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EXPERIMENTAL EVALUATION OF RBD PALM OLEIN AS LUBRICANT IN COLD METAL FORMING

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ABSTRACT

The evaluations of refined, bleached and deodorised (RBD) palm olein as lubricant in cold metal forming by plane strain extrusion were investigated. Billet material was pure aluminum (JIS-A1050). Then, a series of experiments were carried out by applying paraffinic mineral oil and RBD palm olein as test lubricant at 30ºC and 15ºC. The whole experimental and analytical results were compared mutually. Extrusion load and surface roughness of billet were measured after each extrusion experiment. Relative velocity and effective strain were calculated by using visioplasticity method. The result show that the RBD palm olein has lower extrusion load compared to Paraffinic mineral oil. It is confirmed that the lubrication performance of RBD palm olein is as effective as Paraffinic mineral oil in its ability to reduce frictional constraint in a cold metal forming.

Keywords : *Lubricant, extrusion,RBD palm olein, paraffinic mineral oil, relative velocity.*

1.0 INTRODUCTION

Today, vegetable oil is much concerned for its application in a metal forming process as a lubricant because vegetable oil is renewable source and possesses high biodegradability compared to mineral oil. According to the OECD301C testing method, the biodegradability levels of the vegetable oils are more than 60% within 28 days. While, the biodegradability level of the mineral oil is less than 30% within the same period of time [1]. Palm produces 3.66 ton oil for every hectare, which is 7 and 2.5 times more than soybean and rapeseed respectively [2]. Moreover, palm oil has potential to fulfill the supply volume in demand of the vegetable-based lubricants.

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RBD palm olein has a high melting point, which cause crystallization in high temperature. RBD palm olein will be in a liquid form at room temperature of 30ºC. It starts to crystallize at room temperature of 20ºC, where it turns RBD palm olein into semi-solid form. Due to this property, RBD palm olein was questioned for its ability to be used as lubricant in four-season country or in low temperature working condition. In tribological point of view, the physical change from liquid form to semi-solid form may cause differences in viscosity. This could affect the lubrication performance [3].

In this research, investigation were done on the performance of RBD palm olein as a metal forming lubricant at low temperature by carrying out the plane strain extrusion experiments. The plastic flow velocities, strain rate and strain conditions in a deformation zone of extruded material in steady state extrusion were revealed quantitatively by the visioplasticity analyses [4] referring to the flow lines observed by the experiments. The result shows that the ability of RBD palm olein in reducing frictional constraint was excellent in low temperature work condition.

2.0 EXPERIMENTAL PROCEDURE

2.1 Experimental apparatus

The experiments were carried out by plane strain extrusion in which material flow in a steady state extrusion could be measured by the visioplasticity method. The schematic sketch of the experimental apparatus is shown in Figure 1. The main components are taper die and container, plane plate tool and billet (workpiece). The taper die has 45-degree die half angle. The taper die and container is a unit of construction part. The plane plate tool works as the plane plate tool and also as the container wall. Whole extrusion apparatus was made with tool steel, JIS-SKD11, and necessary heat treatment was done. The billet subjects local shearing deformation due to frictional constraint by the tool surface and large bulk shearing deformation when the taper die changes the direction of plastic flow. The latter shearing deformation is most remarkable at the taper die side. While, the billet subjects only the local shearing deformation due to frictional constraint by the tool surface along on the plane plate tool.

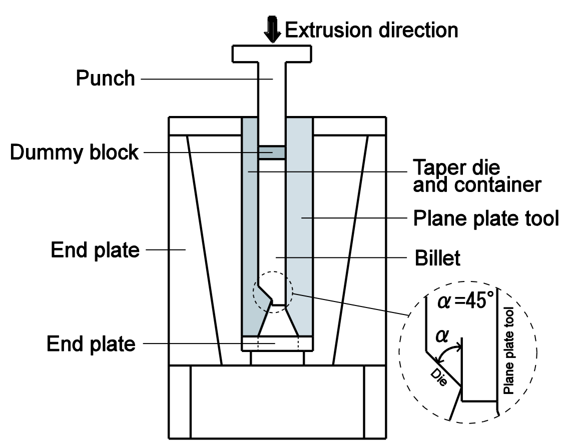


Figure 1: Schematic sketch of the experiment apparatus.

