Research on the Influence of Punching Parameters and Selection of Fracture Damage Model for Punching

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Abstract. Due to the advantages of high efficiency, low energy consumption and wide applicability, die punching has been widely used in the shearing process of automotive parts. However, it is seldom used on ultra-high strength steel due to the high punching force and risk of tool wear. In this paper, study of die punching process for hot stamped steel Usibor 1500P has been carried out. Firstly, the influence of process parameters including punching velocity, die clearance, punch corner radius, sheet thickness, punch diameter and punch shape have been studied through a specifically designed punching tool. Corner radius at the punch edge can significantly improve the sheared edge quality, and tapered flat-bottomed punch and conical shaped punch evidently reduce and raise the maximum punching force respectively. Secondly, based on the damage thresholds obtained from "iterative prediction-correction" method, finite element fracture model for the die punching process of Usibor 1500P has been constructed and validated, the Oyane and MMC damage models are considered as the most suitable for describing the fracture characteristics of the Usibor 1500P during punching.

Keywords: Hot stamped ultra-high strength steel · Die punching · Sheared edge quality · Fracture model

1 Introduction

In order to improve the safety of automobiles and reduce the weight of the body to meet the requirements of energy saving and environmental protection, the application of ultra-high strength steel is rapidly increasing on automotive components [1]. In the processing of the components, the shearing process is usually used for joining, paint removing, attachment, reduction in weight, etc. [2]. Die punching whether in production costs, processing efficiency and equipment investment has certain superiority [3].

In response to the potential problems of poor sheared edge quality and high punching force of the high strength steel punching, scholars have conducted related studies: Study by Hong-Seok Choi et al. [4] on DP980 steel showed that the bending moment generated

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by the punch raises with the increase of the die clearance. A. Mackensen et al. [5] found the punching force decreased significantly as the shear angle of the punch increased. K. Mori et al. [2] showed that the use of punch with small round edge can effectively increase the percentage of burnish zone.

Finite element simulation is common in the study of punching processes. Victor Hugo Cabrera et al. [6] investigated the effect of punch shapes on maximum punching force by ANSYS simulations. Mori K et al. [7] used LS-Dyna to study the mechanism of residual stress generation at the fracture edge during punching. The accuracy of the punching simulation is highly dependent on the selection of the fracture damage model.

In this paper, Usibor 1500P is used as the study object. The effects of punching parameters on the maximum punching force and sheared edge quality are analyzed through experiments and the fracture damage model applicable to the simulation of the punching process is determined.

2 Experimental Set-Up

2.1 Experimental Materials

The experimental material is Usibor 1500P, the microstructure of which is martensitic after hot stamping. The chemical composition of the material is 0.25 wt.% C, 1.40 wt.% Mn, 0.35 wt.% Si, 0.30 wt.% Cr, 0.005 wt.% B and its mechanical properties are: yield strength of 1160 MPa, tensile strength of 1500 MPa and elongation of 6%.

2.2 Setup of Punching Experiments

The experimental punching equipment is shown in the Fig. 1. Parameters can be adjusted by changing the punch and die insert. The values of sheet thickness are 1.2 mm, 1.6 mm, 2.0 mm. Punch diameters include 6 mm, 12 mm, 20 mm. Punching velocity takes the value of 8.25 mm/s, 16.5 mm/s, 49.5 mm/s, 82.5 mm/s. Die clearance is expressed using the percentage of the sheet thickness t, taking the value of 7.5%t, 10%t, 12.5%t, 16.25%t. Besides the conventional punch, flat-bottomed punch with the corner radius of 0.1 mm and 0.2 mm, tapered flat-bottomed, conical shaped punch is also adopted. The baseline working conditions used for the experiments are sheet thickness of 1.6 mm, punch diameter of 12 mm, clearance of 0.16 mm (10% t), punching velocity of 16.5 mm/s, and conventional flat-bottomed punch without rounded corner at the edge.

3 Study of Punching Parameters

3.1 Influence of Punching Parameters on Maximum Punching Force

As shown in the Fig. 2, the maximum punching force increases linearly with the increase of sheet thickness and punch diameter, which is in accordance with the theoretical prediction. As the die clearance increases from 7.5% t to 16.25% t and the maximum punching force decreases by 6.5%. Increase in the corner radius from 0 to 0.2 mm raises the maximum punching force by 4.7%. The maximum punching force decreases when the punching velocity increases. The use of tapered flat-bottomed punch can reduce the maximum punching force significantly, by 10.5%. The conical shaped punch increases the punching force by 10.2%.

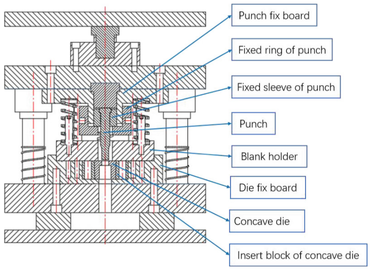


Fig. 1. Schematics of trimming tool for hot stamped part.

