Effects of Lubrication on the Wear Parameters of Metals Using Pin-on-Disk Test Rig

C. F. Onyeanusi[1*], S. C. Nwigbo[1], N. B. Anosike[1] and C. A. Nwajude[1]

[1]Department of Mechanical Engineering, Nnamdi Azikiwe University, Awka, Nigeria.

Authors' contributions

This work was carried out in collaboration among all authors. Author CFO designed the study, wrote the protocol and wrote the first draft of the manuscript. Author SCN supervised the study, Author NBA read proof the work and made useful corrections. Author CAN managed the literature and plotted the graphs and author. All authors read and approved the final manuscript.

Original Research Article

ABSTRACT

Friction and wear control of movable parts in machines remain a critical challenge in the industries. Determination of measurement to control this often involves both the material and the lubricant. A wear test experiment using pin-on-disk apparatus to determine the wear pattern on a sample of aluminium and copper materials, lubricated with vegetable oil of palm kernel origin was conducted. Wear parameters, which include frictional coefficient, wear rate, and heat generation (temperature) were evaluated alongside thermal stress-strains on the pin on disk. Results showed that under the same conditions, the coefficient of friction reduces with the application of lubricant up to 84% and 7% for aluminium and copper respectively. The wear pattern for both materials when lubricated were evaluated and compared with dry condition to establish the relationships.

Keywords: Wear rate; wear; lubrication; pin-on-disk; metal; wear coefficient.

_____

*Corresponding author: E-mail: chekwubeonyeanusi@gmail.com;

1. INTRODUCTION

Research to predict effect of friction wear and friction reduction has intensified. The use of lubricants to overcome friction has been established, with unconventional options including acoustic lubrication which uses sound as a lubricant [1].

This occurs between two plates or between a series of particles. The frequency of sound required inducing optimal vibration, and thus cause sonic lubrication, varies with the size of the particles. This is beyond the use of turbulent fluids or powdery solids such as graphite and talc.

[2] Stated that friction as a first approximation of two kinds: interfacial and bulk (ploughing). As frictional work causes the damage and the subsequent wear, this is a potentially useful means of classifying the wear as `cohesive' and `interfacial' in its nature. The stress-strain on the disk was simulated as a function of the coefficient of friction, average speed even the wear condition.

The impacts of lubricant on wear pattern have been determined with different organic compounds. In this work, it was desired to determine the effect of the vegetable base oil lubricant on metals. Unlike, [3] tried to determine the friction and wear performance of different DLC coatings in aqueous conditions.

However, lubricating oil is still widely used to avoid excessive friction without any competing substitute in some applications. High boiling point, low freezing point, high viscosity index, thermal stability, corrosion prevention as well as high resistance to oxidation. The analysis reveals how much lower or higher coefficient of friction for lubricant when used with different materials.

Finally, interface mechanisms of the lubricant are yet to be tested and studied. It is vital to measure, understand, and to control lubricant as well as behaviour over time. Also, fluid friction analysis has to be determined.

2. LITERATURE REVIEW

Several studies are conducted to improve lubricant as a means of friction reduction especially on contacting (sliding) surfaces with varying loads and speed. There was much literature published on the topic of the wear, and tribology, of elastomers. The book by [4] was a useful survey and the recent books by Zhang [5,6] are very comprehensive. There has also been recent and innovative work on the fundamental basis of the wear processes. The basic idea was that certain polymers, under the action of interface shear gradients, would produce reoriented interface zones and indeed transferred layers [7].

Ameen et al. [8] Studied the wear (adhesion wear) rate for different materials (steel, aluminium and brass) under the effect of sliding speed, time and different loads, using the pin-on-disk apparatus. The experiment had been performed on a group of specimens under different cases of times (5 to 30 minutes), under different loads (0.5 to 2 kg), and different speeds (2.5 to 9 m/sec). Results showed that the rate of adhesion wear will be directly proportional to (time, sliding speed and load) for steel, aluminium and brass.

Friedrich [9] For example, the wear rate can be extremely high if contact pressure is slightly raised, and low friction is not necessarily associate with low wear rate. Although virgin polymers have shown excellent tribological properties in some very uneconomical cases they are rarely used as monolithic one-phase materials.

Zhang et al. [10] studied the coefficient of friction and wear on Al-Li alloys reinforced with 10 wt% SiCp (13 and 30 µm) using scratch testing at a room temperature and 200°C at a scratch speed of 6 mm and a load range of 1-20 N. Scratch tests were performed at both room temperature and 200°C using a scratch speed of 6 mm so' and a load range of l-20 N, A diamond pyramidal indenter with an apex angle of 136^{0} were used. Friction coefficient for the composite containing 30 µm SiCp was found to be independent of load but the coefficient of friction for the 13 µm reinforced material increased with the applied load.

