An Analysis of the Drawing Characteristics of the Deep Drawing Utilizing Lateral Fluid Pressure

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The drawing characteristics of this new deep drawing clarified experimentally in previous paper have been studied theoretically by introducing the idea of drawing force. The drawing force F in this deep drawing was defined as the sum of the derivatives of the works W_p, W_s with respect to depth of drawing S and expressed as $F=dW/dS=dW_p/dS+dW_s/dS$, where W_p and W_s are the works produced by punch pressure and lateral fluid pressure, respectively. These pressures were unified as the components of the drawing force, and the degrees of their contributions to the drawing deformation were made clear.

1. Introduction

The authors[1] have already reported that the drawing characteristics of this new deep drawing are represented by the relation between depth of drawing, punch pressure, and lateral fluid pressure. These pressures act on the center of a blank through the intermediary of a punch and on the perimeter of a blank, respectively. Thus, they act on different surfaces, so it is difficult to estimate the degrees of their contributions to the drawing deformation.

In this study, the drawing force in this deep drawing is defined as the sum of the derivatives of the works produced by the punch pressure and lateral fluid pressure with respect to depth of drawing. By introducing the idea of the drawing force, those pressures are unified as the components of the drawing force, and then the drawing characteristics of this deep drawing clarified experimentally may be elucidated theoretically.

2. Definition of Drawing Force

The drawing characteristics of the deep drawing utilizing lateral fluid pressure were represented by the curves of punch pressure p_p – depth of drawing S under constant lateral fluid pressures p_s[1]. The punch pressure and the lateral fluid pressure act on different surfaces as shown in Fig. 1, so the unification of these pressures is needed to estimate the degrees of their contributions to the drawing deformation.

The drawing force in conventional deep drawing, namely, punch force can be represented as the derivative of drawing work W with respect to depth of drawing S. So, the authors define the drawing force F in this deep drawing as the sum of the derivatives of the works W_p, W_s with respect to depth of drawing S and express as:

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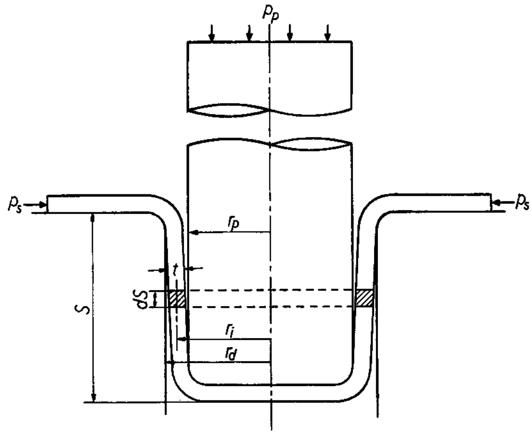


Fig. 1 Explanatory diagram for the work required to draw a blank by dS in this deep drawing process.

$$F=\frac{dW}{dS}=\frac{dW_p}{dS}+\frac{dW_s}{dS}=F_p+F_s\,, \tag{1}$$

where W_p and W_s are the works produced by the punch pressure p_p and lateral fluid pressure p_s, respectively. F_p and F_s are the components of drawing force F due to p_p and p_s, respectively.

One component of the drawing force, F_p, corresponding to the punch force in this deep drawing can be expressed as:

$$F_p=\pi r_p^2\cdot p_p\,, \tag{2}$$

where r_p is radius of punch.

Treating the drawing deformation as the problem of plane strain, another component F_s is formularized as follows. The decrement of volume in flange corresponding to an infinitesimal increment of depth of drawing dS is equal to the volume of the part shown by oblique lines in Fig. 1. Therefore, the work dW_s produced by lateral fluid pressure p_s for the infinitesimal deformation is given by

$$dW_s=2\pi r_i t dS\cdot p_s\,,$$

where $r_i=(r_p+r_d)/2$. Then,

$$F_s=dW_s/dS=2\pi r_i t\cdot p_s\,. \tag{3}$$

From the equation (1)~(3), the drawing force F becomes

$$F=\pi r_p^2\cdot p_p+2\pi r_i t\cdot p_s\,. \tag{4}$$

Thus, the punch pressure p_p and lateral fluid pressure p_s in this deep drawing can be unified as the components of the drawing force F.

