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Assessing the Performance of Nano Lubricant on Zinc Aluminium Alloy

S. Parimala Murugaveni[*] and P.R. Thyla[#]

[*]*Department of Mechanical Engineering, Government College of Technology, Coimbatore - 641 013, India*
[#]*Department of Mechanical Engineering, PSG College of Technology, Coimbatore - 641 012, India*
[*]*E-mail: optimechgct@gmail.com*

ABSTRACT

In the field of tribology, Zinc Aluminium (ZA) alloys have been widely investigated for their superior wear characteristics. They were found to be suitable alternatives for bearing bronzes for the operating conditions of high mechanical load and moderate sliding speeds. Addition of nano-particles in the lubricating oil (base oil) to enhance the characteristics of the base oil is known as nano lubrication. In this study, sliding wear behaviour of ZA27 was investigated under dry, base oil and nano oil lubrication conditions, by varying load, sliding distance and sliding speed. With the base oil as SAE 40, nano graphite was added in two step method which was further used to identify the lubrication regime under different lubrication conditions. From the limited study of single melt samples, the results appear that the wear behaviour of ZA27 alloy improved under nano lubrication conditions with reduction in operating temperature. It could be observed from SEM images that the presence of nano-particles reduced scarring and wear, leading to enhancement in the tribological performance of ZA27 alloy.

Keywords: Nano-lubrication; Nano-graphite; Wear behaviour; ZA27

1. INTRODUCTION

Brass and copper alloys occupy important role in tribological field[5,6]. Due to the environmental laws and the high cost of copper, copper-based materials need to be replaced with alternate materials. Zinc aluminium alloys, where zinc and aluminium are the major constituents are found to be suitable alternatives, in which, ZA27 exhibits good bearing and wear resistance qualities[1, 25]. When compared with copper-based materials, the wear rate of ZA27 was very less[2-4]. To improve the wear behaviour many research works are in progress.

An attempt has been made by Dalmis and Cavalci[3] to improve the tribological behaviour of ZA alloys by adding nano-graphite and found that powder morphology and microstructure of the alloy are influenced by nano-graphite. Sharma[7], *et al.* investigated the bearing characteristics of cast ZA27/graphite composite materials with variation in graphite particles content under lubricated, semi-dry and dry conditions and found that the composite material exhibits lower friction compared to un reinforced one. Veerabhadrappa[2], *et al.* found that normal pressure has highest statistical influence on the dry sliding wear of modified ZA alloy, while the sliding speed has lesser influence on the wear rate. The hardness and dimensional stability of the material were improved by the inclusion of silicon carbide. Babić[8], *et al.* examined the tribological behaviour of heat-treated ZA alloy. Heat treatment results in a reduction of strength, hardness and improvement in the tribological properties. Auras and Scherzo[10] reported that the wear rate of ZA alloys depends on test load and the addition of SiC particles improves the wear rate. In all above studies, the improvement in wear behaviour of ZA alloy is done either by hardening or adding hard materials.

Nano lubricants made of nano particles as a dispersant with base lubricant, being used recently to improve the tribological characteristics. In nano lubricant, the liquid lubricant provides damping and low friction, while the nano particle acting as a solid provides a load supporting strength. The friction reducing and anti-wear behaviour was dependent on the characteristics of nano particles such as mending effect, polishing effect, rolling effect and protective film effect[21,22].

Lee[11], *et al.* showed that the influence of nano particles was more dependent on the magnitude of the applied normal load compared with the surface enhancement effect. The surface modification occurred by nano particle abrasion which enhances the lubrication. Mustafa Akbulut[12] discussed the different types of nano particles that can be added to the lubricant oil. He discussed the influence of the shape and concentration of nano particles on lubrication system. Linghuikong[13], *et al.* reviewed on stability and lubrication mechanism of nanofluid. The stability of nano-fluids can be improved by using surfactant. Lee[14], *et al.* studied the tribological characteristics of graphite nano lubricants and indicated the variation in the operating temperature between the nano graphite added oil and plain lubricant oil. Wan[15], *et al.* showed that boron nitride nano particles have less influence on the viscosity of the oil and improvement in tribological properties.

