

Lubrication Performance of Palm Olein in Cold Extrusion of Aluminum Alloy Using Tool with Pits Arrays Surface

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The effects of lubricants on extrusion load were investigated in the plain strain extrusion experiments using the tool with the micro-pits arrays on its surface. Paraffinic mineral oil and RBD palm olein were used as lubricants in the experiments. The property of RBD Palm olein is affected by temperature for the reason that its melting point is about 23 °C. We investigated the effect of the micro-pits arrays formed on the tool surface in the two different conditions of RBD palm olein. The plane strain extrusion type experimental apparatus consists of the container wall, flat die, workpiece and plane plate tool. The micro-pits arrays were formed on the plane plate tool surface at the deformation zone of a workpiece. Workpiece was Al-Mg alloy A5083 (JIS). The material flow conditions in the deformation zone were analyzed by applying the visio-plasticity method. All results were compared mutually in terms of extrusion load, billet surface roughness and effective strain, comparing with those values measured in extrusion using plane plate tool having flat surface. The steady state extrusion load in extrusion using the micro-pits arrays formed on the tool surface is decreased in the semi-solid condition of RBD palm olein, however, the extrusion loads in the liquid condition of RBD palm olein and paraffinic mineral oil are not affected with the micro-pits arrays on the tool surface, comparing with the plane plate tool having flat surface.

Keywords: *extrusion, visio-plasticity analysis, lubrication, surface texture, palm olein*

1. Introduction

Surface texture of a tool is one of the important tribological parameters in a metal forming process. In metal forming process, proper surface textures can improve the product quality and workpiece formability [1]. In the drawing and ironing processes, small pits formed on the workpiece surface work as the micro oil pools by which the lubricant is supplied to form the fine surface products [1, 2]. In the rolling process and strip drawing tests, the micro textures formed on the tool surfaces reduce the friction between the tool and the workpiece effectively [3, 4].

Previously, we had carried out the cold extrusion experiments by using the apparatus of forward extrusion type [5, 6]. The experiments using the Al-Mg alloy (A5083-JIS) workpiece and the tool with pits arrays were also carried out by the same apparatus [7]. Lubricants used in the above experiments [7] were naphthenic mineral oil, paraffinic mineral oil and RBD palm olein. The high biodegradable vegetable oil such as RBD palm olein as a lubricating oil in the metal forming will contribute to the environment preservation and the CO₂ reduction problem.

The effects of lubricants on the friction condition at the tool and workpiece interfaces, material flow characteristic and product surface condition were investigated. Then, the following aspects written below were observed. The steady state extrusion load in extrusion using the tool with pits arrays increased when the naphthenic mineral oil was used, however, that value decreased when RBD palm olein was used [7].

In the present research, a series of the cold plane strain extrusion experiments were carried out by using the tool with the micro-pits arrays formed on its surface. The workpiece (billet) material was Al-Mg alloy (A5083-JIS) and lubricants were paraffinic mineral oil and RBD palm olein. The extrusion load with regard to press ram stroke and surface roughness of the products were measured and the material flow and effective strain in the workpiece (in the billet) were analyzed quantitatively by using the visio-plasticity method, and we confirmed that the micro-pits arrays could be used as a texture pattern to control the extrusion load.

2. Experimental apparatus and experimental method

2.1 Experimental apparatus

Fig. 1 shows the schematic sketch of the plane strain extrusion apparatus [5-7]. The apparatus consists of the container wall, the flat die, the plane plate tool and the billet. Only the pure shear deformation occurs in the billet by the frictional constraint between the tool and billet surfaces at the plane plate tool side.

