THE EFFECT OF SHEAR-EDGE QUALITY ON HOLE EXPANSION RATIO OF ADVANCED HIGH STRENGTH STEEL

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ABSTRACT: Low stretch flange-ability of AHSS is a main issue for being used in automotive. One of the representative indexes for stretch flange-ability is Hole Expansion Ratio (HER). HER is mainly affected by geometry and clearance of punching tools while shearing the hole. The effect of sheared-edge quality on HER is investigated for several punching tools. Three types, Conventional, sheared-angle and humped types, of punch shape and four die clearances are considered for 780MPa grade automotive steel. In addition, a new type of punch is developed by combining the advantages of these two types, sheared-angle and humped types, of punch. HER is also evaluated for the new-designed punch. Hot rolled Dual-phase steel and Ferrite-bainite steel with 3.2mm thickness are tested. For each case of punch types and clearances, the hardness and roughness are measured at burnish and fracture zone. The result shows that the new-designed punch presents the highest HER among four types of punches. The plastic strain near the sheared-edge called shear-affected zone (SAZ) for punching is a main factor for HER.

KEYWORDS: AHSS, HER, Sheared-edge, SAZ

1 INTRODUCTION

The application of Advanced High Strength Steel (AHSS) is one of the alternative methods for weight reduction by the CO2 regulation in automotive. For the application of AHSS improved forming technology is needed in trimming, punching and shearing process. After the cutting process, the blank is formed through various forming processes. The sheared-edge quality is one of the main factors that affect formability of the blank. Formability of the sheared-edge is decreased as the strength of the material increased. The improvement of the sheared-edge quality has been numerously studied for applications of the AHSS.

In this paper, the characteristics of sheared-edge effects on the whole expansion ratio (HER) has studied for various die clearances and punch shapes in 780MPa grade automotive steel. In section 2, punches with various shapes and material properties are introduced, in section 3, test results and the mechanism of each punch shapes affecting on sheared-edge are discussed and hole expansion ratio is investigated.

2 Tools and materials

Three types, Conventional, sheared-angle and humped types, of punch shape and four die clearances are considered. Test materials are DP (Dual-phase) steel and FB (Ferrite-bainite) steel of 780MPa.

2.1 Test materials

Mechanical properties of the test materials used in this study are given in table 1. DP(Dual phase) steel consist of ferrite and martensite phases that has good formability due to high elongation but low HER due to hardness difference between two phases. FB steel that combined ferrite with bainite has high resistance of the crack propagation due to micro carbide.

Table 1: *Mechanical properties of the materials*

Material	Thickness	YS(MPa)	TS(MPa)
DP	3.2mm	579	747
FB	3.2mm	675	825

2.2 Test procedure

Fig.1 and Fig.2 show punching tools for HET (Hole Expansion Test) tools. At the HET, burr position is up side. Dd is diameter of die and punch diameter is 20mm in punching tools. The conical type punch with 60° is used in HET. HER (Hole Expansion Ratio) is defined as equation (1) and (2). Experiments were repeated three times in each condition.

$$HER\ \lambda(\%) = (\mathrm{Df} - \mathrm{Di})/\mathrm{Di} \times 100 \quad (1)$$

D_f : hole diameter after hole expansion
D_i : hole diameter after hole punching

$$\mathrm{Clearance}(\%) = 0.5 \times (\mathrm{Dd} - \mathrm{Dp})/\mathrm{Di} \times 100 \quad (2)$$

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Dd : diameter of die
Dp : diameter of punch
t : thickness of test material

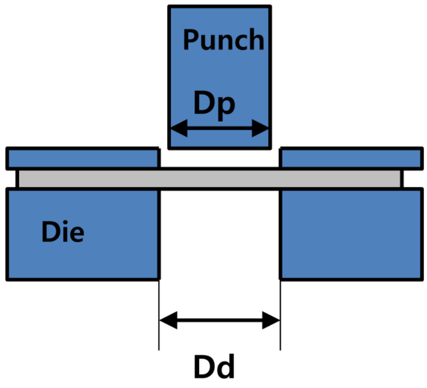


Fig. 1 *Tools for punching.*

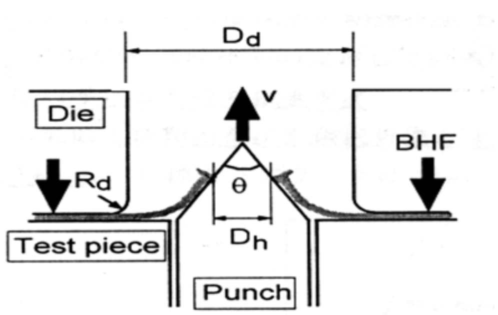
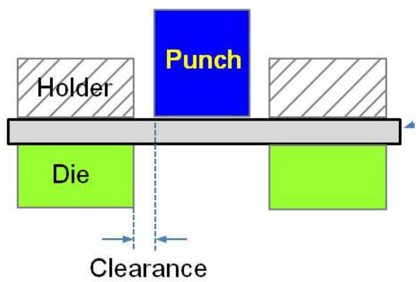


