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TRIBOLOGICAL BEHAVIOR OF LOW-CARBON STEEL-PLATE-REINFORCED AL /SI ALLOY

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ABSTRACT

Aluminium- silicon alloy metal matrix composites reinforced with two types of low-carbon steel-plates were prepared by sand-mould casting technique. Friction and wear tests were performed under dry sliding condition using a pin-on-disc type tribometer. The results showed that Al /Si alloy reinforced with low-carbon steel-plate composites exhibit higher wear resistance than monolithic Al /Si alloy.

تم تحضير المؤتلفات ذات بطانة سبيكة الالومنيوم – سيليكون و المدعمة بنوعين من شرائح الصلب المنخفض الكربون بطريقة السباكة الرملية. أجريت اختبارات البري و الاحتكاك تحت ظروف الانزلاق الجاف باستخدام جهاز القلم و القرص . أظهرت النتائج أن سبيكة الالومنيوم – سيليكون و المدعمة بنوعين من شرائح الصلب المنخفض الكربون تظهر مقاومة للبري اعلي من سبيكة الالومنيوم – سيليكون.

Keywords: composites materials, metallic matrix, unreinforced aluminum alloys

1. INTRODUCTION

Metal matrix composites materials are advanced materials, which combine tough metallic matrix with a hard ceramic or soft reinforcement to produce composite materials [1, 2]. These materials have superior properties compared to the monolithic materials and can be tailarable to a specific applications [3, 4]. Metal matrix composite materials show advantages in a great number of specific applications (aircraft, automobile, machines) due to their high specific strength and stiffness, wear resistance and dimensional stability. Most of the commercial work on MMCs has focused on aluminium as the matrix metals which exhibit better mechanical properties than unreinforced aluminium alloys and have been used as tribological parts in some vehicles for years due to their high ratio of strength density and better wear resistance [5.6]. Unfortunately, only a limited number of publications on the friction and wear of laminated composites are available in the open literature. Alpas and Embury [7], found that, in the sliding wear of laminated composites of copper/amorphous $Ni_{78}Si_{10}B_{12}$ metallic glass, the wear resistance increases with increasing volume fraction of the metallic glass. Their experiments confirmed that the amorphous layers were effective in increasing the wear resistance of the composite by supporting the load with less deformation and by obstructing the damage process initiated in copper layers. Ruff and Lashmore [8] found that metal/metal multilayered composites of copper and nickel offered substantially increased resistance to sliding ear when compared to monolithic copper and nickel. Coefficients of friction of the multilayer composites were intermediate between the coefficients of friction for copper and nickel. Wear tests performed on gold/molybdenum and gold/stainless steel by Courtridge and Patten. [9] showed that decreasing the gold layer thickness resulted in a decrease in wear rate. The study also found that the alternate layers of Au/ Mo did not wear by gradual wearing of successive layers, but rather by delamination in underlying layers as a result of plastic deformation and fracture at the interfaces. Norose and Sasada. [10] prepared metal/metal laminates by depositing thin plates of metal A and metal B. As a result of wear experiments carried out on 33 metal combinations rubbed against pure Fe and pure Cu, they found that laminated composites consistently exhibited higher wear resistance than the pure metals. More recently, nanoscale Al/Sic composites have been synthesized and characterized [11] and found to have superior mechanical properties over conventional laminates. Pauleau and Thiery. [12] found that nanostructured Cu/C laminates exhibit coefficient of friction that is significantly lower than that of diamond-like carbon films (DLC). Others have fabricated ceramic/ceramic laminates [13, 14] and found that the composites have improved wear and friction properties. Farhat [15] investigated wear resistant coatings, nanolaminated composite films. These were composed of alternating metallic and ceramic layers; namely, Al/Al_2O_3 and Ti/TiN were produced using radio frequency magnetron sputtering. It was found that Laminates exhibit higher wear resistance than monolithic metallic films. The peak coefficient of friction of Al/Al_2O_3 having an aluminum layer thickness of 200 nm is 70% lower than that for monolithic aluminum. The peak coefficient of friction and severe and mild wear are sensitive functions of the normalized hardness of the materials in contact.

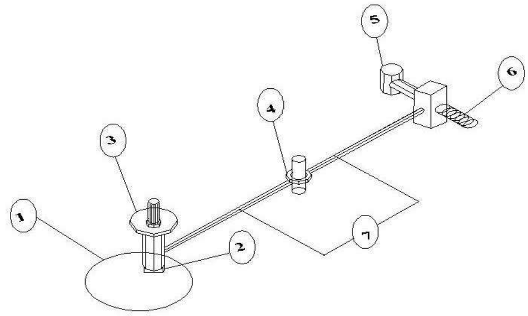
2. EXPERIMENTAL STUDY

2.1 Materials

The MMCs consist of two types (galvanized and black) of low-carbon steel plates with 3 mm thickness as reinforcement and Al /Si alloy as a matrix. The chemical composition of Al /Si alloy and the steel plate are given in Table (1) and Table (2) respectively. Al/Si alloy received from Egyptian Copper Co.While table (3) showed the mechanical properties of Al/Si alloy and steel plates.

