Increasing the dimensional accuracy of U-bend product of high strength steel sheets by controlling the pressure pad

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ABSTRACT

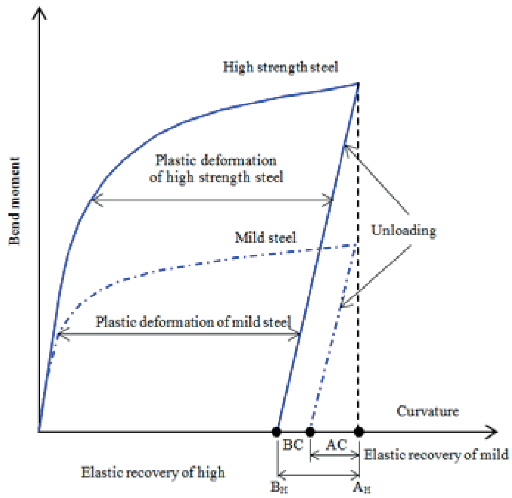
To reduce springback in U-shape of high strength steel sheet, the present paperproposes a new process parameter in U-bending technique. This paper aims to present the effect of clearance between die and counterpunch on springback behavior. The process in this work consists of four steps; (1) clamping of a sheet between a punch and a pressure pad, (2) bending with constant clamping force, (3) pushing-up at bottom of the part by using the pressure pad , and (4) final release tool. From the experimental results, decreasing of bending moment by bottom pushing-up resulted in the springback reduction. An appropriate of the clearance between die and pressure pad combined with bottom pushing-up force can be reduced springback. Our results suggested that the Y-U model, an advanced kinematic hardening, is essential for accurate numerical simulation of springback behavior.

Keywords : High strength steel sheet, U-bending, Springback, Pressure pad

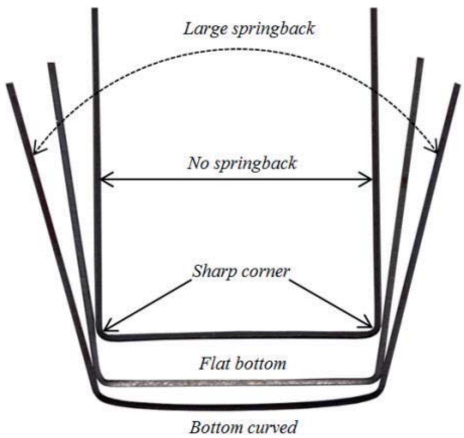
1. Introduction

Springback of sheet metal is the behavior of the material to return to the original shape which is an interesting function of elastic recovery during bending operation. This phenomenon can be explained by bending moment VS curvature response during the forming and tool removal, as schematically in Fig. 1 (a). In this figure, O→AH and O→AC are the responses of forming process; and AH→BH and AC→BC are those of springback process, where subscripts H and C denote the cases for a high strength steel (HSS) sheet and a carbon steel sheet, respectively. From this figure, we can easily understand that a HSS sheet has been much larger springback than that of a carbon steel sheet. The targets of stamping industry always need precision shape as geometry in Fig.1 (b) however it is very difficult to make a high precision shape especially with high strength steel sheet. As shown in Fig. 1(b), for U-shaped channel, the following two geometrical qualities are important.

- precise bending angle (no springback),
- flatness of bottom part and straight bend leg.



(a) Bending moment vs. curvatures path.



b) Example geometry of 980Y sheet after u-bending.

Fig.1. Bending moment vs. curvatures path and springback of high strength steel workpiece (experimental data in the Laboratory).

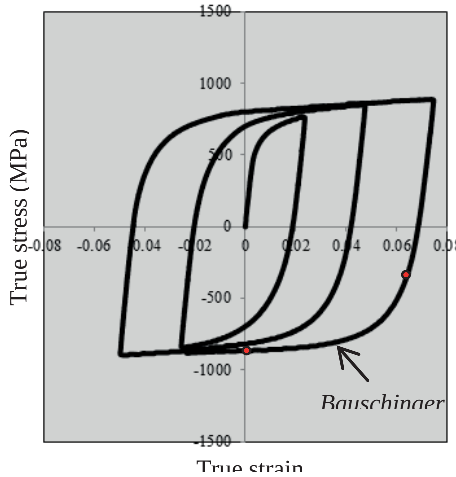
Removing of springback is the major effort in the bending operation process especially springback on a high strength steel sheet. Nowadays, high strength steel sheet is widely used in stamping car component for producing a high resistance crash performance such as side pillar, center pillar, roof tank and front bumper. Although, the u-bending process is the simple operation in stamping industry but an approach of springback compensation of die shape or changing process parameter to a high precision workpiece is very difficult. More recent research has occurred in the field of elimination and compensation springback.

For example, Nagai et al. [1] proposed a techniques to reduce springback, such as bottoming, re-striking and over-bending. Sunseri et al [2] presented a robust technique of the binder force control (double-action servo-controlled) in the forming process for reducing springback. In 2002, Yoshida and Uemori were the first who pointed out that modeling of the Bauschinger effect is a key issue for springback simulation, and they proposed an advanced kinematic hardening model, so called 'Yoshida-Uemori model' [3-4] (hereafter, The Y-U model). It is regarded as one of the world's most popular model for sheet metal forming simulation due to its accuracy of modeling of the Bauschinger effect and cyclic plasticity. Ling et al. [5] presented the process parameters of L-bending process such as die clearance, die radius, step heigh, step distace and their effects on spring-back by using the FEM. Uemori et al. [6] compared the FE simulation and experimental results of springback of draw bending and S-rail forming of 590 and 980 MPa steel sheets. Ogawa and Yoshida [7] investigated the effect of die-corner bottoming. Hamasaki et al. [8] presented parameter identifying of an individual layer of a clad metallic on SS430 stainless steel clade A1100 aluminum alloy sheet. Joonhang et al. [9] used FE numerical simulation with four different temperature conditions to investigate springback and spring go behavior on U-bending with micro-alloyed high-strength steel. Komgrit et al. [10] have recently proposed a new technique to remove springback on U-bending by using bottom pushing-up force. This technique was successful in obtaining precise U-shaped. In this paper, to find out an appropriate clearance between die and counter punch in U-bending for reducing springback and improving the flatness quality of bottom sheet, an alternative forming technology that combines various sizes of the pressure pad is proposed.

