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# Lubricant viscosity: Evaluation between existing and alternative lubricant in metal forming process

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**Abstract**

Lubrication in metal forming process is very important to control wear and friction at the interface between interacting surfaces. Non-renewable resources, such as mineral oil are widely used since a beginning due to its ability to act as a reservoir to the wearing contact which functions as a film material or sustains chemical transformation to become a film material. There is big concern that an alternative metal forming lubricant with similar viscosity able to replace existing metal forming lubricant without neglecting all main factors as demanded by industries. Two additives free paraffinic mineral oil with variable viscosity; VG95 and VG460 and daphnee were choose as existing lubricants, and is compared to an alternative lubricant with similar viscosity; RBD palm stearin and RBD palm kernel. The experiment used a cold work extrusion apparatus consisting of a pair of taper die and a symmetrical work piece (billet). The billet material was annealed pure aluminum A1100 with 45° of edge at the deformation area. It was found that lubricant with high viscosity performed slightly low extrusion load, but resulting higher surface roughness than low viscosity lubricants. However they show no severe wear on product surface.

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*Keywords:* viscosity; mineral based lubricant; plant based lubricant; extrusion load; surface roughness; sliding velocity

## 1. Introduction

Metal forming refer to a number of metal working processes that deform metal stock to create useful parts. In order to ensure that the finish product being well-manufactured, lubricant is one of most important element to be considered. Lubrication act as an agent to reduce friction and severe wear on contact surfaces [1-7]. The lubricant should wet the metal surface, forming a continuous uniform coating at the contact surfaces. This is important for

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consistent friction control and part quality, as well as corrosion protection of the part [1]. Mineral oils are the most commonly used lubricants throughout industry. They are petroleum based and widely used in applications where temperature requirements are moderate such as to gears, bearings, engines etc. [3,8].

Lubricant properties play a big role to ensure the lubricant stay along the metal forming process. In term of lubricant's viscosity, more viscous lubricant will create thicker layer, less metal-to-metal contact, low friction and lesser wear. It is contradict with less viscous lubricant, where thinner layer will be created, more metal-to-metal contact which will result higher friction and severe wear [9-11].

Over the past century, metal forming lubricants is based on mineral oil. But, the resources depletion becomes a major issue to the industry in order to maintain the mineral oil in the next century, and in the other hand, rise up the environmental problems [4]. By looking it as a global issue, some of the researchers from all over the world have studied a few alternatives to substitute this non-renewable lubricant into renewable lubricants. Vegetable oil is categorized as renewable oil because as long as the trees are planted, the resources will remain.

This study was conducted to study an alternative of metal forming lubricant by considering a few aspects to the extrusion product including extrusion load, surface roughness, sliding velocity and others. Plant based lubricants were choose based on their kinematic viscosity which comparable with existing lubricants. [12] and [13] has mentioned that liquid plant oils appear to be well fit for metal forming because of its stability and palatability. It can also improve the condition of work place, where no toxic exposure as compare with mineral based lubricants. This present work hopefully, would help to promote the application of renewable natural resources as well as to protect the environment.

## 2. Experimentals

Fig. 1 illustrates the experimental set-up of the plain strain extrusion apparatus. The main components are container wall, taper die, and work-piece (billet). This experiment had been done with the laboratory press machine at lab temperature. This plain extrusion apparatus was assembled and placed on the load cell to record the load extrusion (Y-axis) during each test. The displacement of ram stroke (X-axis) also was recorded by using the displacement sensor is attached to the holder of plain extrusion apparatus. Extrusion was stopped at a piston stroke of 35 mm, where the extrusion process is expected in steady state condition. The ram speed is constant at 8.10 mm/s, 8.49 mm/s for RBD palm kernel and RBD palm stearin, while for daphnee, PMO VG95 and PMO VG460, it was constant at 8.28 mm/s, 8.84 mm/s and 8.53 mm/s respectively. During extrusion process, the two similar billets were stacked and used as one unit of billet is fixed on a container and extruded through a pair of taper dies. After the experiment, the partially extruded billets were taken out from the plane extrusion apparatus and surface roughness of the billet with the observation plane was measured and the extrusion load was analyzed.

