International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:12, No:1, 2018

Optimization of Process Parameters Affecting on Spring-Back in V-Bending Process for High Strength Low Alloy Steel HSLA 420 Using FEA (HyperForm) and Taguchi Technique

Navajyoti Panda, R. S. Pawar

Abstract**—**In this study, process parameters like punch angle, die opening, grain direction, and pre-bend condition of the strip for deep draw of high strength low alloy steel HSLA 420 are investigated. The finite element method (FEM) in association with the Taguchi and the analysis of variance (ANOVA) techniques are carried out to investigate the degree of importance of process parameters in V-bending process for HSLA 420&ST12 grade material. From results, it is observed that punch angle had a major influence on the spring-back. Die opening also showed very significant role on spring back. On the other hand, it is revealed that grain direction had the least impact on spring back; however, if strip from flat sheet is taken, then it is less prone to spring back as compared to the strip from sheet metal coil. HyperForm software is used for FEM simulation and experiments are designed using Taguchi method. Percentage contribution of the parameters is obtained through the ANOVA techniques.

Keywords**—**Bending, V-bending, FEM, spring-back, Taguchi, HyperForm, profile projector, HSLA 420 & St12 materials.

I. Introduction

MANUFACTURING industries are very much concerned about the manufacturing of high-precision sheet metal. Sheet metals are used in automotive industries, housing-utensil industries, and electronics industries. Every industry is trying to reduce the trial time to deliver the good quality product on time. Sheet metal bending is the most widely used process in sheet metal industries. Spring-back is common and critical or major factor in sheet metal non-cutting operations, which is caused by the elastic redistribution of the internal stresses after the removal of deforming forces from the sheet metals. Spring-back prediction is a driven factor for the achieving exact shape of sheet metal components which are used in the automotive and aerospace industry. The spring-back criteria change from material to material. However, the spring-back is studied in most of these researches: for example:

Yi et al. [1] studied a model based on differential strains after relief from the maximum bending stress, derived for six different deformation patterns in order to predict spring back analytically [1].

Buranathiti and Cao [2] studied an effective analytical model for spring back prediction in straight flanging processes [2].

The effect of punch height on V-bending angle is examined by Thipprakmas [3] using FEM, and results are validated through experiments [3].

Huang [4] studies the effects of process variables on V-die bending process for steel sheet with a model which predicts the correct punch load for bending and the precise accurate shape of products after unloading of the punch pressure, in relation to the tensile properties of the material and the geometry [4].

Slota and Jurčišin [5] analyzed TRIP, AHSS, and mild-steel considering normal anisotropic behavior of the materials for prediction of Springback in V-bending for automotive industry using experimental and numerical approaches [5].

Gajjar et al. [6] focused on application of HyperForm, LS-DYNA for Finite Element Analysis of Sheet Metal Air – bending [6].

Wang et al. [7] and Chan et al. [8] studied the spring-back control of sheet metal air bending process [7], [8].

Imaia et al. [9] study the real-time identification of V-bending metal forming (non-cutting operation) process with one clamped end and another free end, with different die punch parameters like different punch radius and angle which are varied in V-bending system to identify material and material behaviors in order to realize high precision V-bending components [9].

Leu and Hsieh [10] investigated the influence of the coining force on spring-back reduction in V-die bending process [10].

Groze et al. [11] elaborated the simulation model of the V-bending process of sheet metals where ABAQUS is used for finite element simulation for springback prediction of the V-bending Process [11].

Thipprakmas and Phanitwong [12] used the Taguchi technique for process parameter design of spring-back and spring-go in V-bending process where parameters like bending angle, material thickness and punch radius are investigated [12].