Even though many methods were examined to improve the tribological characteristics of ZA27 alloy, the wear behaviour of ZA27 alloy under nano lubricant condition has not been

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investigated much. In this work, the sliding wear behaviour of ZA27 alloy under the dry condition, lubricated with SAE 40 (henceforth referred to as "base oil") and nano graphite added base oil (henceforth referred as "nano oil") is studied. Graphite nanoparticles were selected, as nano-graphite possesses the special properties of quantum size effect, small size effect and interface effect. The experiment was conducted in pin-on-disk machine. The results were analysed with respect to friction and wear. Also, the surfaces are observed with SEM to study the wear mechanism.

2. ALLOY PREPARATION AND TEST PROCEDURE

The ZA alloy was cast by stir casting process. The composition of alloy (ss per ASTM standard) prepared is as given in Table 1. The raw cast material then cut and machined by wire-cut EDM. The chemical composition of alloy were verified using atomic absorotion analysis (results given in Table 1) and examined with SEM using atomic number contrast. The sliding wear test was performed using Ducom pin on disc friction and wear tester (Fig. 1) which conforms to the specification of ASTM G99. The disc used in this experiment was made of EN 25 steel. The wear test was conducted by varying load, sliding speed and distance under dry, base oil and nano oil lubricated conditions.

As ZA27 is mostly preferred for heavy machineries, SAE 40 which is suitable for high load, is selected as base oil. The kinematic viscosity of SAE 40 oil is 126.4 mm^2/s at 40 °C. The nano lubricant was prepared by adding graphite nanoparticles of the size< 100 nm as the size influences the hardness of nano particles. The concentration of nanoparticle additive was one per cent of oil weight[12,15]. The nano lubricant was prepared by a two-step method. The kinematic viscosity of nano oil was found to be 121.3 mm^2/s at 40 °C, using redwood visco meter. The stability of nano lubricant was ensured by using the surfactant alkyl aryl sulfonate[13]. A K type thermocouple is (accuracy ±0.08 °C, range 0 °C – 1200 °C) used to measure the temperature of the specimen. Wear rate was calculated by weight loss technique.

Figure 1. Pin on disc apparatus.

3. RESULTS AND DISCUSSION

The SEM image of standard specimen of ZA27 shows that the microstructure of the alloy has an α-dentrite structure of aluminium surrounded by the laminated α+η eutectoid phase of zinc and meta stable ε phase of Cu-Zn inter metallic compound. A sheet-like form was seen because of α+η eutectoid phase. The α-Al-rich solid solution increases strength and gives thermal stability to the alloys. The hexagonal close packed crystal structure of zinc solid solution provides very good smearing characteristics, acts as a solid lubricant[9].

Graphite is pure carbon cell with atoms arranged in regular hexagonal pattern. The nano graphite shows the lamellar microstructure with the blunt end when observed with SEM. Because of this micro-structure it offers high temperature endurance and self lubrication.

3.1 Wear Behaviour

Figure 2 shows the wear behaviour of ZA27 alloy as a function of applied load under dry condition. The increase in wear rate with respect to load, could be attributed to the increasing severity of wear conditions encountered by the samples[9]. The shift in wear rate in the presence of nano graphite can be observed from the graph. When compared with base oil for the minimum load of 19 N, 33 per cent less wear rate was observed under nano oil lubrication. With the increase in load to 58 N, the wear rate is reduced to 50 per cent in comparison with base oil. The results indicates that presence of nano graphite particles in lubricant oil can lead to enhancement of life of ZA27 alloy by reducing its wear rate.

The wear rate of ZA27 alloy with variation in sliding distance is as shown in Fig. 3. The wear rate is very high in dry condition compared to base oil and nano oil lubrication conditions. The slope of the curve increases with increase in base oil lubrication up to 2000 m. The change with respect to distance is almost linear under nano lubrication. Change in wear rate is uniform of an average of 4 per cent for the change in distance of 1000 m under nano oil lubrication. This may be due to the entry of nano-particles between the contact surfaces.

