Research on parameters optimization of bilateral ring gear blank-holder in thick-plate fine blanking

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ABSTRACT. To compensate for the poor quality of thick-plate blanking parts in cross-section, this paper suggests using the optimizing bilateral ring gear holder parameters to increase burnish zone and improve cutting precision. With the bilateral gear ring, the hydrostatic pressure of shear deformation zone will increase, plasticity of the material will be lifted to maximum and quality of the cross section will be raised. This paper establishes 8mm AISI-1020 fine blanking model by DEFORM2D, analysis different ring gear parameters and clearance that are influenced the stress-strain and cross section quality to predict forming defects. By using the bilateral gear ring blank holder, the poor quality of thick-plate blanking section is successfully enhanced. Therefore, the bilateral gear ring blank holder is vital to improve the quality of blanking parts and provide the reliable theory basis for the practical engineering application.

KEYWORDS. Thick-plate; Fine blanking; Bilateral gear ring blank holder; Cross section quality.

INTRODUCTION

Fine blanking technology has advantages of high efficiency, low energy-expending and low consumption, so it has been widely used in modern industry in recent years. [1, 2] With the wide application in nearly every field, the research on the process has gradually been a hot topic.

T.S.Kwak et al. [3] analyzed the influence rules of width and height of euphotic belt by using the element-delete method in the process of fine blanking, and concluded that the euphotic belt increases as the tooth height grows, while reduces as the tooth pitch grows. Z.H.Chen [4] and Ridba Hambli [5] found tine blanking can achieve maximum brightness by inhibiting the generation of crack, and the distribution rule of stress and strain is given by a detailed analysis on blanking process. Peng Qun et al. [6] simulated the fine blanking process by using strength blank-holder technology. The material flowing law and strain and stress distribution have been studied, which provide the theoretical basis for fine blanking technology. Under the conditions of negative clearance, W.F.Fan et al. [7] simulated the fine blanking process of AISI-1045 and AISI-1025 with finite element method using Cockcroft and Latham criteria. The results showed that the negative clearance blanking could guarantee higher cross section quality than common blanking.

At present, fine blanking technology adopting thick plate is imperfect compared with that using the thin plate. Therefore, to boost production, here higher-quality thick fine blanking pieces is needed. So it is necessary to carry out more researches. The ring gear gag creates optimal conditions for thick plate fine blanking technology that will not only be applied on diversiform material and different thickness of the plank but also be formed into a work piece with high quality. So it has great pragmatic value thus attracts many scholars to research on blank holder with gear ring.

Sutasn Thipprakmas [8] carried the simulation on V-ring blank holder with finite element and researched on the influence rule of material flow and stress distribution of the V-ring blank holder. Wen Limin et al. [9] established the model of fine blanking on blank holder with unilateral V-ring via the finite element, simulated the circular parts with the thickness of 2.9 mm under different tooth pitches, observed the stress distribution of material during the fine blanking process, and obtained the best relative clearance of blank. Lin Guozheng et al. [10] analyzed the 7 mm thickness of blank with finite element and found out the best blanking clearance and die entrance.
From the above study, it is evident that V-ring can restrain the flow of materials in the shear zone and increases the hydrostatic pressure, and then gets a larger euphotic zone.
The blank holder with unilateral V-ring has been widely applied in the plate cutting. However, there may be some problems, such as burr, low shape and dimension precision if the plate is too thick. To solve this problem, this thesis brings forward a new method that is holding the blank with bilateral V-ring. It can not only increase the hydrostatic pressure of shearing deformation zone and allow material give full play to its plasticity, but also enhance the cross section quality of shear plane.

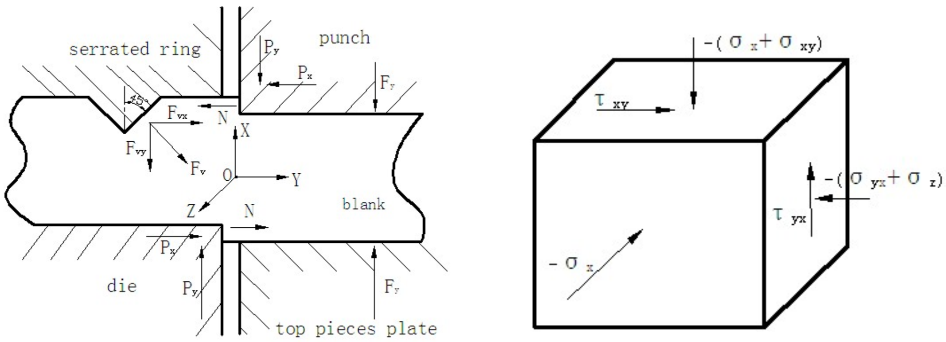
THE MECHANISM AND THEORETICAL BASIS OF METAL PLATE FINE BLANKING

The mechanism of metal plate fine blanking

Fine blanking is a non-chip machining technology. This is a kind of precision stamping method based on common stamping technology. When used in a stamping forming, it can get more precise size precision, more smooth cutting surface, smaller warping and higher quality stampings of interchangeability than ordinary blanking parts and improve the quality of the products under low cost.
Fine blanking is a process of plastic shear, in the special three dynamic fine blanking press with special structure, under the action of the plate in the plastic shear. Before blanking punch contact sheet, a certain pressure makes the V – ring material pressing on the concave die, thus producing lateral pressure on the inner surface of V-shaped teeth and preventing the material tear and metal horizontal flow in shear. In the punch into the materials at the same time, the backpressure of ejector presses the material and in the pressed state, punch down for blanking operation. The material of shear zone in the three directions compresses the stress state, and then improves the material plasticity. The material will produce plastic separation along the punch and die cutting edge.

