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Effect of sheet thickness on deep drawing of metal foils

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ABSTRACT

Purpose: The objective of the present work is to study the influence of sheet thickness on blank holding force and limiting drawing ratio.
Design/methodology/approach: Variation in blankholding force and limiting drawing ratio in deep drawing of metal foils were evaluated by calculation.
Findings: The paper shows variation in the blankholding force required for the elimination of wrinkling and the limiting drawing ratio with sheet thickness. The blankholding force required for the elimination of wrinkling increased rapidly as the sheet thickness decreased. When the sheet thickness was very thin, the blankholding force was strongly influenced by the coefficient of friction. The limiting drawing ratio decreased as sheet thickness decreased and it decreased rapidly below 0.04 mm thickness. When the sheet thickness was very thin, the limiting drawing ratio was strongly influenced by the coefficient of friction.
Research limitations/implications: The control of the loading path of blankholding force will be an effective way to prevent the formation of defects including fractures and wrinkles in deep drawing of metal foils.
Practical implications: When deep drawing of metal foils is carried out, the control of loading path of blankholding force during deep drawing operation can be very effective for improving the limiting drawing ratio.
Originality/value: The contribution of the conducted research is observed in a possible view of improvement of deep drawability of metal foils.
Keywords: Plastic forming; Deep drawing; Metal foils; Sheet thickness

1. Introduction

Miniaturization of various industrial components and products including precise devices and information processing devices is progressing, and accordingly, the metal forming of very thin small components using very thin sheet metals or metal foils has become increasingly important [1]. Many studies on forming precise products from very thin sheets or metal foils using plasticity technology have been carried out [2-19]. New deep drawing processes have also been developed. Okazaki and Kawaguchi [13] improved the deep drawability of aluminum foil by oscillation of a die. Kasuga [16] reported that the control of the blankholding force by oscillation of the blankholder using piezoelectric actuators improved the limiting drawing ratio. Although several studies on deep drawing of metal foil have been done, there are still various unclarified points.

In deep drawing of metal foils, there are two important issues to overcome; considerable decrease in the limiting drawing ratio, and easy occurrence of wrinkles of deep-drawn products. When a metal foil is deep drawn, the development of wrinkling and a decrease in the limit drawing ratio should be simultaneously suppressed. In this study, the effect of sheet thickness of metal foil on the limiting drawing ratio and blankholding force was investigated. In addition, the influence of the loading ways of blankholding force on the limiting drawing ratio was examined.

2. Loading ways of blankholding force

As ways to load the blank holding force, several cases are considered as shown in Fig. 1, which includes a case in which the blankholding force (BHF) is kept constant, a case in which the blankholding pressure (BHP) is kept constant, and a case in which the BHP is varied depending on the current drawing ratio which shows the progress of the deep drawing. In Fig. 1, the current drawing ratio is expressed as a ratio of the radius of the outer rim of a flange of a blank during deep drawing to the radius of a punch 4mm. Therefore, the right-hand edge of each curve in Fig. 1 corresponds to the time at which deep drawing is begun. The left edge of each curve corresponds to the time at which deep drawing is finished

We used Siebel's equation [21] for BHP in the cases of constant BHF and constant BHP. For the BHP in the cases of varying BHP with current drawing ratio, we used Kawai's equation [20].

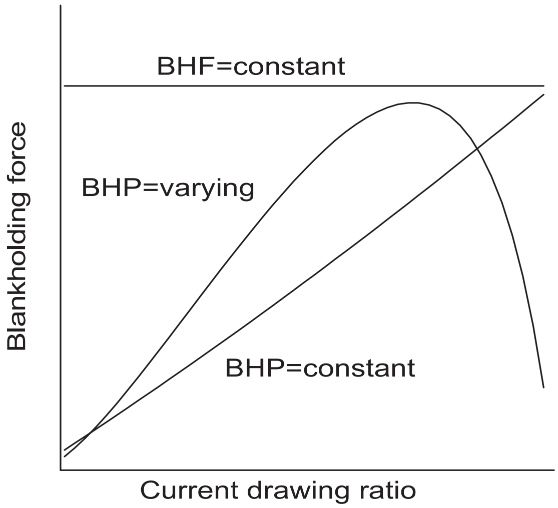

Fig. 1. Variation of blankholding force

3. Blankholding force and limiting drawing ratio

Figures 2 and 3 show the effects of the sheet thickness on changes in the BHF with current drawing ratio. Results in the cases of constant BHP (Fig.2) and varying BHP (Fig.3) are shown. In either case, the BHF required increased as the sheet thickness decreased. It is seen that BHF is strongly influenced by sheet thickness. Figure 4 shows the relationship between the BHF and current drawing ratio for the coefficient of frictionμ at the flange in the case of varying BHP. The required value of BHF increased as the coefficient of friction μ decreased. When the sheet thickness is very thin, the BHF is strongly influenced by the coefficient of friction.

Figure 5 shows the relationships between the limiting drawing ratio and the sheet thickness for different coefficients of friction μ in the cases of constant BHF. For simplicity, the limiting drawing ratio was evaluated using the slab method.

