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# Determination of friction coefficient in the lubricated ring upsetting with palm kernel oil for cold forging of aluminum alloys

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KEYWORDS

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ABSTRACT

The growing of worldwide trend for promoting the use of the renewable material such as vegetable oil is due to the increasing concern about environmental damage that caused by the use of mineral oil which is not biodegradable. This article is present as a case study in highlighting the use of Palm Kernel Oil (PKO) as a bio lubricant in cold forging process. Ring Compression Test (RCT) plays a fundamental role in our understanding of materials science and engineering due to the deformation, friction and wear behaviour. Annealed Aluminium (AA6061) were used in this test to observe the formation of the ring with different sample test (NO-Oil, PKO and CMFOoil) at 10%, 20% 30% and 40% formation by comparing with finites element method (DEFORM-3D) to predict formation of the sample lubricants. The ring compression test conducted by this study indicates that the Tresca friction factor (m) is higher for Palm Kernel oil (0.35) compare to commercial metal forming oil (CMFO) (0.25), where higher load is needed under palm kernel oil test. Palm Kernel oil however has a better in surface protecting to the material where it shows that the roughness of the workpiece is lower compare to the CMFO, besides that the Wear scar observation also shows CMFO has a lot of wear on workpiece surface.

## 1.0 INTRODUCTION

Half usage of the lubricant ends up in the environment as a waste. Most of the lubricant used in the industrial sector were mineral based oil which is environmentally hazardous and poor

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degradability when released (Noorawzi & Syahrullail, 2014; Razak et al., 2015). Besides that, the depletion of mineral oil also motivates researcher concern to find an alternative oil lubricant to substitute the mineral oil which can gives similar or even better lubricating properties compared to the mineral based oil (Sapawe et al., 2016). Vegetable oils is seems to be one of the alternative that has a potential to replace mineral based oil. According to Jabal et al., (2014), vegetable oil is biodegradable and less toxic rather than petroleum based oil, besides they also are renewable source and easy to reproduce. Palm oil is one of the famous vegetable oils that currently been develop in using at many sectors such as biodiesel (Radhakrishnanet al., 2017), lubricant (Dandan et al., 2019), and Pharmaceutical (Efendy et al., 2019).

Palm oil has been tested by several researchers for different engineering applications. Such as studied by Syahrullail et al., (2005, 2011a, 2011b) that investigated the characteristics of palm oil as a metal forming lubricant. Besides that, palm oil was also investigated to be used as diesel engine and hydraulic fluid as proposed by Bari and Wan Nik respectively (Bari et al., 2002; Nik et al., 2005), since the diesel has a bad impact on the environment that emit the hydrocarbon (HC) and carbon monoxide (CO) as discussed by (Syahrullail et al., 2013; Amiril et al., 2018)). There are four major groups of palm oil that were investigated by the researchers around the world, namely 100% palm oil as a test lubricant (Masjuki et al.,1999), Uses palm oil as additives (Castro et al., 2005), Uses palm oil with additive (Chew et al., 2009) and Uses palm oil emulsion (Husawan et al., 2009). All of the research proved and found out that palm oil shows satisfactory results and has a bright future to be used widely in engineering applications. There is no argument on the performance of palm oil as lubricant. It has also been proven that palm oil has good performance in term of lubrication and has the potential to reduce the dependency on mineral based oil lubricants.

Metal forming refers to a series of metal working processes that form metal stock to produce usable components. To ensure the finished product is well manufactured lubricant is one of the most important elements to acknowledge (Nurul & Syahrullail, 2015). Poor surface finishing and downtime from production are challenging problems in metal manufacturing. Those are usually caused by problems associated with inadequate lubrication systems between the two die – workpiece sliding surfaces, which also cause the lubricant film to break down. The lubricant film breakdown induces direct metal-to-metal contact between the two sliding surfaces, resulting in negative effects of metal-to-metal transfers between the two contact surfaces, as well as die wear and galling (Sulaiman et al., 2019). As mention earlier mineral oil is the most commonly used lubricants in industry where temperature requirements are moderate such as bearing, gears, engines etc. (Neil, 2009; Gwidon & Andrew., 2012).