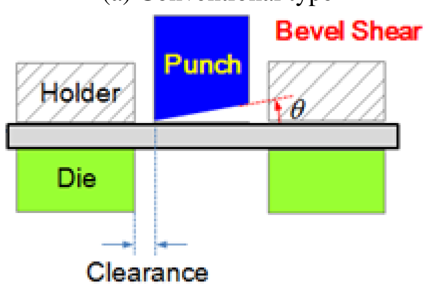
Fig. 2 *Tools for hole expansion test.*

2.3 Punching tools

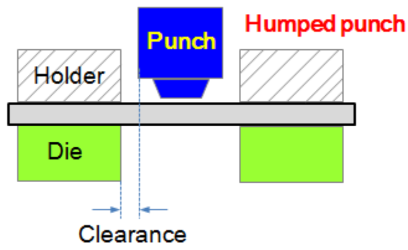
Fig.3 shows punching tools used in this study. Fig.3 (a) is conventional type of punching tools for HET. Fig.3 (b) is the shear angle punch. The punch angle reduces the punching force and gradually shears the surface along the shear angle. Fig. 3 (c) is the humped punch.



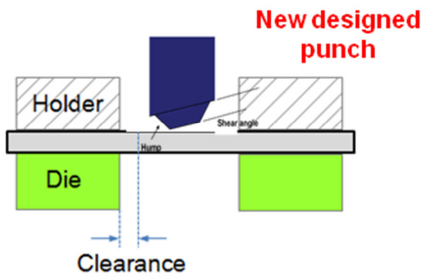
(a) Conventional type



(b) Shear-angled type



(c) Humped type [4]



(d) New designed punch

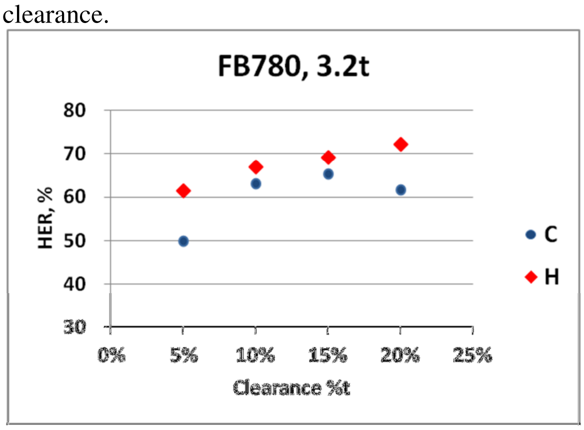
Fig. 3 *Four types of punch geometry for punching process.*

3 Test result of three types of punching tools

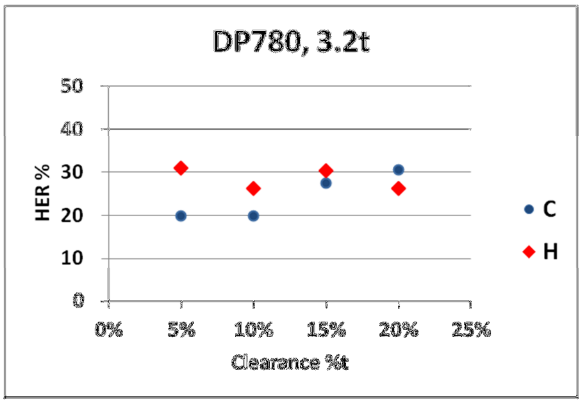
This chapter shows the test results of shearing surface and HER for each of four punch types using FB and DP steel. Die clearances are set up as 5, 10, 15 and 20% of the materials thickness.

3.1 Conventional and humped punch

Fig. 4 shows test result of HER. In Fig.4 (a) for FB steel, the HER result of the humped punch is higher than one of the convetional punch for all cases of clearance. In Fig.4(b) for DP steel, the HER results similar to the FB steel are obtained in all cases of clearance except for the case of 15% clearance.