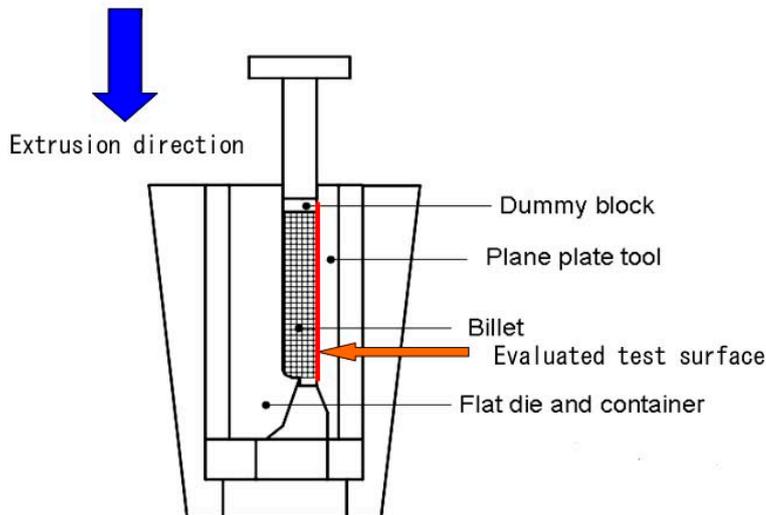


Fig. 1 Forward extrusion-type testing apparatus using the plane plate tool (Extrusion ratio: 2).

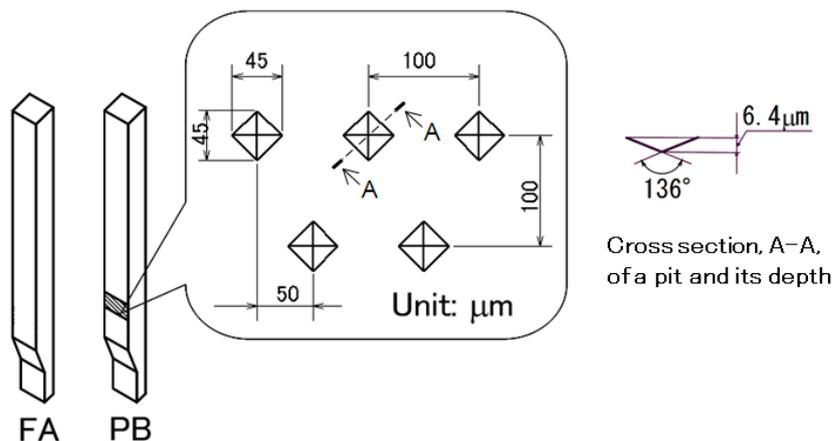


Fig.2 Pits arrays formed on the tool surface and cross section of a pit.

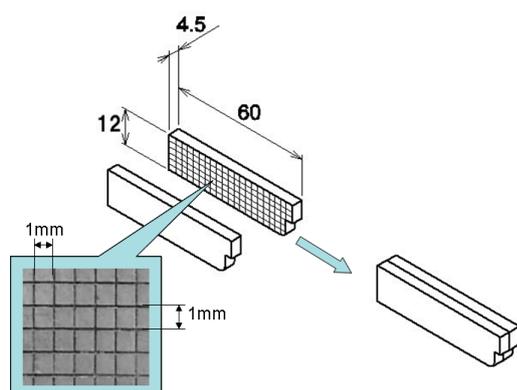


Fig. 3 Schematic illustration and dimensions of the workpiece (billet). (in mm)

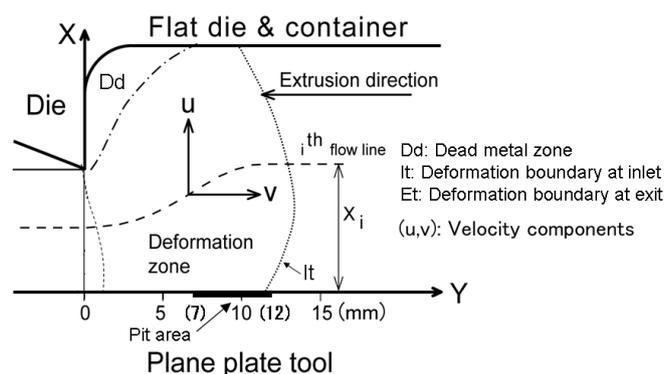


Fig. 4 Coordinate system used in the analysis.

