INTERNATIONAL JOURNAL OF MECHANICAL ENGINEERING AND TECHNOLOGY (IJMET)

ISSN 0976 – 6340 (Print)
ISSN 0976 – 6359 (Online)
Volume 4, Issue 2, March - April (2013), pp. 178-188
© IAEME: www.iaeme.com/ijmet.asp
Journal Impact Factor (2013): 5.7731 (Calculated by GISI)
www.jifactor.com

IJMET
©IAEME

MICROSTRUCTURE AND TRIBOLOGICAL PROPERTIES OF NANOPARTICULATE WC/AL METAL MATRIX COMPOSITES

Amarnath.G[1] , K.V. Sharma[2]

[1] Research Scholar, Department of Mechanical Engineering,
University Visvesvaraya College of Engineering, Bangalore University,
K.R.Circle, Bangalore-560001,India,

[2] Professor, Department of Mechanical Engineering,
University Visvesvaraya College of Engineering, Bangalore University,
K.R.Circle, Bangalore-560001, India,

ABSTRACT

The tribological property of Al metal matrix composites, reinforced with WC Nano-particles is presented. Sliding tests were performed on a pin-on-disk apparatus under different contact loads. It was found that the reinforced Nano-WC particles could effectively reduce the frictional coefficient and wear rate, especially under higher normal loading conditions. In order to further understand the wear mechanisms, the worn surfaces were examined under the scanning electron microscope. A positive rolling effect of the nanoparticles between the material pairs was proposed which contributes to the remarkable improvement of the load carrying capacity of metal matrix nanocomposites.

Keywords: Frictional coefficient, Metal matrix nanocomposite, positive rolling effect, property wear rate, tribological.

1. INTRODUCTION

It is of interest to use nano-sized ceramic particles to strengthen the metal matrix, while maintaining good ductility, high temperature creep resistance and better fatigue [1]. A variety of methods for producing MMCs have recently become available, including mechanical alloying [12], ball milling [5] and nano-sintering [8]. For mechanical alloying, it normally involves mechanical mixing of metallic and ceramic powders or different metallic powders for fabrication of composite in bulk quantities. Mixing of nano-sized ceramic particles is lengthy, expensive, and energy consuming. Compared with mechanical alloying, melt processing which involves the stirring of ceramic particles in to melts, has some important advantages such as better matrix–particle bonding, easier control of matrix structure, simplicity, low cost of processing, and nearer net shape.

Nano particulate reinforced metal matrix composites (MMCs) have been studied widely in recent years, essentially due to their promising advanced properties. Specific attention has been focused to aluminum matrices which are widely used in MMCs [13]. The advantages of aluminum and its alloys used as the composite's matrix among others are high specific strength and stiffness, good damping capacities, dimensional stability [2]. The mechanical and tribological behavior of the MMC's has been studied extensively. Some information concerning to the wear behavior of Mg-based MMCs reveals that tribological property of Mg alloys can be improved by the addition of hard ceramic fiber or particulate reinforcement [14].

In our experimental study the WC-reinforced composite exhibits a continuous decrease in the coefficient of friction with sliding velocity while that of unreinforced alloy is dramatically increased. Wang et al.[9] observed same friction trends for both Al 7091 alloy and SiC reinforced Al7071. Sliding velocities greater than 1.85 m/s for unreinforced matrix alloy surface could lead to the formation of brittle Al_2O_3 layer. Usually Al_2O_3 layer has higher frictional coefficient than Al6061 alloy. Formation of Al_2O_3 layer thickness increases with increase velocities. The thickness of Al_2O_3 layer increases with increase in velocity, whereas in composites MML acts as a solid lubricant to reduce the coefficient of the friction.

2. EXPERIMENTAL TECHNIQUES

2.1 Composite preparation.

The microstructure of any material is a complex function of the casting process, subsequent cooling rates, heat treatments and aging processes. Therefore composites fabrication is one of the most challenging and difficult task. A commercially available Al 6061 was considered as matrix material in this study. Nano WC particulate was selected as reinforcements. The average diameter of nano WC particle of 300 nm was used as reinforcement. Nano MMCs were fabricated in a special reaction chamber under a vacuum atmosphere.