Chen and Muammer Koc [13] studied the simulation of springback variation in forming of advanced high strength steels for advanced high strength steel (AHSS) parts. Design of experiment (DOE), i.e. response surface method and finite

Navajyoti Panda is with the Department of Mechanical Engineering, Shreeyash College of Engineering & Technology, Aurangabad, M.S., India (e-mail: navajyotipanda5@gmail.com).
R. S Pawar is with the Shreeyash College of Engineering & Technology, Aurangabad, M.S., India (e-mail: ramkisanpawar1972@gmail.com).

element analysis (FEA) approach are used for the variation simulation and analysis [13].

Gautam et al. [14] studied the effects of punch profile radius and localized compression on springback in V-bending of high strength steel using Taguchi method. Inamdar et al. [15] presented prediction of springback in air V-bending of metallic sheets using an artificial neural network [14], [15].

Gisario et al. [16] investigated the phenomena of springback control in the bending process of aluminum sheets by hybrid forming process by using experimental analysis, empirical and neural network modeling [16].

Kazan et al. [17] predicted spring-back in wipe-bending process of sheet metal using neural network [17].

Although many researchers studied various factors affecting on spring-back, but the study of factors affecting on springback such as punch angle, die opening, grain direction of sheet metal and pre-bend condition of strip for sheet metal V bending for deep draw steel has not been conducted yet. The aim of the presented work is to examine the degree of importance of process parameters such as punch angle, die opening, grain direction of sheet metal, and pre-bend condition of strip for sheet metal V bending for deep draw steel, using Finite Element Simulation, DOE (Taguchi Method) and the ANOVA. The commercial software HyperForm is used to carry out the prediction of spring-back. The FEM simulation results are verified by the experiments. The percentage contribution of each affecting factor on springback is estimated with help of ANOVA technique. The results elucidated the degree of importance of each process parameter. The punch angle has a major influence on the spring-back along with die opening. Again, it is also found that grain direction of sheet metal and pre-bend condition of strip had less impact on springback for the given case.

II. Methodology

A. Taguchi Method

In the given study, experiments are designed using Taguchi method with L18 orthogonal array. Four process parameters with three levels, including punch angle, die opening, grain directions of sheet metal and pre-bend condition of strip are applied. Process parameters along with their levels selected for the study are shown in Table I. The spring-back angle is taken as process response. The characteristics ''Smaller is better'' for signal-to-noise ratio is considered for process response.

TABLE I
PROCESS PARAMETERS AND THEIR LEVELS

	Process Parameter	Level 1	Level 2	Level 3
A	Punch Angle	860	880	900
B	Die Opening	12t	16t	20t
C	Grain Direction	00	450	900
D	Pre-Bend Condition of Strip	Tension	Compression	Flat

ANOVA is a method of partitioning variability into identifiable sources of variation and the associated degrees of freedom in an experiment.

The percentage contribution of each affecting parameter on springback is estimated with the help of ANOVA technique.

