Study of die punching process for hot stamped high strength steel and its performance evaluation

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Abstract. Using the hot stamping process to produce ultra-high strength steel parts has been regarded as a good option for lightweight of automotive parts. Hot stamped workpieces usually require post-stamping processes like hole machining before they can be utilized. Considering industrial production, die punching process is more attractive than other hole machining methods such as laser cutting due to its high efficiency and low cost. In this study, the die punching process for hot stamped steel Usibor 1500P was investigated, and the performance of the punched parts was also explored. Firstly, the influence of process parameters including punching velocity, die clearance, punch corner radius, punch diameter, etc. was studied through a specifically designed trimming tool. Corner radius at the punch edge significantly improves the sheared edge quality, and tapered punch and conical punch evidently reduce and raise blanking force respectively. Secondly, several finite element fracture models for die punching process of Usibor 1500P were constructed and validated, where the Oyane and MMC damage models are considered suitable for punching simulation. Thirdly, the service performances of hot stamped ultra-high strength steel after die punching were evaluated through some typical experiments, including tensile tests, bending tests, and hydrogen embrittlement tests.

Introduction

Hot stamping steel has been widely used in the automobile industry because of its high properties. Meanwhile, the high strength and hardness bring challenges to trimming and punching processes, thus, the laser cutting is normally adopted as the subsequent treatment for hot stamped parts. In contrast, die punching method has the advantages of high efficiency and low cost, and its applicability in ultra-high strength steel products is worthy of study [1].

Gustafsson et al. [2] studied the effects of die clearance and edge pressure on the blanking force of different strength steels. Victor Hugo Cabrera et al. [3] discussed the effects of different convex die shapes on shear force through experiments and simulation. Li et al. [4] used finite element simulation to study the cross-sectional quality of high-strength steel plates in punching forming. Mori et al. [5] measured the hardness of 1.5GPa hot stamped ultra-high strength steel plate during cold stamping and laser cutting and found that the hardness of the cut edges was significantly improved. Sheng et al. [6] investigated the effects of several cutting processes on hydrogen embrittlement sensitivity and found that the punching specimen has the highest sensitivity to hydrogen embrittlement, which agrees with the results of Mori et al. [5].

This paper focuses on the die punching process of hot formed Usibor 1500P steel, studying the influence of process parameters on punching force and surface quality [7, 8]. Meanwhile, the mechanical properties and hydrogen embrittlement performance of the part after punching are also discussed.

Influence of process parameters on punching force and section quality

The chemical composition of Usibor 1500P in weight percent is 0.25% C, 1.40% Mn, 0.35% Si, 0.30% Cr, and 0.005% B, with Fe balance. After heat treatment consistent with hot stamping process, the yield strength, ultimate tensile strength, and elongation are respectively 1120 MPa, 1526 MPa, and 6.90%. The thickness of the blank is 1.6mm and the punch diameter is 12mm.

The punching experiment was designed with a combination of various process parameters. Where, the punch velocity changes from 8.25 to 82.5 mm/s, the die clearance changes from 0.12 to 0.26mm, the punch corner radius changes from 0 to 0.2mm, and the punch shape includes conventional flat one, conical one, and tapered one with flat bottom on the top.

From the experimental results, the blanking force is linearly related to the punch velocity, die clearance, and punch corner radius, but the amplitude of the change is relatively small. The punch shape has a great influence on the blanking force. Comparing to the conventional flat shape, the tapered punch can reduce the blanking force, while the conical punch increases the blanking force, as shown in Fig.1.

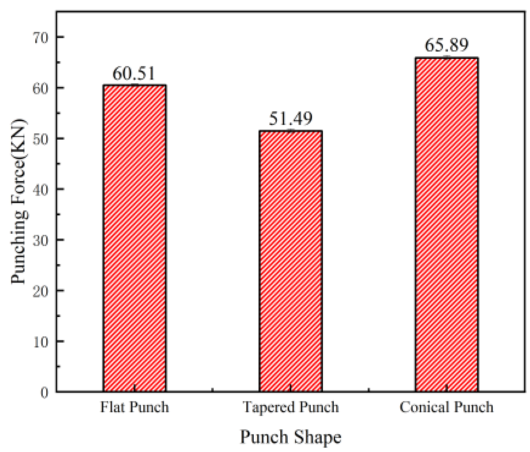

Fig.1. Effect of punch shapes on punching force.

To study the influence of process parameters on punching section, the distributions of different zones are observed. Higher quality of punched section needs small tear zone, burr length, and rollover zone, along with larger burnish zone. From the experimental results, it is concluded that among the process parameters, the punch corner radius has the most effect on the improvement of section quality as shown in Fig. 2. It should be noted that a smaller length of burr is important for the product quality, which reduced with the punch corner radius clearly.

