pb	Ca	Ni
Wt.%	90.17	0.054	0.114	1.350	0.022	2.314	0.277	5.614	0.055	0.017	0.013	0.001

2.2 Micro Structural Analysis

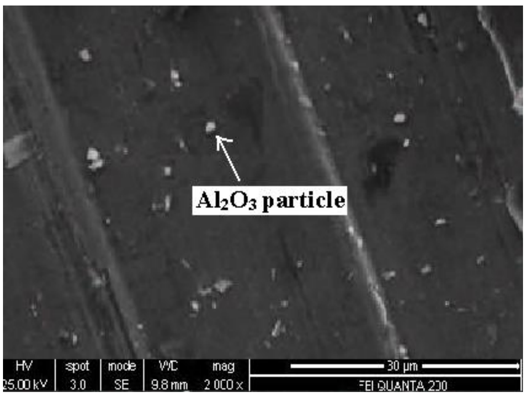

Fig. 1 SEM micrograph of the Al alloy –5 wt. % Al_2O_3 composite

Tribological behaviour of metal matrix composites primarily depends on the reinforcement properties, particle size, shape and distribution in the matrix alloy. Scanning Electron

DOI 10.12776/ams.v22i1.660 p-ISSN 1335-1532
e-ISSN 1338-1156

Microscope (SEM) was used to study the distribution of Al_2O_3 in the Al alloy matrix. Microstructure of the Al alloy – 5 wt. % Al_2O_3 composite (**Fig. 1**) reveals that the Al_2O_3 particles are distributed evenly in the Al alloy matrix. Clustering of Al_2O_3 particles was not observed in the composite.

2.3 Dry Sliding Wear Test

Dry sliding wear tests were conducted employing pin-on-disc wear testing rig. Cylindrical pins (10mm diameter and 25mm height) were prepared and the surface of the specimens was polished by using 1000 grit paper. Average roughness of steel disc and composite pin was about 2-4 µm. The rotating disc was made of EN 32 steel and hardness of 65 HRC. The linear dislodgement of the pin is taken as wear loss which is recorded by the LVDT (Linear Variable Differential Transformer) with an accuracy 0.01 µm. Wear tests were carried out at 25°C room temperature and 60% (± 5) relative humidity for 30 minutes.

3 Taguchi method

Taguchi's method can be used to find out the optimum control factors for achieving the desired process output. In this study, "smaller is better" S/N ratio was chosen to find the optimum level of the factors because smaller wear loss and coefficient of friction were taken into consideration. Mathematical equation of the S/N ratio for "smaller is better" can be represented in the equation (i).

$$\frac{S}{N} = -10Log\left(\frac{1}{n}\sum_i \frac{1}{Y_i^2}\right) \tag{1.}$$

Where, Y is the observed data and n is the number of observations.
In the present investigation, dry sliding wear tests were carried out Al alloy 7075 - Al_2O_3 5 wt. % composite according to the L9 orthogonal array. Accordingly, 9 tests were done and each test was repeated twice in order to reduce the errors. The factors and the corresponding levels are presented in **Table 2**. In addition, the test results were analyzed using analysis of variance (ANOVA) to study the influence of the control factors on wear loss and coefficient of friction.

Table 2 Factors and levels

Level	Load,N (A)	Sliding Velocity,m/s(B)	Particle Size,µm (C)
I	10	0.837	63
II	30	1.674	102
III	50	2.512	165

4 Results and Discussion

4.1 Results of S/N Ratio

Tests were conducted as per the Taguchi's L9 orthogonal array and the corresponding values and S/N ratios of wear loss and coefficient of friction are presented in **Table 3**. The S/N ratio for each factor level is determined by averaging the S/N ratios at the corresponding level. The factor with the highest S/N ratio would give minimum wear loss and coefficient of friction.

