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(MJTS 2017)

28th - 30th August 2017
Malaysia-Japan International Institute of Technology
Universiti Teknologi Malaysia
Kuala Lumpur, Malaysia

Organized by:
Tribology and Precision Machining i-Kohza (TriPreM), Malaysia-Japan International Institute of Technology (MJIIT)

In collaboration with:
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Surface Modification Process based on Combined Mechanical Means

The present study describes surface modification process and its applicability to improve tribological performance of sliding interface of engine components such as a piston skirt and a journal bearing. The proposed process consists of an interrupted micro cutting, a micro shot peening and a roller burnishing. The modified surface composed of solid lubricant such as graphite and sulphides mixed with soft interlayer such as metal or polymer and the textured component surface. The coating process was carried out using a micro shot peening and a roller burnishing process. The texture geometry was determined by the interrupted micro cutting process. Fundamental tribological properties was evaluated with a ball-on-disc and a ring-on-disc type testing apparatuses to optimize the surface characteristics. The material of the mating specimen was chromium alloy steel as the ball and cast iron for the ring. The surface modification process was applied to aluminium cast alloy disc. Results showed that friction coefficient of the modified surface was low and stable in wide range of sliding condition and that the critical load due to seizure increased. In particular, significant decrease of the friction coefficient was found in a boundary lubrication regime. It was found that the optimization of the interlayer such as the element and the volume fraction was effective means to increase of the life of the modified layer. The treatment was applied to the piston skirt surface with selected condition from the results of the fundamental tribological properties, then the friction performance was evaluated with an actual engine system in a firing condition. The relation of tribological properties between the fundamental and firing conditions was discussed.

Tribological Performance of Vegetable-Based Lubricant as a Sustainable Metalworking Fluid for Machining Application

Modifying physicochemical and tribological properties of a vegetable-based lubricant is essential in improving its lubrication performances. This paper presents the effectiveness of a lubricant additive in a bio-based lubricant to improve its tribological performance. Tribology tests on steel/steel contacts were conducted to evaluate the lubricant samples. Test outputs were benchmarked against the neat bio-based lubricant. Results revealed good synergistic effect of the additive blended into the bio-based lubricant. The tribological improvements posed by the bio-based lubricant revealed better than or comparable results to the conventional synthetic ester and therefore is seen suitable for the use as a new advanced renewable bio-based metalworking fluid for manufacturing activities that corresponds to the energy saving benefits and environmental concerns.
## MJTS 2017 Tentative

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<td>Assoc. Prof. Dr. Hatsuhiko Usami, Department of Materials Science and Engineering, Faculty of</td>
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<td>Assoc. Prof. Dr. Erween Bin Abd Rahim, Department of Manufacturing and Industrial Engineering,</td>
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## Oral Presentation

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<td>H. Ariura, T. Morita, T. Yamaguchi, and Y. Sawae</td>
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<td>“Friction Properties of Pva-H as an Artificial Cartilage in Pseudo-Synovial Fluid – Effect of Steady Loading and Intermittent Loading”</td>
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<td>F. Sakai</td>
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<td>Z.A. Subhi and K. Fukuda</td>
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**SPATIOTEMPORAL MAPPING ANALYSIS ON TRIBO-DATA IN BOUNDARY LUBRICATION**

N. Md Ali_1, K. Fukuda_1,2, T. Morita_2,3, and Z.A. Subhi_1

1Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, Malaysia.
2I2CNER, Kyushu University, Japan.
3Faculty of Engineering, Kyushu University, Japan.

1. **INTRODUCTION**

As lubricant existed in between the sliding surfaces, the composition of the lubricant which adsorbed to be a monolayer on the surface withstands the colliding of contacting asperities [1]. The lubrication regime of that phenomenon is known as boundary lubrication. But, when the layer has been broken, the contacting asperities would enhance the adhesive wear development on the surface when surface asperities transferred from one surface and stick to another surface. The nature of metal surfaces as well as the molecular monolayer formed affect the friction and wear of tribosystem [1,2]. Tribological transitions of practical machinery are as known from running-in, steady wear and catastrophic wear. Examine the process of running-in and being able to control it could be a powerful tool in enhancing the system’s life limit and operation stability [3]. Thus, the parameters which govern the period of running-in need to be determined as the objective in this research. As the technique of analysis dry friction using spatiotemporal mapping analysis was found to be effective, the same method could be used as well for analysing running-in time [4-6]. By visualizing the sliding phenomena using the spatiotemporal mapping technology, the dependency of position and time for certain parameters such as pin displacement during sliding could be evaluated [4-6]. Hence, the spatiotemporal mapping is applied to the analysis of boundary lubrication in this study.

2. **EXPERIMENTS**

A pin-on-disc type tribotester was used to analyse the coefficient of friction and specific wear rate of JIS: SUS316 when sliding with each other with the presence of lubricant ISO VG32 base oil. The diameter of sliding track on a disc is 20 mm and pin has a spherical shape head with radius of 4 mm [6]. The material JIS: SUS316 was used due to their popular usage in different aspect of machinery showing typical adhesive wear.

Total of 9 tests were conducted with different load of 5N, 10N, 20N and 40N. Each load is with two samples except for 10N with three samples. The total rotations per sample are 2000 rotations. On each rotation, friction coefficient and pin displacement were collected on 720 points equivalently divided on the disc. The experimental conditions are as mentioned in Table 1.

![Table 1: Test conditions](http://example.com/table1)

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<tr>
<th>Sliding speed (m/s)</th>
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<tr>
<td>Sliding period (s)</td>
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<tr>
<td>Lubricant</td>
<td>ISO VG32 base mineral oil</td>
</tr>
<tr>
<td>Supply rate (L/s)</td>
<td>0.0026</td>
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4. **RESULTS AND DISCUSSION**

4.1. **Coefficient of Friction**

The coefficient of friction for each samples are as shown on Fig. 1 taken from the reading of friction force generated by the TriboMaster software. The period of running-in could be estimated by looking on the graph of Fig. 1 before the steady state reached. 40N samples could not achieve steady state condition while 5N samples have the shortest running-in time compared to other sample’s load. The total samples’ running-in time has been illustrated in Fig. 2.

![Fig. 1: Time dependent change of coefficient of friction data for different load in 2000 rotations.](http://example.com/fig1)

From Fig. 2, the most variety of data can be observed for 10N samples. Therefore, to know the reason of the variation, the surface analyses with microscope as well as with electron-dispersive spectroscopy (EDS) were done on 3 samples of load 10N with the sample name A, B and C. Based on Fig. 2, sample A has the shortest running-in time and thus the sample has the lowest specific wear rate. During the transient running-in process, the wear rate is higher than the steady state period [1]. Thus, the longer running-in process will have higher adhesion forces in the contact areas. The higher adhesion force will lead to phenomena of adhesive wear [1]. Fig. 3 shows the shorter running-in time (sample A) has the lowest specific wear rate. The adhesive wear phenomena could be observed on the samples as the adhesive substances attached on the disc
are from the breakage of metals within the bulk of pin (horizontal white lines became fader after vertical white lines coincided on certain rotations as shown in Fig. 4).

Fig. 2: Distribution of running-in time

![Distribution of running-in time](image)

**4.2. Microscopic Measurements**

The surface observation of sample A, B and C were performed to determine the number of adhesive substances visible with size of micro. The measurements of the each of adhesive substances were tabulated in Table 2 in tangential (T) and radial (R) directions. Based on the same table, it can be concluded that the adhesive substances formed on the surfaces are either small (average 108.5 µm) but more than 10 substances (11 substances on sample C) or big (average 163.8 µm) but in low number (8 substances on sample B).

<table>
<thead>
<tr>
<th>T (µm)</th>
<th>R (µm)</th>
<th>T (µm)</th>
<th>R (µm)</th>
<th>T (µm)</th>
<th>R (µm)</th>
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<td>1</td>
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<td>70.4</td>
<td>217.4</td>
<td>99.5</td>
<td>77.3</td>
</tr>
<tr>
<td>2</td>
<td>127.8</td>
<td>44.1</td>
<td>157.7</td>
<td>85.7</td>
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<tr>
<td>3</td>
<td>134.7</td>
<td>56.9</td>
<td>171.5</td>
<td>82.7</td>
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<tr>
<td>4</td>
<td>184.4</td>
<td>80.4</td>
<td>116.3</td>
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<td>5</td>
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<td>8</td>
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<td>10</td>
<td>91.8</td>
<td>81.9</td>
<td>125.8</td>
<td>60.0</td>
<td>108.5</td>
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4.3. SEM/EDS

The chemical composition of sample were observed using EDS to see whether there is a difference in composition for certain points at adhesive substance, surface at the wear track and out of wear track for sample A, B and C. The samples were in vacuum state inside the scanning electron microscopy (SEM) exposed with electrons of energy levels 20 keV. The result is almost the same for those three areas with all 3 samples with oxygen being the highest number of percentage in terms of atomic and weight composition. The maps of chemical elements distribution were obtained as well to see what element is most concentrated on adhesive substances. The results were similar as former where oxygen concentration was dominated at the adhesive substances area.

**4.4. Spatiotemporal Analysis: Pin Displacement**

The spatiotemporal analysis helped in locating the time when the adhesive substances generated as in Fig. 4 for sample A which are all within 200 rotations. For sample B, total 8 of its adhesive substances were initiated below 600 rotations while sample 32 is below 800 rotations. Hence, from the results obtained, it can be concluded that initiation and the progress of adhesive substances in earlier stage will give much less running-in time. Therefore, since the initial generation of adhesive substances is within the running-in time, shortening the time for them to initialize will decrease the system’s overall specific wear rate.

**7. CONCLUSION**

Controlling the running-in time will benefit tribosystems operation. During that period, the generation of adhesive substances as the substances progress influenced the friction and wear behaviours of the whole systems.

**REFERENCES**

DEFORMATION DETERMINATION OF CULTURED CELLS INSIDE SCAFFOLDS UNDER MECHANICAL LOAD

H. Ariura_1, T. Morita_2, T. Yamaguchi_2, and Y. Sawae_2

1Graduate School of Engineering, Kyushu University, Japan
2Faculty of Engineering, Kyushu University, Japan

1. INTRODUCTION

Osteoarthritis is a severe joint disease that disrupts the function of human synovial joints and reduces patient’s quality of life significantly. The pathology of osteoarthritis has not been fully understood yet. However, unexpected large mechanical loading, for example unbalanced loading on the joint surfaces caused by the O leg and the X leg [1], is one of the possible factors triggering the development of joint diseases. The excessive deformation of chondrocytes, cells embedded in the cartilage tissue, exerted by the hersh joint loading stimulates the biosynthesis of enzymes which digest the cartilage tissue and degrade the mechanical integrity. Also, it might cause cell apoptosis which is related to the activation of caspase 3 enzyme. On the other hand, the moderate mechanical load applied to the cartilage tissue plays an important role to maintain tissue homeostasis [2]. Actually, some types of mechanical loading have been utilized in the cartilage tissue engineering to stimulate the chondrocyte metabolism and promote the mechanically matured regenerative cartilage tissue. However, the optimal value of cellular deformation at which the cell biosynthesis of extra cellular matrix is maximized while the degenerative reaction is not activated has not been identified.

In this study, we aimed to develop an experimental system which can apply quantitatively controlled mechanical strain to cells cultured in a scaffold to explore the relationship between the mechanical strain experienced by living cells and their integrity.

2. MATERIALS AND METHODS

2.1. Specimen

Cartilage tissue was harvested from steer metacarpal-phalangeal joint and chondrocytes were isolated from it using protease and collagenase. The isolated chondrocytes were mixed with agarose sol. The mixture was poured into a mold and subsequently cooled to prepare a agarose-chondrocyte construct which was used as a test specimen in the following experiment. The agarose concentration was varied from 1% to 4% (type VII agarose, Sigma). The specimen shape was 5 mm cube and the initial cell concentration was adjusted to $5 \times 10^6$ cells / ml.

The prepared test piece was placed in a 24-well plate filled with culture medium and cultured in a 5% CO$_2$ incubator at 37 °C. Dulbecco's modified Eagle's medium containing 20 v/v% fetal bovine serum, 1 g/L glucose, 0.584 g/L L-glutamine, 3.7 g/L sodium bicarbonate, 100 units/mL penicillin, 50 mg/ML streptomycin, 20 mM HEPES were used as the culture medium.

2.2. Apparatus

The experimental apparatus developed in this study to apply arbitrary mechanical load to the cultured test specimen is shown in Fig.1. Both compressive load and shear load can be given by controlling 2 axis servo motor with PC. Using rack and pinion gears, it is possible to apply the same phase shear deformation to both sides of the gel. The device was mounted on the observation stage of Confocal Lazer Microscope (CLSM) to observe the deformation of the specimen and cells inside while applying a load.

2.3. Test Method

Prior to the mechanical loading test, the specimen was immersed in 2 mL of PBS supplemented with 4 μL of Calcein AM for 30 minutes to fluorescently ravel viable cells in it. The raveled specimen was placed in a glass-bottom culture dish and immersed in PBS. Then, a mechanical compression was applied to the specimen by glass plates attached to the the gripper of the apparatus. The position of gripper was controlled by a PC to apply an arbitrary compressive strain to the specimen.

Fluorescence observation was carried out by CLSM while applying the mechanical load to the fluorescently stained specimen. To monitor the strain distribution in the mechanically compressed specimen, CLSM images were taken by using x4 objective lens every several seconds for 132 seconds. The distribution of compressive strain in the specimen was obtained from consecutive CLSM images by the image correlation method. CLSM images of distorted cells inside the specimen were also observed by using a x60 objective lens and the cellular strain was calculated from their shape.

![Fig.1 A: Image of the testing device. B: Detail of the loading part.](image-url)
3. RESULTS AND DISCUSSION

3.1. Result

The CLSM image using the 4 × objective lens was analyzed by the image correlation method (Fig.2), and the local compressive strain distribution in the specimen was calculated. The local compressive strain at certain position in agarose specimen, ε1 (%), was obtained by ε1 = ΔL / L × 100, where L is the distance between the original two points of the test specimen and ΔL is the shrinkage after displacement. Compressive strain of the individual cell seeded in the specimen, ε2 (%), was determined from the CLSM image (Fig. 3) with a 60 × objective lens. At this time, when the thickness of the cell in the original compression direction is H, and the shrinkage after deformation is ΔH, ε2 = ΔH / H × 100. The results of the average local strain in the specimen are shown in Fig. 4, and the evaluated individual cell strain is shown in Fig.5. As shown in Fig. 4, the local strain in the specimen was smaller than the applied value. As the agarose concentration was lower, the local strain in the specimen was lower. In addition, the strain of a single cell inside the test piece was also smaller than the applied value, but became larger as the agarose concentration increased, and became almost the same value as the applied value with 3% and 4% agarose.

3.2. Discussion

The reason why the local strain in the specimen became larger as the agarose concentration became smaller was that the smaller the agarose concentration was, the more the water in the specimen was released by compression. In the specimens with a large agarose concentration, water was hardly released even when compressed, and as a result the strain became small. Regarding the strain of each internal cell, when the agarose concentration was small, the agarose gel became soft and there might be a considerable difference in elastic modulus between agarose gel and chondrocyte. Therefore, the mechanical strain successfully transferred to the individual cell was limited. Based on the experimental results, the elastic modulus of agarose gel became comparable to that of the cultured chondrocyte by increasing the agarose concentration to 3%. In that case, the mechanical load applied to the agarose construct can be delivered to individual cells cultured inside.

4. CONCLUSION

We developed a system to observe the local strain distribution in the scaffold under mechanical loading and the strain of individual cell cultured in it. As results indicated, the deformation transmitted to the cultured cell was depended on the agarose concentration. It is due to the difference in elastic modulus between agarose gel and chondrocyte. By increasing the agarose concentration to 4%, the elastic modulus of the scaffold became comparable to that of the cultured cells and the mechanical strain applied to the scaffold was successfully transmitted to cells with a quantitative manner.

REFERENCES

1. INTRODUCTION

Polyvinyl alcohol hydrogel (PVA-H) is proposed as a candidate material for an artificial cartilage. It is said that PVA-H is biocompatible material and is also said that fluid film lubrication is achieved by squeeze film effect because of the high moisture content. Consequently, PVA-H is expected to achieve low friction and to reduce wear of prosthesis simultaneously. According to our early study, the friction of PVA-H increases as the sliding cycles increase. In this study, friction experiment with intermittent loading system is conducted to clarify the effect of lubricant film between PVA-H and glass prism. The contact area between PVA-H and mating prism in lubricant is also estimated.