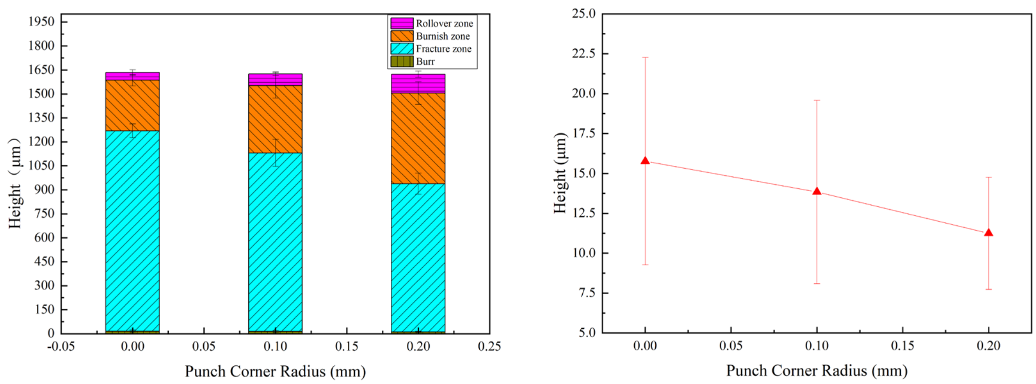

Fig.2 Sectional morphology characteristic zone and burr length

Fig. 3 shows the curves of punching force obtained by simulating different fracture criteria, it is observed that the curves for damage initiation, crack initiation, and crack propagation vary depend on the fracture criterion used. The curves corresponding to the Cockcroft-Latham, Rice-Tracey, and Freudental criteria exhibit a short damage initiation stage, and the punching force drops noticeably at small displacements, while the Oyane criterion and MMC criterion have better results by comprising with experiment.

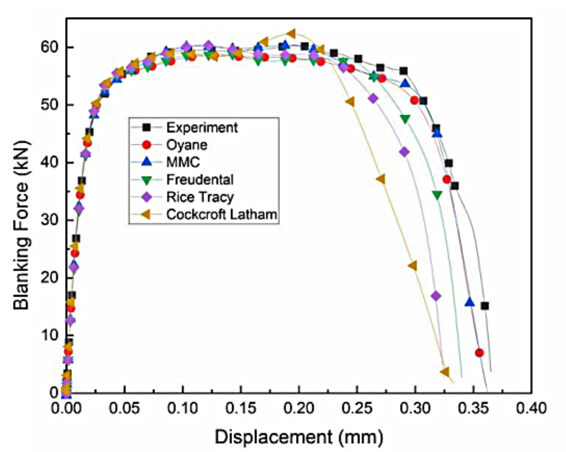

Fig. 3 Simulation results of punching force vs. displacement curve.

Performance evaluation of hot stamped boron steel after die punching

Fig. 4 shows the tensile load-displacement curves of samples corresponding to different shearing processes. Compared with the laser cutting and wire cut electrical discharge machining (WEDM) processes, perforated specimens processed by die punching exhibit reduced tensile strength and ductility after fracture during the stretching process. It is speculated that this difference may stem from the thermal processing involved in laser cutting and WEDM cutting acting as a heat treatment on the specimens, resulting in a larger but softer shear affected zone.

Meanwhile, it also can be found that different punching process has different effects on tensile properties. The die clearance has a relatively smaller impact than that of punch corner radius and punch shape. Especially for the tapered punch case, it has only half maximum tensile displacement comparing to others.

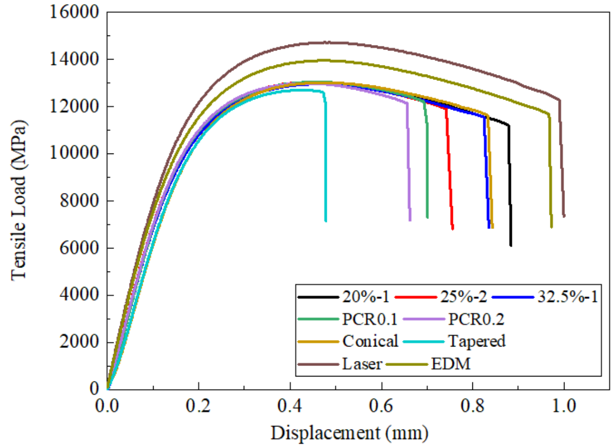

Fig. 4. Tensile load-displacement curves.