$$\tau = mK \tag{1}$$

Friction is one of the main influences of on metal forming process also known as Tresca (shear friction) friction model as shown in equation (1) (Zhang et al., 2019). Where $\tau$ the frictional is shear stress; $m$ is the Tresca friction factor $K$ is the yield stress in shear. The ring compression test is a proven method to evaluate the shear friction (m) for bulk forming process. It's a simple, fast, indirect and inexpensive approach using standard rings and flat dies (Tatematsu et al., 2018; Zhang et al., 2019). The ring compression method offers a methodology to study the frictional behavior of metals and their alloys over a range of test conditions, such as temperature deformation, degree of deformation, deformation rate lubricants, etc (Harikrishna et al., 2018).

To get better prediction in metal forming the calibration curve that created from the finite element method (DEFORM-3D) is been used. According to Groche et al., (2018), finite element method is important in efficient design for the modern process chain, where the input parameters is totally influencing the quality of the result. The friction model plays important role in controlling the accuracy of necessary output results as reported by Tan, (2002).

Palm kernel oil may either be processed by an alkali or by the physical process. However, since most of the fatty acids available are 12 carbon atoms or fewer (Syahrullail et al., 2013), the deodorization temperatures used are lower in the alkali phase–usually 220℃ and 230–235℃ in the physical process. Palm kernel oil has a high lauric and short-chain fatty acid content, and low unsaturated acid content. This study is aimed to study the tribological performance of bio lubricant (Refine bleach and deodorize palm kernel oil) as potential metal forming lubricant to replace conventional mineral oil (CMFO) using standard cold forging test (ring compression test).

## 2.0 MATERIALS AND EXPERIMENTAL SETUP

### 2.1 Lubricant Sample

In this research palm, refined bleached and deodorized (RBD) palm kernel oil (PK) is used as bio-lubricant that obtained from the kernel of palm fruit. RBD Palm kernel is undergoes a purifying process to dissipate the unnecessary fatty acid and odour (Hasan et al., 2016). In order to get the benchmark for the conventional mineral oil, CMFO been used to compare the tribological performance with RBD PKO. Table 1 shows the physicochemical properties of the sample lubricant. For every test 0.1 mg of sample lubricant is been lubricated at both surface of the workpiece.

Table 2 shows the fatty acid composition of RBD palm kernel oil, it is heavily saturated relative to palm oil; the saturated fatty acid content of palm kernel oil is typically above 80 percent. This standard palm kernel oil composition is expressed in its iodine content (IV: 33), which is slightly lower compared to palm oil (IV: 51–53). The higher the iodine value, the more unsaturated fatty acid bonds are present in a fat.

Table 1: Lubricant properties of all sample test.

| **Sample** | **Kinematic viscosity ($mm^2/s$)** | | | **Viscosity Index** | **Density ($g/cm^3$)** |
|---|---|---|---|---|---|
| | 25ºC | 40ºC | 100ºC | | |
| RBD Palm kernel oil | 46.14 | 31.32 | 8.00 | 176 | 860 |
| CMFO | 107.71 | 42.05 | 11.20 | 273 | 900 |

Table2: Chemical composition of RBD Palm kernel oil.

| | C12:0 | C14:0 | C16:0 | C18:0 | 18:1 | C18:2 | C18:3 | C20:0 | SFA | MUFA | PUFA | IV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **%** | 0.16 | 1.16 | 54.31 | 4.71 | 32.31 | 6.68 | 0.3 | 0.37 | 60.71 | 32.31 | 6.98 | 33 |

*N.D=Not detected: SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA:polyunsaturated fatty acids

Figure 1 shows the tensile stress–strain curve determined by equation (2) for AA6061 aluminium alloy. The curve-fitting equation of tensile flow stress ($\bar{\sigma}$) as a function of equivalent plastic strain ($\bar{\varepsilon}^P$) is derived from experimental testing of AA6061 aluminum alloy as (Wilkines et al., 1990):

$$\bar{\sigma} = 284(1 + 125\bar{\varepsilon}^P)^{0.1} \tag{2}$$

Standard relative ring that has dimension ratio of 6:3:2 (Do:Di;h) is been made as a workpiece, where Do is outer diameter Di is inner diameter h is height of the ring. The actual dimension is 30, 15 and 10mm as shown in Figure 2. Both surface (upper and lower) were machined by a milling process to a surface roughness (Ra) of approximately 1.182µm.