Melting of Al alloy reaching the temperature between 650°C and 700°C, the mixture of WC powder of wt. % of 5, 10 and 15%, was then introduced into the melt by carrier Argon gas. The Al melt was agitated by the propeller, and the WC was introduced into the melt. The task was carried out for an appropriate length of time to ensure the complete mixing of WC in the melt then pour into the die. Three-phase resistance type 12 KW capacity furnace is used for melting.

The temperature range of the furnace is 1200°C with a control accuracy of ± 10° C fitted with seven segmented light emitting diode read out and partially integrated differential digital temperature controller. The shooting capacity of the furnace is 500°C per hour. It is fitted with an alumina crucible at its center and it can be tilted by 90 degrees on its horizontal axis enabling pouring of the melt.

2.1.1 Melting of the matrix alloy.

The melting range of Al alloy is 650 - 700°C. A known quantity of the Al alloy ingots were pickled in 10% NaOH solution at room temperature for ten minutes. Pickling was done to remove the surface impurities. The smut formed was removed by immersing the ingots for one minute in a mixture of 1 part Nitric acid and 1 part water followed by washing in methanol. The cleaned ingots after drying in air were loaded into the alumina crucible of the furnace for melting. The melt was super heated to a temperature of 540°C and maintained at that temperature. A Chromel-alumel thermocouple was used to record temperatures. The molten metal was then degassed using purified nitrogen gas. Purification process with commercially pure nitrogen was carried out by passing the gas through an assembly of chemicals arranged in a row (concentrated sulphuric acid and anhydrous calcium chloride) at the rate of 1000 cc/ minute for about 8 minutes.

2.1.2 Preheating of reinforcement

Muffle furnace was used to preheat the particulate to a temperature of 500°C. It was maintained at that temperature till it was introduced into the Al alloy melt. The preheating of the reinforcement is necessary in order to reduce the temperature gradient and to improve wetting between the molten metal and the particulate reinforcement.

2.1.3 Mixing and stirring

Alumina coated stainless steel impeller was used to stir the molten metal to create a vortex. The impeller was of centrifugal type with three blades welded at 45° inclination and 120° apart. The stirrer was rotated at a speed of 500 rpm and a vortex was created in the melt. The depth of immersion of the impeller was approximately one third the height of the molten metal from the bottom of the crucible. The pre-heated reinforcing particles were introduced into the vortex at the rate of 120 gm/min. Stirring was continued until interface interactions between the particles and the matrix promoted wetting.

2.1.4 Casting of Composite Melt under Pressure

The melt was degassed using pure nitrogen for about 3-4 minutes and after reheating to super heated temperature (700°C), it was poured into the pre heated lower half die of the hydraulic press. The top die was brought down by applying a pressure of 100 kg/cm^2 to solidify the composite. Both the lower and the upper half dies were preheated to 280°C, before the melt was poured into it. The applied pressure enables uniform distribution of the particulate in the developed composite. The distribution of particles in Al melt was uniform and without any noticeable agglomeration when the composite melt was cast in permanent dies after applying an optimum pressure in a hydraulic press. The castings were allowed to remain at room temperature for some time before subjecting to any heat treatment.

2.2 Microstructure characterization techniques

In the present work, microstructure characterization of the Al matrix alloy and MMCs are undertaken to study the effect of reinforcement on the matrix. Optical micrographs and SEM studies are also undertaken.

2.2.1 Grinding and polishing

After usual grinding and machining, the specimens were rough polished using 100, 200, 400,600, 800 and 1200 grit silicon carbide papers. These papers are less susceptible to loading than emery papers. The specimens were held firmly in hand and rubbed smoothly against the SiC papers, exercising sufficient care to avoid any deep scratches since the Al alloys are comparatively soft. Excessive heat formation during polishing was avoided as Al alloys contain many metastable phases.

Fine polishing was performed using magnesium oxide paste followed by diamond paste using polishing machine. The platform was covered with billiard cloth. Separate platforms were used for magnesium oxide and diamond polishing. During fine polishing with magnesium oxide paste, hands as well as specimen were washed with water in between to prevent carryover of coarser grit from previous steps. After polishing with magnesium oxide, the specimens were finally polished with 1 µm thin diamond paste after changing the platform. The specimens were then cleaned with alcohol and dried in air.

2.2.2 Etching

The most useful etchant for microscopic examination of Al and Al alloys are aqueous solutions of chromic acid to which sodium sulphate has been added. Etchant composition consists of 200gm chromic acid, 15gm sodium sulfate and 1000 ml water.