DOI 10.12776/ams.v22i1.660 p-ISSN 1335-1532
e-ISSN 1338-1156

Table 3 Measured values and S/N ratios for wear and coefficient of friction

Exp.No	Factors			Measured Values		Signal / Noise Ratio	
	Load, N (A)	Sliding Velocity, m/s (B)	Particle Size,µm (C)	Wear (µm)	CoF	Wear	CoF
1	10	0.837	63	188	0.330	-45.4832	9.6297
2	10	1.674	102	209	0.340	-46.4029	9.3704
3	10	2.512	165	219	0.353	-46.8089	9.0445
4	30	0.837	102	262	0.285	-48.366	10.9031
5	30	1.674	165	281	0.300	-48.9741	10.4575
6	30	2.512	63	351	0.323	-50.9061	9.8159
7	50	0.837	165	425	0.241	-52.5678	12.3596
8	50	1.674	63	499	0.264	-53.962	11.5679
9	50	2.512	102	534	0.273	-54.5508	11.2767

Table 4 Response table for Signal to Noise Ratios

Level	Wear (µm)			Coefficient of friction		
	Load,N (A)	Sliding Velocity, m/s (B)	Particle Size, µm (C)	Load, N (A)	Sliding Velocity, m/s (B)	Particle Size, µm (C)
1	-46.23	-48.81	-50.12	9.348	10.964	10.338
2	-49.42	-49.78	-49.77	10.392	10.465	10.517
3	-53.69	-50.76	-49.45	11.735	10.046	10.621
Delta	7.46	1.95	0.67	2.387	0.918	0.283
Rank	1	2	3	1	2	3

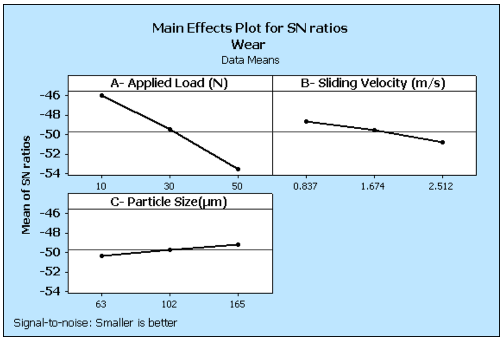

Fig. 2 Response diagram of S/N ratio for wear loss of Al alloy 7075 - 5 wt. % Al_2O_3 composite

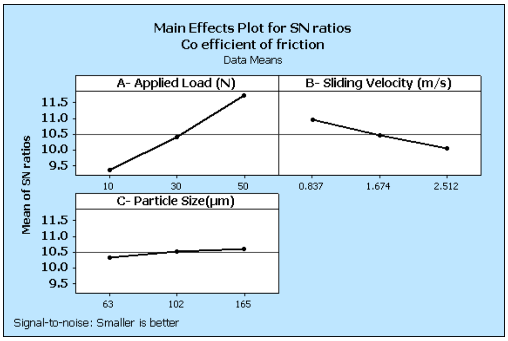

Fig. 3 Response diagram of S/N ratio for coefficient of friction of Al alloy 7075 - 5 wt. % Al_2O_3 composite

The influence of factors on wear loss and coefficient of friction has been analyzed. Ranking of factors was determined according to the delta value which is the difference between the maximum and minimum values of S/N ratio. The factor with the highest value of delta has the most influence on the response. Ranking of factors is presented in **Table 4** for wear loss and coefficient of friction. It was observed that the applied load is a dominant factor on the wear loss

DOI 10.12776/ams.v22i1.660
p-ISSN 1335-1532
e-ISSN 1338-1156

and coefficient of friction followed by sliding velocity and particle size. From the response diagram of S/N ratio (**Fig. 2**), it was found that the optimum level of the factors were load (10N), sliding velocity (0.837 m/s) and particle size (165 μm) in minimizing the wear of the composites. From the response diagram of S/N ratio (**Fig. 3**),it was found that the optimum level of the factors were load (50N), sliding velocity (0.837 m/s) and particle size (165 μm) in minimizing the coefficient of friction of the composites.

4.2 Results of ANOVA

ANOVA was carried out using software package MINITAB15 for a level of significance of 5% to find the contribution of the control factors on the response. The p-value was used to test the significance of each factor. It can be observed from the **Table 5** that p-value of the load, sliding velocity and particle size on the wear loss and coefficient of friction of the Al alloy 5 wt. % Al_2O_3 composite have less than 0.05, which means that they are highly significant at 95% confidence level.