2. EXPERIMENTAL

2.1. Specimens and method

PVA powder having a polymerization degree around 2000 and a saponification degree of 98 mol% or more was used to prepare the PVA-H samples. PVA concentration of the samples was 15 wt%. The PVA powder was mixed with purified water and the mixture was continuously stirred at 95 °C for 90 minutes to obtain PVA aqueous solution. The solution was gelated by alternately repeating a freezing process at -23 °C and a thawing process at 3.5 °C several times. Three types of PVA-H specimens were used; unfilled PVA-H, tricalcium phosphate (α-TCP)-filled PVA-H, and laminated PVA-H. α-TCP was introduced as a filler in order to improve the mechanical properties. Unfilled PVA-H and α-TCP-filled PVA-H were laminated to combine the lower friction coefficient and higher mechanical properties. Pseudo-synovial fluid, 0.5 wt% hyaluronic sodium mixed with saline solution, is used as lubricant.

2.2. Apparatus

The schematic diagram of the apparatus is shown in Fig.1. The PVA-H specimen is rubbed to mating glass prism at reciprocating sliding. Friction force is measured using strain gauge affixed on the parallel leaf springs that PVA-H specimen is connected. The contact area between PVA-H specimen and prism is observed through the prism. Each of the light source and the CCD camera is placed on an arm that the angle to the prism surface is adjustable because the total internal reflection method is used to observe the contact area.

It is well known that human joint received repeated loading and unloading when it moves, so that squeezed synovial fluid seems to return to the space between the articular cartilages. Intermittent loading system is introduced to imitate human joint. Figure 1 (b), and (c) shows the setup of the system. The rolling bearing fixed to the balance arm supports the normal load so that the PVA-H is lifted from the prism surface when the contact region comes to the prism end. The PVA-H is loaded and rubbed to prism at the center of it. The size of PVA-H specimen is 10mm x 10mm. The normal load and sliding speed is 9.8N and 0.9mm/s, respectively.

3. RESULTS AND DISCUSSIONS

The contact area between three PVA-H specimens and prism in pseudo-synovial fluid during sliding are shown in Fig. 2. The differences of the critical angle between PVA-H, hyaluronic solution, and air to the prism represent the shaded density in the total internal reflection images. Therefore the distinguishing of the contact material is...
available. The shaded area represents the real contact area between the PVA-H and glass prism. The white region inside the apparent contact area probably represents the hyaluronic solution between the PVA-H and the prism. It is confirmed that mixed lubrication is produced. 

Figure 3 and Fig.4 represent the variations of PVA-H contact area at repeated sliding at steady loading and at intermittent loading, respectively. The PVA-H contact area increases with the increase in the sliding cycles at steady loading. On the other hand, the contact area is almost constant even if the sliding cycle increases at intermittent loading. The variations of PVA-H contact area and coefficient of friction as a function of sliding cycles are shown in Fig.5 and Fig.6, respectively. The PVA-H contact area increases with the increase in the sliding cycle irrespective of the PVA-H specimens. The coefficient of friction is also increases at steady loading. On the contrary, contact area and coefficient of friction at intermittent loading are constant regardless of the sliding cycle. As a result, it is found that steady loading, in other words continuous contact, squeezes the lubricant from the contact area. Then coefficient of friction increases due to the decrease in the lubricant. The coefficient of friction become steady because of the refill of the lubricant when the contact is interrupted by intermittent loading. Therefore it is found that repeated loading and unloading leads low coefficient of friction. 

The contact area and the coefficient of friction of three kinds of PVA-H specimens show almost same value so that the obvious effect of a-TCP was not observed.

4. CONCLUSIONS

The contact area between PVA-H and prism decreased and coefficient of friction increased at steady loading sliding. On the other hand, both contact area and coefficient of friction were steady at intermittent loading during sliding. The differences of friction properties between PVA-H specimens were not recognized in pseudo-synovial fluid.
DEVELOPMENT OF PALM KERNEL OIL WITH ADDITION OF POUR POINT DEPRESSANTS AS A LUBRICANT USING FOUR-BALL TRIBOTESTER (ASTM D4172)

Aiman Y, Syahrullail S

1 Faculty of Mechanical, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia.

1. INTRODUCTION

The depleting trend of conventional, non-renewable has triggered research and development on alternative renewable energy. Vegetable-based oil products are one of the most promising sources of renewable energy in this century [1]. Campanella et al, 2010 stated that the increase in the use of petroleum-based products has caused the progressive depletion of the world reserves of fossil fuels and there are also concerns on their environmental impact [2]. Many researchers agree that most current lubricants that contain petroleum base stock are toxic to the environment and also difficult to dispose of after use [3]. Low temperature performance is one of the weakness using vegetable oils to be a bio lubricant [4]. Vegetable oil become poor flow properties when it exposed to a lower temperature and become cloudiness and solidified upon a long term exposure [5]. Deliberate modification of the chemical structure of vegetable oils is a sound alternative to allow their direct use as lubricant base stocks [6]. This research is to investigate the effect of the various percentage (w/w %) of pour point depressant (PPD) to the coefficient of friction and wear performance of the refine palm kernel oil (RBD PKO) using four ball machine. The RBD PKO is a refined palm oil product that is solid at room temperature. The bench mark for the test is using mineral oil and also RBD PKO without PPD. The experiment is conducted following the standard ASTM D4172.

2. EXPERIMENTAL PROCEDURE

Four ball tribotester machine was used to conduct the experiment, the machine is used to investigate the characteristic of the lubricant properties and the wear [7]. The lubricant used for this experiment were RBD palm kernel oil and RBD with addition of PPD (5, 10, 20 and 30%w/wPPD) with mineral oil as a benchmark. The test procedure is according to the ASTM D4172 standard fourball test; 1200rpm, 60min, 75C and 40kg

3. RESULT AND DISCUSSION

Table 1: Result of pout point test

<table>
<thead>
<tr>
<th>Sample</th>
<th>Blend ratio (wt/wt)</th>
<th>Solid Phase Temperature (˚C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RBD PKO</td>
<td>100 0</td>
<td>25</td>
</tr>
<tr>
<td>A2-5%</td>
<td>95 5</td>
<td>20</td>
</tr>
<tr>
<td>A2-10%</td>
<td>90 10</td>
<td>20</td>
</tr>
<tr>
<td>A2-20%</td>
<td>80 20</td>
<td>15</td>
</tr>
<tr>
<td>A2-30%</td>
<td>70 30</td>
<td>15</td>
</tr>
</tbody>
</table>

From the result obtain we can see that at 25˚C the PKO liquid start to fully solidified, this show that the pour point of the pure RBD PKO cannot withstand at lower temperature without modifying it or adding any additive. At 15 ˚C, all sample PKO, A2-5%, and A2-10% were completely solidified except for A2-20% and A2-30% where the sample behave a liquid form but in waxy form.

Figure 3: Coefficient of Friction at 40kg

Figure 3 shows the value coefficient of friction at A2-20% is highest that is 0.0819 and the lowest is mineral oil that is 0.0624. The coefficient of friction in mineral oil is lowest because the oil is fully formulated and is already being used in the industrial, our interest is to look at the sample that been added to the RBD PKO. As we look all of the sample, the coefficient of friction for all sample do not have big difference with the pure RBD PKO, but still the value of the COF for pure RBD PKO is the lowest among them. Adding PPD to the RBD PKO shows that the value of the COF is increasing due to the effect of its properties of the lubricants.

Figure 4 illustrate the wear scar diameter for all sample after running in fourball machine
The trend of other sample shows that sample with PPD show lower value of the wear scar diameter compare to pure PKO, this shows adding PPD has a potential to reduce the scar at this condition test. And for the trend of the A2-5%, A2-10%, A2-20% and A2-30%, we can see that the value of the WSD is decreasing as the percentage of the PPD is increase from 0.509mm to 0.4902mm.

From the observation of the wear surface, the nature of asperities can be determined for each types of sample oil being used. Each load variation in experiment cause wear scar and each wear scar have their own characteristic. Figure 5, 6, 7, 8, 9 and 10 shows the surface profile for each sample.

Figure 4: WSD at 40kg

Figure 5: Mineral oil
Figure 6: Palm kernel oil
Figure 7: Palm kernel oil with 5%PPD
Figure 8: Palm kernel oil with 10%PPD
Figure 9: Palm kernel oil with 20%PPD
Figure 10: Palm kernel oil with 30%PPD
Figure 11: Palm kernel oil with 5%PPD

From the result obtain we can see that the mineral oil has highest surface roughness compare the other sample. This show that the RBD PKO has better performance in term of surface roughness compare to the mineral oil. When comparison to the different percentage of the PPD, we can see that the most desired surface roughness occur at A2-10%, and it surface roughness is increasing as the PPD addition is increase.

REFERENCES

FRICIONAL CHARACTERISTICS OF LASER SURFACE TEXTURED PALM KERNEL ACTIVATED CARBON COMPOSITE

Martini Mohmad¹, Mohd Fadzli Bin Abdullah¹,², Noreffendy Tamaldin¹,², Hilmi Amiruddin¹,²

¹Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.
²Centre for Advanced Research on Energy, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.

1. INTRODUCTION

Low coefficient of friction and high wear resistance are two main influences to the energy efficiency and component longevity [1]. Palm kernel in the form of activated carbon composite is one of the lowest cost carbon materials from agriculture waste that has a potential to be a tribological material [2]. Unfortunately, although the value of friction produced by this activated carbon was low, it still cannot achieve the desirable friction coefficient compared to diamond-like carbon (DLC) which less than 0.01. One of the most technique used for friction reduction is laser surface texture. The textured surface helps to control the friction value by acting as a secondary source of lubricant that acts as a reservoir under lubricated conditions [3]. Furthermore, it can reduce the surface contact area and function in trapping wear debris [4]. Previous studies [5-6] showed an enormous contribution of the texture technique within the automotive industry by increasing mechanical seal life, improving the load-carrying capacity of the thrust bearing and reducing friction of the piston ring. Applied loads are one of the most influential parameters with regards to the friction and wearing of varied materials within these parameters in mechanical applications [7-8]. The great potential of palm kernel activated carbon reinforced polymeric composite and the excellent capability of the surface texture technique in previous applications has motivated this research to carry out further in terms of applied load.

2. METHODOLOGY

The materials used in this study are palm kernel activated carbon and high-density epoxy. The activated carbon was obtained directly from the manufacturer, with the preparation of the activated carbon remaining confidential. The 250 μm particle size of 60wt.% activated carbon was mixed with 40 wt.% epoxy (at a resin to hardener ratio of 4:1). The mixed activated carbon and epoxy were then placed into a mould, hot-pressed at 80°C at 2.5 MPa pressure for approximately 5 minutes and left to cool at room temperature for about 15 minutes before being pressed out from the mould. The disc specimen, with a diameter of 74 mm, was left to cure at room temperature for approximately one week. The surface of the composite disc was then textured in the form of a micro dimple by using a CO₂ laser surface texturing machine. The dimple diameter, dimple depth, area density and contact ratio are constant at 1000 μm, 500 μm, 19 % and 0.2, respectively.

The sliding test was performed using a ball-on-disc tribometer against a polished ASTM 52100 (EN31) chrome steel ball under lubricated conditions. The physical-mechanical properties of the disc specimen and ball bearing are tabulated in Table 1. All tests were conducted at room temperature with a constant sliding distance of 150 m. Each test was performed applying different sliding speeds in a range of 50 rpm to 200 rpm with applied loads in the range of 5 N to 20 N, respectively. The entire test was repeated three times to reduce experimental errors.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Disc (60 wt.% activated carbon + 40 wt.% epoxy)</th>
<th>ASTM 52100 (EN31) chrome steel ball</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness (GPa)</td>
<td>8.63</td>
<td>7.45</td>
</tr>
<tr>
<td>Young's modulus (GPa)</td>
<td>7.61</td>
<td>210</td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>1.4</td>
<td>7.81</td>
</tr>
<tr>
<td>Arithmetic roughness (μm)</td>
<td>0.4</td>
<td>0.022</td>
</tr>
</tbody>
</table>

Table 1 Physical-mechanical properties of the ball and disc before sliding test.

RESULTS AND DISCUSSION

Figure 1 presents the graph of the average steady-state friction coefficient against applied load with different sliding speed applied to both non-textured and textured surfaces of palm kernel activated carbon composite disc sample.

The friction coefficient increases as the load increases for both the textured and non-textured surface materials. This is because the lubricant film carried a greater part of the load and caused the increase in shear strength of the lubricant film. As the load increases, the lubricating oil was squeezed out of the contact zone between the ball and the disc sample. This caused a much larger contact area between the ball bearing and the composite disc because the applied load is proportional to the contact area. The shear strength and the friction coefficient value, thereby increases.

Surprisingly, the friction coefficient of the textured surface is lower than the non textured surface. This may be due to the physical nature of the texture acting as an oil reservoir and oil adsorption on the contact surface thereby reduces surface energy during sliding. The oil mass that filled the dimple increases and thus the thickness of the oil film becomes greater. The oil pocket of the texture could
supply lubricant to the tribocontact by relative motion. When the oil film on the surface is broken, the textured surface still produces a lower friction coefficient due to the edge of the dimple possibly acting as a suitable medium for carbon to easily penetrate into the scratch of the ball bearing and induce carbon-carbon contact thus lower the coefficient of friction value.

It is verified that the changes value of load and present of dimple of the textured can contribute a massive effect in controlling the value of friction.

### 4. CONCLUSION

The conclusions that can be drawn from this study is increasing applied load produce higher friction coefficient. In addition, the oil pocket which is the dimples of the texture has reduced the value of friction coefficient regardless load applied and sliding speed.

### REFERENCES


![Figure 1](image_url)  
*Figure 1 Effect of applied load on palm kernel activated carbon composite at different sliding speeds. Error bar is for standard deviation.*

### ACKNOWLEDGEMENT

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TRIBOLOGICAL PERFORMANCE OF TEXTURED DIAMOND LIKE CARBON COATING

Shahira Liza Kami1, Tan Mean Yee2, Nurin Wahidah Mohd Zulkifli2, Masjuki Hj. Hassan2

1TriPreM i-Kohza, Mechanical Precision Engineering Department, Malaysia-Japan International Institute of Technology (MJIT), UTM Kuala Lumpur, 54100 Kuala Lumpur

2Department of Mechanical Engineering, Faculty of Engineering, University Malaya, 50603 Kuala Lumpur

1. INTRODUCTION

Researchers have found out that with the combination of surface texturing and DLC coatings, both the mechanical and tribological properties of the coatings have improved successfully [11]. Previously, researchers successfully proved that texturing improved the tribological properties of material. However, the study on effect of different texture parameters such as texture density, depth and diameter toward materials tribological performance is still lacking [1]. Therefore, the aim of this project is to investigate the tribological performance of DLC coating on different densities of texturing on stainless steel and titanium substrate with silicon interlayer in dry condition.

2. EXPERIMENT DETAILS

In this study, stainless steel (SS304) and titanium alloy (Ti6Al4V) are selected for the material of the substrate which are prepared by undergoing grinding and polishing process. The substrates then are textured by laser texturing process. Different densities of dimples range from 0 to 20% is drawn on the substrate by using laser texturing technique are used to achieve the main objective of this study. Dimples were created with constant power of 50 W but the speed of laser texturing is different for each substrate with different densities. The dissimilarity is because of the different type of laser texturing that depends on the grid size and type of the substrate itself. For stainless steel, the speed are 150 mm/s, 125 mm/s and 75 mm/s respectively for 5 %, 10% and 20% dimple density. On the other hand, the speed of the titanium alloy is constant at 200 mm/s for every dimple density. After laser texturing was performed, the selected surface of the sample was deposited by DLC coating through magnetron sputtering in a vacuum condition. The hardness of coatings are then characterized by using nanoindentation test. After that, the samples will be run under nanoindentation method and tribology test to find out the hardness and the tribology properties. The tribological performance were evaluated by using stainless steel pin on disc sliding tester under dry condition for 30 minutes. Both frequency and the applied load are kept constant at 5Hz and 5N respectively for both type of substrates. After the tribological test, final microstructures of substrate are observed and studied.

3. RESULTS AND DISCUSSION

3.1. Surface characterization

The deposition rate of the DLC coating is 57.8 nm/hr. The average thickness of the coating is 317.8 nm, while for the average hardness of the coating is 6.67 GPa. The thickness and hardness for all samples is the same since the deposition condition is the same. Figure 3.1 shows the examples of surface images taken by 3D optical surface profilers on the surface of DLC textured titanium alloy and stainless steel coating with 5% dimple density. Results indicate that dimples on the stainless steel is more shallow compared that on the titanium alloy.

