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Numerical simulation and optimization of process parameters in fineblanking process

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Abstract: Fineblanking process is a typical large localized plastic deformation process. Based on its forming characteristics, a numerical model is established and an elasto-plastic simulation is performed using the finite element method (FEM). The re-meshing method is used when the severe element distortion occurs to facilitate further computation and avoid divergence. The McClintock fracture criterion is adopted to predict and determine the time and site of crack initiation and propagation. Based on this numerical model, the distribution and developing trend of the stress and strain in the shearing zone are predicted. Furthermore, the influence of several process parameters, such as punch-die clearance, edge radius of punch and die, V-ring force, counter force, etc., on the blanked quality is analyzed. The discipline is in accordance with the actual manufacture situation, which can be a guidance to optimization of process parameters.

Key words: metal forming; fineblanking; ductile damage; ductile fracture; finite element method

Fineblanking (FB) is a manufacturing process formerly developed in Switzerland, aimed at the production of precise blanks in a single operation. The blanks obtained by means of this technology are generally characterized by smoother edges and closer tolerances than the ones obtained through the conventional blanking process. Thus, the FB process is widely investigated and applied in industrial contexts[1]. However, complicated product shapes, particularly ones containing concave and convex portions, and different types of material have an effect on the smoothness of a blanked surface. Namely, under such conditions, it is difficult to obtain a smoothly blanked surface. At present, to avoid such problems, a database of working conditions based on the former approach or trial-and-error approaches is used[2]. However, the former approach is not adequate for obtaining a complete solution, and the trial-and-error approach is too costly and time-consuming.

Additionally, the stress and strain states in FB deformation are complicated and inconstant. The theory studies on FB, especially forming mechanisms and ductile fracture, are not in-depth and thorough. The finite element method (FEM) is an effective technology to study metal forming. With the FEM simulation results, designers can predict forming quality of important process parameters[3–4]. However, the use of the FEM in the field of fineblanking has been delayed compared with other metal forming processes, due to the large and severely localized deformation and the difficulty in introducing criteria for ductile fracture.

Accordingly, this paper aims at establishing a numerical model to simulate the whole fineblanking process, using the elastic-plastic finite element analysis code DEFORM 2D. During the simulation, the element deletion method is used to represent the crack propagation and the McClintock fracture criterion is adopted to predict and determine the time and site of occurrences of fracture. The FEM results are verified by experimental results that have showed agreement. Furthermore, the influence of several process parameters, such as V-ring force, edge radius of punch and die, V-ring force, etc., on the blanked quality is analyzed.

1 Material Ductile Fracture Model

The physical background for ductile fracture in metals is known to be the initiation, growth and coalescence of voids[5]. Voids can initiate at inclusion, secondary phase particles or at dislocation pile-ups. Growth and coalescence of voids are driven by plastic deformation. Therefore, it seems evident to incorporate the deformation history in a ductile fracture model, as shown in Eq. (1). Fracture occurs when the integration value of an element exceeds the critical value D_c[6]. The key issues in fineblanking simulation are to find a suitable ductile fracture model[7–8] and the determination of the critical value.

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$$\int_0^{\bar{\varepsilon}_f} f(\bar{\sigma})\,\mathrm{d}\,\bar{\varepsilon} = D_c \tag{1}$$

In this paper, the strategy to characterize the critica value for different criteria based on tensile test is listed as follows:

① A tensile test is performed and the minimum thickness of the neck after fracture is measured. This minimum thickness of the neck determines the moment of ductile fracture initiation.

② The tensile test is simulated with different ductile criteria. The damage value is updated and stored as a field variable.

③ When the experimentally determined minimum thickness of the neck is reached in the simulation, D_c is determined to be critical value of the ductile fracture criterion.

The McClintock fracture criterion is based on void theory and is known from previous investigations[9] to fit well with experimental results of fineblanking. So this model is applied in the later simulation.

$$\int_0^{\bar{\varepsilon}_f} \left[\frac{\sqrt{3}}{2(1-n)}\sinh\left(\frac{\sqrt{3}(1-n)}{2} - \frac{\sigma_i+\sigma_j}{\bar{\sigma}}\right) + \frac{3}{4}\frac{\sigma_i-\sigma_j}{\bar{\sigma}}\right]\mathrm{d}\,\bar{\varepsilon} = D_c \tag{2}$$

where n is the hardening exponent, $\bar{\sigma}$ is the equivalent stress, $\bar{\varepsilon}$ is the equivalent strain, and $\bar{\varepsilon}_f$ is the equivalent strain at the fracture. In this paper, the critical value D_c is determined as 1.54. The value n is determined as 0.21 by the experiments described below.