2.2 Technique

Sand-mould casting technique was used for the production of both the Al /Si alloy without reinforcement and that with reinforcements. The reinforcements were divided to two groups. Group (1) consisted of three separate steel plates and group (2) consisted of continuous bending steel plate. Friction and wear tests were performed under non-lubricated sliding conditions using an in-house designed and built miniature pin-on-disc type tribometer as shown in Fig. 1. The sliding pin holds and loads a pin specimen vertically , so the reinforcement sheets are perpendicular to the surface of 250 mm diameter rotating gray cast iron tool disk hardened to 65 HRC. The specimens were ground and finished with 220-grit silicon carbide paper. The hardened disk was also polished before each test. Wear tests were made under a constant stress of 0.06 MPa to determine the steady state period and under variable stresses (0.09 MPa, 0.12 MPa, and 0.15 MPa) to determine the wear rate and the coefficient of friction. The load was applied to the tip of the pin which created a circular wear track of about 130 mm diameter on the surface of the disc. A constant sliding speed of 3.13 m s^{-1} was maintained at the centre of the track. Each specimen was weighed immediately before wear test using an electronic balance with an accuracy of 0.00001 g. After the wear tests, the samples were weighed again in the same way.



Part No.	1	2	3	4	5	6	7
Name	Disk	Specimen	Dead Weights	Ball Bearing	Dial Gauge	Spring	Arm

Fig. 1. Pin-on-disk tribometer

3. RESULTS AND DISCUSSION

3.1 Wear rate and sliding time

Wear rate versus sliding time curves give details on the change in the wear behavior of a material as a function of sliding time. Prior to examining the data for the tested composites it should be noted that three important parameters can be obtained from such curves. These are the peak value of the wear rate (W.Rp), the steady-state value of the wear rate (W.Rs.s) and the sliding time at which transition to steady-state (St) occurrs.Table (4) summarizes the experimental data of these parameters.

Table 1, Chemical composition of the matrix (Wt. %)

Element	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Wt. %	6	0.7	0.15:0.4	0.15	0.8:1.2	0.04:0.35	0.25	0.15	95.8:97.16

Table 2, chemical composition of the reinforcement (Wt. %)

Element	Fe	C	Si	Mn	P	S	Cr	Mo	Ni	Al
Wt. %	99.47	0.144	0.0257	0.120	0.00187	.00492	0.0216	0.0008	0.0262	0.116
Element	Nb	Ti	V	W	Pb	As	B	Co	Cu	
Wt. %	0.0039	0.00242	0.00212	0.0139	0.00266	0.0004	0.00066	0.001	0.0445	

Table 3, The mechanical properties for Al/Si alloy and steel plate

Material	Yield strength (MPa)	Tensile strength (MPa)	Ductility %
Al/Si alloy	44.43	130.9	15.2
Galvanized steel plate	170	290	26
Black steel plate	230	360	18

The wear rate curves for all the tested materials have the same overall shape. Each curve is characterized by two regimes; initially, the wear rate increases rapidly until reaching a maximum value (W.Rp).This is followed by a gradual decrease to a steady-state value (W.Rs.s). Wear curves for Al/Si alloy, group 1 and group 2 composites are given in Fig. 2.

Table. 4, Summary of tribological properties for Al/Si alloy, group 1 and group 2 composites

Composite	W.Rp x(10^{-9}) g/cm^2/ MPa	W.Rs s (10^{-9}) g/cm^2/ MPa	St min
Al/Si alloy	4.7	3	15
Galvanized sheet group 1	3.6	2.7	15.2
Black sheet group 1	3.4	2.8	15.4
Galvanized sheet group 2	3.1	2.3	15.5
Black sheet group 2	3.3	2.6	15.7

W.Rp = The wear rate peak value (g/cm^2/MPa), W.Rs.s = The wear rate steady-state value (g/cm^2/ MPa), St = transition time to steady-state (min).

