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Study of Alternative Lubricants for Cold Extrusion Process of A1100 Pure Aluminum

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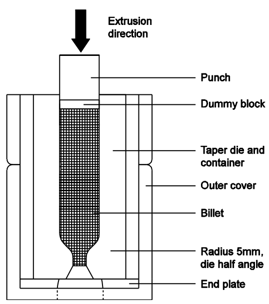
Graphical abstract



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 supplier to the wearing contact which functions as a film material or sustains chemical transformation to become a film material. Since it is will not last for a few more decades, renewable resources had been studied in order to find an alternative lubricant with presents similar results in terms of extrusion load and product quality. Two renewable lubricants were analyzed (Palm Kernel and Palm Stearin) together with additive free paraffinic mineral oil VG460 will act as a comparison lubricant. The experiment used a cold work plane strain extrusion apparatus consisting of a pair of taper die and a symmetrical work piece (billet). The billet material was annealed pure aluminum A1100 with radius of 5mm at the deformation area. It was found that palm Palm Kernel and Palm Stearin performed slightly high extrusion load, however they show no severe wear on product surface. Based on the results, it is proven that renewable based lubricants can be considered as a substitute to common mineral based lubricants used in the industry.

Keywords: Extrusion;palm kernel; palm stearin; sliding velocity; effective strain.

■1.0 INTRODUCTION

Exploration of resources such as mineral, forest, petroleum and natural gas are one of very significant activities for the development of a country. Industrial development, transportation sector and municipal are a few reasons that fuel resources supply become decreasing from day to day. However, all activities need to be done sustainably towards achieving economic development, and in the same time, still preserve the environment.

A mineral natural resource is considered as non-renewable resources. It takes a million years to be produced and by continuous exploration, it only can last for about 40 years onward. Therefore, a few alternatives had been identified and studied for replacing this resources depletion issue. Without ignoring the performance and quality of each alternative, there is a high possibility that it can function as well as mineral natural resources itself.

Over the past century, metal forming lubricants are based on mineral oil. It has been proven that by using mineral oil, it is able to produce a quality product as needed by customers. But, as mentioned before, 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 [1]. By looking at 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. Among which the choice is various types of vegetable oil such as palm oil, corn oil, sunflower oil and so forth. Vegetable oil is categorized as renewable oil because as long as the trees are planted, the resources will remain.

Palm oil industry is one of Malaysia's successes because it is able to transform our economic growth, from main commodity production country with agricultural basis to modern production country for value added food products [2]. It is consistent with Malaysia's privatization policies and in line with the basic of country development policies as stated in Vision 2020.

Basically, the purpose of lubrication is to control wear and friction at the interface between interacting surfaces [3,4]. Lubrication acts as a supplier in the form of either gas, liquid or a solid powder to the wearing contact which functions as a film material or sustains chemical transformation to become a film material.

Lubrication is very important in cold extrusion of metal, mainly related to the reduction of extrusion load and tool wear. Lubrication processes' usage in industries are time consuming and present high costs and important environment impact. Typical examples are plain mineral oil that directly produces a liquid film, a solid lubricant such as molybdenum disulphide and additives in lubricating oil that chemically react with the surface to form a film material [5].

The development of friction between the work piece and punch or dies in metal forming processes becomes a major processing parameter. Surface finish and dimensional precision of the product related to friction directly. Since the benefits of friction and lubrication control can be immense in metal forming, especially cold forming, considerable effort has been directed to the measurement of friction for both general metal working conditions and specific metal working processes so far [6].

This study was conducted to study the alternatives of mineral based lubricant for metal forming by considering a few aspects to the extrusion product including extrusion load, surface roughness, velocity and others. Ilija [7], and Abdulqadir and Adeyemi [8] have 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 oils. This present work hopefully, would help to promote the application of renewable natural resources as well as to protect the environment.

■2.0 MATERIALS AND METHODS

2.1 Procedure

The experimental set-up of the plain strain extrusion apparatus is depicted in Fig. 1. The main components are container wall, taper die, and work-piece (billet). This experiment had been done with the laboratory press machine at room 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 and 8.53 mm/s for palm kernel, palm stearin and VG460 respectively. Lubricant is applied on the taper die (surface which has contact with the billet) before the test. The billets are cleaned using acetone. 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.

