Performance evaluation of lubricant for producing smooth surface product in cold extrusion of aluminum using tool with micro-groove arrays

Shunpei Kamitani*, Kenji Nakanishi, Yong-Ming Guo

Abstract

The effects of lubricating oil on surface quality of the extruded aluminum product were investigated by carrying out a series of plane strain cold extrusion experiments. The forming dies of extrusion apparatus were assembled with a combination of the taper die and the plane plate tool with the micro-groove arrays formed on its surface. Four lubricants were tested by using the above apparatus. Then, adhesion of aluminum billet to the surface section of the plane plate tool on which the micro-groove arrays were formed, surface roughness of the billet after passing through the above section of the plane plate tool and surface conditions of the billet and tool at the die bearing section of a tool were investigated, and performance evaluation of lubricant for producing smooth surface product could be carried out successfully.

Keywords: Aluminum; Cold extrusion; Adhesion; Micro-groove arrays

1. Introduction

Kamitani et al. (2008, 2009, 2011) investigated surface finishing of extruded product of aluminum billet by carrying out a series of plane strain cold extrusion experiments using the apparatus in which a combination of...
taper die and plane plate tool with the micro-groove arrays formed on its surface was used as the forming tools. A proper combination of factors such as tool material, groove shape, groove location on the tool surface and lubricant is important to achieve the smooth surface of product extruded by using the tool with micro-groove arrays.

Then, four lubricants involving two mineral oils and two vegetable oils known as highly biodegradable oils were tested, and the following subjects related to surface finishing of extruded product of aluminum were investigated: i.e., (a) adhesion phenomenon of aluminum billet to the tool at the surface section on which the micro-groove arrays were formed, (b) surface roughness of the billet after passing through the above tool surface section, and (c) surface conditions of the billet and tool at the die bearing part of a tool.

The results which are available to selection of proper lubricant to achieve smooth surface of aluminum product in cold forming by using the tool with micro groove arrays on its surface are reported in the present paper.

2. Experiments of the forming condition in a metal forming process

2.1. Experimental apparatus

Fig. 1 shows the plane strain extrusion apparatus used in the present investigation. The apparatus consists of the container walls, taper die, billet and plane plate tool. The taper die has 45 degrees die half angle. Extrusion ratio was two in this apparatus. The dies and containers were made of the tool alloy steel, SKD11 (JIS), and hardened and tempered. Hardness of the dies is approximately 700 HV and surface roughness of the test surface of plane plate tool, except the micro-groove arrays formed on its surface, is finished in 0.05 μmRa.

Aluminum A1050 (JIS) was used as the billet. The workpiece consisted of two pieces of billet having dimensions of 80 mm length x 15 mm width x 5 mm thickness. The billets were annealed by furnace cooling after heating in half an hour at 350°C. Hardness of the billet was 23 HV. Surface roughness of the test surface of the billet, measured along the direction perpendicular to the extrusion direction, was finished in 0.3 μmRa. The billet was split into two halves along the observation plane. A square grid line pattern was scribed on the observation plane of the plastic flow of the billet. The grid lines were V-shaped grooves with 0.07 mm in depth and 0.1 mm in width and those grid lines were machined with 1mm spacing on the observation plane of plastic flow by using the NC milling machine.

![Fig.1. Plane strain extrusion apparatus.](image)

2.2. Experimental conditions

The simple plane plate tools and the plane plate tools with groove arrays on those surfaces were prepared to investigate the lubricating properties of lubricants applied on the tool surfaces. Fig. 2 shows longitudinal configuration and dimensions of the micro-groove arrays. The micro-groove arrays involve three grooves separated with 1 mm spacing and were located in the range between y=5.5 mm and y=7.5 mm on the surface of plane plate
tool. The depth and width of a groove having cross sectional configuration of U-shape were 0.44 and 0.2 mm, respectively. Those grooves were machined by using the wire-cut electric discharge machine.