Table 5 ANOVA analysis for wear and coefficient of friction

Factor	DoF	SS	F-Value	p-value	Pc%
Wear loss (μm)					
A- Load	2	122705	1257.79	0.001	91.71
B- Sliding velocity	2	8740	89.59	0.011	6.53
C- Particle Size	2	2251	23.07	0.042	1.68
Error	4	98			0.07
Total	8	133794			100
Coefficient of friction					
A- Load	2	0.0100167	15025.00	0.000	86.64
B- Sliding velocity	2	0.0014420	2163.00	0.000	12.47
C- Particle Size	2	0.0001007	151.00	0.007	0.87
Error	4	0.0000007			0.006
Total	8	0.0115600			100

DoF- Degrees of Freedom; Seq.SS- Sequential sums of squares; Pc-Percentage of contribution

4.3 Multiple Linear Regression Model

Multiple linear regression equations were developed to establish the correlation between the factors and the response. The value of regression coefficient, R^2 (0.9993) is in good agreement with the adjusted R^2 (0.9971) for wear loss of the composites. The value of regression coefficient, R^2 (0.9999) is in good agreement with the adjusted R^2 (0.9998) for coefficient of friction.

The regression equation developed for wear loss of Al alloy 5 wt. % Al_2O_3 composite is

$$W = 84.2 + 7.02(A) + 45.6(B) - 0.374(C) \quad (2.)$$

The regression equation developed for coefficient of friction of the Al alloy 5 wt. % Al_2O_3 composite is

$$F = 0.339 - 0.00204(A) + 0.0185(B) - 0.000070(C) \quad (3.)$$

Where, W - dry sliding wear loss, F - Coefficient of friction, A - load, N, B- Sliding velocity, m/s, C - Particle Size, μm.

DOI 10.12776/ams.v22i1.660 p-ISSN 1335-1532
e-ISSN 1338-1156

It was observed from the Eq.2 that the coefficients associated with load (A) and sliding velocity (B) are positive. It infers that the wear loss of the composites decreases with decreasing load and sliding velocity. The coefficient associated with particle size is negative. It can be inferred that the wear resistance of the composites increases with particle size.
Eq.3 infers that the coefficient associated with load (A) and particle size (C) are negative. It shows that the coefficient of friction decreases with increasing load and particle size. In contrast, since coefficient associated with sliding velocity (B) is positive, coefficient of friction of the composite decreases with decreasing sliding velocity.
The last column of the table 5 exemplifies the percentage contribution (Pc.%) which specifies the level of influence of the control factors on the wear loss and coefficient of friction of the composite. It can be observed that the load (91.71%) was the major contributing factor followed by sliding velocity (6.53%) and particle size (1.68%) influencing the wear loss of the composite. The applied load (86.64%) was the major contributing factor followed by (12.47%) and particle size (0.87%) influencing the coefficient of friction of the composites.
The higher wear resistance of the composite was observed at a load of 10N and a sliding velocity of 0.837 m/s. The enhanced wear resistance at low load can be attributed to the load bearing capability of Al_2O_3 particles and good bonding between Al alloy and aluminium oxide particles. Moreover, the wear resistance of composites depends on the formation of MML (Mechanically Mixed Layer) on the surface. Mechanically Mixed Layer will have a mixture of oxides and debris particles during the wear process. Steady MML on the wearing surface could be an effective approach to increase the wear resistance of the tribo-system in the mild wear regime [21].
When the composite is subjected to higher load and sliding velocity, wear resistance tends to decrease drastically within the observed range. It could be attributed to the fact that the area of contact between pin and counter disc tends to increase due to the higher applied load, resulting in plastic shearing. Moreover, the buildup of debris which are partly embedded in to the either surface of the composite pin and counter surface caused three body wear. The SEM observation validates that the adhesion of the debris is mainly accountable for higher wear.
It is noteworthy that the frictional force increased, when sliding velocity was increased at a constant load. Hence, higher interfacial temperature induced by frictional heat, loosens the bonding at the interface between Al alloy matrix and Al_2O_3 reinforcement particles, resulting in higher plastic deformation. The value of coefficient of friction decreases with the increase in load while coefficient of friction increases with the increase in sliding velocity. It could be due to more adhesion between the pin and the counter disc during sliding.
Results shows that the particle size is one of the significant factors which have an effect on wear resistance. Al alloy reinforced with coarse particle size exhibits higher wear resistance. It could be attributed to the ability of the coarse particle size which plays an important role in protecting the bond during sliding action. These results are supported by the findings of Hutchings [22] and Md Abdul Maleque and Md Rezaul Karim [23].
The improvement in the wear resistance of the composites may be attributed to the toughening effect due to the incorporation of larger Al_2O_3particles in the matrix. However, the reinforcing particle size did not have much influence on the wear loss and coefficient of friction of the composites within the observed ranges of the particle size compared to the load and sliding velocity which have more pronounced effect. Ege Anıl Diler and Rasim Ipek [24] studied the