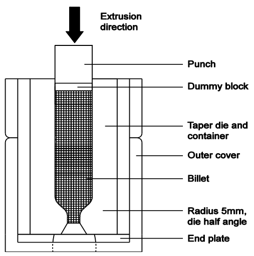


Fig. 1. Schematic diagram of the plane extrusion apparatus

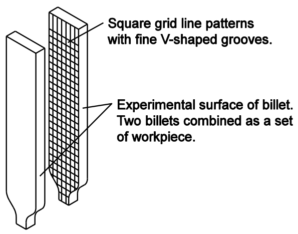


Fig. 2. Schematic diagram for billet used in strain the experimental works.

As shown in Table 1, kinematic viscosities were measured with a rotational viscometer (VCPL 300003, COLE PALMER), over a temperature range of 25–100 °C. While a capillary densimeter, model D3510/H (ZEAL, England), was used to measure sample densities in a lab temperature, 25°C.

### *2.1 Experimental apparatus and procedure*

The taper die has an edge 5 mm at die half-angle and is made from tooled steel (SKD11), with necessary heat treatments were performed before the experiments. The experimental surface of taper dies (surface in contact with the billet) was polished with abrasive paper and has a surface roughness, Ra of approximately 0.15 μm. The polishing process will be repeated for each test to ensure that the result will not be affected by other factors. The Vickers hardness of the taper die was 650 Hv. A specified amount of lubricant was applied to this surface before the experiments. The other surfaces of the experimental apparatus had the same type of test lubricant applied.

Fig. 2 shows a schematic sketch of the billets used in the experiments. The billet material is pure aluminum (A1100). The billets' shapes were formed by an NC wire cut electric discharge machining device. Two similar billets were stacked and used as one unit of billet. One side of the contact surface of the combined billets was the observation plane of plastic flow in plane strain extrusion. The observation plane was not affected by the frictional constraint of the parallel side walls. A square grid pattern measuring the material flow in the extrusion process was scribed by the NC milling machine on the observation plane of the billet. The grid lines were V-shaped grooves with 0.5 mm depth, 0.2 mm width, and 1.0 mm interval length. The billets were annealed before the experiments.

The plane strain extrusion apparatus was assembled and placed on the press machine. The forming load and displacement data were recorded by computer. The experiments were carried out at lab temperature. Extrusion was stopped at piston stroke of 35 mm with speed around 8.0 – 9.0 mm/s. The ram hydraulic pressure is constant at 120 bar. After the experiment, the partially extruded billets were taken out from the plane strain extrusion apparatus and the combined billets were separated for the surface roughness measurement.

*2.2 Lubricants*

The lubricants consist of 2 types of palm oil-based, which are RBD palm kernel and RBD palm stearin. RBD is derived from Refined Bleached Deodorized, which means that oil has gone through a purifying process to dissipate the unnecessary fatty acid and odour. Additive free paraffinic mineral oil, VG95 and VG460 and industrial oil, daphnee will act as the reference lubricant in order to find out the similarity and then, have a big potential to be choose as an alternative metal forming lubricant in the future. One drop of lubricant (approximately 15 mg) was applied on the experimental surface of taper die before the experiment. The initial lubricant amount was predicted to create full film lubrication regime at the early stage of extrusion process.

Table 3.1 Testing Lubricants

| Properties | Kinematic viscosity ($mm^2/s$) | | | Viscosity Index | Density |
|---|---|---|---|---|---|
| | 25c | 40c | 100c | | ($g/cm^3$) |
| Non-renewable | | | | | |
| Daphnee | 107.71 | 42.05 | 11.20 | 273 | 900 |
| PMO VG95 | 249.95 | 71.75 | 13.40 | 192 | 850 |
| PMO VG460 | 1374.60 | 411.25 | 28.10 | 95 | 860 |
| Renewable | | | | | |
| RBD Palm Kernel | 46.14 | 31.32 | 8.00 | 176 | 860 |
| RBD Palm Stearin | 48.29 | 38.01 | 8.56 | 171 | 870 |

***PMO : Paraffinic Mineral Oil*
*RBD : Refined, Bleached and Deodorized*

## 3. Extrusion load

The extrusion load-piston stroke curves are shown in Fig. 3. The extrusion load reached a steady state condition at a 15 mm of piston stroke until 35 mm. PMO VG460 and RBD palm stearin express a nice steady state curves while the other three lubricant, in fluctuated mode. It can be visualize clearly by clustered bar graph (Fig. 4) which exhibit the maximum loads of all tested lubricants. The maximum extrusion load for RBD palm kernel, RBD palm stearin, daphnee, PMO VG95 and PMO VG460 are 77.8 kN, 60.784 kN, 80.535 kN, 60.674 kN and 47.492 kN respectively.

