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Experimental and numerical analysis of friction in high aspect ratio combined forward-backward extrusion with retreat and advance pulse ram motion on a servo press

Ryo Matsumoto*, Kazunori Hayashi, Hiroshi Utsunomiya

Division of Materials and Manufacturing Science, Graduate School of Engineering, Osaka University, 2-1 Yamadaoka, Suita 565-0871, Japan

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ABSTRACT

A method for maintaining lubrication in the backward extrusion of deep holes for lightweight structural components is proposed utilizing a servo press and a punch with an internal channel for liquid lubricant supply. In this forming method, the punch is pushed into the specimen with a servo press in a manner that combines pulsed and stepwise modes. Sufficient liquid lubricant is periodically supplied to the deformation zone through the internal channel upon the retreat of the punch. This forming method with pulse punch ram motion was tested in combined forward-backward extrusion process with a high aspect ratio (height/diameter) in this study. The material flow of the aluminum specimen during the extrusion with pulse punch ram motion was investigated to determine the coefficient of shear friction at the specimen–punch interface. The punch wear was assessed by a finite element analysis of the material flow of the specimen during the extrusion with pulse punch ram motion.

1. Introduction

The programming of the ram speed and motion of servo presses with a servomotor through CNC control has led to new forming processes. Osakada et al. (2011) have reviewed servo press designs and their major applications in sheet metal forming and bulk metal forming processes. For example, Palaniswamy and Altan (2003) developed heating and stamping processes for Mg sheet with a servo press. Maeno et al. (2011) reduced the friction in cold plate forging with a servo press by implementing load pulsation. Groche and Moller (2012) investigated the friction in deep-drawing processes with a servo press that utilizes forming speed control. Terano et al. (2013) investigated the shape accuracy of the products forged on a servo press under several press ram motions.

For the fabrication of lightweight components such as hollow components, we have proposed an extrusion method for forming deep holes with a servo press that utilizes a punch with an internal channel for the supply of liquid lubricant (Matsumoto et al., 2011). The concept of this forming method was derived from the machining of deep holes with tools that have internal channels for lubricant. In machining, an internal channel for lubricant in a drill makes it possible to cut deep holes by supplying lubricant to the cutting part (Weinert et al., 2004). It has been demonstrated that this forming method prevents galling in the backward extrusion of holes with an aspect ratio (height/diameter) of six when the appropriate punch ram motions are applied. In addition, it has been confirmed that this forming method provides formed holes with high shape accuracy (Matsumoto et al., 2013). However, the friction and punch wear in this forming method with pulse punch ram motion have not previously been investigated.

It is difficult to directly measure the friction at the specimen–punch interface during forming with pulse punch ram motion. Sagisaka and Nakamura (2007) developed a testing method for determining the friction at the specimen–punch interface during combined forward-backward extrusion with aspect ratio of one. In this method, the friction was estimated from the material flow of the specimen in the forward and backward extruded parts. Murai et al. (2009) investigated the material flows of specimens during combined forward-backward extrusions with aspect ratios in the range of 0.4–2.0. The material flow and friction in combined forward-backward extrusion with aspect ratios greater than two have rarely been investigated.

In this study, the forming method with pulse punch ram motion is applied to combined forward-backward extrusion with a high aspect ratio. The relationship between the punch motion and the material flow of the aluminum specimen is investigated in extrusion with pulse punch ram motion. The friction and punch wear are determined by analyzing the material flow of the specimen during

* Corresponding author. Tel.: +81 6 6879 7500; fax: +81 6 6879 7500.
E-mail address: ryo@mat.eng.osaka-u.ac.jp (R. Matsumoto).

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extrusion with pulse punch ram motion by both experiment with a servo press and the finite element analysis.

2. Extrusion with pulse punch ram motion

2.1. Combined forward-backward extrusion method

The extrusion method for reducing the friction over the punch surface is shown in Fig. 1 (Matsumoto et al., 2011). The punch with an internal channel for lubricant flow is pushed into the specimen in a manner that combines pulsed and stepwise modes and assists the supply of liquid lubricant from the punch nose. The punch is connected to a lubricant tank, and the lubricant is supplied to the internal channel from the tank. During forming with a manner that combines pulsed and stepwise modes, the internal pressure in the cavity formed in the previous forming steps is depressurized by the retreat of the punch, and the lubricant is sucked into the cavity through the internal channel (Fig. 1(b)). In this method, no pump and/or check valve for the prevention of backward flow is used in the supply of the lubricant from the punch nose. The lubricant is sucked into the deformation zone because of the change in the internal pressure in the cavity. After the retreat of the punch, the punch is advanced again to continue the forming of the hole (Fig. 1(c)). Each advance of the punch can be carried out without seizure because sufficient lubricant is supplied to the forming zone during the retreat of the punch.

To describe the punch motion, the following parameters are defined:

n_{total}: total number of forming steps
s_{ai}: advance stroke in the ith forming step ($i = 1$ to n_{total})
s_{ri}: retreat stroke in the ith forming step ($i = 1$ to n_{total})
s_{fi}: forming stroke in the ith forming step ($= s_{ai} - s_{ri}$) ($i = 1$ to n_{total})
s_{total}: total forming stroke of the punch ($= \sum_{i=1}^{n_{total}} s_{fi}$)

In this study, s_{ai}, s_{ri}, and s_{fi} were set as constant. Thus, s_{ai}, s_{ri}, and s_{fi} can be written as s_a, s_r, and s_f, respectively.