The theoretical basis of metal plate fine blanking

Before finite elements analysis, the fine blanking deformation zone should go first. The outside force and stress in fine blanking of the deformation areas of the material are shown in Fig. 1.



(a) (b)

Figure 1: Force and stress of distribution in fine blanking.

In the figure：

F_y - stamping force for punch act on material, $F_y = F_y^1 + F_y^2$, where F_y^1 、 F_y^2 is stamping force and jacking force,

F_v - force for the inner edges of V-ring act on the material,

N - lateral force,

P_x, P_y - friction force,

σ_{y} - the normal stress caused by F_{y}

σ_{vx}, σ_{vy} - the normal stress caused by component of F_{v} in the X, Y direction

σ_{n} - the normal stress caused by N,

σ_{z} - the normal stress caused by mould to restrict materials,

τ - shear stress caused by friction force.

Take a coordinate system for OXYZ in deformation zone and its stress tensor is

$$T_{\sigma} = T'_{\sigma} + T_{\sigma}'' \tag{1}$$

where

T_{σ}' - spherical stress tensor

T_{σ}'' - stress deviator.

$$T_{\sigma} = \begin{pmatrix} -\sigma_{x} + \sigma_{n} & \tau_{xy} & 0 \\ \tau_{yx} & -(\sigma_{y} + \sigma_{vy}) & 0 \\ 0 & 0 & -\sigma_{z} \end{pmatrix} = \begin{pmatrix} -\sigma_{m} & 0 & 0 \\ 0 & -\sigma_{m} & 0 \\ 0 & 0 & -\sigma_{m} \end{pmatrix} +$$

$$\begin{pmatrix} \frac{1}{3}(\sigma_{vy} + \sigma_{y} + \sigma_{z}) - \frac{2}{3}(\sigma_{n} + \sigma_{vx}) & \tau_{yx} & 0 \\ \tau_{yx} & \frac{1}{3}(\sigma_{vx} + \sigma_{n} + \sigma_{z}) - \frac{2}{3}(\sigma_{y} + \sigma_{vy}) & 0 \\ 0 & 0 & \frac{1}{3}(\sigma_{vx} + \sigma_{vy} + \sigma_{n}) - \frac{2}{3}(\sigma_{n} + \sigma_{vx}) \end{pmatrix} \tag{2}$$

$$T_{\sigma}'' = \begin{pmatrix} -\sigma_{m} & 0 & 0 \\ 0 & -\sigma_{m} & 0 \\ 0 & 0 & -\sigma_{m} \end{pmatrix} \tag{3}$$

$$\sigma_{m} = \frac{1}{3}(\sigma_{y} + \sigma_{z} + \sigma_{vx} + \sigma_{vy} + \sigma_{z}) \tag{4}$$

The plasticity of material (point o) is affected by the hydrostatic pressure in the department of spherical stress tensor. The spherical stress tensor is the static pressure in deformation zone of fine blanking, and the factors that influence the hydrostatic pressure in deformation zone are known from formula 3, so following ways can increase the hydrostatic pressure and then improve the quality of blanking pieces:

1. magnify σ_{y} by increasing the kicking force;
2. magnify σ_{n} through reduce the intensive clearance to some extent;
3. magnify $\sigma_{vx} + \sigma_{vy}$ by enlarging BHF;
4. pressure angle of blank holder sets for optimum value, as shown in Fig. 1(a),

$$F_{vx} + F_{vy} = F_{v}(\cos\alpha + \sin\beta) \tag{5}$$

Take the extreme value:

$$\frac{\mathrm{d}(F_{vx} + F_{vy})}{d_{\alpha}} = 0$$

$$F_{v}(\cos\alpha - \sin\alpha) + \mathrm{d}F_{v}(\cos\alpha + \sin\alpha) \tag{6}$$

BHF is a constant value, $\mathrm{d}F_{\mathrm{v}} = 0$
therefore:

$$\cos\alpha - \sin\alpha = 0 \qquad \alpha = \pi/4$$

THE FINITE ELEMENT SIMULATION ANALYSIS OF THICK PLATE FINE BLANKING

The model of finite elements analysis

Before simulating the process of the fine blanking, the model of V-shaped ring gear blank holder should be built first. Li Chuanmin(2007) [11] found that because of the symmetrical structure, half of the model is adopted to save the time and RAM. AISI-20 steel with 8mm thick is used in the paper and the model is simulated by way of the double-side gear ring blank holder whose results are shown in Fig. 2. The simulating parameters are shown in Tab. 1.

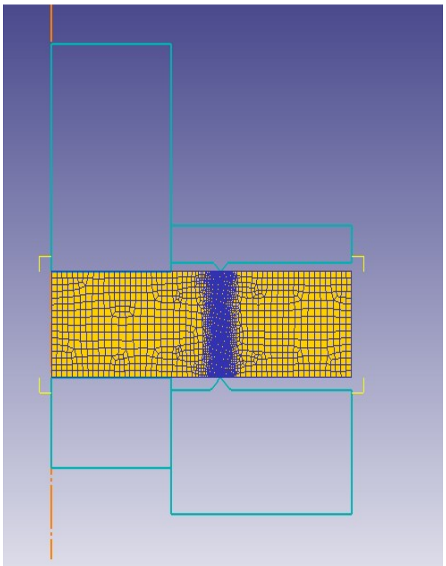


Figure 2: Finite element model.

friction coefficient	0.12
Unit grid	3000
Step	0.002
The pressure/KN	20
BHF/KN	60

Table 1: Simulation parameters.

