Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 9 (19): 3581-3586, 2009
ISSN 1812-5654

Plasticity Analysis of Pure Aluminium Extruded with an RBD Palm Olein Lubricant

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Abstract: In this study, a cold-work plane strain extrusion apparatus was used to perform plasticity analysis of a work piece that was extruded using RBD palm olein as a cold metal forming lubricant. The experimental apparatus consists of a set of two taper dies with 45-degree die half angles and a billet (work piece). The experiments were carried out at room temperature, which was within the range of 28 to 32°C. The testing lubricant was refined, bleached and deodorized palm olein (RBD palm olein). The billet material was annealed pure aluminium, A1100. The experimental results focused on the extrusion force, surface roughness of both the deformation area and the product surface and sliding velocity. The grid lines, which were scribed on the billet, were used to observe and analyze the plastic flow in the material. The velocity distributions on the experimental surface of the billet were calculated using a visioplasticity method. Similar experimental and analytical investigations were carried out using additive-free paraffinic mineral oil and were compared to the investigation with RBD palm olein. The RBD palm olein showed a reduced extrusion force and a better quality surface roughness. The work piece that was extruded with RBD palm olein showed better plastic behavior as compared to those that were extruded with paraffinic mineral oil. It was confirmed that RBD palm olein shows satisfactory lubrication performance as compared to additive-free paraffinic mineral oil.

Key words: Plastic flow, RBD palm olein, paraffinic mineral oil, surface roughness, velocity

INTRODUCTION

The use of vegetable oils in the industrial sector is not a new idea. In Ancient Egypt, vegetable oil and animal fats were used in the construction of monuments (Nosonovsky, 2007). In the early 16th century, European sailors made soap from palm oil. In the 19th century, the people of France and England used palm oil to make candles. They also used palm oil as a gas for lighting. Before the development of petroleum, palm oil was used to grease the axle boxes of railway carriages. In the tin plate industry, palm oil was initially used to prevent the oxidation of iron and as a flux before tinning (Henderson and Osborne, 2000).

In Malaysia, palm oil shows great potential for production as a lubricant. Palm oil is environmentally friendly and has a high biodegradability in comparison to mineral oil. Palm oil is also the most efficient oil-bearing crop in terms of land utilization and productivity. One hectare of palm oil could produce almost ten times more oil than other oilseeds, such as soybean and sunflower. Palm oil could produce an average of 3.74 tons of oil per hectare every year, compared to 0.38 tons and 0.48 tons of oil per hectare per year for soybean and sunflower, respectively (Ming and Chandramohan, 2002). For these reasons, palm oil could fulfil the demand for a vegetable-based lubricating oil. Studies on the feasibility of the use of palm oil in diesel engines (Bari *et al*., 2002) and as a hydraulic fluid (Wan Nik *et al*., 2000) showed satisfactory results in comparison to petroleum-based oil.

Plastic flow of metal in the bulk metal forming process is influenced by many factors, such as the lubricant's condition, friction, die shape and billet temperature (Li *et al*., 2008). From the point of view of lubrication, the plastic flow of a metal in the bulk metal forming process could be used to predict the lubricant's performance and the friction constraint behavior between the tool and work piece (Kamitani *et al*., 2008).

In this study, the performance of RBD palm olein as a lubricant in the cold-work plane strain extrusion process was investigated. The evaluations focused on the forming load, surface roughness and plasticity behavior. The results show that the work piece that was extruded with RBD palm olein as a lubricant has a low extrusion force and better plasticity behavior than those extruded with additive-free paraffinic mineral oil.

In a previous study by Syahrullail *et al*. (2005) the plane strain extrusion apparatus consisted of a taper die, billet and plane plate tool; the billet was not symmetrical. In the current investigation, a symmetrical billet and a pair of taper dies were used. The symmetrical billet performs similarly to the design of the tool in the actual extrusion

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process in the industrial sector. The reduced extrusion force in the present investigation is obvious when compared to the previous investigation and gives a good impression of the ability of palm oil when it is used as a metal forming lubricant.

MATERIALS AND METHODS

Experimental apparatus: Figure 1a shows a schematic sketch of the plane strain extrusion apparatus that was used in the experiments. The main components are the container wall, taper die and work piece (billet). The taper die has a 45-degree die half angle. The taper die is made from tool steel SKD11 and the necessary heat treatments were done before the experiments. The experimental surface of the taper die (surface that contacts the billet) was polished with an abrasive paper and has a surface roughness, Ra, of approximately 0.15 μm. A specified amount of lubricant was applied to this surface before the experiments. The same type of test lubricant was applied to the other surfaces of the experimental apparatus. The taper die has a Vickers hardness of 650 Hv.