(a) FB780



(b) DP780

Fig. 4 *Hole expansion ratio for FB, DP materials corresponding to various clearance in conventional(**C**) and humped(**H**) punch.*

The component length of shear-edge is measured. Sheared surface is divided into four components as roll-over, burnish and fracture and burr zone as shown in Fig.5.

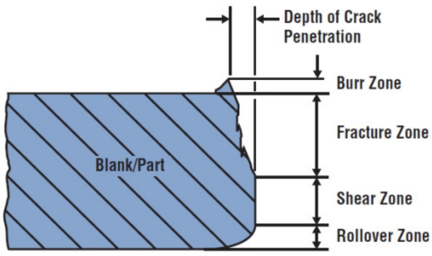
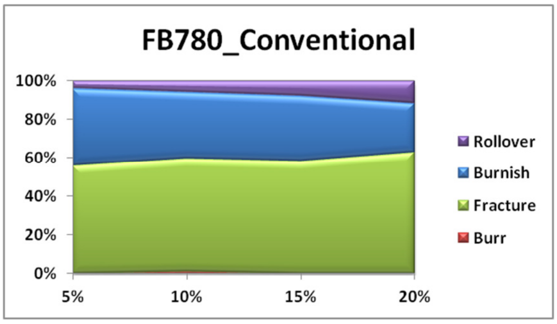


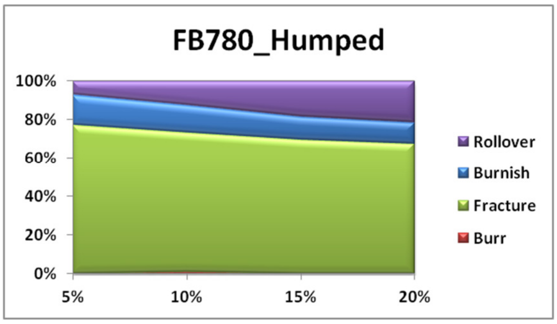
Fig. 5 *Geometric feature of the sheared edge.*

Fig.6 and 7 show the measured length ratio of FB and DP steel repectively for sheared-edge shorn by conventional and humped punches respectively. In the result for FB steel using conventional punch and humped punch(Fig.6), according to the increase of clearances, the roll-over zone increases and burnish zone decreases. The trend of results for DP steel is similar to the FB steel. The roll-over zone increases and burnish zone decreases as the clearances increase as shown in Fig.7.

In comparison of two types of punch, the result of the humped punch representing roll-over zone is higher and burnish zone is lower than the conventional punch. This is attrubutable to that the hump geometry imposes the tension on material in axial direction during the punching preocess and increases of stress triaxiality which is one of significant factors in ductile fracture. As can be seen in the results of Fig.4~7, the humped punch induces the fracture in the relatively lower plastic deformation than conventional punch. Relatively low plastic deformation can improve formability(HER) due to low hardening near the sheared-edge using the humped punch.

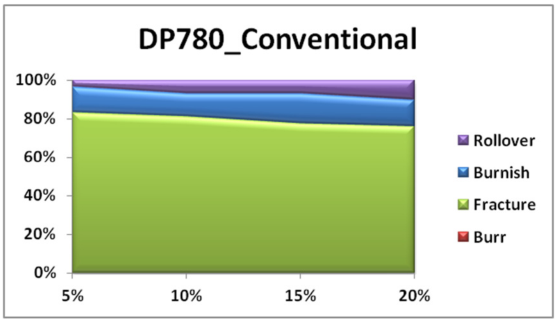


(a) Conventional punch

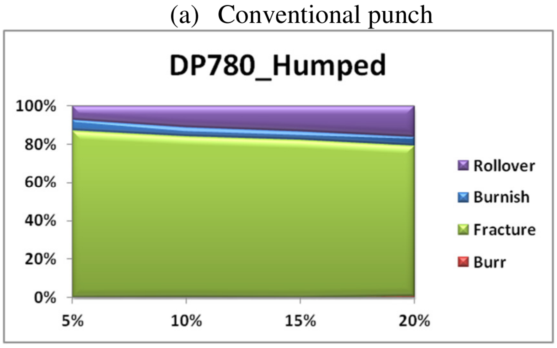


(b) Humped punch

Fig. 6 *Measured length ratio of sheared-edge; roll-over, burnish, fracture and burr to thickness for FB780 material.*