Fig. 3.1 3D image of DLC coatings on (a) titanium alloy, (b) stainless steel substrate with 5% dimple density

3.2. Tribological evaluation

3.2.1. Wear rate

The wear rate of the DLC coating obtained from the tribological test is as shown in Figure 3.2. Result shows that DLC coating on titanium alloy with 20% dimple density has lowest wear rate than other samples.

Fig. 3.2 Wear rate of DLC coatings on titanium alloy and stainless steel substrate at different dimple density
However, the wear rates of DLC coatings of titanium alloy with 5% and 10% of dimple densities are higher than that of the titanium with flat surface which is 0% of dimple density. On the other hand, the wear rate for DLC coatings for stainless steel increased as the dimple densities increases. Thus, this result revealed that introducing dimples on the surface of stainless steel are not suitable method for reducing wear. In addition, the dimple produced on stainless steel is too shallow which may not contribute to the wear reduction during the sliding process. However, 20% is the optimum selection of dimple density for DLC coating of titanium alloy which has better wear resistance than substrate with flat surface.

3.2.2. Worn surface characterization

Figure 3.3 shows the worn surface of DLC coatings on titanium alloy and stainless steel substrate at different dimple density tested under dry condition against stainless steel. All samples are undergone abrasive wear mechanism due to the worn surface is generally characterised by grooves and scratches. DLC coating on titanium alloy with 20% dimple density has experienced less wear compare to other samples. It is also shown that the dimples area are almost not experienced wear compared to the flat area (e.g Fig 3.3c). However, for all samples except for DLC coating on titanium alloy with 20% dimple density, the DLC coating are totally damaged due to rough deep groove exhibited on the worn track.

4. CONCLUSIONS

Hence, introducing surface texture on the titanium alloy coated with DLC is certainly one of the approaches in reducing wear rate of DLC coatings. By choosing the optimum dimple density (20%), the minimum wear rate of DLC coatings can be achieved.

REFERENCES


EVALUATION OF HYDROGEN GAS SEALING ABILITY OF CARBON FIBER FILLED PEEK COMPOSITE

T.Morita_1,2, Y.Sawae_1,2, Joichi Sugimura_1,2,3

1Faculty of Engineering, Kyushu University, Japan
2 International Institute for Carbon-Neutral Energy Research, Kyushu University, Japan
3 Research Center for Hydrogen Industrial Use and Storage, Kyushu University, Japan

1. INTRODUCTION

Hydrogen is a promising energy carrier in energy and transportation systems in the future because it’s low environmental load. Finally, FCV just came out in Japan. For diffusing the use of FCV, it is necessary to resolve a lot of tribological problems associated with hydrogen production, storage and use. In these systems, polymers are used as gas seals in many valves and sliding against metal counterface in hydrogen gas environment. The mechanical properties and wear characteristics of polymers can be improved by adding filler materials[1]. PEEK composites as the seal material in sever conditions are expected because PEEK resins are high-strength and superior in creep characteristic. However the sealing ability of PEEK composites was inferior to that of PTFE based composites in larger region roughness[2]. In this study, we evaluated hydrogen gas sealing ability of carbon filled PEEK composite. Effects of surface roughness of metal and the atmosphere of sliding test for running-in were examined by using lower roughness of carbon fiber filled PEEK composite.

2. MATERIAL AND METHOD

Figure 1 shows schematic drawing of an annular type face-contact tester developed in our laboratory. The upper pipe-shaped polymer specimen is loaded against the lower metal disk specimen by a spring. The internal space between polymer and disk specimens is filled with pressurized hydrogen gas at 200kPa while nitrogen gas of 20kPa was filled in the outer chamber which covered specimens and isolate hydrogen gas from atmospheric air to ensure the safety. Pressure and temperature of sealed hydrogen gas are monitored during a 5-minute experiment. Every second, the mass of the sealed hydrogen gas was calculated sequentially from these values.

30wt% carbon fiber filled PEEK composite was used as the polymer specimens with the same level surface roughness (about 0.2μm Ra) by buff polishing with same condition. SUS440C martensitic stainless steel was used as metal disk specimens with 0.02, 0.05 and 0.08μm Ra. The hydrogen sealing test was first examined under the static contact condition. Then, the sliding test for running-in was conducted under the initial contact pressure of 1.25MPa in hydrogen and air. The metal disc specimens was rotated at the steady speed by servomotor and slid against the polymer specimen at the sliding speed of 100mm/s. Each sliding test was run for 1000m in this test performed twice. The volumetric wear rate of the polymer specimen was evaluated from its weight change. After the sliding test, the formation of the carbon film and also its structure were examined by using optical microscope and microscopic Raman spectroscopy. Then, the hydrogen sealing test were examined twice with no sliding test disk in 0.02μm Ra and after sliding test disk for assess the effects of the polymer transfer film formed on the metal disk specimen during the sliding test.

3. RESULT AND DISCUSSIONS

Figure 2-5 show the gas leakage the through the interface of regin and metal disk were plotted against the ratio of sealed hydrogen gas pressure to average contact stress. Figure 6 shows the picture of the surface of PEEK composite and metal disks after the 2nd sliding test. Figure 7 shows the comparison of the specific wear rate of PEEK composite. Except for the largest roughness metal disk sliding test, the hydrogen sealing ability were improved by every sliding.

Fig.1 Schematic drawing of tester

Fig. 2 Comparison of the hydrogen gas leakage rate with 0.02μm Ra disk in hydrogen sliding test
test. In sliding test with 0.08 µm Ra disk, the specific wear rate showed the maximum and wear debris were observed on the disk surface in large quantities, but smooth polymer transfer film on the metal contact surface was not observed. Furthermore, the hydrogen sealing ability turned worse because the surface of the PEEK composite roughened in this condition.

In metal roughness of 0.02 µm and 0.05 µm Ra, the specific wear rate of PEEK composite were less than that of 0.08 µm Ra and smooth polymer transfer film on the metal contact surface were observed. And the surface of the PEEK composites were very smooth especially inside the surface so that the hydrogen gas sealing ability were improved after the sliding test.

In sliding test in air atmosphere, the specific wear rate was slightly larger than that of in hydrogen but the very smooth area of the surface of the PEEK composite was the most largest and the transfer film on the metal was most clealy and the largest. In this condition, the most largest transfer film on the metal disk was good effect on the hydrogen gas sealing ability.

4. CONCLUSIONS

The hydrogen sealing ability of carbon fiber filled PEEK composite was evaluated and following results about the effects of metal surface roughness and the atmosphere in sliding test for running-in were obtained. The sealing ability in sliding test of smaller roughness of metal sourface were improved by every sliding test. The sealing ability of sliding test in air atomospher was significantly improved by forming smooth polymer transfer film on the metal counterpart. The sealing ability of carbon fiber filled PEEK was highly depended on the sliding test conditions.

REFERENCES


TRIBOLOGICAL BEHAVIOUR OF SURFACE TEXTURED HYDROGENATED AMORPHOUS CARBON COATING IN THE PRESENCE OF PALM BASED TMP ESTER AT VARIOUS TEMPERATURES

A. A. Arslan, B. H.H. Masjuki, C. M. A. Kalam, D N.W.M. Zulkifli, E. M. Varman

1Center for Energy Sciences, University of Malaya, Kuala Lumpur, Malaysia

1. INTRODUCTION

In the last few years, effects of surface texturing have been investigated on diamond-like carbon (DLC) coated surfaces in oil-lubricated sliding conditions. DLC coatings are increasingly being used to improve the tribological performance of engineering components like bearings, gears, seals, metal cutting, and forming tools, magnetic hard disks and biomedical, due to their hardness and excellent mechanical and tribological properties [1]. Because of the higher tribological performance, the use of DLC in automotive components is also increasing. As automotive components are subject to higher temperatures, loads, and oxidative environments, to maintain the performance of DLC at these harsh conditions, DLC is doped with hydrogen, various metals, nitrides, and carbides [2]. Surface texturing has recently been considered as one of the methods to maintain and enhance the tribological performance of DLC coating [3]. Most of the work done in this regard is at room temperature. It is well known that DLC coatings possess lower thermal stability at higher temperatures. Therefore, in the present study, the authors have investigated the effect of textures on hydrogenated amorphous carbon (a-C:H) DLC coating at various temperatures.

To date, most of the automotive lubricants are mineral oil based, which is toxic and non-biodegradable. Because of this reason, vegetable oils are being explored as alternative base oils. In this study, tribological behavior of palm oil based trimethylolpropane (TMP) ester was evaluated as an alternative to the conventional base oil with textured and un-textured DLC.

2. METHODOLOGY

Micro textures with approximate dimensions of dimple depth, diameter, and density of 6 µm, 100 µm, and 20% were created on the substrate using a pico second laser with a power of 10 W and a wave length of 1.06 µm. After surface texturing, the DLC coating was deposited by hybrid magnetron sputtering. To evaluate the a-C:H DLC coating performance under various temperatures, a reciprocating sliding tribological testing apparatus with a ball on a flat configuration was used. The diameter of ball was 6.35-mm. Palm based TMP ester was used as a lubricant. It was acquired from University Putra Malaysia. Experimental conditions used are as follows: load 100 N; temperature 40°C and 125 °C; frequency 5 Hz; test duration was 2 h and stroke length was 2.5 mm.

3. RESULTS

TMP-T40 showed lower COF compared to TMP-C40 (Fig. 1). Textures helped in lowering the COF by acting as lubricant reservoirs and wear particle traps [4]. TMP-T40 showed the lowest wear coefficient compared to un-textured samples (Fig. 2). Textured samples (TMP-T80) showed lower wear coefficient compared to un-textured samples (TMP-C80) (Fig. 2). Higher COF was observed in textured case compared to un-textured DLC at 80 °C (Fig. 1). The reason for the decrease in COF of un-textured DLC at 80 and 125 °C may be due to graphitization transformation. The reduction in COF due to graphitization has been noticed previously [5]. Due to graphitization, the coating layer becomes soft and the load bearing capacity reduces and wear increases [6]. This could be the reason for the higher wear rate in the case of un-textured DLC at 40 °C, 80 °C and 125 °C, as can be seen in Fig. 2. This has been confirmed with Raman spectroscopy. Table 1 shows I_D/I_G ratios before and after tests. The increase in the I_D/I_G ratio indicate an increase in the sp^2 fraction in the DLC film [7, 8]. It can be observed that in textured cases the increase in ratio is less compared to un-textured samples. Which confirms higher graphitic transformation. In the case of textured DLC, COF increases with the increase in temperature (Fig. 1), which is different from un-textured DLC. This may be due to the suppression of graphitization by the textures. The reduction in graphitization transformation can explain the lower increase in the wear rate of textured DLC compared to un-textured DLC at various temperatures tested (Fig. 2).
Figure 1 CoF of DLC coated samples under Palm based TMP lubrication

Figure 2 Wear coefficient of DLC coated samples under Palm based TMP lubrication

Table 1 $I_d/I_G$ ratio of textured and Un-textured DLC samples

<table>
<thead>
<tr>
<th>Sample</th>
<th>$I_d/I_G$ Ratio Before</th>
<th>$I_d/I_G$ Ratio After</th>
</tr>
</thead>
<tbody>
<tr>
<td>TMP-C40</td>
<td>1.17</td>
<td>1.31</td>
</tr>
<tr>
<td>TMP-T40</td>
<td>1.17</td>
<td>1.18</td>
</tr>
<tr>
<td>TMP-C125</td>
<td>1.17</td>
<td>1.57</td>
</tr>
<tr>
<td>TMP-T125</td>
<td>1.17</td>
<td>1.20</td>
</tr>
</tbody>
</table>

4. CONCLUSION

(1) The results show that micro textures improved the wear resistance of a-C:H DLC coating compared to untextured DLC at 40, 80, and 125 °C temperatures under Palm based TMP ester. This was due to textures behaving as fluid/wear debris reservoirs, whereas, at higher temperatures, this was due to the suppression of coating graphitization and textures behavior as fluid/wear debris reservoirs.

(2) At lower temperature, 40 °C, textured DLC showed lower friction and wear compared to un-textured DLC.

(3) As the temperature increased to 80 and 125 °C, the textured DLC showed higher COF compared to un-textured DLC. This finding can be explained by the higher graphitization transformation in case of un-textured samples.

REFERENCES


LOW FRICTION MECHANISM OF SELF-FORMING CARBON FILM FOR CARBON FIBER FILLED PTFE
R.Umei_1, Y.Sawae_2, T. Morita_2

1 Graduate School of Engineering, Kyushu University, Japan
2 Faculty of Engineering, Kyushu University, Japan

1. INTRODUCTION

PTFE has self-lubricating property. Its composite materials are widely used as sealings. It was previously reported that the carbon film self-forms and exhibits low friction when friction test was carried out using PTFE filled with carbon fibers and metal [1]. Besides, friction characteristics are affected by atmospheric gas and moisture content [2]. However, it is not clear the mechanism of self-forming carbon film. If we can clarify the carbon film formation process, we will be able to obtain additional clues to lower friction. This study aimed to explore the process of PTFE filled with carbon fibers forming carbon film on the sliding surfaces. We evaluated the film formation process using a pin on disk friction tester, nano indentation and Raman spectroscopic analysis.

2. EXPERIMENTAL METHOD

Experiments were conducted in high purity nitrogen gas using a pin-on-disk type tribometer installed in an environmental control chamber equipped with a scroll vacuum pump, a turbo molecular vacuum pump and gas filters. In this apparatus, it is possible to perform a sliding test while controlling the moisture content at the ppm level in a high purity gas atmosphere.

PTFE filled with 20 vol.% PAN-based carbon fiber was used for the pin specimen. The steel disk made of SUS440C(JIS). The disk surface was polished to a surface roughness Ra = 0.05 μm. In this experiment, the sliding speed was 2m/s. The contact pressure was 1MPa. The temperature was room temperature. The chamber was evacuated by vacuum pumps until the pressure became less than 10^{-4} Pa before filling gas. The moisture content was adjusted by using a filter when filling the gas. The friction test was stopped at 2000m, 12000m and 40000m, and the surface analysis was carried out. The pin surface was observed with an optical microscope. The formation of the carbon film and also its structure were examined by a microscopic Raman spectroscopy. Mechanical properties of carbon film were evaluated using nano indenter.

3. EXPERIMENTAL RESULTS

Fig.2 and Fig.3 represent transition of friction coefficient against sliding distance in nitrogen gas. In Fig.2, nitrogen gas was charged directly and the moisture content was adjusted to about 3 ppm. In Fig.3, the moisture content was adjusted to 0.8 ppm or less by using the gas purification filter.

Fig.2 In high moisture content

Fig.3 In low moisture content

Up to 2000m, results showed a similar trend. However, from 2000m to 12000m, when the moisture content was lower, it shows stable and low friction. When the moisture content was high, friction rapidly increased and showed unstable behavior.

4. ANALYSIS AND DISCUSSION

The surface of the disk and pin was analyzed at 2000m, 12000m, and 40000m. Using Raman spectroscopy and
indentation, we examined the effects of sliding distance and moisture content of gas atmosphere.

4.1. Raman spectroscopy

Fig.4 and 5 represent raman shift at 2000m in high moisture content. It was confirmed that a carbon film was formed on both pin and disk surfaces. The carbon film on the disk suggests that the carbon fiber of the pin was graphitized and transferred due to friction. Compared to the case of 2000m, 12000m and 40000m, although there were variations in intensity, no change was observed in the carbon film structure. The same result was obtained even when the moisture content was low. From these results, the change in friction coefficient during the film formation process is not due to the composition of the film, but may be due to a change in other factor, such as film thickness.

![Fig.4 In high moisture content (disk)](image)

![Fig.5 In high moisture content (pin)](image)

Compared at a sliding distance of 12000m, a thin film is homogeneously formed when the moisture content is low, whereas the moisture content is high, a thick film similar to graphite is formed. Graphite is said to be useful for lowering friction, but in this result it was suggested that excessive graphite would rather increase friction.

4.2. Nano indentation test

The hardness of carbon film transferred to the metal surface was evaluated using nano indentation tester. The maximum normal force was set to 20 mN and the test was conducted at several points. Fig.7 shows the load and depth curves. The appearance of the carbon film can be classified into three types, and the results of each hardness test are shown. It was confirmed that the film became thicker from (b) to (d) and were softer than metal. When the friction coefficient is low, (b) and (c) were predominant. On the other hand, the formation of thicker films like (d) are confirmed if the friction coefficient is high. The relationship between these films and the coefficient of friction should be investigated.