Figure 3 illustrate the experimental set-up of the standard ring compression test, where the main components at top puncher workpiece (ring) and bottom die. This work had been performed at room temperature with the lab press machine. This ring compression test apparatus was assembled and placed on the load cell to record the load extrusion (Y-axis). The displacement of ram stroke (X-axis) was also documented by mounting the displacement sensor to the top die. The lubricant quantity for each test is estimated to 0.1 mg, and has been spread across the both die surface. The die was weighted before and after being lubricated using micro-weight scale. The hydraulic pressing machine is pressed down 10%, 20%, 30% and 40% deformation. For each punch pressing of 0.01s, the load cell will record the force.

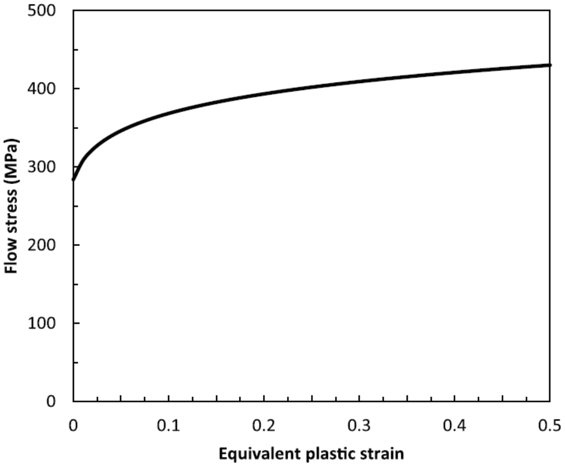

Figure 1: Tensile stress-strain curve of AA6061 aluminium alloy (Wilkines et al., 1990).

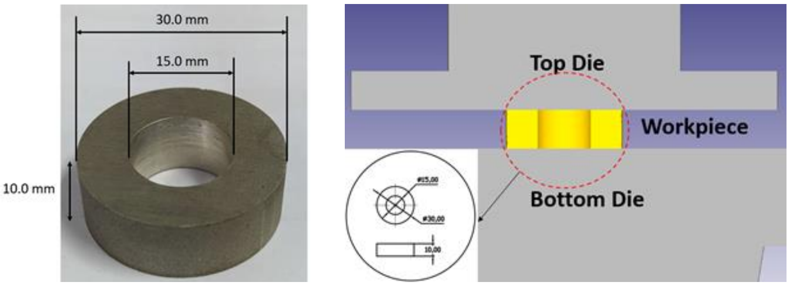

Figure 2: Dimension of the ring specimen.

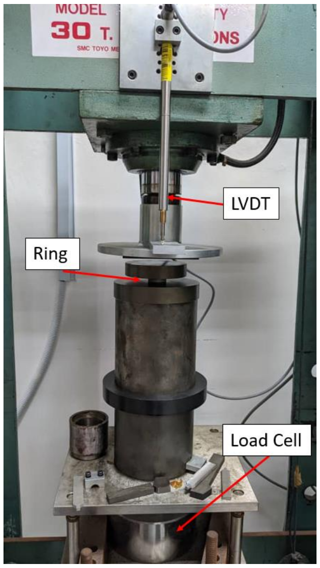

Figure 3: Experiment set-up.

## 2.3 Finite Element Method (FEA)

Finite element method is one of the essential in predicting of the efficient design of modern's process. In this research we are aiming to use the FEA on palm kernel oil lubricant that will be compared to mineral oil based, and to get better view of the result, the experimental condition will be compared to the FEA, so that the performance of the palm kernel oil lubricant can be see clearly by comparing the force, friction and stress behavior of AA6061 after the compression test.

The workpiece (ring) and the actual dimension of the die model that been drawn by CAD is imported to DEFORM-3D simulator as a way of gauging a more realistic fiction condition that occurred at ring compression test (Zhang et al., 2017). Table 3 shows the parameters for condition of simulation process to get a more accurate finite element analysis with a fine mesh. The puncher and the die however are set as a rigid body without any deformed circumstances during the compression. The von Mises yield criterion was adopted within the FE model. Tresca friction models were used to describe the friction at the interface between ring and the die, respectively.