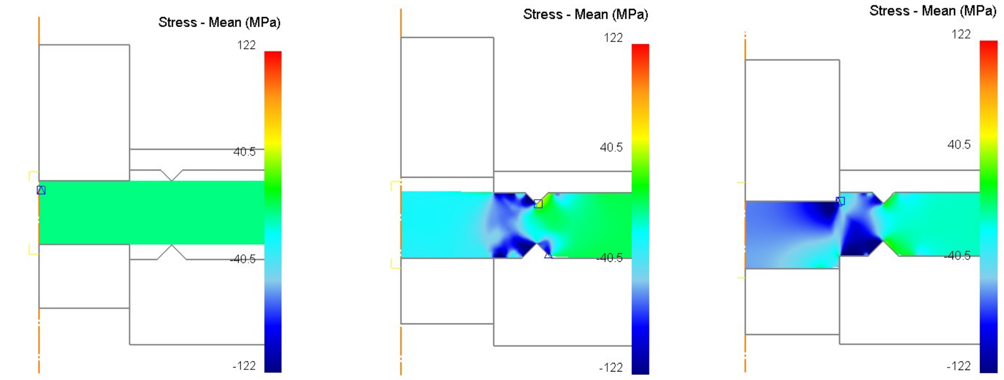
Process simulation of the double ring gear pressure side

From Fig. 3 (a) to (e) it can be seen that in the process of double ring gear blank holder blanking, the shear zone of hydrostatic pressure is significantly higher than other parts, and compressive stress is also larger near the punch and die cutting edge. When the punch is down to ½ of the material thickness, the pressure stress of the die cutting edge greatly decreases. When the material is broken, the compressive stress that shear zone materials bears is further reduced and the tensile stress appears in the die cutting edge of shear deformation zone material. The greater the compressive stress of materials deformation zone is, the more conducive it is to give full play to the material plasticity so as to inhibit the crack generation or expansion and guarantee high quality blanking section. Consequently when the material is broken, the tensile stress that exists in deformation zone exacerbates the material fracture.

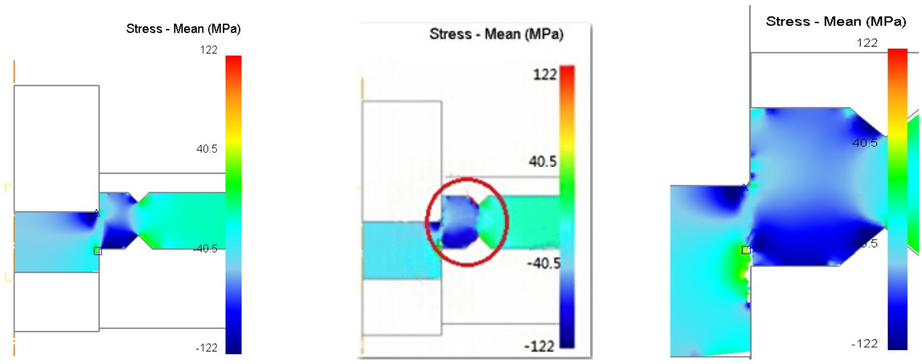
To sum up, if we want to obtain high quality punching parts with double ring gear blank holder blanking, we must try to increase the three to the compressive stress of material shear deformation zone. Because bilateral gear ring blank holder blanking, gear form, tooth height, pitch, the blank holder force and the blank holder force will have different influences on the hydrostatic pressure, we need to simulate and analyze the process parameters [12].

The impact of ring gear form on thick plate fine blanking

Using the V-shape, a step shaped and the cone gear form to finite element simulation, the hydrostatic pressure distribution is shown in Fig. 4. As can be seen from the graph, the hydrostatic pressure distribution that V - ring produced is broad, almost filling the entire fine blanking zone. However, the step shaped and the circular cone gear ring only produce hydrostatic pressure in gear ring near, and the scope is relatively small. Although the step shaped and the cone gear ring blank holder can also play a pressure side effect, but the effect of hydrostatic pressure is far better than that of the V shaped ring gear. In the fine blanking, the gear ring pressure is only one that is large enough to guarantee the materials hydrostatic pressure required in the shear zone. Fig. 5 shows the relationship between the gear form and a hydrostatic pressure distribution. As can be seen from the graph, the hydrostatic pressure generated by V - ring is the largest and advantageous to the sheet of plastic.

