

# An Experimental Investigation of Palm Pressed Fibre Waste as Lubricant in Strip Drawing

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## Article history

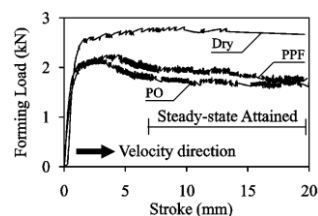
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## Graphical abstract



## Abstract

The abundance of palm pressed fibre (PPF) biomass waste generates greenhouse gases. Therefore, an experimental study on catalytic pyrolysis technology using a tubular reactor on PPF oil was performed at temperature of 450 °C, which gave oil product yields of 44.1 percent. Viscosity of the PPF oil as a function of temperature was measured at different temperatures ranging from 25 °C to 50 °C. The viscosity of the oils was shown to decrease with increases in temperature. Finally, PPF oil was tested as lubricant in strip drawing and compared with palm olein (PO). A comparison of strip drawn aluminium samples show that the lubrication performance of PPF oil varies with PO in a remarkably similar way.

**Keywords:** Lubrication oil; strip drawing; pyrolysis; palm pressed fibre

## Abstrak

Lebih biomas daripada fiber perahan sawit menghasilkan gas yang memberi kesan kepada rumah-hijau. Dengan itu, kajian eksperimen tentang teknologi 'catalytic' pirolisis menggunakan rector tubular ke atas fiber perahan sawit dijalankan pada suhu 450°C, telah menghasilkan minyak sebanyak 44.1 peratusan penghasilan. Kelikatan minyak fiber perahan sawit dengan perubahan suhu diukur dengan suhu yang berbeza dari 25°C hingga 50°C. Kelikatan minyak menunjukkan penurunan terhadap pertambahan suhu. Akhir sekali, minyak fiber perahan sawit diuji sebagai pelincir dalam strip drawing dan dibandingkan dengan sawit olein. Perbandingan sampel strip drawn aluminium menunjukkan prestasi pelincir fiber perahan sawit berubah dengan sawit olein dengan corak yang lebih kurang sama.

**Kata kunci:** Minyak pelincir, strip drawing, pirolisis, fiber perahan sawit

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## 1.0 INTRODUCTION

Palm pressed fibre (PPF) is a by-product produced by palm oil mills after screw-pressing of palm fruits during production of CPO. The PPF generated is normally burnt as solid fuel to supply steam and electricity required for the operation of the mill [1]. It is said that the PPF oil is a high valued product compared to CPO; therefore, this could increase greatly revenue of existing palm oil processing mills. In Malaysia, the annual production of PPF and empty bunches as waste materials amounts to approximately 8 million metric tons [2]. Since Malaysia produces an abundant supply of the PPF and empty bunches which are regarded as wastes and have not been utilised satisfactorily, every opportunity for the reuse of such waste materials either for the purpose of lubrication in metal forming processes is a benefit to the environment as well as to society.

Industrial and automotive lubricants have a significant market of 2.4 billion gallons per year [3]. Vegetable oils currently provide only about 0.1 percent of lubricant supply. It has been estimated that around 12 million ton of lubricant wastes are released into the environmental every year [4]. An alternative to replace the usage of mineral oil as lubricant is important to reduce and eventually put a stop to wastage of natural resources. Saving the world and saving the earth's resources is everyone's responsibility. Due to strict environmental regulations and a concern for depletion of world fossil fuel reserves, there is an increasing demand for environmentally friendly lubricants [5]. In this sense, vegetable oil-based lubricants are being actively demanded for many green industrial activities [6].

Lubricant is used in large amounts in the prime industries of Malaysia. It is used in the automotive industries, metal forming industries, food industries, and semiconductor industries, just to

name a few. Most of the lubricants used are mineral-based oils. Mineral-based oil not only is nonrenewable because of highly depleted sources, it is harmful to the environment because of high toxicity and it is not biodegradable in nature. There have been reported cases of possible contamination of food-related products with hydraulic oil in the past. In older factories, leakage of lubricant is inevitable. Therefore, people are starting to think about replacing mineral-based oil with food grade oil as lubricant.

