Finite element simulation of effect of part shape on forming quality in fine-blanking process

Yanxiong Liua,*, Lin Huaa, Huajie Mabo, Wei Fengb

a Hubei Key Laboratory of Advanced Technology of Automotive Components, Wuhan University of Technology, Wuhan 430070, China
b School of Material Science and Engineering, Wuhan University of Technology, Wuhan 430070, China

Abstract

Fine-blanking as an effective and economical sheet metal cutting process has been widely used in the precision machines, automobiles, electronics and aircraft areas. This process can produce smooth-sheared edges over the full workpiece thickness in one single operation with the optimized process parameters. However, the crack phenomenon always occurred in the fine-blanking process when the part shape is complicated. The forming quality of the part with concave and convex shape has been investigated with finite element simulation and experiment methods. In order to reveal the effect of part shape on the fine-blanking process comprehensively, a simple finite element model in which the part has convex and concave shape were created. The effects of the angle between the neighbouring edges and height of the convex and concave on the surface quality have been investigated. Furthermore, the way to design the parameters for parts with complicated shape has been discussed in this paper.

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Keywords: Fine-blanking; Part shape; Forming quality; Convex and concave

1. Introduction

Blanking process is a very important sheet metal cutting process, which separates the part from the metal sheet blank. The parts produced by conventional blanking process always have crack on the cut surface. The quality of...
the blanked surface directly affects the product quality. Therefore, fine-blanking process have been developed since from 1923, in which the metal is deformed in a localized plastic shear band and separated with the ductile fracture model when the critical value of the fractured area is attained. Parts with smooth-sheared edges over the full workpiece thickness can be obtained by fine-blanking process. The reasons for this are that the blank holder and counterpunch, and a smaller clearance between the punch and die are applied in the fine-blanking process when compared with the conventional blanking process.

Many researches have been performed on the fine-blanking process. Thipprakmas (2009) investigated the material flow and the V-ring indenter mechanism in the fine-blanking process with FE method. Lee et al. (1998) have done a lot of studies to investigate the deformation mechanism such as the strain localization, tearing failure in fine-blanking process. Tekiner et al. (2005) studied the effect of different clearances on burr, smooth-sheared and blanking force with experiment method. Klocke et al. (2001) have done research to improve the tool design for fine-blanking process, and Yin et al. (2013) investigated the wear of the fine-blanking tool with back propagation neural network based calculation model.

These previous researches are mainly focused on process technology development, its mechanism clarification and the tool design. The study of the effect of part shape on the surface quality is very rare. However, the crack phenomenon always occurred in the fine-blanking process when the part shape is complicated. In our previous research (Song et al., 2014), a part with concave and convex shape was fabricated by fine-blanking. It is found that surface quality in different areas of the cutting surface is different. As shown in Fig.1, in the area B and D (straight shape and convex shape, respectively), the cracked surface takes the percentage of about 23.6% and 22.9%, respectively. However, in the area C (concave shape) the cracked surface only takes the percentage of 16.5% over the whole thickness of the part. The finite element simulation result of the surface quality also proved this phenomenon. It can be concluded from this research that surface quality of the part formed by fine-blanking is different in the concave and convex region.

To reveal the effect of part shape on the fine-blanking process comprehensively, a simple finite element model in which the parts has concave and convex shapes was created. The effect of the angle between the neighbouring edges and the height of the convex and concave on the surface quality of the part has been investigated. Moreover,
the way to design the parameters for the parts with complicated shape has been discussed in this paper.

2. Finite element model

In order to investigate the angle and height of the concave and convex on the surface quality, a simple model was created and the dimensions were shown in Fig. 2. The length and the width of the part were 50 and 20mm, respectively, and the thickness is 4mm. As shown in Fig. 2(a), the height $H$ of the concave and convex was all set to 5mm, and the angle $\alpha$ was changed from 30° to 150°. In Fig. 2(b), the angle of the model is 90° and the height of the concave and convex $h$ is changed from 5 mm to 1 mm. The fillet radiiuses were shown in Fig. 2.

![Fig. 2. Dimensions of parts: (a) to investigate angle $\alpha$ and (b) to investigate height $h$.](image)

Based on the parts mentioned above, the FE model was created in the commercial software Deform 3D as shown in Fig. 3. According to the principle of fine-blanking process, this model includes five parts, which are punch, blank holder, die, counter punch and the billet. The fillet radius of the punch and the die were 0.2 and 0.5 mm, respectively. The clearance between the punch and the die is 1% $t$, which is equal to 0.04 mm. For the blank holder, no V-ring was applied in this study in order to reduce the calculation time.

![Fig. 3. Finite element model.](image)

The punch force was calculated based on the empirical equation:

$$P_S = L t \sigma_b \cdot f_1,$$

where $L$ is the total length of the sheared edge, $t$ is the billet thickness, $\sigma_b$ is the tensile strength, $f_1$ is the correction factor.

The blank holder force was set to 0.5$P_S$ and the counter punch force is 0.25$P_S$.

The material used in this study is 16CrMnH with a thickness of 4mm, details of the material model and the fracture criterion can be found in the reference [6]. The validity of the FE model has been verified in that paper, and the model just used to analyse the deformation characteristics during the fine-blanking process.
A detailed geometry of the part and the specific process conditions used in the FE model were summarized in Table 1.