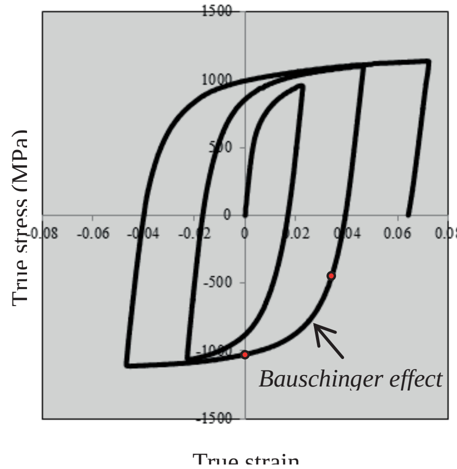
2. FE simulation of U-bending

To investigate the mechanism of springback behavior of high strength steel sheet in this process, MSC MARC was employed to calculate stress distribution and springback behavior. In the simulation, MSC MARC with a 1/2 model was used because of very small geometrical errors in the model and the reduction of time calculation. The model with 4,000 shell elements was employed. The tools were assumed to be made of rigid material. For the accurate numerical simulation of springback, utilization of an appropriate material model is essential, especially for HSS sheets. Also, model of the Bauschinger effect is very important. In the calculation, two types of material models were employed, i.e., a classical model of isotropic hardening (IH model) that neglects the description of the Bauschinger effect, and the advance kinematic hardening the Y-U model [3, 4, 8] that describes its accuracy. Generally, springback angle depends on level of tensile strength of material. In the following of FE-simulation, therefore, only the analytical with 980Y was used. The Y-U material parameters of the 980Y sheet are listed in Table 1(a) and (b). Material constants K and n for the 980Y sheets used in the Isotropic hardening model (IH) are listed in Table 2. The details of FE simulation setup are shown in table 3. Fig. 2 shows the experimental data of stress-strain responses of 980Y and 780G materials under cyclic plasticity deformations. From these results, it is clear that the high strength steel sheet has a high Bauschinger effect.

Therefore, it is necessary to use kinematic hardening the Y-U model for prediction the springback behavior.



(a) 780G



(b) 980Y

Fig.2. True stress-strain curved of 980Y and 780G materials under cyclic plasticity load (experimental data in the Laboratory).

Table 1. Material parameters of The Y-U model.

(a) Plasticity parameters.

Material	Y (MPa)	B (MPa)	b_{sat} (MPa)	R_{sat} (MPa)	m	C	H
780G	204	502	190	330	7.4	400	0.3
980Y	470	800	180	223	19	300	0.36

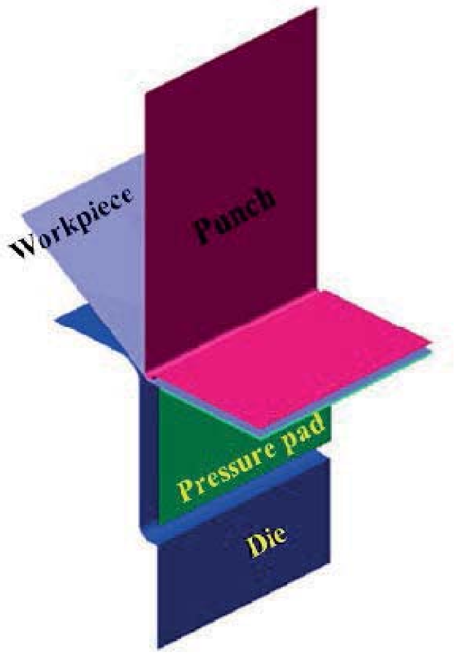
(b) Elasticity parameters

Material	E (GPa)	E_a (GPa)	ζ
780G	204	169	116
980Y	213	160	189.21

Table 2. Material parameters of IH model Details of FE simulation.

Material	K (MPa)	n	ε_0
780G	1450	0.22	0.0009
980Y	1630	0.15	0.001

Table 3. Details of FE simulation.

Simulation details	
Shell element with plain strain condition Punch, Die and Pressure pad : rigid surface Workpiece: elastic-plastic with thickness 1.22 mm Kinematic hardening; The Y-U model Isotropic hardening; IH model Die shoulder corner radius 6.0 mm Punch corner radius 1.2 mm Friction coefficient; 0.12 Clamping force; F_1 Corresponding with experiments	Half model 

3. Experimental procedure

In this paper, we proposed two types of experimental setup in the orders to investigate mechanism of springback. The first type is conventional U-bending experiment. The second type (bottom pushing-up process) will be show in the topic discussion 4.3. To investigate an advantage of pressure pad for decreasing springback, the conventional U-bending experiment is used as schematic illustrations in Fig. 3. The conventional U-bending sequence consists of a punch, a die, and a pressure pad. The conventional U-bending procedure has three-steps (including unloading stage), where (a) clamping of workpiece between the punch and the pressure pad (apply constant force to the bottom of the sheet; F_1), (b) U-bending by keeping constant force of the pressure pad, and (c) unloading the sheet from the die. High strength steel sheets (HSS) 780G and 980Y MPa of 1.22 mm thickness were used in this work. The strip layout of workpiece was rectangular shape with dimensions of 45 x 160 mm. The dimensions of the tools were depicted in Fig. 4. The corner jutting headed punch with a shallow hollow on the punch head (1.5 mm) was used for this experiment. The hydraulic system was used for applying the force to pressure pad. Figure 5 showed the die-set, which the pressure pad was controlled by the hydraulic system.