Figure 1b shows a schematic sketch of the billets that were used in the experiments. The billet material is pure aluminium, A1100. The billet shape was produced using an NC wire cut electric discharge machining device. Two similar billets were stacked and used as one billet unit. One side of the contact surface of the combined billets was the plastic flow observation plane during plane strain extrusion. The observation plane is not affected by the frictional constraint of the parallel side walls. A squre grid pattern that measures the material flow during the extrusion process was scribed by the NC milling machine onto the observation plane of the billet. The grid lines were V-shaped grooves with a 0.5 mm deep, 0.2 mm wide and 1.0 mm interval length. The billets were annealed before the experiments. The experimental surface of the billet (surface that contacts the taper die) has a surface roughness of approximately 2.5 μm. The Vickers hardness of the billet is 38 Hv.

Testing lubricants: The testing lubricant was RBD palm olein (marked as PO). The RBD is an abbreviation for Refined, Bleached and Deodorized. Palm olein is the liquid fraction that is obtained by the fractionation of palm oil after crystallization at a controlled temperature. In these experiments, a standard grade of RBD palm olein, which was incorporated in the Malaysian Standard MS 816:1991, was used (Pantzaris, 2000). The results obtained from experiments using RBD palm olein were compared with those from experiments using additive-free paraffinic mineral oil (VG30) (marked as PF). The viscosity properties

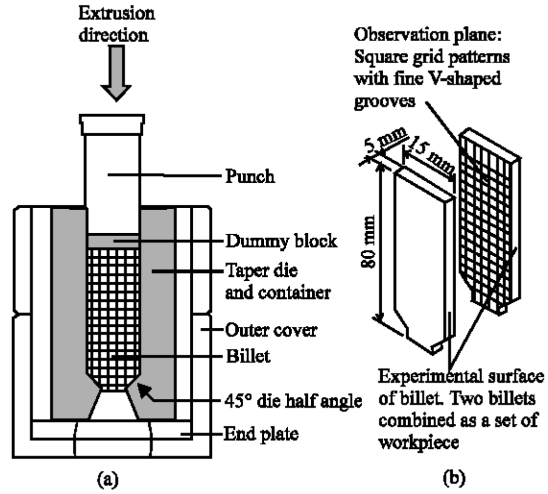

Fig. 1: (a) A schematic sketch of the plane strain extrusion apparatus and (b) the combination of the billets

Table 1: Viscosity of RBD palm olein and the paraffinic mineral oil (VG30)

Properties	RBD palm olein	Paraffin (VG30)
Viscosity index	213	129
Kinematic viscosity at 40°C (cSt)	46	32
Kinematic viscosity at 100°C (cSt)	10	6

for RBD palm olein and the additive-free paraffinic mineral are shown in Table 1.

Experimental procedure: Lubricants were applied onto the experimental surface of the taper die. The amount of lubricant was approximately 25 mg. The mass measurement was done with a digital balance that had a tolerance of 0.1 mg. The billets were cleaned with acetone. After that, the taper die and the billet were assembled as shown in Fig. 1. The plane strain extrusion apparatus was assembled and placed onto the hydraulic press machine. The load cell and displacement sensor were used to record the extrusion force and the ram displacement; the data was saved in a computer. The experiments were carried out at room temperature. The extrusion was stopped at a piston stroke of 35 mm, where the extrusion process is in a steady-state condition. The ram speed is constant at 0.85 mm sec^{-1}. 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 and the plasticity analysis.

Figure 2 shows the pattern of grid lines on the observation plane of the billet after the experiment. Horizontal grid lines (straight line parallel to the extrusion direction) on the observation plane of the billet show the plastic flow lines that appeared during the steady-state extrusion process after the experiment. The horizontal

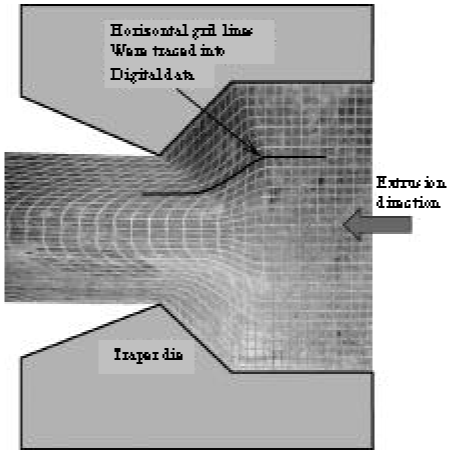

Fig. 2: Picture of the grid line pattern on the observation plane of the billet after the experiment