2 Modeling of Numerical Simulation

2.1 Material model

In order to accurately simulate the localized plastic deformation process, a satisfying material description is essential. However, the flow stress curve is difficult to obtain experimentally for large strains, using a conventional test such as a tension test. Thus, a standard tension test and a torsion test with solid cylinder specimen were elaborated to characterize the material description in our study. The experimental data derived from the tests are plotted in Fig. 1. From the trend of curves, it is obvious that due to the lower triaxiality, the plastic work of the torsion specimen degrades more slowly than the tension specimen and the range of its experimental data is broader and steadier, meaning that the material description based on these data is suitable for large strain deformation. According to the single curve assumption in the plastic theory, we fitted a master curve through the stress-strain curves of a tension test and a torsion test. This fitting procedure yields the following master-curve:

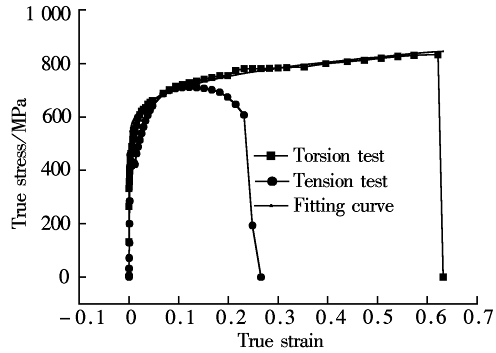

Fig. 1 Experimental curves and fitting curve

$$\bar{\sigma} = 480\,\bar{\varepsilon}^{0.21} + 410$$

Other mechanical characteristics of C45 steel material are listed as follows:

Elastic module

$$E = 210 \text{ GPa}$$

Poisson ratio

$$v = 0.33$$

2.2 Numerical model

In this paper, an axisymmetric FE model with V-ring in the blank holder is created and the part in discussion is a disk with a diameter of 70 mm and a thickness of 5 mm as shown in Fig. 2. In the FEM model, the punch, die, V-ring and ejector were defined as rigid bodies, and the sheet was defined as the elasto-plastic body. Tab. 1 summarizes the parameters used in the simulation. The amount of elements is 4 500. Since fineblanking is a typical localized severe plastic deformation[10-11], and the deforming zone is near the blanking clearance, the elements near clearance were refined to 0.03 mm length and the elements apart from clearance were coarsened. The calculation was performed by re-meshing after three analytical steps using the adaptive re-meshing approach due to the fact that the excessive deformation of elements and excessive penetration of elements into the tool tip were prevented. Crack propagation is represented by the element deletion method.

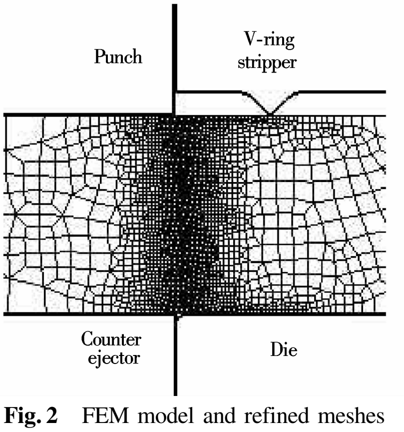

Fig. 2 FEM model and refined meshes

Tab. 1 Dimensions of tool and process parameters

Parameters	Value
Clearance/mm	0.04
Punch corner radius/mm	0.05
Die corner radius/mm	0.1
Thickness of sheet/mm	5
V-ring force/kN	300
Ejecting force/kN	100
Pressing velocity of punch/($mm \cdot s^{-1}$)	10
Friction factor	0.1

3 Results and Analysis

3.1 Analysis of hydrostatic pressure

Hydrostatic pressure σ_h plays an important role in fineblanking. If σ_h is negative and its absolute value is high, the limitation of metal deformation will be prolonged. The distribution of σ_h after the V-ring's penetrating into sheet is illustrated in Fig. 3(a). The material under the V-ring was compressed and the hydrostatic pressure was extended into the plastic shearing zone, so a good hydrostatic state was created before fineblanking. The distribution of σ_h when the punch pressed into sheet for 2.5 mm is illustrated in Fig. 3(b). Good hydrostatic state was still preserved in the shearing zone, so the generation of fracture was restrained.