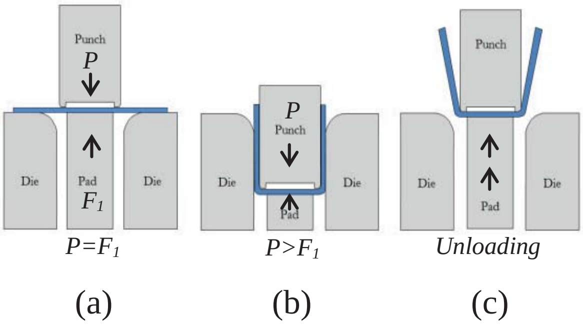


Fig.3. Schematic illustrations of conventional U-bending process. From the conventional U-bending, we can clarify the role of pressure pad for reducing springback.

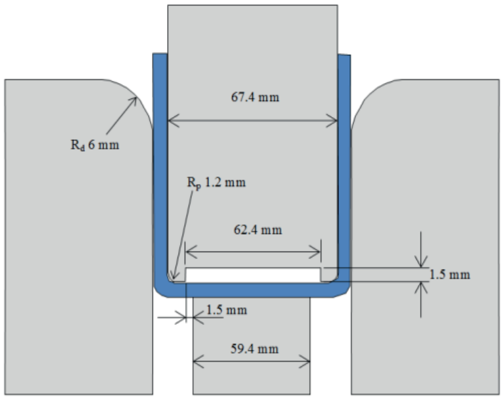


Fig.4. The dimensions of the tools.

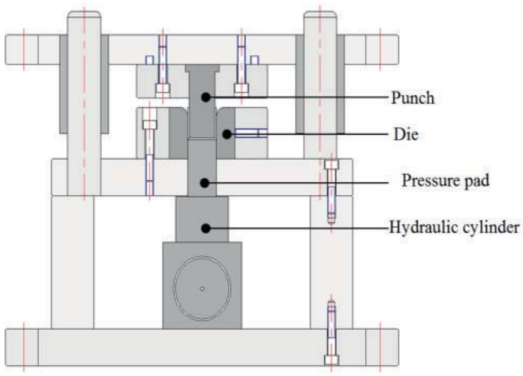


Fig.5. Experiment apparatus

4. Results and Discussion

4.1 Numerical simulation results.

Fig. 6 shows the comparison of the calculated results of springback angles by calculating from the Y-U and IH model with corresponding experimental data in conventional U-bending process for various pad pressure; F_2. From this result, it can be seen that the Y–U model agree well with the experimental data to descript the springback angles than IH model.