Lubricants of petroleum or synthetic base oil have achieved wide acceptance over the years. Research has shown that the free fatty acids which are active as friction modifiers can be obtained by hydrolysis of the vegetable oil [11]. Among the good candidate is the vegetable oil of palm kernel origin which is fairly cheap, readily available and biodegradable. Comparatively it is a healthier option compared to mineral oils with absence of polycyclic aromatics (PCAs) which

are present in mineral oils and posing a high risk to human health, particularly in circumstances where skin contact with oil is involved.

3. EXPERIMENTAL METHODS

Solomon et al. [12] noted ASME G99 Standard test method as classical method commonly used for wear test experiments for a pin-on-disk apparatus. The dry sand rubber wheel abrasion test setup was used to conduct the wear studies. The abrasives are introduced between the test specimen and the rotating wheel. The test specimen was pressed against the rotating wheel at a specified force by means of lever arm; while controlling flow of grits abrades the test surface. The wheel rotation was done such that its contact face moves in the direction of grit flow. The pivot axis of the lever arm lies within a plane, which is approximately tangential to the rubber wheel surface and normal to the horizontal diameter along which the load is applied. The tests were carried out for different loads, number of revolutions, speeds, time as well as sliding distances.

Prior to testing, measurement or weighing of the samples were done. The specimens were cleaned and dried; all dirt and foreign matter were removed from the specimens with non chlorinated, non-film-forming cleaning agents and solvents. The specimen holder is where the cleaned, weighed and measured specimen was mounted on the rig. The specimen holder is a vertical clip on top of the disk. The holding device with the specimen was made to be at 90^0 to the axis of the revolution. This is to maintain the necessary contact conditions during the experiment. A proper mass is added to the system lever or bale to develop the selected force pressing the pin against the disk. This weight helps to reduce unnecessary vibration from the machine. The weight of the lever arm can be divided on both side of the pin. If this is done, the pin will be acting as a fulcrum on the disk. The motor speed is adjusted to the desired value while holding the pin specimen out of contact with the disk.

The free fatty acids which are active as friction modifiers are obtained by hydrolysis of the vegetable oil. The detergent was replaced with the potassium soap of the base oil.

The base oils are refined palm kernel oil and unrefined palm kernel oil. When analyzed gave acid value and free-fatty acid value of 0.4833 and 0.02431 respectively for the refined palm kernel oil. While the acid value and free-fatty acid values were 0.7791 and 0.03919 respectively for the unrefined palm kernel oil.

The current study evaluated the wear resistance performance under the lubricant (vegetable oil of palm kernel origin) for aluminium and copper using a pin-on-disk experiment. Evaluation and comparison of coefficient of friction for the metals was done and compared with a dry condition (without lubricant application). An estimation of stress and strains evolution with the sliding cycles for both metals and the stress concentration on the disk were also evaluated.

The following experimental assumption were adopted in the work

- The pinned surface is assumed to be the same. That is, the thickness and width of the pin same
- The specimen on the disk is fixed perpendicular to the axis of the resolution.
- It's assumed that there is no loss of heat from the disk to the atmosphere even absorption of heat by the disk.
- It's also assumed that the speed of the system does not changed when loaded at different masses.
- The abrasives are maintained a manufacturer specification hardness of P80.
- No unnecessary vibrations are developed on the lever.

The expected wear is between the stationary pin surface hold against rotating disk made up to No. 40 emery cloth grade. The change in length of the pin after each run is estimated to measure the volume loss during wear. Wear results may in some cases be reported as plots of wear volume versus sliding distance using different specimens. Wear results are obtained by conducting a test for a selected sliding distance and for selected values of load and speed. The wear factor can be manipulated to calculate the often more convenient and more physically direct specific wear rate [13], also known as a dimensional wear rate, according to [14] commonly measured in units of mm^3/Nm. The specific wear rate is simply the wear volume divided by the product of the normal load and the sliding distance, equation (1). Archard [15] Also developed the expression for wear rate (volume of material worn) as shown in equation (2).

$$Wear\ rate\ =\ \frac{Volume\ loss}{Load\ X\ distance\ Travelled} \qquad (1)$$

$$W = \frac{KDP}{3H} \quad (2)$$

The unit of wear rate:

$$mm^{3}/Nm = \frac{mm^3}{N \ X \ m}$$

Volume loss (mm^3) is the area of the pinned side of the specimen multiplied by change in length.

With **W** as wear rate, K is wear coefficient, D is sliding distance, P is applied normal load and H is bulk hardness of the material.