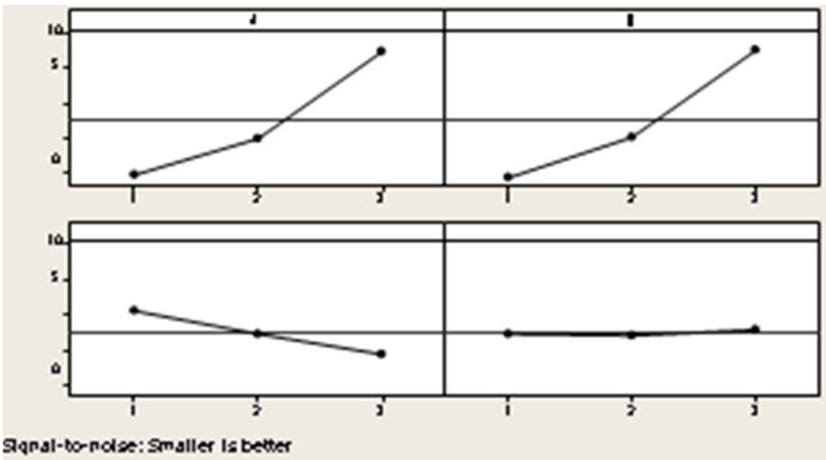

Fig. 1 Main effects plot for S/N ratios

Fig. 1 shows the main plot effect for S/N ratios for four process parameters, i.e. punch angle (A), die opening (B), pre-bend condition of the strip (C) and grain direction of sheet metal (D). The graphs obtained through Taguchi technique show that the S/N ratio is highest for parameter punch angle (A) and then for parameter die opening (B). It is also seen that S/N is lower for process parameter pre-bend condition of the strip (C) and it is lowest for process parameter grain direction of sheet metal (D).

B. Experimental Procedure

For experimental procedure three V-bending dies with die opening 12t, 16t and 20t are used keeping die angle and die radius constant where 't' is the thickness of sheet metal. Three punches with 860, 880, and 900 punch angles are used keeping punch radius constant as shown in Fig. 3. Experiments are performed on universal tensile testing machine in the laboratory with the same FEM simulation conditions. The laboratory experiments are carried out to validate the FEM simulation results. Figs. 2 (A)-(C) show the actual experimental setup used. The V-bending angle of the component is examined using the profile projector.

Fig. 2 (A) Experimental setup on universal testing machine

Fig. 2 (B) Punches and dies for experimentation

Fig. 2 (C) Experimental Setup on Universal Testing Machine

C. FEM Simulation Procedure

In the presented work, FEA simulation of V-bending of sheet metal is performed using HyperForm. Solid elements are used for meshing the sheet metal. Punch and die are meshed with rigid mesh which means that there will not be any effect on punch and die during analysis. Type of mesh and number of elements are kept constant during all simulations. Figs. 3 (A) and (B) show the FEA simulation model in HyperForm. The sizes of strip used for FEA simulation and actual experimentation are 90 mm in length, 30 mm in width, and 2.4 mm in thickness. HyperForm is used as the FEM simulation tool. A punch angle of 860, 880, and 900, a material thickness (t) of 2.4 mm, and die opening of 12t, 16t, and 20t, grain direction of sheet metal 00, 450, and 900 and pre-bend condition of strip, i.e. sample is taken from sheet metal coil and studied from both sides. Another sample is taken from flat sheet and investigated.

The material used is Deep Draw steel IS HSLA 420 and St12. The other material properties like yield strength, ultimate tensile strength, % elongation etc. are determined by tensile testing experiment as per ASTM E8-04.

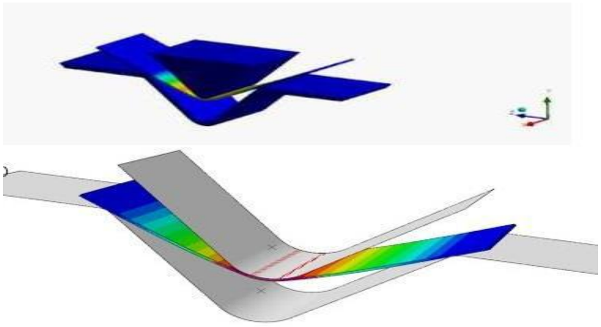

Fig. 3 (A) FEA model for HyperForm simulation

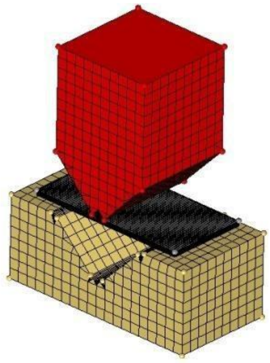

Fig. 3 (B) FEA model Pre-process form Hypermesh

III. Results & Discussion

A. Application of ANOVA

The process parameters and their levels investigated in springback and are listed in Table I. To investigate the degree of importance of the process parameters, the ANOVA technique is carried out in this case. The ‘‘Smaller is better” (S/N) characteristics are considered for the spring-back. The SS, MS, F, P and percentage contributions calculated for each process parameters in the case of spring-back are illustrated in Table II. In the case of spring-back, the percentage contributions of the punch angle, die opening, pre-bend strip condition, and grain direction are 47.45%, 38.52%, 3.57%, and 1.37% respectively. Based on these statistical analysis results, it is found that the degree of importance of process parameters in V-bending process depended on punch angle (A), die opening (B), pre-bend condition of the strip (C) and grain direction of sheet metal (D).