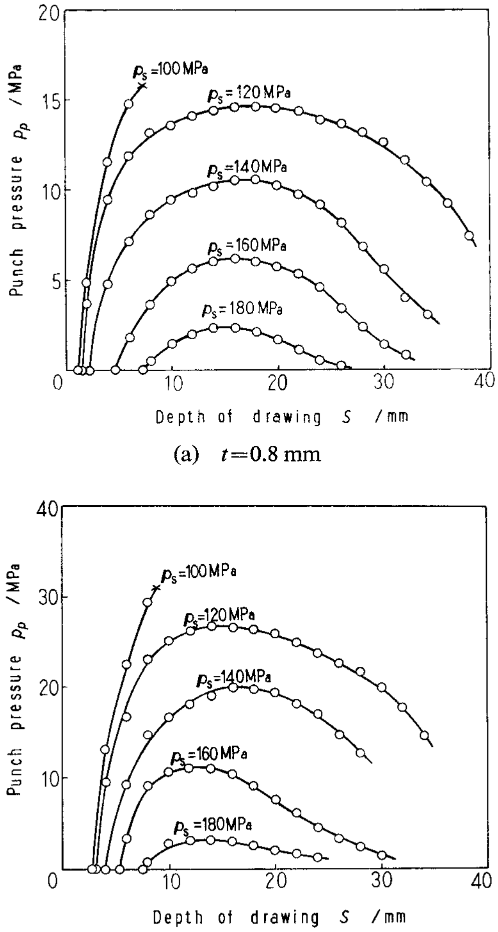
3. Theoretical Analysis of Drawing Characteristics

By introducing the idea of the drawing force, the pressures acting on the different surfaces could be unified as components of the drawing force. The drawing characteristics of this deep drawing clarified experimentally were analyzed theoretically by use of above equations.

3.1 *F–S* curve

The drawing characteristics of this deep drawing for 0.8 mm and 1.5 mm thick aluminum sheets of A1050P–0 were represented as the p_p–S curves obtained experimentally for different set values of lateral fluid pressure $\boldsymbol{p}_s$[1]. In the experiment, the lateral fluid pressure p_s acting on the perimeter of a blank were raised to a set value $\boldsymbol{p}_s$ and then were held constantly throughout the drawing process.

Figure 2 shows the p_p–S curves for 0.8 mm and 1.5 mm thick sheets which were illustrated in previous paper[1]. These curves can be transformed into the curves of drawing force – depth of drawing, hereinafter called *F–S* curves, using the equation (4).



(a) t=0.8 mm

(b) t=1.5 mm

Fig. 2 p_p-S diagram (t: thickness of sheet)[1].

Figure 3 shows the *F–S* curves for 0.8 mm and 1.5 mm thick sheets under $\boldsymbol{p}_s = 140$ MPa (about 1400 kgf/cm^2). For either sheet, the drawing force F

increases to a maximum and then decreases slowly with increasing S. In this figure, two chain lines show the drawing forces $\boldsymbol{F}_s$ ($\boldsymbol{F}_{s\,0.8}$, $\boldsymbol{F}_{s\,1.5}$) due to the set lateral fluid pressure $\boldsymbol{p}_s$ for both sheets. Each of the lines showing $\boldsymbol{F}_s$ divides the drawing force F into two components, F_p and F_s. And their proportions to F are explained schematically using Fig. 4.

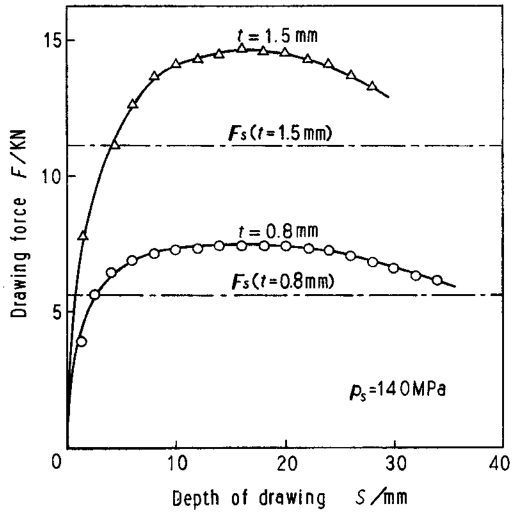


Fig. 3 F-S diagram.

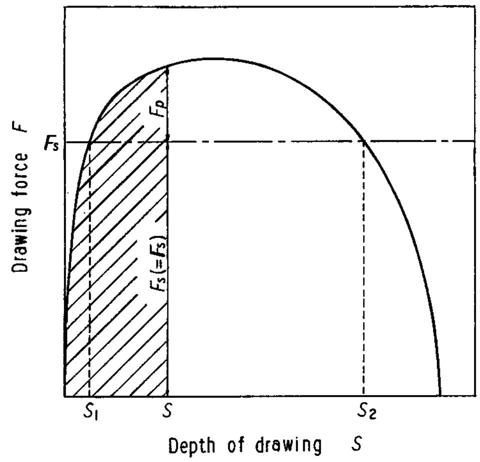


Fig. 4 Explanatory diagram for F-S curve.

