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Research Article

The Experimental and Numerical Study of the Effects of Holding Force, Die Radius, Pin Radius and Pin Distance on Springback in a Stretch Bending Test

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ABSTRACT

The stretch bending test is one of the methods for forming metals, especially sheets. In this method, a piece of a metal sheet simultaneously undergoes compressive and tensile forces, thereby being converted into a curved piece with a great curvature. In the present research, springback was studied using a U-form die in a stretch bending test, and the experiments were performed on st12 steels through a laboratory set-up. Moreover, various parameters were investigated, including die radius, pin diameters, blank holding force (BHF), and distance between pins. The stretching depth was 10 mm. Not to mention, springback is affected by technical and geometric parameters. For example, the results of the present study revealed that increasing the pin spacing led to the reduction of springback and for more spacing, the springback tends to spring-go, additionally, it was observed that a rise in the die radius, pin diameters, and blank holder force resulted in the reduction of springback.

1. Introduction

Considering the fact that most of the automotive bodies are developed by forming processes, one of the methods of producing these bodies is through the bending process on a macro scale [1]. In the Industrial process, prediction of the final dimension of the part after unloading is an essential problem [2]. Springback is a phenomenon that occurs in the last stage of sheet forming due to the presence of residual stress and is uneven throughout the depth of the sheet. Therefore, this is the answer to the question why the study of the effects of physical and metallographic phenomena on springback is very important for factories engaged in shaping [3, 4]. In the last 10 years, researchers have made a concerted effort to reduce springback. For instance, several studies have been conducted on the effects of mechanical parameters on springback. Some authors have shown that high stretch metal always exhibits more springback in comparison with ductile metals. For example, Panti et al. [3], Jiang et al. [5], and Mori et al. [6] reported that a rise in yield stress led to a rise in springback. Mkaddem and Saidan showed that the reduction of the die radius dropped springback [7]. Additionally, Lee and Kim reported that reducing the fillet radius and blank holder force (BHF) increased the springback [8]. In U-shaped dies, increasing the die radius led to the reduction of springback [4], which was also confirmed in another study by Verma and Halder [9]. BHF is another important factor affecting

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springback [10]. Liu et al. [11], and Lee and Yang [12] showed that a rise in BHF resulted in the reduction of springback in steel and aluminum alloys. Furthermore, with the increase of BHF, the yield stress increased in the stretched section, thereby leading to strain hardening and significant plastic deformations in sheet thickness [13, 14]. The oscillatory increase of BHF by Liu et al. (2002) is another technique that reduces yield stress in the wall of the sample and consequently reduces springback [13]. Anisotropy is another plastic factor that has led to conducting studies about springback [4, 9, 15]. In a study performed by Verma and Halder, it was observed that springback was low for isotropic materials [9]. Recovery is another important factor that reduces springback after it being formed in high temperatures. In a study done by Yanagimoto and Oyamada on high stretch steel, it was demonstrated that springback could be decreased at temperatures above 750 K [16]. This phenomenon can be explained by reducing strain and creep. The width and thickness of the shaped sheet also affects the springback [17, 18]. Garcia-Romeu et al. [17] reported that a rise in the width of aluminum and steel sheets increased springback. In another study performed by Serkan et al. [18], it was revealed that a rise in the sheet thickness reduced springback. Springback can also be reduced through the friction between the surface of the sheet and the die. In a numerical study done by Li et al. [14], it was reported that increasing the friction coefficient led to the reduction of springback. It can be claimed that friction coefficient plays the same role as BHF. Samuel reported that springback could be decreased by the gradual increase of friction coefficient [4]. It should be noted that numerical studies have also played a significant role in springback-related research in the last 15 years, which has led to the minimization of optimal geometric and technological parameters of springback [4, 14]. In metal engineering, an increase in the elastic modulus led to a decrease in the springback [19, 20]. The more important springback parameters are the Young modulus, material property, tools radius, and blank holder force [21]. To predict springback, it is necessary to accurately determine the distribution of internal yield stress, which is extremely demanding and requires complex cyclic loading, while numerical simulation can be a convenient and easy solution to solve this problem. In the first step of the present research, a device was made that was easily mounted on a tensile machine. The BHF was easily controlled by a torque meter, and the stretch and springback were calculated at the time of loading and unloading. The present study aimed to investigate the effects of BHF, pin spacing, die radius, and pin radius on springback.