The specimen surface was first cleaned in alcohol, then in running water and etched while wet. To avoid staining after etching, it was immediately rinsed in a solution of 200 gm chromic acid in 1000 ml of water. Etching duration was 4 to 5 sec, followed by rinsing in water. The samples were dipped in alcohol and dried in a stream of warm clean air.

2.2.3 Optical microscopy

Optical micrographs were taken using the Olympus metallurgical microscope (reflection type), fitted with a camera. The magnification used: x 200

2.3 Wear test

The wear test was performed on a Duecom pin-on-disc apparatus according to ASTM standard. The specimen pins were rotated against a polished steel disc with the initial surface roughness of approximately 220 nm. The tests were conducted for 60 min each in a wide range of wear conditions, i.e., the normal load in a range from 10 to 40N and the sliding velocity from 1 to 3 m/s. During the test, the temperature of the disc was monitored by an IR gun which monitors and temperature is recorded. The frictional coefficient was recorded and calculated by a ratio between the tangential force and normal load. The mass loss of the specimen was measured in order to calculate the specific wear rate by the following equation.

$$w_s = \frac{\Delta m}{\rho F_n L} \qquad mm^3Nm^{-1} \quad \text{---------} \ (1)$$

In which F_N is the normal load applied on the specimen during sliding, Δm is the specimen's mass loss, ρ is the density of the specimen, and L is the total sliding distance. All the test results were summarized in Table 1. The frictional coefficient and the contact temperature given in this table are mean values measured during the steady state of the sliding process. After wear tests, worn surfaces of specimens were examined by a scanning electron microscope (SEM).

TABLE 1: Tribological properties of Al and Al/nanoWC MMCs under various loads

Normal Load, N	10	20	30	40	10	20	30	40	10	20	30	40
MMCs	Friction Coefficient				Contact temp, °C				Sp. wear rate, 10^{-6} mm^3Nm^{-1}			
Al	0.43	0.41	0.38	0.34	81	82	93	98	6.73	7.85	8.56	10.2
Al/5% WC	0.36	0.35	0.36	0.35	80	82	91	96	3.32	3.65	3.72	4.1
Al/10% WC	0.35	0.36	0.34	0.35	79	83	89	94	2.75	3.01	3.36	3.75
Al/15% WC	0.34	0.32	0.32	0.35	78	82	86	92	2.83	2.98	3.25	3.54

3. RESULTS AND DISCUSSIONS

3.1 Tribological properties.

The tribological properties of the composite are summarized in Table1.

3.1.1 Frictional coefficient and contact temperature

Fig. 3.1 and 3.2 show typical variations of the frictional coefficient and contact temperature against sliding time of Al matrix and different Al/ nano WC MMCs under normal loads of 10, 20, 30 and 40 N at 1 m/s. It was distinct and the two parameters are closely correlated with each other. This has been reported in a previous study by Wang et al. [9].

The frictional coefficient of matrix material increased during initial wear stage. This was probably caused by the increase of real contact area and contact temperature owing to frictional heating. Thereafter, it stabilizes at a certain value. This resulted in a higher specific wear rate. It shows the stick-slip type frictional behavior of both unreinforced alloy and reinforced MMCs as a function of sliding distance. Initial ploughing of the surface by second body asperates and an increase in adhesion with incubation period is which is then followed by a steep rise in friction, this is associated with a rapid increase in the number of particles entrapped between the sliding surfaces.

In the second stage, however both unreinforced alloy and reinforced MMCs reached a steady state causing decreasing friction with the sliding distance. The sliding surface is covered with Al_2O_3 layer. This layer formed is very brittle and acts as an insulator. It is this layer which raises the temperature, as well increases the coefficient of friction. In the case of the composites, a reduction in the coefficient of friction was observed, due to the formation of the iron oxide phase on sliding surfaces, which can be attributed to the fact that iron oxides act as a solid lubricants [6]. The layer thickness increases with increasing reinforcement content. Hence the average coefficient of friction decreases with increase in reinforcement, although at beginning stage it is higher than that of the matrix alloy.