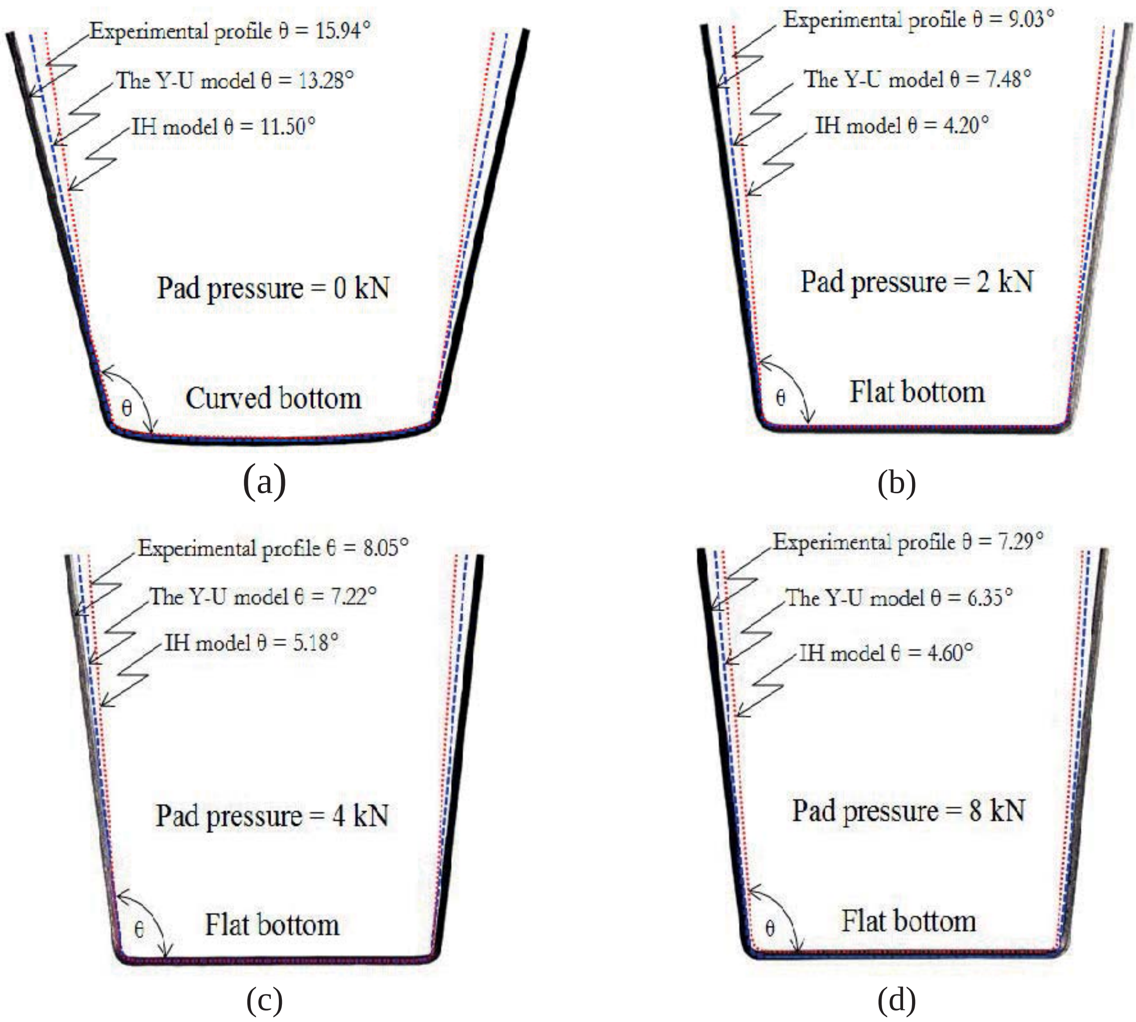
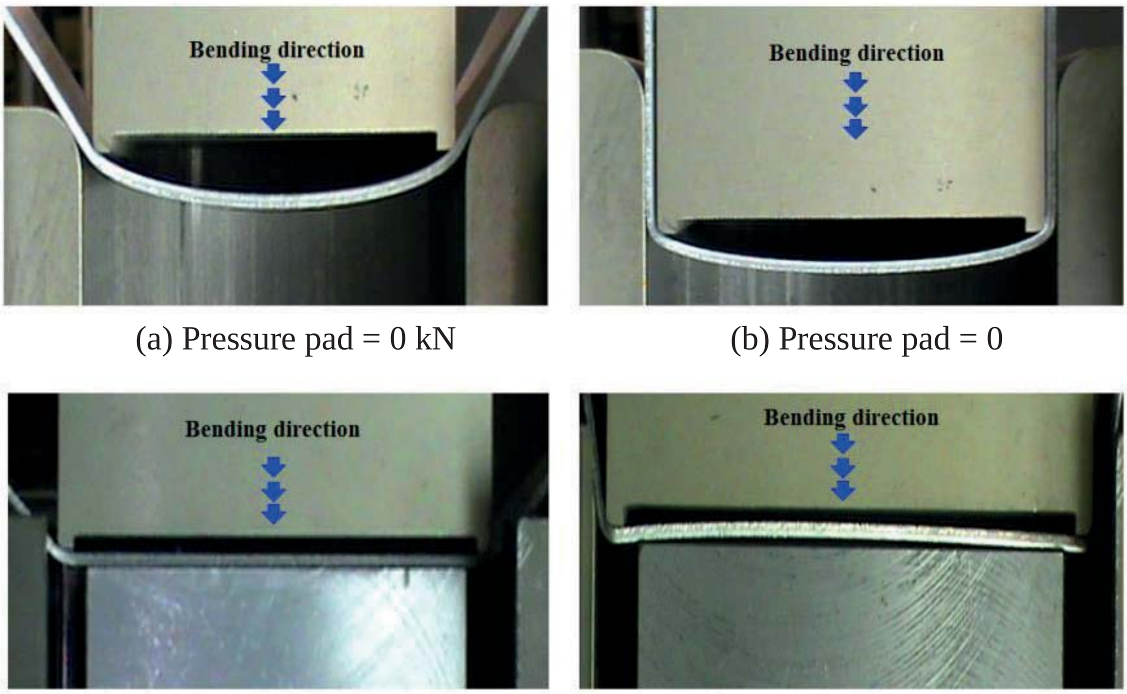


Fig.6. Comparison of the springback calculated by the Y–U model and the IH model for 980Y sheet with the corresponding experimental observations obtained from conventional U-bending process.

Therefore, it should be noted that the description of the Bauschinger effect should be taken into account for springback prediction in numerical simulation. For the discussions of springback behaviour in this paper, solely the analytical results with the Y–U model will be presented in the following discussions.

4.2 An advantage of a pressure pad on the precision workpiece of conventional U-bending process

Fig. 7 (a)-(d) shows the geometries of 980Y workpieces for four cases of pressure pad. Fig 7. (a) and (b) show u-bending without pressure pad it can be seen that the large curved generated at the bottom of the sheet. In contrast, bottom curved decreased with increasing pressure pad (see in Fig.7.(c)). However, for the case of strong pressure pad 8 kN it was found that the bottom sheet deformed and bent in the negative bending direction. Therefore, an appropriate the pressure pad should be determined. From these results, it is found that the level of pressure pad forces is very important to make flatness of the workpiece. The deformations around corner of the 980Y workpiece during bending for different pressure pad forces are showed in Fig. 8.



(a) Pressure pad = 0 kN (b) Pressure pad = 0

(c) Pressure pad = 2 kN (d) Pressure pad = 8 kN

Fig.7. Photo of a bottom curved of 980Y sheet during bending with several of pressure pad.

