Sidewall-curl prediction in U-bending process of advanced high strength steel

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Abstract

Currently Advanced High Strength Steel (AHSS) has been extensively use in automotive industry for the purposed of reduction in weight and therefore in fuel consumption. However, increasing the strength of material leads to the reduction in formability and high degree of springback. Moreover, sidewall-curl has been detected from bending operation of AHSS which caused problem in assembly line. Therefore this work is aimed to explore the side wall curl phenomenon of AHSS grade SPFC 980Y. The die designed parameters of die radius and the process parameters of blank holder pressures are studied to reduce sidewall-curl problem using finite element simulation code AutoForm. U-bending experimental has also been conducted to verify the analytical model.

***Keywords**: sidewall-curl, springback, U-bending, AHSS*

1. Introduction

Bending is a basic process of sheet metal forming and is very important application in automotive industries. The greatest problem of this process is shape fixability after bended cause by the elastic recovery of internal stress during unloading. In recent years, as for unsprung members and reinforcements, various types of AHSS are used depending on the application. Automaker can reduce the thickness of material for making parts while the crashworthiness still remains. It has been contributing to the weight reduction then improving fuel consumption. However, the improvement of strength leads to indicate unsatisfactory shape. In the forming process of a hat-shaped part in U-bending die, the sheet metal is first held between the blank holders, and is subsequently drawn into the die cavity by a moving punch. When the punch and the die are removed, it is found that two phenomenon occurred on the formed part, as springback and sidewall-curl.

There have been many investigations focused on the study of springback in forming of high strength steel (HSS) and AHSS sheet [1-10]. However, there is few research work carried out to study the sidewall-curl in forming of some sheet materials, and no work carried out to study the sidewall-curl in forming of AHSS.

In the present study, the advantage of a FEM commercial code AutoForm is used to investigate the final shape of AHSS part after unloading using various process parameters. For

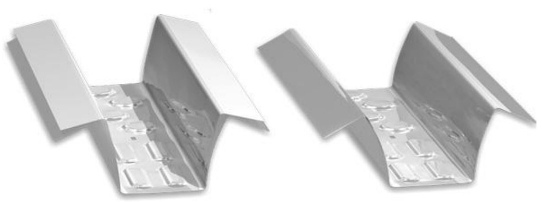
Table. 1 Input data used for simulation

Input data	Descriptions
Material properties	Tensile strength = 1024 MPa
	Yield strength = 712 MPa
	$\bar{\sigma} = K\bar{\varepsilon}^n$ where $K = 1408$ MPa
	and $n = 0.0891$
	Normal anisotropy = 1.05
Coefficient of friction	0.15
Element formulation	Elastic-plastic shell
Number of elements	Auto
Layer number	11 (for springback problem)

verification of the analytical model, experimentally measured for springback and sidewall-curl from U-bending die test are compared with predicted values from the model.

2. Simulation and Experimental Conditions

Accurate springback simulation requires a material model which accurately describes the complex material behavior at unloading. To improve the springback prediction, a novel approach to model the Bauschinger effect has been developed and implemented in the commercial code AutoForm [11]. Comparison of hat-shaped profile simulated without (a) and with (b) the kinematic hardening model is shown in Fig. 1.



(a) (b)

Fig. 1 Comparison of hat-shaped profile simulated without (a) and with (b) the kinematic hardening model [11]

Table. 2 Process parameter variations

Process parameter	Values
Punch radius; R_p (mm)	2
Die radius; R_d (mm)	2, 5*, 8, 11 and 14
BH force (kN)	5, 7.5*, 10, 15, 20 and 25
Punch width (mm)	45
Clearance (mm)	1.4 (one side)

* Value from suggestion and calculation [6]

2.1 Simulation Conditions

The FEM simulation was performed using AutoForm-Incremental^{plus}. The FE model with geometries of tool and initial sheet blank are given in Fig. 2. An AHSS cold rolled sheet of 1.4 mm in thickness, grade SPFC 980Y (JIS), was used as the blank sheet material. The initial rectangular blank size of 210 mm in length and 50 mm in width was employed. The flow stress of sheet material was obtained by the tensile test and expressed with the standard power law model, as described in Table. 1.