Table 4: Simulation parameter.

| **Simulation parameter** | **Values** |
|---|---|
| Material | AA6061-T0 |
| Young's modulus (mPa) | 68.9 |
| Poisson's ratio | 0.33 |
| Mesh number of workpiece | 32000 |
| Forging temperature (◦c) | 28 |
| Tresca friction factor | 0-0.40 |
| Die displacement (mm) | 0.1 |
| Upsetting steps | 40 |

Calibration curves for the ring compression tests are established using either analytical methods or the FEM. The curves formed by the FEM are more precise, as the material properties and conditions of formation can be found. For this analysis, the FEM was used for the elaboration of friction calibration curves. During the compression process the height (h) and inner diameter (d) of the metal ring could then be predicted with numerical simulations. The accompanying calculations could then be used to determine a reduction percentage for both the height (%H) and the inner diameter (%Di).

$$\%H = \frac{H_0 - H}{H_0} \times 100\% \tag{3}$$

$$\%Di = \frac{Di_0 - D}{Di_0} \times 100\% \tag{4}$$

## 3.0 RESULTS AND DISCUSSION

### 3.1 Formation and Calibration prediction curve friction

Figure 4 shows the cross-section of the workpiece for RBD palm kernel (a) and CMFO (b) after undergoes compression of 40% deformation. Both shapes are determined by a profile projector after axial sectioning of the compact ring compression. Ideal deformation can be accomplished if the ring is compressed between the dies and the ring without friction (Tatematsu et al., 2018).

The result shows that for unlubricated part the outer diameter is about 37.03mm and inner diameter is 13.24mm with noticeable barrelling. For lubricated test, the expand of outer diameter is similar for both sample (37.51 mm), but for inner part, we can observe that for RBD palm kernel shows a convex formation that expand the material towards the centre with inner diameter of 13.5mm (barrelling). CMFO however shows contrast result, where the inner part is form like a concave formation due to the movement of material slightly is going away from the centre line. According to Sofuoglu & Rasty (1999), if the interior diameter of the specimen increases during the deformation, the friction is low and if the inner diameter of the specimen reduces during the deformation, the friction is considered as high.

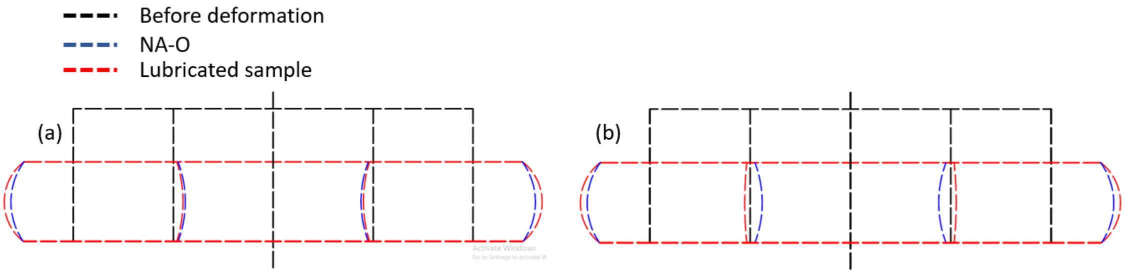

Figure 4: Comparison formation after 40% compression test (a) RBD Palm kernel oil (b) CMFO.

To study the Tresca shear friction behaviour that occur during the experiment, the calibration curve is been made using finite element method (DEFORM-3D) to estimate the value of the friction for unlubricated, RBD palm kernel oil, and CMFO. According to the calibration curve, the inner diameter shrinks at lower reduction when m>0.25. When m=0.25, the inner diameter is expanding at R<30% and it decreases when R⩾30%. Thus, the geometry ratio D0: Di: h (6:3:2), the shear friction of m=0.25 is the boundary between shrinking and expanding of the inner diameter, when using rings compression test.

Figure 5 shows the comparison of the three sample (NA-O, RBD palm kernel oil, CMFO) experimental result formation of ring compression test that has been plotted into the calibration curve. From the result obtain the result shows that RBD palm kernel has improve the shear friction performance from m=0.40 (NA-O) to m=0.35 (RBDPKO). CMFO however shows a better shear friction performance at m=0.25 compare to RBD Palm kernel oil.