As plotted by previous bar graphs, clearly show that lubricant which higher viscosity are tend to produce lower extrusion load. RBD palm stearin and PMO VG460 has a higher viscosity than the others. The viscosity of lubricant can leads to its ability in reducing friction. Due to that, it will result less friction and less extrusion load during extrusion process. A lesser metal-to-metal contact between billet and taper die resulting less friction and less extrusion load. RBD palm kernel and daphnee seems to have more contact and it proved that when more metal-to-metal contact occurs, the process need more energy to shear the material and make the extrusion load becomes higher [14].

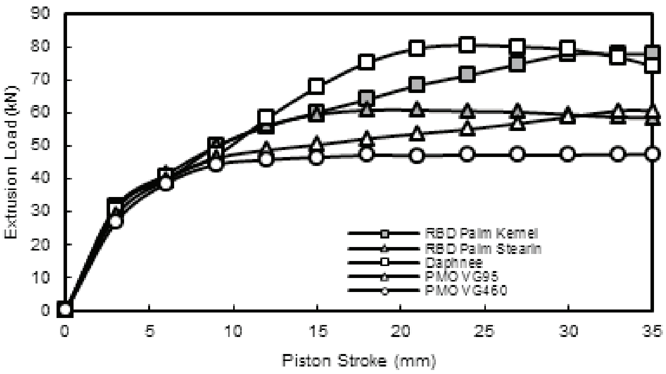


Fig. 3. Extrusion load-piston stroke curves

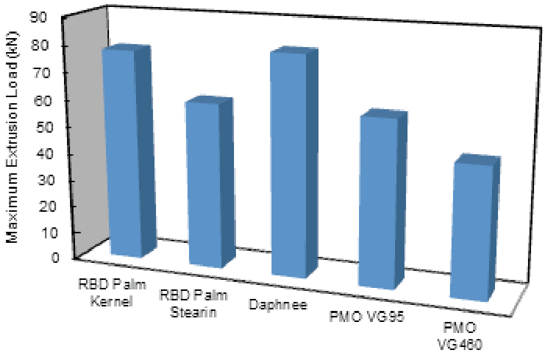


Fig. 4. Maximum extrusion load

## 4. Surface Roughness

The distributions of arithmetic mean surface roughness, Ra along the experimental surface billet (sliding plane) was measured with a surface profiler device. Fig. 5 shows the distribution of Ra in product area.

Along the process, RBD palm stearin's roughness value is higher than other testing lubricants with a different within range 0.10 - 0.30 μm. Physically, RBD palm stearin was the least viscous lubricant and has high possibilities to supply the lubricant until 0 mm. It is differ with RBD palm kernel, daphnee and PMO VG95 where the lubricants tend to stay at the surface of contact area due to their high concentrated physical attributes. The surface roughness values were slightly lower from the beginning of the process towards the end [15]. Nevertheless, the different between each lubricant were obviously small and from the observation by CCD camera as illustrated in Fig. 6, found that no severe wear occurred.