Among readily available source of food grade oil in Malaysia is palm oil. However, utilizing palm oil as lubricant is not practical because it is consumed heavily in food industries. Although palm oil is a vegetable oil which has a high production rate and can satisfy the demand for vegetable-based lubricating oil in the future [7], high usage of palm oil as lubricant will increase commodity price and thus affecting food product which is needed to be kept low. Therefore, this study is expected to uncover PPF oil's potential as an alternative lubricant in order to replace palm oil as a metal forming lubricant. This paper focuses on utilizing PPF waste in catalytic pyrolysis technology using a tubular reactor first and then, the obtained PPF oil was tested in strip drawing. In order to evaluate lubrication performance of PPF oil, measurements of forming load, friction, surface roughness, and surface finish during and after the deformation process were analyzed and compared with palm olein (PO).

## 2.0 EXPERIMENTAL METHODS

### 2.1 Pyrolysis Experiment

The pyrolysis process was performed in accordance to established experimental procedure [8] for the determination of highest oil yield (see Figure 1). Biomass PPF was obtained from palm oil mill North Star Palm Oil Mills which is located in Kuala Ketil, Kedah and dried in an oven for 5 hours at 40 °C. Then it was shredded using a shredding machine and sieved using a Retsch sieve shaker machine. The biomass particle size of interest is in the range of 250-500 µm. It was then stored in airtight container for further use. The pyrolysis process on the biomass was done by using a fixed bed reactor. The major component of the reactor system included a vertical fixed bed reactor tube, furnace, gas cylinder (N<sub>2</sub>), condenser, and thermocouple to monitor reaction temperature and a cooling circulation unit. The reactor was connected to a computer for the data logging using Shimaden Lite programmable controller. The biomass was placed inside the reactor tube, which was a hollow stainless steel tube. The computer was used to control the system with manipulation of pertinent parameters such as the temperature and holding time in the system.

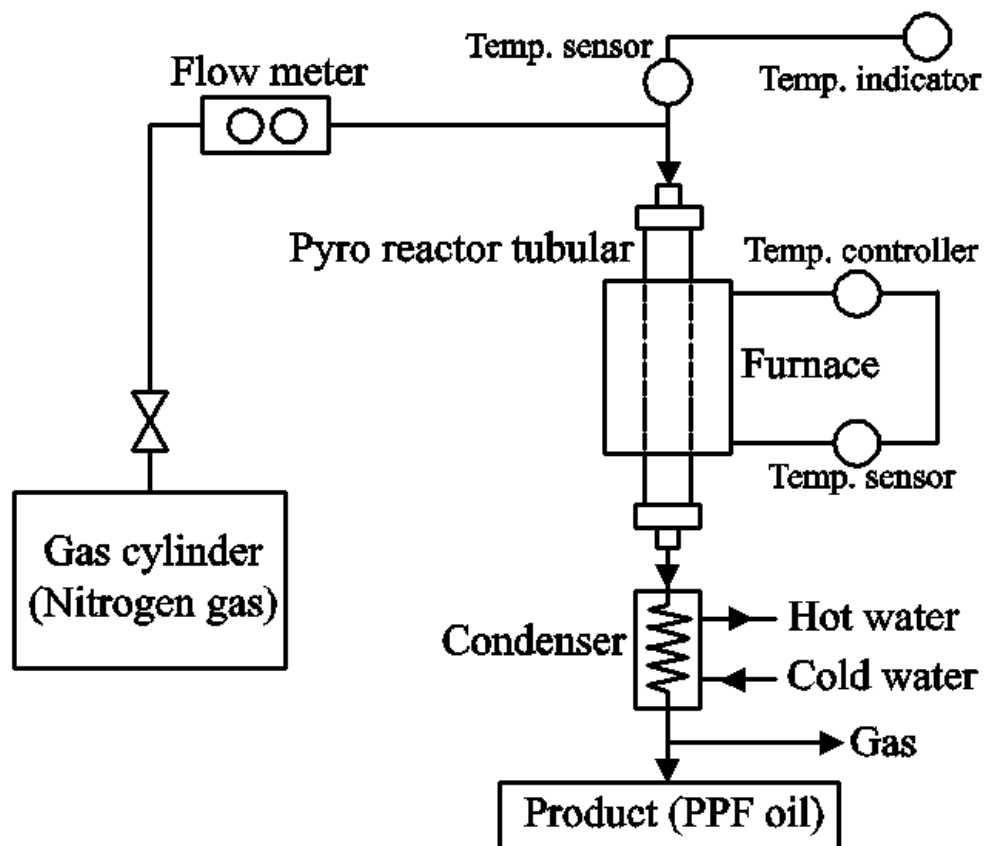


Figure 1 Schematic diagram of pyrolysis technology using a tubular reactor [8]