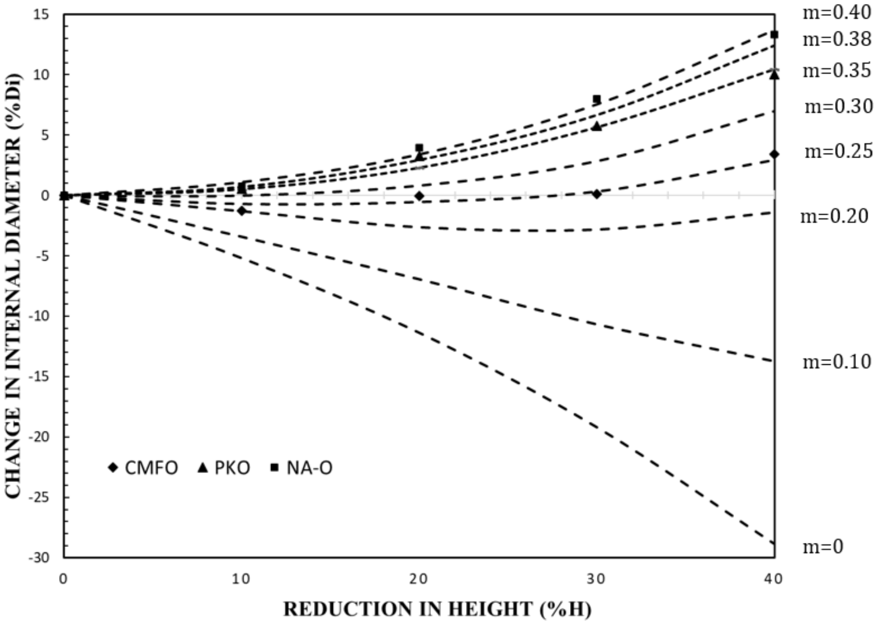

Figure 5: Calibration curve of Aluminium alloy AA6061.

To get a better prediction of shear friction in finite element method of the ring compression test, the results of force according to the displacement in time behaviour during steady-state condition were recorded at different stroke positions in the experimental analysis as shown in Figure 6 and be compared to the simulation in FEM under different shear friction factor. For a good understanding of the physical system being modelled, the best polynomial fit between 0.9953 and 0.9976 was chosen for the data. The FEM is utilised according to ALE mesh formulation to overcome the excessive distortion of mesh.

Figure 6(a) shows that 0.1mg of RBD palm kernel oil has best fitted at m=0.35 in finite element method analysis, where the experimental results are at the steady state condition when compare to the compression load distribution. The same trend is observed for the 0.1mg of CMFO and unlubricated workpiece (Figure 6(b) and 6(c)) at shear friction is equal to 0.25 and 0.4 respectively. All of the force distribution was in good agreement with the calibration curve estimation that was based on ring deformation. The higher friction occur between the surfaces has consume a lot of force needed to form the ring until 40% compress formation of the ring (Stalls et al., 2020).