(a) Conventional punch



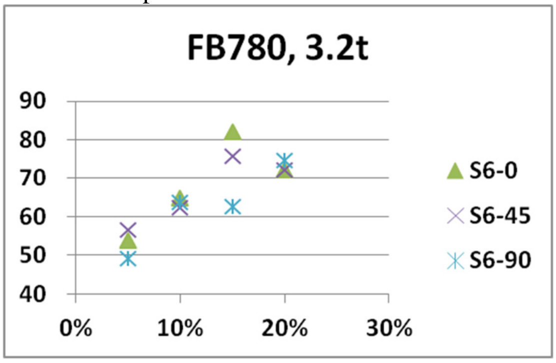
(b) Humped punch

Fig. 7 *Measured length ratio of sheared-edge; roll-over, burnish, fracture and burr to thickness for DP780 material.*

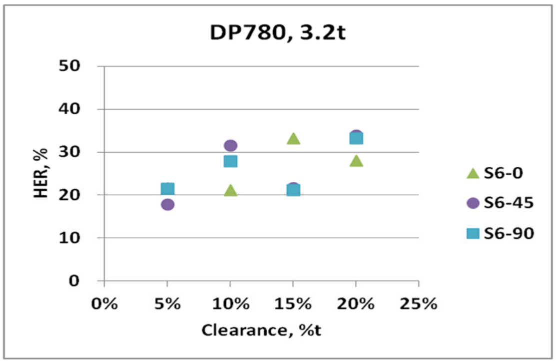
3.2 Shear angle punch

The experimental result of shear angle punch is shown in Fig.8. Because of the punch shape is not axi-symmetry, various punch positions to the rolling direction of materials were tested in order to examine the relation between the rolling direction and punch position. The difference among the HER value can be confirmed the effect of punch location and rolling direction according to the various locations of punch.

In the shear angle punch, the measured length of the sheared-edge is similar to that of the conventional punch.



(a) FB steel



(b) DP steel

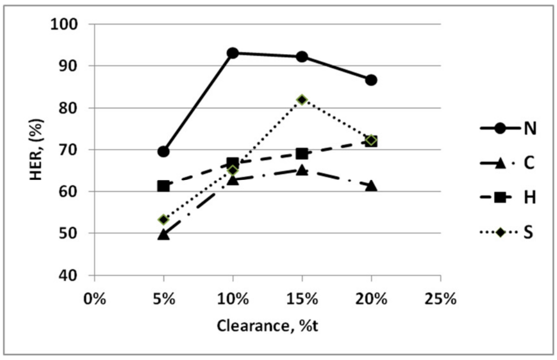
Fig. 8 *Hole Expansion Ratio for FB, DP materials corresponding to various clearance in sheared angle punch.*

3.3 New designed punch

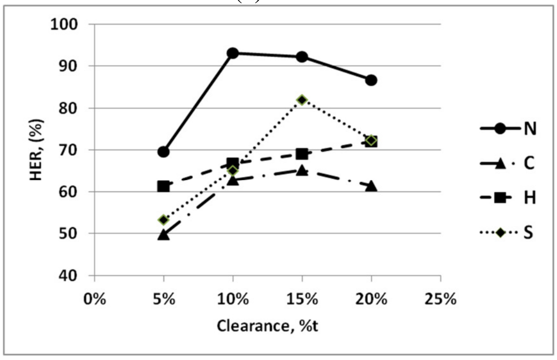
Fig.9 shows the HER results using the New designed punch.

For FB steel of Fig.9(a), the highest value of the HER is obtained by using the new designed punch in every case of the clearances. The HER results for new designed punch increase 30% and 45%pt compared to that of conventional punch. Similar result can be obtained in DP steel(Fig.9(b)). Against the value of HER for the conventional punch, the results of the new deisigned punch were increased up to 38% and 10.5%pt.

These results show that the new designed punch was effective in minimizing the plastic deformation near the sheared-edge .



(a) FB steel



(b) DP steel

Fig. 9 *Test result of HER for new designed punch*

4 Mechanism of punching tools

4.1 Humped punch

Through the observation of the HER results and the sheared-edge, mechanism of the improvement for HER can be confirmed according to the each punch shape. In case of the humped punch, the hump perfom a role that enhanced the stress tri-axiality before the material fracture during shearing. Stress triaxialitiy can be defined as effective stress and mean stess in terms of principal stress such as equation (3)~(5).

$$p = \sigma_m = \frac{1}{3}(\sigma_1 + \sigma_2 + \sigma_3) \tag{3}$$

$$q = \bar{\sigma} = \sqrt{\frac{1}{2}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\right]} \tag{4}$$

$$\eta = \frac{p}{q} = \frac{\sigma_m}{\bar{\sigma}} \tag{5}$$

Increase of the stress triaxiality can be obtained as induce the lower effective stress under the same average stress, then fracture occurs relatively low plastic deformation. In punching process, relatively low plastic deformation can improve the HER.