![Fig.7 Load-depth curves, (a) pure disk surface, (b)(c)(d) carbon films](image)

5. CONCLUSIONS

Friction test of carbon fiber filled PTFE and stainless steel SUS440C was conducted in a nitrogen atmosphere to investigate the influence of the process of forming the carbon film and the amount of moisture on the friction and wear characteristics. It was confirmed that carbon film was formed by sliding and contributed to low friction. No change was observed in the composition of the film formed on the surface, and the graphitized carbon film was transferred to the metal side. It was suggested that the friction coefficient increases when the transfer film has too much graphite component. Further investigation is necessary to evaluate the accurate carbon film thickness and their impact on the friction coefficient.

REFERENCES


NEW STATISTICAL ANALYSIS FOR TOOL WEAR PROGRESSION TRACKING

N. A. Kasim¹, M. Z. Nuawi¹, J. A. Ghani¹, C. H Che Haron¹

¹Department of Mechanical & Materials Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43000 Bangi, Selangor, Malaysia.

1. INTRODUCTION

A reliable analysis method produces a crucial role to a consistent prediction, especially in tool wear estimation. Through cutting force, it acts as a robust indicator for online tool condition monitoring as a tool wear trend in reference for indirect measurement and monitoring of tool wear [1]. A new statistical analysis based on resultant signal of force components is developed in monitoring tool wear progression.

2. EXPERIMENTAL

A sensor system of rotating dynamometer used for tool wear monitoring in milling P20+Ni tool steel using end milling cutting tool insert was tungsten carbide with multi-layer PVD TiAlN/AlCrN grade ACP200 (Code: AXMT170504PEER-G). The analysis involves cutting force $F_c$, thrust force $F_t$ and perpendicular cutting force $F_r$. A milling process experimental is prepared with various combinations of cutting speed (200 and 373 m/min), feed rate (0.10 and 0.20 mm/tooth), radial depth of cut (0.4 and 0.6 mm) and axial depth of cut is kept constant at 1mm.

3. NEW STATISTICAL ANALYSIS METHOD

- Start
- $F_1$
- $F_{n+1}$
- New Y data
- Calculate the followings:
  1. Mean
  2. Distance radius
  3. Standard deviation
  4. Kurtosis
- $Z_{rot} = \sqrt{\sigma_r^2 K_r}$
- Plot graph:
  1. $Z_{rot}$ factor vs Number of cutting
  2. Defect (ie. Wear) vs $Z_{rot}$ factor
- End

Fig. 1: Flowchart of the $Z_{rot}$ analysis.

The new analysis was inspired by the original I-Kaz ($Z\infty$) which was pioneered by Nuawi (2008) [2]. The new symbol with ‘rot’ is referring to the analyzed data that literally ‘rotating’ over its resultant mean. The algorithm in Fig. 1 is referring to $Z$-rot analysis that started with a combination of two or more signal inputs from the same type of sensor to get a conclusive time domain allocation. Hence, several feature extractions are needed with the intention to find $Z_{rot}$.

The factors are outlined in the model data pattern with the respect to wear and number of samples. $Z_{rot}$ is a tracking analysis kurtosis based use to track the severity of wear. It is expected to show a strong relationship over the wear evolution.

4. RESULTS AND DISCUSSION

The analysis of the cutting tool condition at certain times can be done by utilising $Z_{rot}$ analysis. The $Z_{rot}$ is calculated for every signal measured during the cutting process. The plot of $Z_{rot}$ versus flank wear value obtains a nonlinear propagation curve of wear evolution.

Fig. 2: Flank wear, $VB$ versus number of cutting.

Fig. 2 exhibits the flank wear related to number of cutting. As expected, flank wear progression for all test samples were gradually increased upon the number of cutting in each test. According to Taylor’s curve, initially wear rate is rapidly increasing at the beginning. Then the wear rate
slows down and continuously increase linearly [3]. Nevertheless, tool wear appeared (Fig. 2) only some mild wear at the beginning followed by a nearly or no wear phase, which indicate the steady state stage [4]. On the other hand, Fig. 3 shows $Z_{rot}$ factor increase rapidly at the beginning and then slowly decrease to starts growth linearly. The factors increase rapidly again when the tool approaches the end of tool life. The constant use of cutting tool will lead to its fractures. It is observed that the less the linear inclination of the $Z_{rot}$ factor is, the longer the tool life becomes. Such result is the same for all different set of machining conditions.

As the purpose of the study is to apply tracking analysis of the signal that is generated by the developed statistical analysis, thus there is a substantial interest throughout the wear evolution progress. The tools are expected to work in a steady manner under normal operation, particularly after the running in stage [5]. After some time, noticeable wear progression for instance BUE, flank wear, crater wear, flacking, chipping, and notching might be detected [6][7][8]. For example in Fig. 3, a sudden shock cause by a certain type of wear presented at the cutting tool edge at the point 17. Moreover, Fig. 3 reveals an interesting pattern of $Z_{rot}$ factor that appears to have sudden and progressively increase and decrease in the aftermath. These singularities presented through all test samples. The sudden escalate of $Z_{rot}$ factor caused by high cutting force came to pass on the tool edge during the machining on the test sample. It is an indication of tool damage as it statistically change in the shape of the signal [9].

The relative sharp tools at the initial stage of machining under dry cutting conditions produce low cutting forces that lead to the lower value of $Z_{rot}$ factor. With the increase number of cuttings, the tool edge becomes dull, higher friction coefficient and more contact area at the tool/chip and tool/workpiece interfaces are generated. As in Fig. 4, the friction force at the tool/workpiece interface and the contact area of the wear land increased drastically, which would produce a fair amount value upon the $Z_{rot}$ factor. The increasing factors in all cases of this study due to changes in signals amplitude and frequency of the cutting forces. This results in a greater tendency to fracture as the tool is pushed away from the machined surface by a majority of the resultant force [6]. Therefore, the $Z_{rot}$ factor become higher towards the end, thus can be applied to determine tool wear progression during the milling process. 

5. CONCLUSION

The new statistical method was developed to analyze the cutting force signal ($F_c$, $F_z$, and $F_{cn}$) for tool wear progression detection. Throughout the experimental studies, $Z_{rot}$ factors show some significant degree of nonlinearity that appears in the measured impact. $Z_{rot}$ factors correspond with the number of cutting specifies a sturdy correlation over wear evolution. The factor can be utilized to be the parameters for monitoring of tool wear by using threshold values on certain cutting condition. Also as an alternative reference to support experimental findings in the tool wear study to visualize any changes in the signals.

REFERENCES

EFFECT OF ENERGY INPUT ON WEAR BEHAVIOUR OF SiC SURFACE MODIFIED LAYER DUPLEX STAINLESS STEEL

P.H. Lailatul_1, M.A. Maleque_1

1Department of Manufacturing and Materials Engineering, International Islamic University Malaysia, Kuala Lumpur
Laila_7164@yahoo.com, maleque@iium.edu.my

1. INTRODUCTION

Duplex stainless steel (DSS) contains equilibrium amount of ferrite and austenite phase exhibits tremendous corrosion resistance and mechanical properties. However, DSS having drawbacks on low surface hardness and wear resistance in the various industries in oil and gas for piping, drilling rigs and boiler, chemical and cargo tanks and heavy construction vehicle for hydraulic pump piston and transmission gear for bulldozer and excavator. Improvements in these limitations significantly increase the usage in wider applications. Maleque et al. [1] investigated the TiC composite coating on AISI 4340 using TIG torch method. Both microhardness and wear resistance showed significant improvement particularly after TIG coating with AISI 4340. Other finding by Adeleke et al. [2] studied the Fe-C-Si coatings on CP-Ti melted under TIG torch techniques. The hardness value increased of 800 Hv compared to 200 Hv of substrate material. The wear behavior also improved with lower wear rate and coefficient of friction compared to substrate material. Yet, no study has been carried out to melt the SiC powder with DSS by using TIG techniques for surface modification. Therefore, the purpose of this work to investigate the wear behavior of DSS surface with SiC powder preplacement melted at energy input of 480, 768 and 1728 J/mm. The microhardness and wear behavior are presented in this paper.

2. EXPERIMENTAL DETAILS

The material used for this study is duplex stainless steel (DSS) grade ASTM 2205 with the dimension of 50 mm x 33 mm x 10 mm as the substrate material. The SiC powder preplacement with 60 μm was used for surface modification. The SiC powder weighed of 0.5 mg per millimeter square was mixed with a small amount of polyvinyl acetate (PVA) binder and agitated to form a paste with the aid of distilled water and alcohol. The addition of binder is to keep the powder on the surface under the flow of the shielding gas. The DSS substrate with pre-placement reinforcement of SiC was carried out using TIG torch melting technique to produce a series of tracks with different energy input of 480, 768 and 1728 J/mm. The specimen was cut into cross section for microhardness depth profile test. The test was conducted using 500 gram indentation load and 10 second dwelling time. For wear test, the surface modified layer was cut using a wire EDM machine and the surface was ground and polished to make sure the surface was flat. The wear testing under dry condition was conducted using ball-on-disc reciprocating tribometer with constant load of 30 N and frequency of 5Hz for 10 minutes. The counterpart material was alumina ceramic ball with diameter of 6 mm. After wear test, the worn surface was observed under SEM to analyze the mechanism of wear. The surface roughness and wear depth also measured using surface profilometer machine.

3. RESULT AND DISCUSSION

3.1. Microhardness properties

Fig. 1 shows the microhardness depth profile of the cross section sample. The surface modified layer has showed a maximum hardness of 1245 Hv compared to substrate material of 250 Hv. This increment is related to the formation of SiC hard particles with the dense population of dendritic microstructure as shown in Fig. 2a. The hardness value was reduced to 650 Hv at energy input of 480 J/mm. This is might be due to low energy input supplied to complete the melting of SiC and substrate material and low population of dendrite microstructure as can be seen in Fig. 2b.
3.2. Wear Behaviour analysis

The wear rates of substrate DSS and modified layer are presented in Fig. 2. As can be seen in the figure, the wear rates of substrate, surface modified layer at energy input of 480 and 768 J/mm were 7.122, 4.986 and 2.849 mm³/Nm respectively. It revealed that the wear rate of modified surface layer is ~ 2-3 times higher than substrate material. The sample processed with energy input of 768 J/mm showed the lowest wear rate. This is contributed from the higher hardness due to formation of hard phases in the modified layer. The reduction of wear rate observed at sample processed under 480 J/mm. This is directly to low hardness and low population of dendrite microstructures. Similar observation was found by Idriss et al. [3].

Fig. 2 Effect of modified surface layer of wear rate

![Fig. 2 Effect of modified surface layer of wear rate](image)

Fig. 3 Effect of modified surface layer of surface roughness and wear depth

![Fig. 3 Effect of modified surface layer of surface roughness and wear depth](image)

Fig. 4 SEM micrographs showing worn surface (a) substrate DSS (b) 480 J/mm (c) 768 J/mm

Fig. 4a shows the worn surfaces of substrate DSS with severe abrasion marks of wear and ploughing. For modified surface layer in Fig. 4b and 4c, it is noticed that the incorporation of SiC particles has improved the wear resistance with smooth worn surface. It revealed that SiC phases are strongly bonded to the substrate material with less plastic deformation. However, the sample under processed of 480 J/mm shows severe worn surface compared to 768 J/mm due to lower hardness and less bonding between SiC and substrate DSS. Due to this, the SiC particles were easily pull out from the matrix during the reciprocating wear.

Fig. 5 Frictional behavior of (a) substrate DSS (b) 768 J/mm (c) 480 J/mm

Fig. 5 shows the frictional behavior of substrate DSS and modified layer. It can be seen clearly that the friction reduced from 0.7 for substrate DSS to 0.6 and 0.3 for modified layer. The significant improvement of friction is observed under 768 J/mm due to higher population of carbides and higher hardness, which cause the load transferred to the subsurface was reduced.

4. CONCLUSIONS

1) DSS modified layer with SiC preplaced powder exhibited higher hardness and better wear behavior compared to substrate DSS.
2) The improvement of hardness and wear behavior attributed with the hard phases in the modified layer.

REFERENCES

RGB SENSITIVITY MEASUREMENT EXPERIMENT OF OIL FLOW IN JOURNAL BEARING

F. Sakai_1, M. Ochiai_2, Y. Sunami_2, H. Hashimoto_2

1Graduate School of Science and Technology, Tokai University, Hirastuka-shi, Kanagawa-ken, Japan.
2Department of Mechanical Engineering, Tokai University, Hirastuka-shi Kanagawa-ken, Japan

1. INTRODUCTION

Bearing characteristics of journal bearing vary remarkably from cavitation area. For example, it is known that the cavitation area of journal bearing under starved lubrication expands, therefore the stability under starved lubrication increases and while friction torque decreases [1,2]. However, in the conventional visualization method, a lot of processing time is needed to identify the cavitation area. Therefore, a new method measuring the cavitation area is required.

On the other hand, there are bearings used in industrial machine provided with two oil filler port openings to uniformly supply lubricating oil inside. Moreover, the author’s research has shown that the bearings having two filler ports can suppress temperature rise of the oil film under starved lubrication more than the bearing having one filler port [3]. However, it is difficult to visualize the path of the lubricating oil supplied from each oil filler ports.

Under these background, in this study, two color oils are supplied to the bearing from two oil filler port and the bearing surface were visualized under flooded lubrication, oil whip and starved lubrication. Further the RGB sensitivity of bearing surface is measured and the cavitation area and the distribution of oil flowing from each oil filler port are demanded and the validity of the new visualization method was examined by comparing it with the conventional cavitation visualization experiment.

2. EXPERIMENTAL SETUP

In this study, blue oil and orange oil is used for visualization experiment. These color of oil are decided on the basis of the hue ring. Figure 1 shows the Schematic diagram of test rig. Lubricating oil is supplied from the tow oil filler port into the bearing clearance. The size of the bearing diameter $D$, the bearing clearance $C$, the bearing width $L$, the oil filler port diameter $D_f$, the width diameter ratio $\lambda$ are 25.0 mm, 175 μm, 14.5 mm, 8.2mm, 0.58 respectively. The bearing are made of transparent acryl, which allows observations of the formation of an oil film and generation of cavitation. The test rig consists of a rotor installed in its central part and a revolving shaft supported by two bearings on its left-hand and right-hand sides, respectively. The shaft is driven by a DC motor with a possibility to vary the number of revolutions continuously up to 10,000 rpm. An oil tank is placed on the top of the bearing, and the lubricating oil is supplied through a control valve. The viscosity grade of lubricant oil is iso VG22. The halogen light is used as the light source of the light of visualization in surface of bearing.

In this study, the color of bearing surface is quantified as RGB sensitivity by NI Vision Builder AI. Figure 2 shows the measurement point of RGB sensitivity. The wedge side of bearing is visualized by high speed camera. Ten measurement positions are set and the length of the each measurement part is 1.00 mm at the interval of 1.45 mm.

Table 1 shows the RGB sensitivity results of single colors, mixed oil (Orange oil : Blue oil = 1:1) and cavitation area. The value of cavitation area means the color of journal surface without oil.
3. EXPERIMENTAL RESULTS

Figure 3 shows the results of RGB sensitivity under flooded lubrication. The yellow means cavitation area. Moreover, the results are obtained by the conventional visualization method. In fig. 3(a) the difference in the value of red and blue are small between the width position of 0.0 and 5.0 mm, 12.0 and 14.5 mm while, the value of green is smaller compared to the other values. The tendency of these area is the same as cavitation area as shown in table 1 and it is in agreement with the cavitation area obtained by the conventional visualization method. The values of blue are relatively high between the width position of 5.0 and 12.0 mm. Therefore it is found that the blue oil exist in the center of the bearing. As stated above, in the case of under flooded lubrication, it is found that the supplied oil from the opposite wedge side flow at the center of bearing and the cavitation occurred in the side of bearing. In fig. 3(b), the difference in the value of red and blue are small between 9.0 and 13.8 mm and the value of green is smaller compared to the value red and blue. The tendency of these area is in agreement with the cavitation area as shown in table 1 and it is in agreement with the cavitation area obtained by the conventional visualization method. On the other hand, the values of red are high compared to the values of blue between 0.2 and 20mm, 4.2 and 5.5mm despite these are cavitation area. Because in case of the starved lubrication, the thin oil film is formed between air phase and bearing surface and the orange color of thin oil film is observed on the surface of journal. The values of blue increase at the center of bearing and the values of red are the same as the values of green. Therefore, it is considered that the blue oil exist at the center of bearing. Moreover, in the case of further area, the values of red are high and the values of green and red are the same, and thereby it is considered that the orange oil exist at the area. As stated above, in the case of under starved lubrication, it was found that the supplied oil from opposite wedge side flow at the center of bearing and the supplied oil from wedge side flow at the area between the side of bearing and the center of bearing.