The mass of initial oil film on the test surface of plane plate tool was set to 5 mg (0.48 mg/cm²) at each testing by using the electronic balance. Approximately equal amount of paraffinic mineral oil VG460 was applied to all other contact surfaces in experiments. Test oils having almost the same degree of viscosity were paraffinic mineral oil VG32 (P2), naphthenic mineral oil VG22 (N2), rapeseed oil (RS; equivalent to VG32) and soybean oil (SB; equivalent to VG32). Experiments were carried out at room temperature.

Kamitani et al. (2008, 2009) reported that once the cross sectional configurations of the grooves were changed with inflow of billet material to the grooves at an initial extrusion process, additional inflow of billet material to the grooves did not occur and pickup on the tool surface was peeled off at the successive extrusion processes. While, depth of U-shape groove formed on the tool surface was designed deeper in the present tools than that of previous tools, so that adhesion of billet material to the tool surface section on which micro-groove arrays were formed could occur heavily.

For the above reasons, two types of tests were carried out for performance evaluation of the lubricants. For the evaluation of adhesion of aluminum billet to the tool surface at the section of micro-groove arrays, new tool with the micro-groove arrays on its surface was used in the first experiment. Then, successive extrusion tests were carried out by using the same tool at several times without polishing the surface of the tool and with only wiping the tool surface with acetone.

For the evaluation of surface conditions of the billet passing from the section of micro-groove arrays to the die bearing section of a tool, re-polished used tools with micro-groove arrays on those surfaces were used for the experiments. In those cases, adhesion to the tool surface section with micro-groove arrays and inflow of billet material to the grooves did not occur and the conditions of grooves were kept as same as those at before experiment in the extrusion tests.

2.3. Experimental method

The oil-hydraulic press was used for experiments. The extrusion was ceased abruptly at press ram stroke 33mm in the steady state extrusion condition in which the extrusion speed was held at the constant value. Extrusion load and displacement of press ram were measured during the extrusion process.

After the experiments, surface qualities of plane plate tool and partially extruded billet were evaluated by measuring the surface roughness and by microscopic observation.

3. Results

3.1. Adhesion of the micro-groove arrays section on tool surface

Fig. 2. (a) Coordinate system, y-direction and location of micro-groove arrays formed on plane plate tool and (b) cross section photographs of new and re-polished used groove arrays tools before any experiment run.
Fig. 3 shows the photographs of the micro-groove arrays section of tool surface in some extrusion tests. Adhesion of aluminum to the tool surface occurred at the micro-groove arrays section in the all conditions of tested lubricating oils. But the degree of adhesion to the tool surface was different between mineral oils and vegetable oils. Amount of adhesion of aluminum to the tool surface at the section of micro-groove arrays was larger when vegetable oils were used as lubricants than that when mineral oils were used. The volume of adhesion of aluminum on the groove arrays section diminished with the accumulative number of extrusion test for the same oil conditions. The degree of aluminum adhesion to the tool surface was ordered as rapeseed oil > soybean oil > paraffinic mineral oil = naphthenic mineral oil.

<table>
<thead>
<tr>
<th></th>
<th>Paraffinic mineral oil</th>
<th>Naphthenic mineral oil</th>
<th>Rapeseed oil</th>
<th>Soybean oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st test</td>
<td>P2</td>
<td>N2</td>
<td>RS</td>
<td>SB</td>
</tr>
<tr>
<td>2nd test</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 3. Photographs of micro-groove arrays section of tool surface after any experiment run.

3.2. Evaluation of the billet surface after passing through the section of micro-groove arrays by using re-polished used micro-groove arrays tool

Fig. 4 shows the extrusion loads for each oil condition using the simple plane plate tool without the micro-groove arrays and with the micro-groove arrays.

The extrusion loads increased in all extrusions using the tool with micro-groove arrays on its surface. Fig. 5 shows the arithmetic mean surface roughness Ra of billet measured perpendicular to the extrusion direction on the simple plate tool without the micro-groove arrays as (a) and with the micro-groove arrays on its surface as (b). Figure 6 shows the photographs of the test surface of extruded billets in each experimental condition. The values of surface roughness of billet for product surface (y<0 mm) were constant in the tool conditions without the micro-groove arrays, while the values in the tool conditions with the micro-groove arrays varied with lubricating oils. The surface roughness of the product surface in paraffinic mineral oil were smooth, on the other hand, that of the billet in soybean oil was rough due to aluminum adhesion after passing through the micro-groove arrays.
section on the tool. The values of surface roughness of the product surface in rapeseed oil and naphthenic mineral oil increased rapidly after passing through the exit of plane plate tool (y=0 mm).

