JJMIE

Volume 8 Number 6, December 2014
ISSN 1995-6665
Pages 351 - 358

Jordan Journal of Mechanical and Industrial Engineering

Sliding Wear Response of an Aluminium Metal Matrix Composite: Effect of Solid Lubricant Particle Size

Gajendra Dixit [a*], Mohammad Mohsin Khan [b]

[a] *Professor, Maulana Azad National Institute of Technology Bhopal-462051, India*

[b] *Research Scholar, Maulana Azad National Institute of Technology Bhopal-462051, India*

Received 21 jun 2014 *Accepted 3 Dec 2014*

Abstract

The present work investigates the partial lubricated sliding wear behavior of 10 wt% SiC reinforced aluminum composites produced by Vortex method with the help of a pin on disc wear testing machine. The wear tests were conducted at the sliding velocities of 2.1 and 8.4 m/sec and at an applied load of 10 to 200 N in different lubricated environment [oil, oil+ 5wt %graphite (7-10 µm), and oil+ 5wt % graphite (100 µm)]. The influence of changing graphite particle size in the oil lubricant towards controlling the wear behavior of the samples has been studied. The (Aluminium-based) matrix alloy was also characterized under identical conditions to examine the influence of the dispersoid (SiC) phase on the wear behavior. The parameters studied are wear rate, frictional heating and friction coefficient. Results showed a large improvement in wear resistance of the Aluminium-based alloy after reinforcement with SiC particles. The composite experienced a higher frictional heating and friction coefficient than the matrix alloy in all the cases. The wear rate and frictional heating increased with load and speed while friction coefficient was affected in an opposite manner. Test duration influenced the frictional heating and friction coefficient of the samples in a mixed manner.

Keywords: *Aluminium Alloy; Composite; Lubricated Sliding Wear Behavior; Solid Lubricant*.

1. Introduction

In many engineering applications, aluminium alloys are desirable because of their low density and high strength-to-weight ratio. In several such applications, improved wear resistance of the alloys becomes imperative. Al–Si alloys form an interesting series of the alloy system in this context. Their composites containing hard particles are gaining importance. These materials have properties like high specific strength, high specific stiffness, improved high temperature performance as well as good wear and seizure resistance. The properties of composite materials can be tailored by suitably selecting the matrix alloy and the dispersoid phase. Owing to their versatile properties, composite materials hold a potential for applications in automotive, aerospace, sporting goods and in general engineering.

Available literature posits that the wear behavior of materials depends on a number of operational and material related conditions in a complex manner and even they have synergistic effects on the overall response of materials [1-14]. Chemistry, microstructure and shape, size, content and mode of distribution of the microconstituent, in terms of hardness, strength, cracking tendency, lubricating characteristics, load bearing capability as well as thermal stability are some of the important factors to affect wear behavior [1-14]. The sliding wear behavior is controlled by a number of experimental parameters such as speed, load, conditions, distance, etc. [1-28].

The conditions may be dry, lubricated, high temperature, oxidizing, reducing etc. Lubricants may be liquid, semi-solid, or solid. Nowadays, solid lubricants are added in order to further improve the performance of the liquid lubricants. A variety of solid lubricants are in existence. They are generally lamellar solids with (open) hexagonal structure with c/a ratio larger than that of an ideal close packed hexagonal [29, 30]. This enables them to easily smear along the contacting surfaces producing lubricating effect and thereby to improve wear performance. For the effective working of solid lubricants, the presence of a liquid lubricant is essential and the quantity of solid lubricant to be added to the liquid lubricant that would lead to the best wear performance. This depends on a number of factors like the ones related to material as well as test parameters and need to be determined /optimized for effective utilization of a liquid/solid lubricant. Recent studies have led to a limited understanding of some of the aspects but the role of lubricant's particle size has not practically been studied on the wear behavior of Aluminium based alloys. Moreover, there is a paucity of information pertaining to the influence

* Corresponding author. e-mail: dixitgajendra1@gmail.com.

of hard particle reinforcement on the partial lubricating wear behavior of the (Aluminium-based) matrix alloy(s).

In light of the above, an attempt has been made in this study to analyze the sliding wear behavior of an Aluminium alloy and its composite reinforced with 10 wt% SiC particles under the influence of varying applied loads and speeds in partial lubricated conditions [oil, oil+ 5wt %graphite (7-10 µm), and oil + 5wt % graphite (100 µm)]. The influence of changing particle size of graphite in the oil lubricant towards controlling the wear behavior of the samples has been studied.

Table 1. Chemical Composition of the Test Materials

Element	Elements, wt%							
	Si	Mn	Mg	Cu	Fe	Ni	Al	SiC
ADC-12	10.29	0.12	0.47	1.98	0.75	0.80	Balance	-
ADC-12 + SiC Composite	10.29	0.12	0.47	1.98	0.75	0.80	Balance	10

2. Experimental

2.1. Material Preparation

The experimental alloys and composite were prepared by the liquid metallurgy route in the form of 16 mm diameter,170 mm long cylindrical castings. The composite was synthesized by dispersing 50-100 µm silicon carbide particles at the vortex of the alloy melt. Table 1 shows the chemical compositions of the sample materials.

