Foil Blanking Mechanism Research Using Rubber Tool by Finite Element Simulation and Experiment

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Abstract. For foil blanking process, the usage of flexible tool can effectively reduce the requirement of the manufacturing and assembling precision, compared with using conventional tool. However, the blanking mechanism using rubber tool is not clear. To investigate this question, the Finite Element (FE) model of rubber and process is established using ABAQUS package. The result of FE simulation affirm that the fracture emerges as a result of shear, not tensile. Then, for titanium foil with 0.08mm thickness, the cutting experiment is executed to verify the validity of blanking mechanism and FE simulation.

1. Introduction

Micro-Electro-Mechanical System (MEMS) is attracted the attention of the scholars, recently, as its widely application, in many fields such as medical science and biological science. The mechanical parts in each MEMS are small in size, most of them are foil with micron grade thickness. High dimensional and assembly precision must be guaranteed, which go against cost and time reduction, for forming and blanking of foil sheet using rigid tools. Therefore the method substituting flexible tools for rigid mould, die or punch, are greatly used.

The effects of many parameters using rigid tools are carried out, such as relative blanking clearance, corner radius of tools and punch speed[1][2][3].

In the light of our view, one reach only is in regard of flexible blanking process. F. Takahashi[4] developed a novel method of blanking using rubberlike materials for punch instead of rigid tool. The influence on the product quality of some parameters was investigated, such as the counter pressure, punch material and punch penetration into the die. They conclude that the counter pressure at the blanking completion should range from 200 to 400MPa.

However, the mechanism is not clear. To explore this mechanism, this work carries out finite element analysis firstly. Then the tool set with rubber punch is build and achieve the experiment based on this set. The morphology of fracture surface is obtained.

2. Fracture Criterion

\[ \int_{0}^{e_{eq}} \frac{d\varepsilon_{eq}}{\varepsilon_{eq}} = 1 \]

(1)

Fracture criterions proposed by researchers mainly include constant equivalent strains, the plastic instability theory, forming limit diagram (FLD) and maximum shear stress. In this work, the criterion represented in formula (1) is applied, in which a non-linear strain path is taken into account. This
comprehensive criterion can predict not only ductile fracture but also shear fracture with different expression of $\varepsilon^*$. The validity of this criterion is verified by results of the three point bending process and the uniaxial compression test using square steel tube in Hooputra et al.[5].

3. Modelling and Experiment

3.1. Finite Element Model
Sheet blanking processes are considered as plane strain problems. The geometry model of die cutting edge, which is crucial in rubber blanking process, is established as shown in Figure 1. The thickness of sheet is 0.08mm and rubber 1mm. The binder ring and male die are the same rubber.

![Figure 1](image)

**Figure 1.** the geometry model of flexible blanking mould

3.2. Material property
The sheet metals are 0.08mm thickness for both finite element analysis and experiment. The uniaxial tensile test is executed with Zwick(100KN) tensile testing machine. The material is TA1. The value of parameters for power exponent constitutive equation are showed in Table 1.

| Young’s modulus E(GPa) | Yield strength (MPa) | Strength coefficient k(MPa) | Hardening exponent $n$ |
|------------------------|----------------------|-----------------------------|-----------------------|
| 108                    | 260                  | 1004                        | 0.44                  |

Rubber is one of the hyperelastic materials. The mechanical properties of hyperelastic materials are described in terms of a strain energy potential $W$, which defines the strain energy stored in the material per unit of reference volume (volume in the initial configuration) as a function of the strain at that point in the material. The Mooney-Rivlin form, formula (2) based on isotropic materials, is applied in this article to predict the rubber’s behavior on account of its validity.

$$W = C_1 \left( T_1 - 3 \right) + C_2 \left( T_2 - 3 \right) + \frac{1}{D_1} \left( J - 1 \right)^2$$

where $W$ is the strain energy per unit of reference volume; $C_1$, $C_2$ and $D_1$ are material parameters; $T_1$ and $T_2$ are the first and second deviatoric strain invariants; $J$ is the elastic volume ratio.