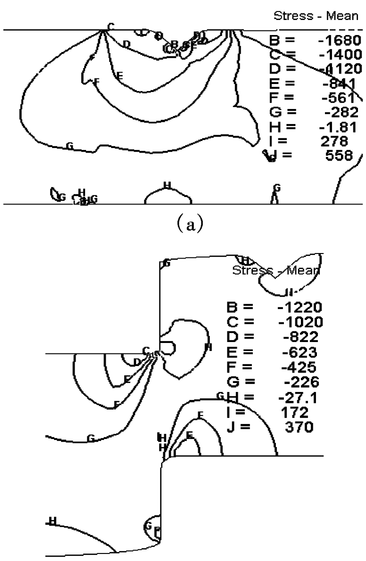

Fig. 3 Distributions of σ_h in different phases. (a) V-ring penetrating into sheet; (b) Punch pressed into sheet for 2.5 mm

3.2 Analysis of stress and strain distribution in the shearing zone

Fig. 4 shows the distribution of $\bar{\sigma}$ and $\bar{\varepsilon}$. The plastic deforming zone mainly concentrated near the limited clearance between punch and die, where severe plastic deformation took place and no plastic deformation occurred in other regions. The maximum effective strain occurred near the radius of punch and die. Because the edge of punch and die consists of lines and arcs, the variational curvatures caused uneven metal flow. Furthermore, the stress concentration phenomenon in the shear band is quite apparent during the simulation, due to the large localized plastic deformation of the fineblanking process.

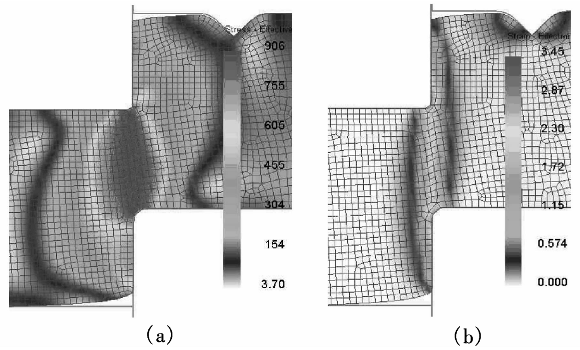

Fig. 4 Distributions of $\bar{\sigma}$ and $\bar{\varepsilon}$ when punch penetrated into 50% of sheet thickness. (a) Distributions of $\bar{\sigma}$; (b) Distributions of $\bar{\varepsilon}$

3.3 Effect of clearance on blanked quality

Fig. 5 shows the ductile fracture state when the clearance is 0.04 mm and 0.15 mm. The element was deleted when its damage value exceeded the critical value mentioned in section 2. In Fig. 5(a), only fewer elements were deleted at the final stage of punch penetration, while in Fig. 5(b) element deletion occurred earlier and

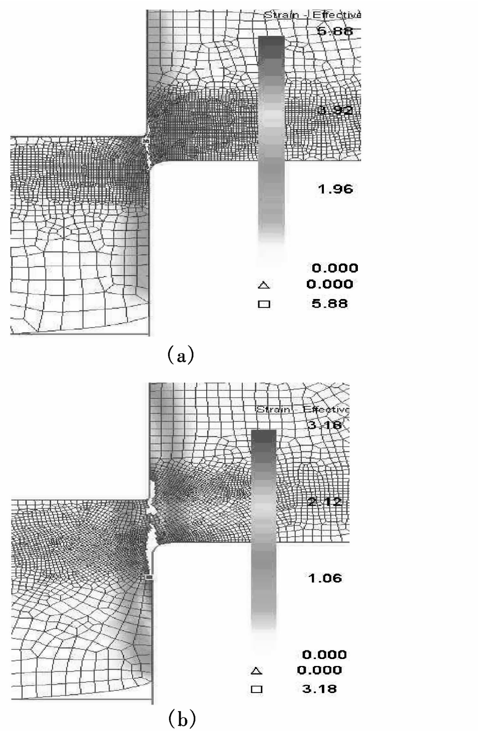

Fig. 5 Clean cut height under deferent blanking clearance. (a) 0.04 mm of blanking clearance; (b) 0.15 mm of blanking clearance

more times. Since the hydrostatic pressure is higher when clearance is smaller, which can effectively restrain the initiation and propagation of ductile fracture, the degree of plastic deformation will be larger and the effective strain when ductile fracture occurs will be higher. It can be concluded that small clearance in fineblanking improves the clean cut height.