2.2 Process parameter variations

The influences of two parameters which are die radius and blank holder (BH) pressure

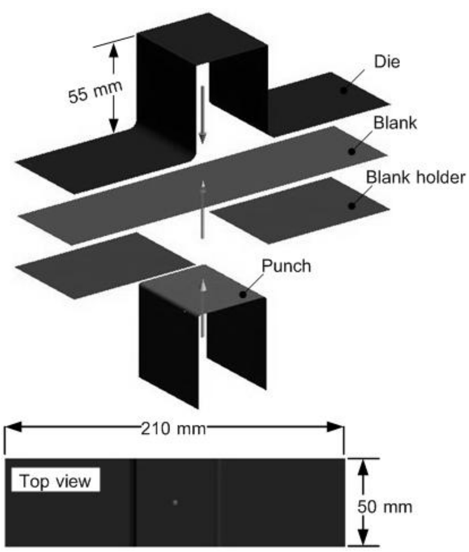
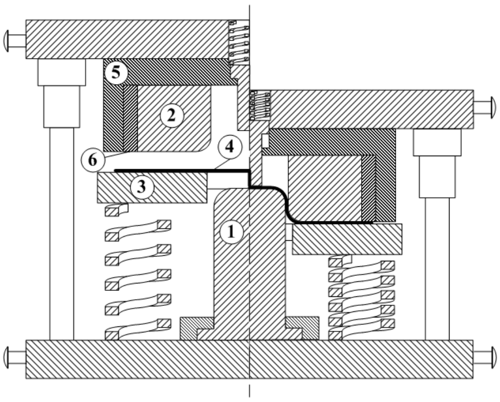


Fig. 2 Hat-shaped simulation model



Notes: 1 punch, 2 dies, 3 pressure pad, 4 work material, 5 die holder and 6 spacer

Fig. 3 Outline of the U-bending die

on the deformation behavior were explored. The variations of die radius and BH force used in this work are listed in Table. 2.

2.3 Experimental Conditions

U-bending experiments were conducted to verify the analytical model. The initial rectangular blanks of 210 mm in length and 50 mm in width were bended into hat-shaped parts. Experiments were carried out using the U-bending die shown in Fig. 3 on a 1500-kN hydraulic press machine.

Ram speed was determined to be constant at 10 mm/s. Load cell and LVDT have been mounted in order that force-travel diagram could be real-time monitored. The width of the punch was 45 mm having the corner radius of 2 mm. Die radius was 5 mm. Punch and die clearance was designed at 1.4 mm (one side) same as the sheet thickness. The blank holder force of 7.5 kN was used through experiment. The springback and sidewall-curl amount of the part after bend were detected by Mitutoyo profile projector.

3. Results and Discussion

The analytical model was verified by maximum bending force. The U-bending die testing required 25.96 kN for bending an AHSS hat-shaped part. While the simulation indicated maximum bending force for 27.88 kN. This confirms that the numerical results agree well with the experiment.

The comparisons of experiment result and simulation predicted of wall opening angle (θ_1), flange angle (θ_2) and sidewall-curl radius