For each pyrolysis run, 20 g of pretreated biomass was used. The biomass was packed in the reactor tube. The reactor tube was placed in the furnace for catalytic testing. The analysis began when the pyrolysis temperature was set at 450 °C, at ramp rate of 50 °C/min. The nitrogen pressure was purged for 30 minutes at 2 bars with a flow rate of 100 cc/min. The

function of nitrogen gas was to ensure the absence of oxygen in the reactor as well as a sweeping gas. The temperature of the furnace was increased accordingly upon ignition while the temperature inside the reactor was measured by a thermocouple. After the set temperature reached 450 °C, the temperature was maintained according to the studied holding time. The products

were obtained after the holding process had completed. The experiment took approximately one hour to complete.

Each pyrolysis experiment run yielded PPF oil of about 7 to 8 g. The production of char and liquid obtained during the pyrolysis reaction were determined on weight basis according to Equation 1 and Equation 2. Viscosity test was conducted on PPF oil with the measurement of 16 mL required for each viscosity test run using Brookfield viscometer. The viscosity was measured at different temperature, ranging from 25 °C up to 50 °C with the increment of 5 °C at one time. Viscosity as a function of temperature was recorded at every 10 s and graphical data plotted by computer software.

$$\text{Char Yield} = \frac{\text{Mass of Char (g)}}{\text{Mass of PPF (g)}} \times 100\% \quad (1)$$

$$\text{Oil Yield} = \frac{\text{Mass of oil (g)}}{\text{Mass of PPF (g)}} \times 100\% \quad (2)$$

## 2.2 Strip Drawing Experiment

The present investigation was based on previous experimental procedures [9, 10] for the evaluation of lubricant in aluminium strip drawing (see Figure 2) at room temperature. In this study, the experimental material was commercial pure aluminium A1100. The tool die used in the experiment was hot work hardened tool steel SKD11. The reference lubricant used to compare with the PPF oil was Palm Olein (PO). The PO properties are described in details in Table 1 [11]. The general material properties of aluminium A1100 and SKD 11 such as mass density  $\rho$ , elastic modulus  $E$ , and Poisson's ratio  $\nu$ , are shown in Table 2. In the cold work drawing experiment, the aluminium A1100 workpiece was drawn through a tool die exit angle at room temperature. The SKD11 tool dies with wedge angle  $\theta$  of 45° were used during investigation.

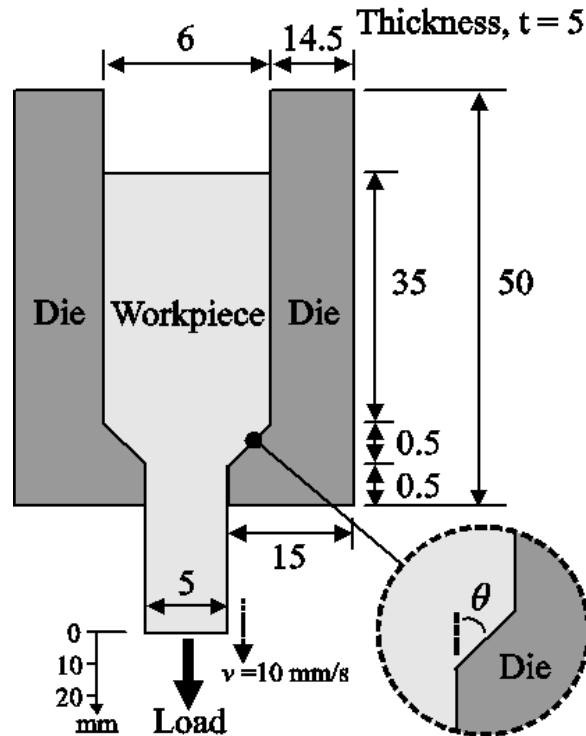


Figure 2 Schematic of cold aluminium strip drawing (all dimensions in mm)

Table 1 Lubricant properties of palm olein (PO) [11]

Properties	Value
Specific density 25 °C	0.873
Dynamic viscosity at 40 °C (mPa.s)	38.9
Dynamic viscosity at 100 °C (mPa.s)	5.3

Table 2 Material properties of aluminium A1100 and tool steel SKD11

Properties	A1100	SKD11
Density $\rho$ (kg/m <sup>3</sup> )	2700	8030
Young's modulus $E$ (GPa)	69.97	210
Poisson's ratio $\nu$	0.33	0.3