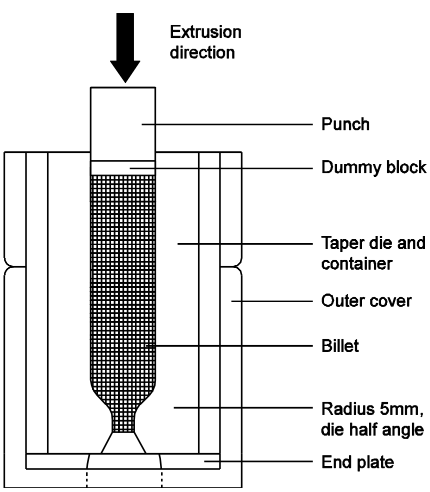


Figure 1 Schematic diagram of the plane strain extrusion apparatus

2.2 Apparatus

The experimental set-up of the plain strain extrusion apparatus consists of main components, namely the container wall, taper die, and work piece (billet). The taper die has a radius 5 mm die half-angle. The taper die is made from tooled steel (SKD11), and 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' shape was 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 sidewalls. 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.

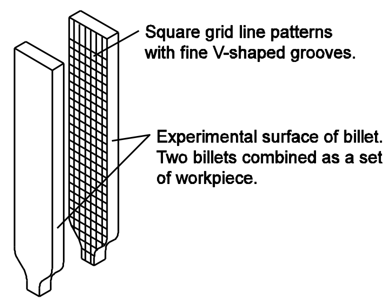


Figure 2 Schematic diagram for billet used in the experimental works

2.3 Testing Lubricants

The testing lubricants consist of 2 types of palm oil, which are Palm Kennel and Palm Stearin. Additive free paraffinic mineral oil VG460 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. The lubricant's viscosity values are a bit higher due to its semi solid physical condition as presented in Table 1. 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 1 Test lubricant properties

	Renewable		Non-renewable
	Palm Kernel	Palm Stearin	Mineral oil VG460
Relative density	0.86	0.87	0.86
Viscosity index	205	171	95

2.4 Procedure

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 room 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.

■3.0 RESULTS AND DISCUSSION

3.1 Extrusion Load

The extrusion load-piston stroke curves are shown in Fig 3. The figure shows that the extrusion load reached a constant level during the process and the extrusion process becomes a steady state condition at a piston stroke 15 mm onwards. As piston stroke reached 35 mm, the extrusion value for Palm Kernel, Palm Stearin and VG460 are 66.61kN, 65.47kN and 45.97kN respectively.

A few researches had been done and proved that VG460 is among the preferable mineral based lubricants for metal forming process, especially for cold extrusion process. Consistent with the finding by Syahrullail *et al.* [9], Palm Stearin shows the lowest extrusion load if compared to Palm Kernel. In addition, the viscosity value also higher because the lubricant is thicker and more concentrated. Due to that physical condition, it will result in less friction and less extrusion load during extrusion process in such a way lesser metal-to-metal contact between billet and taper die had occurred [10]. Palm Kernel 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.

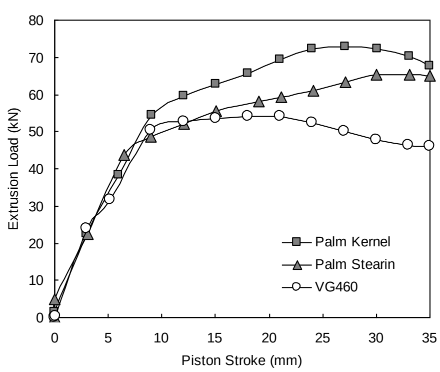


Figure 3 Extrusion load-piston stroke curves

3.2 Surface Roughness

The distributions of arithmetic mean surface roughness, Ra along the experimental surface billet (sliding plane) were measured with a surface profiler device. The experimental surface is defined as the surface of billet, which contacts each other with taper die and container during the extrusion process. The measure direction is perpendicular to the extrusion direction. The distribution of arithmetic mean surface roughness, Ra is shown in Fig 4.