In all cases the average coefficient of friction of composite decreases with increase in wt. % of reinforcement. The above results are in consistent with the trends reported by Skolianos and Kattanis [7] , who have worked on SiC particle reinforced Al-4.5% Cu-1.5% Mg alloy composites. A similar trend was obtained by Rana and Stefanescu[3] **.**The value of the coefficient of friction decreased with an increase in volume fraction of SiC particle, when they studied the friction coefficient existing between an Al-1.5%Mg alloy reinforced with SiC particles and a steel counter face. Saka et al. [4] examined friction and wear in Cu reinforced with Al_2O_3 with similar results, viz., for steady state wear, the coefficient of friction decreases with increase in alumina content.

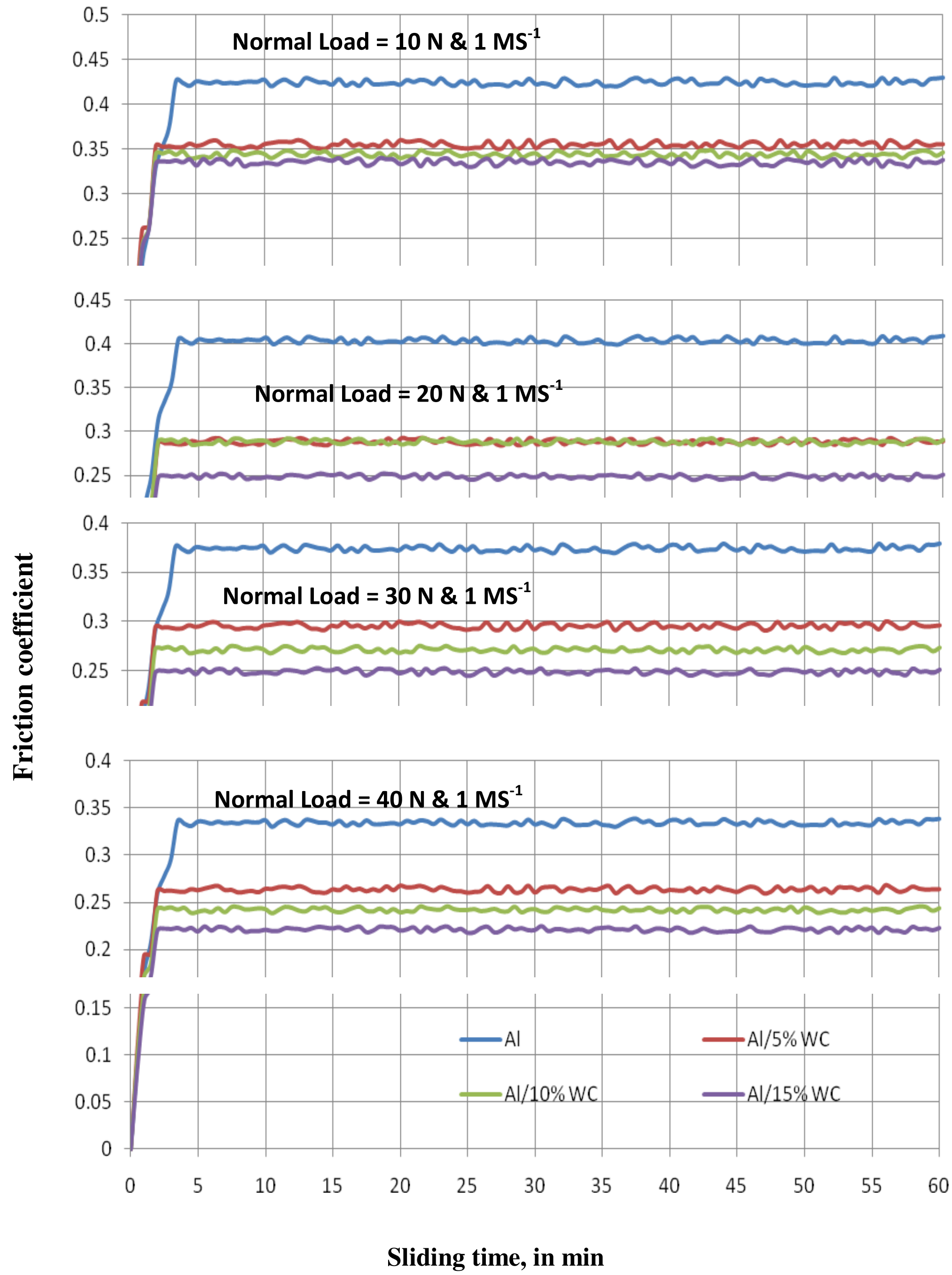

Fig. 3.1: The typical sliding process curves of frictional coefficient against sliding time under a standard wear condition.

