EVALUATION OF BIODEGRADABLE LUBRICANTS BY FORWARD CONICAL CUP – BACKWARD STRAIGHT CUP EXTRUSION TEST

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ABSTRACT: There is a constant need to replace the existing hazardous lubricants by environmentally friendly products extracted from renewable sources. In this paper, the lubrication performance of two biodegradable lubricants (palm oil and boric acid combined with the rapeseed oil) was evaluated using the combined forward conical can-backward straight can extrusion test. An AA 6060-T5 annealed aluminum alloy was used to prepare the test specimens. A finite element simulation of the combined extrusion process was conducted to investigate the material flow and to estimate the friction factors for the two lubricants.

KEY WORDS: metal forming, biodegradable lubricants, combined extrusion, boric acid, palm oil.

1 INTRODUCTION

The friction at the tool-workpiece interface is an important parameter in all metal forming processes. The friction affects the material formability; in general, the material tearing during the forming process occurs in the areas where the friction is high. The friction also influences the required force for carrying out the process. The surface quality of the formed part, and the lifetime of the tools are also influenced by the friction. It is generally desirable the friction be small. This issue can be reached by using a suitable lubricant.

At the same time, the current requirements are that toxic lubricants to be replaced by biodegradable lubricants extracted from renewable sources. Researchers have turned their attention to the use of biodegradable lubricants in metal forming processes. Numerous existing studies have focused their attention on the boric acid lubricant. (Rao et. al., 2011) concluded that the forging speed and the hardness of the coating have no effect on the lubrication performance of the boric acid.

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(Lovel et. al., 2007) concluded that the boric acid and canola oil lubricant outperformed other lubrication conditions in sheet metal forming processes. The boric acid lubricant was also tested in the machining process by the authors of the paper (Damera et. al., 2008). It was concluded that the boric acid lubricant reduces the cutting forces and tool wear and improves the surface finish. The authors of the paper (Nuraliza & Syahrullail, 2015) investigated the friction and wear characteristics of double fractioned palm oil using the pin-on-disk test. They have suggested that the palm oil can be used as lubricant oil. The authors of the paper (Syahrullail et al., 2012) have conducted experimental studies on the evaluation of BRD palm olein, palm stearin and palm oil, respectively in cold extrusion process of aluminum. They have concluded that the three lubricants show sufficient lubrication performance. The authors of the paper (Carcel et. al., 2005) evaluated some vegetable oils lubricants in sheet metal stamping. They concluded that vegetable oils have similar or even better lubrication performance than mineral base oils.

This literature review reveals that the idea of using the environmentally friendly lubricants is still in the incipient phase and there are none or very little industrial applications.

The objective of this research is to investigate the lubrication performance of palm oil and boric acid combined with rapeseed oil, as environmentally friendly lubricants, by using the combined forward conical can-backward straight can extrusion test. Experiments and finite element simulation of the extrusion process were conducted to achieve the objective of this study.

2 COMBINED FORWARD CONICAL CUP – BACKWARD STRAIGHT CUP EXTRUSION TEST

During a bulk metal forming process, the material flow is significantly influenced by the friction at the tool-workpiece interface. In the areas where the friction is small, the material flows faster than in the areas where the friction is higher. Based on this principle, some extrusion friction tests have been developed. A friction test, using a double cup extrusion process, has been developed by Buschhausen (Buschhausen et. al., 1992). The authors of the paper (Schrader et. al., 2007) evaluated the double cup extrusion test with respect to its sensitivity to some geometrical and process parameters. They suggested the testing of lubricants by adopting both a smaller and larger extrusion ratio. The authors of the paper (Nakamura et. al., 1998) used the combined forward conical can-backward straight can extrusion test for the investigation of friction characteristics on conical punch and the combined forward straight can-backward straight can extrusion for the evaluation friction characteristics on die surface. A review of friction tests based on the extrusion process is presented in the paper (Wang et. al., 2012).