The cold work strip drawn rig was designed in accordance to the appropriate criteria for the evaluation of load-displacement behaviour for cold work drawing process. The principal material of aluminium A1100 workpiece with 5 mm thick  $t$  sheet with tolerance 0.05 mm was shaped using a NC wire cut electric discharge machining device. The workpiece was heated for 3 hours at 350 °C to adjust the chemical composition of the workpiece, annihilate rolling texture and establish a recrystallised structure with isotropic mechanical properties. The preparation of die used the same method as well. The die was hardened for 10 hours at 950 °C and then, quenched into water to improve wear resistance and reduce friction.

Figure 3 shows friction measurements are presented for a range of conditions, including changes in lubricant, strip

reduction and strip roughness. Measurement of friction coefficient on the contact sliding surface, particularly at 45° tool die reduction area, in strip drawing are given by Equation 3 [12]. The strip is assumed elastic-perfectly plastic and the relationship obtained in Equation 3 is used to derive the friction coefficient from the measured pull and indentation forces through the tapered die reduction angle  $\theta$  of 45°. The measurement of initial roughness of aluminium strip is 1.785  $\mu\text{m}$ .

$$\frac{F}{N} = \frac{2(\mu + \tan \theta)}{1 - \mu \tan \theta} \quad (3)$$

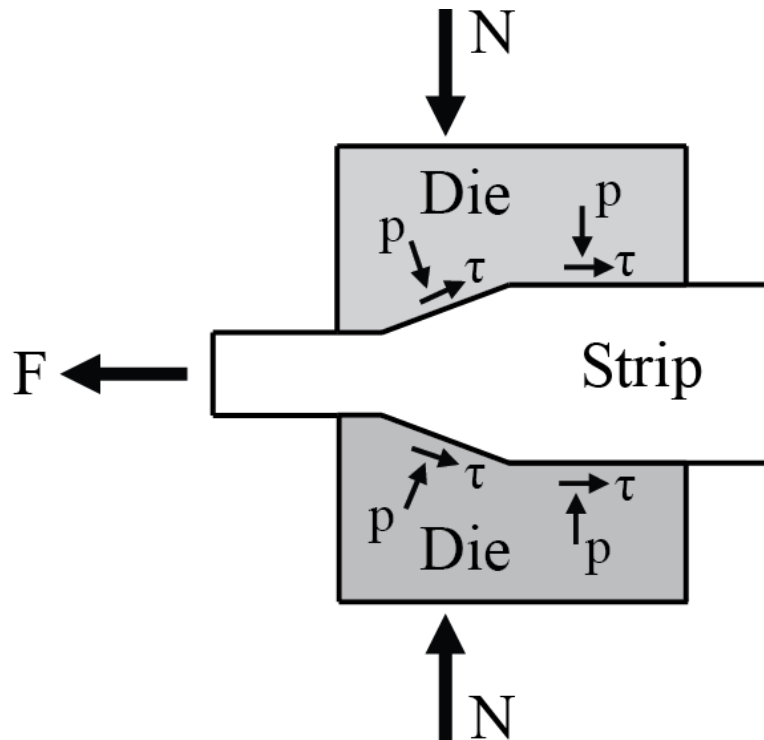


Figure 3 The mechanics of cold aluminium strip drawing

For each specimen in the experiment, the surface of SKD11 tool dies that was in contact with the aluminium workpiece was cleaned and polished with abrasive paper and acetone to ensure that all components were clean and in good condition. The outer wall, tool dies, and aluminium strip were cleaned with acetone to remove oil, grease, and other surface contaminants. Lubricant was painted generously over the tool die plane. The lubricated dies were carefully and symmetrically positioned in the die holder. The hydraulic press machine moved the workpiece downward to produce drawn product. Load cell recorded forming load as a function of displacement in time behaviour and displayed the load data in a computer software. The load readings were recorded for every 0.01 s downward movement of the end tip of workpiece. Finally, once the workpiece movement was stopped at 20 mm downward, the dies were disassembled and the split dies were opened to remove the drawn strip. The load-displacement graph was plotted for the test lubricant. The whole procedure was repeated with other lubricant conditions on the tool die-workpiece contact surfaces. This procedure was adopted to simulate the

industrial situation where, although stable transfer films generally develop on the drawing, they are rather thin and do not significantly affect the roughness of the tool die-workpiece surface [10].