Table 1. Composition of ZA27 alloy

Elements	Aluminum	Magnesium	Copper	Iron	Lead	Cadmium	Tin	Zinc
Weight %	27	0.02	2.5	0.075	0.006	0.006	0.003	70.39

Chemical composition of the alloy (Result of atomic absorption analysis)

Alloy/Elements	Chemical composition (wt %)		
	Zn	Al	Cu
ZA27	71.3	26.5	2.2

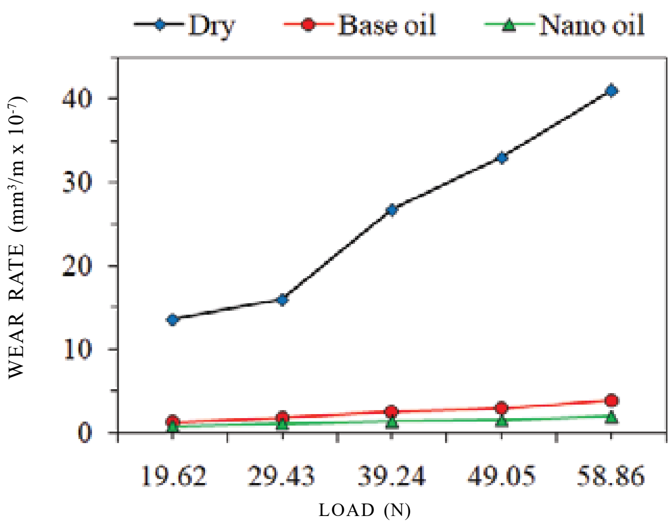

Figure 2. Load vs wear rate.

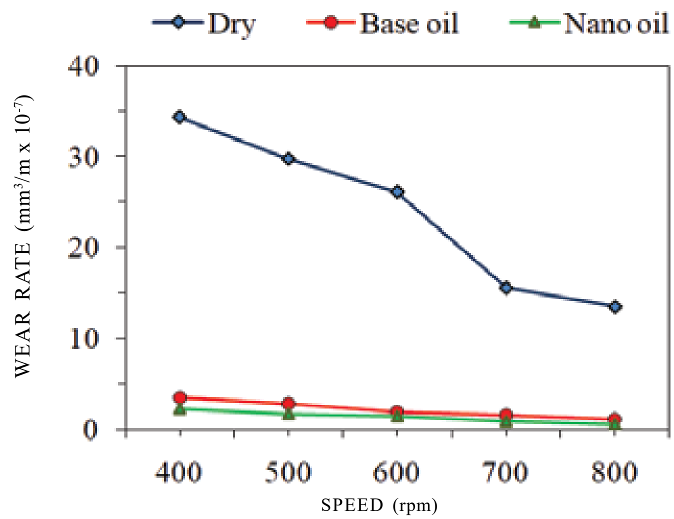

Figure 4. Speed vs wear rate.

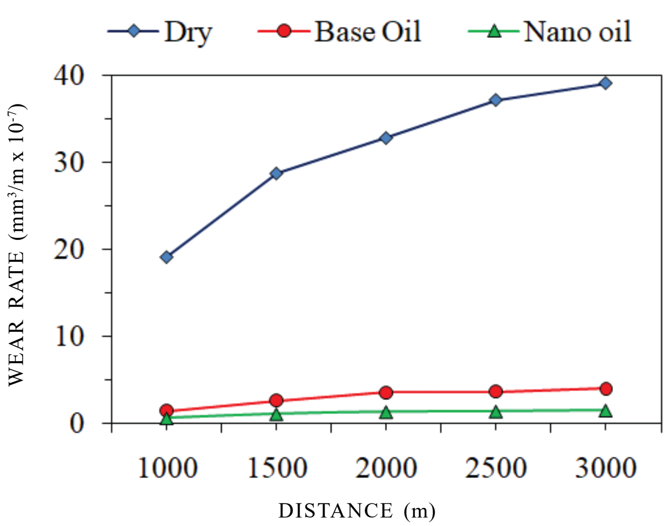

Figure 3. Sliding distance vs wear rate.