The principle of combined forward conical can-backward straight can extrusion test is shown in Figure 1. A cylindrical billet is placed into the die cavity, between the two punches. During the test, the upper punch is movable while the lower punch and the die are stationary. When the billet is loaded in the axial compression, due to the downward movement of the upper punch, the material will flow into the space between the punches and the die. Due to the relative displacement of the upper punch, more material will flow upwards than down. The lower the friction between the conical punch and the workpiece is, more material will flow down.

As a consequence, the evaluation of the different lubrication conditions will be done by measuring the upper high (H_U) and the lower high (H_L) values of the extruded test specimen. A certain lubricant exhibits a better lubrication performance than other, when H_L is higher and H_U is lower in the case of considered lubricant. The ratio $H_L/H_U>1$ means a low friction, while $H_L/H_U<1$ signify a high friction at the conical punch-workpiece interface. Often, the finite element simulation of the extrusion process is used to establish a set of calibration curves. By overlapping the experimental data on the calibration curves, the friction factor or the friction coefficient can be estimated.

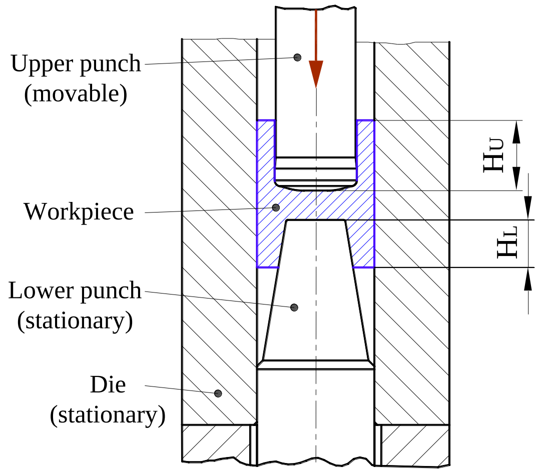


Figure 1. Schematic representation of material flow during the combined forward conical can-backward straight can extrusion test

3 EXPERIMENTS

3.1 Lubricants

Two friction conditions were considered in this study. In the first case a palm oil and in the second case, a combination between the boric acid and the rapeseed oil, respectively, were used. Figure 2 shows the lubricants used in this study.

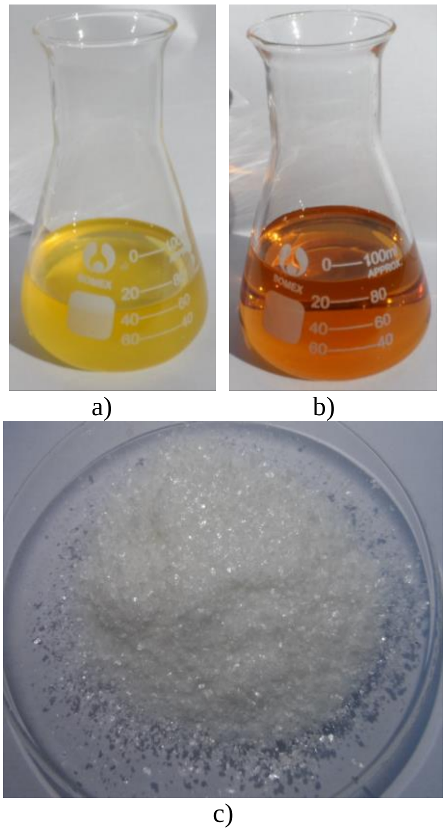


Figure 2. Lubricants: a) – palm oil; b) – rapeseed oil; c) – boric acid

The palm oil is mainly used in the food industry. In this study, a commercial palm oil was used without modifications. The boric acid was passed through several sieves to obtain a fine grain. For an ease of use, the boric acid was mixed with rapeseed oil until a homogeneous mixture was obtained. The rapeseed oil was previously degummed and filtered.

3.2 Material

The material used to prepare the test specimens was an AA6060-T5 aluminum alloy in form of a round bar. Table 1 shows the main mechanical properties of the as received AA6060-T5 aluminum alloy. In order to reduce the load on the die set, an annealing heat treatment was performed consisting of a heating at 250°C, followed by a holding for 30 minutes and cooling with the furnace for 180 minutes to the ambient temperature.