On the Pin on disk, two specimens were tested. A pin with radius tip was positioned perpendicular to a flat circular disk. The test machine causes either the disk or the pin specimen to revolve about the disk centre. In either case, the sliding path is a circle on the disk

Table 1. Composition of the vegetable base oil lubricant

S/N	Mixture	Name	Composition (%)
1.	Base oil	Palm kernel oil	55
2.	Emulsifier /Rust inhibitor	Hydrogenated castor oil	30
3.	Extreme pressure agent	Free fatty acid	1.5
4.	Coupling agent	Glycorol	3.5
5.	Dispersants	IUPAC: 2-Methoxyethanol ($C_3H_8O_2$)	5.0
6.	Water	Water	2.0
7.	Anti-foam agent	Methyl silicone	0.5
8.	Preservative		-
9.	Demulsifiers	Xylene	

Fig. 1. Pictures of the fabricated pin-on-disk test rig: (a) Side View (b) Top View

Table 2. Wear test conditions

	Wear parameters	Unit	
1	Material	-	Aluminium and Copper
2	Load	N	1,2,3N
3	Sliding Speed	rpm	120,129,133 rpm
4	Counterpart material	-	40 Mesh abrasive Sand paper
5	Relative Humdity	%	78
6	Laboratory air	^{0}C	30
7	Duration of Rubbing	Sec	13,28,40
8	Wear Condition	-	Dry and Wet

surface. The plate of the disk may be oriented horizontally or vertically.

The pin specimen is pressed against the disk at a specified load usually by means of an arm or lever and attached weights. The wear rate for aluminium and copper samples wear rate that is obtained from the pin-on-disk testing are grouped into dry and wet conditions. The dry test was done without application of lubrication on and wet conditions (particularly of interest) imply the use of lubricant.

4. RESULTS AND DISCUSSION

4.1 Coefficient of Friction

The comparison between dry and wet was done. Similarly, combinations that were shown below can be compared on the wear results. 0.00014 and 0.0013 as the wear coefficient show that is lubricant effects on the material slightly.

The wear rate of copper in dry sliding friction was not as much as aluminium results, dry results are in better surface roughness than the wet one. In Summary, the regression models at different conditions of the work during the experiment.

4.1.1 DRY aluminum

The regression equation is

Y = 0.003109 + 0.001057X_1 - 0.00109 X_2 + 0.00316X_3 -8.9 x10^9X_4 + 62.5412X_5 + 18914834X_6 -4.20837X_7

4.1.2 WET aluminium

The regression equation is

Y = 0.001827 + 0.000168X_1 - 0.00044X_2 + 0.000475X_3 - 5.4X109X4 + 11522651X_6 + 1.35X10^{-5}X_7

4.1.3 DRY copper

The regression equation is

Y = 0.001883 − 0.0026X_1 − 0.00035X_2 − 0.000804X_3 -2.1 X10^9X_4 + 4465171X_6 + 2.8X10^{-5}X_7

4.1.4 WET copper

The regression equation is

Y = 0.000379 − 5.1X10-5X_1 -7.2X10^{-4}X_2 +9.93X10^{-5}X_3 + 21.31x10^8X_4 - 489590X_6 +1.49X10^{-5}X_7

Where: K = wear coefficient

From the Achard Model, the wear coefficient was evaluated as

Dry Alumiuim:

$$0.003109 = \frac{K \ x \ 1891483 \ x \ 0.00109}{3 \ x \ 40}$$
K = 0.00018

Wet Aluminum:

$$0.001827 = \frac{K \ x \ 11522651 \ x \ 0.00044}{3 \ x \ 40}$$
K = 0.000029

Dry Copper:

$$0.001883 = \frac{K \ x \ 4465171 \ x \ 0.00035}{3 \ x \ 40}$$
K = 0.00014

Wet Copper:

$$0.000379 = \frac{K \ x \ 489590 \ x \ 7.2X10-4}{3 \ x \ 40}$$
K = 0.00013

The variation of the coefficient of frictions shows that the wear mechanisms have been altered from the dry to wet result. The degree of changes can be traced the amount of lubricant, properties of the compound etc

4.2 Metal Wear Pattern

In both samples of metals, the wear rate of dry condition is always greater than the wet condition. The sample diameters were 4.35 mm (area 14.862 mm^2) for aluminium and 3.45 mm (area 9.348 mm^2) for copper.

Figs. 2 and 3 depict wear rates obtained for aluminium and copper samples respectively. The maximum volume loss for aluminium was 129.74 mm^3 and 85.53 mm^3 for dry and wet conditions respectively while for copper, the maximum was 35.71 mm^3 and 22.71 mm^3 for dry and wet conditions respectively. The corresponding wear coefficients are given as dry aluminium 0.00018, wet aluminium 0.000029, dry copper 0.00014, and wet copper is 0.00013.