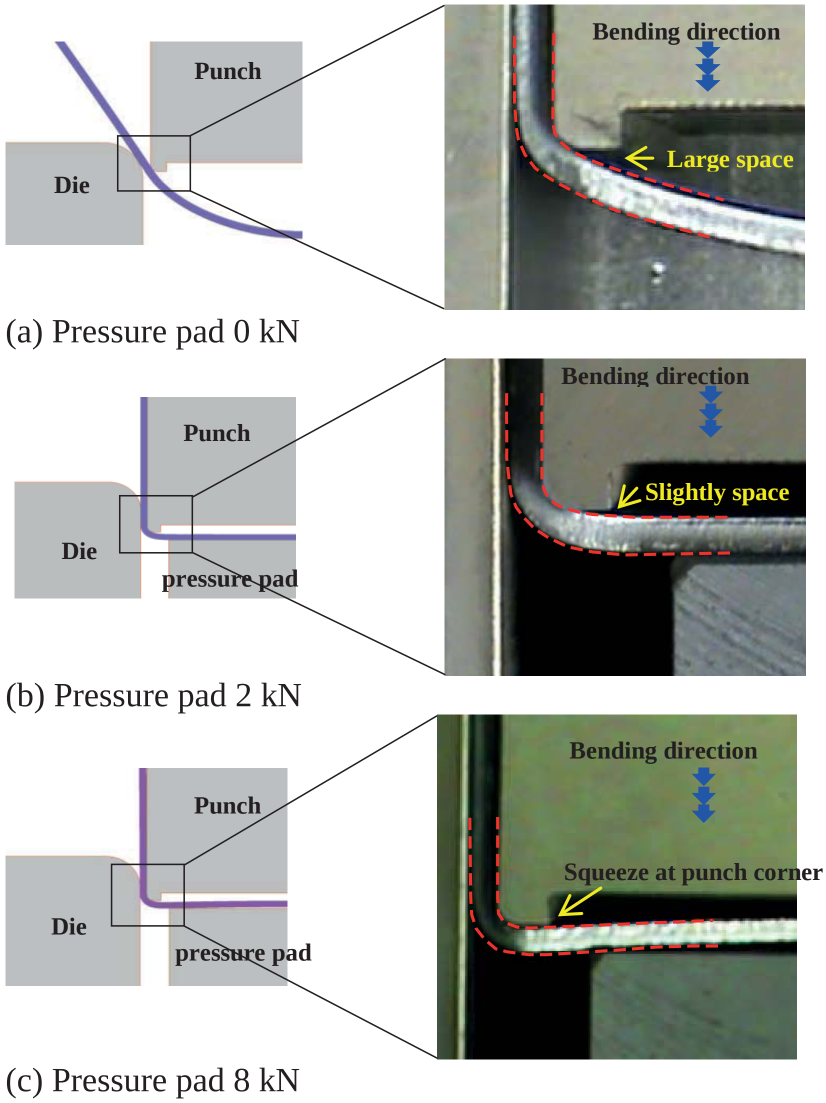


Fig.8. Photos of the deformations during bending.

Fig. 8 (a) shows the large curved at the bottom of the sheet because the bottom sheet has not contact to the punch corner. At the u bending with pressure pad 2kN, the bottom sheet was raised by pressure pad as shown in 8 (b). Fig. 8 (c) shows the case of high pressure pad 8 kN, the curved at bottom of the sheet generated in the negative of bending direction. Therefore, we can summarize that the springback On the 2016, the authors presented a new technology to eliminate springback by applying the pushing-up force to the angle decreases slightly with increasing the pad pressure, but its effect is not strong enough to remove springback.

4.3 Effects of clearances between the die and pad pressure to the precision of workpiece

Before the discussion the effect of process parameter in this paper, let's back to see our published paper.
bottom of the sheet (call "bottom pushing-up") at final stage of U-bending as schematically illustrated in Fig. 9.

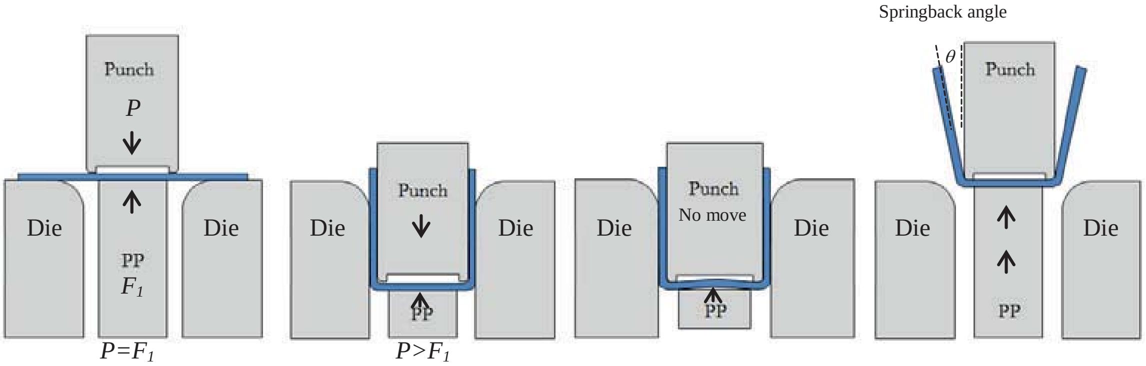


Fig.9. Schematic illustrations of bottom pushing-up technology

In the original bottom pushing-up process has four sequential steps, where clamping of a sheet between a punch and a pressure pad, U-bending keeping the pad pressure force constant, bottom pushing-up and unloading the sheet from the die.

From this technology, the author succeeds to control spring back of the workpiece. For example, Fig.10 shows the geometry of HSS 780G and 980Y obtained from bottom pushing-up technology.

