Journal of Materials Processing Technology 213 (2013) 770–778

Contents lists available at SciVerse ScienceDirect

Journal of Materials Processing Technology

journal homepage: www.elsevier.com/locate/jmatprotec

Shape accuracy in the forming of deep holes with retreat and advance pulse ram motion on a servo press

Ryo Matsumoto*, Jae-Yeol Jeon, Hiroshi Utsunomiya

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

A R T I C L E I N F O

Article history:
Received 12 September 2012
Received in revised form 3 November 2012
Accepted 24 November 2012
Available online 3 December 2012

Keywords:
Forging
Extrusion
Lubrication
Shape accuracy
Servo press

A B S T R A C T

A method for keeping 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. 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. The appropriate punch motions for prevention of galling of the formed hole for extrusion ratios in the range 1.07–1.80 were determined in the proposed forming method using a servo press. Furthermore, the proposed method was found to produce the formed holes with high shape accuracy. The shape accuracy of the formed hole is discussed with experimental and finite element simulation results in terms of lubrication state and temperature change.

1. Introduction

Since the ram speed and motion of servo presses can be programmed with a servomotor through CNC control, servo presses have led to new forming processes (Ernst, 2011; Osakada et al., 2011). For example, Wang et al. (2009) have controlled the product shape in free forging for artificial bones with a servo press and a 6-axis freedom robot. Groche et al. (2010) have developed a 3D servo press to realize flexible forming processes. Maeno et al. (2011) have reduced the friction in cold plate forging through load pulsation using a servo press.

Forged products are desired with high accuracy in the shape. The desire has been gradually strict in net shape cold forging process. Shape accuracy of the forged product is complexly determined by many forging parameters such as forging temperature, strain, friction and rigidity of the dies and so on. Although the control of these forging parameters is limited in conventional forging process using a mechanical press, servo presses with flexible ram motion are useful to control temperature, strain and stress of billet and dies during forging. Ishiguro et al. (2010) have investigated the shape accuracy of the forged product under several press ram motions on a servo press, however the effective ram motions for obtaining the forged product with high shape accuracy have not been specified.

For the fabrication of lightweight components such as hollow components, we proposed an extrusion method for forming of deep holes that utilizes a punch with an internal channel for the supply of liquid lubricant using a servo press (Matsumoto et al., 2011). The concept of the proposed forming method is derived from the machining of deep holes with tools that have internal channels for lubricant. In machining, a drill with an internal channel for lubricant makes it possible to cut deep holes by supplying lubricant to the cutting part (Weinert et al., 2004). The proposed forming method has been confirmed to prevent galling in the backward extrusion of aluminium alloy under a low extrusion ratio, however, the relationship between the extrusion ratio and the appropriate punch motions for prevention of galling and the accuracy of the shape of the formed specimen have not previously been investigated.

In this study, the appropriate punch motions for prevention of galling of the formed hole at several extrusion ratios are investigated with the proposed forming method using a servo press. The accuracy of the shape of the formed hole with the proposed forming method is examined and discussed in terms of lubrication and temperature changes through the experimental and finite element simulation results.

2. Extrusion with pulsating lubricant supply

2.1. Backward extrusion method

The proposed 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

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

0924-0136/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.jmatprotec.2012.11.023

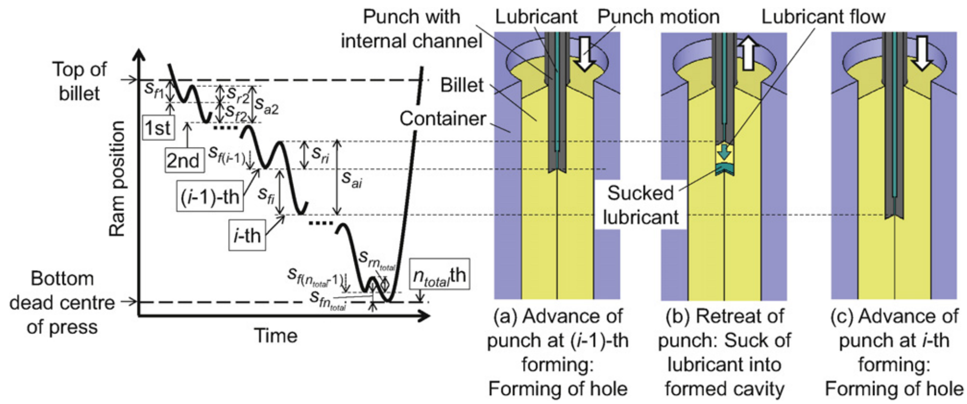

Fig. 1. Retreat and advance pulse ram motion of a punch with an internal channel for pulsating lubricant supply in backward extrusion (s_{ai}: advance stroke of punch at ith forming; s_{ri}: retreat stroke of punch at ith forming; s_{fi}: forming stroke of punch at ith forming; i = 1–n_{total}).