The dynamic friction coefficients are found to be very high compared to the dry condition and may be due to the poor transport of the particles in the suspension to the area of contact. Although same size of specimen was used in both the test condition. Lubricant plays an important role in dispersion of the particles and friction [16].
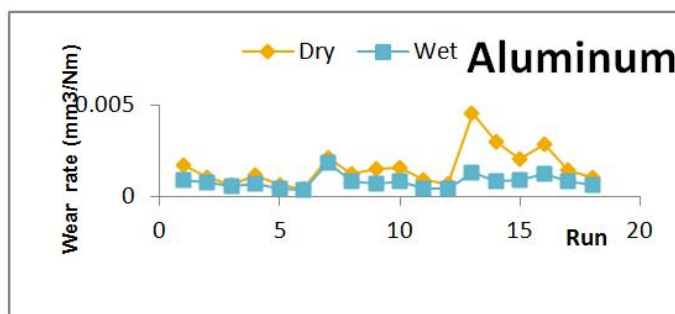
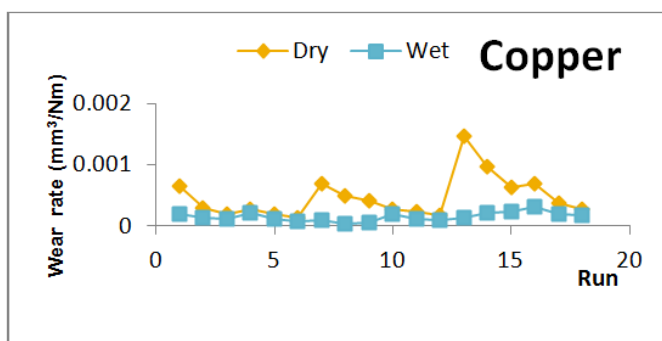**Fig. 2. Graph of Wear rate for Dry and Wet Conditions of Aluminium Sample**

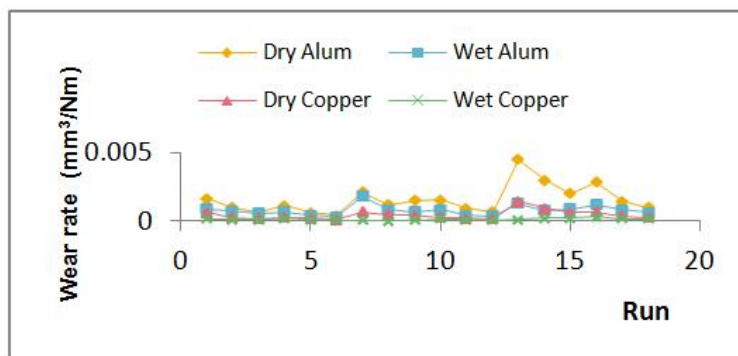**Fig. 3. Graph of wear rate for dry and wet conditions of copper sample**

Fig. 4. Graph of wear rate for dry and wet conditions comparison for aluminium and copper samples

Lubricants therefore play a major role in altering wear volume. Fig. 4 shows that average wear rate of aluminium sample without lubricant is relatively high compared to copper sample. Dry aluminium has the maximum wear rate of 0.001458 mm^3/Nm while wet copper shows the least tendency to remove its particles producing wear rate of 0.000309 mm^3/Nm at the same speed of 1.963 m/s. The effective particle disintegration decreases with the use of dispersants. The change in coefficient of friction from dry to wet particles can be traced to high affinity that exists with the addition of the dispersants.

4.3 Temperature Generation and Distribution

Consider a two-bodies sliding (or rolling/sliding) on a contact (Pin and Disk) .Here, the pin which is the specimen moving with relative velocity and contact area on a disk are considered. The rate of total energy dissipated in the sliding contact is

determined by the friction force and the relative sliding velocity.

For instance, most of failures in automotive friction clutches occur due to the excessive heat generation between the contact surfaces during the slipping period. A finite element technique has been used to study the temperature field; the heat generation and the contact pressure distribution when the specimen is pin on the friction disk slides.

Assumptions on the Heat Measurement:

1. Steady state conduction.
2. It is assumed that the pressure was evenly distributed on the disk.
3. Environmental conditions are negligible.
4. it is also assumed that all of the energy is dissipated as heat on the sliding surfaces

Some of the heat generated as the material slides over the Pin on disk was immediately dissipated into the surrounding air by means of convection. This fraction is only small compared to the amount that will be retained. The fraction of heat that is absorbed by the disk of rig is greater than the heat lost by convection.

This energy dissipation, called frictional heating, is responsible for increases in the temperatures of the sliding bodies, especially within the contact region on their sliding surfaces where the temperatures are highest. Evolution of contact temperature and friction coefficient of the metals and wear appearance with increasing speed shows that friction coefficient varies between 0.00018 and 0.000029 for aluminium and 0.0004 to 0.00013 for copper. The maximum contact temperature decreases from 3.6°C to 2.4°C
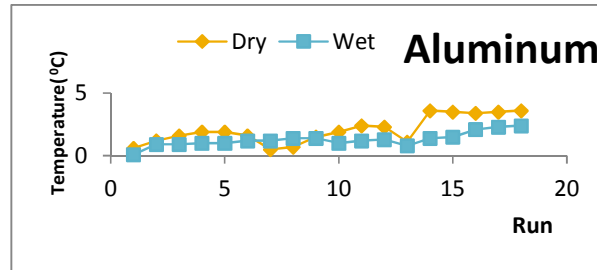

Fig. 5. Graph of temperatures changes in dry and wet aluminium against number of run
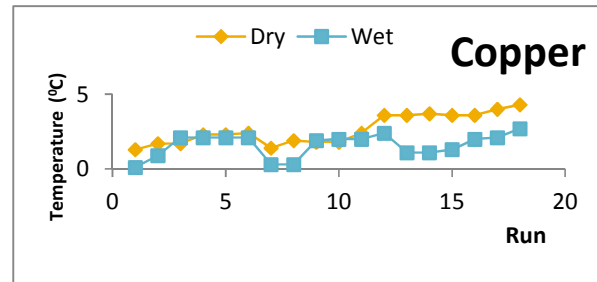