4. CONCLUSION

This paper describes a new visualization method which can visualize oil film distribution and cavitation area on journal bearing. The distribution of oil supplied from two sites is visualized by two color oil, and the blended color and cavitation area are measured by RGB representation. As results, cavitation area by the new observation method agree with a result of conventional experiment. Moreover it is found that the distribution of oil film of lubrication condition have been changed.

REFERENCES

ADHESION OF POLYTE-TRAFLUOROETHYLENE (PTFE) ON AUSTENITIC STAINLESS STEEL (JIS SUS316) DURING THE INITIAL STAGE OF SLIDING AT DIFFERENT ATMOSPHERIC HUMIDITY

Z. A. Subhi 1, and K. Fukuda 1

1Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, Malaysia
aszaid3@live.utm.my

1. INTRODUCTION

Polyte-trafluoroethylene (PTFE) is widely used as self-lubricated sliding materials due to its very low coefficient of friction resulted from its nature of low surface energy. In the practical world of tribology applications, the variation of humidity is influencing the tribological performance of materials, especially metallic materials due to their highly reactive surface. Although PTFE is a polymer and considered as chemically inert but it was reported that changes of relative humidity (RH) can give impact on the tribological performance of PTFE when sliding on a metallic counter face [1]. The current study is motivated by the findings of our previous studies when investigated the humidity influences on the sliding phenomena of metallic materials [2,3]. Both studies have found the medium rate of RH (50-60 %) might be a critical condition from the perspective of severe adhesion initiation and adhesive wear of metallic materials. We have inferred that multiple factors such as the meniscus effect due to the presence of adsorbed water layer on the surface as well as the solid-solid adhesion have probably dominated the phenomenon at the interface and leaded to the initiation severe adhesion in medium RH rate during the early stage of sliding. Our previous findings showed the necessity for more investigation to determine the accomplished picture on the mechanism of the atmospheric humidity changes and the material type on the adhesion during the early stage of sliding. In the current paper, a study is undertaken to understand the fundamental aspects of atmospheric humidity changes to influence the tribological performance during the early stage of sliding of unfilled-PTFE (as a hydrophobic polymer material) ball specimens sliding against austenitic stainless-steel grade 316 (JIS SUS316) (as a hydrophilic metallic material) ball specimens.

2. METHODOLOGY

A custom made unidirectional ball-on-ball configuration tribo-contact simulator (T-CS) was used in the current study. The schematic drawing of T-CS and the configuration of the specimens are shown in Fig. 1. T-CS is equipped with data acquisition system which acquires the data from the sensors of friction force, normal force, specimen displacement, RH rate, and electrical conductivity. Each datum acquired was synchronized to the measurement position on the specimens while sliding. The spatial resolution of data collection for each measured item was set to 5 µm. The T-CS is also equipped with an air-humidity controller and the RH range can be regulated at the value between 4% and 95%. The flow rate of humidity controlled air delivered to the testing chamber was regulated to 4 square cubic feet per hour (SCFH). In the current study, the friction force and specimen displacement were evaluated as a function of distance in different RH rates. The experiments were performed at 8, 55, and 95 % RH, respectively. The material of the upper ball specimens was unfilled-PTFE with 8 mm diameter, and the material the lower ball specimens was SUS316 with 8 mm diameter. To maintain the spherical shape, the surface of the ball specimens was not polished and used with original surface finishing as purchased. The measured average surface roughness (Ra) of PTFE and SUS316 ball specimen was 0.35 and 0.06 µm, respectively. All the ball specimens were ultrasonically cleaned in a 50:50 mixture of acetone and hexane for 10 minutes and subsequently the samples were installed inside a humidity controlled chamber of the T-CS. T-CS was set to operate at 2,000 µm/s sliding speed. The sliding distance per one cycle of measurement was 2,500 µm. An overlap distance between the ball specimens was essential to generate the area of contact while sliding. The overlap distance was adjusted to 60 µm before the test is conducted. The applied load while sliding was 5 N. The surface morphology of the specimens was checked using scanning electron microscope (SEM).

3. RESULTS AND DISCUSSION

Generally, the results of friction force in Fig. 2 (a) showed its highest values during the first cycle in all RH rates. This is perhaps because of the PTFE adherence process onto the fresh surface of SUS316. Unlike the trend shown in our previous study [4] when metallic material slid against itself, the results have shown the lowest friction values during the first cycle in all RH rate when the protective layer of the oxides and surface contaminations were capable to fully or partially prevent direct metal-metal contact. For the low and medium RH experiments, the friction force and specimen displacement patterns looks nearly the same. However, the adherence of PTFE onto SUS316 seems to be happened in two stages. They can be classified as the severe adherence stage (highlighted in the red rectangle), and the normal adherence stage (highlighted in the blue rectangle). In the severe adherence stage, the PTFE surface experienced severe plastic deformation and going uphill. In the normal adherence stage, PTFE seems to be adhered on the surface of SUS316 in the same manner as can be seen from the specimen displacement results in Fig. 2 (b). However, in dry
RH the adhered film of PTFE looked more homogenous than in Medium RH experiments, as shown the SEM results Fig. 2 (c). In high RH experiments, lower friction force has been recorded. This is because of thick adsorbed water layer prevented the PTFE to adhere on the SUS316 as can be seen from specimen displacement results in Fig. 2 (b). The adsorbed water layer maybe resulted in in boundary or mixed lubrication situation.

3. CONCLUSIONS

The results show that sliding of PTFE on SUS316 can experience higher friction force in dry and medium RH. In high RH there is a significance reduction in the friction force and adhesion of the PTFE film on the surface of SUS316 balls.

A future study for investigating the adhesion of the filled-PTFE against metallic material in different humidity is necessary to be considered.

REFERENCES

MEASUREMENT OF TANGENTIAL FORCE COEFFICIENT BETWEEN THE TIRE AND THE ROAD SURFACE DURING DRIVING A CAR

R. Imaizumi¹, T. Iwai¹ and Y. Shoukaku¹

¹Graduate School of Natural Science and Technology, Kanazawa University, Japan

1. INTRODUCTION

Measuring the tangential force coefficient between the tire tread and road surface during driving a car is required for the next intelligent tire. Authors have measured the deformation of inner surface of tire by using a stereocamera in laboratory, and showed that it is possible to estimate the tangential force coefficient between tire and road surface [1]. The purpose of this study is to estimate the tangential force coefficient between tire and road surface when driving a car.

2. EXPERIMENTAL

It is necessary to know spring constant of the tire before the experiment of car driving. The tire is deformed in radial and circumferential direction by applying the load and tangential force respectively, therefore, by researching the relationship between a given force and deformation of the tire, the spring constant of the tire is obtained.

After the spring constant has obtained, the car is driven with experimental wheel as shown in Fig.1. From the deformation of the tire, load and tangential force applied to the tire are estimated. Tangential force coefficient between the tire and road surface is calculated by these forces. Acceleration of the car is also measured.

3. RESULTS AND DISCUSSIONS

From result of static experiment at laboratory, it is found tangential force and circumferential deformation have linear relationship and proportional constant, circumferential spring constant $K_y$, was 541N/mm. Radial force and radial deformation have also linear relationship and proportional constant, radial spring constant $K_r$, was 218N/mm.

Radial and tangential force applied to the tire and acceleration of car starting to run is shown in Fig.2.

Figure 3 shows the relationship between the acceleration and the tangential force coefficient. The tangential force coefficient is probably in proportion to acceleration at car starting to run. This tendency resembles relation of tangential force coefficient and slip ratio curve ($\mu$-s curve). This result possibly locate before the peak of tangential force coefficient in the $\mu$-s curve, so the slip ratio between the tire and road surface of this experiment is possibly low slip ratio.

4. CONCLUSION

1) The deformation of inner surface of the tire during driving a car was measured by non-contact method.
2) The relationship between tangential force coefficient and acceleration of car was proved and it has proportional relation.

REFERENCES

TWO-PHASE FLOW ANALYSIS OF OIL FILM DISTRIBUTION ON ROLLER SURFACE IN TRACTION DRIVE

T. Suwa_1, M. Ochiai_2, Y. Sunami_2,3, and H. Hashimoto_3

1 Graduate School of Tokai University, Course of Mechanical Engineering, 2Tokai University, Department of Mechanical Engineering, 3Tokai University, Micro/Nano Technology Center

1. INTRODUCTION

Half toroidal continuously variable transmission is a revolutionary transmission having features of high transmitting efficiency and high allowable torque. It can swing a power roller between input and output disks to shift the transmission speed and torque. The power roller is pressed against the disks and oil is supplied to its contacts. In the contact points, the oil viscosity becomes high and when the input disk begins rotation, the roller transmits a tangential force by shear stress of the oil film. However, the heat by the shear stress and the spin cause obstacle the product development. Akimoto et al examined the influence of amount of supply oil on traction characteristics by deriving the oil distribution on the roller surface by CFD analysis[1]. As a result, the cooling effect of the oil was confirmed from the void ratio distribution and speed vector of oil formed on the roller surface when the supply oil amount and the rotation direction of the roller were changed. However, it doesn’t take into consideration the case where the peripheral speed of the roller is changed or the problem of heat. Moreover, since this analysis model has a very large number of meshes, it takes much analysis time. In this study, we created an analytical model aimed at reducing the number of meshes and compared it with the analysis results of previous study.

2. ANALYTICAL METHOD

2.1. Analytical model

In this analysis, we employ the model of the high power two roller traction tester[2] because finally to compare the analysis result with the experiment result. Figure 1 shows schematic of analysis model. The analytical model of Akimoto et al only analyze the roller that has the curvature in side. We tried to reduce the calculation height of Akimoto’s model to reduce the calculation cost this time.

2.2. Analytical condition

In this analysis, ANSYS Fluent that is a general purpose CFD soft is used. The oil film and the air are formed on the roller and its boundary face is done two-phase flow analysis. From the viewpoint of convergence, the VOF method is used for calculating the interface. The oil type from the oil filter port is KTF-1 and the flow rate is 6 L/min and the temperature is 100 ºC. The peripheral velocity of the roller is 10 m/s.

3. ANALYSIS RESULT

Figure 2 shows the analysis results. The number of mesh of the modified model can be reduced about half than the conventional model because the height of the model is reduced. Moreover, the analysis result of the modified model is almost the same as the analysis result of conventional one.

REFERENCES

Molecular Dynamics Simulation for Solvent Effect to Physical Adsorption of Organic Additives

M. Konishi and H. Washizu

Graduate School of Simulation Studies, University of Hyogo

1. INTRODUCTION

Oiliness agents are widely added to reduce boundary friction in many kinds of lubricants such as vehicle engine oils. At the contact area in machine elements, oiliness agents adsorb on metal surface and makes self-assembled organic monolayer.

Although the friction properties of the monolayer is widely studied in molecular level, the formation process is not well-known. In order to include the effect of base oils, the cost of calculation increase so high, since the number of the additive molecules are only a few percent of the hole system. In this study we calculate the initial process of adsorbing of additive molecules in explicit base oil molecules using molecular dynamics (MD). We found another effect of base oil other than “chain matching” [1].

2. SIMULATION METHOD

All-atom MD simulations of a oil mixture confined between solid walls are executed 12 ns using the following procedure. The solvent of n-hexadecane and 2,4-dimethyltetradecane, the solute of palmitic acid, and solid walls of iron are chosen to model a typical condition for boundary lubrication of oiliness agent. On the z axis, non-periodic boundary condition is adopted, where z is the direction of the fluid film thickness, and the periodic boundary conditions are adopted for the other direction.

In the MD simulation, the base oil and additive molecules are dynamically treated using the Dreiding force field. Atomic charges are calculated with MOPAC6 using Hamiltonian: AM1. The concentration of additive is set to low enough value of 4 %. All organic molecules are melt-quenched from 1000K to room temperature.

The solid plate of an alpha-ferrous crystal is modeled as a solid atom layer with a lattice of in the x, y, z directions, respectively, and the lattice parameter is set to 0.287 nm. The Lennard-Jones interaction and the potential from the solid wall are adopted for the other direction. The charged condition is supposed to iron oxide, or newly formed surface of iron which is activated.

3. RESULTS AND DISCUSSION

Figure 1 shows a snapshot of the system of the n-hexadecane base oil. It is clearly shown that the base oil forms an adsorbed layer in the vicinity of the solid Fe layer [2]. This is because the number of base oil molecules are much larger than the additives. Then the additive molecules attack the base oil layer to adsorb on the surface, using long-range Coulomb force. The dynamics indicates that even though the base oil molecules are combined by weak van der Waals interaction, the hardness of the adsorbed oil film may change the initial dynamics of formation process of boundary film. Then we compared the system of the n-hexadecane base oil (linear alkane) and the 2,4-dimethyltetradecane base oil (branched alkane). In each system, we simulated MD in 12 ns. At the n-hexadecane system, we can not observe the adsorption in 2 systems in 12 ns MD run. In the other system, the adsorption is found after 1550 ps run. At the 2,4-dimethyltetradecane system, all 3 system showed the adsorption within 275 ps to 3678 ps. Therefore, the system of branched alkane base oil shows faster adsorption than linear alkane.

Branched methyl groups inhibit to make clean crystalization structure, the potential from the solid wall does not show oscilation as shown in Fig. 2. Since the potential barrier is lower in the case of branched alkane, adsorption ratio is higher in the branched alkane. This mechanism is also confirmed from the atom distribution profile of the base oil molecules, and the diffusion constant distributions.

4. CONCLUSIONS

Using all-atom molecular dynamics with explicit base oil shows that the molecules of additives break through the adsorbed layer of base oil. The result reveals that the structuring of base oil molecules near the solid wall causes a limitation for the adsorbing process.

REFERENCES

1. INTRODUCTION

Diamond like carbon (DLC) films [1] has long been favored by Tribology researchers due to their high performance in low friction, high wear resistance and chemical stability. The tribological properties, however, have not been cleared for long time. This is due to the complexity of the basic structure, i.e. amorphous structure of sp, sp2, sp3 carbons, effect of hydrogen and other doped elements, with mesoscopic structure including vacancy, which has strong relation with the production process. From the point of view of molecular simulations, DLC is considered to be a formidable research target. A structure of solid materials in quantum level can be treated by DFT (density functional theory) or MO (molecular orbital) simulation, if it has a periodic structure. In DLC, since the periodic structure do not exist, at least more than 10,000 atoms are needed to compute the bulk structure, which is heavy task for quantum simulation. In this paper we briefly survey a studies for molecular simulation of DLC friction and report our recent results in this field.

2. MOLECULAR SIMULATIONS FOR FRICTION OF DLC

The first MD simulation of DLC is reported by Gao et al. [2], after several works of sliding between diamonds. The method they used are reactive empirical bond-order (REBO) potential [3], which first proposed by Tersoff to simulate silicones mainly, and extended to carbons. Advance of the computational resource made possibility to use more quantum chemical based simulation. Friction of hydrogen rich DLC with complex chemical reaction is studied used by tight-binding method [4], which the molecular orbitals are tightly bound to each atom, and the interactions between heterogeneous atoms are parametrized. Car-Parinello’s first order method is more fundamental method. This is used to understand surface water dynamics on Si doped DLC (DLC-Si) [5], but due to the computational resource, diamond surface is used to model DLC [6]. DLC-Si is good candidate for coatings of automotive machine elements since the balance of robustness and low friction. The low friction of DLC-Si is due to an ability to make boundary water films on the surfaces to protect from counter parts in sliding condition. On the surfaces, Si atoms are oxidized as silanol (SiOH), which makes hydrophilic nature. Since the water molecules strongly adsorb on SiOH using hydrogen bonds, the molecular water film act as boundary lubrication film. This dynamics of water film on SiOH surface is simulated using classical MD and the stability of the film under GPa range is confirmed by the simulation [7]. Therefore the friction of DLC films can be analyzed by first order to classical MD simulations, including chemical reactions and dynamics of surface adsorbates.

3. MD SIMULATION OF FHDLC

Fully hydrogenated diamond-like carbon (FHDLC) shows very low friction which drops to $10^{-4}$ when ZrO$_2$ slide on the surface [8]. The phenomena named Friction Fade Out (FFO), contains complex chemical reactions such as catalysis effect of ZrO$_2$ with H$_2$, ethanol, water in the environment. The mechanism is assumed to the effect of gas lubrication due to the generation of gaseous hydrocarbon by ZrO$_2$ catalysis to hydrogen molecules.

Molecular Dynamics simulation is used to study the FFO phenomena. Since FFO is very complicated phenomena, consisted of many process, i.e. running-in process of formation of transfer polymer layer, friction between transfer layer and DLC, hydrocarbon gas production process, and ultra-low friction due to gas lubrication, the simulation is divided to explain each process.