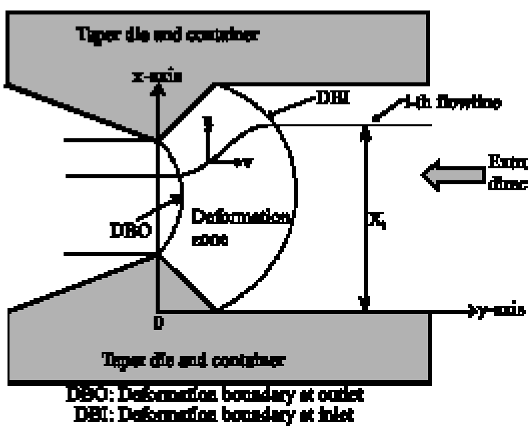

Fig. 3: Coordinate system that was used in the analysis

lines were traced with tracing software, according to the coordinate system that is shown in Fig. 3. After tracing, the digital data were prepared as raw data input for the visioplasticity analysis.

Figure 3 shows a schematic diagram of the x-y orthogonal coordinates system that was used to analyze the deformation zone; the plastic flow lines that appeared during the steady-state extrusion condition were used. Figure 3 also shows some of the variables that were used in the analysis and calculations and the position that was established in the same coordinates system in the observation plane of the billet.

The plastic flow velocity in the deformation zone, the effective strain rate and the effective strain were calculated using Eq. 1-5. Since, the analytical calculation procedure is explained in an earlier publication, it is omitted here (Syahrullail *et al.*, 2005).

Flow function:

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

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

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

Strain rate component (sec^{-1}):

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

Effective strain rate (sec^{-1}):

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

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_o is the velocity of the press ram in mm sec^{-1} and X_i is the distance in mm from the y-coordinate axis (X = 0) of the i-th flow line in the region where deformation does not occur.

RESULTS AND DISCUSSION

Extrusion force: Figure 4 shows the extrusion force with the piston stroke curves. Figure 4 shows that the extrusion force reached a constant level during the process and that the extrusion process became a steady-state condition at a piston stroke of more than 30 mm. The extrusion force difference at steady-state conditions (at a piston stroke of 35 mm is about 6 kN. A comparison of the extrusion forces in the presence of these lubricants shows that the extrusion force was lower for RBD palm olein, as compared to the paraffinic mineral oil (VG30). This is because the fatty acids in the palm oil reduced the frictional constraint between the tool and billet surfaces. Previous research also shows that the palm oil has a low friction coefficient (Abdulquadir and Adeyemi, 2008).

Surface roughness: The values of the arithmetic mean surface roughness, Ra, along the experimental surface of the billet were measured with a Mitutoyo Formtracer profilometer device. The measured direction is perpendicular to the extrusion direction. The experimental