### 3.0 RESULTS AND DISCUSSION

In order to investigate the effect on the composition of PPF, the product distributions were analyzed. Figure 4 shows the various products yield (oil, char and gaseous) from subjecting PPF at temperature of 450 °C. The results in Figure 4 show that with the right temperature set during pyrolysis process, the PPF oil product yields are relatively high values. In this study, temperature of 450 °C was used in order to produce high percentage of PPF oil products. Figure 5 shows viscosity test was carried out at increasing temperature ranging from 25 °C and 50 °C. Viscosity of the PPF oil was measured within 24 hours and after 24 hours prior to the production of PPF oil. We observed that the reaction of the PPF oil caused by temperature

has reduced the viscosity of the PPF oils as the temperature increased regardless of the measurement within and after 24 hours prior to the PPF oil product yield. The PPF oil from biomass pyrolysis process composed of a mixture of aqueous phase and non-aqueous or organic phase. The aqueous phase contains light oxygenated compounds such as phenols, furans, alcohols, acids, ethers, aldehydes and ketones [13]. The non-aqueous phase or organic phase has high molecular weight aromatic organic compounds [14]. The PPF oil is actually

resulted from a series of complex chemical reactions occurring during biomass pyrolysis such as oxidation, hydrolysis, water and carbon dioxide expulsion reactions like dehydration and decarboxylation respectively [15]. The PPF oil is formed from rapid quenching of hot vapours produced from biomass pyrolysis in the reactors. Therefore, it contains many reactive species which tend to repolymerize upon standing or undergo ageing [16]. This contributed to its instability and it's a time-dependent behavior [17].

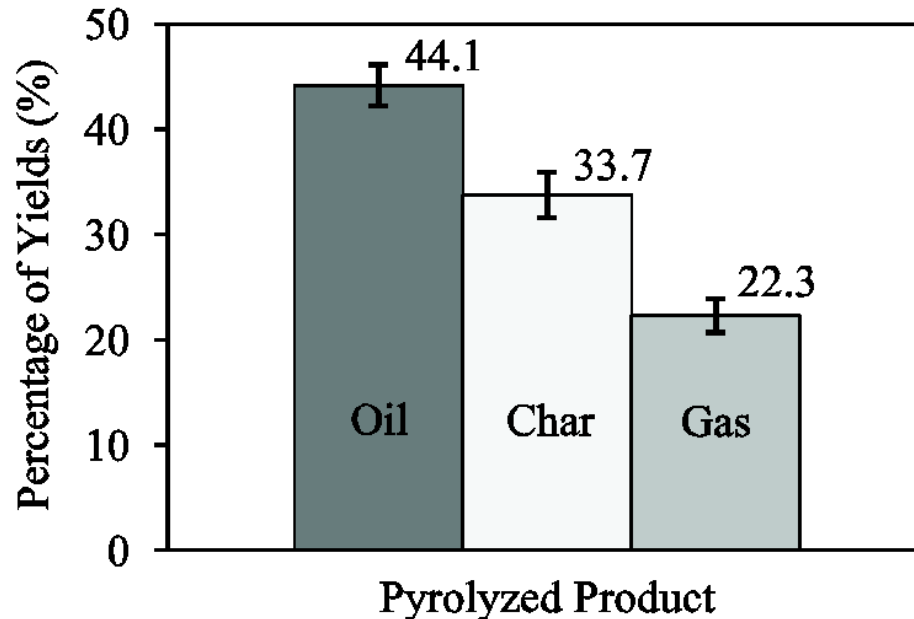


Figure 4 Various products yield (oil, char and gaseous) from subjecting PPF with the standard deviation of 1.97, 2.16 and 1.61, respectively