2.2. Microstructural Examination

Microstructural studies were carried out on 10 mm diameter, 15 mm thick samples. The samples were polished metallographically and etched suitably. Killer reagent was used for etching the samples of the aluminium (matrix) alloy and composite. A microstructural characterization of the samples was carried out using scanning electron microscopy.

2.3. Measurement of Hardness and Density

Hardness measurements were carried out on metallographically polished samples using a Vickers hardness tester. The applied load in this case was 30 kg. The water displacement technique was adopted for density measurement. A Mettler microbalance was used for weighing the samples in water and air.

2.4. Sliding Wear Tests

Sliding wear tests were carried out using SAE 20W-40 oil, SAE 20W- 40 oil plus (5 Wt %) graphite particles (size 7-10 µm), and SAE 20W- 40 oil plus (5 Wt %) graphite particles (size 100 µm) as lubricant using a Magnum Engineers (India) make pin-on-disc machine shown in Figure 1. Cylindrical test pins (8 mm diameter and 30 mm length) were held against a rotating heat-treated En31 steel disc conforming to AISIE 52100 (1.0 % C, 1.4 % Cr, 0.40 % Mn, 0.2 % Si, 0.05 % S, 0.05 % P and balance Fe). Hardness of the disc was HRC 62. The steel disc was polished mechanically up to a roughness (Ra) level of 1-2 µm prior to each test.

Wear tests were conducted over a range of applied loads and sliding speeds. The track diameter of 100 mm enabled the rotational speeds of 400 and 1600 rpm (selected in the present investigation) to attain linear sliding velocities of 2.09 and 8.38 m/s, respectively. The wear testing procedure involved inserting the disk into lubricant /lubricant mixture and allowing it to rotate at a speed of 3.35 m/s for 5 s. The lubricated disk was rotated in order to generate a low and uniform thickness by spinning off the excess lubricant. Thereby, maintaining conditions close to mixed lubrication generally encountered by components in situations dealing with sparse lubrication as well as during starting and stopping operations in the case of fully lubricated sliding. Further sample was fixed in the specimen holder, allowing the disk to rotate at the predetermined sliding speed up to the fixed distance of 2500 m or until specimen seizure, whichever occurred earlier. Specimen seizure was noticed in terms of large material adhesion on to the disc, higher rate of temperature rise of the test pin, and abnormal vibration and noise from the pin-on-disc assembly.

Frictional heating was monitored using a chromel-alumel thermocouple inserted in a 1.5 mm diameter hole on the test pin 1.5 mm away from the sliding surface. Output of the thermocouple is fed into a PC-based data logging system which continuously records the frictional heating of sample during each test. The loads were vertically applied on to the pin sample against the disc. Output from strain gauge is also fed into a PC-based data logging system which continuously records the tangential load on the pin sample during each test.

Coefficient of friction was calculated by dividing the tangential load with the applied normal load. The specimens were thoroughly cleaned in acetone for 10 min using ultrasonic cleaner (34 ± 3 kHZ), dried and weighed prior to and after each test. A Mettler instrument make microbalance was used for weighing the specimens. Weight loss was then converted into volume loss per unit sliding distance to compute wear rate.

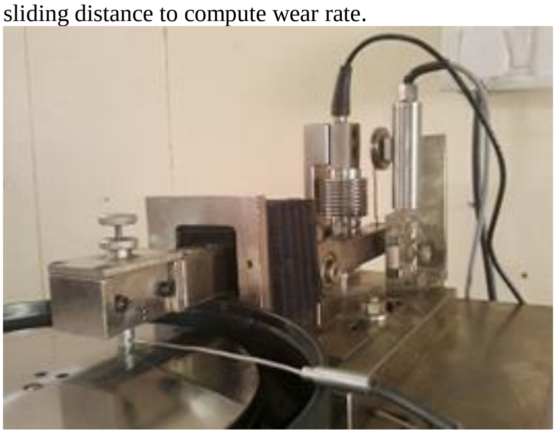

Figure 1. Schematic representation of the wear test configuration.

3. Results

3.1. Microstructure

Microstructure of Aluminum alloy (ADC12 alloy) solidified in a cast iron mold shows aluminum dendrites with dendretic arm spacing in the range of 25 microns. The eutectic silicon solidifies in the inter-dendretic region and around the dendrites. The micrograph (Figure 2) depicts plate shaped eutectic silicon and the other intermetallic phases. The plate shaped eutectic silicon is usually 20-30 micron in length and 2-5 micron in width. The composite showed features similar to the matrix alloy except the presence of the dispersoid SiC particles (Figure 3).

3.2. Hardness and Density

Table 2 represents various properties of the specimens. The composite attained somewhat a higher hardness than the corresponding matrix alloy. So far as the density of the specimen is concerned, it was highest for the composite followed by matrix alloy.

Table 2. Hardness and Density of Specimen

S No.	Type	Vickers Hardness (HV)	Density g/cm^3
1	ADC-12 Matrix Alloy	92.3	2.64
2	ADC-12 Matrix Alloy + Composite	98.7	2.78

3.3. Wear Behavior

3.3.1. Wear Rate

Wear Rate of the samples has been plotted as a function of applied load in Oil + 5% Graphite (7-10 µm), Oil + 5% Graphite (100 µm) & Oil Lubricated environment at sliding velocity of 2.1 and 8.4 m/sec in Figure 4 to Figure 6, respectively. Wear rate increases with the load and sliding velocity for all the sample material and in all environments. Incorporation of SiC significantly reduces the wear rate of the alloy irrespective of the test conditions (Figure 4 – Figure 6). The presence of solid lubricant reduces the wear rate for all the test material. However Oil + 5% Graphite (7-10 µm) is proven to be more effective than the Oil + 5% Graphite (100 µm) {Figure 7-Figure 8}.