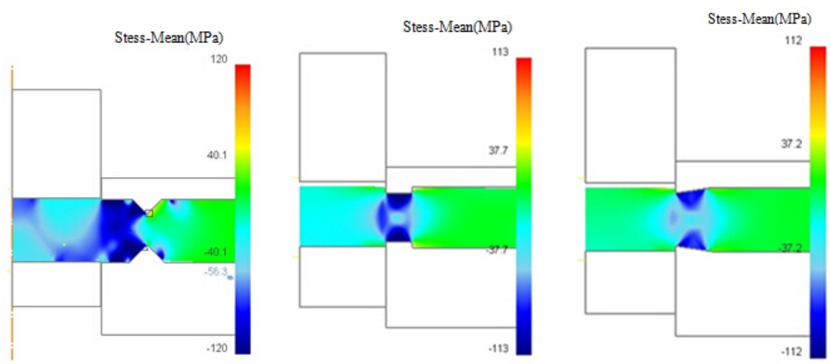


(a) Before the blanking began (b) Ring gear is pressed into the sheet (c) Fine blanking 1/4



(d) Fine blanking 1/2 (e) Material fracture (f) Partial view

Figure 3: Fine blanking process simulation of ring gears with both sides



(a) V shape (b) step shaped (c) cone gear form

Figure 4: The hydrostatic pressure distribution with different gear ring form.

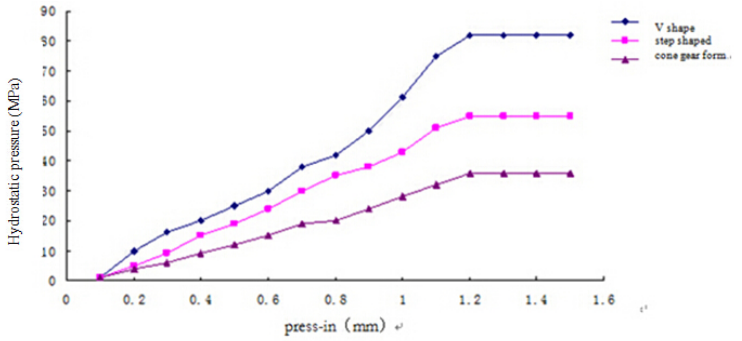
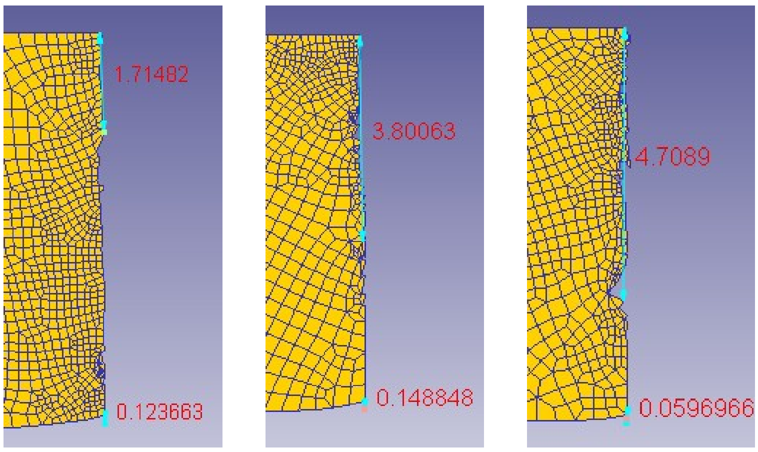


Figure 5: The relation of gear ring form and hydrostatic pressure distribution.

Fig. 6 shows the blanking pieces cross section under different forms of gear ring. It is apparent that different forms of gear ring hedge cutting will produce different effects, and bring about different forming results. In addition, Fig. 6 demonstrates that the blanking pieces of V-shaped ring gear have a top quality and the change of euphotic zone length is as high as 50%. The blanking pieces of step shaped have a relatively rough cross section and nearly no euphotic zone. The cross section of blanking pieces with cone gear ring is not ideal, and the cross section of blanking pieces is less than V gear ring form. This is because the hydrostatic pressure that produced by steps form and conical gear ring is not big enough to replace the plastic material in the blanking process.



a) V shape b) step shaped c) cone gear form

Figure 6: The shearing section with different gear ring form.

The impact of tooth depth on thick plate fine blanking

In the case where other conditions remain unchanged, it takes four different sizes of the tooth depth to simulate the process of fine blanking with bilateral gear ring blank holder. As the V-ring on the die cannot change and is easy to wear, V-ring on the die must be set slightly bigger than on the punch. And simulation parameters of the tooth depth are listed in tab.2.

Tooth depth(mm)		Pitch(mm)	Clearance(mm)
upper(under)	0.8(1.2)	3.5	0.05
upper(under)	1.2(1.6)	3.5	0.05
upper(under)	1.6(2.0)	3.5	0.05
upper(under)	2.0(2.4)	3.5	0.05

Table 2: Simulation parameters of tooth depth.

Fig. 7 shows the distribution of hydrostatic pressure which is under the condition of ring gear blank into sheet. Hydrostatic pressure is produced when ring gear blank presses in sheet and increases with the growth of press-in and reaches the maximum value when different sizes of the tooth depth are all pressed into the sheet as indicated in Fig. 7. Thus, the hydrostatic pressure increases with the growth of the tooth depth. The depth of teeth is larger and hydrostatic pressure is greater in the fine blanking area, so that the whole process can make full use of plasticity of sheet and achieve high quality section pieces.