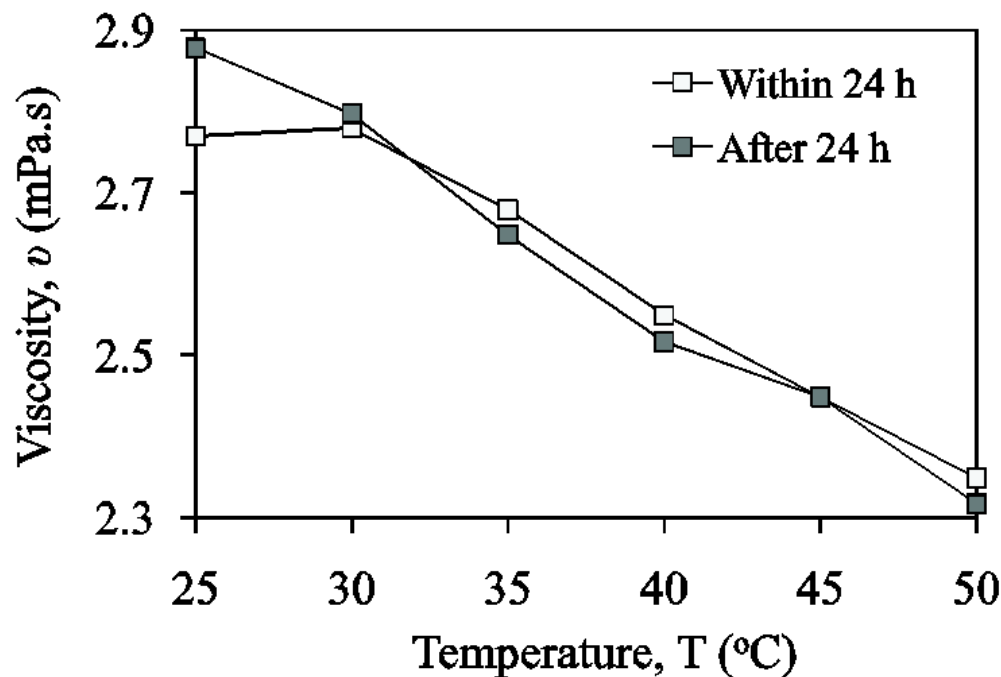


Figure 5 PPF oil viscosities were measured in a temperature range of 25 °C to 50 °C

The mechanics of cold work strip drawing operation began by placing the workpiece in the die container at the die opening reduction region. The forming load was applied to the end of the workpiece. This forming load was increased until it reached a

peak value that coincided with the peak radial normal pressure in the die wall. In this instance, the drawn strip began to yield throughout the die opening. In the cold work strip drawing experimental analysis, three zones of deformation were

identified; zone I was the undeformed region, zone II was the plastically deformed in a zone that has  $\theta$  of  $45^\circ$  tool die reduction, and zone III was the final deformed (product) region. The experimental forming load as a function of stroke in steady-state condition was considered and referred to the condition in which there was no more increment of forming load; this occurred when a volume of plastically deformed zone emerged from the die until the end of the strip drawing operation.

In order to evaluate the lubrication performance in cold strip drawing, the contact surface between tool die and workpiece was evaluated in both dry and lubricated conditions. For lubrication, PO and PPF oils were selected as test lubricant and the forming load as a function of stroke were plotted in order to compare the lubrication performance. The PO was chosen because it will not shear too easily and allow rupture and failure during drawing operation [11]. The significance of the strip drawing is to evaluate the lubrication performance in metal forming process where the main factor influence during metal forming process is the friction occurs on die-workpiece contact surfaces, which maximized the forming load. Therefore, it is important to optimize lubricant condition to control friction, residual stress and the shape precision of the product [18].

Figure 6 shows the experimental result of forming load as a function of stroke for the cold strip drawing with the dry and lubricated conditions on the die-workpiece contact sliding surfaces for the tool die exit angle  $\theta$  of  $45^\circ$ . The lubricated conditions were measured based on the lubricant quantity in an amount of 5 mg, which gave the best lubrication performance [19]. Among the three lubrication conditions investigated, PO gave the best lubrication performance during steady-state condition. On the lubricated contact surface, the results of PPF oil in a steady-state condition were quite close to that of PO. And for all forming load as a function of stroke, dry contact surface gave the highest value. This means that the increase in forming load was resulted from the increase in frictional force on the tool die-workpiece contact surface and the value of lubricant viscosity, where small value of PPF exhibit a greater resistance to shear and the frictional force at zone II in the deformation region. These conditions can also be explained by the increasing contact pressure that particularly occurred at the taper die region [18].

Figure 7(a) shows the measurement of friction coefficient as a function of lubrication conditions. Among the three

lubricated conditions investigated, PO gave the lowest friction coefficient, which is quite close to that of PO. We found that the increase in coefficient of friction is resulted from the increase in radial normal force to the taper die contact surface during strip drawing operation. In addition, poor surface roughness of the strip surface after cold strip drawing operation under the dry contact condition may initiate galling and caused a great damage to the surface quality of the product. It can be said that the design of proper surface texture of the product based on lubrication properties is a method to manufacture products as well as to manufacture materials [20].