3.4 Effect of radius of die edge on blanked quality

Since the materials flow via die edge from the outer surface of the part, the rounded die edge can make the materials flow via it before reaching the deformation limitation and the clean cut surface can be received. Fig. 6 shows the plot of clean cut height under different radiuses of die edge. The clean cut increases with increasing radius and reaches a peak value of 92% of sheet thickness when the radius is 0.1 mm. Then it decreases with increasing radius because extrusion force and stretching force increase when a radius exceeds a suitable magnitude.

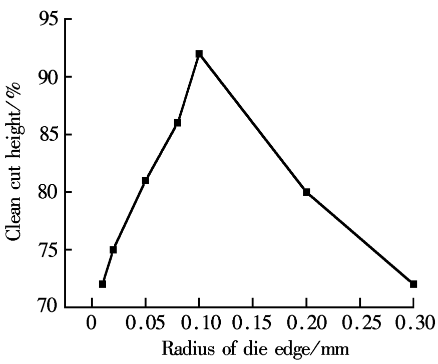

Fig. 6 Effect of radius of die edge

3.5 Effect of V-ring force on blanked quality

Fig. 7 shows the plot of clean cut height under different V-ring forces and a constant counter force of 100 kN. The clean cut increases with increasing V-ring force and reaches a peak value of 95% of sheet thickness when the V-ring force is 300 kN, then it does not increase rapidly when the V-ring force exceeds 300 kN. Too large a V-ring force is not recommended

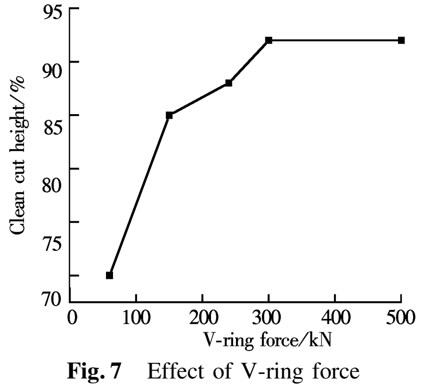

Fig. 7 Effect of V-ring force

because it increases the suffering of the tools.

3.6 Effect of counter force on blanked quality

Fig. 8 shows the plot of roll-over height under different counter forces and a constant V-ring force of 250 kN. The height decreases with increasing counter force, then it does not decrease rapidly when the counter force exceeds 120 kN.

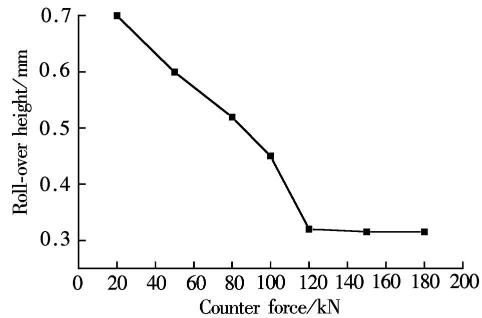

Fig. 8 Effect of counter force

3.7 Prediction of cutting force

The conventional computation formula of cutting force is simple but not accurate, because it does not consider the effect of part geometry, shearing state, blanking clearance and friction. With the aid of a correct model and FEM simulation, the cutting force and changing tendency of load distribution in the forming process can be obtained. From the viewpoint of Ref. [1], the experimental and the numerical load vs. stroke curves for the fineblanking process are in high coincidence. It can be concluded that the numerical results based on a correct model is more correct than the one from the conventional computation formula in most cases. Fig. 9 shows the plot of change of force when the blanking clearance is 0.04 mm, and the other process parameters adopted optimized ones from the above research.

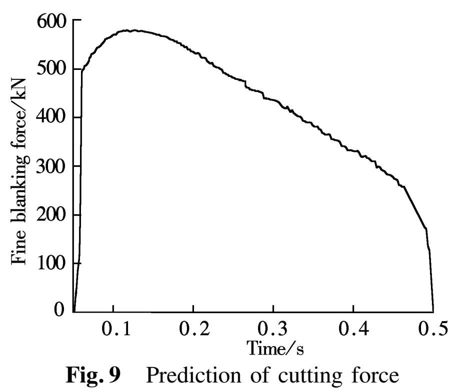

Fig. 9 Prediction of cutting force

4 Conclusions

The utility of the FEM code in the field of the fineblanking has been investigated from the perspective of simulating or predicting ductile fracture, the punch and die clearance, tool radius and V-ring force, counter force, which are believed to be important process parameters for fineblanking. The main conclusions of the present research are as follows:

1) The key issues in the simulation of the fineblanking process are to choose a suitable fracture criterion and the determination of the critical value. Furthermore, a correct material model is essential. Based on the experimental results of tension tests and torsion tests, it can be concluded that the fitting curve meets well the requirements of large plastic deformation problems.