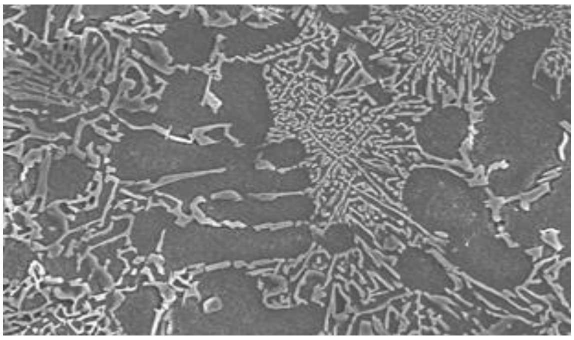

Figure 2. Microstructure of ADC-12 Alloy

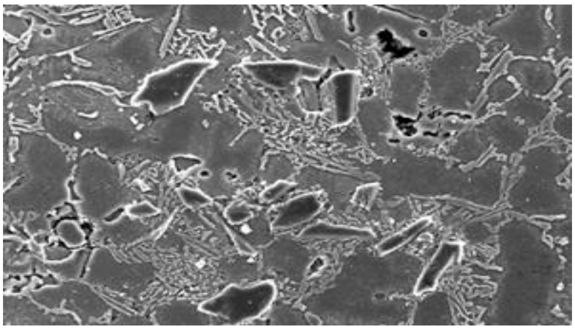

Figure 3. Microstructure of ADC-12 Alloy+ 10% SiC Composite

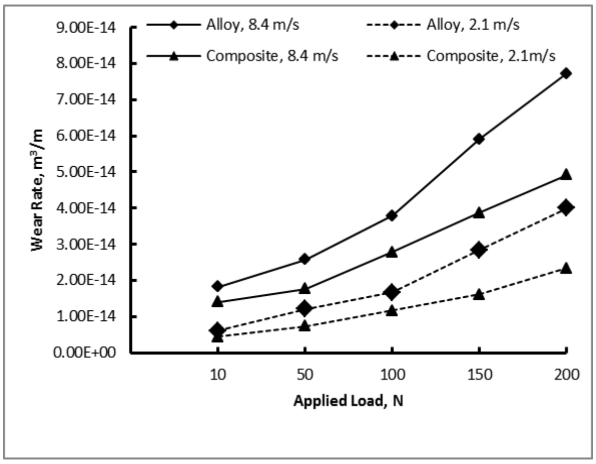

Figure 4. Wear Rate of Alloy and Composite plotted as function of a Applied load in Oil + (7-10µm Graphite) Lubricated Environment

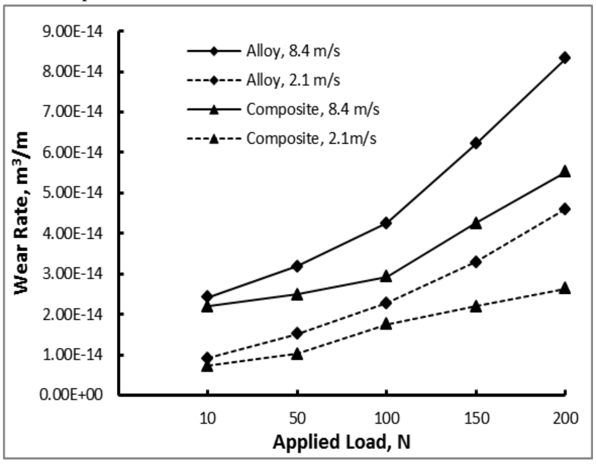

Figure 5. Wear Rate of Alloy and Composite plotted as a function of Applied Load in Oil + (100µm Graphite) Lubricated Environment

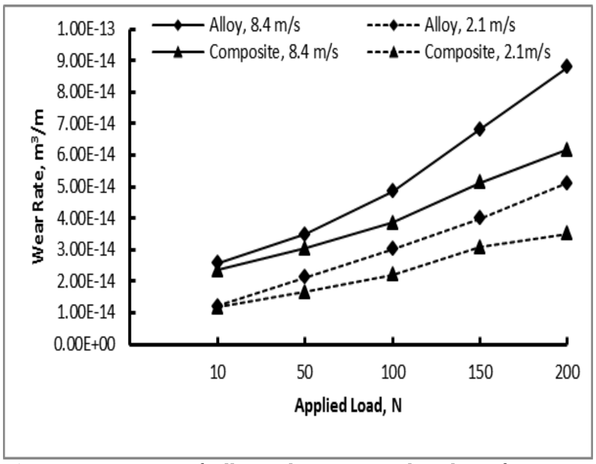

Figure 6 .Wear Rate of Alloy and Composite plotted as a function of Applied Load in Oil Lubricated Environment