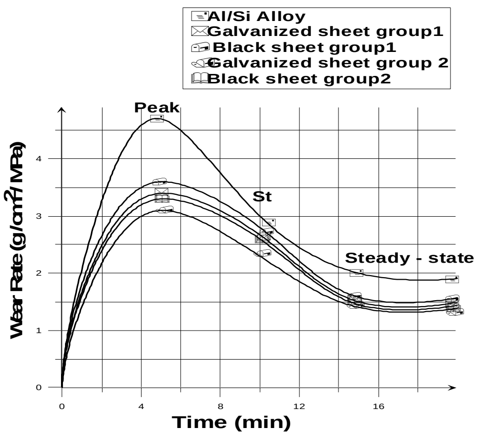


Fig. 2. Wear rate versus sliding time curves, obtained using a normal stress of 0.06 MPa and a sliding speed of 3.13 m s^{-1} under unduplicated sliding condition, for Al/Si alloy, group 1 and group 2 composites

Initially, the wear rates are high (severe wear) but after a certain sliding time, the wear rates decreased to a lower value (mild wear). Severe wear is characterized by high wear rate, high coefficient of friction and heavy surface deformation. Mild wear, on the other hand, is associated with low wear rate and coefficient of friction as well as a small amount of plastic deformation. The transition from severe to mild wear generally corresponded to a similar transition from the peak to steady state coefficient of friction regime. During the first wear stage tiny debris attaches within the wear track. Grains beneath the worn track kink and delaminate. Interaction of deformed grains with different orientations leads to intergranular and transgranular microcracks. Under repeated sliding contact, the surface and subsurface damages accumulate, accompanied with high contact stresses due to rough contact surfaces after wear, surface and subsurface material finally fails by severe intergranular and transgranular microfracture. Then fracture dominated severe wear is onset.

The lower wear rate observed in the third group (galvanized steel) in comparison to the other groups is shown in Table 4, which could be due to the lower contact area in this group at a given load resulting from its higher level of strength. The observed behavior of the wear rate can also be explained on the basis of different oxidative wear behavior.

It has been found that a harder subsurface is able to hold a thicker transfer layer of oxide more firmly compared to a softer one.

3.2. Wear rate and coefficient of friction with the applied load

Figure 3, shows the variations in wear rate with load for group 1, group 3 steel sheet - reinforced Al/Si alloy composites and Al/Si alloy under unduplicated sliding condition. The data for the un-reinforced matrix alloy are also displayed for comparison. The measured maximum and minimum values of coefficient of friction (μ) obtained for each specimen type under the corresponding test conditions are given in as shown in Fig. 4.

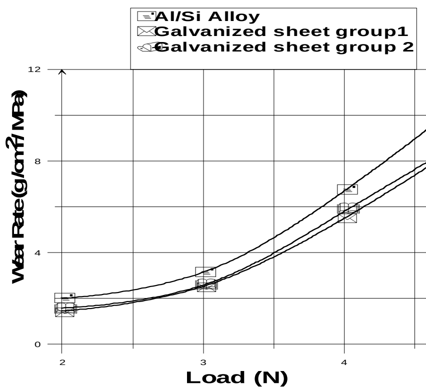


Fig. 3. Variations in the rate of wear with applied load for group 1 and group 3 steel sheet - reinforced Al/Si alloy composites. The data for the un-reinforced matrix alloy is also included for comparison

It is clear from Fig. 3, that the wear rate increases with increasing load for all the specimens in accordance with the proposition of Archard [16] , which states that wear-rate generally increases with the applied load. More interestingly, one can see that there appears to be two regimes of wear behavior:

one with a lower wear-rate while the other with a higher wear-rate. Once the sliding condition enters this higher-wear regime, changes in wear rate are much more gradual.

Within the set of test conditions used, group 1 and group 3 steel sheet - reinforced Al/Si alloy composites have consistently exhibited a higher wear rates than the un-reinforced matrix alloy.