Table 1. Mechanical properties of AA6060-T5 aluminum alloy

Material parameter	Value
Yield stress [MPa]	165
Ultimate strength tress [MPa]	205
Elongation [%]	10
Young's modulus [MPa]	68947.6
Poisson's ratio [-]	0.3

In order to determine the strain – stress curve of the AA6060-T5 aluminum alloy, compression tests were performed using cylindrical specimens with 20 mm diameter and 20 mm height. The compression test were carried out using a universal material testing machine Instron, model 1343. The test speed was 2 mm/min. Figure 3 shows the load versus stroke curves during the compression test, before and after the annealing.

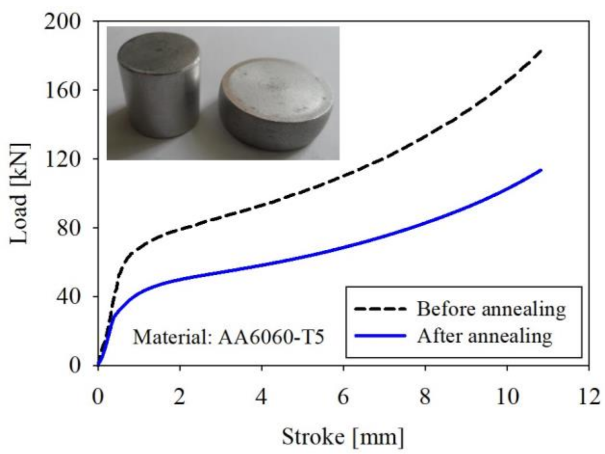


Figure 3. Load - stroke curves during the uniaxial compression test

The following formulas were used to calculate the true stress - true strain curves, based on the experimental data shown in Figure 3.

$$\sigma_E = \frac{F}{A_0}; \quad (1)$$

$$\varepsilon_E = \frac{h_0 - h}{h_0}; \quad (2)$$

$$\sigma_T = \sigma_E \cdot (1 - \varepsilon_E); \quad (3)$$

$$\varepsilon_T = \ln(1 - \varepsilon_E); \quad (4)$$

where, σ_E is the engineering stress;

ε_E – the engineering strain;

σ_T – the true stress;

ε_T – the true strain;

F – the load;

A_0 – the original cross-section of the compression test specimen;

h_0 – the original height of specimen;

h – the current height of specimen.

Figure 4 shows the true stress–true strain curves obtained based on the formulas (1)-(4) and the data in Figure 3. These data were used for the modeling of mechanical material behavior during the finite element simulation of the extrusion process.

3.3 Experimental equipment

The experiments were carried out using test specimens with similar dimensions as in the compression test: 20 mm diameter and 20 mm height.

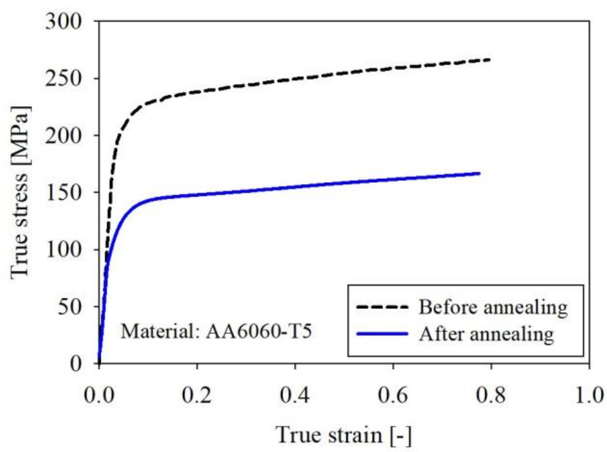
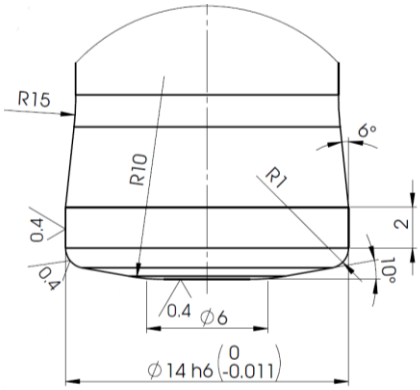
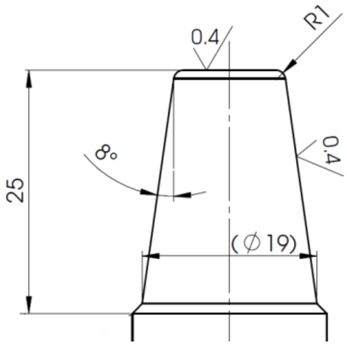