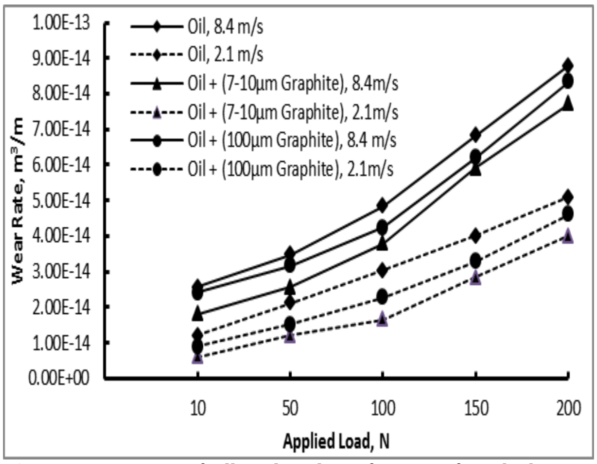

Figure 7. Wear Rate of Alloy plotted as a function of Applied load in various Environment

3.3.2. Frictional Heating

Temperature near the contacting surface for Alloy and composite at Sliding Velocity of 2.1 & 8.4 m/sec plotted as a function of applied load in various lubricated test environments in Figure 9 to Figure 13, respectively. The temperature increases with increase in load and velocity however the increment is more for the composite than the base alloy (Figure 9-Figure 11). The pattern of temperature is similar in all the environments despite of the fact that the addition of the solid lubricant peculiarly affects the pattern of temperature variation. For all the testing materials, the maximum temperature rise is observed at 8.4 m/sec sliding velocity is in Oil + 5% graphite (100 μm) lubricated environment followed by Oil and Oil + 5% graphite (7-10 μm) lubricated environment.

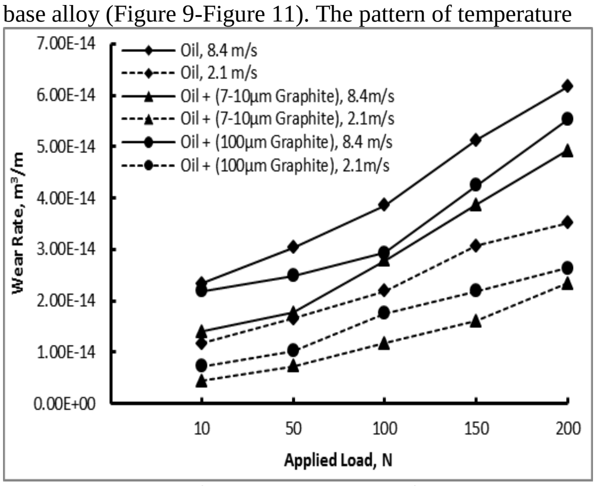

Figure 8 .Wear Rate of Composite plotted as a function Applied load in various Environment

