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Experimental evaluation of palm oil as lubricant in cold forward extrusion process

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ABSTRACT

Today, vegetable oil is much desired for its application as a lubricant in metal forming processes, because it is a renewable resource and has high biodegradability compared to mineral oil. According to the Organization for Economic Cooperation and Development for the European Union 301C (OECD) testing method, the biodegradability levels of vegetable oils are better compared to petroleum-based lubricants. Palm oil is used more often than other vegetable oils. Therefore, palm oil has the potential to fulfill the demand for vegetable-based lubricants. The purpose of this paper is to evaluate the viability of palm oil when used as a lubricant in cold work such as the forward plane strain extrusion process. The performances of palm oil were compared with additive-free paraffinic mineral oil. Experimental work with a plane strain extrusion apparatus with a symmetrical workpiece was carried out at room temperature. The material of the workpiece is annealed pure aluminum A1100. The visioplasticity method was used to calculate the velocities and effective strain in the deformation zone of the workpiece. The results obtained from the experimental work showed that palm oil has satisfactory lubrication performances, as compared to paraffinic mineral oil, and has advantages in reducing the extrusion load.

1. Introduction

Ecological factors are gaining importance in our society. Bearing in mind that our environment is being increasingly contaminated with all kinds of pollutants, any reduction is welcome. From an environmental point of view, and compared to a number of other chemical products, lubricants are not particularly problematic. A large proportion of lubricants pollute the environment either during or after use. It has been stated that 5–10 million tons of petroleum-based oleochemicals enter the biosphere every year. About 40% comes from spills, industrial and municipal waste, urban runoff, refinery processes, and condensation from marine engine exhaust [1]. These oleochemical pollutants are derived from the food industry, petroleum products, and byproducts such as lubricating, hydraulic, and cutting oils.

The terminology used in connection with environmental compatibility can be split into two criteria, i.e., subjective and objective. The non-measurable or subjective criteria are environmentally friendly and environmentally compatible. The objective criteria, among others, include biodegradability, water solubility, ecological toxicity, efficiency improvements, etc. Normally a biodegradability of at least 60%, according to OECD 301, is considered the main objective criterion for bio-lubricants. One of the possible lubricants that can satisfy this need is vegetable oil, which can offer significant environmental advantages with respect to resource renewability, biodegradability, and adequate performance in a variety of applications [2].

Natural fatty acid oils such as castor oil, palm oil, rapeseed oil, soybean oil, sunflower oil, and tallow oil have been used in lubricants for years. They are the so-called triglycerides of more or less unsaturated fatty esters. This type of base is biodegradable and, compared to mineral oils, will show excellent tribological qualities such as low friction coefficients and good wear protection. Their range of use is limited by lower stability against thermal oxidative and hydrolytic stress and partly inferior cold flow properties. These limits can be improved gradually with additives.

In Malaysia, palm oil has the possibility to be used as an industrial lubricating oil. Palm oil is vegetable oil, which is biodegradable, and also has a high production rate, which could fulfill the demand for vegetable-based lubricating oil in the future. One hectare of palm trees can produce almost 10 times as much oil compared to other sources of vegetable oil [3]. Therefore, palm oil has the potential to fulfill the supply volume in the demand for vegetable-based lubricants.

In this research, we examine RBD palm stearin (a type of refined palm oil) used as a lubricant in a cold work forward plane strain extrusion process. The extrusion load from the experimental work

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was recorded. The surface roughness of billets was measured after the experimental work. The velocity and effective strain distribution in the deformation area of the workpiece extruded with RBD palm stearin was investigated using the visioplasticity method [4]. The evaluations were focused on extrusion load, surface roughness, velocity distribution, and effective strain distribution. The velocity and strain distribution in the deformation region is important in metal forming in order to know the quality of the product. It also provides information about the lubricant quality that can prevent tool wear and control the material flow [5].

2. Experimental conditions

2.1. Experimental apparatus

Fig. 1(a) shows a schematic sketch of the plane strain extrusion apparatus used in the experiments. The main components are the container wall, taper die, and workpiece (billet). The taper die has a 45-degree die half-angle. The taper die is made from tooled steel (SKD11), and necessary heat treatments were performed before the experiments. The experimental surfaces of taper dies (surface in contact with the billet) were polished with abrasive paper and had a surface roughness Ra of approximately 0.15 μm. 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. 1(b) 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 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 experimental surface of the billet (surface, which contacts the taper die) had a surface roughness Ra of approximately 2.5 μm and a Vickers hardness of 38 Hv. Table 1 shows the properties of SKD11 and pure aluminum A1100.