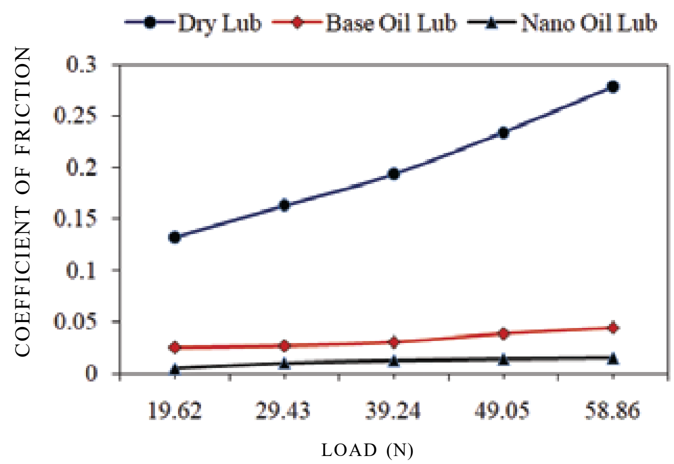

Figure 5. Load vs coefficient of friction.

Due to shear, parallel to the crystal planes, graphite tends to form flat particles which preferentially stick to flat surfaces in the desired orientation, resulting in reduction of slope of wear rate. These observations are in agreement with the studies of Su[16] and Wan[18].

The increase in speed shows a reduction in the wear rate up to 600 rpm (Fig. 4).With increase in speed, there is no significant variation in the wear rate.

3.2 Coefficient of Friction

In evaluating the characteristics of lubricants, coefficient of friction (COF) is an important factor. In Fig. 5, for dry, base oil, and nano oil conditions, the friction coefficient is found to be increasing with an increase in load. This is in agreement with the observations made by Babic[1], *et al.* and S.C. Sharma[7] in their work. Under dry condition, the friction coefficient increases to the highest value of 0.2772 at the load of 58 N and it is found to be the lowest under nano lubrication condition. Under nano lubrication, the curve follows a straight line after 39 N, indicating that there is less metal contact under nano lubrication condition[17].

The friction coefficient versus sliding distance is plotted in Fig. 6. Change in COF is 62 per cent less in nano oil lubrication compared to base oil at the distance of 2500 m to 3000 m. From the diagram, it is found that the value of friction coefficient stabilises under nano oil lubrication. Such a dependency of COF is in accordance with the wear behaviour in the presence of nano-particles. The grooves created at the initial stage of lubrication are filled with nano graphite, and the ball bearing effect has led to less variation with increase in distance[9].

Variation of friction coefficient as a function of speed is as shown in Fig. 7. Reduction in friction coefficient is especially prominent in the range of 400 to 600 rpm under dry and base oil environment. Under nano oil lubrication, the coefficient of friction is relatively constant with change in speed as nano particles are distributed all over the surface[14,16.]

3.3 Stribeck Curve

To identify the lubrication regime under base and nano oil lubrication, Stribeck curve is used. The standard Stribeck curve is a plot between coefficient of friction and Stribeck number, which shows an overall friction behaviour in the entire range of lubrication, including hydrodynamic, mixed, and boundary lubrication[1,18].