Two types of plane plate tools were prepared. One was the plane tool with flat surface, FA. The other was the plane tool with the pits arrays, PB. The pits arrays were formed on the surface of the plane plate tool at the position in the deformation zone of a billet. Configuration of the pit was the reverse pyramids having 136 degrees apex angle between the faces of the pyramid and 45 μ m diagonal length. The location of pit on the plane plate tool is shown in Fig.2. The total area occupied by the pits arrays was about 11% of the shaded area of the tool surface (ref. to Fig.1). The dies and the containers were made of the tool alloy steel, SKD11 (JIS), and hardened and tempered. Extrusion ratio was two. Hardness of dies was 720HV and surface roughness on the test face was finished in 0.05 μ mRa.

Fig. 3 shows the schematic illustration of the billet split into two halves along the observation plane. Workpiece was Al-Mg alloy A5083 (JIS). The surface roughness, measured along on the direction perpendicular to the extrusion direction, on the contact surface, is 0.25 μ mRa.

Then, one side of the contact surfaces of the stacked billets was the observation plane of plastic flow in plane strain extrusion, which was not affected with the frictional constraint by the parallel sidewalls. 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 0.07mm deep and 0.1mm wide, and those grid lines were machined with 1mm spacing on the observation plane of plastic flow by using the NC milling machine. The billets prepared by the above procedure were annealed by furnace cooling after heating 2 hours at 350 $^{\circ}$ C so that the rolling texture was annihilated and the recrystallized structure with isotropic mechanical properties could be established. Hardness of the billet was 80HV.

2.2 Experimental conditions

The effects of lubricants on the extrusion load and material flow of workpiece were investigated in the plain strain extrusion experiments by using the plane tool with the pits arrays formed on its surface and the plane tool with flat surface.

RBD palm olein, PO (PO in semi-solid state at 18 $^{\circ}$ C and PO in liquid state at 30 $^{\circ}$ C) and paraffinic mineral oil, P2 (VG32, kinematic viscosity: 90mm²/s at 18 $^{\circ}$ C and 48mm²/s at 30 $^{\circ}$ C) were used as lubricants in the experiments. Pour point of PO is in the range 23 to 24 $^{\circ}$ C and its kinematic viscosity at 30 $^{\circ}$ C in liquid is 46mm²/s.

Application of Initial lubricant on the test die surface is set in 15mg (2.2mg/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.

The effect of lubrication condition can be observed as metal flow characteristics affected with the difference of friction on surfaces of dies. All experiments were carried out at room temperature 18 $^{\circ}$ C or 30 $^{\circ}$ C.

2.3 Experimental and analytical method

The workpiece (billet) in the apparatus was extruded by the oil-hydraulic press, and the extrusion was ceased abruptly at press ram stroke in the range 33 to 38mm, in the steady state extrusion condition in which the extrusion speed was held at the constant value. The extrusion load and the displacement of press ram were measured during extrusion process. Surface conditions were evaluated by measuring the surface roughness and by microscopic observation. The material flow characteristics and effective strain, in steady state extrusion was observed and analyzed by applying the visio-plasticity method [5-8].

Fig. 4 shows the coordinate system used in the analyses and the following equations (1) to (6) were used in the numerical analyses.

Flow function ψ_i (mm²/s) :

$$\psi_i = X_i |V_0| \quad (1)$$

Velocity components (u, v) (mm/s) :

$$u = \frac{\partial \psi}{\partial Y} \quad (2)$$

$$v = -\frac{\partial \psi}{\partial X} \quad (3)$$

Strain rate components ($\dot{\varepsilon}_X, \dot{\varepsilon}_Y, \dot{\gamma}_{XY}$) (s⁻¹)

$$\dot{\varepsilon}_X = \frac{\partial u}{\partial X}, \quad \dot{\varepsilon}_Y = \frac{\partial v}{\partial Y}, \quad \dot{\gamma}_{XY} = \frac{\partial u}{\partial Y} + \frac{\partial v}{\partial X} \quad (4)$$

Effective strain rate $\dot{\varepsilon}$ (s⁻¹)

$$\dot{\varepsilon} = \frac{2}{3} \sqrt{3\dot{\varepsilon}_X^2 + \frac{3}{4}\dot{\gamma}_{XY}^2} \quad (5)$$