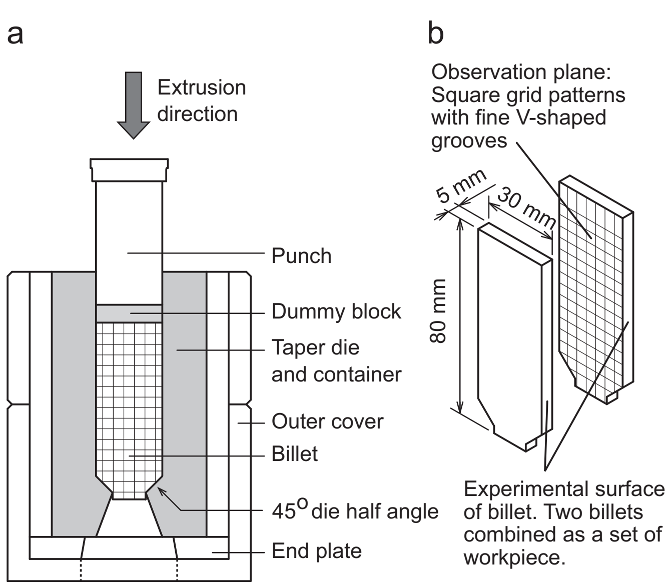

Fig. 1. (a) Schematic sketch of the plane strain extrusion apparatus and (b) combination of billets.

2.2. Lubricants

The testing lubricant is RBD palm stearin. RBD is an abbreviation for Refined, Bleached, and Deodorized. Palm stearin is the solid fraction obtained by fractionation of palm oil after crystallization at controlled temperature. It is, thus, a co-product of palm olein. The average ratio of stearin to olein is about 25:75. The physical characteristics of palm stearin differ significantly from those of palm oil, and it is available in a wider range of melting points and iodine values [6]. In these experiments, a standard grade of palm stearin, which incorporated Malaysian Standard MS 815:1991, was used. The properties of RBD palm stearin are shown in Table 2. RBD palm stearin has a high melting point. As a result, in this experiment, RBD palm stearin remained in a semi-solid condition.

The results obtained from the experiments that used RBD palm stearin were compared with additive-free paraffinic mineral oils, VG95 (written as Paraffin VG95) and VG460 (written as Paraffin VG460). The properties of paraffinic mineral oil VG95 and paraffinic mineral oil are shown in Table 2. The changes of the viscosity for all test lubricants against temperature were measured and plotted as shown in Fig. 2. From the figure, paraffin VG460 has higher viscosity compared to paraffin VG95. At 40 °C, paraffin VG95 and paraffin VG460 have kinematic viscosity of 95 and 461 cSt, respectively. RBD palm stearin has a similar viscosity–temperature curve than paraffin VG95. It has kinematic viscosity of 46 cSt at 40 °C.

Testing lubricant was applied on the experimental surface of the taper die before the experiment. The initial mass amount of lubricant applied was 5 mg (0.4 mg/cm^2).

2.3. Experimental procedure

The plane strain extrusion apparatus was assembled into the confinement fixture (outer cover in Fig. 1) and placed on the hydraulic press machine, as shown in Fig. 3. The load cell and

Table 1
Properties of (a) SKD11 and (b) pure aluminum A1100.

Chemical composition for SKD11 (mass %)								
Element	C	Si	Mn	Cr	Mo	V	S	P
Specification	1.55	0.30	0.35	11.75	0.75	0.95	0.005	0.020

Chemical composition for pure aluminum A1100 (mass %)							
Element	Si	Fe	Mg	Cu	Ti	Zn	Al
specification	0.08	0.33	0.0016	0.054	0.013	0.013	99.00 (Min)

Table 2
Properties of RBD palm stearin, paraffin VG95, and paraffin VG460.

Properties	RBD palm stearin	Paraffin VG95	Paraffin VG460
Apparent density at 50 °C, g/ml	0.8969–0.8977	0.8725	0.9035
Refractive index n_D at 50 °C	1.4589–1.4592	–	–
Saponification value, mg KOH/g oil	194–202	–	–
Iodine values	56.0–59.1	–	–
Slip melting point, °C	19.2–23.6	−12.5	−12.5
Viscosity index	159	102	97
Viscosity at 40 °C, cst	46	95	461
Viscosity at 100 °C, cst	12	10	31
API gravity	0.13	29.66	25.03