Fig. 6. Graph of temperatures changes in dry and wet copper against number of run
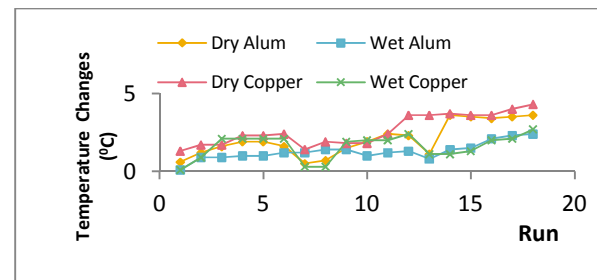

Fig. 7. Comparing the graphs of temperature generated for aluminium and copper samples under wet and dry condition

7

for aluminium and from 4.3°C to 2.7°C for copper, Fig. 5 and 6 respectively. Frictional heating can cause surface temperatures to reach the melting or softening temperature of thermoplastic polymers, and these results in a drastic change in the friction and wear behaviour of the polymer. The combination of contact pressure and sliding velocity can cause the surface temperature to reach the critical temperature [17].

Fig. 7, the wet curves for both aluminium and copper appeared under the dry curves for the respective materials. It means that the lubricant not only reduce the wear rate but also the temperature generation. Temperatures generated in the pin and at the contact surface are shown dry copper has the maximum temperatures on the contact surface of 4.3°C. The speed, load as well as lubricant play a vital role in the temperature generation. The temperatures strongly decrease along the pin axis since the heat is conducted into the surrounding, absorbed by the disk as well as cooled by the lubricant. These factors are behind the nature of the curves when compared alongside the dry and wet behaviour.

This temperature change can often be responsible for changes in the friction and wear behaviour of the material. This is extended to the

behaviour of any lubricant present in the contact. Among the most important effects of frictional heating on tribological processes are the following:

Contact temperatures and the resulting thermal stresses can play an important role in wear of sliding metallic components. The fact that temperature gradients around the contacts are very large can be responsible for softening and shear failure of the near-surface layer of the material in many situations [18]. The effect of temperature on the lubricant and its additives is also important [19]. Contact temperatures may play an even greater role in wear transitions for ceramics than in those for metals [20]. The temperature rise at the contacting ice asperities may not be sufficient to cause melting at very low sliding speeds; as a result the friction coefficient of ice and snow at very slow velocities may be as high as 0.6 to 0.8, but as soon as higher sliding velocities cause sufficient melting of the surface to produce a lubricating layer, the friction coefficient drops below 0.1 [21].

4.4 Strain Deformation

Strain results for the metals are shown in Fig. 8 and 9 for aluminium and copper respectively. Since it was assumed that wear rate is also dependent upon stress.
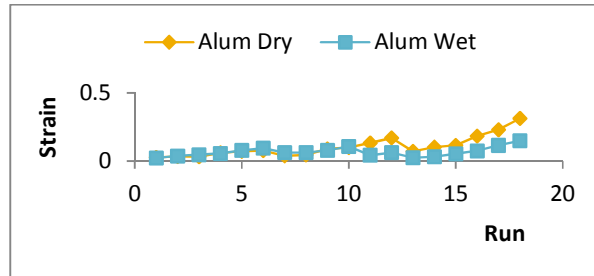

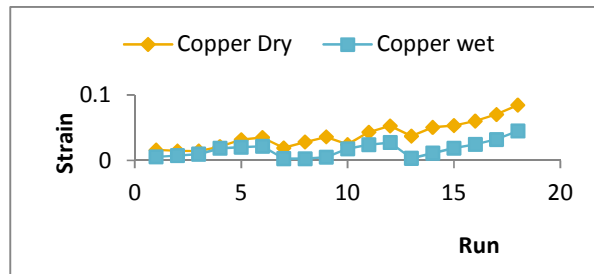**Fig. 8. Strain deformation curve on the wear track for aluminium sample**

Fig. 9. Strain deformation curve on the wear track for the copper sample

Dynamic strain curves of wet and dry aluminium test as shown in Fig. 9 were plotted based on both wear behaviour as calibrated on strain measuring device. The two curves agree for the most part, except near the end where the difference in strain measured tends to increase. Specimen strains versus time plots were used to determine the strain rate. Because of the absorbers used in dynamic testing, the initial part of the strain–time curve was not truly indicative of the effective strain rate experienced by the specimen.

Stress values are changing over time due to the wear and the changing contact then, wear at any particular location is changing over time. This can be seen from an examination of the contact pressure. The contact pressure at different times representing different amounts of wear.