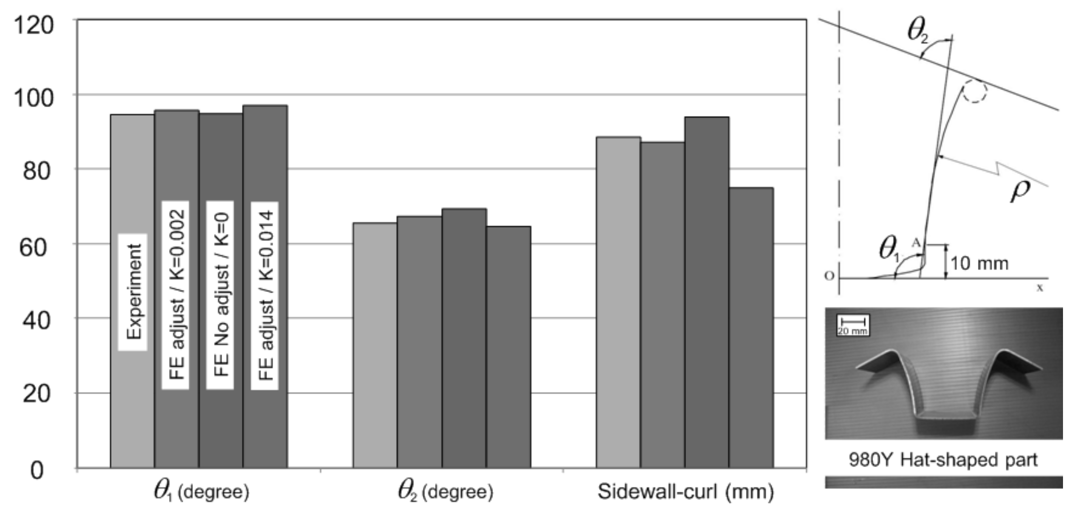


Fig. 4 Comparison results by experiment and FEM

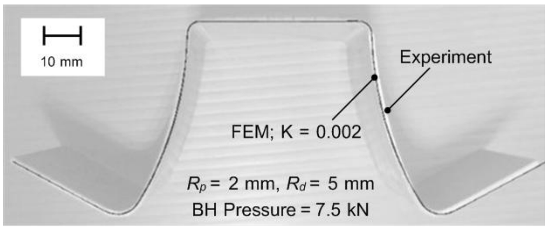


Fig. 5 Final shape of experiment and FEM model with K = 0.002

(Sidewall-curl;ρ) are displayed in Fig. 4. The results of simulation show that considering the Bauschinger effect improving by Transient Softening (K) values, especially θ_2 and the Sidewall-curl. In this study, the optimization of K value is 0.002. It was found that θ_1, θ_2, ρ and maximum bending force by FE results show a good match with the experimental results. Hence, the K value was set to 0.002 through all conditions as listed in Table. 2.

In case of investigating the effect of R_d on the final shaped of U-bending part and the bending force, the BH force was set to be constant at 7.5 kN. The results of die radius effects on the θ_1, θ_2, ρ and maximum bending force are shown in Fig. 6.

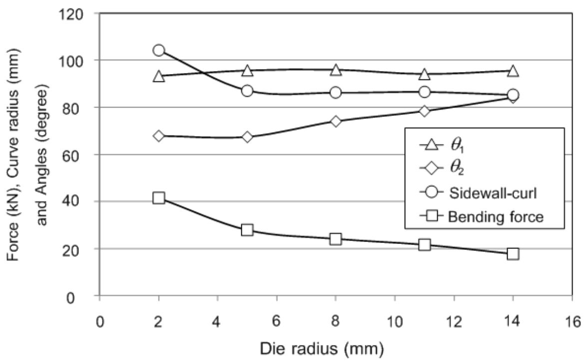


Fig. 6 Variation of the springback, sidewall-curl and bending force amount to the die radius

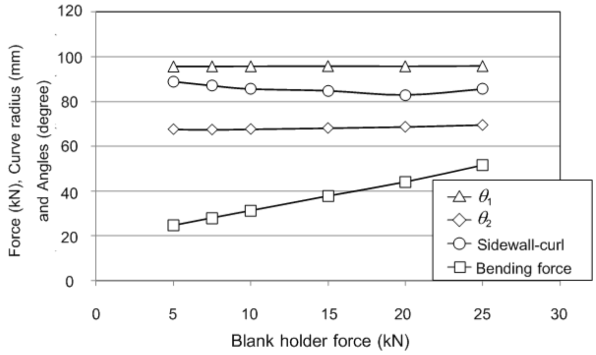


Fig. 7 The influences of blank holder force on the degree of the springback, sidewall-curl and bending force

The springback amount, θ_1 is slightly increased with increasing die radius. Degree of sidewall-curl, θ_2 is significantly increased with increasing die radius. However, the bending process must require the higher bending force when uses a smallest die radius to eliminate springback and sidewall-curl.

In case of investigating the effect of BH force on the final shaped of U-bending part and the bending force, the R_d was set to 5 mm same as condition on the experiment. The effect of BHF on the sidewall-curl, corner angles (θ_1, θ_2,) after springback and bending force in all studied cases is provided in Fig. 7. The bending force increased when increasing the BH force. However, the final shaped was tiny changed when adjust the BH force. This result may cause by used the optimum die radius.

4. Conclusions

An AutoForm model is developed for prediction of springaback and side wall curl of new material such as AHSS in U-bending process related to springback phenomenon. The predicted results are in good agreement with experiment. Several conclusions can be drawn from the results of the study:

- The larger the die radius, the smaller is the side wall curl radius which means increasing of side wall curl amount.
- The effect of side wall curl can be reduced by using small die radius tool. However, the force require will be high.
- In this study, the side wall curl radius decreases slightly with increasing blank holder force. Therefore, increasing blank holder pressure is not the method to reduce side wall curl problem.

5. Acknowledgement

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6. References

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