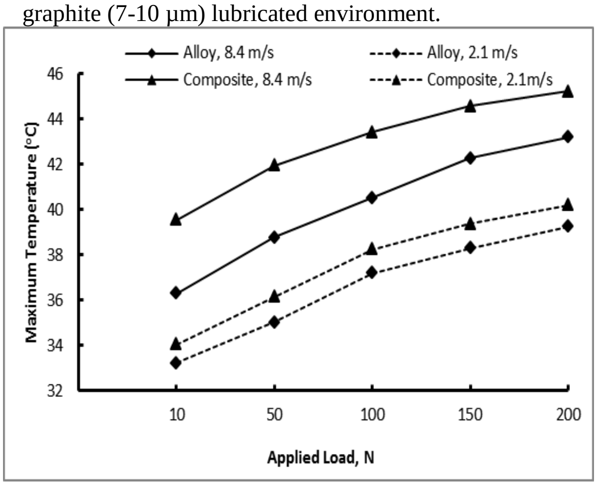

Figure 9. Maximum Temperature in Oil Lubricated Environment

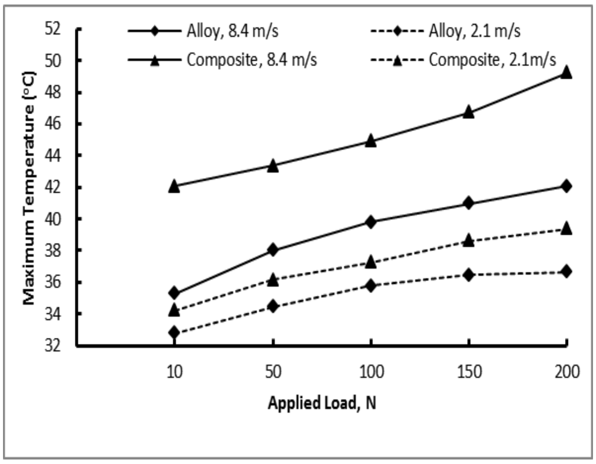

Figure 10. Maximum Temperature in Oil + (7-10µm Graphite) Lubricated Environment

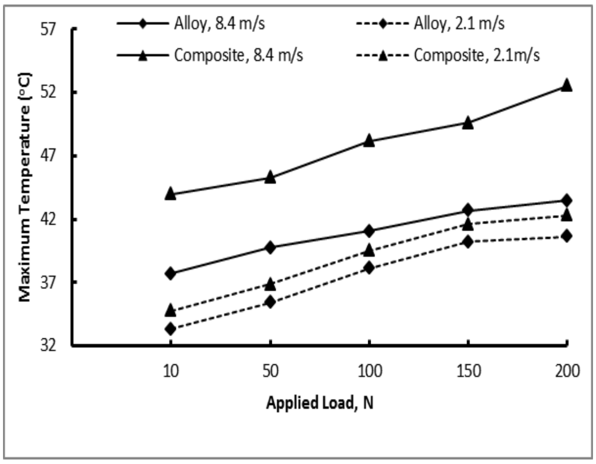

Figure 11. Maximum Temperature in Oil + (100µm Graphite) Lubricated Environment

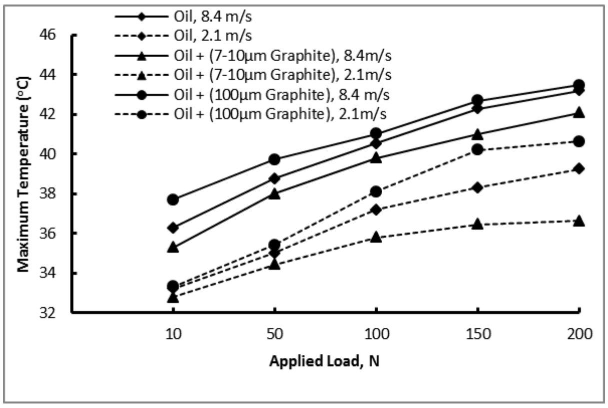

Figure 12. Maximum Temperature of Alloy in Various Environments

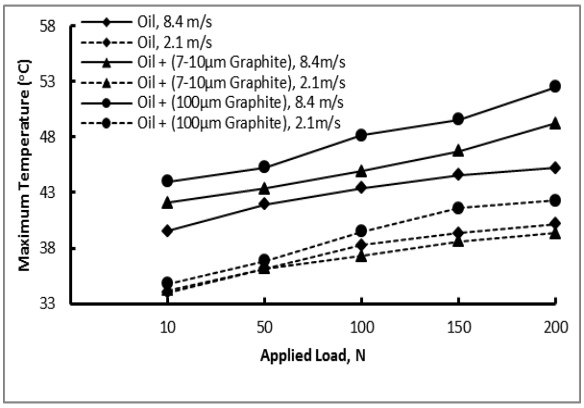

Figure 13. Maximum Temperature of Composite in Various Environments

3.3.3. Friction Coefficient

Figure 14 to Figure 16 represent the friction coefficient for Aluminium-Alloy and Aluminium -SiC composite as a function of Applied Load in various lubricated condition at a sliding velocity of 2.1 and 8.4 m/sec. friction coefficient decreases with the increase in applied load while it varies directly with the sliding speed irrespective of the test material. Incorporation of SiC particle increases the friction coefficient in Oil and Oil + 5wt% graphite (100 µm) lubricated environment however in Oil + 5wt% graphite (7-10 µm) environment it varies in some other manner.

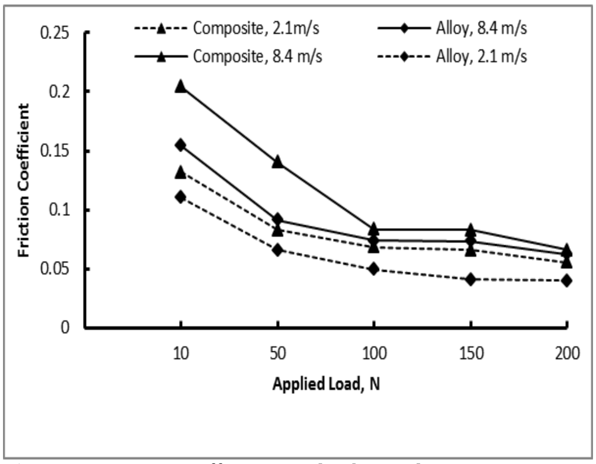

Figure 14. Friction Coefficient in Oil Lubricated Environment

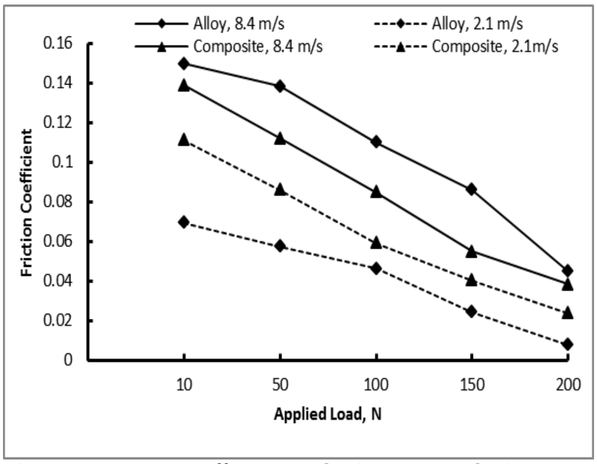

Figure 15 . Friction Coefficient in Oil + (7-10µm Graphite) Lubricated Environment