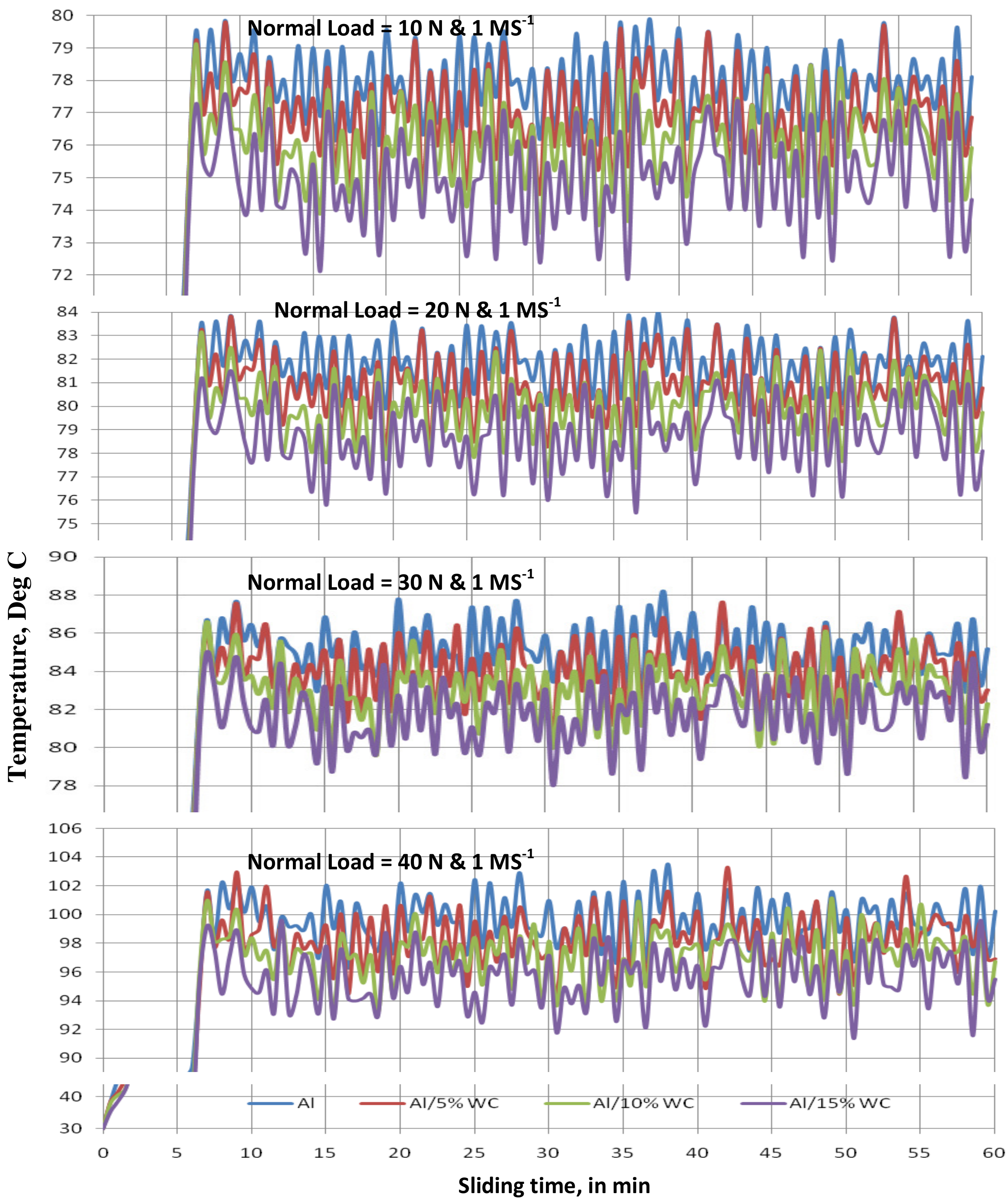

Fig. 3.2: The typical sliding process curves of contact temperature against sliding under a standard wear condition.