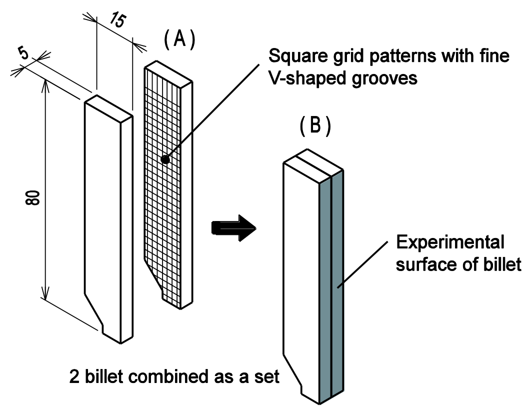


Figure 2: Schematic sketch of the combined billets.

The billets were prepared from rolled of 5 mm aluminum sheets, JIS-1050, by NC wire cut electric discharge machining device. The leading edges of the billets were shaped to fit tool cavity of the extrusion apparatus in order to achieve the steady state extrusion condition in short punch stroke. Two similar billets were combined to one unit, and used as a billet in the experiments as depicted in Figure 2. Meanwhile, one side of the contact surfaces of the combined billets was the observation plane of plastic flow in plane strain extrusion, which was not affected by the frictional constraint by the parallel sidewalls. A square grid line pattern was scribed on one side of the billet; i.e., the observation plane of the plastic flow of the billet. The grid lines were the V-shaped grooves with 0.5 mm deep and 0.2 mm wide and those grid lines were machined with 1mm spacing on the observation plane of plastic flow by using the NC milling machine. The billets prepared by the above procedure were annealed by furnace cooling after heated 2 hours at 350ºC, so that the rolling texture was annihilated and the recrystallized structure with isotropic mechanical properties could be established. Table 1 shows specifications of the billets and tools; i.e., the materials, the Vickers hardness of the billets and tools after the heat treatment, and the surface roughness, measured along on the direction perpendicular to the extrusion direction, on the contact surface.

Table 1: Specifications of billets and tools.

Items	**Billet**	**Taper die**	**Plane plate tool**
Material	JIS-A1050	SKD11	SKD11
Vickers hardness	21HV	690HV	690HV
Surface roughness (Ra)	0.3μm	1μm	0.05μm

2.2 Testing lubricants

The lubricants used in the present experiments are RBD palm olein and additive free paraffinic mineral oil, VG7. Test lubricant was applied on the surface of plane plate tool that has a contact with billets and was noted as the experimental surface of plane plate tool. Some specifications of the test lubricants and quantities of application in the tests are listed in Table 2. RBD palm olein at both the liquid state and the solid state were used in the present experiments. Photographs of RBD palm olein in liquid at 30ºC and solid state at 15ºC are depicted in Figure 3.

Table 2: Specification of testing lubricating oil.

Lubricants	**RBD palm olein**	**Paraffinic mineral oil, VG7**
Viscosity at 30ºC, mm^2/s	45	13
Specific gravity	0.908	0.884
Flash point, ºC	-	138
Pour point, ºC	Max 24	-20
Free fatty acid	Max 0.1%	-
Iodine number	Min 56	-
Quantity of application	5 mg	5 mg

RBD palm olein at 30ºC

RBD palm olein at 15ºC

Figure 3: Pictures of RBD palm olein at 30ºC and 15ºC.

A specific amount of additive free Paraffinic mineral oil VG460 was applied on the surfaces of the smooth sidewall tools so that the plastic deformation of the billet will be little along the thickness direction and plane strain condition could be achieved. A specific amount of additive free Paraffinic mineral oil VG460 was also applied on the surface of the taper die which squeezed the billet in the extrusion process.

2.3 Experimental procedure

The plane strain extrusion apparatus was assembled into the confinement fixture (outer case in Figure 1), and positioned on the bolster of a hydraulic press machine. The extrusion experiments using RBD palm olein and paraffinic mineral oil were carried out at the room temperatures of 30ºC and 15ºC. Extrusion experiments at 30ºC were done during summer season and extrusion experiments at 15ºC were done during winter season. All the experimental works were conducted in Japan.

Extrusion was stopped at a punch stroke in the steady state extrusion condition where the extrusion load and the extrusion speed were maintained at constant values. Then, partially extruded billets were taken out from the extrusion apparatus and the combined billets were separated. The absence of protrusion on the surface of sidewall tool was examined after each extrusion experiment, so that smooth surface conditions will be maintained on the sidewalls during the extrusion. After each experiment, there was no mixing of the applied lubricants between the experimental surface and other surfaces of the billet were confirmed by observation. The parallel lines to the direction of extrusion in grid lines on the observation plane of plastic flow of a billet became curved lines and represent the plastic flow lines in the steady state extrusion condition.

