Original Research Article

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

ABSTRACT

Friction and wear control in movable machines parts remains a critical challenge in the industry. A measure to control this often involves both material and lubricant tests. A wear test experiments 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 is presented. Wear parameters to include frictional coefficient, wear rate, and heat generation (temperature) were evaluated alongside thermal stress-strains on the disk. Results showed that the coefficient of friction reduces with the application of lubricant up to 84% and 7% for aluminium and copper respectively under the same conditions. The wear pattern for both materials when lubricated were evaluated and compared with dry condition to establish a relationship between them.

Keywords: Wear rate, Wear, lubrication, Pin-on-disk, Metal, Wear Coefficient

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 happens 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.

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.

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. [2] 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. Their experiment had been performed on a group of specimens under different cases of times (5 to 30 minutes), under different loads (0.5 to 2kg), and different speeds (2.5 to 9m/sec). Results showed that the rate of adhesion wear will be directly proportional to (time, sliding speed and load) for steel, aluminium and brass.

[3]studied the coefficient of friction and wear on Al-Li alloys reinforced with 10 wt% SiCp (13 and 30μm) using scratch testing at a room temperature and 200℃ 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℃ using a scratch speed of 6 mm so’ and a load range of I-20 N, A diamond pyramidal indenter with an apex angle of 136^0 were used. Friction coefficient for the composite containing 30μm 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 gained 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 [4]. 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. The free fatty acids which are active as friction modifiers are obtained by hydrolysis of the vegetable oil. The detergent is to be replaced by the potassium soap of the base oil. The other compounds used to satisfy the additive requirements as highlighted by [4] are:

i. Liquid fatty acid soap of the base oil.
ii. Fatty acids in the base oil which serve as corrosion inhibitor, anti-oxidant and extreme pressure (EP) additive.
iii. Glycerol and ethylene glycol, forming ethylene glycol mono methyl ether, which act as biocide, preservative, pour-point depressant (anti-freeze) and dispersant.
iv. Methyl silicone as anti-foam agent. Agitation and aeration of a lubricant occurring during application may result in formation of air bubbles in the oil (foaming).
v. Demulsifiers (xylene), which holds water molecules in suspension, preventing corrosive action.

For the additives, detergent (potassium soap of the base oil) is blended by adding to the base oil a solution of 0.1M of potassium hydroxide in the ratio of 6:1 respectively. The reaction is at room temperature a milky solution of soap-less detergent is formed. Dispersant/Biocide (Ethylene-glycol-mono-methylether) is a mixture of 4% glycerol and 96% ethylene glycol. The other compounds used to satisfy the additive requirements are:

- Base Oil (Palm kernel oil)
- Detergent (potassium soap of base oil)
- Dispersant/Biocide (Ethylene-glycol-mono-methylether)
- Demulsifier (Xylene)
- Anti-foam (Methyl silicone)
- Emulsifier (Hydrogenated castor 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 disc were also evaluated.

3. EXPERIMENTAL METHOD

[5] Standard test method is 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 is 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 is 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.

(a) (b)

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

Prior to testing, measurement or weighing of the samples were done. The specimens are clean and dry, 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 following experimental assumption was 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 disc 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 [6], also known as a dimensional wear rate, according to [7] 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). [8] also developed the expression for wear rate (volume of material worn) as shown in equation (2).

$$\text{Wear rate } (mm^{3/}Nm) = \frac{\text{Volume loss}}{\text{Load X distance Travelled}} \qquad (1)$$

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

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

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.

For the Pin on disk, two specimens are required. A pin with radius tip is positioned perpendicular to a flat circular disc. The test machine causes either the disc specimen or the pin specimen to revolve about the disc centre. In either case, the sliding path is a circle on the disc surface. The plate of the disk may be oriented horizontally or vertically. The pin specimen is pressed against the disc 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 DISCUSSIONS

4.1 METAL WEAR PATTERN

In both samples of metals, the wear rate of dry condition is always greater than the wet condition. The sample diameters are 4.35mm (area 14.862 mm^2) for aluminium and 3.45mm (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 [9].