The billet's surface that contact with taper die and container wall was the experimental surface area. It was then labeled as x-axis. Along the surface, three major points were measured.-4 mm until 0 mm,are the product area where the extrusion process was just finished (no metal-to-metal contact area). Range between 2 until 10 mm represent as deformation area were located accordingly. While for 12 mm and above, there was the area where the billet still maintaining its original size (undeformed area).

In the beginning of extrusion process, Palm Kernel's Ra value seems the lowest if compared to the other two lubricants. The situation remains the same until deformation area. Physically, Palm Kernel was the least viscous lubricant among the rest and has high possibilities to supply the lubricant until 0 mm. It is differ with Palm Stearin and VG460 where the lubricants tend to stay at the surface of contact area due to their high concentrated physical attributes. The Ra value was a bit higher from the beginning of the process towards the end. Nevertheless, the different between each lubricant were between 0.1 to 0.25 micron and from the observation by CCD camera as illustrated in Fig 5, found that no severe wear occurred.

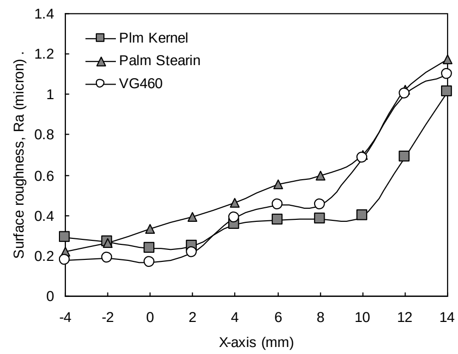


Figure 4 Surface Roughness distributions on the experimental surface of billet

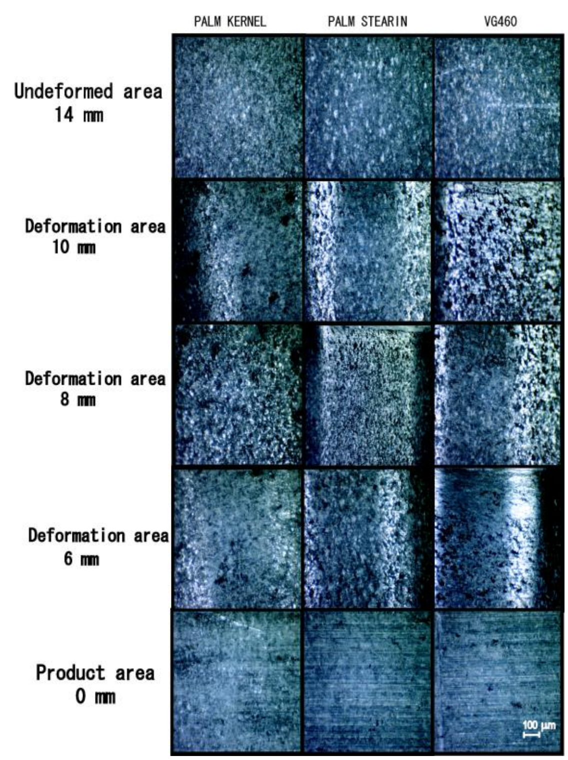


Figure 5 CCD pictures of billet's experimental surface at product area

3.3 Relative 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. In order to acquire the relative component velocity, the velocities component values were divided with ram speed, Vo.

Comparison of the relative velocity of the relative velocity for v- (horizontal direction velocity) and u- (vertical direction velocity) of the plastic flow velocity along the experimental surface of the billet are shown in Fig 6 and Fig 7, respectively. Meanwhile, the resultant relative velocity, *q*, which is calculated using Equation (1), has been plotted in Fig 8. Since the relation is about two velocity directions, u represents the relative u-component velocity and v represents the relative v-component velocity.