2.4 Experimental analysis

Figure 4 depicts schematic diagram of the x-y orthogonal coordinates system used in the analyses of the deformation condition. Some variables used in the analyses are shown in the figure. The plastic flow velocity, strain rate components, effective strain rate, and effective strain in the deformation zone were calculated by using the equations, (1) to (5). Since the analytical calculation procedure was explained in the earlier publications [5], it is omitted here.

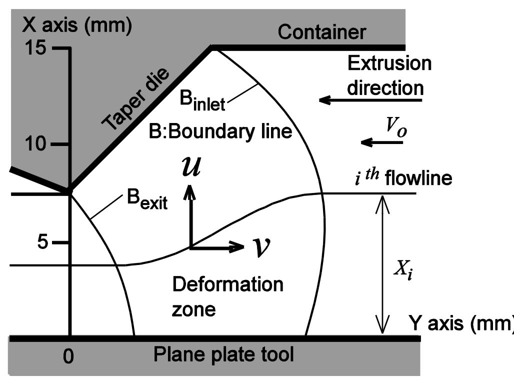


Figure 4: Coordinate system used in visioplasticity analyses.

Flow function

$$\psi_i = X_i |V_0| \tag{1}$$

Velocity component (velocity in x-direction: *u*, velocity in y-direction: *v*)

$$u = \frac{\partial \psi}{\partial Y}, \quad v = -\frac{\partial \psi}{\partial X} \tag{2}$$

The strain rate component (s^{-1})

$$\dot{\varepsilon}_X = \frac{\partial u}{\partial X}, \quad \dot{\varepsilon}_Y = \frac{\partial v}{\partial Y}, \quad \dot{\gamma}_{XY} = \frac{\partial u}{\partial Y} + \frac{\partial v}{\partial X} \tag{3}$$

The effective strain rate (s^{-1})

$$\dot{\varepsilon} = \frac{2}{3}\sqrt{3\dot{\varepsilon}_X^2 + \frac{3}{4}\dot{\gamma}_{XY}^2} \tag{4}$$

The effective strain (time integration value of the effective strain rate along the flow line)

$$\varepsilon = \int \dot{\varepsilon}\, dt \tag{5}$$

In the equations, V_0 is the velocity of the press ram in mm/s, and X_i is the distance of the i-th flow line from the y coordinate axis (X=0), in mm, in the region where deformation does not occur.

3.0 RESULTS AND DISCUSSION

3.1 Extrusion load

The extrusion load-punch stroke curves are shown in Figure 5. Extrusion temperatures were 30ºC in Figure 5(a) and 15ºC in Figure 5(b). The notation P1 shows that those results were obtained when Paraffinic mineral oil VG7 was applied as test lubricant on the experimental surface of plane plate tool. While, PO shows that those results were obtained when RBD palm olein was applied as test lubricant on the particular surface. The steady state extrusion condition starts around the punch stroke, Y = 20 mm, in the extrusion applied with two lubricants above. The experimental results at 30ºC; i.e. Figure 5(a) shows that the steady state extrusion load in extrusion applied with RBD palm olein as test lubricant is lower than that in extrusion applied with paraffin mineral oil VG7 as test lubricant. This is due to the fact that the fatty acids in the palm oil reduce the frictional constraint. Additional reason can be considered as below.