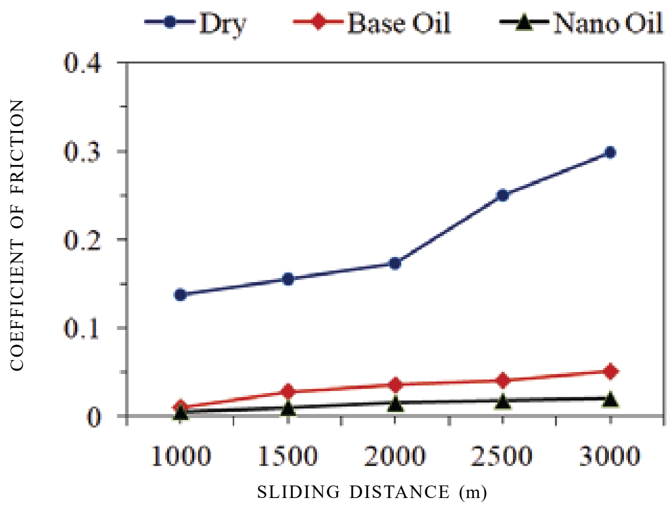

Figure 6. Sliding distance vs coefficient of friction.

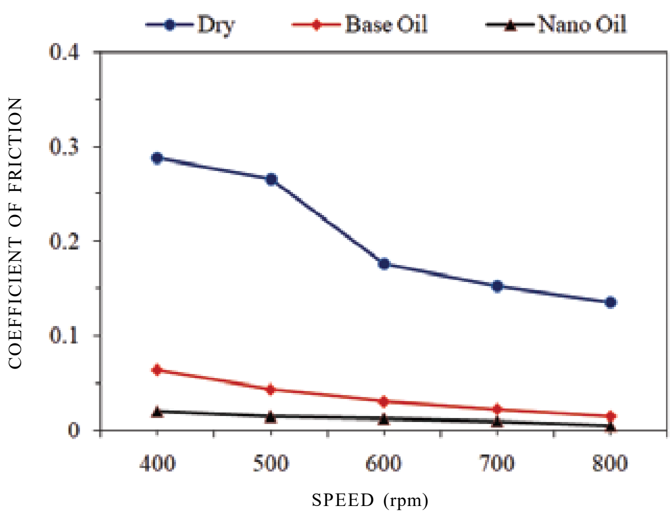

Figure 7. Speed vs coefficient of friction.

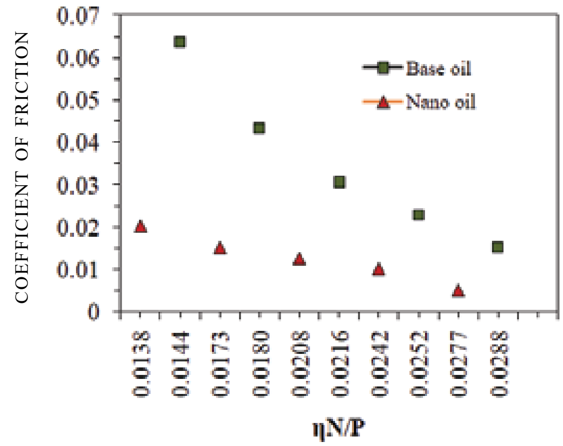

Figure 8. Stribeck curve from experimental results.

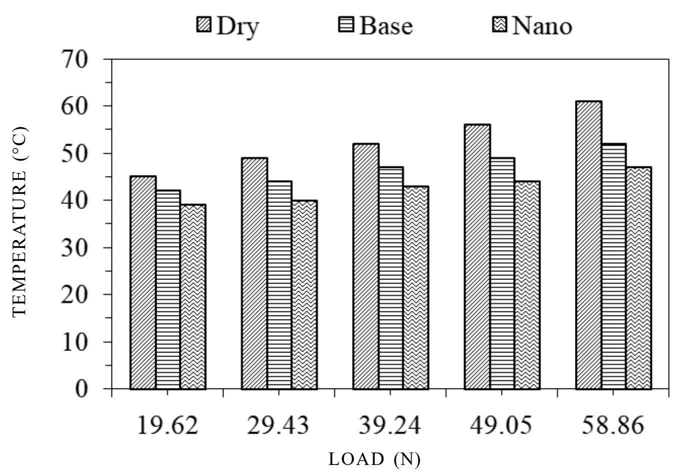

Figure 9. Load vs temperature.