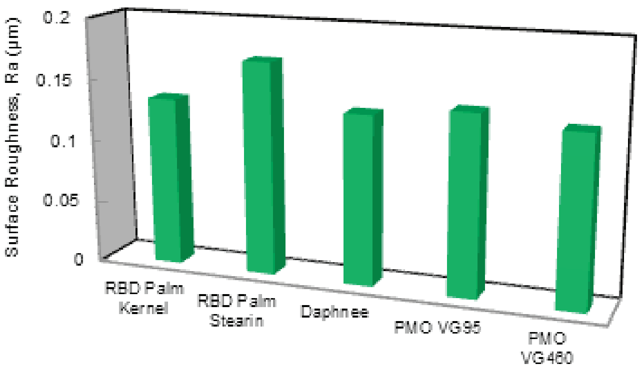


Fig. 5. Arithmetic mean surface roughness distributions, Ra

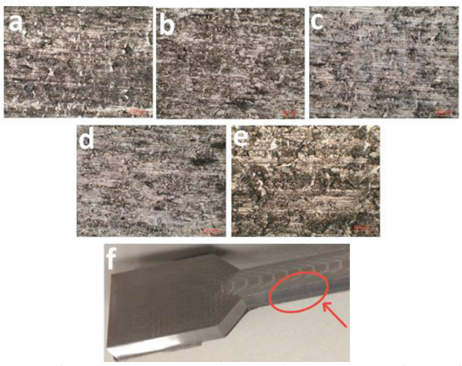


Fig. 6. CCD pictures of sliding plane surface at (a) Daphnee, (b) RBD Palm Kernel, (c) RBD Palm Stearin, (d) PMO VG95 and (e) PMO VG460 of sliding plane surface product area 45

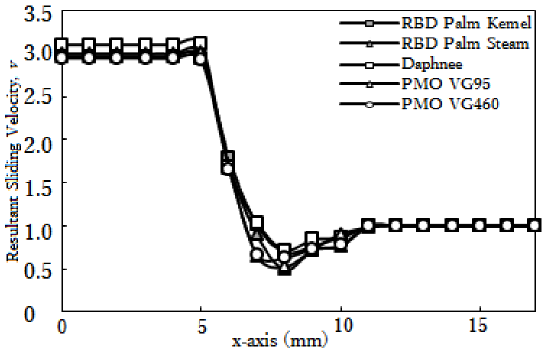


Fig. 7. Resultant sliding velocity of extruded billet

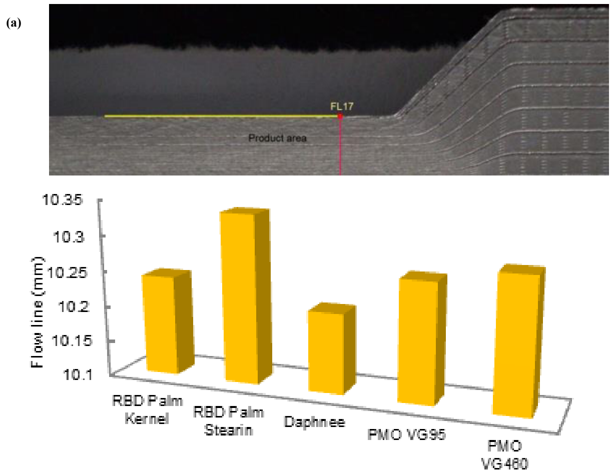


Fig. 8(a). Testing point for flow line observation (FL17);
(b). Flow line observation at product area (FL17)

## 5. Resultant Sliding Velocity

The velocity component of the billets that slides on the taper die's surface was obtained from data tracing and been calculated using visioplasticity method. Lesser load and lesser friction will result high velocity of sliding action. As shown in Fig. 7, RBD palm stearin tends to have higher sliding velocity if compared to RBD palm kernel. From the previous discussion of extrusion load, it is equivalent with this outcome where the extrusion process by using RBD palm stearin as lubricant, requires more velocity to slide during deformation process. It is because less metal-to-metal contact between billet and taper die will lead to low extrusion load usage and low friction effect [16].

## 6. Flow line observation

Fig. 8(a) shows a sliding contact of flow line (namely as FL17) in product area, which was taken to be observed. As plotted by bar graph in Fig. 8(b), clearly show that RBD palm kernel, daphnee and PMO VG95 creates a high friction between tool and the billet surface, resulting smaller flow line deformation as the metal flows to the inner side of the billet. High friction may cause the billet deform more than usual during extrusion process [17]. This force resists the edge of billet from flowing toward extrusion direction. By comparing this finding with surface roughness's result, it proves that lubricants which lesser viscosity has more metal-to-metal contact as the result was among the lowest compared to the other lubricants.

## Conclusions

With a main purpose to find an alternative of mineral based lubricant for metal forming process, a study was successfully done with a cold work plane strain extrusion process on A1100 pure aluminum billet. The result shows that high viscosity of renewable lubricant tends to have similar attributes with recommended non-renewable lubricant in a term of lesser extrusion load and lesser friction condition. With higher viscosity value, RBD palm stearin has low metal-to-metal contact between billet and taper die. Due to that, more sliding velocity needed during the extrusion process. However, there is no obvious different at surface quality from surface roughness findings and observation of the product area surface.

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