



11th International Conference on Technology of Plasticity, ICTP 2014, 19-24 October 2014,
Nagoya Congress Center, Nagoya, Japan

Effect of punch speed on the amount of springback in U-bending process of auto-body steel sheets

Min Kuk Choi, Hoon Huh*

School of Mechanical, Aerospace and Systems Engineering, KAIST, 291 Daehak-ro, Yuseong-gu, Daejeon 305-701, Korea

Abstract

This paper deals with the experimental and numerical investigation of the effect of the punch speed on the amount of springback in U-bending of auto-body steel sheets. U-bending tests and finite element analysis of SPCC and DP780 steel sheets were conducted for springback evaluation at different punch speeds with the geometry adopted from the NUMISHEET '93 benchmark problem. For the U-bending test, INSTRON8801 dynamic materials testing machine and a newly designed U-bending jig were used to conduct U-bending tests at different punch speeds. Experimental results show that the amount of springback of SPCC decreases but that of DP780 increases as the punch speed increases. For the finite element analysis, mechanical properties of SPCC and DP780 steel sheets considering the strain rate were obtained and the results of the analysis are presented in comparison to experimental measurements and to investigate the effect of punch speed on the amount of springback.

© 2014 The Authors. Published by Elsevier Ltd.

Selection and peer-review under responsibility of Nagoya University and Toyohashi University of Technology

Keywords: Springback; Punch speed

* Corresponding author. Tel.: +82-42-350-3222; fax: +82-42-350-8120.

E-mail address: hhuh@kaist.ac.kr

1. Introduction

The sheet metal forming process is a popular manufacturing technique to obtain the desired shape of a product by imposing the plastic deformation. After the sheet metal forming process, residual stress remains in the final product due to the plastic deformation. The residual stress leads elastic recovery of the formed part called springback, which causes shape error in final product. Recently, high strength steels have been widely used in auto-body structure to improve the crashworthiness maintaining the weight of the body light. Evaluation of the amount of springback is more important for high strength steels since the amount of springback becomes significant for those materials so that dimensional inaccuracy after spring-back seriously deteriorates the assembly quality among formed parts.

In the sheet metal forming process, a blank sheet experiences a wide range of strain rates during the forming process since the punch progresses with the velocity of several m/s to form the product. However, strain rate is known to be an important parameter to influence the hardening behavior of sheet metals. Moreover, Bae and Huh (2011) recently carried out the tension/compression test of steel sheets in order to investigate the effect of the strain rate on the tension/compression hardening behaviour. The tension/compression hardening behaviour of steel sheets changes sensitively with the variation of the strain rate. Therefore, it is necessary to investigate the effect of punch speed on the amount of springback for auto-body steel sheets.

This paper deals with the experimental and numerical investigation of the effect of the punch speed on the amount of springback in U-bending of auto-body steel sheets. U-bending tests and finite element analysis of SPCC and DP780 steel sheets were conducted for springback evaluation at different punch speed with the geometry adopted from the NUMISHEET '93 benchmark problem. The experimental and numerical results of the analysis are presented in comparison to experimental measurements and to investigate the effect of punch speed on the amount of springback

2. U-bending tests at different punch speeds

2.1. Geometry investigated

To investigate springback behavior of auto-body steel sheets at different punch speeds, U-bending tests were conducted with the geometry adopted from the NUMISHEET '93 and NUMISHEET '2011 benchmark problem as shown in fig. 1 (a). The amount of springback of each blank was measured using springback parameters of springback angle θ_1 , springback angle θ_2 and radius of sidewall curvature as shown in fig. 1 (b).