The stribeck curve between dimensionless number, ηN/P and CoF, under base and nano oil lubrication conditions is as shown in Fig. 8 where η is dynamic viscosity ($N.s/m^2$), N is speed (rps) and P is normal load (N/m^2).The range of COF under nano lubrication is 0.0204 to 0.0051, it indicates the mixed lubrication regime[19]. The asperities are filled with nano-particles which increase the pressure limits of the base lubricant, leads to increase in the load carrying capacity. The shape of the graphite particles makes it play the role of ball bearings between the friction surfaces. Hence, the direct contact between the surfaces reduced infers fall in friction coefficient. These observations found to be matched with other research results[11]. The wear is less under high load, low speed condition in presence of nano graphite, leads to conclusion that nano graphite improves the load carrying capacity of ZA27 alloy.

3.4 Temperature

In Fig. 9, there is a distinguished shift in operating temperature under nano oil lubrication condition. The rate of change in temperature with increase in load under dry and base oil is higher than that under nano oil condition. The rate of change in temperature with respect to load is an average of 40 per cent under nano oil lubrication. And under base oil, it is 65 per cent which ensures the dimensional stability of ZA27 alloy under nano lubrication working environment.

Reduction change in temperature implies less energy loss. As graphite is a good heat conductor, there is a remarkable reduction in the temperature rise, which indicates low energy loss at high load. With respect to speed and distance, there is no significant rate of change in temperature under base and nano oil lubrication conditions.

3.5 Worn Surfaces

In all specimens, along the direction of sliding, scratches and ploughing grooves were observed on the surfaces. Debris was observed in dry lubrication which is as shown in Fig. 10. In dry sliding, ploughing of material and spalling of the material indicates the occurrence of adhesive wear. Under dry lubrication, the wear volume is proportional to sliding distance and load, which is a required condition for the adhesive wear to be initiated. The volume loss at high load is high compared to other two lubrication conditions.

The worn surface under base oil lubrication is as shown in Fig. 11. Under base oil lubrication condition, the scratches and wear are found to be uniform all over the surface of the specimen. The oil present in the contacting surfaces has led to reduction in wear and the depth of grooves indicates the change of wear mode from adhesion to abrasive wear. Scratching is a

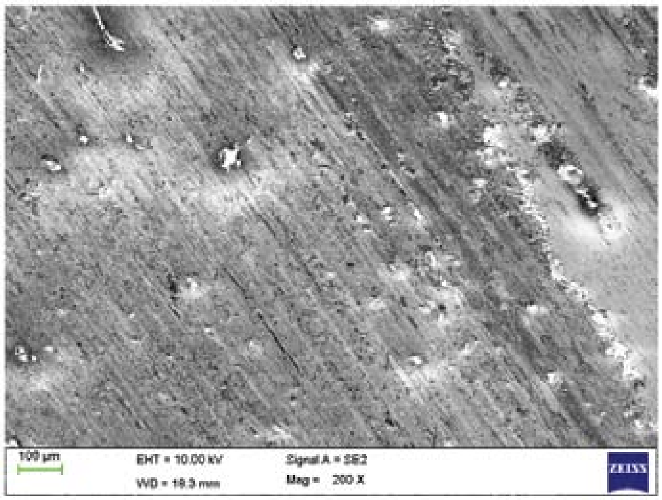

Figure 10. SEM image under dry lubrication.

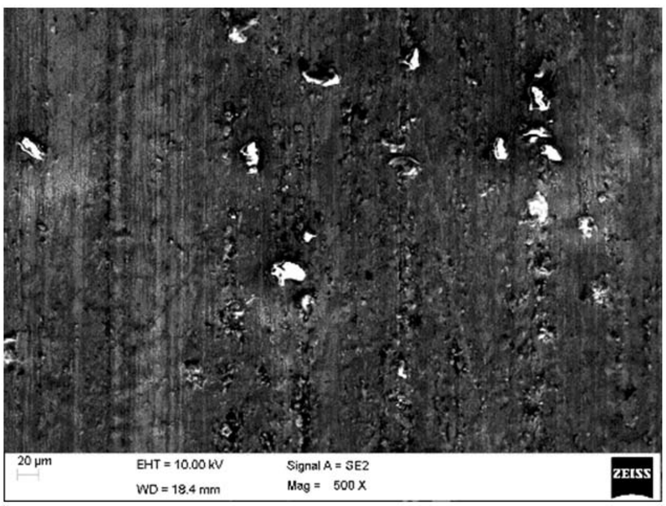

Figure 11 SEM image under base oil lubrication.