In Fig. 4, S_1 and S_2 denote the S coordinates of intersections of the F–S curve and the chain line showing $\boldsymbol{F}_s$. In this figure, for the depth of drawing S ranging from S_1 to S_2, the drawing force F ($>\boldsymbol{F}_s$) is divided into F_p and F_s ($=\boldsymbol{F}_s$) by the chain line. And, for S below S_1 or above S_2, which corresponds to early or late stage of the drawing process, $F=F_s$ ($<\boldsymbol{F}_s$) and $F_p=0$. The work W required to draw a blank up to the depth of drawing S is represented by the area of the region shown by oblique lines, and the areas of its parts above and below the chain line represent the works W_p and W_s produced by punch pressure p_p and lateral fluid pressure p_s, respectively. Thus, by drawing the line showing $\boldsymbol{F}_s$ in the F–S diagram, the proportions of F_p, F_s to F for any depth of drawing S become clear and the degrees of contributions of p_p, p_s to the drawing deformation are made clear.

In the same manner, their degrees for 0.8 mm and 1.5 mm thick sheets can be read off Fig. 3. And the upper parts of the F–S curves divided by the chain lines correspond to the F_p–S curves, into which the p_p–S curves shown in Fig. 2 are transformed with equation (2).

3.2 Proportions of $\boldsymbol{F}_s$ to F_{max} and $F_{p \cdot max}$ to F_{max}

Figure 5 shows the relation between $\boldsymbol{p}_s$ and $p_{p \cdot max}$ for 0.8 mm and 1.5 mm thick sheets which was illustrated in previous paper[1]. Using the equation (4), this relation can be transformed into the relation between $\boldsymbol{p}_s$ and maximum drawing force F_{max} shown in Fig. 6. In Fig. 6, F_{max} shown by solid line increases slightly with increasing $\boldsymbol{p}_s$ in either sheet, which is caused by an increase in friction between the blank and tools.

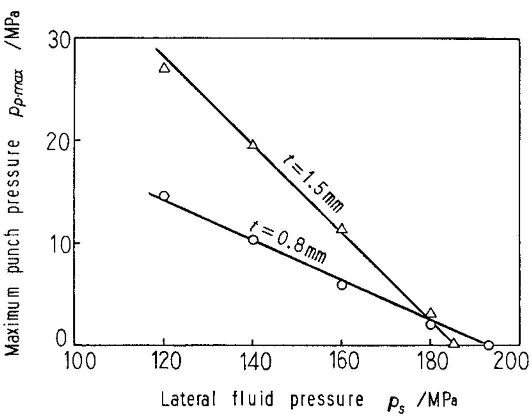


Fig. 5 Relation between lateral fluid pressure $\boldsymbol{p}_s$ and the maximum value of punch pressure $p_{p \cdot max}$ in p_p-S curve.

In Fig. 6, two chain lines represent the drawing forces $\boldsymbol{F}_s$ due to $\boldsymbol{p}_s$ for both sheets, and the differences between F_{max} and $\boldsymbol{F}_s$ shown by segments with arrow heads represent the drawing forces $F_{p \cdot max}$ due to $p_{p \cdot max}$. And the coordinates of intersection of the solid line and chain line for each sheet represent the maximum lateral fluid pressure and maximum drawing force in the punchless drawing[1),2)].

$\boldsymbol{F}_s$ increases in proportion to $\boldsymbol{p}_s$ (constant of proportion: $2\pi r_i t$), so the ratio of $\boldsymbol{F}_{s1.5}$ to $\boldsymbol{F}_{s0.8}$ is independent of $\boldsymbol{p}_s$, and its value is nearly equal to a thickness ratio of 1.5/0.8, because the area of the surface receiving the lateral fluid pressure $\boldsymbol{p}_s$ increases in proportion to the thickness of sheet. On the other hand, the ratio of $F_{max1.5}$ to $F_{max0.8}$ is nearly equal to the thickness ratio, too, as seen from Fig. 6. Therefore, the proportions of $\boldsymbol{F}_s$ to F_{max} for both sheets are nearly equal as shown in Fig. 7.