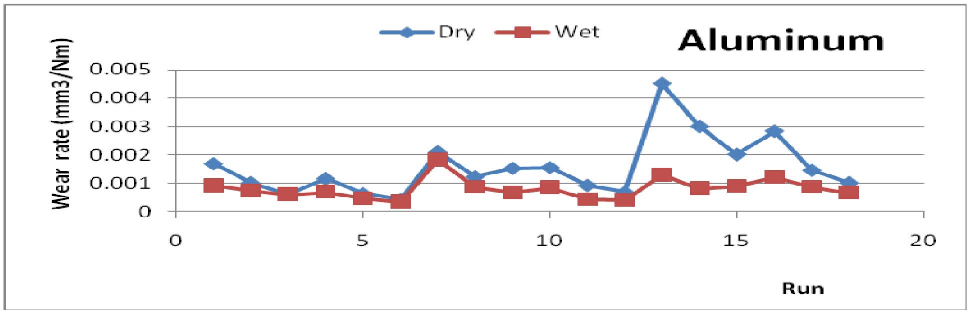


Fig. 2 Wear rate for Dry and Wet Conditions of Aluminium Sample

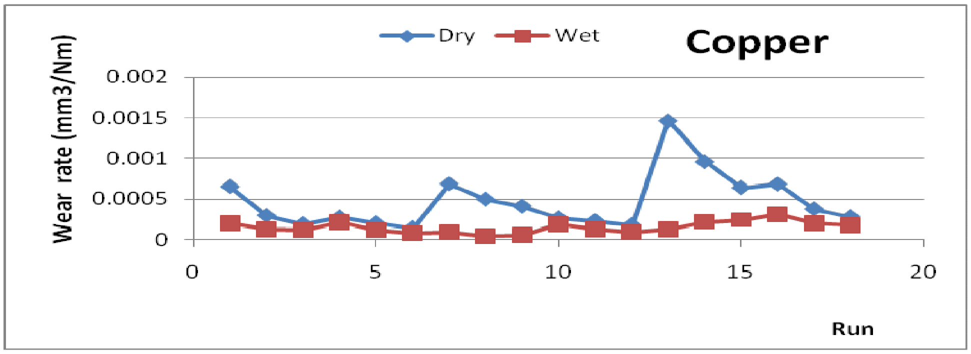


Fig. 3 Wear rate for Dry and Wet Conditions of Copper Sample

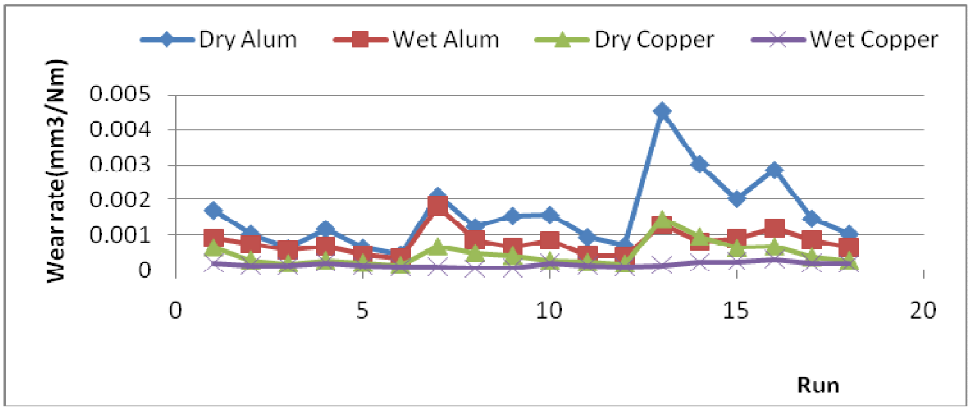


Fig. 4 Wear rate for dry and wet conditions comparison for Aluminium and Copper Samples

Lubricants therefore played 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 0.001458mm^3/Nm while wet copper shows the least tendency to remove its particles producing wear rate of 0.000309mm^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

4.2 TEMPERATURE GENERATION AND DISTRIBUTION

Consider a general two-body sliding (or rolling/sliding) contact on a Pin On Disk, which is the specimen moving with velocity relative to the contact area and the disc is moving with velocity relative to the same contact area. The rate of total energy dissipated in the sliding contact is determined by the friction force and the relative sliding velocity.