The shear strain behaviour, which is also matrix dominated, shows high nonlinearity with a disintegration stress level that increases significantly as the strain rate increases. The yield point of the curve also increases with increasing strain rate. For the strain, the curve obeyed a similar pattern as the aluminium, which means the lubricant has an effect on the result.

4.5 Stress-Strain on the Disk

COSMOSPRESS showed the stress on the disk under the von mises scale. "Von Mises stress value" which can be simply compared to yield strength of the material. If it's greater than the yield strength, the part is failing according to his criteria.

Fig. 11 shows the free body diagram of the disk as it rotates. A distinct wear track was developed at a different speed and load. The results of the wear track are simulated with COSMOXPRESS.

The results on stress- strain on the disk for the metals were evaluated using Von Mises stress criterion. These are the equivalent tensile stresses between pin and disk material when both materials are in sliding contact and material start to yield. The Von Mises stress satisfies the property that two stress states with equal distortion energy have equal Von Mises stress. Several yielding criteria are available.

The Von Mises criterion is commonly used to check the yielding failure of ductile materials. The idea is to verify if the Von Mises stress is below the yield strength of the material. By this

criterion, the material is not in plastic (permanent, damaging) deformation. Maximum principal stress is an example of different yield criteria. It states simply that if any of the maximum principal stresses are above yield stress, by these criteria the part is in failure. For the different experimental conditions, the Von Mises result varies as shown Figs. 11 and 12
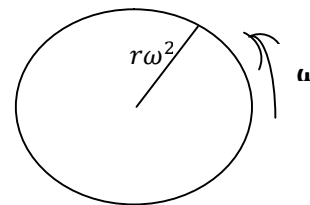

Fig. 10. Disk with the emery paper

Fig. 11. Schematic diagram of a wear rotating disk

Results produced as the effect of coefficient of friction are very similar, but not identical. The stress plot shows the boundary value along the wear tracks. This boundary values are most often used to present stress results. In the dry and wet conditions, the maximum normal stress is 1.912 N/m^2 and 4.354 N/m^2 respectively. This result is comparable to the results for the whole disk.

The stress plot for copper sample along the wear tracks, gave the maximum normal stress as 0.2419 N/m^2 for dry Copper tests and 1.929 N/m^2 for the wet condition. In both aluminium and copper samples, the wet conditions exhibits greater maximum stress compared to dry conditions. Unlike [22] where the stress pattern for composite was investigated with large amount of abrasive debris removed from the Composites during the wear test. These in turn substantially increased the wear rate of both the composites and the emery paper. The result was obtained in the absence of lubricants or depressants.

Flow occurs at a constant maximum value of the strain energy of distortion. This quantity was

obtained by subtracting the elastic energy of volume dilatation from the total elastic energy stored in the material. To locate the point of greatest positive stress and regulate the constant of integration, one may see from stress pattern on the wear track for all the metals, the wear track border is most positive stress region. Stresses are quantities that cannot be observed directly; their direction and magnitude may only be inferred from their effects. Therefore, the method of analyzing fault patterns shows the observed orientation of faults at certain boundaries. The analysis was used to reconstruct the whole potential fault pattern within the boundaries. This appears to be more direct in situations where it can be applied, than methods that depend upon complete knowledge of boundary stresses.