form of abrasive wear, characterised by short scratch-like lines in the direction of sliding, which is noticed in the SEM images. A long, curled ribbon-like particle will be generated under micro cutting mode, under abrasive wear which is also clearly visible in the SEM image[18].

Under the nano oil lubrication condition, the wear track is uniform and smooth as shown in Fig. 12. The presence of nano-particles between the contact surfaces reduces the contact between the surfaces. Presence of debris and grooves is reduced. There is no scoring and instead, only flat and shallow grooves are seen which matches with the observations of Zhang[23], *et al*. The shape and structure of nano graphite particles indicated that they act as ball bearings and load bearers leading to a reduced CoF at high load[20] as shown in Fig. 5.

4. CONCLUSIONS

In this study, the wear behaviour of ZA27 under nano oil lubrication condition was studied and compared with dry and base oil lubrication conditions. By varying the load, sliding speed and sliding distance, the wear rate and COF were measured. High load and slow speed always leads to high wear rate. In this limited study, it is found that the nano graphite significantly reduces the rate of wear under high load, low speed conditions in ZA27. From the SEM images, the surface finish is found to be high and the nano graphite act as load bearer which is identified from the minimum value of friction coefficient at high load. The observations of the study have shown that ZA27, lubricated with nano oil can be used as an alternate for bronze for bearings with significant improvement in the tribological behaviour.

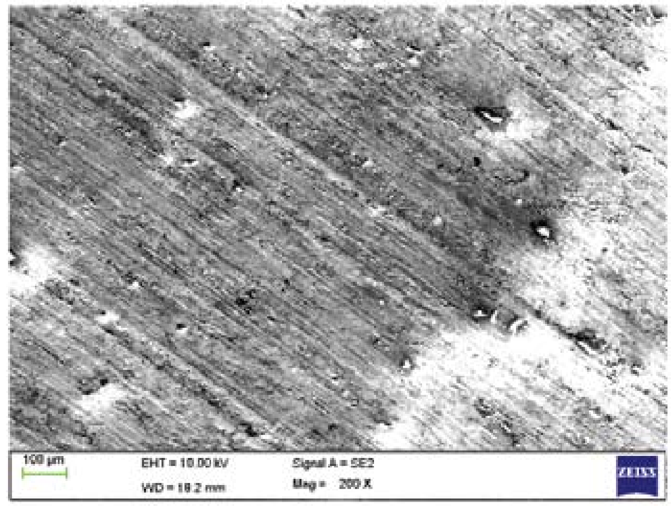

Figure 12. SEM image under nano lubrication.

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CONTRIBUTORS

Ms S. Parimala Murugaveni received the BE in Mechanical Engineering from Bharathiyar University, Coimbatore in 1999. She received her ME in Engineering design from Anna University, Chennai, Tamilnadu, in 2005. She is currently an Associate Professor (CAS) at Department of Mechanical Engineering, Government College of Technology, Coimbatore, Tamilnadu. Her research interests are tribology, nano lubrication and mechatronics.

Dr P.R. Thyla graduated from the Mechanical Engineering Department, PSG College of Technology, Coimbatore in 1987. She received MTech Machine design 1990 from the IITM, Chennai. She received PhD in 2005, from Bharathiyar University, Coimbatore. She is currently Head of Department, Department of Mechanical Engineering, PSG College of Technology, Coimbatore, Tamil nadu. Having 30 years of experience in teaching she published more than 50 research papers in international journals. Her current research interest includes Machine design and dynamics and Composite materials.