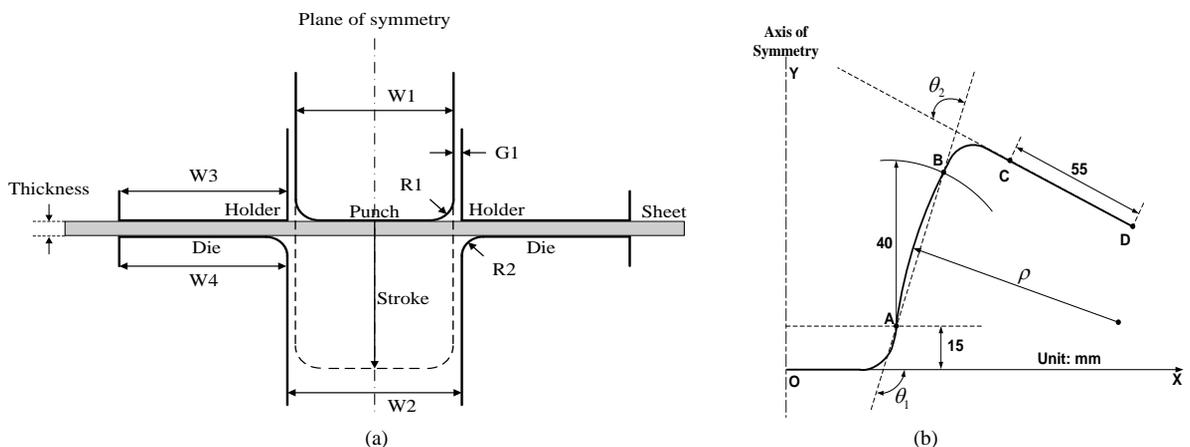


Fig. 1: (a) Schematic diagram of the U-bending test (b) Definition of springback parameters.

2.2. Testing machine

U-bending tests were conducted with a dynamic material fatigue testing machine Instron 8801 since conventional press machine couldn't impose uniform punch speed. The dynamic material fatigue testing machine has a maximum stroke of ± 75 mm and maximum speed of 200 mm/s in the vertical direction actuated by a hydraulic system.

2.2. Material

Testing materials are SPCC and DP780 steel sheets with a thickness of 1 mm. These steel sheets were chosen since they are in relatively wide spread use in the automotive industry. A length of blank is 400 mm with a width of 40 mm.

2.3. Tooling

For the U-bending test with Instron 8801 machine, it is necessary to setup a newly designed U-bending jig to the machine. Qualifications of newly designed U-bending jig are as follows; it is able to impose uniform blank holding force to exclude the effect of blank holding force on the springback behavior of sheet metals and there's no plastic deformation on the jig. Also, alignment of the blank can be checked.

The jig was manufactured and setup to Instron 8801 machine and it was confirmed that uniform blank holding force is imposed to the blank by using a pressure sensitive paper. These advantages are favourable for easy and convenient for U-bending test with various punch speeds.

2.4. Test conditions

Test conditions were established by comparing finite element analysis and pre-test results. Condition of punch speed was determined by finite element analysis of the blank during the U-bending test. Finite element analysis was conducted in order to investigate equivalent strain rate distribution of the blank with respect to punch speed. During the U-bending test, maximum strain rate could be found at first deformed surface element of the blank and equivalent strain rate varied 0.001/s to 1/s when punch speed varied 0.07 to 70 mm/s. And the strain rate change during the U-bending test can be regarded as negligible. Therefore, U-bending tests with various punch speeds of 0.07, 0.7, 7 and 70 mm/s were conducted for SPCC and DP780 steel sheets.

2.5. Springback measurement

The amount of springback of each blank after the U-bending test was investigated by measuring springback parameters. Measured springback parameters are quantitatively compared as listed in Table 1.

In the case of DP780, springback angle θ_1 is higher and springback angle θ_2 and radius of sidewall curvature lower value than in the case of SPCC for all conditions of punch speed. The amount of springback of DP780 is larger than that of SPCC since DP780 has higher values of yield stress and flow stress than SPCC.