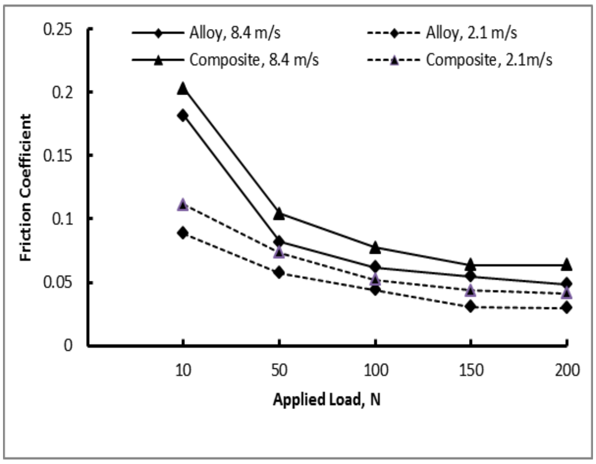

Figure 16. Friction Coefficient in Oil + (100µm Graphite) Lubricated Environment

4. Discussion

4.1. Microstructure

From microstructural characteristics point of view, the aluminium based alloy depicts plate shaped eutectic silicon and the other intermetallic phases (Figure 2). Reinforcing the alloy system with thermally stable micro-constituents through alloying with high melting elements and/or incorporation of hard ceramic particles improves its strength (Figure 3). Wear resistance under severe conditions also improves because of improved thermal stability while ambient temperature properties deteriorate over the matrix alloy due to enhanced cracking tendency introduced by the thermally stable micro-constituents [1-10].

4.2. Wear Behavior

4.2.1. Wear Rate

Coming to the sliding wear tests, factors affecting the wear response of materials are applied load, sliding velocity, sliding distance and test environment. Applied load directly influences the wear rate, i.e., the higher the load is the greater the wear rate becomes. Other variables, such as distance and velocity, do not have well defined effects on the wear response of materials [1-10, 31-41]. As far as the environmental (lubricated, oil / oil + graphite) effects are concerned, a lot of complexity exists [1-10, 31-41].

Normally, the use of a lubricant improves the sliding wear characteristics of material because of the formation of a lubricating film consisting of a variety of reaction products [42-44]. The introduction of a solid lubricant into the liquid / semi solid lubricant brings about a further improvement in wear behavior by increasing the stability of the film. It looks logical for an optimum quantity of the (solid/liquid) lubricating constituents to exist in the (lubricant) mixture leading to the best wear performance of materials. The optimum of course may vary with material characteristics as well as operating conditions and, above all, the nature of the lubricating constituents. This is in view of the fact that the lubricant mixture should not lose adherence with the contacting surface and, at the same time, it should have enough lubricating characteristics. The question of losing adherence arises when the mixture become too dry, i.e., when the quantity of the solid lubricating phase in the mixture becomes too much to cause tearing-off the thick and dry lubricating film. Subcritical quantity of the solid lubricating phase reduces the probability of forming a stable lubricating film on the contacting surfaces. Accordingly, either side of the content of the solid lubricant constituent phase in the lubricant mixture may deteriorate the wear response of materials.

Having discussed the role of various material and operating variables on wear behavior, we will be able to better understand the observed wear response of the samples in this investigation.

The addition of graphite to oil lubricants increased the possibility of the formation of a more stable lubricating film causing further in the wear rate. However, this could be realized that for the (7-10 µm) size of graphite particle in the oil, minimum wear rate was obtained.

4.2.2. Frictional Heating

Increasing rate of frictional heating with test duration could be attributed to the increasing effective area of contact thereby reducing the severity of wear condition. A higher rate of temperature rises in some cases towards the end of the tests owing to the sticking /adhering tendency of the specimen material to the disc surface. A more severe wear condition, due to increasing applied load, led to a higher increase in the rate of temperature. The matrix alloy exhibited the generation of least frictional heat due to its excellent lubricating tendency. The abrasion caused by the fragmented dispersoid SiC particles caused larger frictional heating than the matrix alloy [9, 10]. The presence of the lubricant leading to the formation of a more stable lubricating film substantially reduced the temperature increase over dry wear. The addition of graphite further decreased the frictional heating through the formation of a still more stable lubricating film. The matrix alloy was most favorably affected in this case in view of the major constituent being solid lubricating in nature.

4.2.3. Friction Coefficient

The probability of more effective formation of a lubricant film caused the friction coefficient to decrease with an increase in the load. The abrasion caused through the entrapped dispersoid phase after fragmentation during wear led to higher friction coefficient of the composite than matrix alloy. More effective formation of lubricating film in the presence of liquid /liquid + solid lubricant led to a reduced friction coefficient. The lack of cracking tendency in the matrix alloy led to its reduced friction coefficient considerably under identical test conditions. Least friction coefficient in the event of adding graphite particle in the lubricating oil could be attributed to the formation of most stable lubricating film.

An appraisal of the observations made in this study clearly suggests varying effects of parameters like cracking tendency, lubricating characteristics, thermal stability, etc. of material constituents and experimental parameters like load and conditions. The overall effect of the parameters on the wear behavior of the samples seems to be complex in nature.

5. Conclusion

Based on the observations made in this study, the following conclusions could be drawn:

- The Matrix Alloy depicts plate shaped eutectic silicon and the other intermetallic phases while the composite revealed the presence of the dispersed SiC particles in addition to the features of the matrix alloy.
- The density was the least for aluminium-based (matrix) but the composite exhibited the maximum hardness.
- Wear Rate increased with load and speed. Testing the samples in oil plus graphite lubricated conditions led to less wear rate than that in oil alone. Addition of 5 wt% graphite (7-10 µm) to the oil lubricant led to minimum wear rate. The composite exhibited lowest wear rate while it was the maximum for the matrix alloy.
- Frictional heating increased with load and test duration; the frictional heating increased at a higher rate initially

followed by a lower rate of increase at longer test durations. Testing the samples in oil plus graphite lubricants led to a marginal change in frictional heating.