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 action of the punch, and the lubricant is sucked into the cavity through the internal channel (Fig. 1(b)). In this method, a pump and/or a check valve for prevention of flow backward is not used for supplying the lubricant from the punch nose. The lubricant is supplied to the deformation zone only by 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)). When sufficient lubricant is supplied to the cavity during the retreat of the punch, the forming of the hole can be carried out without seizure during the next advance of the punch (Fig. 1(c)). A hole with a high aspect ratio can be formed without seizure by using a stepwise mode that consists of repeated retreats and advances 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–n_{total})
s_{ri}: retreat stroke in the ith forming step (i = 1–n_{total})
s_{fi}: forming stroke in the ith forming step ($= s_{ai} - s_{ri}$) (i = 1–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 at each forming step. 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 backflow of lubricant was used. Mineral oil with a kinematic viscosity of 32 mm^2/s (at 40 °C) was used as the lubricant. The punch diameter is D_P = 6.0 mm, and the diameters of the internal channel are D_I = 1.5 and 0.5 mm. To vary the extrusion ratio (R) of the hole, containers with inner diameters D_C = 24, 18, 12, and 9 mm were prepared. The outer diameter of the containers was 75 mm. The extrusion ratios are R = 1.07, 1.13, 1.33, and 1.80, and the wall thicknesses of the formed specimens are 9, 6, 3, and 1.5 mm, respectively. The materials used for the punch and containers were cemented tungsten carbide (DIJET Industrial Co., Ltd., WC-10 mass% Co) and matrix high speed tool steel (Hitachi Metals, Ltd., YXR3), respectively. Each punch and container surface was polished to a mirror finish with Ra = 0.02–0.04 μm. The picture of the punch and container is shown in Fig. 3. The specimen material was an AA6061-T6 aluminium alloy. 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 total step number (n_{total}) was limited to less than five because of the press specifications. The advance and retreat punch speeds–stroke diagram is shown in Fig. 4.

2.3. Amount of lubricant sucked into the cavity by the retreat of the punch

The amount of lubricant sucked into the cavity was estimated from the weight changes in the specimen including the lubricant before and after the retreat of the punch on the assumption that the sucked lubricant adhered to the surface of the hole. Fig. 5 shows the measured volume (V_{Lub}) and the nominal thickness (h_{Lub}) of the lubricant sucked through the internal channel into the cavity. The nominal thickness of sucked lubricant was estimated by dividing the sucked volume by the surface area of the cavity, as given in the following equation:

$$h_{Lub} = \frac{V_{Lub}}{\pi (D_P/2)^2 + \pi D_P s_r} \quad (1)$$

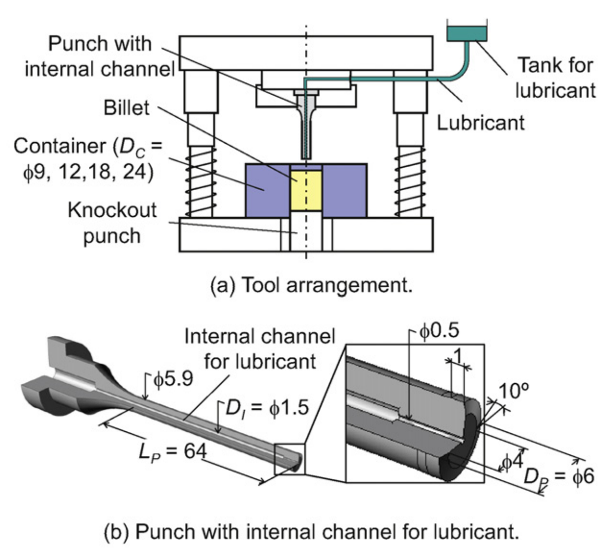

Fig. 2. Schematic illustrations of the tool arrangement and a punch with an internal channel for lubricant supply (D_C: inner diameter of container; D_P: punch diameter; D_I: diameter of the internal channel; L_P: punch length).