Effect of Frictional Conditions in Deep Drawing on Formability

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Introduction

This study investigated the stress and strain behavior caused in the forming process via simulation analysis using the finite element method, for suppressing punch shoulder and head plate thickness reduction die shoulder stress concentration by controlling the friction conditions.

Material Testing and Processing Experiments

Thin Plate Tensile Test. For the test material, the SG325 steel plate to form a high-pressure gas container was used. A No. 5 Standard Test Piece was prepared and performed the tensile test. The mechanical properties of the test piece from the relationship curve were determined obtained for the measured load and displacement.

Deep Drawing Experiment. A disk-shaped test piece with diameter $D_0 = 80$ mm and thickness $t_0 = 2.55$ mm, was prepared and conducted a forming experiment according to the forming process shown in Fig. 1.

Simulation Analysis Using Finite Element Method

Analytical Model. Die, wrinkle holder, and punch were modeled into rigid surfaces, and four-node tetrahedral isoperimetric elements were used for the blank. A 1/4 model was used accounting for the blank shape and symmetry of the applied load. Material properties were used the measured values obtained via tensile tests. Apart from the symmetrical conditions for the x and y axes in boundary conditions, the load was applied to a measured spring to the wrinkle holder. Then the finite element method software MSC Marc was used to examine the influence of applying the bilinear Coulomb friction law on material deformation behavior. The friction coefficient between the blank and die/wrinkle holder was 0.01, whereas the friction coefficient μ between the blank and punch was varied between 0.01, 0.1, 0.4, and 0.5.

Evaluation of Formability. The plate thickness reduction ratio $\Delta t/t_0$ and forming limit parameter (FLP) were used as indexes for evaluating formability. Δt is an absolute value of the difference in plate thickness before and after processing. Additionally, a forming limit

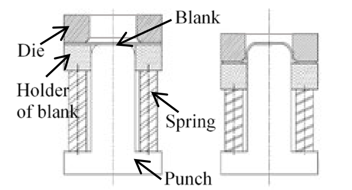

Fig. 1 Deep drawing process schematic diagram

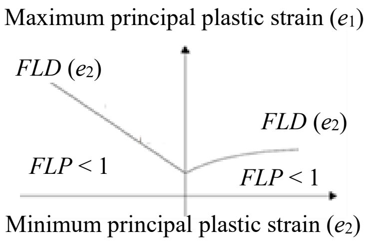

Fig. 2 Forming limit parameter

diagram (FLD) was used, and it was determined from localized necking theory, according to R. Hill, and diffusive necking theory, according to H. W. Swift. For fracture prediction using analytical results, FLP is defined as the ratio of the maximum principal strain to the maximum allowable principal engineering strain obtained from the *FLD*, as shown in Eq. (1).

$$FLP = e_1 / FLD\,(e_2) \quad (1)$$

Here, e_1 and e_2 are the maximum and minimum principal distortions. FLD (e_2) is the forming limit corresponding to e2, as shown in Fig. 2. If $FLP = 1$, it indicates that the forming limit has been reached and the plate is broken. However, $FLP < 1$ indicates that the forming process is successful.

Results and Discussion

Change in Plate Thickness Reduction

Ratio due to Frictional Conditions. Figure 3 shows the relationship between the friction coefficient and plate thickness reduction ratio. Incidentally, μ = 0.4 to 0.5 is close to the non-lubricated friction condition. As shown in Fig. 4, it was found that the larger the coefficient of friction between the punch and blank, larger the frictional stress.

Changes in FLP due to Friction Conditions. Figure 5 shows the relationship between the maximum value of FLP and the friction coefficient. The maximum value of FLP tends to increase slightly owing to the increase in the friction coefficient, but the limit value 1

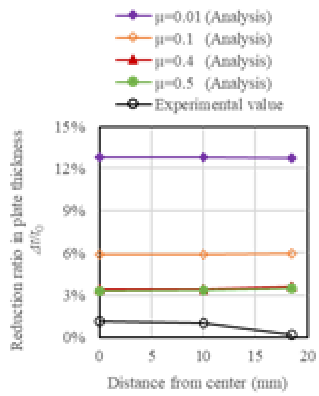

Fig. 3 Reduction ratio in plate thickness from bottom center to punch shoulder part

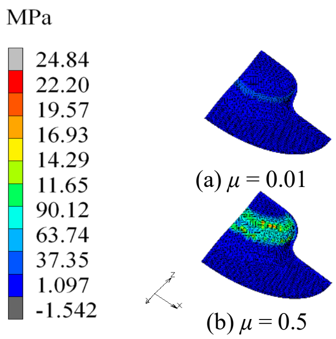

Fig. 4 Contact friction stress contour in z direction

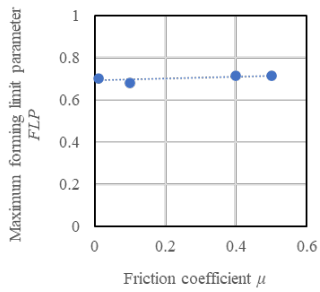

Fig. 5 Relationship between friction coefficient and forming limit parameter

was not attained. can be performed safely without mechanical damage even when the friction coefficient μ = 0.5, which is close to non-lubrication.

Conclusions

When the formability is comprehensively evaluated using the plate thickness reduction ratio and *FLP*, the friction coefficient μ = 0.4 to 0.5 is reasonable.