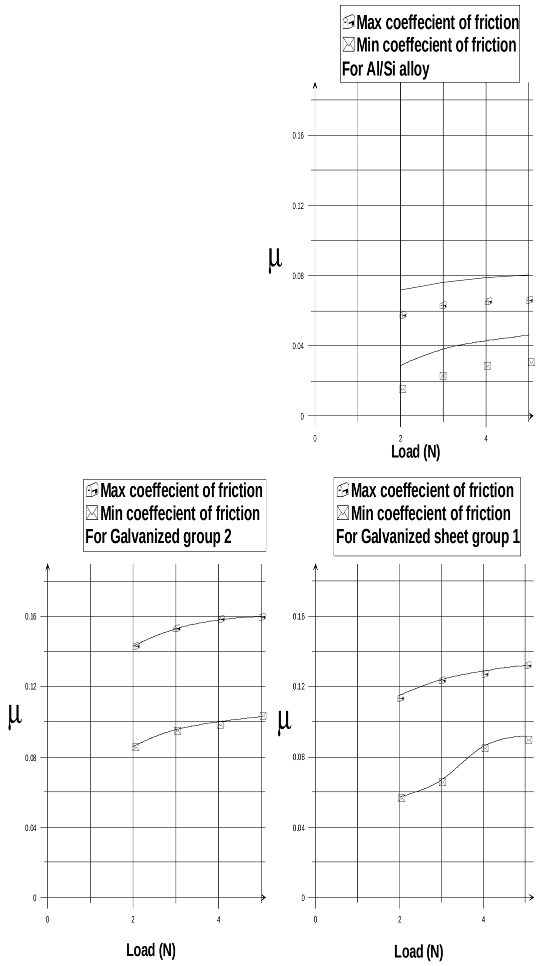


Fig. 4. Values of maximum and minimum coefficient of friction (μ) obtained for the tests where the wear-rate data were obtained

Figure 4, shows that maximum and minimum values of coefficient of friction (μ) also increase with increasing load for all the specimens. There is no adhesion between the matrix and reinforcement in the case of black sheets reinforcement, so it is interesting to note that this reinforcement failed with increasing load.

When the test sample is under dry sliding wear, the frictional heating helps atmospheric oxidation over the sliding surface. The oxide layer is removed by repeated and multiple contacts, and wear debris of the oxide particles is generated. The wear debris gets trapped between the sliding surface and is compacted into a layer. The completion between the removal of a transfer layer and its reformation and thickening could result in the deviation of the friction coefficient as shown in Fig. 4.

4. CONCLUSIONS

The following conclusions are deduced from the results of tests performed on the specimens, which fabricated from Al/Si alloy and low carbon steel plates reinforcement:-

1-Al/Si alloy and the composites reached the steady state at nearly the same times.

2-The wear rate and the coefficient of friction increase with increasing the contact pressure from 0.06 MPa up to 0.15 MPa for the Al/Si alloy and the composites.

3-With increasing the contact pressure from 0.06 MPa up to 0.15 MPa, the reinforced Al/Si alloy was found to lowering the wear rate, while raising the coefficient of friction than the unreinforced Al/Si alloy.

5. REFERENCES

[1] Ibrahim A, Mohamed FA, Lavernia EJ. Metal matrix composites – a review. J Mater Sci 1991; 26:1137–57.

[2] Surappa MK. Aluminium matrix composites: challenges and opportunities. Sadhana 2003; 28:319–34.

[3] Rohatgi PK, Asthana R, Das S. Solidification, structures, and properties of cast metal–ceramic particle composites. Int Metal Rev 31(3); 15–39. 1986.

[4] Goni J, Mitexelena I, Coleto J. Development of low coat metal matrix composites for commercial applications. Mater Sci Technol; 16:743–2000.

[5]Shihata K. and Ushio H. Tribological application of MMCs for reducing engine weight. Tribal. ht., 1994, 27. 1, 3941.

[6]Chellman D.J. and Langenheck S.L. Aerospace applications of advanced aluminum alloys. Key Etzg. Mater. 1993, 77-78, 49-60.

[7] Alpas AT, Embury JD.Wear mechanisms in particle reinforced and laminated metal matrix composites. In: Ludema KC, Bayer RG, editors.Wear of materialsASME; 1991. p. 159–66. New York.

[8] Ruff AW, Lashmore DS. Effect of layer spacing on wear of Ni/Cu multilayer alloys. Wear 1991; 151:245–53.

[9] Courtright EL, Patten JW. Wear behavior in thin layered Au/SS and Au/Mo coatings, Office of Naval Research, Battelle, Pacific Northwest Laboratories, Technical Report, Washington; 1982.

[10] Norose S, Sasada T. Anti-wear property of metal laminates.Proc. Japan, Int. Tribo. Conf., Japanese Society of Tribologists,Nagoya; 1990. p. 689–94.

[11] Deng X, Chawla N, Chawla K, Koopman M, Chu J. Mechanical behavior of multilayered nanoscale metal-ceramic composites.Adv Eng Mater 2005;7:1099–108.

[12] Pauleau Y, Thiery F. Deposition and characterization of nanostructured metal/carbon composite films. Surf Coat Technol 2004; 180:313–22.

[13] Portu G, Micele L, Prandstraller D, Palombarini G, Pezzotti G. Abrasive wear in ceramic laminated composites. Wear 2006; 260:1104–11.

[14] Toschi F, Melandri C, Pinasco P, Roncari E, Guicciardi S, De Portu G. Influence of residual stresses on the wear behavior of alumina/alumina–zirconia laminated composites. J Am Ceram Soc 2003; 86:1547–53.

[15] Zoheir N. Farhat. Wear resistant composite coatings. Materials Characte rization 6 0 (2 0 0 9), 3 3 7 – 3 4 5.

[16] Archard, J. F., Journal of Applied Physics, 1953, 24, 981.