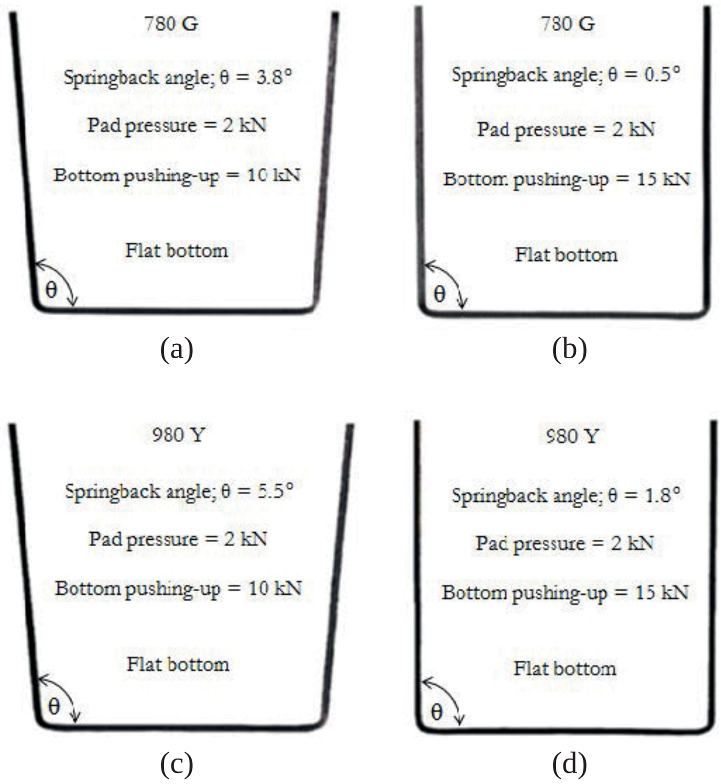
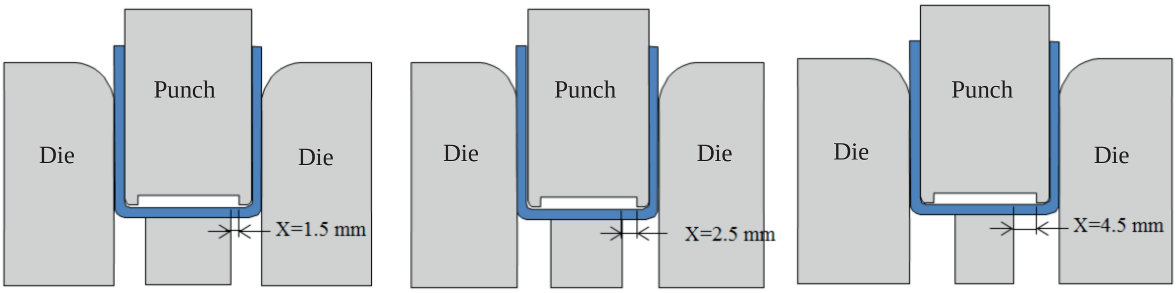


Fig.10. Experimentally obtained geometries of 780G and 980Y HSS sheets after unloading when using the pressure pad clearances X = 2.5 mm.

Fig. 10 shows geometries of 780G and 980Y sheets for various bottom pushing-up forces F_2. From these results, it was found that springback decreased with increasing bottom pushing-up force F_2. To obtain a perfect shape (no springback, a flat bottom) of the bent-sheet after springback, an optimum bottom pushing-up forces F_2 should be determined. The best result of 780G and 980Y for the springback angle (almost 0 degree), together with the flat bottom, was obtained at the clamping force of 2 kN and the bottom pushing-up force of 15 kN as shown in Fig. 10(b) and (d) respectively. However, when this technology will be directly applied to the real stamping operation, an appropriate size of the pressure pad is essential.

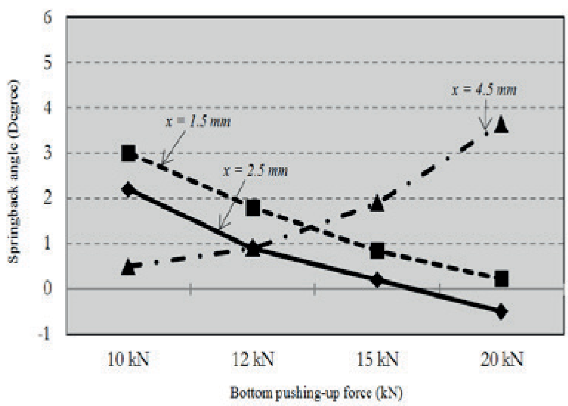


(a) X = 1.5 mm (b) X = 2.5 mm (c) X = 4.5 mm

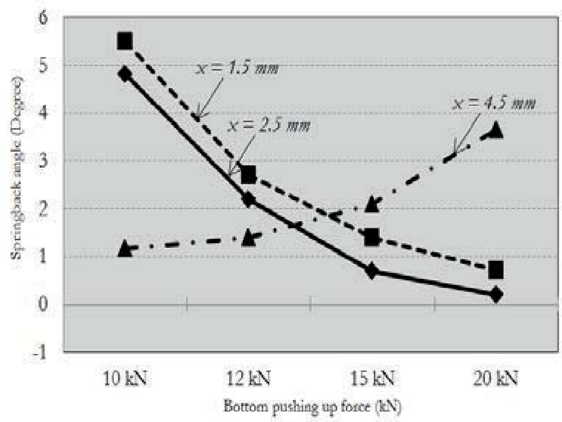
Fig. 11. The dimensions of X distance.

Therefore, the aim of this section is to demonstrate the effect of the clearance between the die and the pressure pad (hereafter x as already shown in Fig. 11) on the quality of workpiece. Three different clearances between the die and the pressure pad of 1.5 mm, 2.5 mm, and 4.5 mm were used in this experiment (see also x distance in Fig. 11). As mentioned earlier, the major concept idea of this paper not only intends to find out an effective process parameter to remove springback of HSS sheet but also aim to easily tool setup for stamping industry. In real stamping industry, a large clamping force and bottom pushing-up force will give severe damages to the die and hydraulic system. Consequently, it is better to use a minimum of clamping force at 2 kN.

Fig. 12 shows springback angles for 780G and 980Y sheets obtained from U-bending experiments with a various X distances and bottom pushing-up forces under the constant clamping force 2 kN.From these results, it was observed that the springback angle θ decreased with increasing clearance X when low bottom pushing-up force was applied.



(a) Springback for 780G sheet



(b) Springback for 980Y sheet

Fig. 12. Springback angles of 780G and 980Y HSS sheets obtained from experiments under various pad pressure forces and pressure pad sizes.