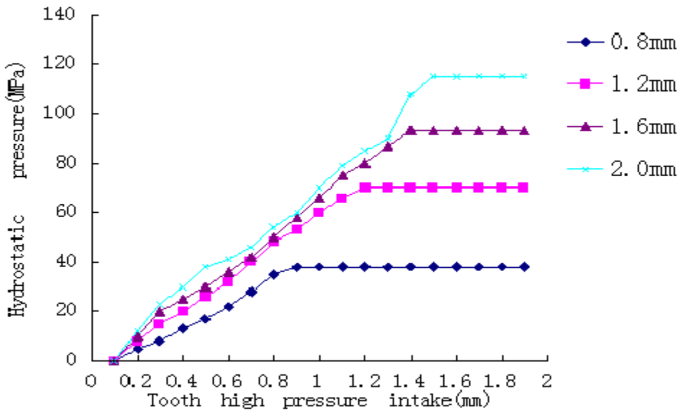
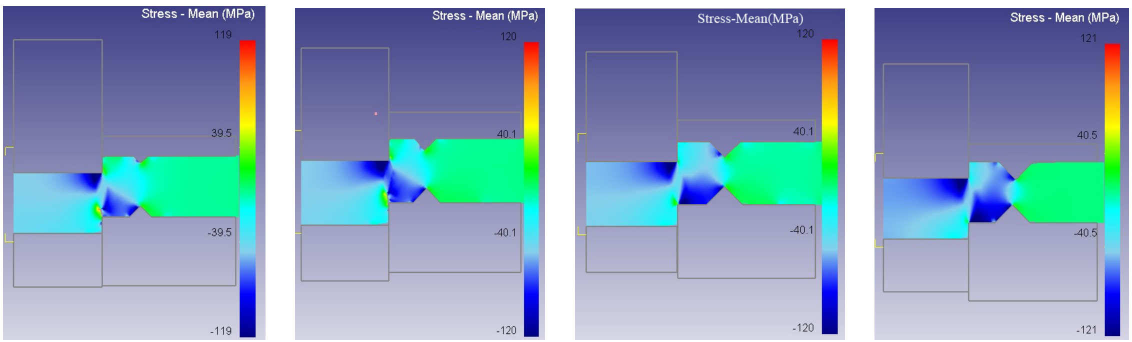


Figure 7: Relation of tooth depth and hydrostatic pressure.

Fig. 8 indicates the distribution of stress in shear deformation zone when fine blanking process is half finished. Along with fine blanking, compressive stress is decreasing in the zone of materials shear deformation and tensile stress is produced near the convex and concave die as it is in Fig. 8. Tensile stress occurs in the process of punching which leads to the cracks. On the contrary, compressive stress can restrain the generation and extension of cracks and effectively improve the plasticity of materials.



a) 0.8mm b) 1.2mm c) 1.6mm d) 2.0mm

Figure 8: Stress distribution of fine blanking 1/2 in deformation zone.

The relationship between the maximum contact pressure and punch in plate is shown in Fig. 9. Before the punching, there is a certain value of hydrostatic pressure in shear zone and it creates a better plastic state for the further deformation of material. Fig. 9 signifies that the compressive stresses in shear zone are generally large and they increase obviously with the growth of depth tooth, but less when the upper tooth depth exceeds 1.2mm. The average value of compressive stresses is around 75MPa.

Fig. 10 shows the effect relation curve of blanking quality by tooth depth. While bright zone increases, Fillet belt and fault zone decrease as the tooth depth increases. However there is not a linear relationship between the increasing bright zone and the increasing tooth depth. In the meantime hydrostatic pressure also increases with the increasing of tooth depth, but it will leave deep impressions on the sheet if the tooth depth is too large, thus 1.2 mm is the best value for the tooth depth.

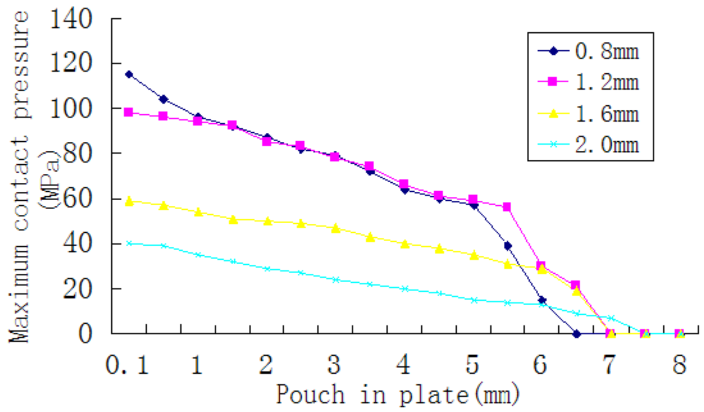


Figure 9: The relation of maximum contact pressure and punch in plate.

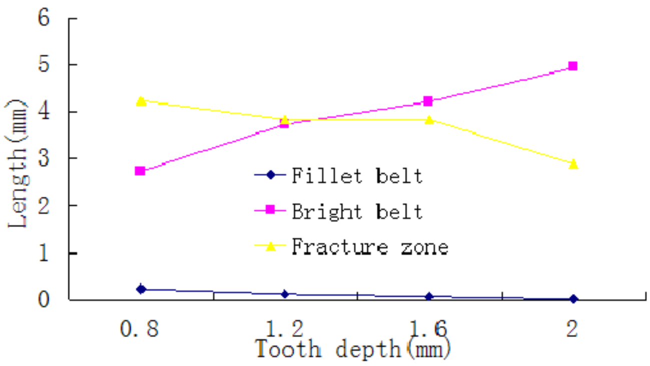


Figure 10: The effect of blanking quality by tooth depth.

The impact of pitch on thick plate fine blanking

The optimum parameter of upper tooth depth is 1.2 mm, and the simulation parameters of tooth pitch are shown in tab.3.

Pitch(mm)	Upper tooth depth(mm)	Clearance(mm)
2.6	1.2	0.05
3.5	1.2	0.05
4.6	1.2	0.05
5.7	1.2	0.05

Table 3: Simulation parameters of tooth pitch.