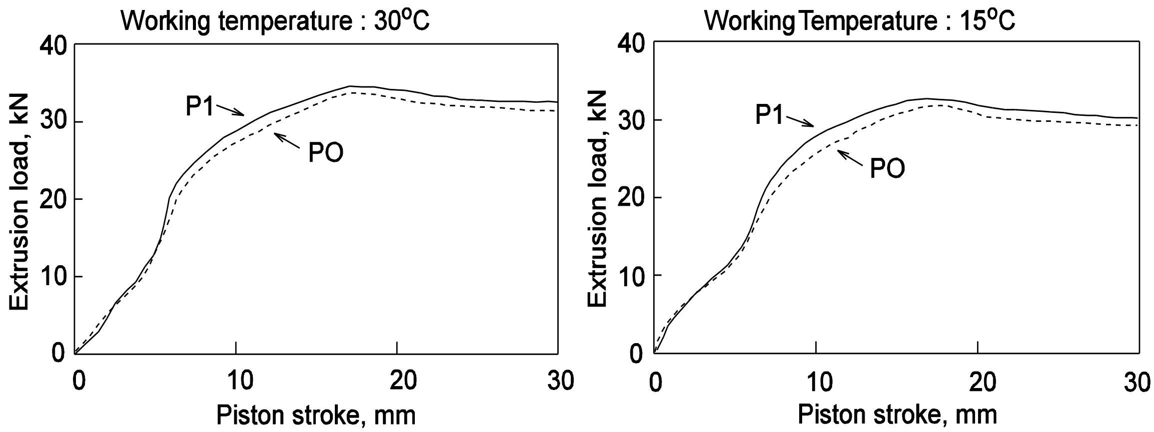
The roughness of the experimental surface of an extruded billet at Y=0 mm in the product area was almost equal to the surface roughness (Ra = 0.05µm) of experimental surface of plane plate tool before the experiments, as depicted in Figure 6. Then, the lubrication condition between billet and tool surfaces was predicted as mixed lubrication condition with a thin lubricant film or boundary lubrication, and adsorption of fatty acids from the palm oil plays the role of maintaining the thin lubricant film [6].

The experimental result at 15ºC; i.e. Figure 5(b) shows that steady state extrusion load in extrusion applied with RBD palm olein as test lubricant is lower than that in extrusion applied with paraffin mineral oil VG7 as test lubricant. RBD palm olein was in solid state at 15ºC, and thick lubricant layer between tool and workpiece surface should be considered. Then, the direct contact area and frictional constraint between billet and tool surfaces could be reduced, and extrusion load in extrusion applied with RBD palm olein as test lubricant was reduced. Decrement percentage of extrusion load in the steady state condition in extrusion applied with RBD palm olein as test lubricant in comparison to that value in extrusion applied with paraffin mineral oil VG7 as test lubricant was calculated by an equation (6).

$$\Delta L = \frac{L_{P1} - L_{PO}}{L_{P1}} \times 100\% \tag{6}$$

L_{P1} = Steady state extrusion load for P1
L_{PO} = Steady state extrusion load for PO

The results show that ΔL is 3.8% in working temperature 30ºC and 3.0% in working temperature 15ºC. This reduction percentage was also confirmed with previous researches [7, 8]. The different of extrusion load of test lubricant at 30ºC and 15ºC was occurred due to the changes of the viscosity of the test lubricant.



(a) (b)

Figure 5: Extrusion load – piston stroke curves.

3.2 Surface roughness

The arithmetic mean surface roughness (Ra) was measured along the perpendicular direction to the extrusion direction at product side (Y = -6 mm to 2 mm) of workpiece. The results are depicted in Figure 6. The solid line shows the range between the maximum and minimum values of Ra and the open circle shows the most frequent value of Ra. It is confirmed that surface roughness of the extruded product applied with RBD palm olein as test lubricant has a resemble characters with the applied paraffin mineral oil VG7 but possess a high possibility of being coarse at 15ºC. The photographs of experimental surface of billet were taken around Y = 0 mm are shown in Figure 7. It is seen that the experimental surface of billet became coarser when lubricant's viscosity increased due to low work temperature. Surface condition measured in extrusion at working temperature 15ºC of applied RBD palm olein as test lubricant is the coarsest.

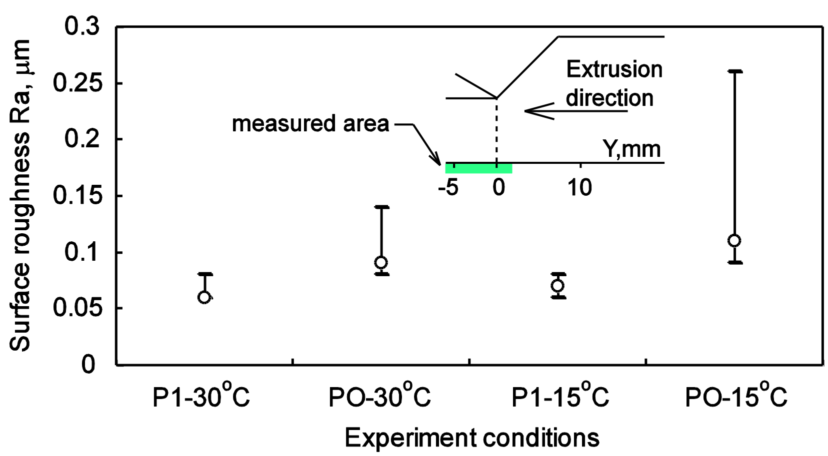


Figure 6: Average value of surface roughness Ra at product side.

