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COMBINED FORWARD-BACKWARD EXTRUSION WITH REVERSE RAM MOTION -APPLICATION TO FORMING OF GEAR-

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Summary

Extrusion of forward-gear and backward-rod by combined extrusion with controlling the extrusion velocity using a counter tool is studied. In the combined forward-backward extrusion with controlling extrusion velocity, only parts with short gear can be formed. To obtain longer gear parts, extrusion with reverse ram motion is carried out after the combined forward-backward extrusion process. In this method, combined forward-backward extrusion is carried out until excessive extrusion length is attained and then, the motion of the punch is stopped and the counter tool is moved in the inverse direction and returned to the position for obtaining the desired extrusion length. The experiment is carried out by using lead for billets as a model material. With reverse ram motion, longer gear teeth without under-filling defect can be formed than that by only combined extrusion with controlling extrusion velocity.

keywords: combined extrusion, extrusion, counter tool, reverse ram motion

1 Introduction

In forward-backward extrusion, the extrusion lengths are specified and the die is usually so designed as to stop one of the flows because it is not possible to give an arbitrary extrusion lengths. After stopping the flow to one direction, the material flows only to the other direction and the extrusion pressure is increased to a great extent.

To keep the extrusion pressure low throughout the process, it is desirable to maintain extrusion to both directions until the end of the process [1]. In forward-backward extrusion without a counter tool, the flatness of the extruded top surface is low because the top surface has no constraint. To keep a low extrusion pressure and high flatness of the top surface, forward-backward extrusion with controlled exit velocity was proposed [2]. The maximum extrusion length is, however, not so long.

In this study, to improve the maximum extrusion length, forward-backward extrusions with and without back pressure are carried out and then, the counter tool is reversely moved. Reduction of under-filling defects at the gear teeth and improvement of the flatness of the extruded top surface are also examined.

2 Experimental method

In this study, lead billets are extruded into the shape with forward-gear and backward-rod. The initial and desired shapes are illustrated in Fig. 1. Tables 1 and 2 show the experimental conditions and desired gear shapes, respectively.

Four types of extrusion process are carried out.

(i) Forward-backward extrusion with only upper punch and fixing the lower punch. (Fig. 2(a)-(b))

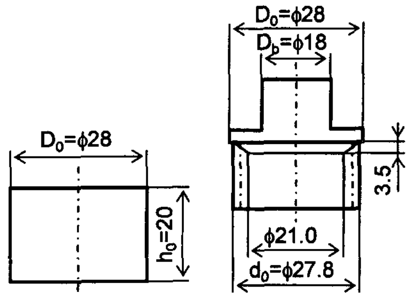
(ii) The ram is moved reversely after process (i). (Fig.2(a)-(b)-(c))

(iii) Forward-backward extrusion with controlled exit velocity. (Fig. 3(a)-(b))

(iv) The ram is moved reversely after process (iii). (Fig. 3(a)-(b)-(c))

Although the gear can be formed with the length of only 6 mm by the forward-backward extrusion process with controlling exit velocity without reverse ram motion (process (iii)), gear length of 18 mm is obtained with reverse ram motion (processes (i), (ii) and (iv)).

In the experiment with reverse ram motion, forward-backward extrusion is carried out by moving the upper punch with the constant velocity for 60 s (Reduction $\Delta h/h_0$=90%). In this time the formed gear length is 19 mm and this is longer than the desired one (18 mm). After excessive extrusion, the upper



(a) Initial *(b) Desired*

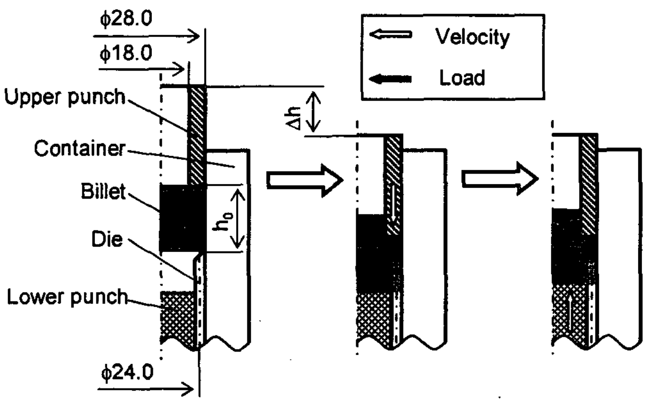
Fig. 1 Initial and desired shapes.