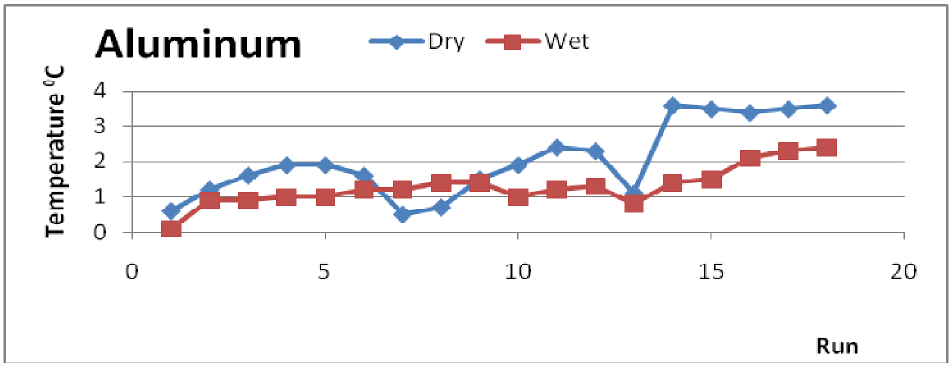


Fig. 5 Temperatures changes in Dry and Wet Aluminium with Number of run

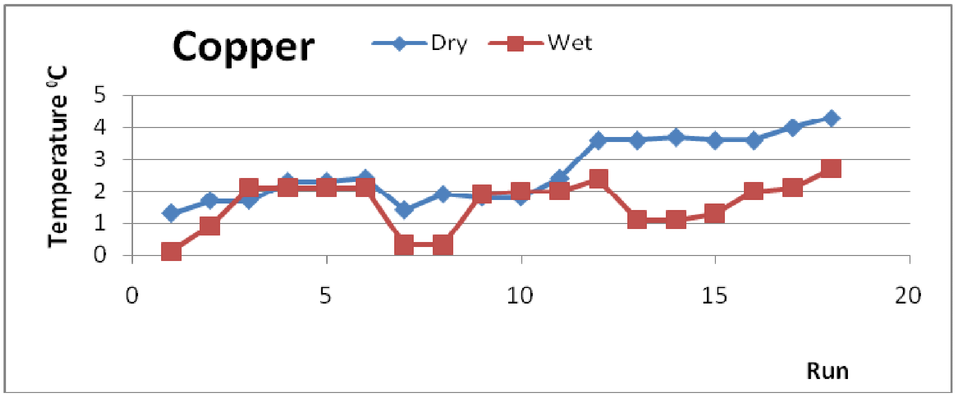


Fig. 6 Temperatures Changes in Dry and Wet Copper with Number of run

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 ℃ to 2.4℃ for aluminium and from 4.3 ℃ to 2.7℃ 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 behavior of the polymer. The combination of contact pressure and sliding velocity can cause the surface temperature to reach the critical temperature [10].

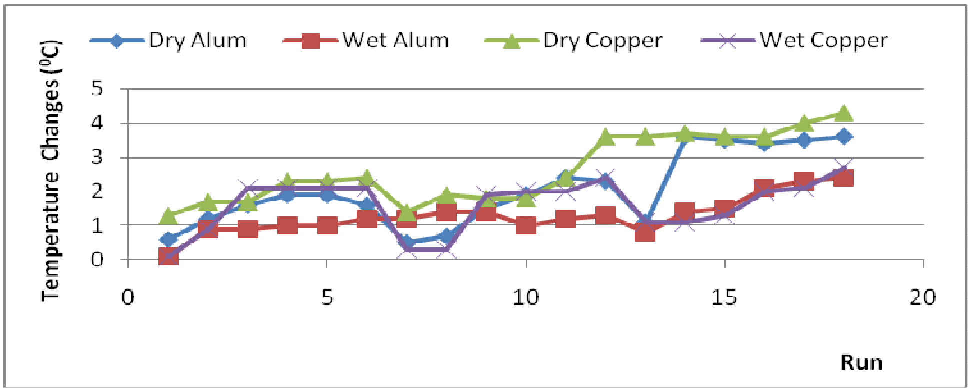


Fig.7: Temperature Generation Comparison for Aluminium and Copper Samples

In Fig. 7, the wet curves for both aluminium and copper appeared under the dry curves for the respective materials. Meaning that the lubricant did not only reduce the wear rate but also the temperature generated. 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^{0}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 disc as well as cooled by the lubricant. These factors are behind the nature of the curves when compared alongside the dry and wet behaviour.