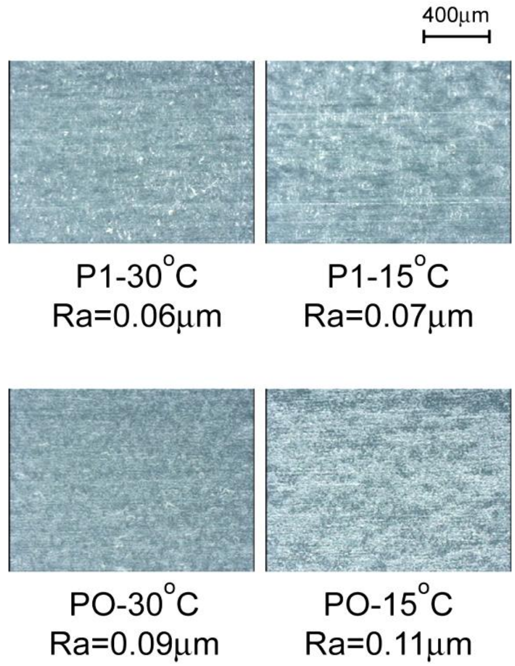


Figure 7: Photographs of experimental surface of billets at Y = 0 mm.

3.3 Deformation characteristic

Figure 8 shows that the flow lines observed around the experimental surface of billet in steady state extrusion applied with RBD palm olein or Paraffinic mineral oil VG7 as test lubricant at both working temperatures. The observation area was chosen because the difference of frictional constraint by the experimental surface of plane plate tool with regard to the applied lubricant could be detected clearly. It is confirmed that frictional constraint on the experimental surface of plane plate tool is lower in extrusion applied with RBD palm olein as lubricant in comparison to the one applied with Paraffinic mineral oil VG7. The above characteristics can be observed clearly at working temperature of 15ºC in which thick lubricant layer is created by RBD palm olein at solid state.

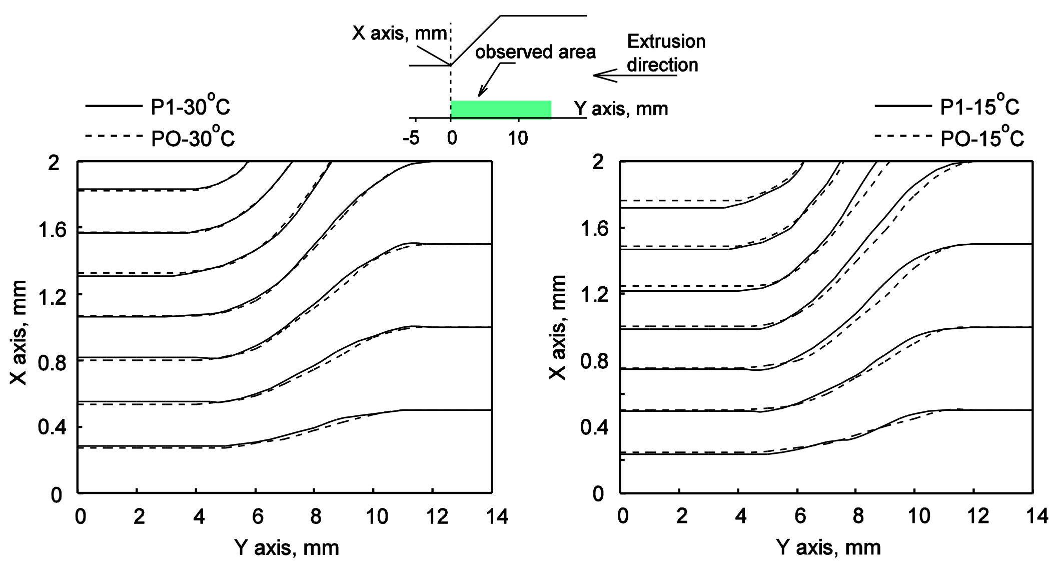


Figure 8: Comparisons of flowlines near the experimental surface of billets.