2) Small clearance can preserve fine hydrostatic pressure in the shearing zone which can restrain the occurrence of ductile fracture in blanked surfaces. Besides, a suitable rounded edge of punch and die can improve the quality of clean cut blanked surfaces.

3) The clean cut increases with increasing V-ring force and remains steady when the V-ring force reaches a definite magnitude. The roll-over height decreases with increasing counter force, and it remains steady when the counter force reaches a definite magnitude. The simulation shows the same result as the experiments. Additionally, with FEM simulation, accurate cutting force and changing tendency of load distribution can be obtained.

References

[1] Filice L, Micari F. Numerical and experimental analysis of fine-edge blanking operations[A]. In: *Simulation of Materials Processing: Theory, Methods and Applications*[C]. Lisse: Swets & Zeitinger, 2001: 971 − 976.

[2] Schlagau S, Christen Th. Potentials of the fineblanking/forming technology — actual developments[A]. In: *Advanced Technology of Plasticity, Proceedings of the 6th ICTP*[C]. Berlin, 1999, **3**: 19 − 24.

[3] Qin Siji, Li Hongbo, Peng Jiageng, et al. Numerical simulation and optimization of clearance in sheet shearing process [J]. *Trans Nonferrous Met Soc China*, 2003, **13**(2): 407 − 411.

[4] Hatanaka N, Yamaguchi K, Takakura N. Finite element simulation of the shearing mechanism in the blanking of sheet metal [J]. *Journal of Materials Processing Technology*, 2003, **139**(1 − 3): 64 − 70.

[5] McClintock F A. A criterion for ductile fracture by the growth of holes [J]. *J Appl Mech Trans, ASME*, 1968, **35**: 363 − 371.

[6] Clift S E, Hartley P, Sturgess C E N, et al. Fracture prediction in plastic deformation processes [J]. *Int J Mech Sci*, 1990, **32**(1): 1 − 17.

[7] Goijaerts A M, Govaert L E, Baaijens F P T. Evaluation of ductile fracture models for different metals in blanking [J]. *Journal of Materials Processing Technology*, 2001, **110**(3): 312 − 323.

[8] Rao A Venugopal, Ramakrishnan N, Kumar R Krishna. A comparative evaluation of the theoretical failure criteria for workability in code forging [J]. *Journal of Materials Processing Technology*, 2003, **142**(1): 29 − 42.

[9] Zhao Zhen, Xie Xiaolong, Gu Shengguang, et al. Elasto-plastic large deformation FE simulation for fine-blanking process [J]. *China Metalforming Equipment & Manufacturing Technology*, 2005(5): 47 − 49. (in Chinese)

[10] Zheng Pengfei. Finite element analysis of the combined fine blanking and extrusion process [D]. Hong Kong: Hong Kong Polytechnic University, 2000.

[11] Chen Zhanghua. Process modeling of fine-blanking using thermo-mechanical coupling method [D]. Hong Kong: Hong Kong Polytechnic University, 2002.

精冲过程的数值模拟及工艺参数优化

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摘要:精冲过程是典型的局部塑形大变形过程,基于其成形特点建立有限元数值仿真模型,对精冲工艺进行弹塑形大变形有限元仿真.模型采用网格重划分方法解决网格畸变情况严重时造成计算终止以及计算结果不收敛的问题,同时引入 McClintock 韧性断裂准则来预测裂纹出现和扩展的时间及位置.在此基础上,给出了剪切区内应力、应变的分布以及发展趋势,同时针对精冲过程中的工艺参数,如凸凹模间隙、刃口圆角、压边力、反顶力等,对精冲成形面质量的影响加以了分析,给出了工艺参数的影响规律,模拟结果与实际生产情况基本符合,可用于指导工艺参数优化.

关键词:金属成形;精冲;韧性损伤;韧性断裂;有限元方法

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