Figure 4. True stress – true strain curves

The geometry and the main dimensions of the two punches, used in the experiments, are shown in Figure 5.



a) – Upper punch



b) – Lower punch

Figure 5. The shape and the main dimensions of the punches

A universal material testing machine Instron, model 1196, was used to conduct the extrusion test, shown in Figure 6. The test speed was 5 mm/min in all cases. For each friction condition the test were repeated three times. The test specimen were deformed up to 11 mm punch stroke.

Figure 6. Experimental setup used for the combined forward conical can-backward straight can extrusion

During the tests the load and stroke were continuously recorded. Figure 7 shows the test specimen extruded in the two friction conditions. After the tests, the upper height (H_U) and the lower height (H_L) (Fig. 1) were measured using a digital dial gauge indicator.

a) – Palm oil

b) – Boric acid combined with rapeseed oil

Figure 7. Extruded test specimens using different lubricants (punch stroke: 11 mm)

4 FINITE ELEMENT SIMULATION

The results of finite element (FE) simulation of the combined forward conical can-backward straight can extrusion process were used for the estimation of friction factor "*m*" for the two friction conditions considered in this study. The DEFORM 3D finite element software was used for the modelling and simulation of the experimental extrusion tests. The dimensions of the tools and the billet are similar with those used in the experiments. The finite element model of the extrusion test is shown in Figure 8. The model includes: the billet, the upper punch, the lower punch and the die. The billet was modelled as a plastic isotropic deformable material using 40000 tetrahedral mesh elements, while the tools were modeled as rigid, non-deformable bodies.

The friction at the billet-die/punch interfaces was modeled using the Tresca's friction model. The frictional force is defined by

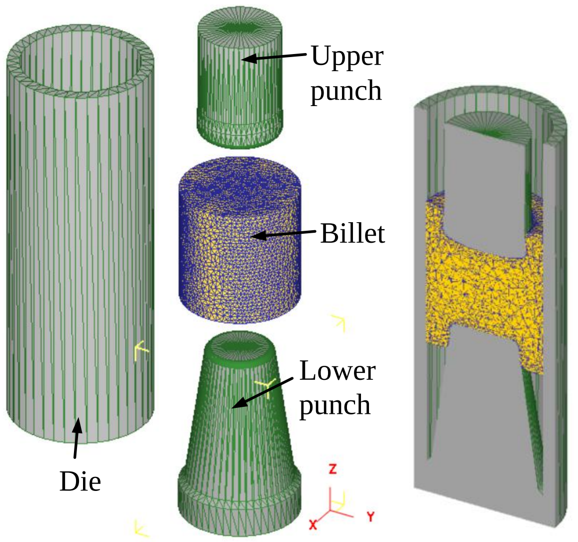
$$\tau = m \cdot k = m \cdot \frac{\sigma_y}{\sqrt{3}}, \tag{5}$$

where, τ is the frictional force;

m – the friction factor;

k – the shear yield stress;

σ_y – the yield stress.



a) b)

Figure 8. FE simulation model of combined forward conical can-backward straight can extrusion test: a) – components of the FE model; b) – during the FE simulation