St12 sheet is widely used in the automotive industry. Much research has been done on the St12 sheet in the form of U, V, and L shapes. But no research has been conducted on the topic of the present study, that the distance and radius of the pins and the radius of the die and the holders force were variable. In this research, in addition to obtaining optimal bending conditions by two experimental and numerical methods, an equation is derived to obtain the amount of springback.

2. Experimental Procedure

In the present study, Rectangle specimens with dimensions 120 mm, 20 mm, and 1 mm (thickness) have been considered while the die and the stretching rods were made of VCN-150 steel, and 0.003 m^2 of the surface of the holder was considered on the die on both sides of the specimens (Fig. 1). As illustrated in Fig. 1, the die has two holders both of which have been connected to it (see Fig. 2). The holder's load may be calculated by a load cell. The properties of the St12 was achieved from the literature review [22]. In addition, the tests on springback were carried out using a die made at the laboratory [23]. Additionally, the setup consisted of a die, pins, tensile mechanisms and blank holders (BHF). The design of the die is such that it can be mounted on a tensile machine, and the stretching mechanism is also mounted on the movable jaw of the tensile machine. This mechanism plays the role of a punch, in which two cylindrical rods cross over and perform the stretching action (See Fig. 2). In addition, the two ends of the sheet are held under pressure by BHF and the tensile force is generated by a displacement speed of 3 mm/min [23].

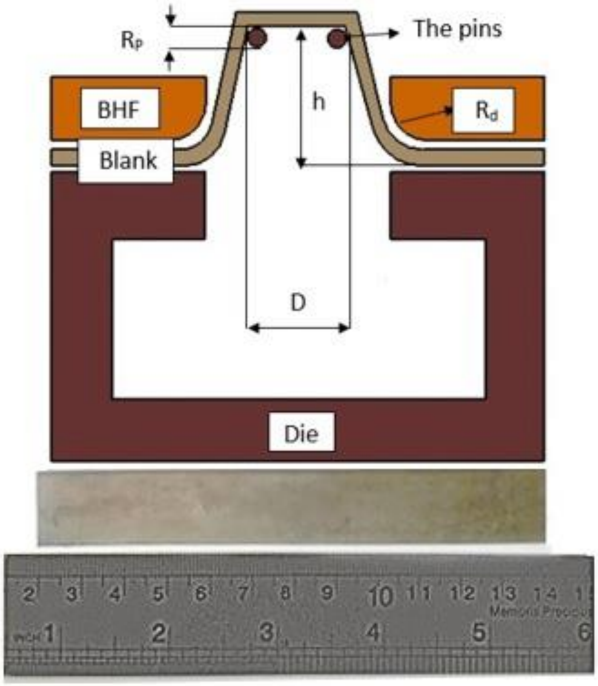

Fig. 1. Schematic of the setup.

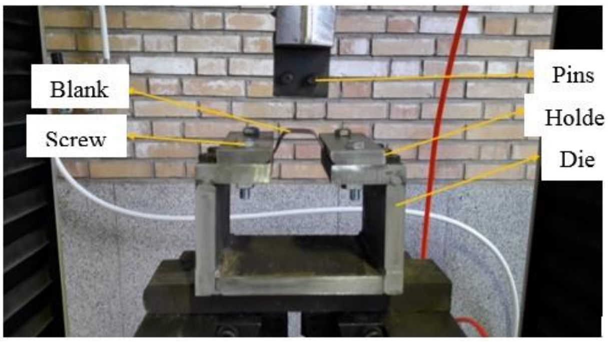

Fig. 2. The set of die and sheet on a hydraulic press (R_d=10 mm, R_p=6 mm, D=30 and h=20 mm).

