Load-displacement Behavior of RBD Palm Stearin Oil Lubricant Quantity in Cold Extrusion

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Abstract—Large consumption of lubricant may affect the environment due to their high potential of pollution. Therefore, there is significant demand to provide a solution to this current condition by using alternative lubricant that can demonstrate the same lubrication performance as the existing lubricants. In this paper, solid faction lubricant, Refined Bleached Deodorised (RBD) palm stearin has been used to reduce friction resistance between die and billet surface. The RBD palm stearin is less expensive and has good lubrication properties compared to RBD palm olein that is liquid, which often used for cooking. In order to investigate load-displacement behavior and friction coefficient between die-billet interfaces, finite element (FE) analysis has been applied. The extrusion model was built in accordance to experiment. Four different quantities of lubricant were analyzed; 0.1 mg, 1 mg, 5 mg and 20 mg. The results show that the lubricant quantity of 5.0 mg produced the optimum extrusion load and friction coefficient.

Keywords—finite element method; extrusion load; friction coefficient; lubricant; RBD palm stearin; cold forward extrusion

I. INTRODUCTION

Palm oil lubricant has good lubrication properties and it is beneficial to be utilized in metal forming. Manufacturers are seeking for less pollutant lubricant that can demonstrate similar characteristic to the present lubricant in terms of extrusion load and product quality while maintaining low manufacturing cost. Lubricants are often used for die-workpiece sliding surfaces in metal forming processes [1, 2] as to improve the surface quality of a manufactured product. An effective lubrication is needed to meet the increasing operational conditions in metal forming such as cold work forward extrusion. Poor lubrication may result in wear losses and high friction, which in turn can adversely affect the mass productivity and production cost [3].

Previous studies [4, 5] proved that lubrication performance was influenced by contact pressure on the die-billet interfaces. An analysis by S.Syahrullail et. al. had ascertained that RBD palm olein lubricant produced an effective lubrication performance in terms of extrusion load and surface roughness [5]. The analysis shows the palm oil lubricant provides good lubrication properties in terms of performance, efficiency and durability. The development and extensive uses of low friction material and coating are among the effective ways to get better operational performance condition for the extrusion process [6, 7]. Friction is caused by the relative movement on the die-billet contact surfaces. The friction acts as a main indicator, which is dependent on material, contact surface and lubricant. It was reported [8] that the friction between the workpiece and the tool has a great influence in deep drawing process.

An analysis by FE method proved that the friction increases the extrusion load which is caused by the rate of change in normal and tangential forces on the die sliding surfaces [9]. It showed that the extrusion load reach a peak value because the high stresses in the billet occurred at the sharp curve edges of the die. This paper provides the FE analysis of cold work plain strain forward extrusion extruded with four different lubricant quantities of the RBD palm stearin (PS). FE method was applied in the analysis in order to investigate the extrusion load and friction coefficient between two contact sliding surfaces in steady state condition.
II. EXPERIMENT

The investigation was carried out at room temperature. In this experiment, annealed pure aluminium A1100 was used as billet. Meanwhile, taper die was treated to heat treatment which is made of hot work tool steel SKD11. The RBD palm stearin lubricant was used and the conditions employed are 0.1 mg, 1 mg, 5 mg and 20 mg. The extrusion rig is in accordance to the appropriate criteria for the experiment. The hydraulic press machine was used to press the punch in the extrusion process. The data results were collected by using computer software. The micro-weight scale was used to measure the lubricant quantities. The billet and taper dies were shaped by using NC wire cut electric discharge machining device. The surface of taper dies which is in contact to the billet, was cleaned and polished with ethanol and abrasive paper.

The first experiment set up was to ensure all components are clean and in good condition. The outer wall, container, dies, punch and billets were cleaned with ethanol as to remove grease before all components were lubricated with lubricant in each experiment. The lubricant quantity in amount of 20 mg was applied constant onto the plane of the dies and it was measured by using micro-weight scale. The lubricated dies were carefully placed in the dies holder and it must be symmetrically positioned. The billet was placed in between of the dies carefully. The extrusion rig was assembled together and then it was put at the centre part of the hydraulic press machine. Load readings were recorded at every 0.01 s downward movement of the punch which was measured by the dial gauge indicator. As a result, the extrusion load vs. stroke graph was plotted for four different lubricant quantities. Once the punch movement is stopped at 30 mm downward, the dies were disassembled and the split dies were opened to remove the extruded product. The whole procedure was repeated for the other lubricant quantities.

III. FINITE ELEMENT METHOD

A. Finite Element Model

The FE model in the simulation is shown in Figure 1, which is designed in accordance to actual specimen in experimental work. The die-billet geometries were in accordance to the experimental work thus gave an extrusion ratio of 3, extrusion angle of 45°, and square billet. The square billet has an initial width of 15 mm, final width, W of 5 mm, container height of 70 mm, taper height of 5 mm and thickness of 9 mm. The geometry, constraint condition, and displacement for pure aluminium plain strain forward extrusion are two-dimensional half symmetry. The FE model utilized 4-node elements and a fine uniform mesh was applied in the billet to reduce computational cost and to ensure accurate analysis. The billet was treated as elastic-plastic material behaviour. The punch and die were modelled by an analytical rigid surface because they were assumed to be rigid bodies and no deformation occurred during extrusion.