TABLE II
ANOVA TABLE

Source	SS	MS	F	P	% Contribution
A	27.6711	13.8352	20.4001	0.0000	47.46%
B	22.4640	11.2320	16.9600	0.0010	38.52%
C	0.7985	0.3993	0.6000	0.5680	1.37%
D	2.0804	1.0402	1.5700	0.2600	3.57%
Error	5.3042	0.5894			9.10%
Total	58.3172				

As shown in the results, for the given case of spring-back, the process parameters of the punch angle had the most influence, followed by similar influence of die opening and the small influence of the pre-bend strip condition and the grain direction.

B. Effects of Process Parameters on the Spring-Back

In the presented work, the effects of punch angle, die opening, grain direction, and pre-bend condition of strip are clearly investigated and identified based on the tensile and compressive stress distribution analysis using HyperForm.

The results showed that, as punch angle is changing from 860 to 900, tensile and compressive stresses are also increasing. It is also observed that percent strain is higher for 860 and lower for 900 after removal of punch causing lower springback. It is also observed that, as the die opening is increased, the amount of spring-back is reduced. In addition, the pre-bend strip condition is also simulated, and it is found that for given case it also had impact on springback on lower scale. With FEM simulation as well as experimental validation, it is observed that grain direction did not influence the springback significantly.

During the past research, it is observed that lots of work have been performed on the phenomenon of springback and parameters influencing it.

In the presented work, the mechanism of spring-back related to process parameters punch angle (A), die opening (B), pre-bend condition of the strip (C) and grain direction of sheet metal (D) is clearly identified based on the tensile and compressive stress distribution analysis. It found that, as the die opening increased, tensile and compressive stresses are also increased. It is investigated that the increase in punch angle also increased the tensile and compressive stresses.Hence, with these characteristics, as the die opening increased, the amounts of spring-back decreased. However, it is also observed that tensile and compressive stresses are higher for flat condition of the strip. In FEM simulation, for the grain directions, no significant change is observed in tensile and compressive stresses and thereby in springback.

The results illustrated that the punch angle had a great influence on the tensile and compressive stresses, whereas die opening is found to be the second most influencing parameter on tensile and compressive stresses. The grain direction and pre-bend condition of strip had a less influence on tensile and compressive stresses and hence on springback. Fig. 4 explains the effect of each process parameter on tensile stresses and compressive stresses. However, Fig. 5 shows the effect of each process parameter on percent strain.