In this study, the Taguchi method, as an important tool for robust design, has been using by combining experimental design theory and the concept of quality loss function to statistically investigate different parameters. Results from Ouakdi et al. 2011, revealed that the effective parameters on springback are: the pin radius (R_p), the die radius (R_d), the pins distance (D), and the blank holding force (BHF). They considered BHF and h as main variable parameters in their study. We investigate the effect of R_p, R_d, D, and BHF on springback as variable parameters. Table 1 shows the factors and their levels. These levels are selected based on [1]. Different conditions obtained from the Taguchi method are shown in table 2.

Table 1. The range of the process variables of computer simulation and experimental tests

Factors	Levels
R_p (mm)	4 6 8 10
R_d (mm)	4 6 8 10
BHF (kN)	3 6 9 12
D (mm)	26 30 34 40

This setup allows for the BHF to be changed at the two ends of the samples through a torque meter. Moreover, the force between the die and the holder can be changed through changing the torque of bolts at the two ends of the samples. The amount of pressure can be calculated via dividing the clamping force by the cross-section of BHF. Moreover, the die radius could be changed in the design of the die (Fig. 2). The springback falls into two categories: primary and secondary. If 'h' is the initial height of the specimen after the stretching depth, and 'h1' is the tensile height after suppression of the stretching force, then the initial springback (Δh_1) is calculated from the difference between h and h1. However, after discharging from set-up, the specimen height changes to h2, and the secondary springback (Δh_2) is obtained from the difference between h and h2 [23]. This aims to measure the second springback which plays a crucial role in the engineering design. In order to measure the second springback, instead of the height measurement, we may compute the second springback using the graph paper. The second springback of specimen was calculated after unloading and separating the samples from the die.

Table 2. The factors and levels of the Taguchi method

SN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	1	1	4	1	1	4	1	1	2	2	3	2	3	2	2	2	3	3	3	3	4	4	4	4
B	4	2	3	4	4	2	3	4	4	1	4	4	4	4	2	4	4	4	4	4	4	4	4	4
C	3	3	2	3	3	1	3	3	3	3	2	3	1	3	3	3	3	3	3	3	3	3	3	3
D	1	1	1	2	3	3	3	4	1	1	1	2	3	3	3	4	1	2	3	4	1	2	3	4

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2.1 ABAQUS simulation

Numerical simulation is used widely in product design. ABAQUS is one of the adaptable finite element software that can be used to model structures both homogenous and nonhomogeneous [24]. In this investigation ABAQUS software was employed for two purposes, to obtain the proper circumstance of stretching pins, the die radius, the blank holder force and to compare the results of experimental and simulation tests [25]. Of the most important factors in the metal forming simulation, the relationship between stress and strain is the most influential. For this purpose, a tensile test according to BS EN ISO 6892-1 was performed. The mesh convergence was assessed and the sheet was simulated as a deformable body utilizing 14531 Solid elements (C3D8R) with 8 integration points through the thickness (Fig. 3). Therefore, the number of elements has been assumed to be 25342. The tools (pins, die, and blank holder) were modeled as discrete rigid body. The rigid body movements were controlled by the reference points. The boundary conditions imposed on the tools were intended to describe as accurately as possible the experimental conditions.

It was constrained in all of the directions and the pins moved in the perpendicular direction as much as 10 cm (Fig. 4). After applying the mechanical properties, density, Young's modulus, and Poisson ratio, the matrix, pitch, and roller set were drawn as a rigid piece and assembled on the assembly. In this study, the blank set between the holder and the die and holder force was varied based on different toques. In simulation, no friction was established between holder-blank and die-blank. The period time was 0.01 and a dynamic explicit solver was used in this study. The simulations were carried out for different set numbers obtained from the Taguchi method shown in Table 2.