5 RESULTS

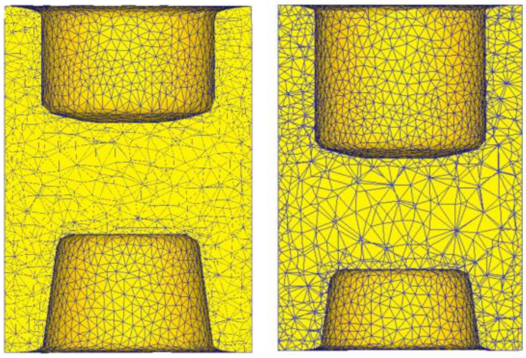
5.1 Evaluation of lubricants based on the friction effect on the material flow

Figure 9 shows the experimental test specimens deformed at 11 mm punch stroke, while Figure 10 shows the FE simulation deformed specimens for two values of friction factor: 0.1 and 0.5, at 11 mm punch stroke.

From Figure 9 it is obvious that the application of different lubricants implies different changes of the upper height (H_U) and lower height (H_L) of the extruded test specimen. Such changes, in the heights of the extruded specimen, are confirmed by the results of FE simulation, as shown in Figure 10.

a) b)

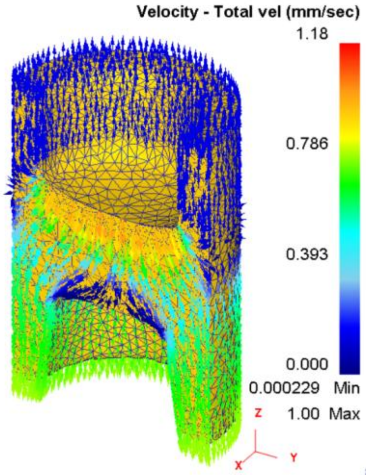
Figure 9. Axial section of the test specimens extruded in different friction conditions: a) - palm oil; b) – boric acid combined with rapeseed oil (punch stroke: 11 mm)



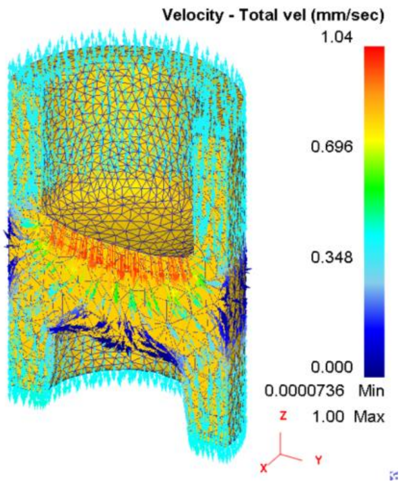
a) *m* = 0.1 b) *m* = 0.5

Figure 10. FE simulation extruded billets for two values of friction factor (*m*) (punch stroke: 11 mm)

Figure 11 shows the flow field of billet deformed at 11 mm punch stroke, in the case of friction factors of 0.1 and 0.5. From this figure, one can see that in the case of the friction factor of 0.1, the material flows faster than in the case of the friction factor of 0.5.



a) *m* = 0.1



b) *m* = 0.5

Figure 11. Effect of friction factor on the material flow (punch stroke: 11 mm)

For a quantitatively evaluation of the two lubricants, the measured upper height (H_U) and lower height (H_L) of extruded test specimen are plotted in Figure 12 against the FE simulation results. From this figure one can see that a friction factor of approximatively 0.2 corresponds to boric acid in combination with the rapeseed oil, while a friction factor of approximatively 0.47 was obtained in the case of palm oil.

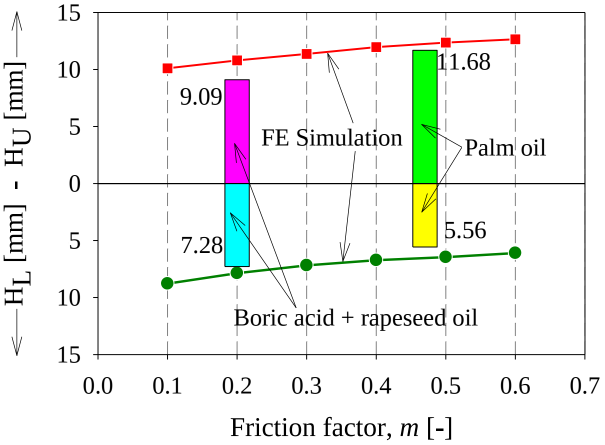


Figure 12. Friction calibration curves and experimental results (punch stroke: 11 mm)

5.2 Evaluation of lubricants based on the friction effect on the extrusion force

The experimental variation of the load during the extrusion process is shown in Figure 13 for the two friction conditions. The test was repeated three times for both friction cases. From this diagram it is obvious that the boric acid combined with the rapeseed oil exhibits better lubrication properties as the palm oil.