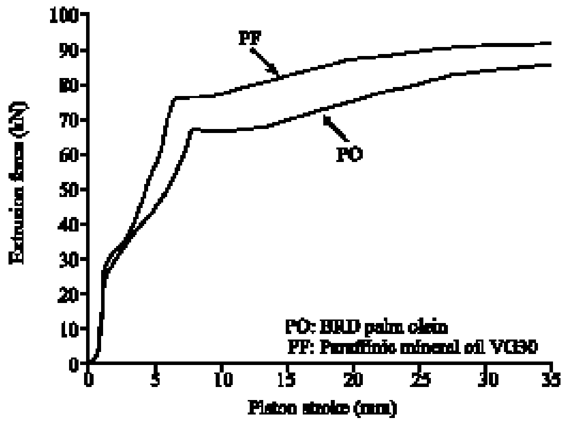

Fig. 4: Extrusion force-piston stroke curves

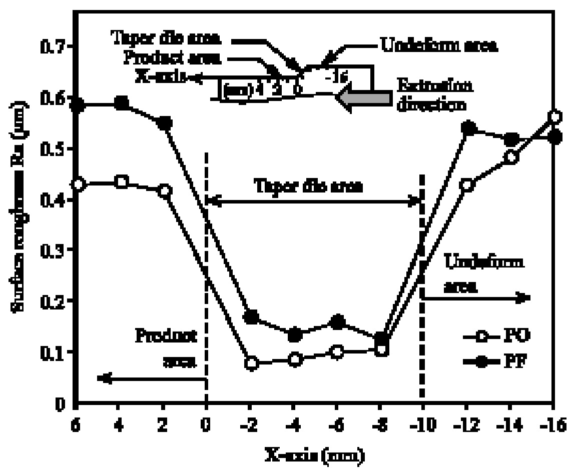

Fig. 5: Surface roughness (Ra) of the experimental surface of the billet

surface of the billet is the surface of the billet that contacts the taper die and the container. The experimental surface of the billet is labelled as the X-axis. The distribution of the arithmetic mean surface roughness, Ra, is shown in Fig. 5. As a result, the surface roughness for the product area of the billet that was extruded with RBD palm olein is smaller as compared to those that were extruded with paraffinic mineral oil (VG30). The experimental surface of the billet at the location X = -8 mm is connected to the taper die surface. When the experimental surface of the billet slides on this area, the wedge effect starts to occur and creates a thin layer of lubricant (Seiji, 2002). The condition between the material and the tool constituted mixed lubrication by a thin lubricant film (boundary lubrication); the adsorption of fatty acids from the palm oil played the role of maintaining the thin lubricant (Bowden and Tabor, 2001). This would

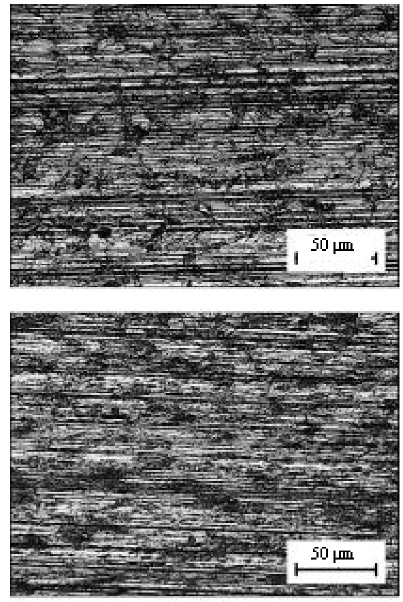

Fig. 6: CCD pictures of the product surface condition at the location X = 4 mm

reduce the ratio of metal-to-metal contact between the tool and billet surface for RBD palm olein (as compared to the paraffinic mineral oil (VG30)) and reduce the extrusion force. Since, the lubricant thickness is very thin, the product will reflect the surface roughness of the tool and make the billet's surface product of RBD palm olein smaller in comparison to the billet that was extruded with paraffinic mineral oil (VG30).

Figure 6 a and b show CCD pictures of the product surface condition at the location X = 4 mm with 85 times magnification. From the observed surface of the experimental billet, we can confirm that there is no severe wear. Both of the lubricants show satisfactory lubrication performances. In application, both of the lubricants could be used; however, RBD palm olein shows a reduction in the forming load, which could save the energy consumption.

Velocity at the experimental surface of the billet: From the digital tracing data, the velocity component of the billet that slides on the taper die's surface was calculated using the visioplasticity method, see Eq. 2. A comparison of the v- (horizontal) and u-components (vertical) of the plastic flow velocity along the experimental surface of the billet (the velocity condition of the billet sliding on the taper die's surface) are shown in Fig. 7 and 8, respectively. The results show that the velocity distribution in the billet that was extruded with RBD palm olein is clearly different in comparison to those that were

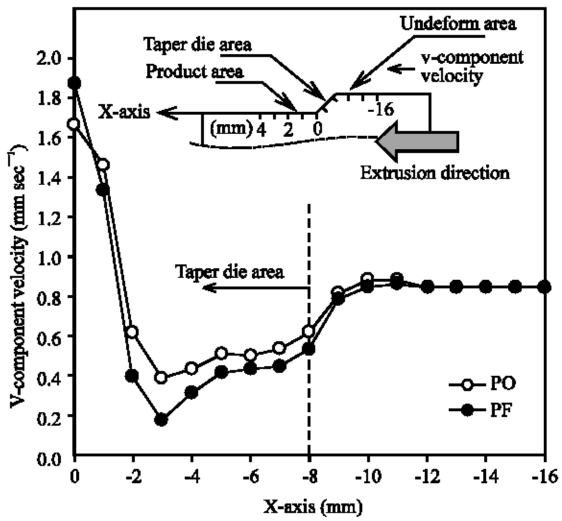

Fig. 7: Distribution of the v-component (horizontal) of the velocity along the experimental surface of the billet