![Graph showing surface roughness](image)

Fig. 5. Surface roughness Ra of billet measured perpendicular to the extrusion direction on plane plate tool after second runs of the experiment (a) without micro-groove arrays and (b) with re-polished micro-groove arrays.

![Comparisons of extruded billet surface](image)

Fig. 6. Comparisons of extruded billet surface after second runs of experiment for each oil condition using plane plate tool without micro-groove arrays and with re-polished micro-groove arrays.

### 3.3. Evaluation of adhesion to the tool surface part from the micro-groove arrays to the die exit

Several experiments were carried out by using the re-polished used tool. New adhesion to the micro-groove arrays part of the tool was not observed after experiments using the re-polished used tool. After experiment, on the tool surface part from the micro-groove arrays to the die exit, adhesion of aluminum was observed in the condition of soybean oil, but in other lubricants, adhesion to the tool surface were not observed until the die exit, and the billet surface were smooth.

### 3.4. Evaluation of adhesion on the die bearing section

The product surface of billet passed through on the die bearing section with elastic recovery and slip. In this part, in the case of naphthenic mineral based oil and rapeseed oil, heavy adhesion was observed and surface
roughness of billet increased. Similar adhesion was observed in the case of soybean oil and that occurred from the micro-groove arrays part to the die exit. Product surface in the case of paraffinic mineral oil was only maintained the smooth surface on the die bearing parts as shown in Fig. 6.

4. Discussion

In the experiments, the contact condition between tool and billet was under very thin oil film, the high pressure and shearing force and sliding by using the micro-groove arrays tool. In these results, mineral oils show better lubrication characteristics than vegetable oils. Moreover, lubrication performance of paraffinic mineral oil and rapeseed oil was better in the same kind of oils.

The reasons for these results are considered as below. Syahrullail et al. (2012) reported that refined, bleached, and deodorized palm olein and palm stearin reduce the frictional constraint and extrusion load in cold extrusion. Miyagawa et al. (1979) reported that the spreading behavior of oils could be decreased by polar molecular included in the lubricant. Fatty acids contained in vegetable oil behave as the boundary lubricating film and reduce the friction. While, the contact surface conditions between billet and tool after passing through the tool section with groove arrays were severe to supply sufficient volume of oil in the present experiments. Then, the bad liquidity of oils was induced by strong absorption of rapeseed oil and soybean oil. Israelachivili et al. (1990) found that the properties of molecularly thin liquid films between two surfaces depend not only on the type of forces between the liquids and surfaces, but also on the atomic structure of the confining surfaces. Two types of mineral oil have different viscosity characteristics due to the difference of molecular structure. The viscosity characteristic of naphthenic mineral oil is affected strongly by naphthene ring structure included in the oil. Naphthenic mineral oil is considered to show higher viscosity behavior and bad liquidity than paraffinic mineral oil due to naphthene ring structure in the very thin oil film condition.

5. Conclusions

In the present investigation, performances of four lubricants were tested and the results were summarized as follows:

(1) Amount of adhesion of aluminum to the tool surface at the area of micro-groove arrays is larger when vegetable oils are used as lubricants than that when mineral oils were used.

(2) Surface roughness of the billet becomes large in the plastic deformation zone after passing through the area of micro-groove arrays in lubrication condition using soybean oil. While, surface roughness of the billet is kept in smoothness until near the exit zone of the plastic deformation zone in lubrication condition using the other lubricants.

(3) Surface roughness of the billet tends to become rough at the die bearing section after passing through the deformation zone due to occurrence of adhesion of aluminum to the tool surface when the naphthenic mineral oil, rapeseed oil and soybean oil are used as lubricants. Whereas, smooth surface roughness of the billet is maintained at the above part when paraffinic mineral oil is used as lubricant.

References