However, when bottom pushing-up 15 kN, the angle θ became minimum at X = 2.5 mm. Although, springback can be removed by changing X distance, however a large of X distance will give a curved bottom plate and obtuse corner.however a large of X distance will give a curved bottom plate and obtuse corner. In case of the maximum bottom pushing-up force (F_2= 20 kN), the angle θ increased with increasing clearance X.

Such an increase in the angle θ under the large clearance x and large pushing-up force F_2 was induced by not only springback but also permanent plastic deformation bending at the bottom sheet. Figure 13 summarizes the experimentally obtained geometries of 780G and 980Y workpiece after U-bending for pad pressure clearances X = 4.5 mm and various bottom pushing-up forces F_2, with constant clamping force F_1 of 2 kN (Arrows in the figure show contact positions of the pad pressure).

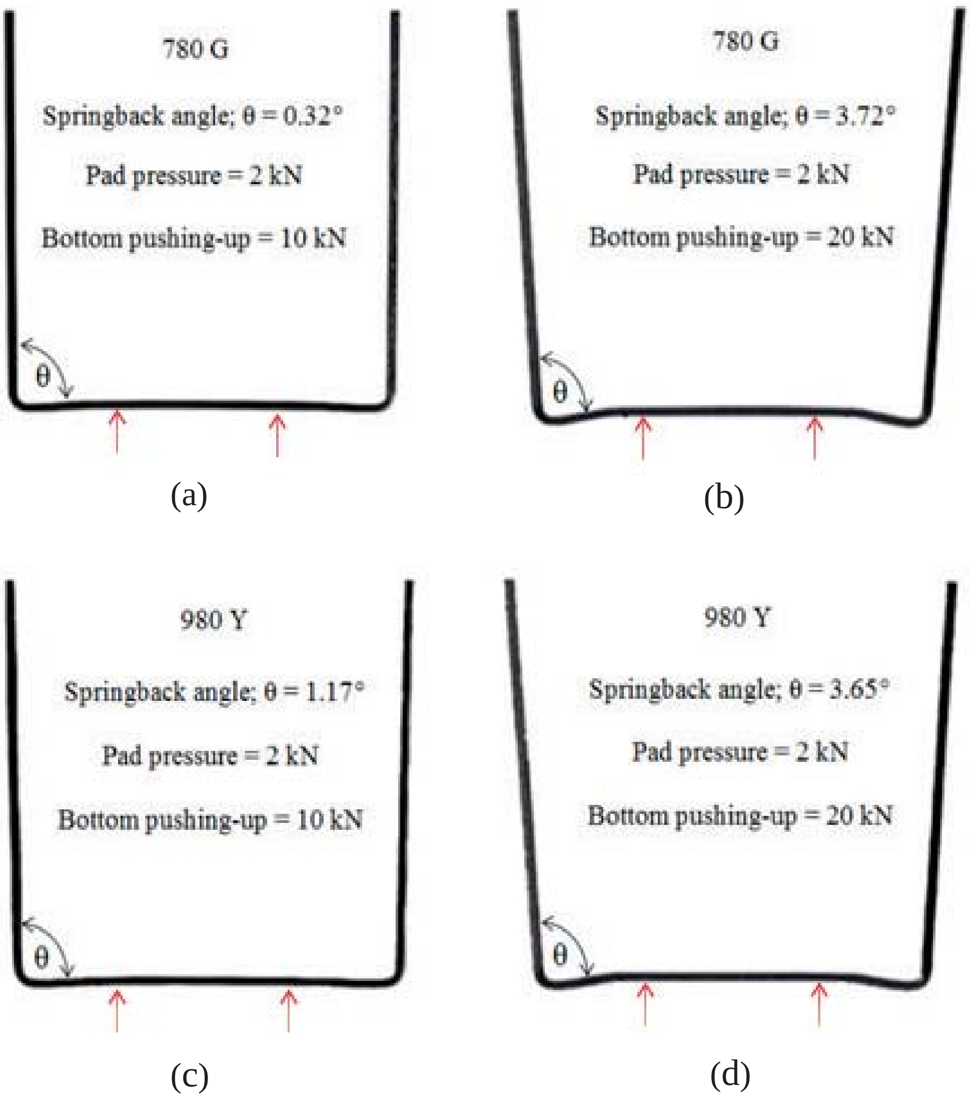
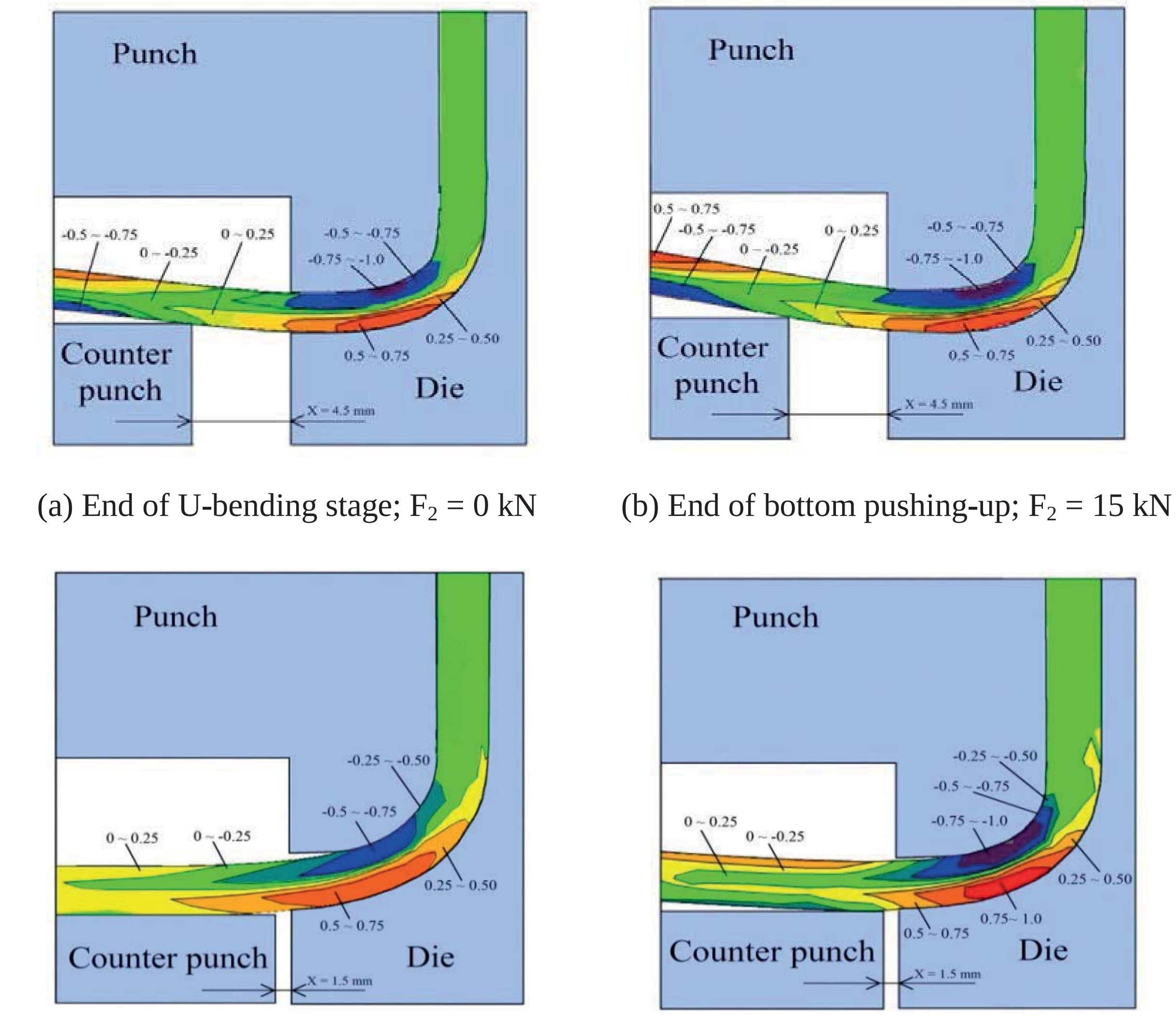