![Figure 2](image)

**Figure 2** blanking tool

| Table 2. Mooney-Rivlin constants of rubber evaluated by ABAQUS |
|----------------------|----------------|--------|-------|
| Hardness shore A     | $C_1$            | $C_2$  | $D_1$ |
| 60                   | 0.123            | 0.0272 | 0     |

Poisson’s ratio 0.4

The rubber with Shore hardness 60HA and density 1.1g/mm3 is used in this text. The uniaxial tensile test is performed on Zwick(100KN) tensile testing machine and the biaxial tensile test is accomplished on biaxial tensile testing machine described in R. Xiao et al.[6]. The material parameters evaluated using the above test results in ABAQUS, is shown in Table 2.
3.3. Blanking Experiment
The blanking tool are shown in Figure 2. Both the width and depth of groove are 2mm. Quenching is implemented to confirm the stiffness and abrasive resistance of cutting edge. The female die is pushed down by electric pushrod with 5mm/s velocity and the maximum force of 15KN.

4. Results and Discussion

4.1. Rubber blanking process
The rubber blanking process is shown in Figure 3, the left one is contour map of hydrostatic pressure (MPa) and the other is contour map of the shear(MPa) stress corresponding to left one. The diagonal section line regions represent the hydrostatic pressure greater than 0MPa.

With the movement of die, the elastoplastic deformation of the sheet occur and the sheet metal enter in the groove. There is no crack shown in Figure 3(a). It is obvious that the hydrostatic pressure of die region is larger than the groove zone, demarcated by the line perpendicular to die upper surface through the point near groove edge. The maximum value meet in the area close to die top face. The greater plastic deformation is generated than conventional rigid blanking process because of whole blank under continuous increase of pressure. In this process, blending and stretching of blank fiber exist if friction between rubber and other parts is taking into account. Graph on right side indicates that the maximum shear stress takes place above the cutting edge. The decreasing proportion and increasing shear force lead to a raising shear stress. The crack occur when the shear stress comes to shearing stretch.

![Contour Maps](image)

**(a) relative crack length 0 (no crack)**

**(b) relative crack length 25%**

**(c) relative crack length 99%**

*Figure 3. crack propagation process(hydrostatic pressure on left and shear stress)*

It is obtain from Figure 3(b) that the crack grows along vertical direction due to tension applied on no fracture zone by fracture part which is consistent with the contour map of hydrostatic pressure. The shear stress meet its maximum value over the crack tip from shear stress graph.

The state of stress show in Figure 3(c) represent that tensile stress is far lower than compressive stress near the crack tip according to hydrostatic pressure around. Meanwhile the isoline map of shear...
stress figures out the maximum shear stress appears at the crack tip and the fracture zone perpendicular to blank surface. That is to say, the shear stress play a major role in crack growth even in the end of rubber blanking process.

![Finite element analysis and experiment](image)

**Figure 4.** fracture surface morphology of rubber blanking process

4.2. Fracture surface morphology

Similar to conventional blanking process, the morphology of rigid micro-blanking is composed of rollover, smooth zone, fracture zone and burr[7]. However in rubber blanking process, there are only rollover, fracture zone and burr, shown in Figure 4, which is different from rigid blanking process, observed using JSM 6010 scanning electron microscope (SEM). The first part is rollover. In the second zone, fracture zone, the maximum shear stress result in crack growth in vertical direction with rough face. The last zone is burr formed with the initialization of crack. Smooth zone is not included in rubber blanking morphology which is different to rigid blanking, because of flexible tool rubber.

5. Conclusion

In this paper, the finite element method is used for analyzing the flexible tool blanking process. Then the experiment is executed to validate the results. The followed conclusion can be drawn.

(a) The initialization and growth of crack are performed as a result of the shear stress, not the tensile stress.

(b) The direction of crack growth is perpendicular to the sheet face at the at the crack tip.

(c) The components of morphology of the shear plane are Rollover, Fracture zone and Burr without smooth zone comparing with rigid tool blanking process.

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