The mechanism of wear is discussed on the basis of the results of these experiments and electron microscopy of the friction surfaces.
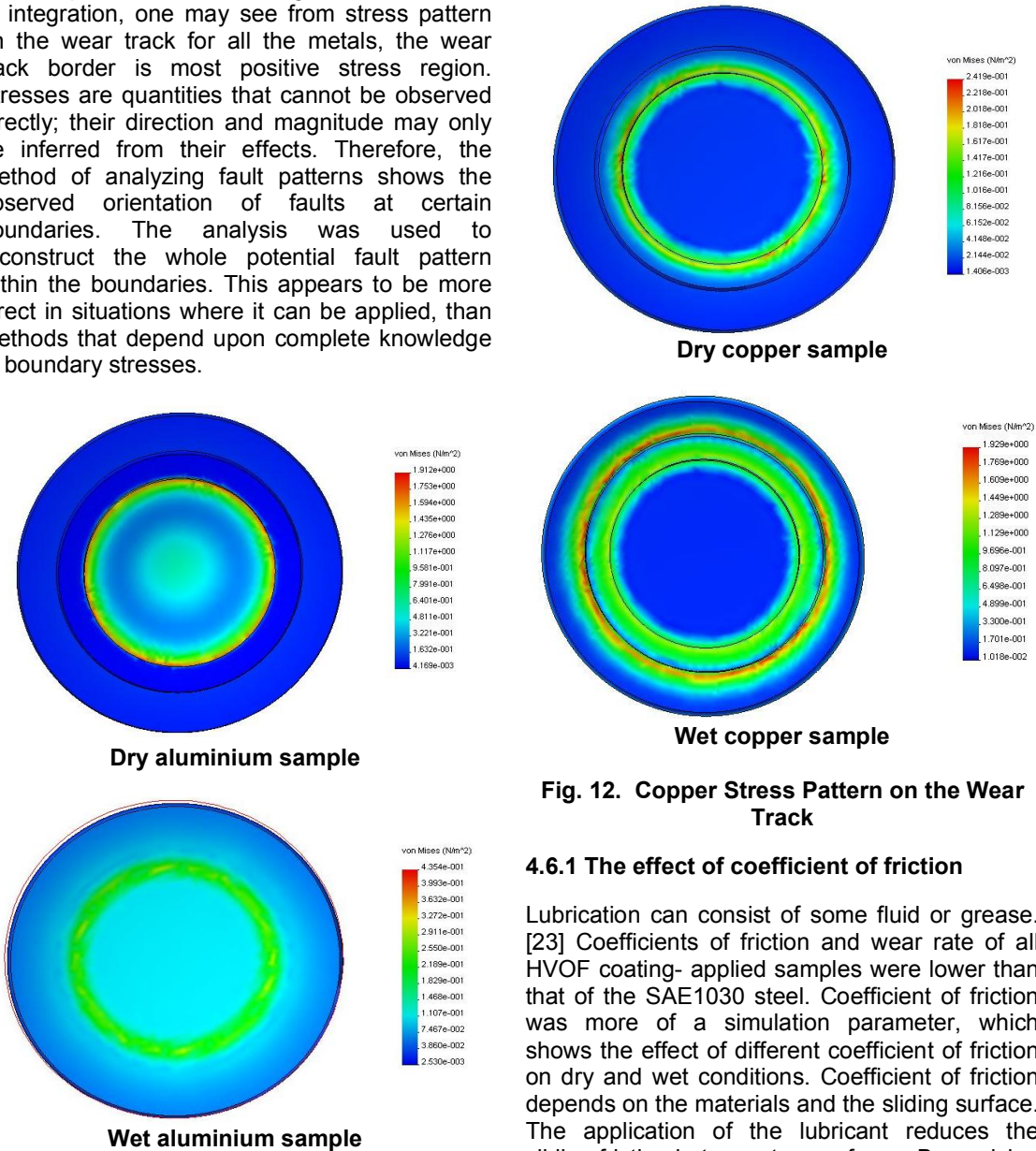
Dry copper sample

Wet copper sample

Fig. 12. Copper Stress Pattern on the Wear Track

Dry aluminium sample

Wet aluminium sample

Fig. 11. Aluminium stress pattern on the wear track

4.6 The Mode of Wear Mechanism

The effects of coefficient of friction, temperature generation as well as the stress/strain on disk on the friction and wear properties of aluminium and copper had been carried out on this experiment.

4.6.1 The effect of coefficient of friction

Lubrication can consist of some fluid or grease. [23] Coefficients of friction and wear rate of all HVOF coating- applied samples were lower than that of the SAE1030 steel. Coefficient of friction was more of a simulation parameter, which shows the effect of different coefficient of friction on dry and wet conditions. Coefficient of friction depends on the materials and the sliding surface. The application of the lubricant reduces the sliding friction between two surfaces. By applying a form of lubrication method between the objects, this is to ensure that an equal amount of lubricant was used.

4.6.2 The effect of temperation generation

The main results show that the observed wear mechanisms are extremely dependent on the system temperature, which increases slightly when increases the sliding speed and load.

Table 3. Comparing the error results for aluminium and copper

	Metal			
	Dry alum	**Wet Alum**	**Dry Copper**	**Wet Copper**
Error	3.70E-4	1.48E-4	9.42E-5	4.3E-5
Percentage Error (%)	21.17	20.47	7.24	20.74
Standard deviation	5.06E-4	1.77E-4	1.57E-4	5.27E-5

* Wet condition uses an organic based lubricant

In both materials, the dry conditions always generate a higher temperature than the wet condition. Wang et al. [24] Confirmed Increased in deformation, the deformation in the disk will be greater around the contact point with rise temperature.

4.6.3 The effect of the stress/strain on the disk

The existence of the strain state and stress state on the wear track were considered responsible for the generation of temperature and wear debris. The effect of temperature on the stress and strain distributions at the disk interface was altered as a lubricant was added. In other words, the wear track wear is a function of the apparent contact area, directly related to the applied load during testing.

Figs. 8 and 9, showed the clear effects of the lubricant on the material. In both the aluminium and copper, the strain was reduced.

4.7 Validation of Results

The validation of results looks into the error in measurements as a mathematical way to show the uncertainty in the measurement. The most common ways to calculate experimental error: Error and percentage error of the experimental and theoretical values are estimated. The results are limited to wear rate only.

The percentage error showed variation between the experimental and true values. The implication of this result can be seen as not only comparing the output performance of the rig but determining the level of accuracy in the result. With Dry aluminium condition having the percentage error of 21.17% and dry copper condition with the lowest error of 7.24%.