Figure 9 shows the contour maps of relative velocity (speed) and Figure 10 shows the effective strain in deformation zone in extrusion applied with RBD palm olein or Paraffinic mineral oil VG7 as lubricant at working temperatures of 30ºC and 15ºC. The definition of relative velocity is given in equation (7). It is confirmed that the relative velocity (speed) and effective strain contours show similar patterns depicting that RBD palm olein has equivalent performance of lubrication with Paraffinic mineral oil VG7.

$$\text{Relative velocity, } V_R = \sqrt{u^2 + v^2} \tag{7}$$

u = Velocity component of y – axis

v = Velocity component of x - axis

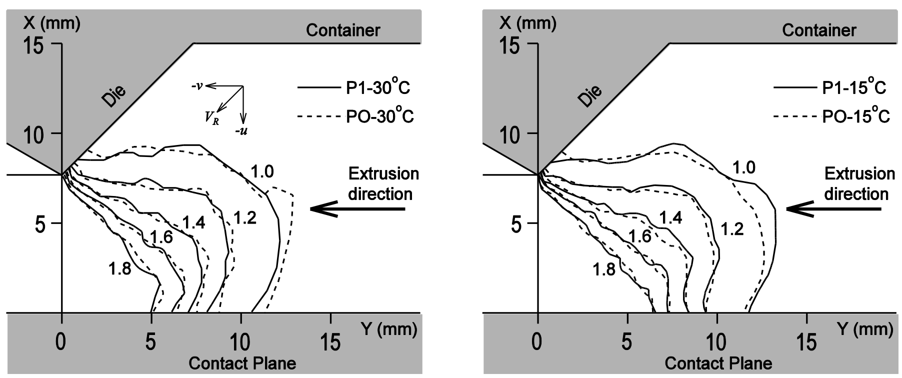


Figure 9: Comparisons of relative velocity distribution in the deformation zone.

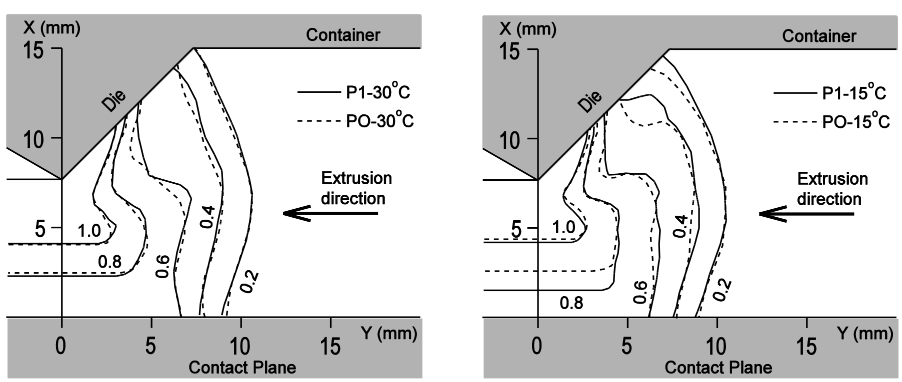


Figure 10: Comparisons of effective strain distribution in the deformation zone.

4.0 CONCLUSIONS

The performances of RBD palm olein as lubricant in cold metal forming were investigated by the plane strain extrusion experiments at working temperatures of 30ºC and 15ºC. The performances were evaluated by mutual comparison of the results obtained by experiments both applied with RBD palm olein and Paraffinic mineral oil VG7. The experiments were carried out by using the plane strain extrusion apparatus equipped the flat contact surface; i.e., the experimental surface of plane plate tool. The results and analyses can be summarized as follows;

i. RBD palm olein lubricant could reduce the extrusion load up to 3.8% at both working temperature of 30ºC and 15ºC, in comparison to Paraffinic mineral oil VG7 lubricant. These experiments confirm that RBD palm olein could work as cold metal forming lubricant and its transformation to solid condition due to its high melting point does not affect the performances.
ii. Surface of the extruded billet in steady state extrusion applied with RBD palm olein as lubricant was in a similar condition with the one applied with Paraffinic mineral oil VG7 as lubricant at working temperature of 30ºC. However, RBD palm olein has possibility to create thick lubricant layer between tool and workpiece, and cause the surface roughness of extruded billet to become even coarser at working temperature of 15ºC.
iii. Observations of flow lines of billet at around the experimental surface show that RBD palm olein creates better flow condition.
iv. Overall observations of relative velocity and effective strain distribution in the deformation zone of billets show that RBD palm olein works as effective as Paraffinic mineral oil in its ability to reduce frictional constraint in cold metal forming.

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