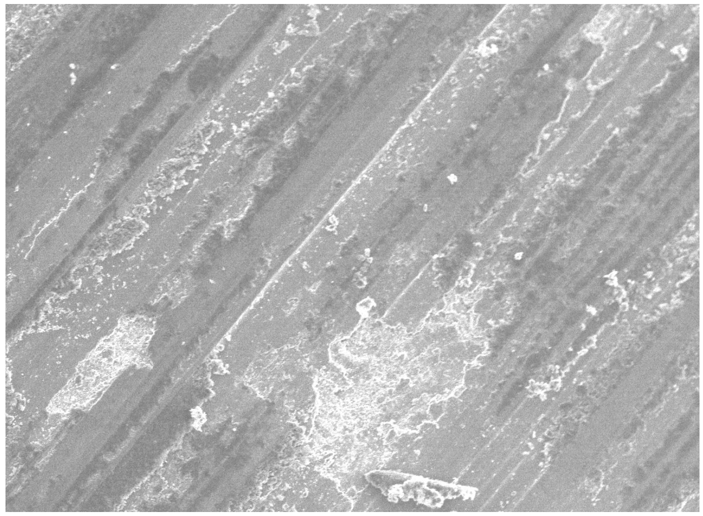

Fig. 3.3: SEM micrographs of the worn surfaces of matrix metal (Al) measured at 1MPa and 1 m/s

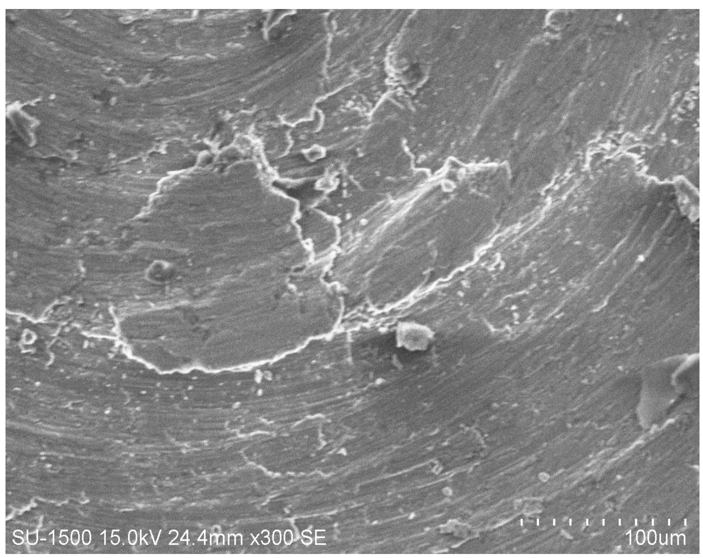

Fig. 3.4: SEM micrographs of the worn surfaces of Al/5% of WC MMCs measured at 1MPa and 1 m/s

The worn surface of matrix Al is given in Fig. 3.3 Grooves paralleled to the sliding direction are clearly observed which suggest the wear process governed by abrasive wear mechanism. In this case, aluminum matrix material generally obtains a high wear rate depending on the original roughness of harder counterpart and the contact pressure [10, 11].

In a magnified view, viscous flow of materials is observed in a micron scale due to the high flash temperature occurring in real contact area. Owing to the low load carrying capacity, the softened Al was rapidly removed by the hard asperities of the metallic counterpart surface.

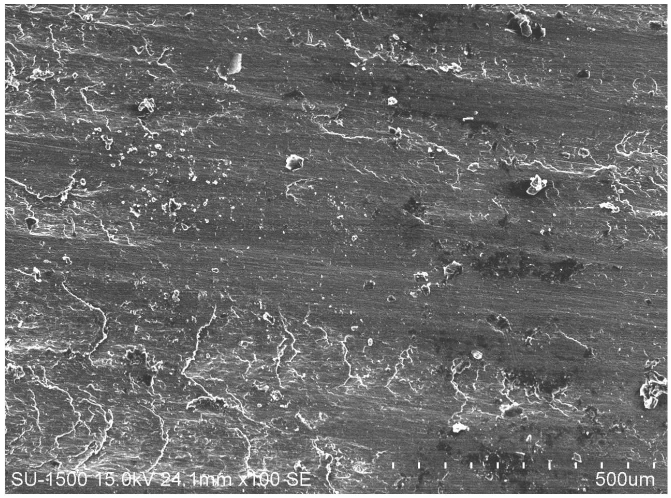

Fig. 3.5: SEM micrographs of the worn surfaces of Al/10% of WC MMCs measured at 1MPa and 1 m/s