- The friction coefficient decreased with test duration. Testing the samples in oil lubricated conditions decreased the friction coefficient of the samples especially at low loads. Test duration had a mixed influence on friction coefficient. The addition of graphite to the lubricating oil further reduced the coefficient of friction. No definite influence of the graphite content (to the oil) on friction coefficient of the materials was noted.

References

[1] B. K. Prasad, A. H. Yegneswaram, A. K. Patwardhan, "Characterization of the wear response of a modified zinc-based alloy vis-à-vis a conventional zinc-based alloy and a bearing bronze at a high sliding speed". Metallurgical & Material Transaction A, Vol. 27A (1996) 3513-3523.

[2] B.K. Prasad, "Mechanical Properties & Sliding Wear Characteristics of Zinc Based Alloys: Effects of Partially Substituting Copper by Silicon". Zeitschrift fur Metallkunde, Vol. 88 (1997) 929-933.

[3] B. K. Prasad, "Tensile Properties of Some Zinc Based Alloys Comprising 27.5% Al: Microstructure & Test conditions". Materials Science & Engineering A, Vol. 245A (1998) 257-266.

[4] B. K. Prasad, A.K. Patwardhan and A.H. Yegneswaram, "Microstructural Modifications through Compositional alterations and their Influence on the Mechanical and Sliding Wear Properties of Zinc-Based Alloys". Scripta Materiallia, Vol.37 (1997) 323-328.

[5] B.K. Prasad, A.K. Patwardhan and A.H. Yegneswaram, "Microstructure- Property characterization of some zinc based alloys: Effect of heat treatment parameters". Zeitschrift fur Metallkunde Vol. 87 (1996) 967-972.

[6] B.K. Prasad, "Response of Some Cast Zinc 37.5% Al Based Alloys Comprising Nickel/Silicon under Different Tensile Loading Conditions". Journal of Materials Engineering and Performance, Vol. 7 (1998) 632-636.

[7] B.K. Prasad, "Effect of Microstructure on the Sliding Wear Performance of a Zn-Al-Ni Alloy". Wear, Vol. 240 (2000) 100-112.

[8] H.X. Zhu and S.K. Liu, "Mechanical Properties of Squeeze Cast Zinc Alloy Matrix Composites Containing α-Alumina Fibers" Composites, Vol. 24 (1993) 437-442.

[9] B.K. Prasad, S.Das, O.P. Modi, A.K. Jha, R. Dasgupta, A.H. Yegneswaram, "Wear Response of a Zinc-Based Alloy in the Presence of SiC Particle Reinforcement: A Comparative Study with a Copper Base Alloy". Journal of Materials Engineering and Performance, Vol. 8 (1999) 693-700.

[10] B.K. Prasad, A.K. Jha, S. Das, O.P. Modi, R. Dasgupta and A.H. Yegneswaram, "Sliding wear response of a Zinc Aluminium alloy as affected by SiC particle dispersion and test condition". Journal of Materials Science Letters, Vol. 18, (1999) 1731-1734.

[11] B.K. Prasad, A.K. Jha, O.P. Modi, S. Das and Yegneswaram, "Abrasive Wear Characteristics of a Zn - 37.2 Al - 2.5 Cu - 0.2 Mg Alloy Dispersed with Silicon Carbide Particles". Materials Transactions of Japan Institute of Metals, Vol. 36 (1995) 1048-1057.

[12] B.K. Prasad, S. Das, A.K. Jha, O.P. Modi, R. Dasgupta and A.H. Yegneswaram, "Factors Controlling the Abrasive Wear Response of a Zinc-Based Alloy Silicon Carbide Particle Composite" Composites A, Vol. 28A (1997), 301-308.

[13] B.K. Prasad, "Abrasive Wear Characteristics of a Zinc-Based Alloy and Zinc-Alloy/SiC Composite". Wear, Vol. 252 (2002) 250-263.

[14] B. K. Prasad, "Effects of Alumina Dispersion on the Erosive-Corrosive Wear Response of a Zinc-Based Alloy under Changing Slurry Conditions and Distance" Wear, Vol. 238 (2000) 150-158.

[15] B.K. Prasad, A.K. Patwardhan and A.H. Yegneswaram, "Wear characteristics of a Zinc based alloy compared with a conventional bearing bronze under mixed lubrication condition: Effects of material & test parameters" Canadian Metallurgical Quarterly, Vol. 40 (2001)193-210.

[16] B.K. Prasad, "Effects of Heat Treatment on the Partially Lubricated Sliding Wear Behaviour of a Zinc-Based Alloy" Materials Transactions of Japan Institute of Metals, Vol. 40 (1999) 578-585.

[17] S. W. Kima, U. J. Leea, S. W. Hana, D. K. Kima and K. Ogib, "Heat treatment and wear characteristics of Al/SiCp composites fabricated by duplex process". Composites: Part B, Vol. 34 (2003) 737–745.

[18] R.K. Uyyuru, M.K. Surappa and S. Brusethaug, "Effect of reinforcement volume fraction and size distribution on the tribological behavior of Al-composite/brake pad tribo-couple". Wear, Vol. 260 (2006) 1248–1255.