Lesser load and lesser friction will result high velocity of sliding action. As shown in Fig 7, Palm Stearin tends to have higher sliding velocity if compared to Palm Kernel. From the previous discussion of extrusion load, it is equivalent with this outcome where the extrusion process by using 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 [11].

$$q = \sqrt{u^2 + v^2} \quad (1)$$

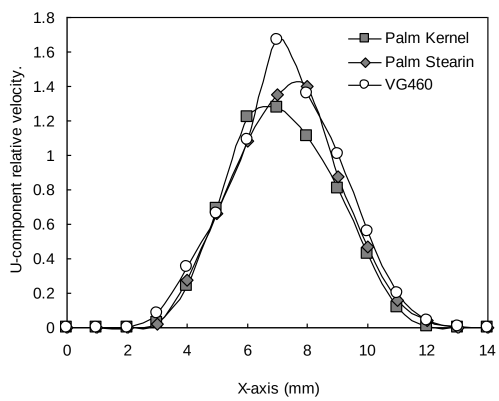


Figure 6 u-Component velocity distributions along the experimental surface of billet

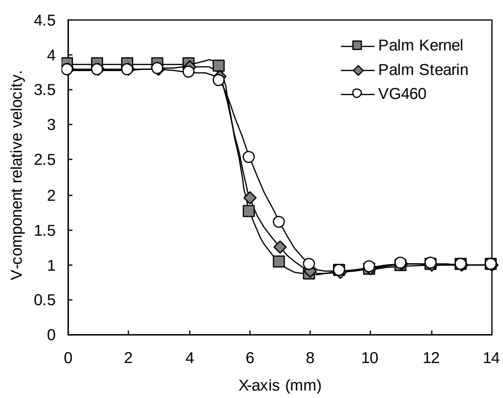


Figure 7 v-Component velocity distributions along the experimental surface of billet

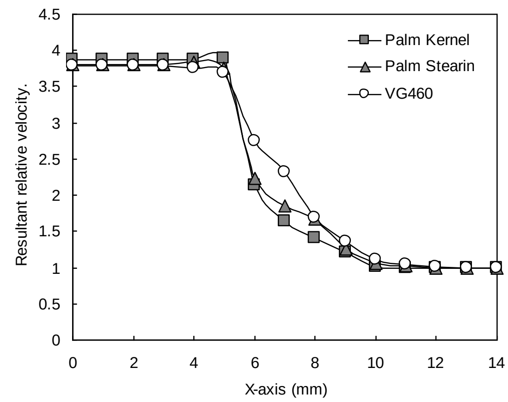
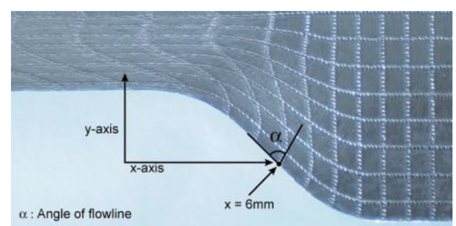


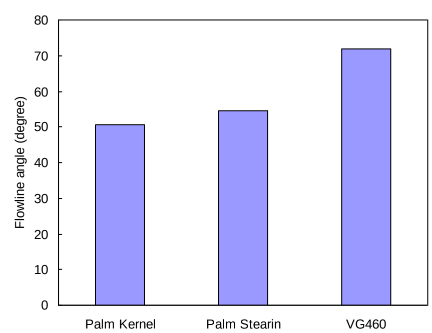
Figure 8 Sliding velocity of extruded billet

3.4 Flow line Observation

It is an important issue to study the behaviour of the billet's metal flow extruded in this experiment in order to add value, yet strengthen the existing findings. Therefore, the horizontal flow lines of extruded billet were compared by measuring flow line angle using microscope. The measurement was done at the deformation area (x=6mm) which represents x-axis (Fig 9a). In order to obtain the flow line angle, the billet's gridlines within measurement area had been measured and the value was plotted at y-axis. Fig 9 presents the comparison of the flow line angle for each lubricant.



(a)



(b)

Fig 9(a) Location to measure the angle of flowline and (b) Angle of flowline at deformation area

As plotted by bar graph in Fig 9b, clearly show that flow line angle in deformation area, obviously varies from other areas. Palm Kennel creates a high friction between tool and the billet surface, resulting smaller flow line angle as the metal flows to the inner side of the billet. High friction may cause the billet deform more than usual during extrusion process [12]. This force resists the edge of billet from flowing toward extrusion direction. By comparing this finding with surface roughness's result, it proves that Palm Kernel have more metal-to-metal contact as the Ra result was the lowest compared to the other lubricants.

■4.0 CONCLUSION

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 alternative lubricants were chosen among the renewable lubricant. 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, 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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