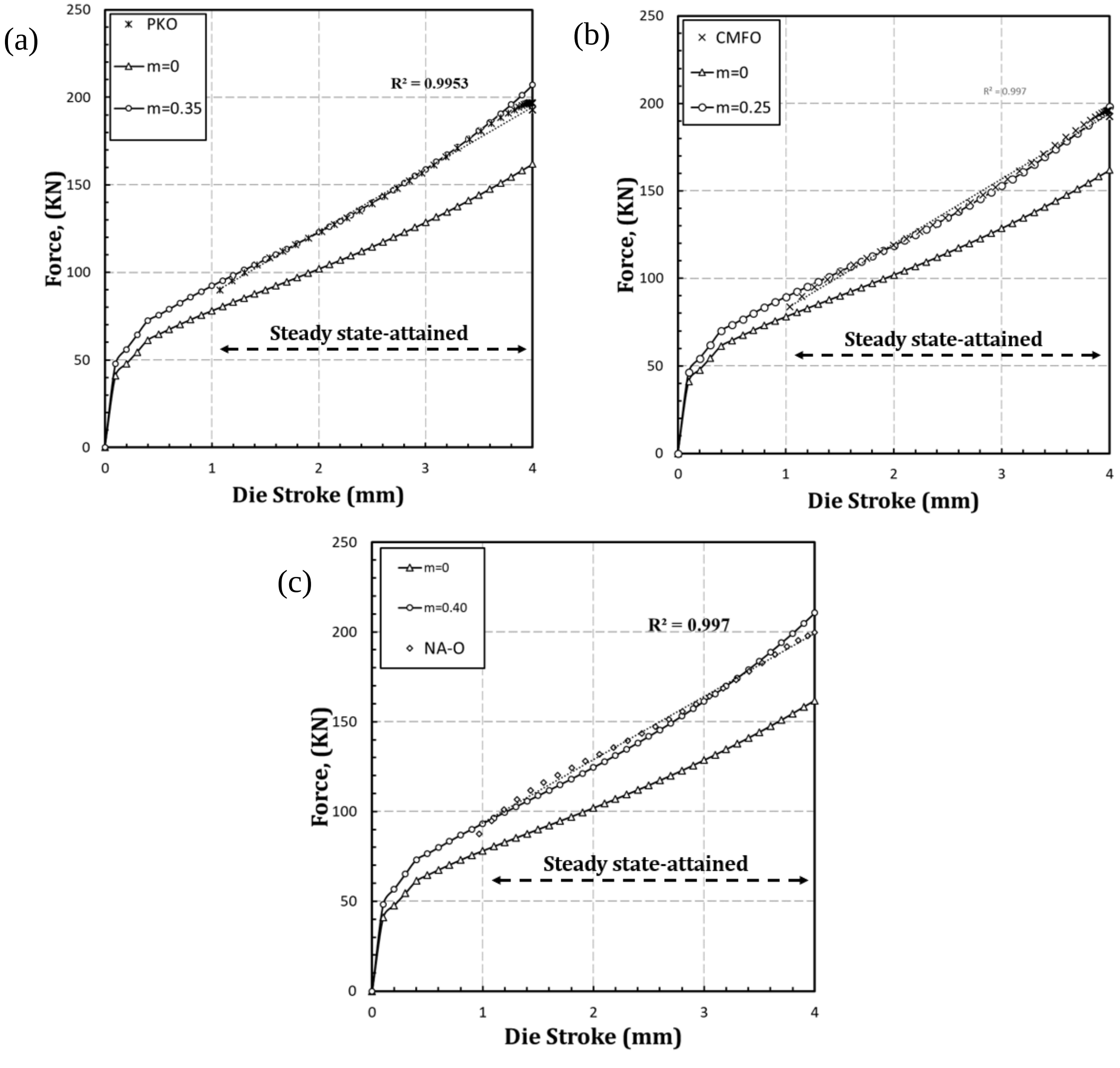

Figure 6: FEM and experimental compression load as a function of stroke with different type of lubricant (a) RBD PKO (b) CMFO(c) Unlubricated (NA-O).

As for viscosity, it has been stated in previous research that palm oil has a constant viscosity that maintains a steady shear rate (Mahdi et al., 2011). But in the case of RBD palm kernel oil, it rapidly decreased. According to Razak et al., (2015) when oil lubrication is taking place, the viscosity of the palm oil has a significant impact of the friction. The approximate density and dynamics of the viscosity were calculated from 25 ºC as shown in Table 1. At 25 ºC the viscosity for RBD palm kernel oil and CMFO is 46.14 and 107.71 $mm^2/s$ respectively. The low viscosity of the RBD palm kernel oil is believe resulted in slightly higher friction and the load under ring compression test.

### 3.2 Surface Roughness and Observation On the Ring

Analysis of surface roughness was carried out using surface profilometer. The detectors were measured the surface roughness level at the surface of the workpiece (ring). The moving distance of the detectors during the measurement was fixed at 5mm for all specimen. Figure 7 show the surface roughness value for all sample at different percentage of formation. It was found from the graph that all lubricants show a similar trend as the percentage of deformation is increase (10%-40%) the surface roughness value also increase.

Both lubricated samples show higher surface roughness compared to the non-lubricated sample measurement of the surface roughness. RBD Palm kernel oil however shows a low value of surface roughness when compare to the CMFO with a different range of 0.01-0.04 µm at 10-20% deformation and increase drastically at 30-40% deformation with 0.08-0.2 µm range different.