Fig. 11 shows the hydrostatic pressure profiles of the different pitch circle of gear pressure style. We can learn from the numerical results that the position of ring gear also has an effect on the hydrostatic pressure, and the hydrostatic pressure decreases with the increasing of pitch. Therefore in the process of stamping sheet, appropriate pitch should be chosen to ensure the sufficient hydrostatic pressure blanking, and to fully improve the plastic sheet to obtain the ideal blanking section.

Fig. 12 shows that, in different pitches, the materials stress distribution of the punch downward 1/6. Before the start of the blanking, the shear zone produced a certain value of hydrostatic pressure, creates a better plastic state for the further deformation of material. In the graph, as the pitch increases and compressive stress area reduces deformation, the shear zone compressive stress becomes larger, but stress is smaller far away from the area of fine blanking parts of the compressive.

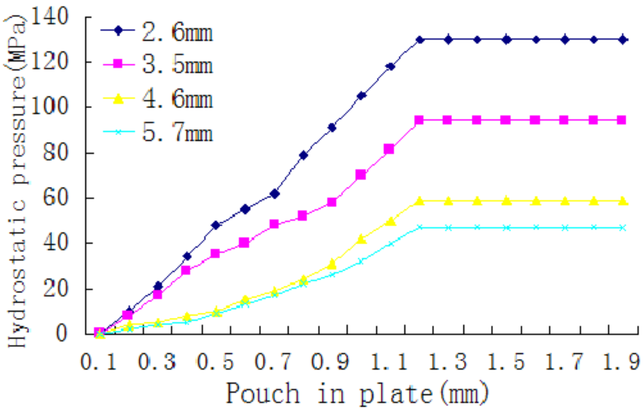
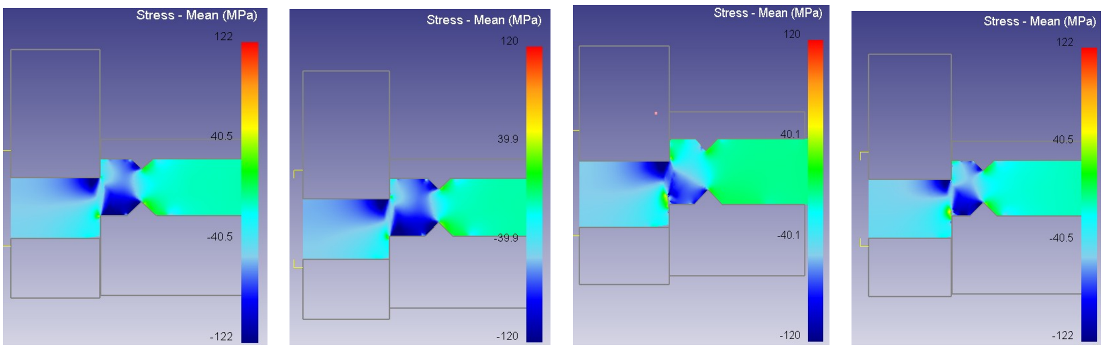


Figure 11: The hydrostatic pressure with different pitch.



a) 2.6 mm b) 3.5 mm c) 4.6 mm d) 5.7 mm

Figure 12: Stress distribution of fine blanking 1/6 in deformation zone.

Fig. 13 shows the relationship between the maximum compressive stress and the convex molding quantity. It is obvious that the stress of the compressive deformation zone significantly increases along with the increasing pitch. Because under the same press, pitch that is too big will produces less hydrostatic pressure. Thus the quality of the obtained blanking off surface is relatively poor. If the BHF is increased to obtain a good cutting surface, there will be a corresponding increase in punching die load. Through many times of finite element simulations, it can be obtained that smooth surface can reach about 80% when the pitch is equal to 3.5mm, which is considered as the ideal pitch.

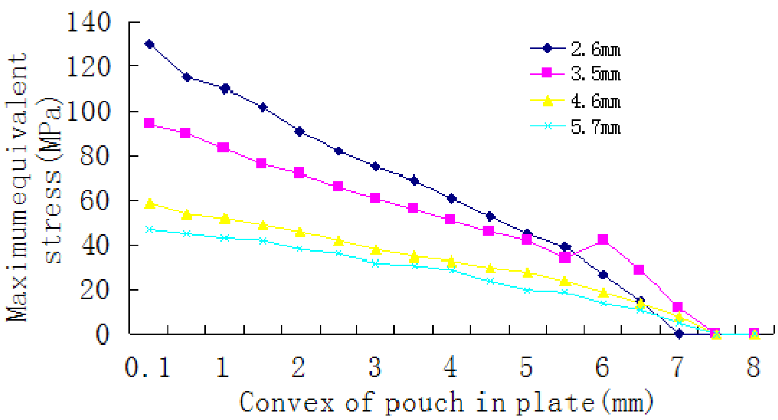


Figure 13: The relationship of maximum equivalent stress and convex of pouch in plate.

As can be seen from Fig. 14, with the increase of radius of tooth pitch, changes are relatively stable. The euphotic zone decreases with the bright belt length down by 50%; the fracture zone increases thus the bright band increases. As teeth pitch does not increase linearly, the ring gear is closer to the die cutting edge (i.e. pitch is small), the shear zone will produce higher hydrostatic stress, and metal materials tend more to flow to the shear zone and improve the quality of the cross section. In conclusion, the quality of blanked parts is most ideal when the pitch is 3.5mm.