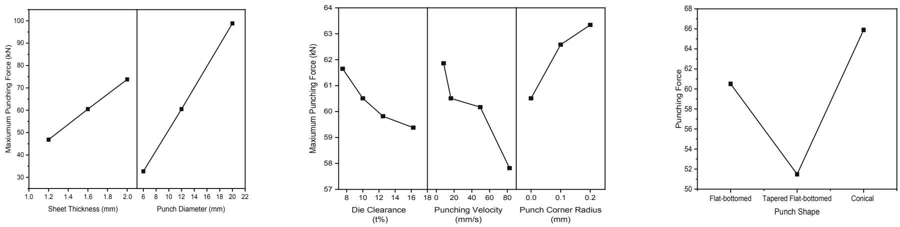
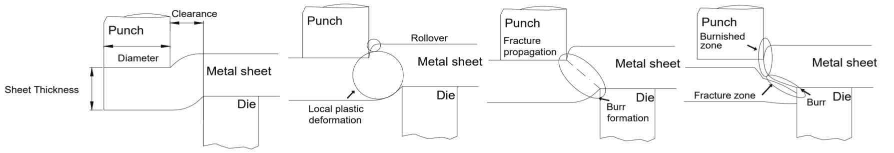


Fig. 2. Influence of punching parameters on maximum punching force.

3.2 Influence of Punching Parameters on Sheared Edge Quality

The sheared edge of punching is mainly composed of four areas: rollover, burnish zone, fracture zone and burr as shown in Fig. 3.

For different punching parameters, the percentage of each area in the sheared edge is shown in the Fig. 4. For different thicknesses of the sheets, the percentage of burr length to total thickness is less than 1.0%, and the percentages of the burnish and fracture zones are similar for the sheet thicknesses of 1.6 mm and 2.0 mm. As the punch diameter increases, the percentage of the burnish zone gradually decreases, while the percentage of the other areas increases slightly. When the punching velocity goes up to 82.5 mm/s, the burnish zone decreases by 13.9% and the fracture zone increases by 5.0% compared with the velocity of 8.25 mm/s. When the clearance increases from 10% t to 12.5% t, the burnish zone decreases by 21.9% and the fracture zone increases by 4.2%. As the punch corner radius increases from 0 to 0.2 mm, the rollover and the burnish zone increase dramatically, the fracture zone and the burr decreases. For the tapered flat-bottomed punch, there is a secondary fracture zone in the sheared edge, and there is a secondary burnish zone for the sheared edge of conical shaped punch. The fracture zone is reduced by using the special-shaped punch.



(a) Punch contacts with the sheet (b) Plastic deformation of the sheet (c) Initiation and propagation of crack (d) Fracture of the sheet

Fig. 3. Schematic diagram of die punching process.

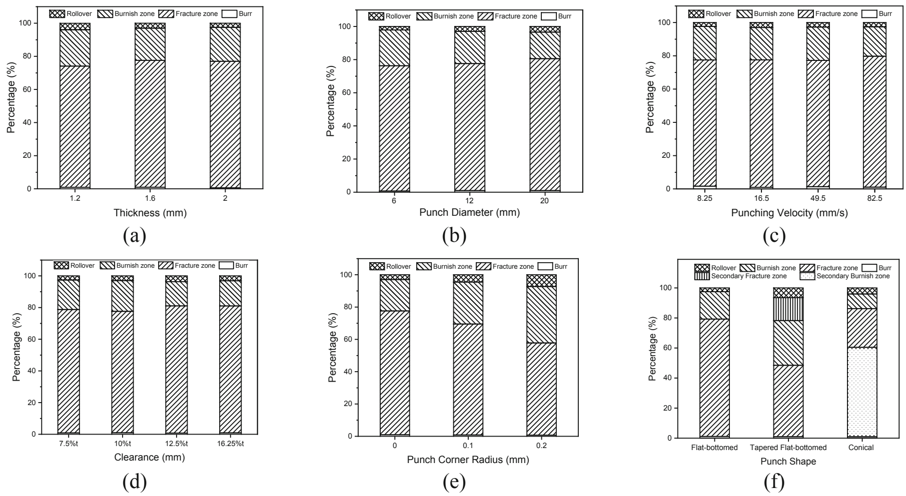


Fig. 4. Variation of the distribution of the characteristic zone of the punching edge with the parameters: (a) Thickness; (b) Punch Diameter; (c) Punching Velocity; (d) Clearance; (e) Punch Corner Radius; (f) Punch Shape.

4 Fracture Criteria Selection of Punching Process

The fracture damage models including Oyane model, Rice-Tracy model, Modified Mohr-Coulomb (MMC) model, Cockcroft-Latham model and the Freudental model are chosen to simulate the punching process with ABAQUS. The punching force-stroke curves obtained from experiments and simulations are used to select the most suitable one. Simulation parameters are set with reference to the baseline working condition. As shown in the Fig. 5, the closest to the experimental curves are the Oyane and MMC models.

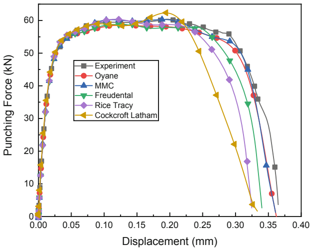


Fig. 5. Punching experiment and simulation of punching force versus displacement curve.

5 Conclusion

The main conclusions drawn in this paper are as follows:

(1) Punch shape has the most significant effect on the maximum punching force, as the tapered flat-bottomed punch decreases the punching force, while the conical shaped punch has the opposite effect, and the magnitude of the impact is about 10%.
(2) Using punch with corner radius increases the burnish zone and decreases the fracture zone, thus improves the sheared edge quality significantly.
(3) The Oyane model and MMC model are considered as the most applicable to describe the fracture characteristics of Usibor 1500P during punching in view of the punching force variation with stroke.

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