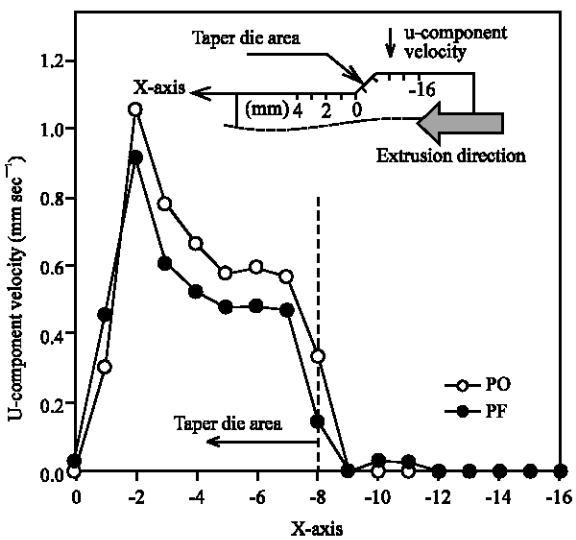

Fig. 8: Distribution of the u-component (vertical) of the velocity along the experimental surface of the billet

extruded with the paraffinic mineral oil (VG30). The reduced extrusion force of RBD palm olein shows a reduced friction between the taper die and the billets. Due to the low value of RBD palm olein friction coefficient and the RBD palm olein's capability to stick very well onto the taper die's surface, which makes the metal-to-metal contact ratio decrease, the sliding velocity on the taper die of the billet that was extruded with RBD palm olein is higher in comparison to those that were extruded with the paraffinic mineral oil (VG30).

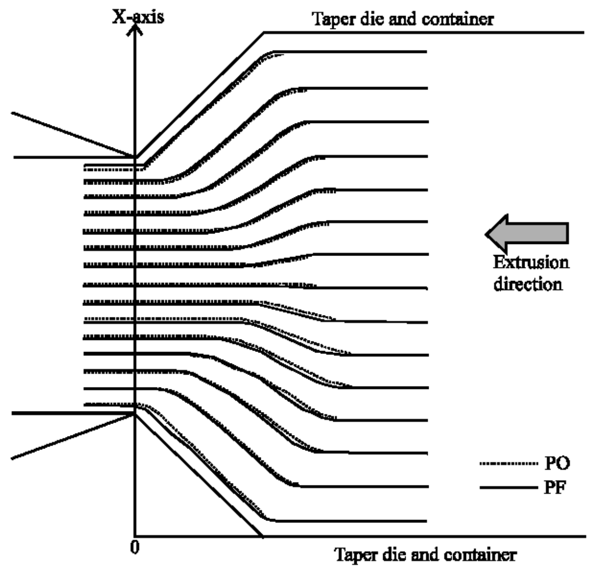

Fig. 9: Mutual comparisons of the horizontal flowlines in the deformation area

Flow lines observation: From the digital tracing data, the flow lines (horizontal grid lines) of the billet, which was extruded with RBD palm olein, were compared with the billet that was extruded with the paraffinic mineral oil. For a better comparison of the results, the digital tracing data were recalculated and repositioned at a constant distance of X_i (Fig. 3) for both of the lubrication conditions. Figure 9 shows a mutual comparison of the horizontal grid lines. A comparison of the flow lines of the billets show the plasticity flow behavior of the billet, while it was extruded through the taper die at a steady-state condition during the extrusion process. For the billet that was extruded with RBD palm olein, due to the low friction condition between the tool (taper die) and billet, the flow lines (plasticity flow) are slightly influenced in comparison to those that were extruded with the paraffinic mineral oil (VG30).

CONCLUSION

The plastic flow in pure aluminium was evaluated with RBD palm olein as a lubricant in a plane strain extrusion apparatus. The results of the experiment and the analysis show that RBD palm olein could reduce the extrusion force, lower the value of the surface roughness, Ra and increase the sliding velocity in comparison to the paraffinic mineral oil (VG30). From the results, we confirm that RBD palm olein showed a satisfactory lubrication performance in comparison to the paraffinic mineral oil (VG30).

ACKNOWLEDGMENTS

The authors would like to thank the Mechanical Engineering Faculty at the Universiti Teknologi Malaysia for their cooperation during the preparation of this study. The authors also wish to thank the Universiti Teknologi Malaysia for financial support through the grant vote 77024.

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