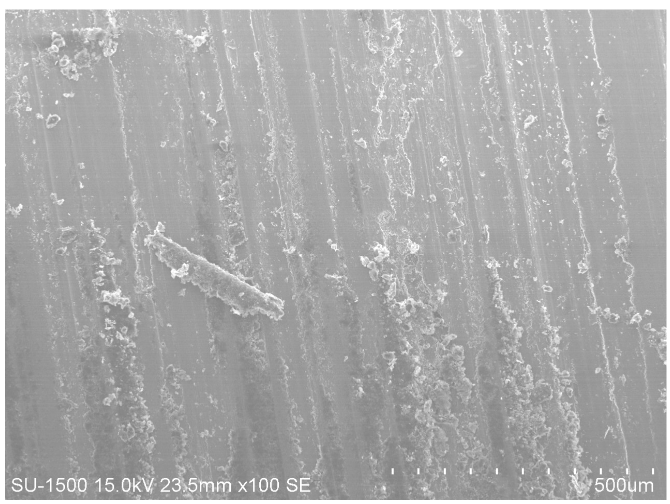

Fig. 3.6: SEM micrographs of the worn surfaces of Al/15% of WC MMCs measured at 1MPa and 1 m/s

Figs.3.4, 3.5 and 3.6 present the worn surfaces of three composites with nano-WC, respectively. It is clear that the surfaces of both composites were quite smooth resulting from adhesive wear. In a magnified view, local matrix micro-cracks may occur, which were probably caused by the ‘‘fatigue wear’’ of adhesive contact. A metal layer may transfer onto the metallic counterpart surface during running-in stage, which then results in this adhesive wear mechanism. For the nanocomposite, slight nano-grooves were observed which are parallel to the sliding direction.

`The worn surface of the nanocomposite, because of the reduction of friction and contact temperature, the particles could effectively bear the load and were then gradually removed within a normal process. The particle thinning, particle fracture, and finally particle peeling shows the patterns of the particle fracture of nanocomposite with good interfacial bonding even under high pressure. It can be seen that the particle surface is relatively smooth. Therefore, during friction process, the exposed particle underwent most of load and was impacted by the asperities of counterpart, the interfacial damage between particle and matrix did not occur due to the better interfacial bonding of Al matrix and WC nano particle. As a result, the worn surface of the material was quite smooth and no serious particle removal was observed.

4. CONCLUSIONS

In the present work, tribological properties of nano-WC reinforced Al metal matrix composites were systematically studied under different sliding conditions. The following conclusions are drawn:

1. It was found that conventional nanoWC particle could effectively reduce the frictional coefficient and wear rate of Al MMC. Consequently, the wear rates of three composites were remarkably reduced, which are more than 2 to 3 times lower compared to that of matrix material as shown in Table 1
2. The serious particle removal and rapid increase of wear rate were occurred and the contact temperature increased up to the 100 °C of matrix. In comparison with WC particle reinforced composites, the wear damage in the interfacial region of particle and metal was slight due to the ductile nature of the matrix material.
3. With the addition of nano-WC, the stable frictional coefficient was reduced to a mean value of about 0.4 after the initial wear stage as shown in Fig.3.1
4. The specific wear rate as shown Table1, decreased rapidly from 10.2 to 3.54 for normal load of 40N, similar effect is also seen for corresponding loads of 10, 20 and 30N.
5. Based on SEM observations, a positive rolling effect of the nanoparticles between the material pairs is proposed. This rolling effect helps to reduce the shear stress and consequently contact temperature, especially at high sliding pressure and speed situations.

REFERENCES

1. L. Falcon-Franco, E. Bedolla-Becerril, J. Lemus-Ruiz, J.G. Gonzalez-Rodríguez, R. Guardian and I. Rosales, "Wear performance of TiC as reinforcement of a magnesium alloy matrix composite" Composites Part B: Engineering, Volume 42, Issue 2, March 2011, Pages 275-279.
2. M. Paramsothya, Q.B. Nguyena, K.S. Tuna, J. Chanb, R. Kwokb, J.V.M. Kumac, M. Guptaa,, Mechanical property retention in remelted microparticle to nanoparticle AZ31/Al2O3 composites, Journal of Alloys and Compounds 506 (2010) 600–606
3. Rana, F., and Stefanescu, D.M., Friction properties of Al-1.5Pct Mg/SiC particulate metal-matrix composites. Metall. Trans. A, 1989, vol. 20A, pp.1564-1566.