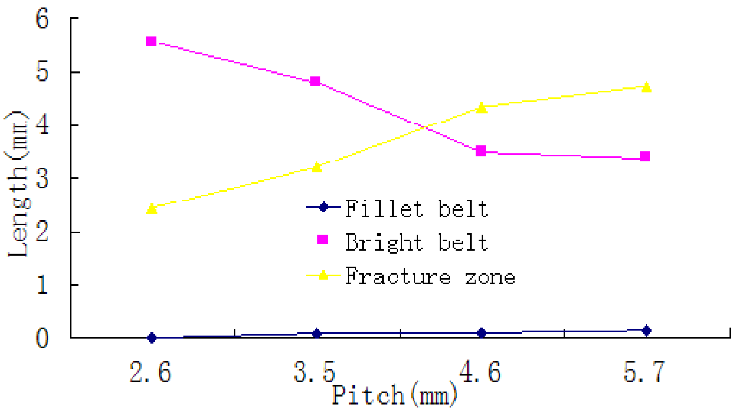
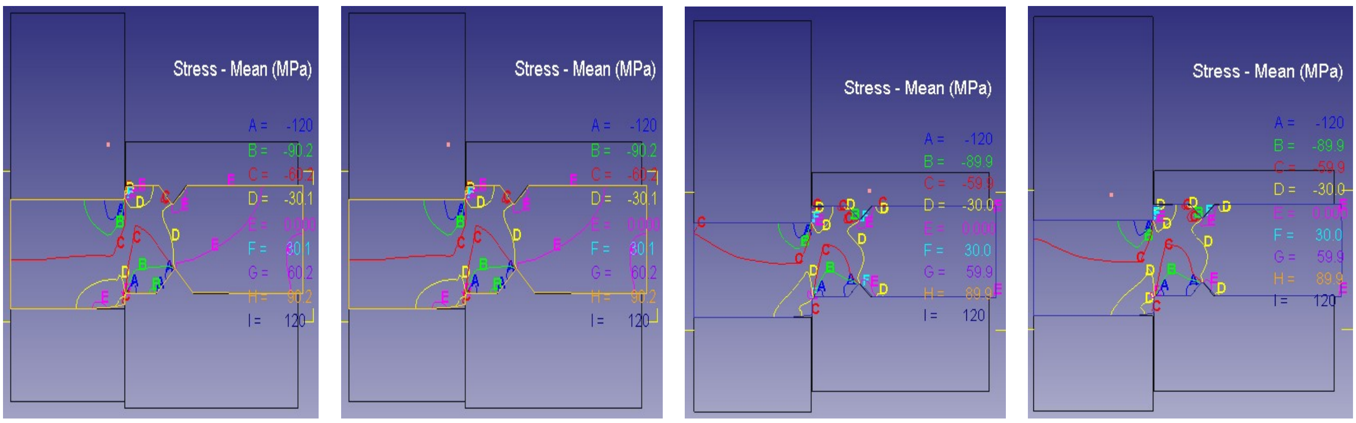


Figure 14: The effect of blanking quality by tooth pitch.

The impact of blanking clearance on thick plate fine blanking

The influence of different blanking clearances on the stress distribution is shown in Fig. 15. The equivalent stress concentrating near the shear zone when the clearance value is zero and its values vary from 19MPa to 100MPa. The stress values in the zone near the euphotic belt are basically uniform. When clearances are 0.8%t and 1.6%t, the equivalent stress distribution of the areas spreads and has no big changes. When clearance is 2.4%t, the areas of equivalent stress distribution decrease but still with no big changes.



(a) 0 (b) 0.8%t (c) 1.6%t (d) 2.4%t

Figure 15: Equivalent stress of fine blanking 1/4 with different clearance.

The effect of blanking quality by blanking clearance is shown in Fig. 16. The fault zone length increases as clearance does. The fault zone of cross section achieves the shortest and euphotic zone the longest when the clearance is 0.8%t. So 0.8%t is the best value optimum for blanking clearance. It is consistent with the theoretical value about 0.5%t. The euphotic zone proportion will decrease with the increase of clearance in the process of plate fine blanking. It is because compressive stress is delayed in deformation zone and its crack propagation velocity is less than that caused by tensile stress when the die clearance is too large.