B. Material Characteristics

The material behaviour was an essential parameter for the FE analysis. It was used as an input parameter to generate an output for specific material based on its characteristics. Material utilized in the extrusion process has to be compressible, so that the material can be easily flow through the die opening. The aluminium A1100 was tested and the specimen geometry was designed from ASTM E-8 standard. Table 1 shows the general value of material properties. The true stress-strain data shown in Figure 2 was utilized by Abaqus. Hence, in this FE analysis, the aluminium A1100 behaved as a ductile and deformable material, meanwhile, the material for the die was steel SKD11 and performed as a rigid wire body.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density, ( \rho )</td>
<td>kg/m³</td>
<td>2700</td>
</tr>
<tr>
<td>Modulus of elasticity, ( E )</td>
<td>GPa</td>
<td>68.9</td>
</tr>
<tr>
<td>Initial yield stress, ( \sigma_y )</td>
<td>MPa</td>
<td>56.3</td>
</tr>
<tr>
<td>Poisson ratio, ( \nu )</td>
<td>-</td>
<td>0.33</td>
</tr>
</tbody>
</table>

Figure 3. Uniaxial tensile test results for aluminum AA1100.

IV. VALIDATION OF FINITE ELEMENT METHOD

The cold work forward extrusion model was verified by attaining a load-displacement result comparison between the FE computation and Gouveia et. al. [10]. An accurate and
reliable result produced could be then used to substantiate the data from FE analysis. Figure 3 demonstrates the result computed using FEM, which overlapped onto the result produced by Gouveia et. al. Based on this evidence, FE computation has proved that it was reliable and can be used to generate precise data that was close enough to the experimental value [9]. As a result, the FE analysis of cold forward extrusion was behaved as in the actual process and that makes it agreed to perform further investigation.

Figure 3. Comparison of extrusion load-displacement for the FE model.

V. RESULTS AND DISCUSSION

Figure 4 illustrates the extrusion load curve recorded during experiment and predicted by FE analysis as a function of punch stroke imposed on top of the aluminum billet. In this case, steady state FE analysis was performed in order to verify the experimental work. The steady state cold work forward extrusion was analyzed using Arbitrary Lagrangian-Eulerian (ALE) mesh formulation, which was readily derived from FE software; Abaqus. The non-linear FE analysis using Adaptive Lagrangian Eulerian was designed for the cold forward extrusion to solve the excessive distortion of mesh elements and to reduce computational cost.

The extrusion load produced exhibit undesirable oscillations. In particular, the maximum deviation was found between 17 percent and 21 percent. To reduce the oscillations, the size of FE model was enlarged by increasing the total number of elements [10]. The FE analysis showed that the extrusion load obtained from the billet extruded with 0.1 mg lubricant quantity was greater compared to 1.0 mg, 5.0 mg and 20.0 mg lubricant quantities. Meanwhile, the lowest extrusion load distributions obtained on the billet extruded with 5.0 mg PS lubricant quantity, while 20.0 mg lubricant quantity increased the extrusion load. It can be seen that the lubricant quantity was depended on friction coefficient [11].

Figure 4. Steady state analysis of load-displacement for (a) 0.1 mg, (b) 1.0 mg, (c) 5.0 mg, and (d) 20.0 mg.
From Figure 5, this phenomenon showed that the lowest friction coefficient of 0.08 extruded by 5.0 mg lubricant quantity was within mixed lubrication regime. From Table 3, it is evident that the maximum extrusion load corresponds to friction coefficient. The FE analysis represented the largest friction coefficient extruded by 0.1 mg lubricant quantity which required the largest extrusion load to successfully extrude the aluminium billet. Meanwhile, the 5.0 mg lubricant quantity required the lowest extrusion loads. Figure 6 clearly revealed that the extrusion load is a function of friction coefficient. The FE analysis of cold work forward extrusion utilized extrusion loads of 52850 kN, 44486 kN, 42992 kN and 43558 kN were obtained numerically using friction coefficient of 0.13, 0.10, 0.08 and 0.09, respectively. These results indicated that the low friction coefficient reduced the extrusion loads. This is due to the reduced lubricant quantity between die and billet sliding surface leading to lower friction coefficient and as a consequence, the extrusion loads reduced as well.

Table 2. Maximum extrusion load (kN).

<table>
<thead>
<tr>
<th>Lubricant</th>
<th>Friction Coefficient, $\mu$</th>
<th>Experiment</th>
<th>FE Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 mg</td>
<td>0.13</td>
<td>50,413</td>
<td>52,850</td>
</tr>
<tr>
<td>1.0 mg</td>
<td>0.10</td>
<td>42,760</td>
<td>44,486</td>
</tr>
<tr>
<td>5.0 mg</td>
<td>0.08</td>
<td>40,708</td>
<td>42,992</td>
</tr>
<tr>
<td>20.0 mg</td>
<td>0.09</td>
<td>41,889</td>
<td>43,558</td>
</tr>
</tbody>
</table>

Figure 6. The effect of coefficient of friction on the extrusion load.

VI. CONCLUSION

A successful experimental and FE analysis for solid fraction RBD palm stearin lubrication on the die-billet contact surface has been discussed. The extrusion load distributions were successfully evaluated based on lubricant quantities and friction coefficients on the die-billet contact surfaces. The FE model was reliable once a good agreement with the established work was found thus it confirmed the accuracy of the FE model. The extrusion loads obtained for the four different weights of RBD palm stearin lubricant quantities experimentally was within 40.7 kN and 50.4 kN, and the analysis using FE method between 42.9 kN and 52.9 kN, meanwhile the friction coefficients was observed using FE method in a range of 0.08 to 0.13. The analysis shows the influence of the RBD palm stearin lubricant quantity outside the range of 1.0 mg and 5.0 mg causes the greater friction resistance on the tapered die sliding surfaces, particularly close to the exit of the die region. The extrusion load and friction coefficient from experiment and FE results lead to the conclusion that the optimum lubricant quantity can reduce the friction resistance on the taper die contact surfaces, particularly close to the die exit. The FE method and experimental analysis performed show that the lubricant quantity in an amount of 5 mg can results the lowest extrusion load and friction coefficient compared to other lubricant quantities.

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