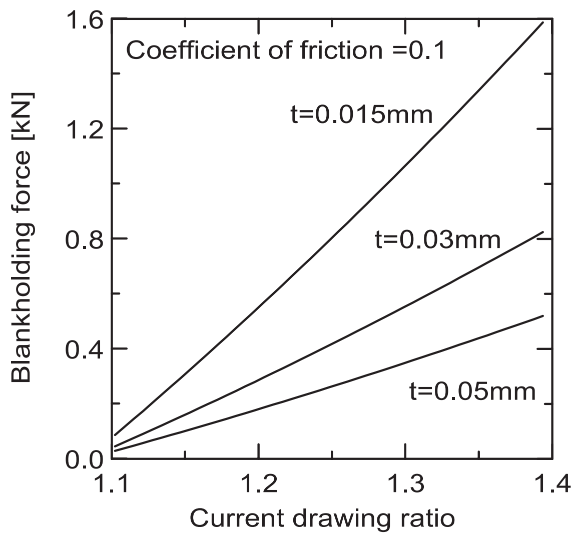

Fig. 2. Variation in BHF with current drawing ratio in the case of constant BHP

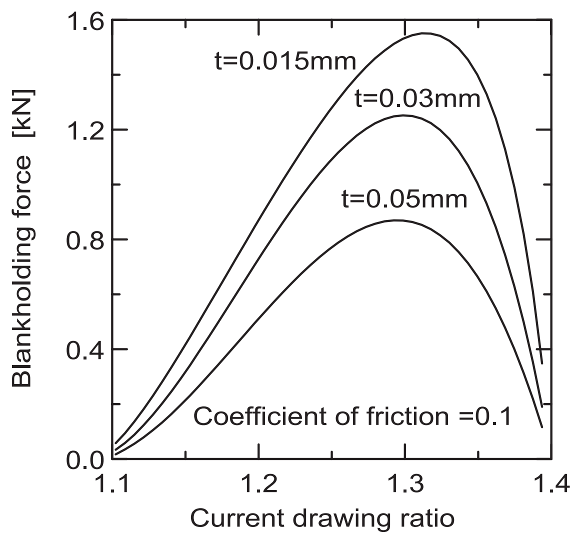

Fig. 3. Variation in BHF with current drawing ratio in the case of varying BHP

For any value of coefficient of friction μ, the limiting drawing ratio decreased as sheet thickness decreased, and it decreased rapidly below approximately 0.04 mm in thickness in this case. We see that the blank breaks easily when its thickness is substantially decreased. In addition, the limiting drawing ratio decreases as the coefficient of friction μincreases. When the sheet thickness is very thin, the limiting drawing ratio is strongly influenced by the coefficient of friction. In cases of constant BHP, the trend in the change of the limiting drawing ratio is similar to that observed in the cases of constant BHF.

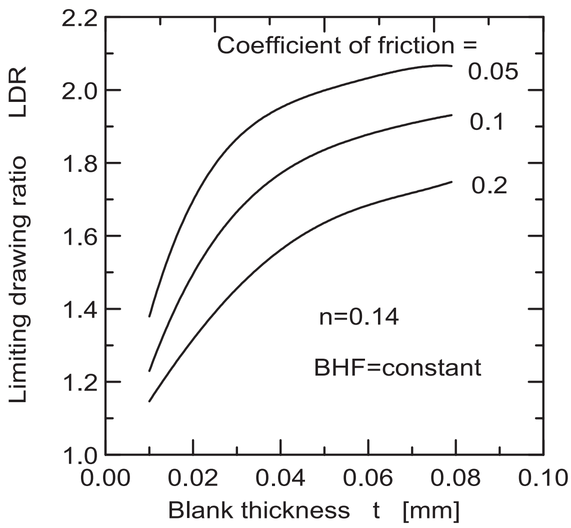

Fig. 4. Variation in BHF with current drawing ratio in the case of varying BHP

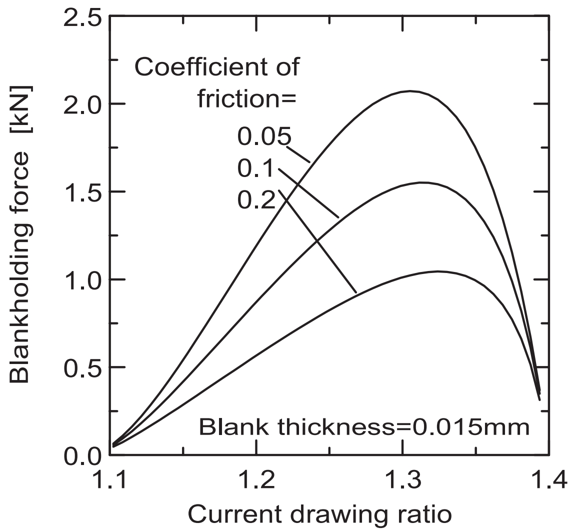

Fig. 5. Influence of sheet thickness on the limiting drawing ratio in the case of constant BHF