DOI 10.12776/ams.v22i1.660 p-ISSN 1335-1532
e-ISSN 1338-1156

effects of matrix particle size, reinforcement particle size and volume fraction on wear characteristics of Al–SiC_p composites. They have reported that after a certain volume fraction, large sized reinforcement particles had a negative effect on the wear resistance. Ram Prabhu et al [25] investigated the friction and wear properties of Fe/SiC/graphite hybrid composites considering two particle size ranges (1–30μm and 150–180μm) and three particle volume fractions (10%, 15% and 20%) of SiC. They observed that at low sliding speeds the composites with large particle sizes and high volume fractions were found to be more effective in controlling wear. On the other hand, at higher sliding speeds the high volume fraction composites were found to be more effective in controlling wear for all particle sizes. It should be noted that the contribution of particle size of the reinforcement on the wear resistance depends on the applied load, sliding velocity and weight percentage of the reinforcement incorporated in the matrix.

4.4 Confirmation Test

The confirmation experiments were carried out as per the conditions given in the **Table 6** and results are presented in the **Table 7**. Typical superimpose curves of wear of Al alloy 7075 - 5 wt. % Al_2O_3 with 165 μm composite are shown in **Fig. 4**. The experimental values for the wear loss and coefficient of friction of the composites and calculated values from the regression equation are nearly same with least error (± 6 %). It can be noted that the resulting equations are capable of predicting the wear loss and coefficient of friction.

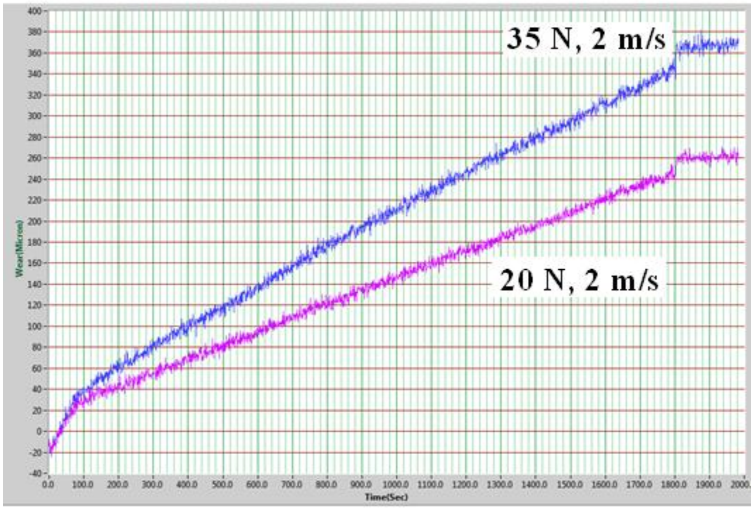

Fig. 4 Typical superimpose curves of wear of Al- 5 wt. % Al_2O_3 composite against steel as a function of constant sliding velocity of 2 m/s at 20 N and 35 N

Table 6 Factors used in the confirmation test

Test	Load,N (A)	Sliding Velocity,m/s (B)	Particle Size, μm (C)
I	20	2	165
II	35	2	165

DOI 10.12776/ams.v22i1.660 p-ISSN 1335-1532
e-ISSN 1338-1156

Table 7 Results of confirmation tests

Test I			Test II		
Wear Loss (µm)					
Model equation	Expt.	Error (%)	Model equation	Expt.	Error (%)
254.09	240	5.54	359.39	350	2.61
Coefficient of friction					
0.32365	0.311	3.90	0.29305	0.282	3.77