4.2 Sheared angle punch

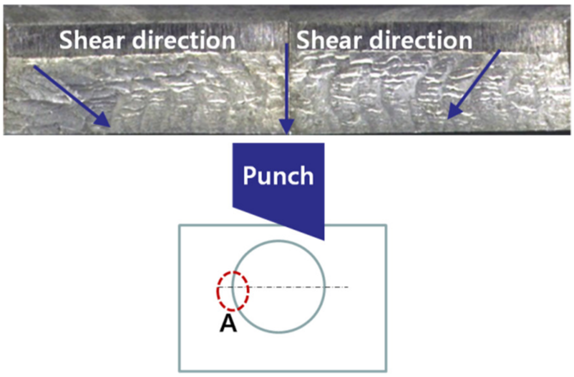


*Fig. 10 Picture of sheared edge at part **A** in sheared angle punch.*

In Shear angle punch, the shearing continuously proceeds along the contact between blade and material. Fig.10 is a picture of sheared surface at part A after shearing. The fracture surface is symmetric on the basis of the start and end points.

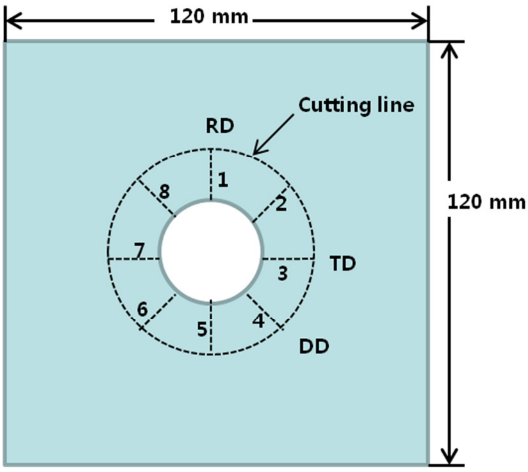


Fig. 11 Specimen number of sheared edge for sheared angle punch .

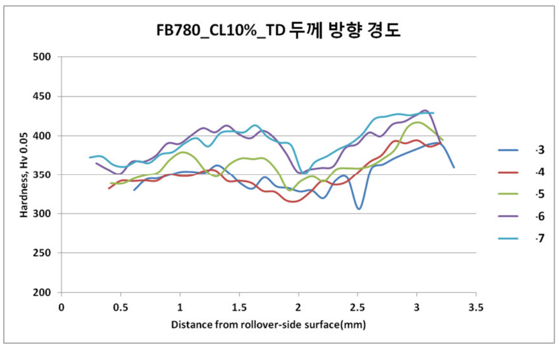


Fig. 12 Hardness corresponding distance from roll over surface to burr zone along the shear sequence for sheared angle punch.

Fig. 12 shows hardness of sheared-edge for the shear angle punch. The specimen is divided as five segments form the start of the shear (No. 7) to the end point (No. 3) and the hardness across the thickness is measured. Decrease of the hardness near the sheared-edge can be seen in the result along the shearing progress. It is shown that the hardness is maximally decreased in the center of the thickness where is fracture surface. These results can be observed at both FB and DP steel. Shear angle punch generates continuously the sheared-edge along the circumferential direction. Since the punch sequentially contacts along the circumferential direction, the fracture mode is different from that of the axi-symmetric punch, and the hardness of the sheared-edge was decreased as the results due to change of the fracture mode. The reduction of hardness in punching process is the main factor in improvement of the HER formability.

4.3 New designed punch

Humped punch induced fracture relatively in condition of low plastic deformation, shear angle punch generate the different fracture mode from axi-symmetric punches allowing to reduce the hardness near the sheared-edge respectively. New designed punch is designed to combining these two mechanisms within a single punch. The results of the HER prove that the mechanism of new designed punch is effective.

5 CONCLUSIONS

In this paper, various clearances and punch shapes are considered of HER of DP780 and FB780 steel. Consequently, it is summarized as below.

1) In case of the Humped punch, increasing the stress triaxiality can reduce the plastic deformation near the sheared-edge and increases the HER.
2) The shear angle punch generates a change in fracture mode of the fracture surface. Changed fracture surface have low hardness, and it can increase the HER.
3) The new designed punch is designed to combine increasing stress triaxiality of humped punch with changing the fracture mode of shear angle punch within a single tool and the higher value of HER is obtained than other results of punch shapes.

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