4. Saka, N., & Karalekas, D.P., Friction and wear of particle-reinforced metal-ceramic composites, Proc. Conf. Wear of Materials, ASME, New York, 1985, pp.784-793.
5. S.K. Sinha, S.U. Reddy, M. Gupta, Scratch hardness and mechanical property correlation for Mg/SiC and Mg/SiC/Ti metal–matrix composites, Tribology International 39 (2006) 184–189
6. S.C.Sharma, B.M.Girish, D.R. Somashekar, B.M.Satish, & Rathnakar Kamath, Sliding wear behaviour of zircon particles reinforced ZA-27 alloy composite materials, Wear, 224, (1999) pp.89-94.
7. Skolianos, and T.Z. Kattanis, Tribological properties of SiCp- reinforced Al-4.5% Cu-1.5% Mg alloy composites, Mat. Scie. & Engng., A163 (1993) pp.107-113.
8. J.P. Tu, N.Y. Wang, Y.Z. Yang, W.X. Qi, F. Liu, X.B. Zhang, H.M. Lu, M.S. Liu, "Preparation and properties of TiB nanoparticle reinforced copper matrix composites by in situ processing" Materials Letters, 52 2002. 448–452.
9. D.Z.Wang, H.X.Peng, J.Liu, & C.K. Yao, Wear behaviour and microstructural changes of SiC-Al Composite under unlubricated sliding friction, Wear, vol. 184, (1995) pp.187-192.
10. LI Wen-sheng, WANG Zhi-ping, LU Yang, YUAN Li-hua. Corrosive wear behavior of Al-bronzes in 3.5% NaCl solution [J]. The Journal of Materials Engineering and Performance, 2006, 15(1): 102−110.
11. LI Wen-sheng, WANG Zhi-ping, LU Yang, JIN Yu-hua, YUAN Li-hua, WANG Fan. Friction and wearing behaviors of a novel aluminum bronze material for stainless steel utensils [J]. Wear, 2006, 259(2): 155−163.
12. Yong Yang, Jie Lan, Xiaochun Li, "Study on bulk aluminum matrix nano-composite fabricated by ultrasonic dispersion of nano-sized SiC particles in molten aluminum alloy", Materials Science and Engineering A 380 (2004) 378–383.
13. Youren Xu, Avigdor Zangvil & Albert Kerberb, "SiC Nanoparticle-Reinforced Al,O, Matrix Composites: Role of Intra- and Intergranular Particles, Journal of the European Ceramic Society 17 (1997) 92 l-928
14. X.N. Zhang , L. Geng, G.S. Wang, Fabrication of Al-based hybrid composites reinforced with SiC whiskers and SiC nanoparticles by squeeze casting, Journal of Materials Processing Technology 176 (2006) 146–151
15. Manjunatha L.H., P.Dinesh, "Development and Study on Microstructure, Hardness and Wear Properties of as Cast, Heat Treated and Extruded CNT- Reinforced With 6061al Metal Matrix Composites" International Journal of Mechanical Engineering & Technology (IJMET), Volume 3, Issue 3, 2012, pp. 583 - 598, ISSN Print: 0976 – 6340, ISSN Online: 0976 – 6359.
16. R.Maguteeswarana, Dr. R.Sivasubramanian and V.Suresh, "Methodology Study and Analysis of Magnesium Alloy Metal Matrix Composites" International Journal of Mechanical Engineering & Technology (IJMET), Volume 3, Issue 2, 2012, pp. 217 - 224, ISSN Print: 0976 – 6340, ISSN Online: 0976 – 6359.
17. R.Maguteeswarana, Dr. R.Sivasubramanian and V.Suresh, "Study and Investigation of Analysis of Metal Matrix Composite", International Journal of Mechanical Engineering & Technology (IJMET), Volume 3, Issue 2, 2012, pp. 171 - 188, ISSN Print: 0976 – 6340, ISSN Online: 0976 – 6359.