4.5 Worn Surface Morphology

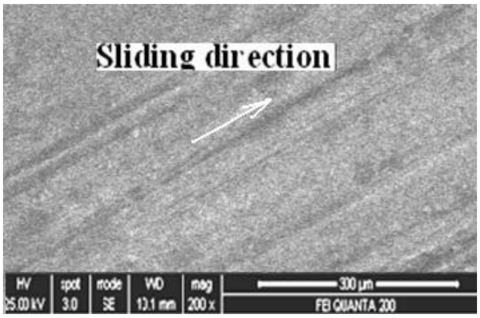

Fig. 5 SEM micrograph of the worn surface of the Al alloy - 5 wt. % Al_2O_3 composite at a normal load of 10N with 0.837 m/s sliding velocity

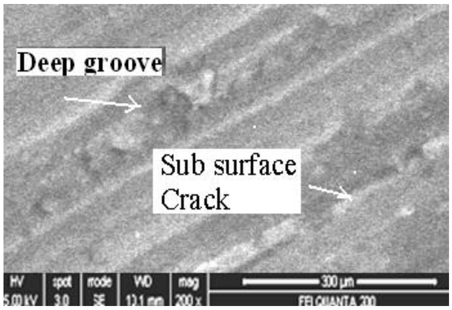

Fig. 6 SEM micrograph of the worn surface of the Al alloy - 5 wt. % Al_2O_3 composite at a normal load of 50N with 2.512 m/s sliding velocity

Fig. 5 shows the worn surface of Al alloy - 5 wt. % Al_2O_3 composite at a load of 10N with 0.837 m/s sliding velocity. It was observed that sliding marks and fewer voids were seen on the worn surface.It may be due to the wear resistance offered by hard Al_2O_3 particles. When the composite was subjected to the higher load (50N) with higher sliding velocity (2.512 m/s), wear grooves spread in the sub surface region as shown in **Fig. 6**. The morphology of the worn surfaces changes from small cracks to deep grooves. The worn surface of the composite is relatively rough and the material is removed by delamination.

Adherence of the debris was also seen on the worn surface, which leads to three body wear process and higher coefficient of friction. It can be concluded that the material removal occurs at an accelerated rate and wear mechanism changes from mild to severe wear, with increasing load and velocity. The SEM observation supports the wear of the composites is apparently influenced by the applied load and sliding velocity.

5 Conclusions

Optimal conditions for attaining minimum wear loss and coefficient of friction were obtained using Taguchi S/N ratio analysis.

It was observed that the coefficient of friction decreases and wear loss increases with the increase in load whereas both coefficient of friction and wear loss increases with the increase in sliding velocity. The wear loss and friction coefficient of the composite were found to decrease with increase in particle size.

DOI 10.12776/ams.v22i1.660 p-ISSN 1335-1532
e-ISSN 1338-1156

From ANOVA analysis, it was found that applied load has the significant factor on wear loss and coefficient of friction of composites followed by sliding velocity and particle size. The wear loss of the composites was influenced primarily by applied load (91.71%), sliding velocity (6.53%) and particle size (1.68%).On the other hand the coefficient of friction was influenced by applied load (86.64%), sliding velocity (12.47%) and particle size (0.87%). It was observed that the composite with coarse Al_2O_3 particles carry a greater portion of the applied load compared to the fine and intermediate particle sizes.