In order to observe the friction with bond formation / breaking reaction of FHDLC, and ZrO$_2$, we use the reactive empirical bond order (REBO) potential and Reax Force Field (ReaxFF) [9]. These methods treat breaking and making of chemical bonds regardless of the classical Molecular Dynamics.

Friction simulation between DLC surfaces using REBO potential, we found the friction coefficient drops to 1/10 by surfaces termination by H atoms. Dehydrogenation reaction is observed by ethanol-ZrO$_2$ friction simulation using ReaxFF. The other process to understand the whole mechanism is under investigation.

REFERENCES

PREDICTION OF COEFFICIENT OF FRICTION (COF) FOR A LONG DROP-SHAPED DIMPLE STRUCTURE USING COMPUTATIONAL FLUID DYNAMIC ON A CYLINDRICAL PART

H.A.Rahman_1, A.Z. Juri_1, J.A.Ghani_1, and W.F.W.Mahmood_1

1Department of Mechanical and Material Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia.

1. INTRODUCTION
Surface texture such as dimple structure can be produced through various processes like electrochemistry, electrolysis, laser and machining process. Tribology is closely associated to wear and friction which need to be minimized in order to ensure that the original function of a mechanical component moving in contact between the two or more surfaces of the working parts is correct and effective. Structured surfaces, alternatively termed textured surfaces or engineered surfaces, are becoming more and more important in advanced industrial technologies [1]. As an application of the surface structures, the tribological properties have been associated with the surface structures. Because the friction coefficient depends on the surface roughness, friction at the interfaces between substances is controlled by the surface structure. The mechanical, optical, tribological, and fluidic characteristics, as well as many other properties, can be altered by fabricating textures and micro-structures on a flat or curved surface. Typical surface structures are micro-dimples arrays, prism arrays, pyramid arrays, and micro-grooves [2]. Computational fluid dynamics (CFD) has become a popular and vital simulation tool in sector of fluid dynamics. Fluid mechanics that requires deep analysis and equipment’s locals effect can be obtained by using CFD [3]. Other than that, CFD has become an essential part of engineering design and analysis environment of numerous companies due to its capability to present the optimum performance of new design or processes before implementation and allows difficult calculation of parameter to be obtained without conducting experimental beforehand [4]. Various studies have been conducted in analysis of dimple structure and tribological characteristic of coefficient of friction by using Computer Fluid Dynamic (CFD). Yong et al. [5] conducted CFD simulation to study journal bearing with semi-spherical dimples on the lubrication behaviours. It was discovered that surface sliding with textured generate smaller friction coefficient than smooth surface sliding. Friction coefficient can be reduced with increasing dimple depth and dimple profile has slight effect on friction coefficient. This project focuses on the simulation of of long drop dimple structure shape that can be fabricated using turning process on the cylindrical shape of parts such as on the piston wall.

2. METHODOLOGY
The model of piston with dimple structure is generated using Autodesk Inventor software. The tribological characteristics such as coefficient of friction (COF) of the long drop shape dimple was predicted using a commercial STAR CCM+ computational fluid dynamics (CFD) software.

3. RESULT AND DISCUSSION
The simulation results revealed that the surface with the dimple structure resulted in a low coefficient of friction (COF) compared to the non dimple structure surface. In addition, it can be seen that area ratio plays an important role in reducing the COF for this shape of dimple. Higher area ratio will result in higher COF, which neglect the effect of dimple towards friction reduction. Reducing the area ratio results in better COF in which area ratio of 0.022% provide a reduction in COF of 0.35% compared to non dimple surface, i.e. at the maximum wall shear stress of 20.33Pa is recorded at the cylinder wall.

4. CONCLUSION
The surface parts with an optimum textured density of dimple structure and shape would reduce the friction and wear during the sliding process. Further study can be done to include higher area ratio and simulating actual reciprocating piston movement to understand more on the effect of dimple towards COF.

REFERENCES

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DESIGN AND FABRICATE PRESS TOOL MACHINE AND EXPERIMENTAL THE FORMATION OF BURR WITH DIFFERENT CLEARANCE AND THICKNESS

N.A. Abdullah

ABSTRACT

This project aim to design fabricate and study the burr formation when using different cutting clearance and different sheet thickness. Bur formation is common sheet metal defect and burr control/debarring is an important issue for industrialist and engineers. It is produces in cutting operations. In sheet metal parts burr is usual but after a specified limit it takes a form of defect. So controlling this defect is the issue of quality as well so a study of all relevant factors is done in this project. Before start to design the product want to produce, need to know all the element and factors including machinery in workshop in order to easy to fabricate tooling. From the various type of tooling are selected, all the data drawn on paper and design in 2D and 3D view using the Solidworks Software. The criteria used in material selection such as hardness, cost, durability, and machining ability are carefully selected. Aluminium is an excellent material to be used in the blanking process and commonly used conduct electric current.

This machine produced also is to show to student how the cutting clearance influence the burr formation and the stamping process. Based on the result, it is found that the punch clearance is the most relevant parameter, which carried out experimentally. The fabrication process start by discussing a drawing need to producing a several part using CNC machine, High Speed Machine, and EDM wirecut. Other part will fabricate using Conventional Milling Machine, Surface Grinding and other. Fabricate tooling focused on punch because its will replace another punch. The data will measure by using Nikon Microscope Model MM400. The data collected and recorded.
VISUALIZATION OF VELOCITY DISTRIBUTION AND CAVITATION AREA IN JOURNAL OIL FILM BEARING

B. Kuramoto_1, M. Ochiai_2, Y. Sunami_2, 3, and H. Hashimoto_2

1Graduate School of Engineering, Tokai University, 2Department of Mechanical Engineering, Tokai University, 3Micro/Nano Technology Center, Tokai University

1. INTRODUCTION

Reynolds equation is generally used for the design of journal oil film bearings. It can obtain pressure distribution etc of the oil film by assuming the oil film velocity gradient etc in the Navier-Stokes equation. Since the pressure distribution and the actual one in journal oil film bearing generally agree with each other, the assumption of the velocity gradient is said to be correct. However, the velocity gradient of the oil film in the bearing clearance has not been confirmed. On the other hand, Cavitation area is generated due to the negative pressure at the reverse wedge side clearance of the journal oil film bearing. For that reason, it is necessary to solve the Reynolds equation in consideration of cavitation influence a bearing design. Generally, the Coyin-Elrod boundary condition is used [1]. It’s boundary condition assumes the cavitation region by considering the surface tension of the oil film. However, the cavitation interface shape in the radial direction has not been confirmed experimentally.

In this study, the velocity gradient and the cavitation interface shape of the oil film were visualized from the axial direction of the journal oil film bearing clearance.

2. EXPERIMENTAL APPARATUS AND METHOD

In our test apparatus, a shaft with rotor math is driven by a Three-phase motor and supports with a test bearing and an oil-impregnated bearing. The axial load is given by the rotor installed between the two bearings.

At first, in the visualization experiment, the bearing clearance was photographed from the axial direction using the high-speed camera with microscope lens, and the sheet laser was used as the light source. Next, in the visualization of the velocity gradient, the experiment was conducted under the conditions of a shaft rotation speed of 200 rpm, a zoom magnification of 5.0 times, and the photographing speed of 5000 fps. In addition, the velocity gradient of the oil film was confirmed by performing PIV measurement using the visualized image. In the visualization of cavitation, the experiment was conducted under the conditions of a shaft rotation speed of 540 rpm, a zoom magnification of 6.4 times, and the imaging speed of 2500 fps.

3. RESULT

Fig. 1 shows the results of PIV measurement in the bearing clearance. The red arrow indicates the rotation direction of the shaft, and the area surrounded by the white line is the bearing clearance. As can be seen from Fig. 1, since the velocity gradient of the oil film can be confirmed, it is found that the inside of the clearance of about 80 μm can be visualized.

It is thought that this is due to the shearing force acting on the oil film by the rotation of the shaft. A velocity vector of about 150 mm/s in the vicinity of the shaft surface and about 25 mm/s minimum in the vicinity of the bearing can be confirmed.

Fig. 2 shows the shape of the cavitation interface shown under the boundary condition of Coyne-Elrod. In addition, Fig. 3 shows the visualization result of cavitation. The red arrow indicates the rotation direction of the shaft, and the area surrounded by the white line is the bearing clearance.

From Fig. 2 and Fig. 3, as a result of cavitation visualization, a cavitation region along with the bearing surface and an oil film along with the shaft surface as shown in Coyne-Elrod boundary conditions were confirmed.

4. CONCLUSION

The clearance of the journal oil film bearing was visualized from the axial direction. The results obtained by this study are shown.

(1) The velocity gradient of the oil film in the bearing clearance was about 150 mm/s at the maximum in the vicinity of the shaft and about 25 mm/s in the vicinity of the bearing.

(2) Cavitation along with the bearing surface was confirmed as shown in Coyne-Elrod boundary conditions.

REFERENCES

PHYSICAL CHARACTERISATION OF PALM OIL AND WASTE COOKING OIL BIODIESEL AT VARIOUS BLENDING RATIO

S.C Lee¹, N. Tamaldin¹-², M.F.B. Abdollah¹-²

¹Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka, Durian Tunggal, Malaysia
²Centre for Advanced Research on Energy, Universiti Teknikal Malaysia Melaka, Durian Tunggal, Malaysia

1. INTRODUCTION

The diesel uses petroleum diesel to operate. Due to increasing concern over pollution produced by the diesel engine, the biodiesel is created as an alternative fuel for the diesel engine to reduce pollution. A novel breakthrough was found which biodiesel can be created from waste material, however its compatibility to the current diesel engine remains unknown. Therefore, physical characterisation of biodiesel is important and is discussed in this study [1].

2. MATERIALS AND METHODOLOGY

Characterisation of various ratios of biodiesel of both palm oil and waste cooking oil were in 5 different physical parameters which were biodiesel yield, density, kinematic viscosity, flash point and lastly lower heating value.

3. RESULTS & DISCUSSION

3.1 Density & Kinematic Viscosity

Based on Figure 3.1, there was an increase in both density and kinematic viscosity with increasing biodiesel content with waste cooking oil biodiesel showed higher density and kinematic viscosity compared to palm oil biodiesel. The increase in both density and kinematic viscosity was due to bigger molecules of biodiesel and waste cooking oil biodiesel contained more double carbon bond which had stronger bond between carbon atoms, increasing its density.

3.2 Flash Point & Lower Heating Value

Based on Figure 3.2, there was an increase in flash point with increasing biodiesel content with waste cooking oil biodiesel showed slightly higher flash point compared to palm oil biodiesel. The lower heating value decreased with increasing biodiesel content with both feedstocks showed similar decrease. The increase in flash point was due to similar reasons mentioned in Section 3.1, thus making the biodiesel harder to ignite. The decrease in lower heating value of biodiesel was due to shorter chain of hydrocarbon in the biodiesel molecules. Both feedstocks showed the same decrease in lower heating value.

4. CONCLUSION

With increasing biodiesel content in diesel fuel, its density, kinematic viscosity and flash point increased with waste cooking oil biodiesel showing higher values compared to palm oil biodiesel. Besides that, with increasing biodiesel content in diesel, its lower heating value decreased with both palm oil and waste cooking oil showed similar decrease in lower heating value.

REFERENCES

AN ALTERNATIVE BASED LUBRICANT: A COMPARISON OF PHYSICOCHEMICAL PROPERTIES FOR VIRGIN AND WASTE COOKING OILS

M.A. Md Alias¹, M.F.B. Abdollah¹,², M.A. Azhari²,³

¹Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka, Durian Tunggal, Malaysia
²Centre for Advanced Research on Energy, Universiti Teknikal Malaysia Melaka, Durian Tunggal, Malaysia
³Faculty of Engineering Teknologi, Universiti Teknikal Malaysia Melaka, Durian Tunggal, Malaysia

1. INTRODUCTION

The urge from limited source of mineral-based lubricant and environment awareness make researcher to find an alternative lubricant to substitute the mineral-based lubricant. Multiple researcher from previous studies focus on virgin vegetable oil (VVO) as an alternative solution to substitute mineral-based lubricant. Increasing waste material from kitchen, recycle awareness and increase prices of VVO has motivated us to do this research. However, there is no extensive studies conducted upon the physicochemical properties of waste cooking oil (WCO) as lubricants. Therefore, the objective of this study to investigate the physical and chemical properties in terms of flashpoint, viscosity index and acid number of virgin and waste cooking oils.

2. MATERIALS AND METHODOLOGY

In this study, virgin cooking oil (VCO) and waste cooking oil (WCO) from commercialized cooking palm oil were used as lubricant. The WCO was treated using a physical method [1]. The samples were tested for their flashpoint by using Seta Small Scale Flashpoint Tester in accordance to ASTM D3828. The kinematic viscosity of the sample was tested at 40°C and 100°C in accordance to ASTM D445. The viscosity index was calculated based on ASTM D2270. Besides, another test was executed for their acid number by using Automatic Potentiometric Titration in accordance to ASTM D664. All of the experimental results were compared to mineral-based lubricant.

3. RESULTS & DISCUSSION

3.1 Flash Point Temperature

The results of flash point for each sample were tabulated as in Figure 1. From Figure 1, flash point temperature for VCO is the highest as compared to WCO and mineral oil. This might be due to the volatile component of WCO and mineral oil.

3.2 Kinematic Viscosity & Viscosity Index

Figure 2 shows the kinematic viscosity and viscosity index for VCO, WCO and mineral oil. In terms of viscosity, VCO is much stable than WCO and mineral oil due to the higher value of viscosity index.

3.3 Acid Number

Based on Figure 3, mineral-based lubricant inherits the lowest acid number as compared to VCO and WCO. This might be due to the present of additive. A higher number of acid number in WCO due to the oxidation process during frying process.

4. CONCLUSION

The results from this study exhibited that VCO have most standout physicochemical properties than WCO, hence, it is most compatibility to be substitute as lubricant. With a higher value of flash point, viscosity index and acid number, it showed that the usage of vegetable oils is applicable in industrial for a high temperature application such as electrical insulating oil or for an internal combustion engine application.

REFERENCES

THE EFFECT OF LOAD AND TEMPERATURE ON BIOBASED LUBRICANT ADDED WITH GRAPHENE NANOPlatelets

M.H. Harith1, N.W.M. Zulkifli1, H.H. Masjuki1, M.N.A.M. Yusoff1, A.Z. Syahir1, L.S. Khuong1

1 Centre for Energy Sciences, Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur

1. INTRODUCTION

Lubricants are widely used in industries especially in automotive, marine and metal working application. There are many roles that lubricant plays however the most important one is to reduce the frictional losses of a machine. With the increasing environmental awareness, lubricant industry is more focused on creating a more environmental friendly product that is on par with the performance of commercial lubricant.

Bio-based lubricant is a good alternative to conventional lubricant as they have many renewable sources [1]. This allows easy access to bio-based lubricant worldwide. The high viscosity index, high flash point and cost efficient aspect of bio-based lubricant gives it an edge to mineral based oil.

The poor extreme pressure and anti wear performance of bio-based lubricant can be overcome by using additives. The advent of nanotribology allows the possibility of using nanoparticle as an additive. In this study, graphene nanoplatelets was used as an additive and the its tribology performance under different load and temperature is studied.

The tribological test was done using fourball tribotester. The operating temperature of the test ranges from 40°C, 60°C and 80°C. The test was also done under 15kg and 40kg.

2. RESULT AND DISCUSSION

The result shows that there is little to no changes in physicochemical properties of the sample.

Table 1 Physicochemical properties of pure and mixed superolein

<table>
<thead>
<tr>
<th>Sample</th>
<th>Density (g/cm³)</th>
<th>Kinematic Viscosity (cSt) @40°C</th>
<th>Kinematic Viscosity (cSt) @100°C</th>
<th>Dynamic Viscosity (cP) @40°C</th>
<th>Dynamic Viscosity (cP) @100°C</th>
<th>Viscosity Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superolein</td>
<td>0.876</td>
<td>83.1</td>
<td>10.1</td>
<td>73.6</td>
<td>8.3</td>
<td>97.2</td>
</tr>
<tr>
<td>0.02 GNP + superolein</td>
<td>0.876</td>
<td>87.3</td>
<td>9.9</td>
<td>71.6</td>
<td>8.1</td>
<td>97.3</td>
</tr>
<tr>
<td>0.1 GNP + superolein</td>
<td>0.876</td>
<td>85.6</td>
<td>10.1</td>
<td>75.1</td>
<td>8.4</td>
<td>97.7</td>
</tr>
</tbody>
</table>

Figure 1 shows the performance of the superolein after the addition of nanographene. It can be seen that the at high load and high temperature the performance of the lubricant degrade significantly. Another thing that can be noted is the increase of average coefficient of friction due to the increase in load.