Figure 7 shows the relation between the proportion of $\boldsymbol{F}_s$ (or $F_{p \cdot max}$) to F_{max} and $\boldsymbol{p}_s$ (or $\boldsymbol{F}_s$.). In either sheet, $\boldsymbol{F}_s/F_{max}$ increases linearly to 1 with increasing $\boldsymbol{p}_s$ (or $\boldsymbol{F}_s$),

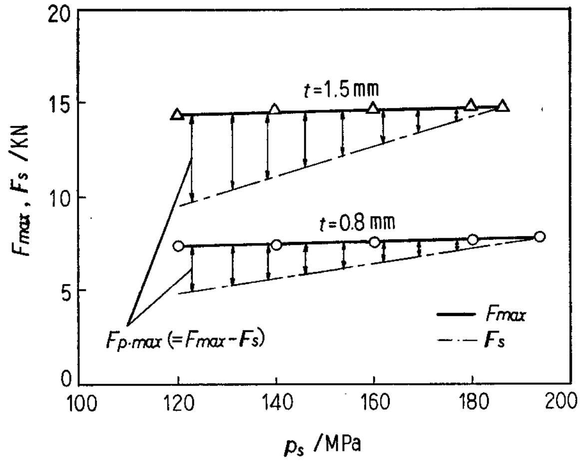


Fig. 6 Maximum drawing force F_{max} and its component $\boldsymbol{F}_s$ due to $\boldsymbol{p}_s$ ($F_{p\cdot max}$: component of F_{max} due to maximum punch pressure $p_{p\cdot max}$).

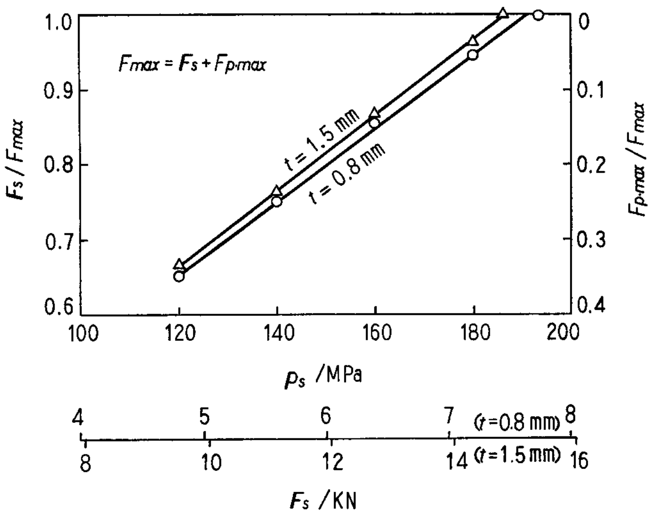


Fig. 7 Proportions of $\boldsymbol{F}_s$ to F_{max} and $F_{p\cdot max}$ to F_{max}.

and $F_{p\cdot max}/F_{max}$ decreases linearly to zero. Even the minimum value of $\boldsymbol{F}_s/F_{max}$, which corresponds to the lowest value of $\boldsymbol{p}_s$ required to draw blanks without fracture, is 0.65. And its maximum value, $\boldsymbol{F}_s/F_{max}=1$, is obtained for the punchless drawing. Thus, it is found that the proportion of $\boldsymbol{F}_s$ to F_{max} is considerably large for the deep drawing with drawing ratio of 4.

4. Conclusion

In this study, the drawing characteristics of the deep drawing utilizing lateral fluid pressure for soft aluminum sheets clarified experimentally in previous paper were analyzed theoretically by introducing the idea of the drawing force.

The results obtained may be summarized as follows.

(1) The drawing force F is defined as the sum of the derivatives of the works W_p, W_s produced by the punch pressure and lateral fluid pressure with respect to depth of drawing S, and is expressed as:

$$F=dW/dS=dW_p/dS+dW_s/dS=F_p+F_s\,.$$

(2) The punch pressure p_p and lateral fluid pressure p_s acting on the different surfaces can be unified as the components of the drawing force F, which is expressed as:

$$F=\pi r_p^2\cdot p_p+2\pi r_i t\cdot p_s\,.$$

(3) p_p–S diagram obtained by the experiment can be transformed into F–S diagram. By drawing the line showing $\boldsymbol{F}_s$ in the F–S diagram, the proportions of F_p, F_s to F for any depth of drawing S become clear and the degrees of contributions of p_p, p_s to the drawing deformation are made clear.

(4) The proportions of $\boldsymbol{F}_s$ to F_{max} for 0.8 mm and 1.5 mm thick sheets increase linearly to 1 with increasing $\boldsymbol{p}_s$ and they are nearly equal independently of thickness of sheet. And these proportions are considerably large for the deep drawing with drawing ratio of 4.

Reference

1) K. Asakura, N. Kobayashi, T. Hanamoto and M. Kohzu, Bull. Univ. Osaka Prefecture, **31A**, 171 (1982).

2) K. Asakura, N. Kobayashi, M. Kohzu and N. Suzuki, ibid., **32A**, 37 (1983).