From the observation on the normal pressure at 40% deformation, as shown in Figure 8, we can see that RBDPKO has higher value at 79.31kN compare to CMFO that is 74.157kN. And from this finding we can see that the increasing normal pressure on the workpiece has shown a decreasing trend on the surface roughness value. This phenomenon may due to the surface flattening as the normal pressure is higher.

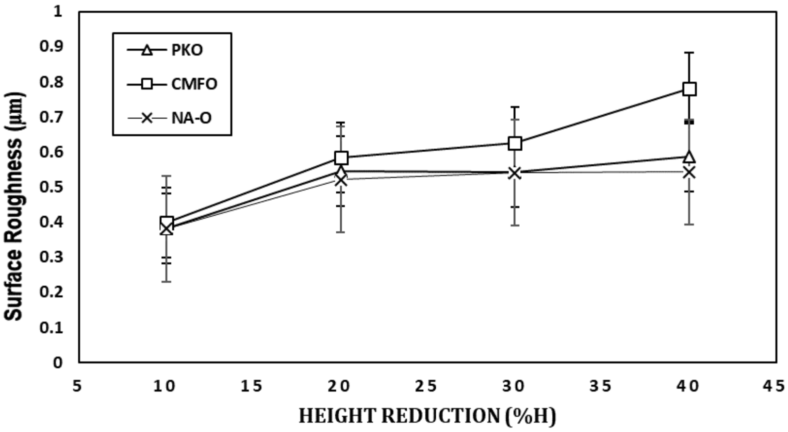

Figure 7: Surface roughness of all sample.

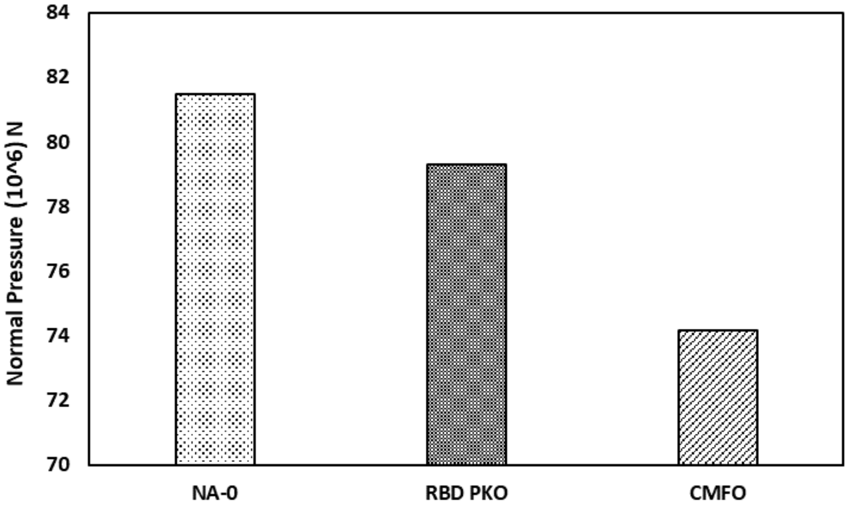

Figure 8: Pressure on the workpiece at 40% deformation.

Figure 9 shows the observation of the ring sample surface at 40% deformation, it can see that the unlubricated sample has different structure compare to the lubricated sample where the line groove structure is still form after the compression. This line grooves form is believed increase the friction during the compression. And after lubricated the surface of the grooves is filled by the oil that function as a friction reducer. The ring expansion caused by oil-filling of the cavity contributes to the neutral point shifting towards the inner side. Although the friction is high at unlubricated lubricant but when compare in terms of surface roughness CMFO has a rougher surface due to the high wear at the ring surface (Aiman & Syahrullail, 2017). the surface observation is correlated to the result of the surface roughness.

## 4.0 CONCLUSION

With a focus on to find the tribological ability of palm stearin in a cold forging test, a study was successfully done with ring compression test using aluminium alloy AA6061 as a workpiece. The result shows that RBD palm kernel oil has successfully reduce the load of the compression from 0.4 to 0.35 in friction but when compare to CMFO, it shows that it has high friction that lead to high compression load. From surface roughness observation, RBD palm kernel oil has a better performance in surface roughness compare to the CMFO. The observation from the ring surface shows that the parallel line grooves on the surface also may lead to the higher friction without lubricant. RBD palm kernel oil however need a modification to the lubricant as it tribological performance is poor compare to the CMFO.