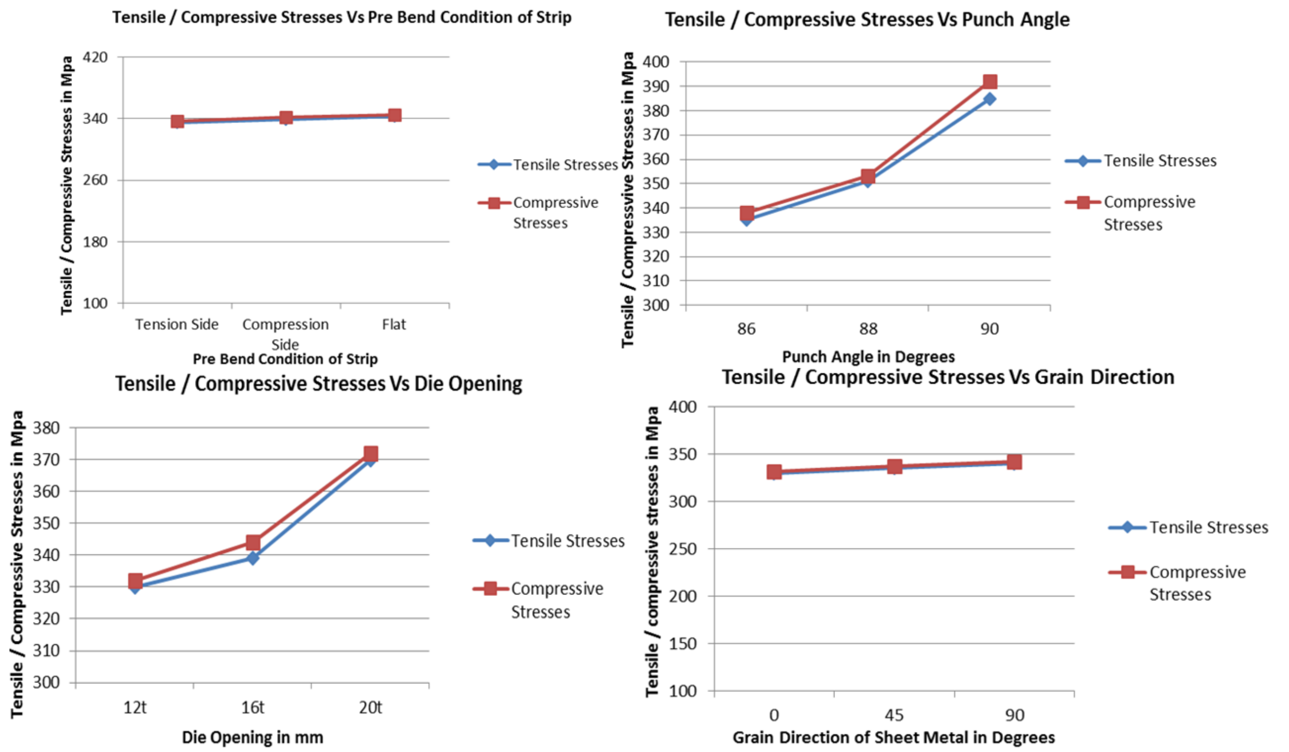

Fig. 4 Tensile stress & compressive stresses

Figs. 6 (a) and (b) show a tensile and compressive stresses generated during one experiment with 90° punch angle, 20 ton die opening, flat strip condition, and 0° grain direction. Similarly, results are obtained for all 18 experiments as per Taguchi Technique for percentage of strain after removal of bending force for all cases.

Based on the tensile and compressive stress distribution, the effects of process parameters and degree of importance of process parameters are clearly analyzed by the ANOVA technique. It observed that the punch angle and die opening had a major influence on spring-back.