[19] S. Zhang and F.Wang, "Comparison of friction and wear performances of brake material dry sliding against two aluminum matrix composites reinforced with different SiC particles". Journal of Materials Processing Technology, Vol.182 (2007)122–127.

[20] R.N. Rao, S. Das, D.P. Mondal and G. Dixit, "Dry sliding wear behaviour of cast high strength aluminium alloy (Al–Zn–Mg) and hard particle composites". Wear, Vol. 267 (2009)1688–1695.

[21] R.N. Rao, S.Das, D.P.Mondal and G.Dixit, "Effect of heat treatment on the sliding wear behaviour of aluminium alloy (Al–Zn–Mg) hard particle composite". Tribology International, Vol. 43 (2010) 330–339.

[22] S. Suresha and B.K. Sridhara, "Effect of addition of graphite particulates on the wear behaviour in aluminium-silicon carbide-graphite composites". Materials and Design, Vol. 31, (2010)1804-1812.

[23] R.N. Rao and S. Das, "Effect of matrix alloy and influence of SiC particle on the sliding wear characteristics of aluminium alloy composites". Materials and Design, Vol. 31 (2010) 1200–1207.

[24] G. Naveen Kumar, R. Narayanasamy, S. Natarajan, S.P. Kumaresh Babu,K. Sivaprasad and S. Sivasankaran, "Dry sliding wear behaviour of AA 6351-ZrB2 in situ composite at room temperature". Materials and Design, Vol.31 (2010) 1526–1532.

[25] R.N. Rao and S. Das, "Effect of SiC content and sliding speed on the wear behaviour of aluminium matrix composites". Materials and Design, Vol. 32, (2011)1066–1071.

[26] G.B. Veeresh Kumar, C.S.P. Rao and N. Several, "Studies on mechanical and dry sliding wear of Al6061–SiC composites". Composites: Part B, Vol.43 (2012)1185–1191.

[27] M. Uthayakumar, S. Aravindan and K. Rajkumar, "Wear performance of Al–SiC–B4C hybrid composites under dry sliding conditions". Materials and Design, Vol. 47 (2013) 456–464.

[28] Devaraju, A. Kumar, A. Kumaraswamy, B. Kotiveerachari, "Influence of reinforcements (SiC and Al2O3) and rotational speed on wear and mechanical properties of aluminum alloy 6061-T6 based surface hybrid composites produced via friction stir processing". Materials and Design, Vol. 51 (2013) 331–341.

[29] E.R.Braithwaite and G.W. Rowe, “Principles and application of lubrication with solids”. Scientific Lubrication, (1963) 92-110.

[30] Y. Ttsuya, R. Takagi, “Lubricating properties of lead films on copper”. Wear, Vol. 7 (1964) 131-143

[31] Rac, “Influence of load and speed on wear characteristics of grey cast iron in dry sliding — selection for minimum wear”. Tribology International, Vol 18 (1985) 29-33

[32] E. Takeuchi, “The mechanisms of wear of cast iron in dry sliding” Wear, Vol. 11 (1968) 201–212.

[33] R.S. Montgomery, “The mild wear mechanism of nodular iron”. Wear, Vol. 13 (1969) 337–343.

[34] F. Wilson, T.S. Eyre, “Effect of matrix structure and hardness on the wear characteristics of an S.G. cast iron”. Wear, Vol. 14 (1969) 107–117.

[35] M. Kawamoto, K. Okabayashi, “Study of dry sliding wear of cast iron as a function of surface temperature”. Wear, Vol. 58 (1980) 59-95.

[36] Y. Zhang, Y. Chen, R. He, B. Shen, “Investigation of tribological properties of brake shoe materials — phosphorous cast irons with different graphite morphologies”. Wear, Vol. 166 (1993) 179-186.

[37] E.P. Fordyce, C. Allen, “The dry sliding wear behaviour of an austempered spheroidal cast iron”. Wear, Vol. 135 (1990) 265-278.

[38] J. Sugishita, S. Fujiyoshi, “The effect of cast iron graphites on friction and wear performance I: Graphite film formation on grey cast iron surfaces”. Wear, Vol. 66 (1981) 209-221.

[39] P. W. Leach, D. W. Borland, “The unlubricated wear of flake graphite cast iron”. Wear, Vol. 85 (1983) 257-266.

[40] Y.S. Lerner and G.R. Kingsbury, “Wear Resistance Properties of Austempered Ductile Iron”. Journal of Materials Engineering and Performance, Vol. 7(1) (1998) 48-52.

[41] S.M.A. Boutorabi, J.M. Young, V. Kondic, M. Salehi, “The tribological behaviour of austempered spheroidal graphite aluminium cast iron”. Wear, Vol. 165 (1993) 19-24.

[42] D.A. Rigney, L.H. Chen, M.G.S. Naylor, A.R. Rosenfield, “Wear processes in sliding systems”. Wear, Vol.100 (1984) 195-219.

[43] F. P. Bowden and D. Tabor, “The Lubrication by Thin Metallic Films and the Action of Bearing Metals”. Journal of Applied Physics, Vol. 14 (1943) 141-151.

[44] G.D. Gamulya, I.L. Lebedeva, Yu.V. Vvedensky, T.P. Yukhno, “Secondary structure formation and wear mechanisms for solid lubricant coatings under friction in vacuum”. Wear, Vol. 171 (1994) 143-148.