2.2. Experimental conditions

The tool arrangement for the forming method is shown in Fig. 2. The punch with an internal channel for lubricant flow is connected to the lubricant tank by a tube. No equipment such as a pump or a valve to prevent the backflow of the lubricant is used. Schematic illustrations of the punch with an internal channel for lubricant supply and the counter punch are shown in Fig. 3. The punch diameter was $D_P = 6.0$ mm, and the diameters of the internal channel were $D_I = 1.5$ mm at the inside of the channel and 0.5 mm at the output of the channel. A counter punch with diameter $D_{CP} = 4.5$ mm was prepared to examine the material flow of the specimen in the forward and backward extruded parts. There is no internal channel for lubricant in the counter punch. The inner diameter of the container was $D_C = 9$ mm. The extrusion ratios for the forward and backward parts were 1.80 and 1.33, respectively. The materials used for the punches and container were high speed tool steel (HRC63–65) and matrix high speed tool steel (Hitachi Metals, Ltd., YXR3, HRC59–62), respectively. The punches and container surfaces were polished to a mirror finish with $Ra = 0.02$–0.04 μm. The initial dimensions of the specimen was 8.9 mm in diameter and $L_0 = 30$ mm in height. The specimen material was an AA6061-T6 aluminum alloy. Mineral oil with a kinematic viscosity of 32 mm^2/s (at 40 °C) was used as the lubricant.

The tools were installed on a 450 kN servo press (Komatsu Industrial Corp., H1F45). The servo press was driven by an AC servomotor through a mechanical link (0–70 spm). The punch position–time and speed–position diagrams for the retreat and advance pulse ram motion are shown in Fig. 4. The total step number (n_{total}) was limited to less than five because of the press specifications. The forming stroke in every forming step was set in the range $s_f = 6$–24 mm ($s_f/D_P = 1.0$–4.0), and the total forming stroke of the punch was fixed at $s_{total} = 24$ mm ($s_{total}/D_P = 4.0$). The retreat stroke of the punch in every forming step was fixed at $s_r = 6$ mm ($s_r/D_P = 1.0$) because it was confirmed that sufficient lubricant (approximately 18 mm^3, nominal thickness: 110 μm) enters the forming zone during the retreat action of the punch when $s_r/D_P \geq 0.5$ (Matsumoto et al., 2013). The average forming speed range was $v_{avg} = 20$–80 mm/s.

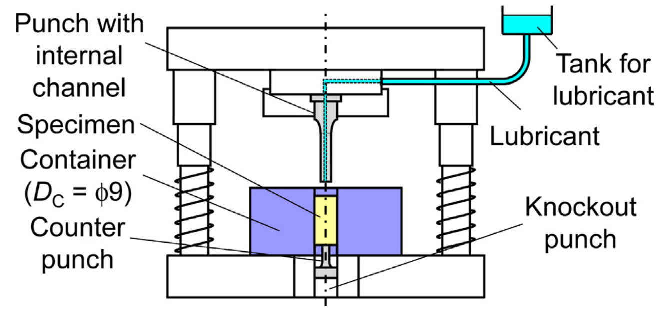

Fig. 2. Schematic illustration of the tool arrangement for combined forward-backward extrusion (D_C: inner diameter of the container).

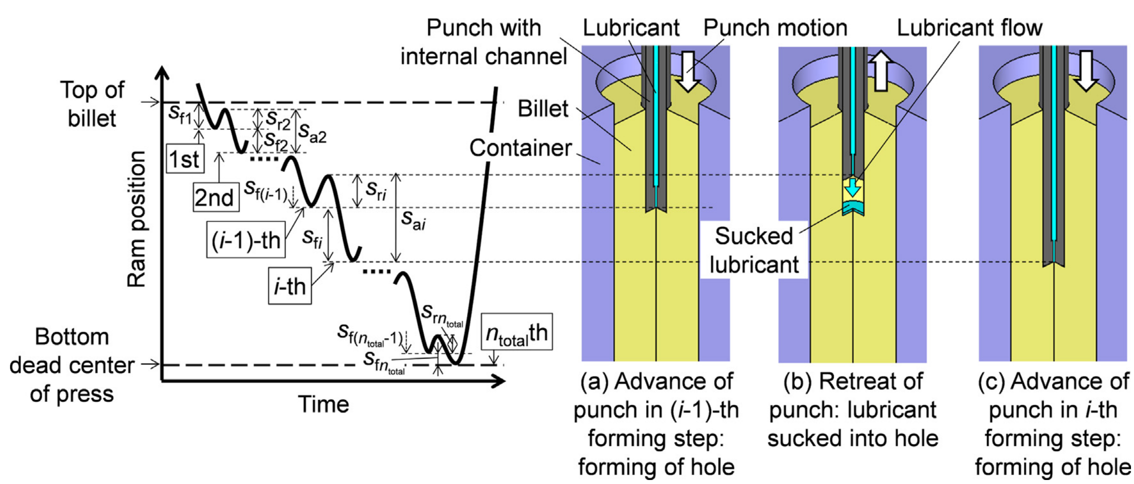

Fig. 1. Retreat and advance pulse ram motion of a punch with an internal channel for pulsating lubricant supply during extrusion (s_{ai}: advance stroke of punch in the ith forming step; s_{ri}: retreat stroke of punch in the ith forming step; s_{fi}: forming stroke of punch in the ith forming step, $i = 1$ to n_{total}).