Effective strain ε (time integration value of the effective strain rate along the flow line)

$$\varepsilon = \int \dot{\varepsilon} dt \quad (6)$$

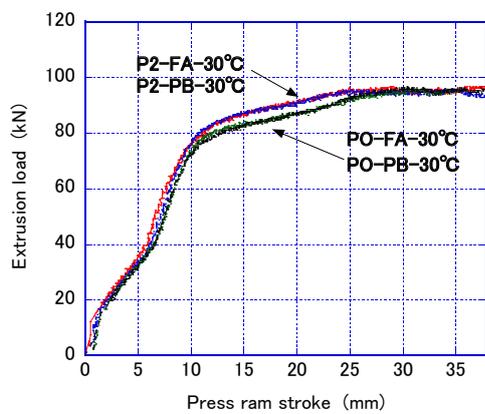
In the equations, V_0 is the velocity of the press ram, and X_i is the distance of the i -th flow line from the Y coordinate axis ($X=0$), in the region where deformation does not occur.

3. Results and discussion

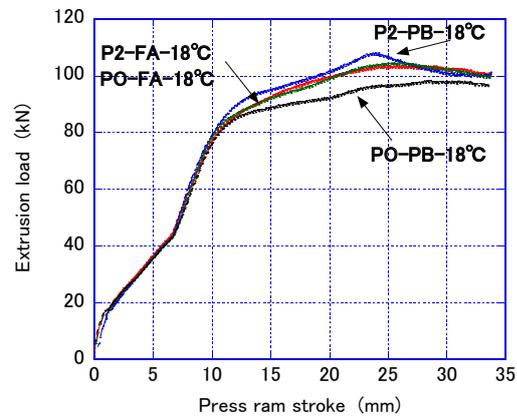
3.1. Extrusion load-stroke curves

Fig. 5 shows the relation between extrusion load and press ram stroke in extrusion speed in the range 4.66 mm/s to 4.89 mm/s. In the temperature condition at 30 °C (the liquid condition for PO), extrusion load could not be affected by lubricants and pits arrays at press ram stroke 30mm in steady state condition. In the range of press ram stroke in the range 10 to 25mm, the extrusion load in extrusion using PO (PO-FA-30 °C, PO-PB-30 °C) is lower than that in extrusion using P2 (P2-FA-30 °C, P2-PB-30 °C) regardless of the difference of tool surface texture. It is considered that the difference of increasing rate of viscosity under high pressure affects loads in the range of press ram stroke in the range 10 to 25mm. The extrusion load was decreased in extrusion using the plane tool with the pits arrays and PO-PB-18 °C in the semi-solid condition. The pits arrays formed on the tool could reduce the work load. It could be considered that the above reduction of extrusion load is caused by the reduction of generated pressure and reduced contact area due to occupation of the pits arrays on the tool surface.

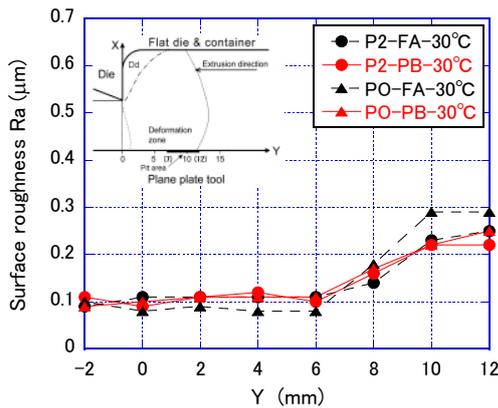
These results suggest that the selection of lubricant is very important for the utility of tool surface texture.



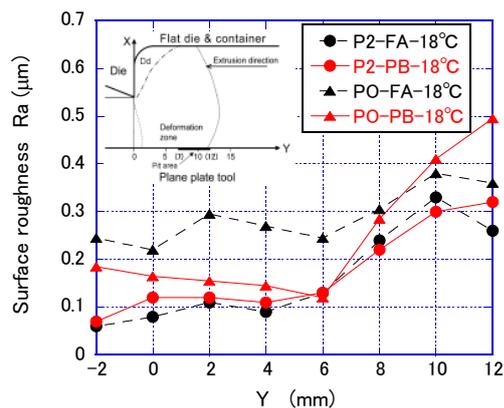
(a) PO in liquid condition at 30 °C.



(b) PO in semi-solid condition at 18 °C.