Table 1 Experimental conditions.

Material of billet	Lead
Flow stress / MPa	$\bar{\sigma}=33\,\bar{\varepsilon}^{0.09}$
Lubricant	Machine oil
Coefficient of friction	0.20
Temperature / °C	20
Velocity of upper punch / $mm\cdot s^{-1}$	0.3
Reduction $\Delta h/h_0$ / %	90
Velocity of lower punch / $mm\cdot s^{-1}$	0.1

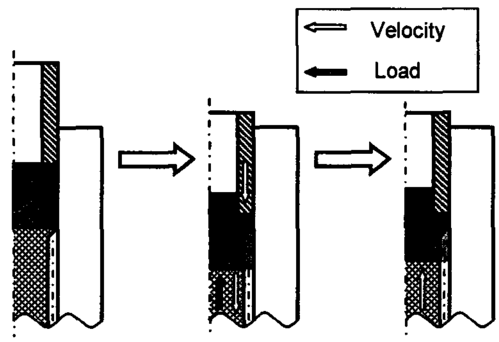
Table 2 Shape of gear.

Number of teeth	16
Addendum modification coefficient	+0.250
Module / mm	1.50
Pressure angle / °	20.0
Face diameter / mm	27.8
Root diameter / mm	21.0
Pitch diameter / mm	24.0



(a) Initial *(b) Extrusion* *(c) Moving ram reversely*

Fig. 2 Press motion with fixing lower punch.



(a) Initial *(b) Extrusion* *(c) Moving ram reversely*

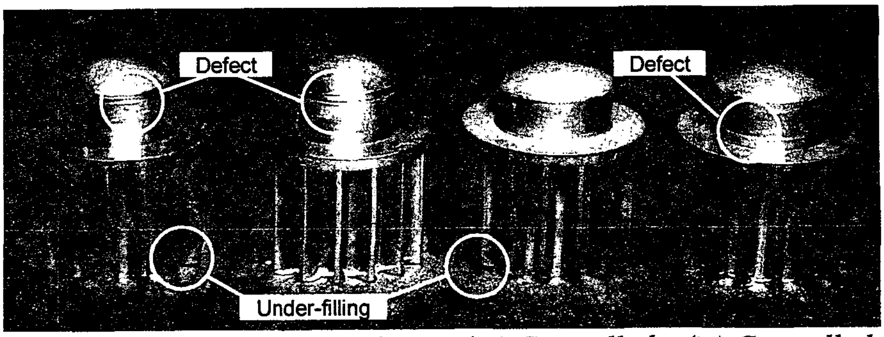
Fig. 3 Press motion with controlled exit velocity.

punch is stopped and the top of the gear is finished by moving the lower punch for 1 mm reversely.

To make the extrusion pressure P_f and the back pressure P_b dimensionless, extrusion pressure ratio P_f^* and back pressure ratio P_b^* are defined.

$$P_f^* = P_f / \bar{\sigma}_1 \quad (1)$$

$$P_b^* = P_b / \bar{\sigma}_1 \quad (2)$$



(i) *Fixing lower punch* (ii) *Fixing lower punch and reverse ram motion* (iii) *Controlled exit velocity* (iv) *Controlled exit velocity and reverse ram motion*

Fig. 4 Formed shape of specimen.

Where $\bar{\sigma}_1$ is the equivalent flow stress of billet at the equivalent strain of $\bar{\varepsilon} = 1$.

3 Experimental result

3.1 Formed shape

Formed shapes of billet are shown in Fig. 4. In the cases with reverse ram motion (processes (ii) and (iv)), no under-filling defects are observed at the gear teeth near the top and the gear teeth are formed precisely.

Defects perpendicular to the backward extruded direction are observed at the side of rod near the top part in the processes with fixing the lower part (processes (i) and (ii)). These defects are appeared at the moment when the top of the forward extruded part touches the lower punch and the extrusion velocity is changed. The defects are not observed in the cases with reverse ram motion. In the case with controlling exit velocity and reverse ram motion, the defect perpendicular to the backward extruded direction is also observed at the root of backward extruded part. This is considered that the defect is formed when the ram is started to move in the reverse direction and the backward extrusion velocity is changed.