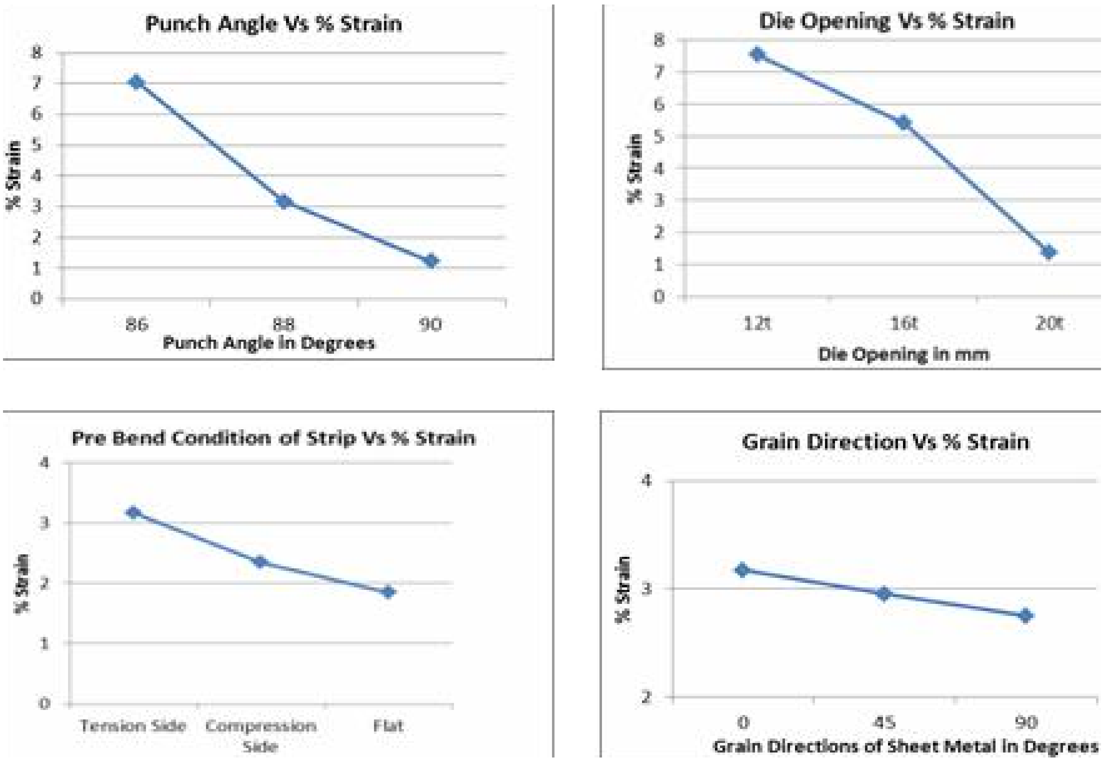

Fig. 5 % Strain after removal of applied force

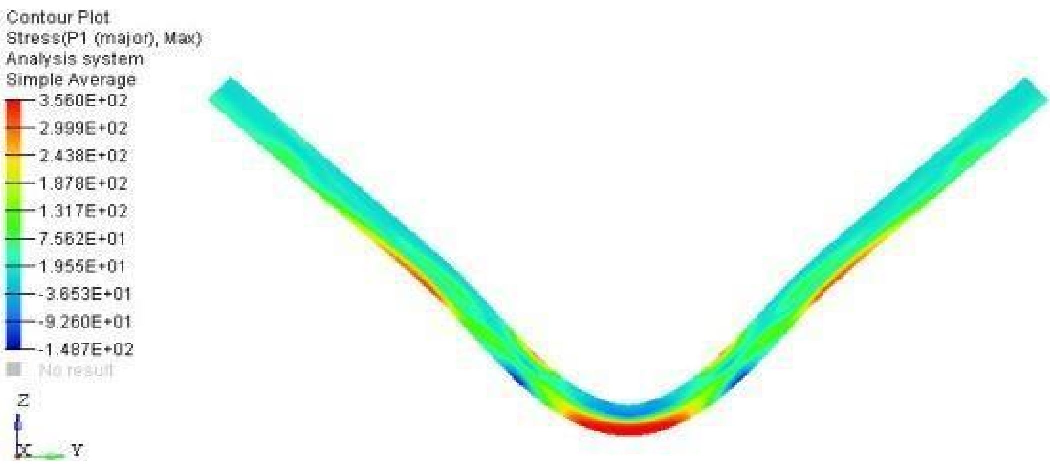

Fig. 6 (a) Tensile Stress during bending

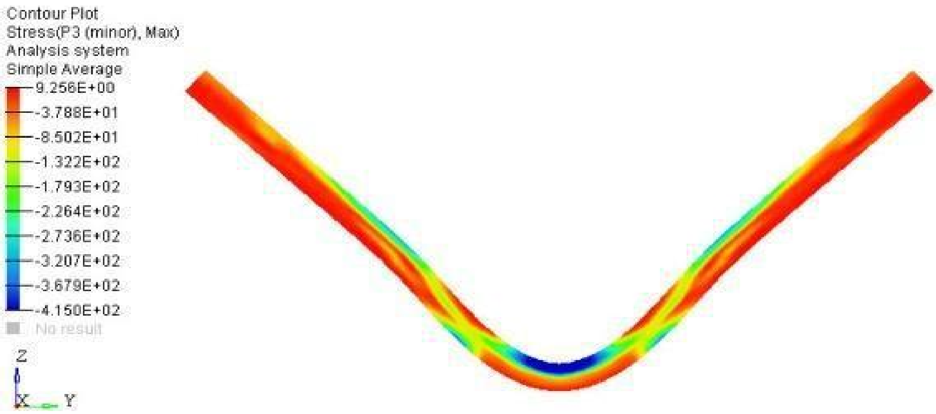

Fig. 6 (b) Compressive stresses during bending

C. Comparing the FEM Simulation and Experimental Results

The accuracy of the FEM simulation results is validated by laboratory experiments. Commercial FEM software HyperForm showed good agreement with the experimental results. In this study, the experimentation is performed in which the errors in analyzed springback angle are approximately 5% compared with the experimental results. In this study, experiments are carried out to confirm the accuracy of FEM simulation results especially for the case of punch angle, die opening, pre-bend strip condition and grain direction for deep draw steel. Fig. 7 shows the comparison between the FEM simulation and the experimental results.

IV. Conclusions

In the presented work, four process parameters like punch angle, die opening, grain direction and pre-bend condition of strip affecting on springback in V-bending process for deep draw steel HSLA 420 and St12 are analyzed and studied using FEM simulation, Taguchi, and the ANOVA techniques. The results obtained through FEM simulation are validated by Laboratory experimentation. From the above study, it is observed that two process parameters punch angle and die opening had major influence on springback with their approximately calculated percentage contribution of 47.45% and 38.52% respectively because, as punch angle increased from 86^0 to 90^0, tensile and compressive stresses induced into the strip are also increasing from 335 MPa to 385 MPa and 392 MPa to 486 MPa, respectively. The higher stresses generated during the process yields the material to plastic state which results into the less straining after removal of the bending force. The percentage straining after removal of bending force for the punch angle from 86^0 to 90^0 is found to be 7.04% to 1.22%. Same is the case for die opening as die opening is increasing from 12t to 20t tensile and compressive stresses induced into the strip are also increasing from 320 MPa to 380 MPa and 385 MPa to 485 MPa, respectively. On the other hand, the unique parameter studied here, i.e. pre-bend condition of strip, also had influence on springback with its approximately calculated percentage contribution of 3.57%. Grain direction is identified as the parameter with least influence on springback with its approximately calculated percentage contribution of 1.37%. The effects of above process parameters could be clearly identified through tensile stress and compressive stress distribution analysis using HyperForm. It is presented that, the punch angle and die opening had a major effect on the tensile and compressive stresses. Hence, to find the optimum value of springback, the designer has to concentrate on punch angle and die opening.