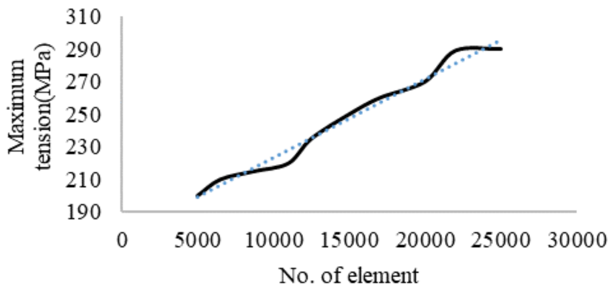

Fig. 3. Mesh convergence.

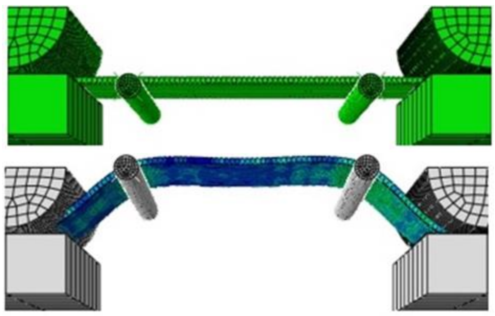
Fig. 4. Specimen simulation.

3. Results and Discussion

3.1. The relationship between BHF and tensile height

In this process, the stretching height was 10mm. One of the factors that affect stretching height is the BHF. This relationship was determined by computer simulations using the Abaqus software version 6.13. The simulation results demonstrated that increasing the BHF caused tearing and its reduction resulted in wrinkling. The best BHF for stretching height of 20 mm was 9 kN.

When the BHF is too large, the sliding between the specimen and the die reaches its minimum level, and ruptures occur. Additionally, if the BHF is lowered to a certain extent, there will be sliding between the sheet and the die, and finally, before the bending process, the sheets layers move freely on the pins, and wrinkles are formed. Demonstrated in Fig. 5 is a distribution of von Mises stress in which the holder's force, the pin radius, and the height are 9 kN, 6 mm, and 20 mm, respectively.

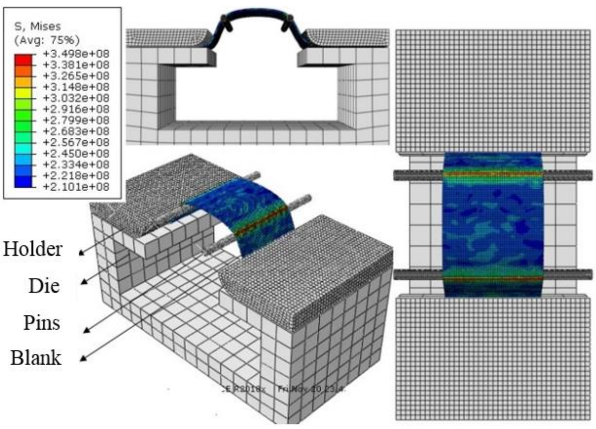

Fig. 5. Distribution of von Mises yield in terms of the R_d= 10 mm, R_p= 6 mm and BHF=9 kN.

3.2. The effects of the die radius on the yield created on the sheet

As it can be seen in Fig. 5, two areas, marked in red, displayed the most sensitivity in the stretching process, namely the contact area of the sheet with the radius of the die and the contact area of the sheet with the pins. The results revealed that the material flow zone decreased in the plastic area with the decrease of the die radius, and the accumulation of residual stresses occurred in a small area of the sheet, thereby leading to a rise in the yield stress in these two areas. Table 3 shows the tension for the various die and pin radiuses while an upsurge in die and pin radii result in decreasing the tension. According to the simulations, the best radius of the die was achieved 10 mm. The springback and maximum force for Taguchi levels are shown in Table 4. The Taguchi levels were done based on experimental tests and computer simulation**.**