The effect of lubrication conditions on the strip roughness in strip drawing was shown in Figure 7(b). The measured strip surface finish is the surface that in contact with the taper die and the container walls. The direction of surface roughness measurement is perpendicular to the strip drawing direction. We observed that the strip surface with PPF achieved a slightly higher surface roughness  $R_a$  and coarser strip surface finish compared to the lubricated contact surfaces with PO. This phenomenon can be explained by the occurrence of a thick layer of lubricant produced between die-workpiece contact surfaces and the asperities on the strip surface are not further to be flattened by the tool surface. Hence, the boundary lubrication condition would not occur, which allowed the strip to deform similarly to the tool surface quality [7].

Figure 8 shows the effect of dry and lubricated contact conditions with PO and PPF on the strip surface finish by capturing using optical microscope. We observed the surface finish after drawing with PPF contact condition varies with PO in a remarkably similar way for the measurements of forming load, coefficient of friction, contact pressure, and surface roughness. It can be seen that the dry contact condition gave the highest value because of a great influence on the friction behavior when the strip under plastic deformation during the cold work drawing process. Besides, it can be explained that the uneven surface finish was generated due to the surface expansion grain slip. This means that metal forming process cannot perform satisfactorily under dry friction because the plastic deformation is the most severe near the taper die edge surface of the billet where peak stress occurred where the lubricant is needed to overcome the friction on the die-workpiece sliding surface.

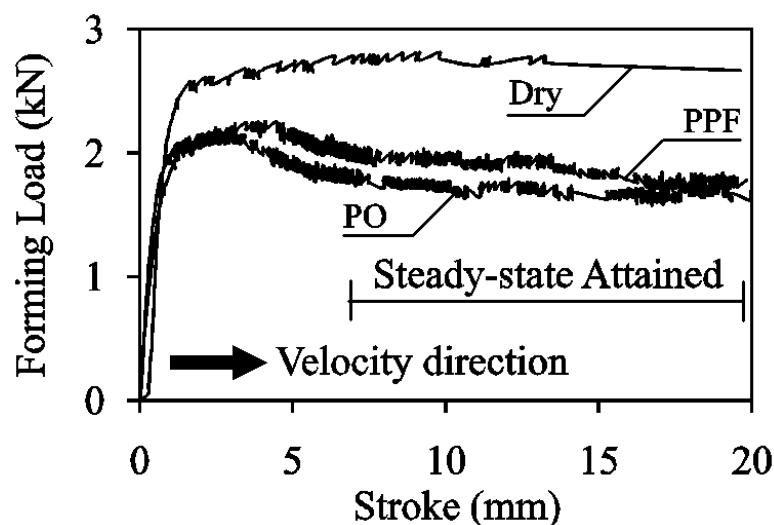


Figure 6 Forming load as a function of stroke for the dry and lubricated (PPF and PO) contact conditions