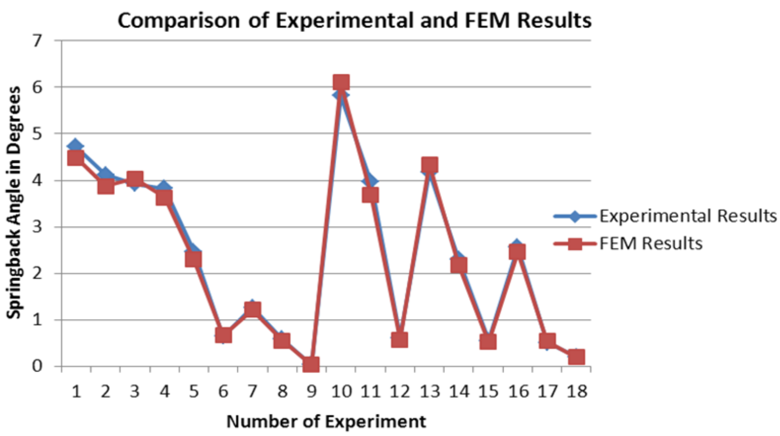

Fig. 7 Comparison between experimental and FEM results

REFERENCES

[1] H. K. Yi, D. W. Kim, C. J. Van Tyne, and Y. H. Moon, Analytical prediction of springback based on residual differential strain during sheet metal bending. Int. J. Mech. Sci., 2008, 117- 129.
[2] Thaweepat Buranathiti and Jian Cao, An effective analytical model for spring back predictionin straight flanging processes, Int. J. Materials and Product Technology,2004,137-153.
[3] Sutasn Thipprakmas, Finite element analysis of punch height effect on V-bending angle, Materials and Design 31 (2010) 1593– 1598.
[4] You-Min Huang and Daw-KweiLeu, effects of process variables on v-die bendingprocess of steel sheet, Int. J. Mech. Sci. Vol. 40, No. 7, 631 - 650, 1998.
[5] Ján SLOTA and Miroslav JURČIŠIN, Experimental and Numerical Prediction of Springback in V-Bending of Anisotropic sheet metals for automotive industry, Mechanika z. 84 (3/12) 2012, 55-68.
[6] Himanshu V. Gajjar, Anish H. Gandhi, and Harit K. Raval, Finite Element Analysis of Sheet Metal Airbending Using Hyperform LS-DYNA, World Academy of Science, Engineering and Technology 8 2007, 92-97.
[7] Wang J, Verma S, Alexander R, Gauc J. Spring-back control of sheet metal air bending process. J Manuf Process 2008;10:21– 7.
[8] W. M. Chan, H. I. Chew, H. P. Lee, B. T. Cheok, Finite element analysis of springback of V bending sheet metal forming processes, Journal of Materials Processing Technology 148 (2004) 15-24.
[9] KazunariImaia, Junichi Koyama, Yingjun Jin, High-accuracy V-bending system by realtime identifying material property, journal of materials processing technology 2 0 1 (2008) 193– 197.
[10] Leu DK, Hsieh CM. The influence of coining force on spring-back reduction in V-die bending process. J Mater Process Technol 2008; 196:230–5.
[11] Florica Mioara Groze Gheorghe Achimaş, Springback Prediction of the V Bending Process using Finite Element Simulation, 7th International Multidisciplinary Conference, Baia Mare, Romania, May 17-18, 2007, ISSN-1224-3264.
[12] Sutasn Thipprakmas, Wiriyakorn Phanitwong, Process parameter Design of springback and spring-go in V bending process using Taguchi technique, Materials and Design 32 (2011) 4430-4436.
[13] Peng Chen, Muammer Koc¸ Simulation of springback variation in forming of advanced high strength steels, Journal of Materials Processing Technology 190 (2007) 189–198.
[14] Vijay Gautam, Parveen Kumar, Aadityeshwar Singh Deo, Effect of Punch Profile Radius and Localised Compression on Springback in V-Bending of High Strength Steel and its FEA Simulation, International Journal Of Mechanical Engineering And Technology (Ijmet), Volume 3, Issue 3, (2012), 517-530.
[15] M. V. Inamdar, P. P. Date, U. B. Desai, Studies on the prediction of springback in air vee bending of metallic sheets using an arti®cial neural network, Journal of Materials Processing Technology 108 (2000) 45 – 54.
[16] A. Gisario, M. Barletta, C. Conti, S. Guarino, Springback control in sheet metal bending by laser-assisted bending: Experimental analysis, empirical and neural network modeling, Optics and Lasersin Engineering49(2011)1372– 1383.
[17] Kazan R, Firat M, Tiryaki AE. Prediction of spring back in wipe-bending process of sheet metal using neural network. J Mater Des 2009;30:418–23.