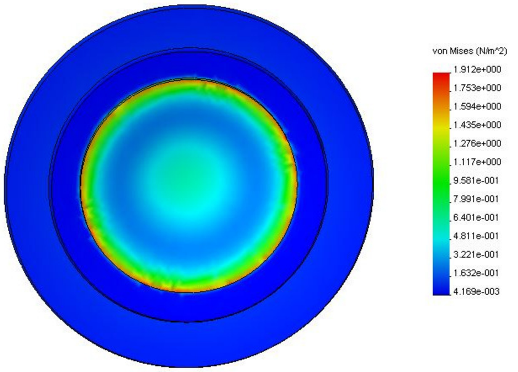
These temperature changes can often be responsible for changes in the friction and wear behaviour of the material. This is extended to the behaviour of any lubricant present in the contact. Among the most important effects of frictional heating on tribological processes are the following:

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 [11]. The effect of temperature on the lubricant and its additives is also important [12]. Contact temperatures may play an even greater role in wear transitions for ceramics than in those for metals [13]. 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 [14].

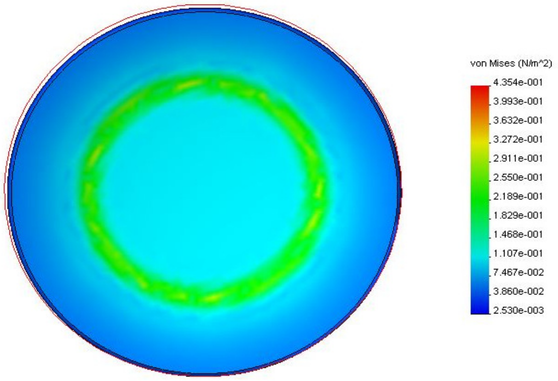
4.3 STRESS- STRAIN ON THE DISK

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 disc 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 Fig. 8 and 9.



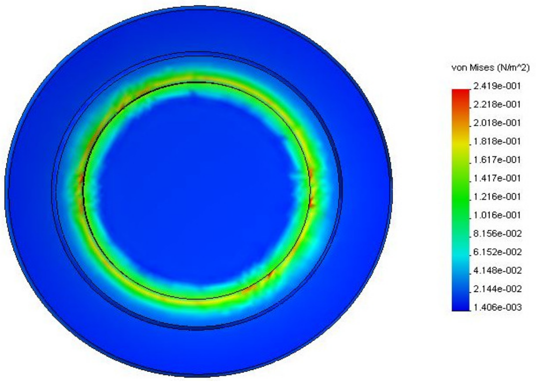
Dry Aluminium Sample



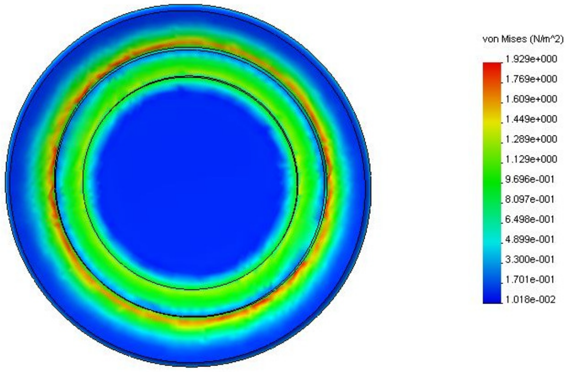
Wet Aluminium Sample

Fig. 8 Aluminium Stress Pattern on the Wear Track

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 disc.