If we examine the effect of punch speed, springback angle θ_1 increases and springback angle θ_2 and radius of sidewall curvature decrease as the punch speed increases in the case of SPCC, meanwhile springback angle θ_1 decreases and springback angle θ_2 and radius of sidewall curvature increase as the punch speed increases in the case of DP780. Therefore, the amount of springback in the case of SPCC decreases but the amount of springback in the case of DP780 increases as the punch speed increases. However, the amount of springback of SPCC has negative punch speed sensitivity which is on the contrary to that of DP780. Reason of negative punch speed sensitivity of the amount of springback of SPCC will be investigated by numerical analysis.

Table 1. Springback measurements results with various punch speeds.

Punch speed [mm/s]	SPCC 1.0t			DP780 1.0t		
	Springback angle θ_1	Springback angle θ_2	Radius of curvature	Springback angle θ_1	Springback angle θ_2	Radius of curvature
0.07	98.35	84.72	280.65	117.0	68.39	87.84
0.7	98.26	84.78	320.40	117.19	68.23	87.49
7	97.75	85.18	486.19	117.82	67.52	86.36
70	96.83	86.09	677.42	118.57	66.72	84.28

3. Numerical analysis

3.1. Finite element modeling and material property

The simulation of the U-bending test was modeled using the commercial finite element code ABAQUS/Explicit and then springback analysis was conducted using ABAQUS/Standard. The simulation was carried out with punch speed of 0.7 mm/s and 70 mm/s to investigate different tendency of springback behaviors of the steel sheets with various punch speeds. The static friction coefficient for the case of punch speed of 0.07 mm/s was defined to be 0.091 and the dynamic friction coefficient for the case of punch speed of 70 mm/s was defined to be 0.082.

Using experimental method proposed by Bae and Huh, 2011, tension/compression tests of SPCC and DP780 were carried out at the strain rates of 0.001/s and 1/s. True stress–true strain curves were obtained after the tension/compression tests and hardening curves expand with the increase strain rates for both steel sheets. The Bauschinger effect, transient behavior as well as permanent softening could be found in the tension/compression test results for both steel sheets. Also, we can find that strain rate sensitivity of SPCC is larger than that of DP780.

In order to apply the tension/compression hardening behavior to numerical simulation, the proper plasticity model was required to constitute the hardening curves accurately. In this study, nonlinear kinematic/isotropic hardening model was used for the simulation. The model includes a nonlinear kinematic hardening component as shown in Eq. (1).

$$d\mathbf{\alpha} = \sum d\mathbf{\alpha}_i, \quad d\mathbf{\alpha}_i = \frac{2}{3} C_i d\varepsilon_p - \gamma_i \mathbf{\alpha}_i |d\varepsilon_p|, \quad (1)$$

where C_i and γ_i are material parameters that must be calibrated from tension/compression test data. C_i is the initial kinematic hardening moduli and γ_i determines the rate at which the kinematic hardening moduli decrease with increasing plastic deformation (ABAQUS User's Manual). The isotropic hardening behavior of the model defines the evolution of the yield surface size as a function of the equivalent plastic strain ε_p . This evolution can be introduced by

$$d\mathbf{R} = b(R_\infty - \mathbf{R})d\varepsilon_p, \quad (2)$$

where R_∞ and b are material parameters. The tension/compression test results of SPCC and DP780 at each strain rate were fitted with the model as shown in fig. 2. 2 backstress are used for those steel sheets to improve fitting results and material coefficients for each steel sheet and each strain rate condition are shown in Table. 2. The model well predicts tension/compression hardening behavior of both steel sheets including the Bauschinger effect, transient behavior and permanent softening. Since the strain rate change during the U-bending test is negligible, material coefficients for the tension/compression test results at the strain rate of 0.001/s and 1/s were directly used for the simulation with punch speed of 0.07 mm/s and 1/s, respectively.