3.2 Working load

Fig. 5 plots the history of extrusion pressure ratio and back pressure ratio. In the cases of fixing the lower punch (processes (i) and (ii)), since the top of the forward extruded part does not touch the lower punch until about 50 s ($\Delta h/h_0$=70-80%), extrusion pressure ratio is smaller than that of the case with controlled exit velocity (processes (iii) and (iv)). After the top of the forward extruded part touches the lower punch, both the extrusion pressure ratio and back pressure ratio increase rapidly due to becoming almost closed die forging.

In the cases of controlling the exit velocity (processes (iii) and (iv)), as the forming proceeds, the extrusion pressure ratio and back pressure ratio are increased and after reaching the peak values, they are decreased. They increase again in the final stage of forming.

Comparing the cases of fixing lower punch and controlling the exit velocity, maximum values of extrusion pressure ratio and back pressure ratio are smaller when the exit velocity is controlled.

The extrusion pressure ratio and back pressure ratio increase steeply while the ram moves reversely.

3.3 Formed shape

To investigate the effect of the motion of the lower punch on the flatness of the forward extruded top surface and forming accuracy of the teeth part, flatness ratio F and under-filling ratio L are defined as shown in Fig. 6.

$F=d_p/d_0$ (3)

$L=l/h_0$ (4)

Where d_p is a diameter of flat part of the forward extruded top surface, d_0 is face diameter of gear part, l is a length of under-filling part and h_0 is the initial height of the billet.

The effect of lower punch motion on the flatness ratio and under-filling ratio are plotted in Fig. 7. The flatness ratio and under-filling ratio without reverse ram motion are about 70% and 15%, respectively, however, by employing reverse ram motion, they are improved to 100% and 0%, respectively.

4 Conclusion

Employing reverse ram motion after forward-backward extrusion improves forming accuracy and maximum extrusion length. It is confirmed that combining controlled exit velocity with reverse ram motion is most efficient.

References

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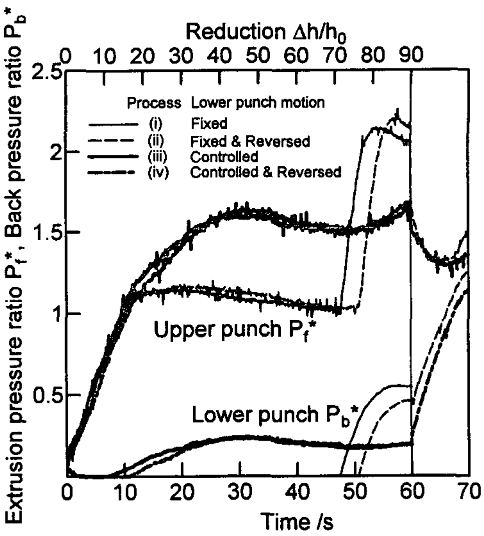

Fig. 5 Variations of extrusion pressure ratio and back pressure ratio.

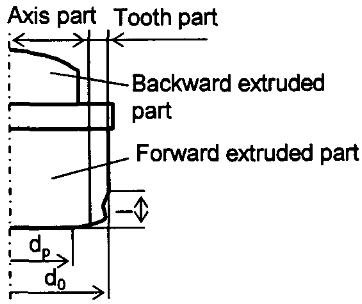

Fig. 6 Definitions of flatness ratio and under-filling ratio.

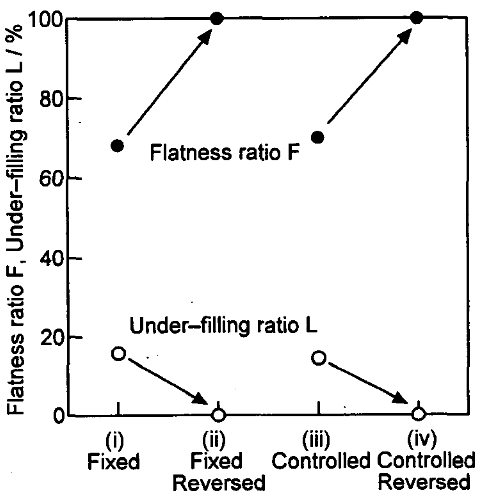

Fig. 7 Effect of lower punch motion on flatness ratio and under-filling ratio.