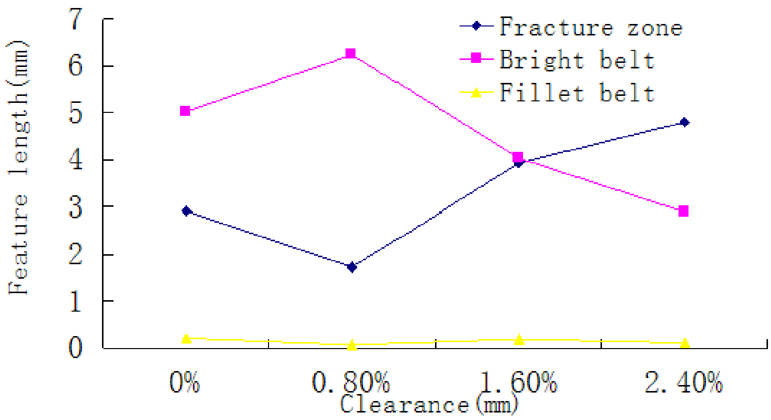
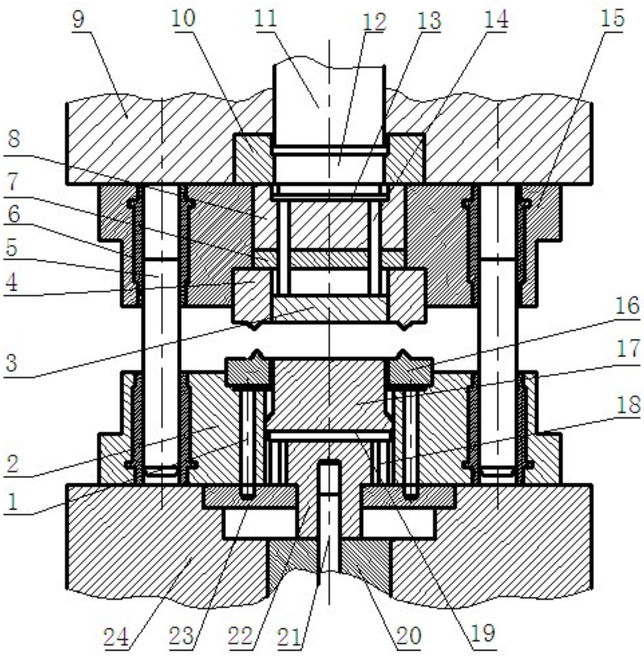


Figure 16: The effect of blanking quality by blanking clearance

EXPERIMENTAL RESULTS

This experiment in Fig. 17 uses fine blanking dies that are of different thickness (6mm, 8mm and 10mm) of steel plate to confirm the feasibility of bilateral ring gear blank holder. Parts of this experiment are shown in Fig. 18. Compared with the simulation, the experiment has consistent results as delivered in Fig. 19. The blanking part that blank by bilateral gear ring have a high section quality and the experimental results can satisfy the requirement of practical production.



1-plunger	,13-rubber washer
2-punch seat	14-plunger
3-knockout plate	15-die seat
4-die	16-ring gear gag
5-guide Pillar	17-punch
6-guide sleeve	18-plunger
7-guide sleeve of pinger	19-bridge plate
8-backing plate	20-hydraulic slide
9-press countertop	21-pull rod
10-adapter ring,	22-punch fix plate
11-hydraulic piston	23-adapter ring
12-pressure pad	24-hydraulic platform

Figure 17: Structure diagram of fine blanking die.

It can be seen that the section quality of final parts is higher, the fault zone is also improved, and fillet and burr get smaller. The quality of the eventual parts is ideal.

Figure 18: Sample of blanking parts.

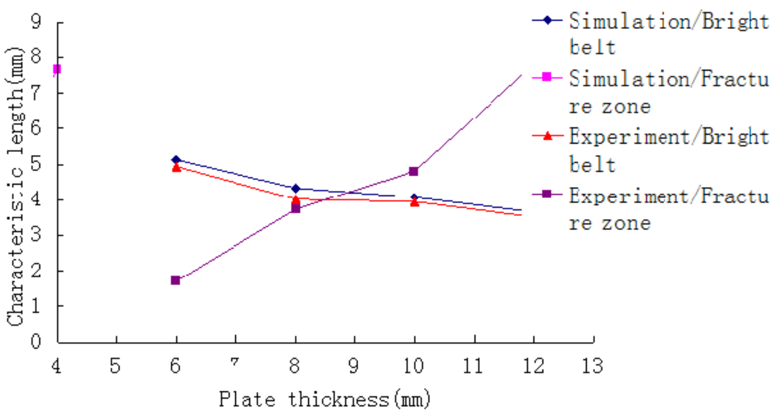


Figure 19: Compare results between simulation and experiment.

CONCLUSIONS

In this paper, 8mm AISI - 1020 steel on both sides of the ring gear blank holder of the fine blanking mechanism is studied with the commercial finite element software DEFORM. In the fine blanking deformation zone of bilateral gear ring blank mode, analyzed of the material flow law and the state of stress and strain. When to blanking AISI – 1020, simulation the influence law that the different ring gear parameters to hydrostatic pressure and cross section quality of blanking parts and optimized its parameters. In the finite element simulation, when choosing Nomalized Cockroft & Latham fracture criterion predicted cracks and expansion, the conclusion are as follows:

1) Adopting fine blanking method that uses bilateral gear ring hold blank can achieve smooth blanking section. At the beginning, three-dimensional compressive stress in shear zone gets the maximum value and then declines gradually throughout the process of fine blanking.

2) Hydrostatic pressure increases with the increase of tooth depth. When different sizes of tooth depth are all pressed into the sheet, hydrostatic pressure gets its maximum value. The proportion of bright belt also increases in that process. However, if the tooth depth is too big, it will left a deep imprint on sheet metal and affect the next blanking. For 20 steel material with thickness of 8mm, the blanking pieces will get the top quality when tooth depth is 1.2 mm.

3) The hydrostatic pressure decreases with the increase of pitch. The tooth circle is closer to mold parts (while the pitch is smaller), the shear area can produce higher hydrostatic stress, the metal material tends more to flow to the shear zone, and the proportion of bright band is greater. Through the finite element simulation, we can find the best relative pitch: a=3.5mm.

4) The blanking clearance is smaller, the proportion of blanking euphotic zone is higher. When the relative blanking clearance is 0.8%t, the bright band proportion of 20 steel approaches 95%.

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