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<th>Table 1. Dimensional information for FE model and specifications of fine-blanking process employed in this study.</th>
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<td>Concave and convex angle $\alpha$ /°</td>
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3. Result and discussion

3.1. Effect of the angle on the deformation characteristics in fine-blanking

Fig. 4 shows the effect of the angle on the die roll height (Fig. 4(a)) and the crack surface height (Fig. 4(b)) of the parts. It can be seen form Fig. 4(a) that, the die roll in the convex is much more severe than that in the concave. In the convex, the height of the die roll reduced with the increasing of the angle. When the angle is 30°, the die roll of the part is very severe and the height is almost 3.25mm. When the angle increased to 90°, the effect of the angle on the die roll becomes small, and the die roll height is about 1mm. For the concave, the die roll at the vertex (marked in Fig. 4(a) is close to 0 when the angle is smaller than 120°, and the die roll height just increased to 0.7mm when the angle is 150°. However, the die roll height it is varied along the edge of the concave as shown in Fig. 5. From point 5 to point 1, namely far away from the vertex of the concave, the die roll height increased. That is because point 5 is just on the other convex.

Fig. 4(b) shows that with the increasing of the angle, the crack on the cutting-surface becomes severe for both the convex and the concave. But the crack surface heights in the concave are all smaller than that in the convex in different angles. The distribution of the crack along the side surface of the concave is also varied as shown in Fig. 5. From point 5 to point 1, the crack surface height increased.

From the above discussion, we can get that in the concave the crack surface and the die roll heights are all smaller than that in the convex. The die roll is always existed in the fine-blanking process due to the gap between
the punch and the die. In the convex, the maximum hydrostatic stress is firstly existed in the top surface of the vertex as shown in Fig. 7(a), and the metal is very difficult to be flowed into the cavity of the die. When the punch moves down, this phenomenon becomes much more severe as shown in Fig. 7(b). Therefore, the die roll is very severe in the convex when the angel is very small. As the increasing of the angle, the maximum hydrostatic stress decreased as shown in Fig. 6. So, the die roll height reduced with the increasing of the angle. However, for the concave, the maximum hydrostatic stress is firstly existed in the bottom surface of the vertex. Therefore, the die roll height is smaller than that in the convex. Only when the angle increased to 150° and the maximum hydrostatic stress decreased to -2150 MPa, the die roll height was increased to 0.7 mm.

Generally, as the punch moving down, the hydrostatic stress will be changed from the compressive stress to the tensile stress, and then the crack will be occurred in the cutting surface at the end of the fine-blanking process when the damage of the material reached to the critical value. For the convex, since the die roll is very severe the material beards the tensile stress at the later stage of the fine-blanking process (shown in Fig. 7(b)). Therefore, the crack is more severe in the convex than that in the concave. The hydrostatic stress decreased with the increasing of the angle, therefore, the crack surface heights increase for all the convex and the concave.

Fig. 5. Die roll and crack distribution along the edge of the concave ($\alpha=90^\circ$). Fig. 6. Maximum hydrostatic stress versus angle.

Fig. 7. Hydrostatic stress distribution: (a) punch displacement is 0.5mm and (b) punch displacement is 2.5mm.

3.2. Effect of the height on the deformation characteristics in fine-blanking

Fig. 8(a) shows the effect of the convex height on the die roll and the crack surface. With the decreasing of the convex height, the height of die roll decreased. That is because the outline of the part becomes smoothly when the convex height decreased, then the material becomes easier to be flowed into the die cavity. However, from Fig. 8(a), we can also get that the crack surface increased with the decreasing of the convex height. That is because with the decreasing of the convex height the maximum hydrostatic stress decreased, and the crack will be occurred earlier.
From Fig. 8(b), when the concave height decreased, the die roll and crack surface heights are both increased, which means that increase the concave height can improve the parts surface quality. That is because the maximum hydrostatic stress increased with the increase in concave height.

![Graph](image)

Fig. 8. (a) Effect of convex height on die roll and crack and (b) effect of concave height on die roll and crack.

3.3 Parameters design

Lots of parts have the convex and concave shape, especially for the gear and ratchet wheel. Proper fine-blanking process parameters are highly required to get good surface quality for these parts. From the above discussion, it can get that at the addendum of gear the die roll will be very severe, because it is in the vertex of the convex. Generally, in order to decrease the height of die roll the V-ring is applied in the blank holder or both in the blank holder and the die to increase the hydrostatic stress both in the top and bottom surface. The distance between the blank holder and the V-ring also affect the die roll height. Decreased the distance can reduce the die roll height. Moreover, because at the vertex of the convex and the concave the crack surface height is very small, the gap between the punch and the die at the addendum and dedendum can be a little larger than that at the arc surface of the gear.

4. Conclusion

From this study, we arrived at the conclusion that the part shape affects the cutting surface quality during the fine-blanking process. The convex shape increases the die roll height and decrease the crack surface height. The concave shape decreases the die roll and crack surface height. With the decreasing of the convex or concave height, these influence is decreased.

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Reference