References

[1] S. Wernick, R. Pinner, P. G. Sheasby: The Surface Treatment and Finishing of Aluminium and Its Alloys, ASM International, 1987
[2] M. Babic, S. Mitrovic, R. Ninkovic: Tribology in Industry, vol. 31, 2009, p.15-28
[3] S. A. Sajjadi, H. R. Ezatpour, M. T. Parizi: Materials and Design,vol. 34, 2012, p.106-111, doi:10.1016/j.matdes.2011.07.037
[4] B. G. Park, A. G. Crosky, A. K. Hellier: Journal of Materials Science, vol. 36, 2001, no.10, p. 2417-2426, doi: 10.1023/A:1017921813503
[5] S. B. Venkata Siva, K. L. Sahoo, R. I. Ganguly, R. R. Dash: Journal of Materials Engineering and Performance, Vol. 21, 2012, No.7, p.1226-1231, doi: 10.1007/s11665-011-0027-9
[6] A. V. Aleksandar, Dj. B. Llija, Z. S. Blaza: Industrial Lubrication and Tribology, Vol. 66, 2014, No. 1, p. 66-74, , doi: 10.1108/ILT-06-2011-0047
[7] J. I. Song, K. S. Han: Journal of Composite Materials, Vol. 31, 1997, No.4, p. 316-344, doi:10.1177/002199839703100401
[8] J. Lakshmipathy, B. Kulendran: Tribology in Industry, Vol. 36, 2014, No.4, p. 117-126
[9] A. M. AI-Qutub, I. M. Allam, M. A. Abdulsamad: Journal of Materials Science, Vol. 43, 2008, No. 17, p. 5797-5803, doi: 10.1007/s10853-008-2867-8
[10] M. Kathiresan, T. Sornakumar: Industrial Lubrication and Tribology, Vol. 62, 2010, No. 6, p. 361–371, doi: 10.1108/00368791011076263
[11] V. S. Aigbodion, S. B. Hassan, G. B. Nyior, T. Ause: Acta Metallurgica Sinca (English Lett.), Vol. 23, 2010, No. 2, p. 81-89
[12] R. N. Rao, S. Das: Materials and Design, Vol. 32, 2011, No. 2, p. 1066–1071, doi: 10.1016/j.matdes.2010.06.047
[13] M. Kök, K. Özdin: Journal of Materials Processing Technology, Vol. 183, 2007, No. 2-3, p. 301–309, doi: 10.1016/j.jmatprotec.2006.10.021
[14] Y. N. Liang, Z. Y. Ma, S. Z. Li , S. Li, J. Bi: Journal of Materials Science Letters, Vol. 14, 1995, No. 2, p. 114-116
[15] K. Ravi kumar, K. M. Mohanasundaram, G. Arumaikkannu, R. Subramanian: Tribology Transactions, Vol. 55, 2012, p.723-729, doi: 10.1080/10402004.2012.700763
[16] S. Mahdavi, F. Akhlaghi: Journal of Materials Science, Vol. 46, 2011, p. 7883-7894, doi: 10.1007/s10853-011-5776-1
[17] M. Rahimian, N. Parvin,N. Ehsani: Materials Science and Engineering A , Vol. 527, 2010, No. 4-5, p. 1031–1038, doi: 10.1016/j.msea.2009.09.034
[18] S. Mitrovic et al.: Journal of the Balkan Tribological Association, Vol. 19, 2012, p. 548-559
[19] Y. Sahin, Y. Cetinkaya: Journal of the Balkan Tribological Association, Vol. 21, 2014, p. 1-25

DOI 10.12776/ams.v22i1.660 p-ISSN 1335-1532
e-ISSN 1338-1156

[20] S. D. Saravanan, M. Senthilkumar, S. Shankar: Tribology Transactions, Vol.56, 2013, p. 1156-1167, DOI:10.1080/10402004.2013.831962
[21] Y. Zhan, G. Zhang, Y. Zhuang: Materials Transactions, Vol. 45, 2004, No. 7, p. 2332-2338, doi: 10.2320/matertrans.45.2332
[22] I. M. Hutchings: Materials Science and Technology, Vol. 10, 1994, No. 6, p. 513-517 DOI:10.1179/mst.1994.10.6.513
[23] M. A. Maleque, M. R. Karim: Industrial Lubrication and Tribology, Vol. 60, 2008, No. 4, p. 189–194, doi: 10.1108/00368790810881533
[24] E. A. Diler, R. Ipek: Composites Part B, Vol. 50, 2013, p. 371-380, doi:10.1016/j.compositesb.2013.02.001
[25] T. Ram prabhu, V.K. Varma, S. Vedantam: Wear, Vol. 309, 2014, No.1-2, p. 1–10, doi: 10.1016/j.wear.2013.10.006

DOI 10.12776/ams.v22i1.660 p-ISSN 1335-1532
e-ISSN 1338-1156