A series of three-point bending tests were also carried out through the bending test machine, and the results are shown in Fig. 5. According to Fig. 5(a), the ultimate cold bending angles of different samples are all above 50°, which meets the performance index of this steel. Fig. 5(b) shows the maximum bending loads, it can be found that the influence of the parameters on bending load is small. Meanwhile, the specimens processed by WEDM cutting and laser cutting show a relatively higher bending load compared to those processed by die punching.

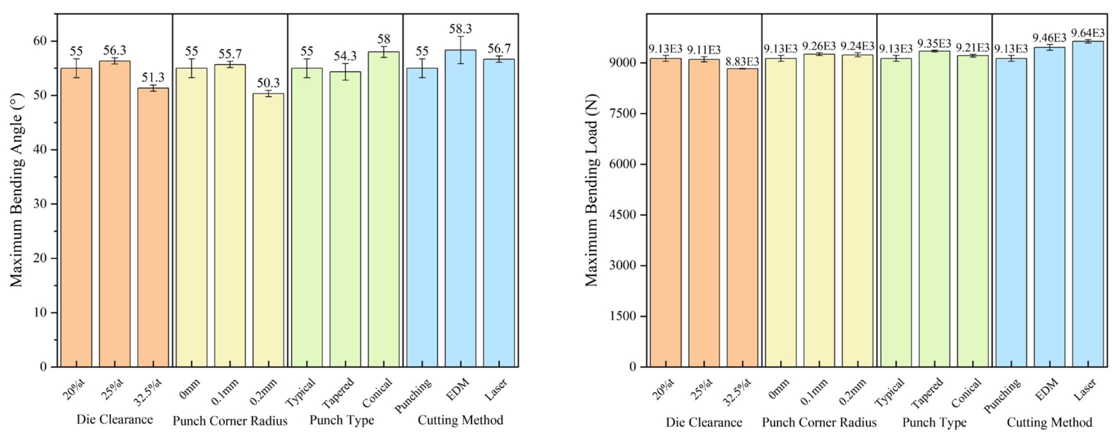

Fig. 5. Maximum bending angles and bending loads.

Through slow tensile tests with a constant strain rate of 10^{-4}/s, the influence of different punching processes on hydrogen embrittlement sensitivity was examined, before which hydrogen was firstly charged into the samples by the electrochemical hydrogen charging method with a current density of 5mA/cm^2 for 0.5h. As shown in Fig. 6, it can be found that the machinal properties decrease for all samples after hydrogen charging, especially for maximum displacement that reflects ductility. By comparing with different cutting methods, both strength and ductility of die cutting sample are worse than those of laser cutting and WEDM samples.

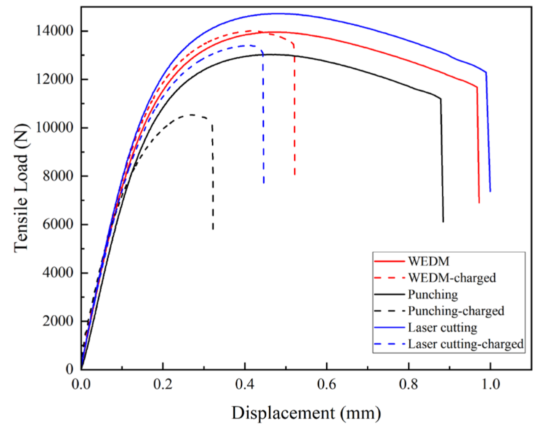

Fig. 6. Tensile load-displacement curves before and after hydrogen charging.

Summary

This paper studied the die punching process for hot stamped high strength steel, and evaluated the mechanical and hydrogen embrittlement performance after punching. The main conclusions are as follows:

(1) The punching force is linearly associated with the punching velocity, die clearance, and punch corner radius, but the variation is relatively small, while the punch shape has a larger impact. For the quality of the punching section, the main process parameter is punch corner radius, where larger radius leads to better surface quality. The finite element simulation with Oyane model can predict the punching process well.

(2) The mechanical properties under different parameters are mainly reflected in the maximum tensile deformation. The tensile performance of the conical punch sample is similar to that of the regular one, while that of the tapered punch sample shows a steep drop. As for the bending test, the maximum bending angle and bending load under all the parameters show a small relation to the change of parameters. Similarly, the HE susceptibility is also less dependent on the punching parameters.

(3) Compared with the die punching samples, the losses of tensile mechanical properties of laser cutting and WEDM cutting samples after hydrogen charging are relatively small, that is, the sensitivities of hydrogen fragility of these two samples are lower.

Acknowledgments

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