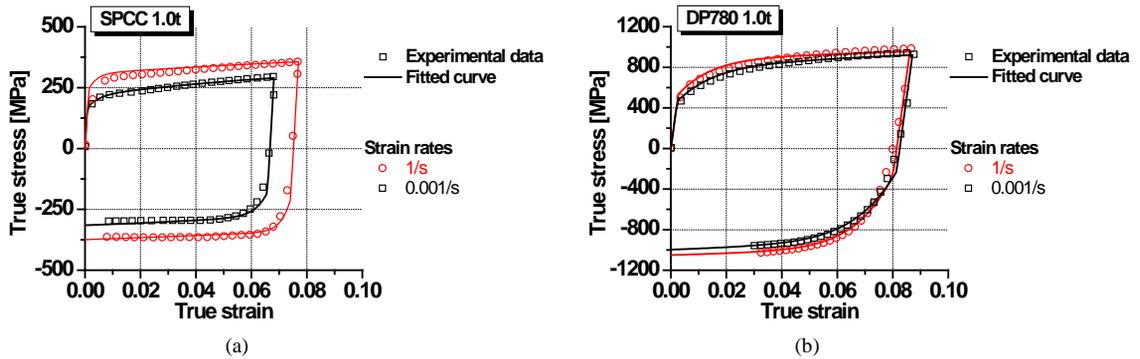


Fig. 2: Tension/compression test results with fitted curve of (a) SPCC (b) DP780.

Table 2. Material coefficients for SPCC and DP780.

	σ_y	C_1	γ_1	C_2	γ_2	R_n	b
SPCC, 0.001/s	168	12423	254	88	0	128	11.02
SPCC, 1/s	242	22879	248	104	0	115	5.87
DP780, 0.001/s	467	28627	83.5	36	0	481.6	3.10
DP780, 1/s	570	32526	94.3	38	0	416.3	2.16

3.3. Result and discussion

Numerical simulations of U-bending tests at the case of punch speed of 0.07 and 70 mm/s for both steel sheets were conducted and springback parameters were analyzed. Blank profiles after the numerical simulations with test results are displayed in fig. 3. The simulation results well predicted the test results as well as springback behavior with various punch speeds although small discrepancy appears in the flange region. Discrepancy between the test results and the numerical results can be reduced by using more accurate hardening model considering variation of unloading modulus as well as the strain rate.

To investigate different springback behavior of SPCC and DP780 with various punch speeds, tangential stress distribution in the blank was investigated by defining local coordinate system in the FEA model since the amount of springback is determined by tangential stress difference through thickness direction of blank. From this investigation, it seems to be due to the inertia effect of SPCC at the punch speed of 70 mm/s. When the punch moved fast, the deformation of SPCC blank at the sidewall region through the tangential direction was not uniform

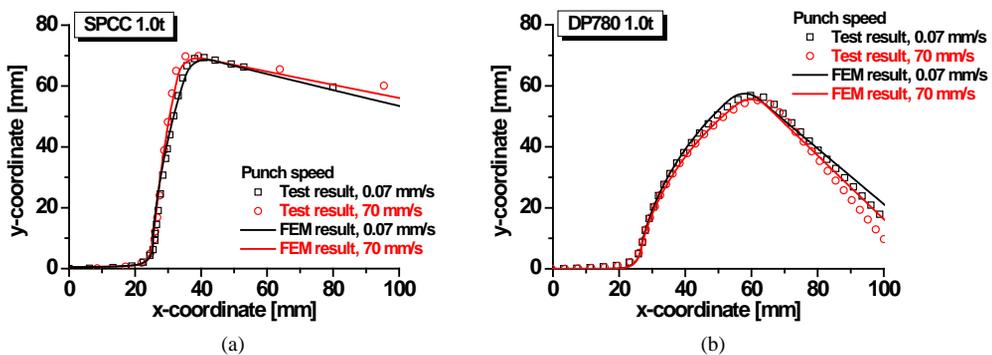


Fig. 3: Blank profiles after numerical simulations with test results for (a) SPCC (b) DP780.

by the inertia effect thus the amount of reverse bending was different along the sidewall. This led to small difference of tangential stress between top and bottom layer at the sidewall region so that the amount of springback decreased with increase of punch speed. On the other hand, the amount of springback increased with increase of punch speed in the case of DP780 due to strain rate sensitivity of hardening behavior.