Fig. 13. Experimentally obtained geometries 780G and 980Y HSS sheets after U-bending for constant pressure pad clearances X= 4.5 mm and various bottom pushing-up forces; F_2.

It can be clearly seen that the bottom sheet was plastically bent at the edge of the pad pressure when applied strong bottom pushing-up force (20 kN) with large clearance X = 4.5 mm. Such permanent plastic bending of the bottom sheet made the angle θ larger and induced geometrical imperfection of the bottom part. The combination of strong bottom pushing-up force and large clearance X should be avoided in order not to spoil geometrical accuracy of the U-bent sheet. By the way, we can reduce a bottom pushing force by using the X distance 4.5 because the contact area between bottom sheet and pressure pad are small region. Therefore, when comparing between the contact area of the bottom sheet of X distance 4.5 mm and the X distance 1.5 mm with a constant bottom pushing-up force (for example 20 kN), the use of X distance 4.5 mm can be generated the curved at the bottom plate more than the use of X distance 1.5 mm. To apply clearance of pressure pad in stamping industry, it should be noted that the large

X distance can be eliminate springback by using a low bottom pushing force but the slightly obtuse corner are showed. Consequently, it is necessary to calculate the clearance of pressure pad with accuracy FE-simulation. In order to evaluate stress distribution during the bottom pushing-up stage, simplified 2D FE analysis was also conducted using the Y–U model. The bending moment at the punch corner was calculated based on the stress distribution at a certain cross section near the corner of the workpiece obtained from FE analysis.

Fig. 14 (a) – (d) illustrates calculated stress distribution (σ_{xx}) for various bottom pushing-up forces and pressure pad sizes with constant clamping force 2kN. In case of U-bending without bottom pushing-up (X = 1.5 mm, F_2 = 0 in Fig. 14 (a)), large tensile stress appeared near the outer edges of the sheet, from the corner to middle of pressure pad. When applied bottom pushing-up with F_2 = 15 kN at the bottoming of the sheet (see Figs 14(b), the tensile stress decreased and reduced springback of the sheet. For bending used pressure pad clearances X= 4.5 mm and bottoming pushing-up 10 and 15 kN (see figure 14(c) and (d)), the large tensile stress appeared at the middle of the sheet. It was also induced permanent plastic deformation of the sheet as experiment result shown in figure 13(c) and (d). The reason of springback decreasing by bottom pushing-up is described as follow. The mechanism of the springback reduction resulting from bottom pushing-up is explained by the fact that the bending moment, which is driving force of elastic recovery, reduces due to the large compressive stress appeared at the punch corner.



(a) End of U-bending stage; F_2 = 0 kN

(b) End of bottom pushing-up; F_2 = 15 kN

(c) End of bottom pushing-up; F_2 = 10 kN

(d) End of bottom pushing-up; F_2 = 15 kN

Fig. 14. Calculated stress (σ_{xx}; GPa) distributions of 980Y HSS steel during bottom pushing-up for various bottom pushing-up forces and pressure pad sizes.

5. Conclusions

To reduce springback of high strength steel sheets, we have been proposed a process parameter of U-bending process. The research paper findings are concluded as follows:

(1) The pressure pad can be improved the bottom flatness of workpiece.

(2) An appropriate a pressure pad force reduced springback significantly.

(3) The reduction of bottom pushing force in this technology is attributed to the change the clearances between the die and the pressure pad.

(4) For the accurate simulation of springback results, the selection of material models is very importance. The advance kinematic the Y-U model is very well captures the springback behavior in the present paper.

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