3. CONCLUSION

As a conclusion, graphene was able to decrease the friction and wear of superolein. However, it was found that under high load and high temperature the performance of graphene additive starts to degrade.

4. ACKNOWLEDGEMENT

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REFERENCES

LUBRICITY EFFECT OF BUTANOL ISOMERS-GASOLINE FUEL BLENDS

MNAM Yusoff 1, NWM Zulkifli 1, HH Masjuki 1, MH Harith 1, AZ Syahir 1, LS Khuong 1

1Centre for Energy Sciences, Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur.

1. INTRODUCTION

Fuel lubricity in recent years became increasingly important with the introduction of direct injection (DI) gasoline engines. The engine which will require high pressure gasoline injection pump, therefore it can affect the lifespan of engine parts such as rotary pump. Over the years, there is a very little experimental works and publications exist as the gasoline lubricity is not technically problems on multi-port fuel injection (MPFI) gasoline engines [1]. The lubricity assessment of various fuel blends including hydrous and anhydrous ethanol in gasoline fuel blends and the effect of physicochemical properties on lubricity were studied by several researchers [2, 3].

Since butanol is perceived as more competitive alternative fuel for a gasoline engine, a follow up study on its lubricity effect was conducted to ensure the lifespan of the engine parts. Four different butanol isomers (n-butanol, sec-butanol, tert-butanol and isobutanol) with a volume fraction of 20 vol.% in gasoline fuel blends were mixed and the physicochemical properties of the blends were determined. In this present work, the fuel blends were tested using a conventional High Frequency Reciprocating Rig (HFRR) at 27°C. The results of coefficient of friction (COF) and wear of the fuel blends were then compared with pure gasoline. This study further solidify the prospect of alcohol blends usage in new engine technologies for a greener future.

2. RESULTS AND DISCUSSION

The results indicate that the nature of the fuel is an important factor for the lubrication properties of each fuel. The physichochemical fuel properties were determined in Table 1 since they are directly related to exhaust emissions.

Table 1. Phsicochemical properties of butanol isomers-gasoline fuel blends

<table>
<thead>
<tr>
<th>Properties</th>
<th>Gasoline</th>
<th>nBu20</th>
<th>sBu20</th>
<th>tBu20</th>
<th>iBu20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen content (wt.%)</td>
<td>0</td>
<td>4.32</td>
<td>4.32</td>
<td>4.32</td>
<td>4.32</td>
</tr>
<tr>
<td>Density at 15°C (kg/m3)</td>
<td>754.3</td>
<td>766.0</td>
<td>765.5</td>
<td>760.9</td>
<td>764.6</td>
</tr>
<tr>
<td>Kinematic viscosity at 20°C (mm²/s)</td>
<td>0.5199</td>
<td>0.6837</td>
<td>0.6617</td>
<td>0.6399</td>
<td>0.6762</td>
</tr>
<tr>
<td>Dynamic viscosity at 20°C (MPa.s)</td>
<td>0.3879</td>
<td>0.5219</td>
<td>0.5043</td>
<td>0.4844</td>
<td>0.5148</td>
</tr>
<tr>
<td>Reid vapor pressure (kPa)</td>
<td>63.9</td>
<td>53.6</td>
<td>53.9</td>
<td>54.8</td>
<td>53.7</td>
</tr>
<tr>
<td>HOV (kJ/kg)</td>
<td>352</td>
<td>423.2</td>
<td>415.8</td>
<td>387.0</td>
<td>418.9</td>
</tr>
</tbody>
</table>

The COF of the tested fuel blends is shown in Figure 1. It can be observed that all the fuel blends have an increase in COF relative to that pure gasoline (Bu0). The increase in COF of nBu20, sBu20, tBu20 and iBu20 are 58.33, 41.67, 33.33 and 50.00% respectively, relative to Bu0. This is in line with the values of for viscosity of the fuel blends as shown in Table 1. In fact, tBu20 which has the lowest viscosity give the lowest COF among the fuel blends. Besides that, nBu20 and iBu20 show more wear compared to other fuel blends. The wear properties of fuel blends is significantly depend on the fuel viscosity [4].

3. CONCLUSIONS

In conclusion, all the fuel blends increase the COF and wear relative to pure gasoline due to higher value of viscosity of the butanol isomers.

4. ACKNOWLEDGEMENT

The authors gratefully acknowledge University of Malaya for funding this work through the FRGS (Project no.: FP051-2015A) titled ‘Improvement of diesel engine key fuel properties by optimizing alcohol-biodiesel-diesel blend ratio for low greenhouse gas emission’.

REFERENCES

EFFECT OF DIETHYL ETHER TOWARDS FRICITION AND WEAR CHARACTERISTICS OF SOYBEAN BIODIESEL BLENDS


Centre for Energy Sciences, Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

1. INTRODUCTION

Biodiesel has been recognized as a suitable alternative to conventional diesel fuel as it furnishes several advantages such as reduced environmental emissions and renewability. Biodiesel was found to exhibit better lubrication performance than diesel fuel by reducing the friction of sliding components. However, biodiesel poses various tribological challenges such as material compatibility issues, corrosive attacks and different lubricity shown by distinct types of biodiesel feedstocks that can directly affect the performance and lifespan of engine components. Fuel injectors and fuel pump require lubrication and these are lubricated by the engine fuel. Lubrication properties of the fuel depends on the dynamic viscosity, which is the function of operating temperature, viscosity and pressure.

Diethyl ether, an oxygenated cold starting additive is produced from ethanol. It has a very high cetane number, high oxygen content, low autoignition temperature and high miscibility in diesel. Biodiesel blends added with 5% diethyl ether improved the combustion and emission characteristics through higher engine brake power, lower BSFC, higher BTE, lower CO and NO emission than the conventional diesel [1]. As the previous researches involving this additive were focused mainly on performance and emission of engine fueled with biodiesel-diesel blends, there is the need for information regarding tribological aspects which are key to indicate the lifespan of engine components. To fill up this gap, the aim of this study was to investigate the tribological behavior of a 20% blend of soybean biodiesel with diesel fuel (B20). For the improved biodiesel, the ratio of 80% diesel, 15% soybean biodiesel and 5% diethyl ether (B15DE5) was used in order to maintain 20% of biofuel content in the blend. Four-ball tribo-tester was used at room temperature under 40 kg loads at a constant speed of 1800 rpm for all samples.

2. RESULTS AND DISCUSSION

Table 1 shows the physicochemical properties of various fuel blend compositions. It can be observed that the addition of diethyl ether reduced the viscosity of the blend by 19%.

Table 1: Physicochemical properties of fuel blends and additive

<table>
<thead>
<tr>
<th>Properties</th>
<th>Diesel</th>
<th>DEE</th>
<th>B100</th>
<th>B20</th>
<th>B15DE5</th>
</tr>
</thead>
<tbody>
<tr>
<td>KV @ 40°C (mm²/sec)</td>
<td>3.46</td>
<td>0.22*</td>
<td>4.18</td>
<td>3.74</td>
<td>3.03</td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td>833</td>
<td>712*</td>
<td>867</td>
<td>852</td>
<td>834</td>
</tr>
<tr>
<td>Flash point (°C)</td>
<td>69.5</td>
<td>-</td>
<td>168</td>
<td>89.5</td>
<td>77.5</td>
</tr>
</tbody>
</table>

*Measured at 20°C

Figure 1 shows the variation of COF for various fuel blend composition during run-in period (unsteady state). At unsteady state, soybean biodiesel showed 26.6% lower COF than conventional diesel. The addition of diethyl ether reduced COF by about 19% when compared to B20 blends. This might attribute to lower viscosity of B15DE5 as high viscosity fuel needed longer time duration in order to effectively reduce the friction [2]. Pure biodiesel (B100) showed lowest COF, which can be attributed to the formation of lubricating oil film from the adsorption of long-chained polar molecules on friction surfaces. B100 quickly transitioned from unsteady to steady state as the fatty acid molecules within biodiesel can act as friction reducing agent.

3. CONCLUSION

Soybean biodiesel exhibited better friction characteristics compared to conventional diesel. The addition of diethyl ether not only improved the combustion characteristic of biodiesel blends, it also improved the tribological behavior.

4. ACKNOWLEDGEMENT

The authors would like to acknowledge University of Malaya, Malaysia for financial support through the Grand Challenge Project (NO: GC001E-14AET).

REFERENCES

Palm-oil trimethylolpropane (TMP) esters have great potentials in replacing mineral-based lubricants due to their biodegradability and eco-friendly properties. The major problem of vegetable oils is they have low oxygen stability thus becoming more corrosive to the engine. This research focus on investigating the effects of TMP ester mixed in mineral based lubricants at different compositions to the oxidation stability and tribology.

2. METHODOLOGY

The mineral lubricant used is DURASYN 170 Polyalphaolefins (PAO) and bio-based lubricant used is Palm-oil trimethylolpropane (TMP) ester. Blank PAO and TMP ester were prepared as the reference lubricants. Then, TMP ester was added to PAO at different volume percent (5%, 10% and 15%). All samples were heated for 144 hours at 95°C using magnetic stirrer for the oxidation process, similar to Baader test which followed DIN 51 554 (Part 3). Samples were collected after being heated for 72 hours and 144 hours to be tested.

3. RESULTS AND DISCUSSIONS

3.1. Oxidation and physiochemical properties

From figure 1 blank PAO showed a significant increase in the viscosity during oxidation process which caused by formation of high molecular weight (HMW) materials in the lubricants while other samples showed only slightly increase in the viscosity which caused by the existence of low molecular weight (LMW) materials such as alcohols, ketone, acids and monoesters in the lubricants\(^1\). Mixture of PAO and TMP producing better oxidation stability lubricant due to the existence of ester product which were proved to have better thermal stability if compared to mineral based lubricant\(^2\). This was supported by the VI values in Figure 2.

3.2. Tribological properties

From figure 4, it can be seen that the COF of blank PAO increased with respect to the heating hours. However, when PAO was added with TMP ester, the COF values were comparable to the blank TMP. By increasing the number of esters will resulted in stronger binding between molecules, thus stronger protection from shear forces\(^2\), 3\). The WSD values tabulated in Figure 5 supported the discussion above, where the existence of TMP esters resulted in small WSDs compared to WSDs produced from blank PAO.

4. CONCLUSION

Based on the changing of viscosity before and after heating, it can be concluded that HMW compounds were the dominant oxidation product in PAO while samples consisting TMP ester, LMW compounds were the dominant oxidation products. Since the VI values were nearly maintained for all the samples, it can be concluded that temperature changes will not affect the samples’ viscosity thus resulted in better thermal stability, COF and WSD values.

5. ACKNOWLEDGEMENT

The authors would like to thank the University of Malaya, which made this study possible through the research grant FP051-2015A.

REFERENCES

TRIBOLOGICAL PROPERTIES OF PLASTIC MATERIALS SLIDING AGAINST 6061-T6 ALUMINUM ALLOY IN HYDROGEN ATMOSPHERE

T. Yasugi, T. Iwai, and Y. Shoukaku

Graduate School of Natural Science and Technology, Kanazawa University, Japan

1. INTRODUCTION

The purpose of this study was to clarify the influence of the hydrogen atmosphere on the tribological properties of plastic materials rubbed against 6061-T6 aluminum alloy.

2. EXPERIMENTAL METHOD

Unfilled polytetrafluoroethylene (PTFE), polyamide (PA 610), and ultra high molecular weight polyethylene (UHMWPE) were used as the pin specimen with 3-mm diameters. The surface roughness (Ra) of 6061-T6 aluminum disk was adjusted to 0.02 µm, the contact pressure was 0.7 MPa, and sliding speed was 0.05 m/s.

3. RESULTS AND DISCUSSION

As shown in Fig. 1, the differences in friction coefficients and specific wear rates between the atmospheres were not large. Specific wear rates of unfilled PTFE at 150 °C were around 1/100 compared to those at 23 °C. On the other hand, specific wear rates of PA 610 at 150 °C were around 10 times as large as those at 23 °C. Figure 2 shows the profile curves and surface roughness of the sliding surface of disks in hydrogen. The aluminum disk was damaged under each condition. Disk damage from rubbing against unfilled PTFE at 150 °C was smaller than at 23 °C. Conversely, the amount of damage at 150 °C was larger than at 23 °C when rubbed against PA 610.

Figure 3 shows the energy dispersive x-ray spectrometry (EDX) maps of the sliding surface of each pin specimen under hydrogen at 23 °C. Some aluminum (Al) and fluorine (F) were observed in the same area on the sliding surfaces of unfilled PTFE. It has been reported that aluminum fluoride was generated [1], so aluminum fluoride may have been produced in this experiment. On the sliding surfaces of PA 610 and UHMWPE, abundant oxygen (O) was observed in the Al area, so this substance was probably aluminum oxide.

4. CONCLUSION

6061-T6 aluminum alloy was damaged sliding against unfilled PTFE, PA 610 and UHMWPE under hydrogen atmosphere at 23 °C and 150 °C.

REFERENCE

INFLUENCING FACTORS OF RELATIVE HUMIDITY ON BEARING SYSTEMS IN THE PIANO

C. Y. LIM_1, Kanao FUKUDA_1,2

1Malaysia Japan International Institute of Technology (MJIT), Universiti Teknologi Malaysia (UTM)
2I2CNER, Kyushu University

1. INTRODUCTION

Piano is a very precise musical instrument and the most complicated musical instrument with over 2500 parts. [1] Though the best humidity condition for a piano RH (Relative Humidity) 42%[2] most of the countries experience humidity swings. Therefore, a robust piano action system against humidity is an ideal. Figure 1 shows the light load bearing system of the piano at the hammer flange butt and their materials which have been studied in this research.

Figure 1 Light Load Bearing System in Piano

When the bearing is exposed to different humidity level, it is expected that the friction force experienced by the bearing changed due to the effects of humidity on the static friction coefficient and the internal load as stated in the equation (1).

\[ F_s = \mu_s (RH) \times [L_{\text{internal}}(RH) + L_{\text{Hammer}}] \] (1)

2. EXPERIMENTAL METHOD

Figure 2 shows a newly developed light load bearing tester to study the effects of humidity on the bearing system of the piano.

Figure 2 Schematic diagram of a light load bearing tester

By increase the load applied on the bearing, the friction force experienced by the bearing and shaft would increase. Internal load was estimated by extrapolating the relationship between the internal load and a static friction force.

3. RESULTS AND DISCUSSION

The results shows that RH 90% gives the highest friction force for the bearing system. Besides, figure 3 indicates that the internal load applied by the bearing to the shaft is higher at RH 10% while the static friction coefficient shows its extreme at RH 90%.

Figure 3 Internal Load and Static Friction Coefficient VS Relative Humidity

4. CONCLUSION

As a conclusion, when the part being exposed to different humidity level, it is expected that the friction force, \( F_s = \mu_s (RH) \times [L_{\text{internal}}(RH) + L_{\text{Hammer}}] \) where the static friction coefficient and the internal load are the function to the humidity level.

ACKNOWLEDGEMENT

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REFERENCES

INFLUENCES OF LAPLACE FORCE DUE TO ADSORBED WATER ON A BALL-ON-BALL MICRO-SLIDING TEST

K.K. Yap, K. Fukuda, and Z.A. Subhi

Malaysia-Japan International Institute of Technology, University Technology of Malaysia, Kuala Lumpur, Malaysia

1. INTRODUCTION

On most solid surfaces, there is a layer of adsorbed water due to atmospheric humidity. Its thickness is only a few nanometer. When it comes to precise and miniature engineering systems such as Micro-Electro-Mechanical Systems (MEMS), influences of adsorbed water on the tribological performance become very dominant due to the high surface force to body force ratio [1]. An interesting phenomenon is found in a unidirectional ball-on-ball tribotest [2]. Theoretically, friction should be higher when the balls are approaching each other than when they are away from each other. However, in reality, high friction is found when the balls are away from each other. It is believed that this phenomenon is due to the Laplace force generated by the meniscus formed by adsorbed water. This research aims to propose a new physical model for friction and wear based on Laplace force due to adsorbed water.