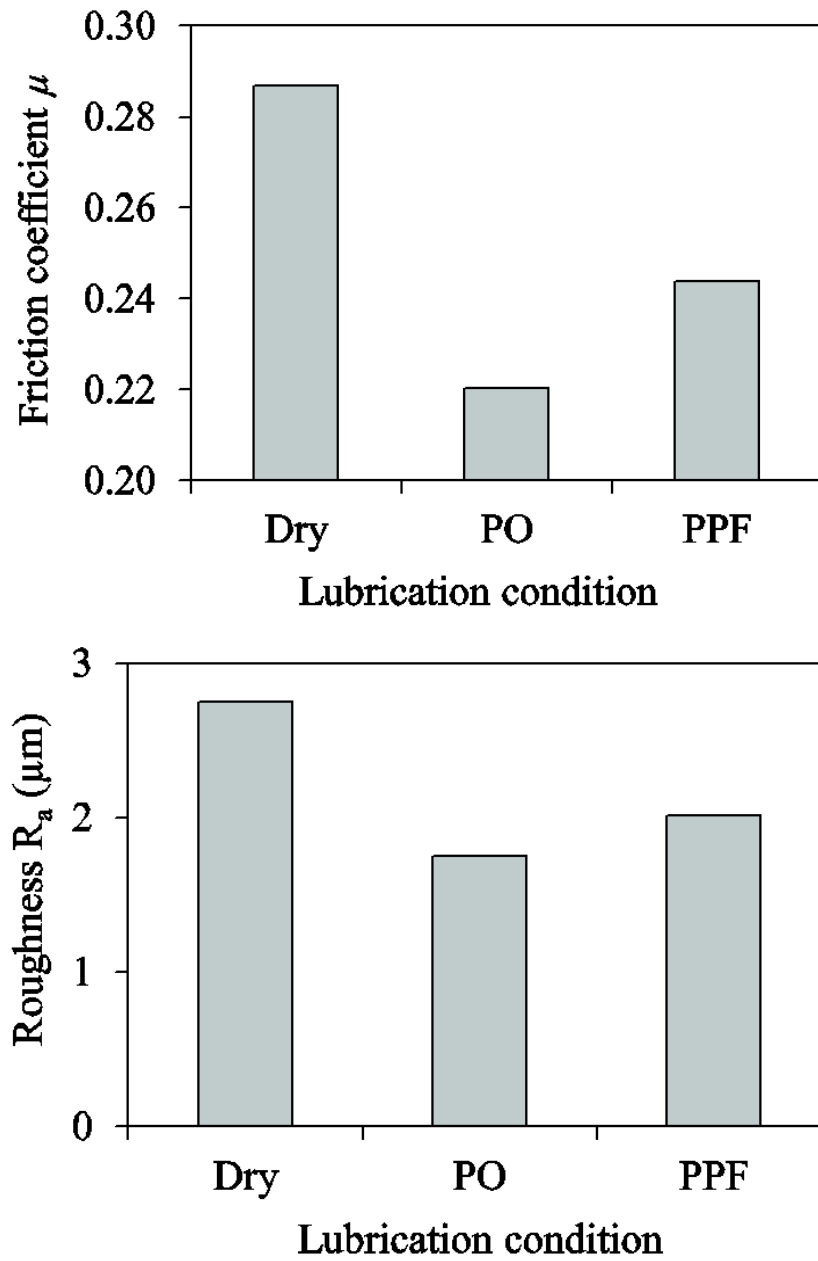


Figure 7 The effect of lubrication conditions on (a) friction coefficient and (b) roughness in strip drawing

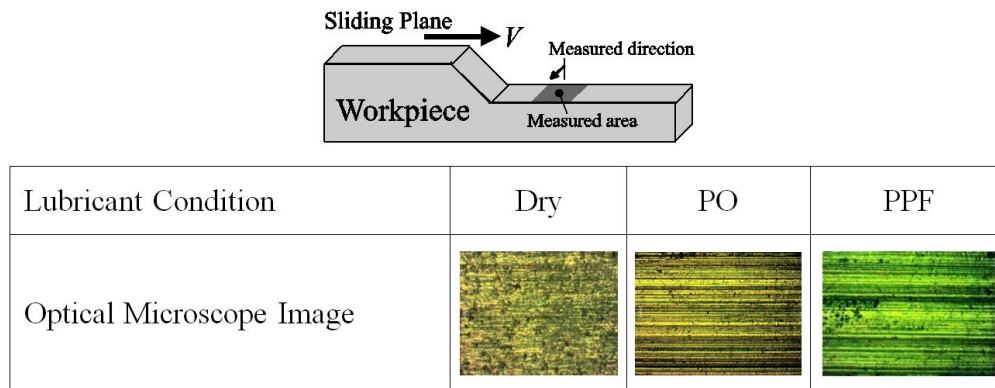


Figure 8 Strip surface pattern image after drawing with dry and lubricated conditions (PO and PPF) and tool die reduction angle  $\theta$  of  $45^\circ$

#### 4.0 CONCLUSION

The performance of PPF oil functioning as green lubricant in strip drawing of aluminum A1100 was evaluated successfully. Based on the oil, char and gas yields, temperature of 450 °C of catalytic pyrolysis process was needed to extract maximum oil yield about 44.1 percent from PPF waste. It is shown that viscosity decreases with the increasing temperature. In strip drawing experiment, the performance of lubricant was influenced significantly by the changes in the oil viscosity and the changes in the friction coefficient on die-workpiece contact surface. It is found that there is significant increase in friction and forming load with reduction in oil viscosity. Further investigation should be done to improve the fixed bed reactor system and the properties of PPF oil which may result a significant impact on the cold work metal forming process.

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