Table 3. Von Mises yield zones created in the stretch bending test on St12 sheet

	R_d=4 mm	R_d=6 mm	R_d=8 mm	R_d=10 mm
R_P=4 mm	556	491	472	440
R_P=6 mm	460	432	431	349
R_P=8 mm	418	393	372	298
R_P=10 mm	370	350	332	289

3.3. The Effects of pin diameter on stretching force

Based on the results in Table 3, the best die radius is 10 mm because this radius had minimum tension in the bending area. Shown in Table 5 is the maximum forces for different pins radius. The simulation results revealed that there is a direct relationship between the tensile force applied by the pins and the diameter of the pins. In Table 5, the result of computer simulations and experimental tests have been compared [26]. It is seen that the tensile force is decreased by increasing the pin diameter since the contact with the surface of the sheet is increased and a larger area of the sheet caused a decrease in the pressure.

Table 4. Springback and maximum force based on Taguchi levels

					Experimental		Simulation							Experimental		Simulation	
SN	A	B	C	D	F	SP	F	SP	SN	A	B	C	D	F	SP	F	SP
1	1	4	3	1	27.1±0.3	3.2±0.3	28	3.5	**13**	3	4	1	3	18.8±0.1	1.5±0.2	17.8	2.5
2	1	2	3	1	27.8±0.2	3.4±0.3	29.2	3.7	**14**	2	4	3	3	20.2±0.4	1.84±0.2	21.1	2
3	4	3	2	1	18.9±0.1	1.2±0.1	20	1.8	**15**	2	2	3	3	20.8±0.4	2±0.4	22	2.2
4	1	4	3	2	25.4±0.4	2.5±0.2	26.1	2.7	**16**	2	4	3	4	19.2±0.3	1.34±0.3	20.2	1.5
5	1	4	3	3	22±0.3	2±0.3	21.7	2.2	**17**	3	4	3	1	21.2±0.2	2±0.3	22.7	2.3
6	4	2	1	3	16.5±0.2	1±0.2	17.9	1.3	**18**	3	4	3	2	20.5±0.3	2±0.4	19.3	2.3
7	1	3	3	3	22.5±0.1	2.5±0.3	22.5	2.8	**19**	3	4	3	3	18.5±0.4	1.3±0.3	17.4	1.3
8	1	4	3	4	20±0.3	1.7±0.1	19.5	1.77	**20**	3	4	3	4	17.7±0.3	1.1±0.1	17.4	1.4
9	2	4	3	1	24.4±0.3	3±0.3	25.5	3.2	**21**	4	4	3	1	18.5±0.2	1±0.2	19.1	1.5
10	2	1	3	1	24.8±0.3	3.2±0.4	26.5	3.5	**22**	4	4	3	2	17.1±0.2	1.3±0.3	18	1.3
11	3	4	2	1	21.4±0.2	2.3±0.3	23	2.5	**23**	4	4	3	3	16.3±0.3	0.9±0.2	17.1	1.1
12	2	4	3	2	23.1±0.2	2.35±0.2	22.8	2.45	**24**	4	4	3	4	15.4±0.3	0.7±0.4	14.8	0.9

Set Numbers, Force (kN):F, Springback: SP

Table 5. The effects of pins radius on bending force

		The maximum force [kN]	
R_p (mm)	R_d(mm)	Numerical	Experimental
4	10	28	27.1±0.3
6	10	25.5	24.4±0.3
8	10	22.7	21.0±0.2
10	10	19.1	18.5±0.4