2. EXPERIMENTAL METHODS

Figure 1 shows the experimental setup. The specimens are Ø8mm SUS304 balls. The applied load is 10N, equivalent to 1.74 GPa of maximum Hertzian contact pressure. The sliding speed is 2000μm/s with overlap distance between two balls of 100μm. RH is set at 5%, 50%, and 95% while Ra is 0.04μm for polished balls and 0.08μm for unpolished balls. Each experiment is repeated thrice. Since Laplace force is a function of the multiplication of the reciprocal for surface roughness (1/Ra) and the natural logarithm for relative humidity (lnRH), the most negative Laplace force can be observed at low Ra and low RH [3]. The effect of Laplace force on friction can be analyzed utilizing Pearson’s skewness. The more negative the skewness, the higher the Laplace force. The effect of Laplace force on adhesive wear can be analyzed utilizing wear depth. The deeper the wear at the contact where the balls are away from each other, the higher the Laplace force.

3. RESULTS & DISCUSSION

Figure 2 shows the graph of skewness against relative humidity. The dotted circle shows that the most negative skewness is found at low Ra and low RH. Hence, Laplace force is significant to friction at low Ra and low RH.

Laplace force affects not only friction but also adhesive wear. Figure 3 shows the graph of wear depth against contact position. The dotted circle shows that wear depth is high when the balls are away from each other at low Ra and low RH. This means that Laplace force is significant to adhesive wear at low Ra and low RH.

4. CONCLUSION

The influences of Laplace force due to adsorbed water on the ball-on-ball sliding test are significant. Negative Laplace force is the largest at low Ra and low RH, which causes higher friction and wear of SUS304 stainless steels.

REFERENCES

INFLUENCE OF HUMIDITY LEVEL ON WATER ADSORPTION-HUMIDITY RATIO

N. D. A. Manaf$^1$, K. Fukuda$^{1,2}$, Z. A. Subhi$^1$, M. F. M. Radzi$^1$

$^1$Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, Malaysia.
$^2$I2CNER, Kyushu University, Japan.

1. INTRODUCTION

The adsorption of water on metallic surface has received considerable attention in recent years. It has been considered as one of the major influencing factors on the tribological properties, especially for the metallic surfaces [1]. Recently, quantitative study of adsorbed water on austenitic stainless steel was done by Zaid et al. [2]. However, the experimental data was not sufficient to elucidate how water adsorbs on the metallic surface. In this study, a sensitive measurement instrument which enables a measurement of adsorbed water with more details changes in humidity was devised to clarify and the influencing mechanism of humidity on the water adsorption-humidity ratio. There was a good correlation between the water adsorption and relative humidity for metallic surface regardless of their humidity condition.

2. EXPERIMENTAL METHOD

The experimental apparatus used in this investigation was a water-adsorption evaluation system which consists of the air humidity controller as shown in Fig. 1. The experimental conditions are shown in table 1.

Table 1: Experimental conditions

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Austenitic stainless steel (JIS SUS304)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Finishing</td>
<td>#1000</td>
</tr>
<tr>
<td>Dimension</td>
<td>100 x 100 x 0.2 mm (thk)</td>
</tr>
<tr>
<td>Surface Roughness</td>
<td>0.1068 µm</td>
</tr>
<tr>
<td>Cleaning Method</td>
<td>Ultrasonic cleaner with 50:50 hexane and acetone for 600 sec</td>
</tr>
</tbody>
</table>

3. RESULTS AND DISCUSSION

Fig. 2: Adsorption on surface finishing of grit size #1000.

The adsorbed water on the SUS 304 surface as a function of relative humidity is plotted in Fig. 2. In stage I, the water adsorption-humidity ratio is high in the low humidity condition with the gradient is $1.9084 \times 10^5$ g/RH%. Then, the slope increases rapidly with the gradient of $4.6436 \times 10^6$ g/RH% and occurred in stage II. This indicates that the water adsorption of the sample gives a response to various humidity levels. In stage III, around 70-90%RH, the slope shows linearly with the uniformity of weight. It is because, the outermost adsorbed water layer is completely dominated by liquid water configuration and reaching the saturation state at RH 90%. In the case of adsorption isotherm, the adsorption mechanism of the ratio depends on the material, surface properties, texture of a surface and environmental condition.

4. CONCLUSIONS

It is clarified that the change of water adsorption-humidity ratio with relative humidity can be expressed by a relation involving the weight of the water adsorbed. The transition of these three stages has an impact on water adsorption isotherm in different humidity condition.

REFERENCES

INFLUENCE OF HUMIDITY ON TRIBOLOGICAL PROPERTIES OF NON-LUBRICATED BALL BEARINGS

M.F.M. Radzi1, K. Fukuda1,2, Z.A. Subhi1

1Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, 54100 Kuala Lumpur, Malaysia
2International Institute for Carbon-Neutral Energy Research (I2CNER), Kyushu University, 733 Motoooka, Nishi-ku, Fukuoka 819-039, Japan

1. INTRODUCTION
In this paper, the influence of humidity on the tribological properties of non-lubricated ball bearing is investigated by employing a custom-made light-load bearing tribotester with controllable relative humidity enclosure. The purpose of the investigation is to elucidate the effect of humidity on the performance of non-lubricated bearings.

2. METHODOLOGY
The experimental setup consists of a custom-made light-load bearing tribotester with controllable relative humidity. The sample bearing is open-type hybrid ceramic bearing, which consists of silicon nitride (Si₃N₄) balls and AISI 52100 inner/outer races, non-lubricated. 10N load is applied on the sample. T_{friction} (frictional torque) is detected by the strain gage amplifier. Tests were run for 10 hybrid ceramic bearings. The motor speed was 120rpm and tests are run for 60 hours for a total of 432,000 revolutions. RH% (relative humidity) is controlled by the humidity controller.

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Bearing</th>
<th>Lubricant</th>
<th>RH%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-3</td>
<td>Hybrid ceramic bearing</td>
<td>None</td>
<td>8-12%</td>
</tr>
<tr>
<td>4-6</td>
<td>Hybrid ceramic bearing</td>
<td>None</td>
<td>50-55%</td>
</tr>
<tr>
<td>7-9</td>
<td>Hybrid ceramic bearing</td>
<td>Light oil</td>
<td>88-94%</td>
</tr>
<tr>
<td>10</td>
<td>Hybrid ceramic bearing</td>
<td>Light oil</td>
<td>54%</td>
</tr>
</tbody>
</table>

3. RESULTS AND DISCUSSION
The specific wear rate of the bearing increases by 16.7%, 27.7% and 38.8% in low, medium and high RH% respectively, using the wear rate of the bearing in lubricant as reference for percentage calculation.

Figure 1: Comparison of specific wear rate of bearing

Figure 2: Comparison of T_{friction} in relation to time

The T_{friction} at the 60th hour measured for samples in medium RH% is approximately 75% greater than samples in low and high RH%. This is attributed to the combined effects of meniscus pull of asperities and wear occurrence.

Figure 3: Micrograph images of inner races in low, medium, high RH% and lubricated

EDX (electron-dispersive X-ray) analysis on inner race of a sample in medium RH% shows that the adhered dark-brown material is possibly a combination of silicon dioxide (SiO₂) and ferrosilite (FeSiO₃). [1]. X-ray scanning of the all the other samples show the same makeup of element.

Figure 4: X-ray mapping of inner ring of sample in medium RH%

4. CONCLUSIONS
1. Wear rate of hybrid ceramic bearing increases with increasing RH%.
2. T_{friction} of hybrid ceramic bearing is the greatest at medium (50-55 RH%) humidity.

REFERENCES
NATURE INSPIRED DESIGN OF LASER TEXTURED Al$_2$O$_3$-13%TiO$_2$ COATINGS FOR MITIGATING EROSION WEAR

J.A. Wahab, M.J. Ghazali, and Z. Sajuri

1Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia.

1. INTRODUCTION

Al$_2$O$_3$-13%TiO$_2$ coatings are one of the most potential hard ceramic coatings for tribological application especially in high aggressive environment [1]. Excellent mechanical properties of the coatings had intrigued researchers to expand their applications in the marine environment. In the case of erosion wear, it has been a serious problem for many marine industrial structures such as hydraulic turbines, pumps and pipelines conveying solid particles [1]. Despite using inert ceramic coatings like Al$_2$O$_3$-13%TiO$_2$ to mitigate the problems, improvement works are on going. This includes modification on the coated surfaces. The implementation of short-pulsed laser via micro machining had managed to carved out micro-groove textures on the coating surface. It was found that the coating performance had significantly improved. The aim of this study is to investigate the effects of micro-grooves on erosion wear behaviour of Al$_2$O$_3$-13%TiO$_2$ coating. By modifying the coating surface characteristics, the rate of erosive wear was found to be improved, thus enhancing the performance and lifespan of the material components especially for the marine environment.

2. EXPERIMENTAL

In this study, Al$_2$O$_3$-13%TiO$_2$ coatings on mild steel were prepared via plasma spray method. Optimized micro-grooves were textured on the coating surface by using a laser surface texturing (LST) technique. All erosion wear tests were conducted using a standard slurry pot erosion tester [1]. The erosion wear of textured coating (TC) was compared to that of the non-textured coating (nTC). In the slurry pot test, the samples were placed on a holder (propeller) that was later rotated in SiO$_2$ slurry at two constant rotation speeds of 750 and 950 rpm for 6 hours [1]. Two different impact angles (30° and 90°) were investigated in this process. The cumulative erosion was then determined by measuring the mass loss of each sample.

3. RESULTS & DISCUSSION

Fig. 1 shows the cumulative mass loss of the coatings. In the case of the TC coatings, there was a reduction of cumulative mass loss compared to that of the nTC coatings at both impact angles of 30° and 90°. Further investigation into the erosion of coatings was carried out by increasing the rotation speed of the slurry to 950 rpm. The cumulative mass loss for both nTC and TC coatings had increased; compared to that of the 750 rpm, implying that the existence of grooves on the surface could reduced the erosion rate. Based on Han and co workers [2], the grooves had acted as a flow disturber to the fluid with impact particles. The grooves greatly enhanced the rotating flow, which led to a change in the flow around the groove areas. This affects the impact velocity and the direction of the particle’s motion; resulting in a reduction of the particle momentum. Thus, the number of high velocity particles that tend to hit the surface were also be decreased.

Fig. 1 Cumulative mass losses of coatings at a) 30° b) 90° of impact angle with rotation speeds of 750 rpm and c) 30° of impact angle with 950 rpm.

4. CONCLUSION

The performance of textured Al$_2$O$_3$-13%TiO$_2$ coatings was found to be improved particularly for tribological applications. In short, the erosion of the coatings increased as the impact angle and the rotation speed increased. It was noted that at 30° of an incident angle, the textured coating (TC) showed a great reduction of 45% in the cumulative erosion, implying an improved erosion resistance. This would be very beneficial to marine industries in particular.

REFERENCES

EFFECT OF FLY ASH COMPOSITION ON HARDNESS AND WEAR PROPERTIES OF NICKEL-FLY ASH COMPOSITE COATED AA7075 SUBSTRATE

Muhammad Khaizaki Ahmad1,*, Intan Sharhida Othman1,*, Muhammad Zaimi Zainal Abidin1, Qumrul Ahsan1, Syahrul Azwan Sundi2

1) Carbon Research Technology Research Group, Advanced Manufacturing Centre, Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
2) Faculty of Engineering Technology, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

*Corresponding e-mail: intan_sharhida@utem.edu.my, khaizakiahmad@gmail.com

1. INTRODUCTION

Aluminium alloy 7075 (AA7075) which has high strength-to-density ratio is widely used in marine, automotive and aerospace industry. However, it has low hardness and wear resistance, as well as susceptible to surface degradation when exposed to elevated temperatures [1, 2]. Therefore, nickel (Ni) composite coating is introduced to AA7075 to improve its properties. In this study, the fly ash (FA) particles are added to the Ni watts bath solution. The FA can be employed as inexpensive strengthening particles which can increase wear resistance and enhanced micro-hardness. The effect of FA composition on Ni-FA composite coating deposited on AA7075 substrate are still less known. Thus, the present work is aimed to investigate the influence of various FA composition on the hardness and wear properties of Ni-FA composite coating.

2. METHODOLOGY

The AA7075 substrate with dimension of 40 mm x 30 mm x 3 mm was ground using silicon carbide papers of 180, 600, 800 and 1200 grits. The substrates were then cleaned with acetone, and followed by immersion in sodium hydroxide (NaOH) solution of 10% wt and finally immersed in 50 vol. % of nitric acid (HNO3). Eventually single zinctacing process was carried out for 5 minutes at room temperature to remove the oxide layer of aluminum and at the same time, apply a layer of zinc.

The depositions of Ni-FA composite coating on zinctated substrates were performed by electroplating at an applied current density of 5 A/dm² for 1 hour at 40°C. The composition of the electrolyte is as follows: nickel sulphate hexahydrate (200 g/l), nickel chloride (20 g/l), sodium citrate (30 g/l) and FA particles (0, 10, 50, and 90 g/l). The micro-hardness and wear testing were performed on coating by using micro Vickers hardness tester and high frequency reciprocating wear rig respectively.

3. RESULTS AND DISCUSSION

Figure 1 shows the result of hardness of the Ni-FA composite coating. The hardness value increased as the FA particles in the Ni matrix solution increase from 10g to 90g. This is because of the presence of hard SiO2 and Al2O3 particles in the FA. Besides, the modification of microstructures of the composite coating due to the co-deposition of FA particles to the coatings results in refining the nickel grains. Other than that, the dispersion hardening occurs as the fly ash particles are deposited along the grain boundaries of the crystalline Ni matrix [3, 4].

Figure 2 shows the SEM images of wear tracks on Ni-FA composite coatings. Introduction of FA particles into the nickel matrix has reduced the width of worn- out patches on the wear tracks as the composition of FA increased. The worn patches consist of longitudinal furrows and small size grooves along the sliding direction of the steel ball [5]. Furthermore, the width of the wear tracks also decreases as the concentration of FA particles increases from 10g to 90g in the Ni matrix.

CONCLUSION

The incorporated of FA particles in the Ni matrix made the worn-out patches on the wear track reduce as the composition of FA increased. The hardness value increase as the composition of FA particles increased in the Ni-FA composite coating solutions.

REFERENCES

MICRO-TEXTURING OF DIAMOND LIKE CARBON COATING AND ITS TRIBOLOGICAL PERFORMANCE

Tan Mean Yee¹, Shahira Liza Kamis², Nurin Wahidah Mohd Zulkifli¹, Masjuki Hj. Hassan¹

¹Department of Mechanical Engineering, Faculty of Engineering, University Malaya, 50603 Kuala Lumpur
²TriPreM i-Kohza, Mechanical Precision Engineering Department, Malaysia-Japan International Institute of Technology (MJIIT), UTM Kuala Lumpur, 54100 Kuala Lumpur

1. INTRODUCTION

Surface modification of coating is to modify the creating new wear resistant surface in order to improve the tribological performance by not affect the mechanical behavior [1]. Textured coating can be used in tools, engine part and orthopaedic implants. Recent study shows that indirect surface texturing is used to achieve 3D shape. The main objective of this study is to investigate tribological performance of textured diamond like carbon (DLC) coating under dry condition.

2. METHODOLOGY

The surface of 15mm x 15mm mirror polished titanium (Ti6Al4V) alloy is being texturized using laser machine into dimple texture surface with constant diameter of 200 µm, dimple density of 20% and depth of 6 µm. DLC coating will be deposit onto titanium alloy using physical vapor deposition (PVD) method for 5.5 hours. Thickness of the coating will be characterise using profilometer and hardness of the coating will be characterise by using nano-indentation machine. Tribological test using reciprocating machine with pin-on-disc is being done in dry condition for 5 Hz frequency, 5N load and duration of 30 minutes in order to study the tribological performance of the coating.

3. RESULTS AND DISCUSSION

3.1 Film characterisation

The deposition rate of the coating will be 57.8 nm/hr. The average thickness of the coating is 317.8 nm, while for the average hardness of the coating is 6.67 GPa. The thickness and hardness for all samples is the same since the deposition condition is the same. The optical image of the textured titanium alloy coating is being taken using and as shown in Figure 3.1.

3.2 Tribological properties

The wear rate of the coating and counterpart that obtained from the tribological test is as shown in Figure 3.2 below. The counterpart used for the test is Ultra-high-molecular-weight-polyethylene (UHMWPE) pin with the diameter of 6 mm and the height of 6 mm.

From Figure 3.2, coating with 20% dimples texture have the lower wear rate for both DLC coating and UHMWPE pin. The results show that wear rate of the coating and UHMWPE can reduce by texturized the coating. According to previous study, surface texture can be improved the tribological performance of coating by reduced the coefficient of friction.

4.0 CONCLUSION

By texturized the surface of the coating, the tribological performance of the coating and counterpart can improve by reducing the wear rate.

REFERENCES

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Email: shahrizal@taatbestari.com, shahrizalsaupi@yahoo.com
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Address:
University Technology Malaysia Kuala Lumpur,
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