Fig.5 Extrusion load – press ram stroke curves.

(a) PO in liquid condition at 30 °C.



(b) PO in semi-solid condition at 18 °C.

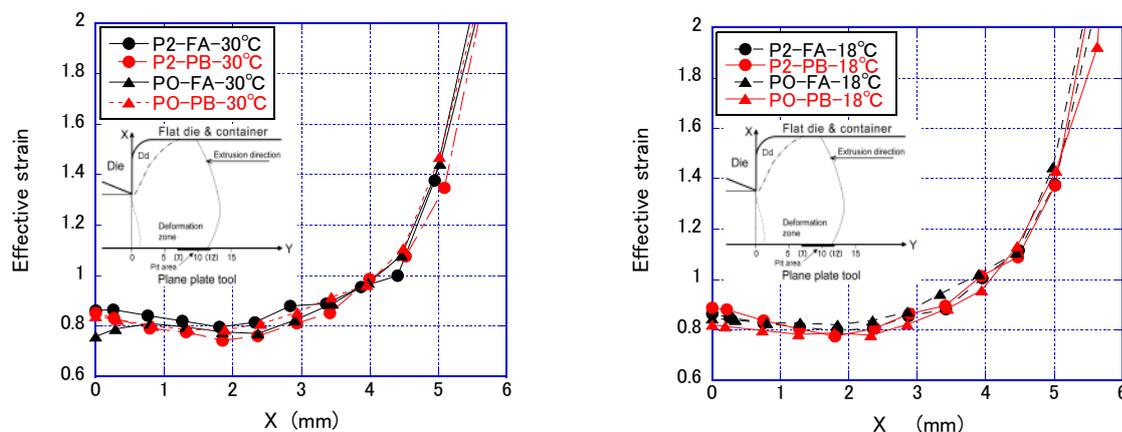
Fig. 6 Surface roughness Ra of workpiece along the plane plate tool.

3.2. Surface roughness

Fig. 6 shows the arithmetic mean surface roughness Ra of workpiece measured perpendicular to the extrusion direction on the plane plate tool. There is no adhesion on the tool surface in each condition.

For the conditions at 30 °C (the liquid condition for PO), there is no difference of product surface between the extrusion using the plane tool with flat surface and that using the plane tool with the pits arrays. The values of the surface roughness of the product ($y=-2\text{mm}$) were in the range 0.09 to 0.11 μmRa in each condition. For the conditions at 18 °C (the semi-solid condition for PO), the values of the surface roughness of the product surface ($y=-2\text{mm}$) in P2 lubricant were 0.07 μmRa in extrusion using the plane tool with or without the pits arrays. However, the values of the surface roughness of the product surface ($y=-2\text{mm}$) in PO lubricant were 0.25 μmRa in the PO-FA-18 °C condition and 0.19 μmRa in the PO-PB-18 °C condition.

3.3 Distribution of the effective strain



(a) PO in liquid condition at 30 °C.

(b) PO in semi-solid condition at 18 °C.

Fig. 7 Distribution of the effective strain of workpiece along X axis at exit of deformation zone.

Fig. 7 shows the distribution of effective strain in the workpiece (billet) at the exit deformation zone. The effective strains in extrusion were almost same in extrusion using the plane tool with or without the pits arrays.

Effective strain of PO-FA-30 °C in the liquid condition, at around the contact surface (within 0.5 mm depth from the test surface) is smaller than those of the other conditions. It is considered that the constraint of tool surface in PO-FA-30 °C in liquid condition was stronger than the others for the reason of small surface roughness referred in Fig.6 (a) .

4. Conclusions

The plane strain cold extrusion tests using the billet of Al-Mg alloy A5083 were carried out. The effect of the pits arrays formed on the plane plate tool was investigated when RBD palm olein and paraffinic mineral oil were used as lubricants. It is found that the extrusion load is affected with the micro-pits arrays. The extrusion load decreases in the semi-solid condition of RBD palm olein with the pits arrays. The above effect could not find in the other conditions. These results suggest that the selection of lubricant is very important for the utility of tool surface texture. The effective strains in extrusion were almost same in extrusion using the plane tool with or without the pits arrays.

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