Dry Copper Sample



Wet Copper Sample

Fig. 9 Copper Stress pattern on the Wear Track

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, [15] 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.

4.4 STRAIN DEFORMATION

Strain results for the metals are shown in Fig. 10 and 11 for aluminium and copper respectively. Since it was assumed that wear rate is also dependent upon stress. 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.

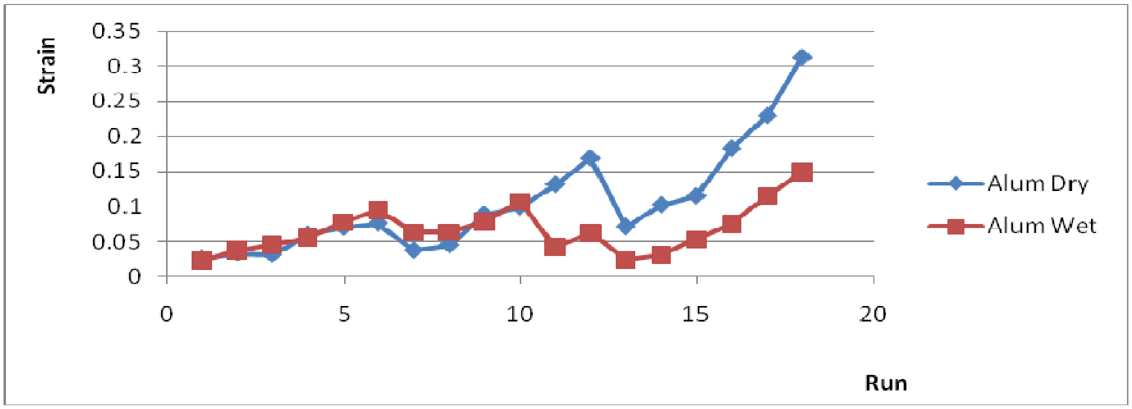


Fig. 10 Strain Deformation Curve on the Wear Track for Aluminium Sample

Dynamic strain curves of wet and dry aluminium test as shown in Fig. 11 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.

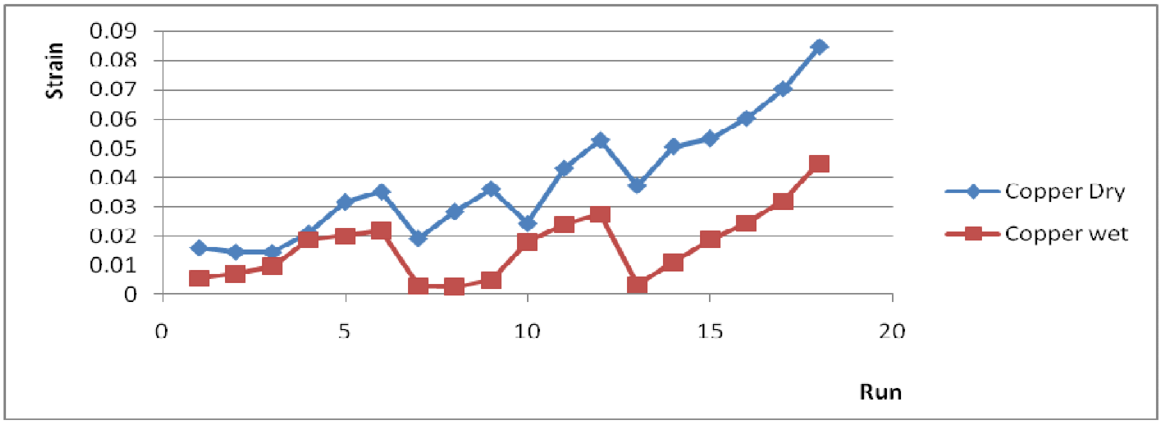


Fig. 11 Strain Deformation Curve on the Wear Track for the Copper Sample

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.

5. CONCLUSION AND RECOMMENDATION

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

1) The results of temperatures generated show some relevant characteristics of temperature distribution profile which is increases with load, speed and time. Temperature lost also exists along the disc. 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 disc. The stress plot shows 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, strain and heat generated.

The following recommendations therefore 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 generated 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.

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