4. Conclusion

This paper investigates the effect of punch speed on the springback behavior of SPCC and DP780 steel sheets by conducting U-bending tests and numerical analysis. Contributions in this paper are summarized as follows:

1) U-bending tests of SPCC and DP780 steel sheets with various punch speeds were conducted and springback parameters of the blank after U-bending test were measured. The amount of springback of DP780 is larger than that of SPCC. For SPCC steel sheets, the amount of springback decreases as punch speed increases. On the other hand in the case of DP780, the amount of springback increases as punch speed increases but the effect of punch speed on the springback behavior is not much severe for both steel sheets. Hence, in general, to improve the dimensional accuracy of a formed part, it is necessary to investigate effect of punch speed on the springback behavior of the material.

2) Numerical simulations of U-bending tests at the case of punch speed of 0.07 and 70 mm/s for both steel sheets were conducted and springback parameters were analyzed by using the hardening model which is able to predict tension/compression hardening behavior of both steel sheets. The simulation results well predicted the test results. Tangential stress distribution in the blank was investigated to find out different springback behavior of SPCC and DP780 with various punch speeds. For SPCC, negative strain rate sensitivity of springback behavior is because there's smaller difference of tangential stress between top and bottom layer at the sidewall region due to the inertia effect. For DP780, positive strain rate sensitivity of springback behavior is due to strain rate hardening.

References

- Uemori, T., Okada, T., Yoshida, F., 1998, Simulation of springback in V-bending process by elasto-plastic finite element method with consideration of Bauschinger effect, *Metals and Materials International*, Vol. 4, pp. 311–314
- Lee, M.G., Kim, D., Kim, C., Wenner, M.L., Chung, K., 2005., Spring-back evaluation of automotive sheets based on isotropic-kinematic hardening laws and nonquadratic anisotropic yield functions part III: Applications, *International Journal of Plasticity*, Vol. 21, pp. 915–953.
- H. Huh, S. B. Kim, J. H. Song, J. H. Lim, 2008, Dynamic tensile characteristics of TRIP-type and DP-type steel sheets for an auto-body, *International Journal of Mechanical Sciences*, Vol. 50, pp. 918–931.
- H. Huh, J. H. Lim, S. H. Park, 2009, High speed tensile test of steel sheets for the stress-strain curve at the intermediate strain rate, *International Journal of Automotive Technology*, Vol. 10, No. 2, pp. 195–204.
- H. Huh, J. H. Yoon, C. G. Park, J. S. Kang, M. Y. Huh, H. G. Kang, 2010, Correlation of microscopic structures to the strain-rate hardening of SPCC steel, *International Journal of Mechanical Sciences*, Vol. 52, pp. 745–753.
- H. Huh et al., 2014, Evaluation of dynamic hardening models for BCC, FCC, and HCP metals at a wide range of strain rates, *Journal of Materials Processing Technology*, Vol. 214, p.1326-1340
- G. H. Bae, H. Huh, 2011, Tension/compression test of auto-body steel sheets with the variation of the pre-strain and the strain rate, In: *Proc. 5th Int. Conf. on Computational Methods and Experiments in Materials Characterisation*, Kos, Greece.
- NUMISHEET '2011 benchmark problem No. 4
- Gihyun Bae, Hoon Huh, Sungho Park, 2012, A Simulation-Based Prediction Model of the Restraining and Normal Force of Draw-Beads with a Normalization Method, *Metals and Materials International*, Vol. 18, No. 1, pp. 7-22
- ABAQUS User's Manual