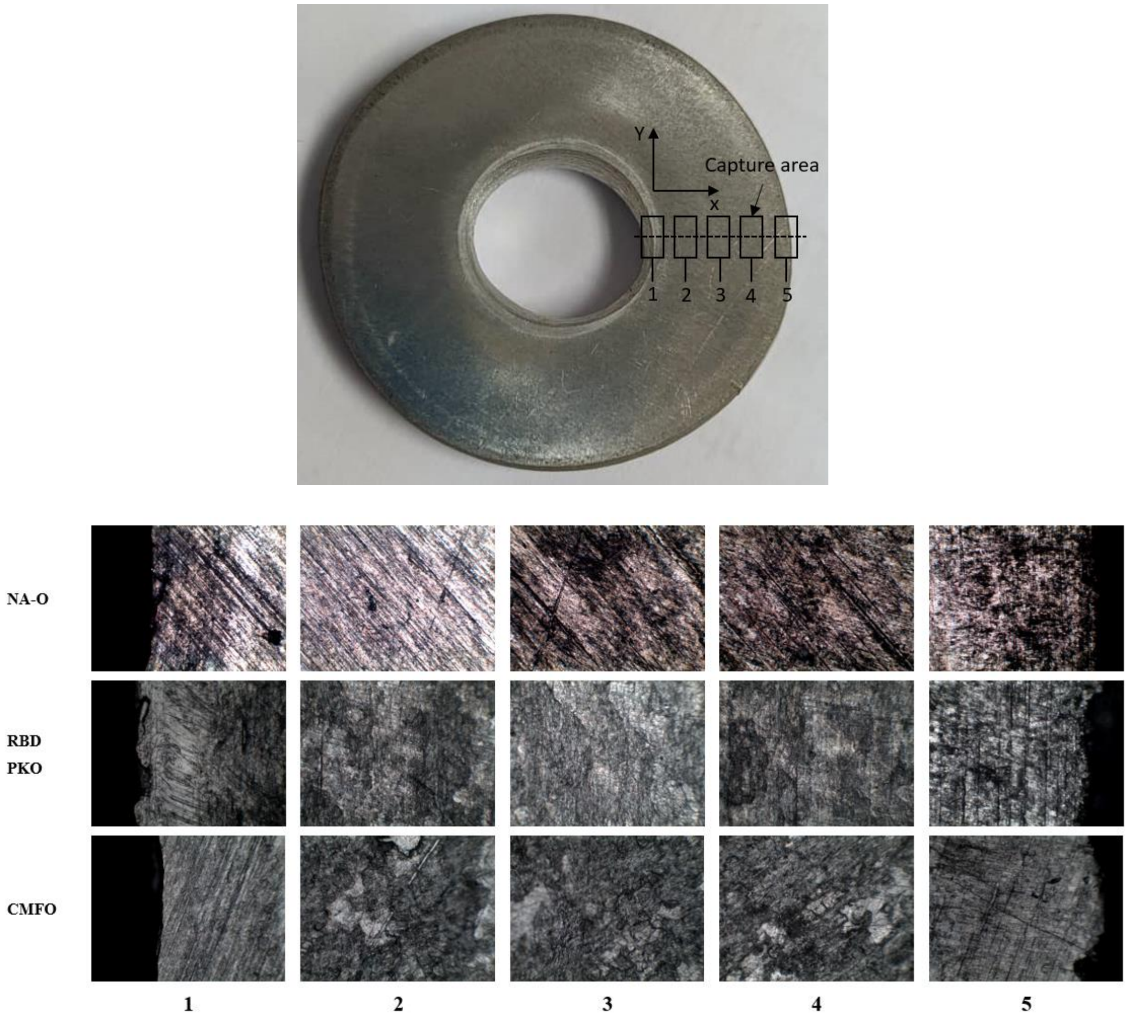

Figure 9: Surface observation at 40% deformation.

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