5. CONCLUSION AND RECOMMEND-ATION

Generally, the application of lubricant affected the wear behaviour of the metal. Volume wear, coefficient of friction as well as temperature generated. A quality changes were recorded on the application of the lubricant. From the results of the investigation and discussions, the following conclusion was made:

1. The results of temperatures generation shows some relevant characteristics of temperature distribution profile which increases with load, speed and time. Temperature lost also exists along the disk. This is due to the heat dissipation ability of disc material.
2. For the metals, under dry and wet conditions, coefficient of friction reduced in both aluminium and copper. The wet condition having the least coefficient of friction is as a result of favourable interaction between material and emery cloth in the presence of lubricant.
3. The wear track border is most positive stress region on the disk. The stress plot showed along the wear tracks, boundary regions noticed greater stress pattern on the wear track while on Disk.
4. Its clears from the graph, that the wet results are lower than the dry wear result. Meaning that the lubricant has an effect on the wear rate, strain and heat generation.

The following recommendations are hereby made in furtherance of this research work. Efforts should be made towards the having a system with an instant temperature measuring device. Such as the use of a thermostat can be added, so that heat generation can be read. This will prevent heat lost to the environment. The relationship on the effect of wear resistance, relative wear resistance and pressure wear resistance for non-heat treated metals can also be verified.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Adnan Akay. Acoustics of frictiona). Mechanical Engineering Department, Carnegie Mellon University, Pittsburgh, Pennsylvania 15213; 2002.
2. Briscoe BJ, Sinha SK. Wear of polymers. Journal of Engineering Tribology. Proc Instn Mech Engrs. 2002;216:401-414.
3. Ronkainen H, Varjus. S, Holmberg. K. Tribological performance of different DLC coatings in water-lubricated conditions. Elsevier Wear. 2001;249:267–271.
4. Moore DF. The friction and lubrication of Elastomers, (Pergamon Press, Oxford); 1972.
5. Zhang S. W. Wear of elastomers (Petroleum University Press, Dongying, Shandong Province, PRC); 2001.
6. Denton R, Keshavan MK. (Eds) Wear and friction of elastomers. ASTM Special Technical Publication. 1992;1145.
7. Sugishita J, Fujiyoshi S. The effect of cast iron graphite on friction and wear performance and graphite film formation on gray cast iron surfaces, Wear. 1981;66: 209.
8. Hani Aziz Ameen, Khairia Salman Hassan, Ethar Mohamed Mhdi Mubarak. Effect of loads, sliding speeds and times on the wear rate for different materials. American Journal of Scientific and Industrial Research Science. 2011;649.
   DOI: 10.5251/ajsir.2011.2.99.106.2011
9. Friedrich K. Friction and wear of polymer composites. Elsevier, Amsterdam; 1986.
10. Zhang ZF, Zhang LC, Mai YW. Modelling friction and wear of scratching ceramic particle reinforced metal composites. Wear 1994, 2004;176:231-237.
11. Nwigbo Solomon, Mgbemena Chika, Ajoboru Famous, Obiamiwe Chioma, Eriobu Ebele. Development of new copper wire drawing lubricant. Journal of Applied Sciences Research. INSInet Publication. 2010;6(11):1669-1673.
12. Annual Book of ASTM Standards, American Society for Metals, West Conshohocken, PA. 1999;544.
13. Stachowiak GW, Batchelor AW. Engineering tribology. 2005, Oxford: Elsevier; 2004.
14. Williams JA.Engineering tribology, Oxford: Oxford University Press, Inc; 1994.
15. Archard JF. Contact and rubbing off at surfaces. Journal of Applied Physics.1953; (24)8:981-988.
16. Aralihalli S, Biswas SK. Grafting of Dispersants on MoS2 nanoparticles in base oil lubrication of steel. Tribology Letters. 2013;49(1):61-76
17. Lancaster JK. Composite self-lubricating bearing materials. Proc Instn mech Engrs. 1967;182:1(2):33-39.
18. Rozeanu L, Pnueli D. Two temperature gradients models for friction failure. ASMEJ. Lubrication Technology. 2008; 100:479-484.
19. Enthoven JC, Cann PM, Spikes HA. Temperature and scuffing. Tribology Trans. 2003;36:258-266.
20. Hsu SM, Shen MC. Ceramic wear maps. Wear. 2006;200:154-175.
21. Kennedy FE, Schulson EM, Jones DE. The friction of ice on ice at low sliding velocities. Phil. Mag. A. 2000;80:1093-1110.
22. Nwigbo SC, Onyeanusi CF. Wear Resistance and Wear Pressure of Natural Reinforced Composites. International Journal of Scientific and Engineering Research. 2016;7(9):1401-1412.
23. Buytoz. S, Ulutan M, Islak S, Kurt B, Çelik ON. Microstructural and wear characteristics of High Velocity Oxygen Fuel (HVOF) sprayed NiCrBSi-SiC composite coating on SAE 1030 steel. Arabian Journal for Science and Engineering. 2013;38(6):1481–1491.
24. Wang L, He Y, Zhou J, Duszczyk J. Effect of temperature on the frictional behaviour of an aluminium alloy sliding against steel during ballon- disc tests. Tribology Interational. 2010;43:299-306.