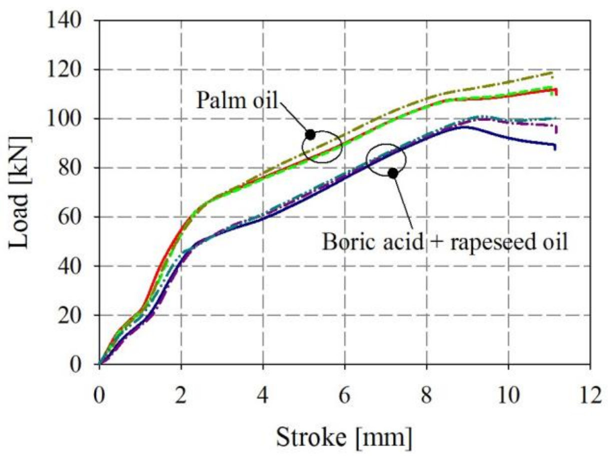


Figure 12. Load-stroke curves for two friction conditions

6 CONCLUSIONS

Based on the results of this study, the following conclusions can be formulated:

1. The boric acid combined with the rapeseed oil has better lubrication properties as palm oil.
2. A friction factor of 0.2 was found in the case of combination between the boric acid and rapeseed oil. A friction factor of approximatively 0.47 corresponds to palm oil.

7 REFERENCES

►Buschhausen, A., Weinmann, K., et. al., (1992). Evaluation of lubrication and friction in cold forging using a double backward-extrusion process, J. Mater. Process. Technol., 33: 1–2, pp. 95-108.

►Carcel, A.C., Palomares, D., et. al., (2005). Evaluation of vegetable oils as pre-lube oils for stamping. Materials & Design, 26:7, pp. 587-593.

►Damera, N.R., Pasam, V.K. (2008), Performance profiling of boric acid as lubricant in machining, J of the Braz. Soc. of Mech. Sci. & Eng., 30: 3, pp. 239-244.

►Lovell, M., Higgs, C.F., et. al., (2007), Increasing formability in sheet metal stamping operations using environmentally friendly lubricants, J. Mater. Process. Technol., 177: 1–3, pp. 87-90.

►Nakamura, T., Bay, N., Zhang, Z.L. (1998). FEM Simulation of a friction testing method based on combined forward conical can-backward straight can extrusion, J Tribol, 120, pp. 717-723.

►Nuraliza, N., Syahrullail, S. (2015). Tribological effects of vegetable oil as alternative lubricant: a pin-on-disk tribometer and wear study. Journal Tribology Transactions, 59:5, pp. 831-837.

►Rao, K.P., Prasad, Y.V.R.K., Xie C.L. (2011), Further evaluation of boric acid vis-à-vis other lubricants for cold forming applications, Tribology International, 44, pp. 1118–1126.

►Schrader, T., Shirgaokar, M., Altan, T. (2007). A critical evaluation of the double cup extrusion test for selection of cold forging lubricants, J. Mater. Process. Technol., 189, pp. 36–44.

►Syahrullail, S., Kamitani, S., Nakanishi, K. (2012). Experimental Evaluation of Refined, Bleached, and Deodorized Palm Olein and Palm Stearin in Cold Extrusion of Aluminum A1050. Tribology Transactions, 55:2, pp. 199-209.

►Wang, L., Zhou, Z., Duszczyk, J., Katgerman, L. (2012). Friction in aluminium extrusion—Part 1: A review of friction testing techniques for aluminium extrusion, Tribology International, 56, pp. 89–98.