Figure 6 shows the result of evaluation of the limiting drawing ratio in cases when BHP was varied during deep drawing. The limiting drawing ratio decreased as sheet thickness decreased; however, no rapid decrease in the limiting drawing ratio with a decrease in the sheet thickness. Figures 7 shows the effects of sheet thickness on the limiting drawing ratio for each loading way of blankholding force when $\mu = 0.05$. When BHF=const or BHP=const, the limiting drawing ratio decreases considerably below 0.04 mm thickness. However, when BHP varies, considerable decrease in limiting drawing ratio is not observed. The similar trend is observed when $\mu=0.1$ as shown in Fig 8. The control of blankholding force during deep drawing operation can be very effective for improving the limiting drawing ratio. We can see that when deep drawing of metal foils is carried out, the loading ways of blankholding force is very important for improving the limiting drawing ratio. In addition to the appropriate selection of the loading ways, the application of auxiliary sheets will be very effective for prevention of wrinkling and fracturing in deep drawing of metal foils including stainless-steel foil.

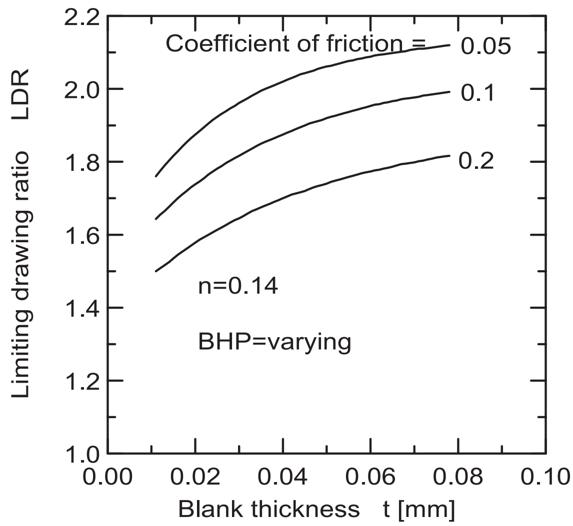

Fig. 6 Influence of sheet thickness on the limiting drawing ratio in the case of varying BHP

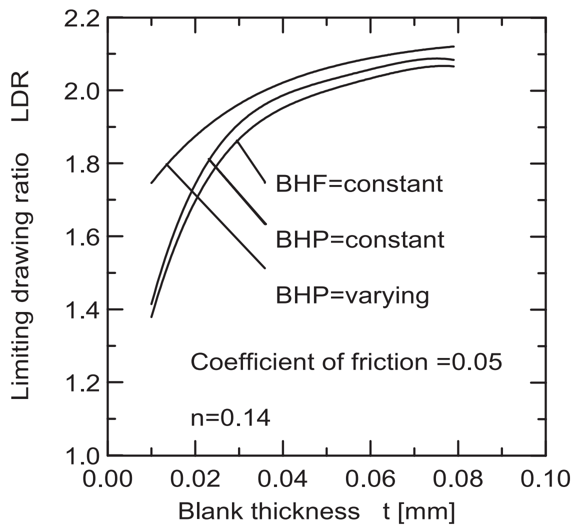

Fig. 7. Influence of sheet thickness on the limiting drawing ratio ($\mu = 0.05$)

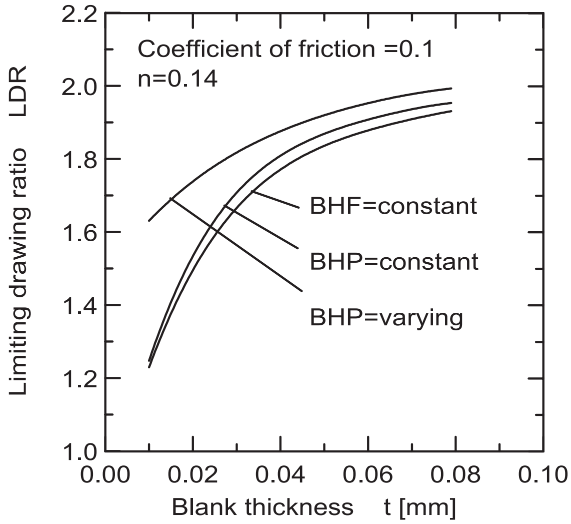

Fig. 8. Influence of sheet thickness on the limiting drawing ratio ($\mu = 0.1$)

4. Conclusions

The blankholding force required for the elimination of wrinkling increased rapidly as the sheet thickness decreased. The blankholding force was strongly influenced by sheet thickness and the coefficient of friction. The limiting drawing ratio decreased as sheet thickness decreased and it decreased rapidly below 0.04 mm thickness. When the sheet thickness was very thin, the limiting drawing ratio was strongly influenced by the coefficient of friction. When the blankholding force was appropriately varied during deep drawing operation, considerable decrease in limiting drawing ratio was not observed. When deep drawing of metal foils is carried out, the control of loading path of blankholding force during deep drawing operation can be very effective for improving the limiting drawing ratio.

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