3.4. The effects of BHF, die radius and pin distance on springback

The results of empirical and simulation experiments showed that, by increasing BHF and die radius, the springback decreased and even went down to zero (See Fig. 7) [27]. It was also observed that there was springback for the force F> 12 kN (the torques of the toughness of BHF screws was 36 N.m) and the sheets got wrinkled in the form of M shapes (Fig. 6). As the torque increased, the BHF increased as well, and there was less slid between the sheet and the die. As explained earlier, when slid decreases in the contact areas of the sheet between the holder and the die, stretching and residual stresses increase at the same time, and before any change in the sheet layers, it slips on the pin, and the M-shaped piece is created. Moreover, when torque is reduced, the slid goes become higher in the contact areas of the sheet between the holder and the die and the samples are easily shaped. Furthermore, with the increase of the diameter of the pin and BHF to 9 kN, the springback decreased, which is due to the reduction in the distribution of yield stress in the contact area of the sheet and the radius of the die. the lowest springback has occurred in the range of 9 kN (See Fig. 7). In addition, the impact of the pin distance on the springback at the different pin radius has been illustrated in Figs 8, 9 and 10. Whilst it is seen that a surge in the pin distance causes the springback to decrease. Additionally, increasing the value of the pin distance and its radius simultaneously causes the decreasing in springback. In Fig. 10 the effects of the pin radius on springback are shown for 10 mm die radii. As the pin radius increases, the residual stresses are distributed in a larger area and the springback decreases as a result of increasing the deformed region. The results demonstrated that the lowest springback was found in the 10 mm pin radius.

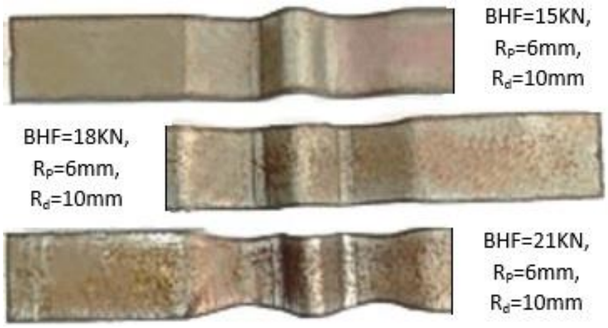

Fig. 6. The wrinkled samples obtained from the stretch bending test for torques of T> 36 N.m.

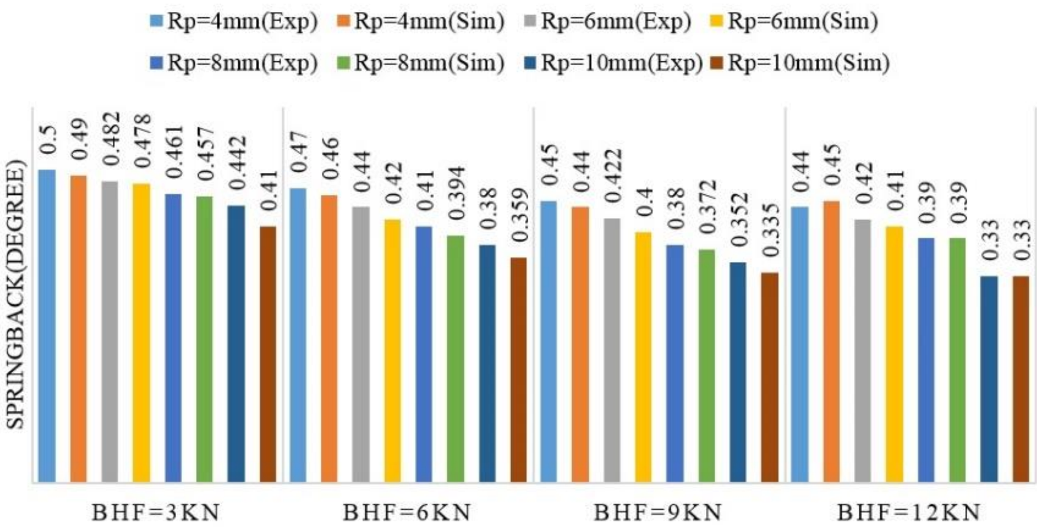

Fig. 7. The springback rate for different BHF, R_d=10 mm and h=20 mm.

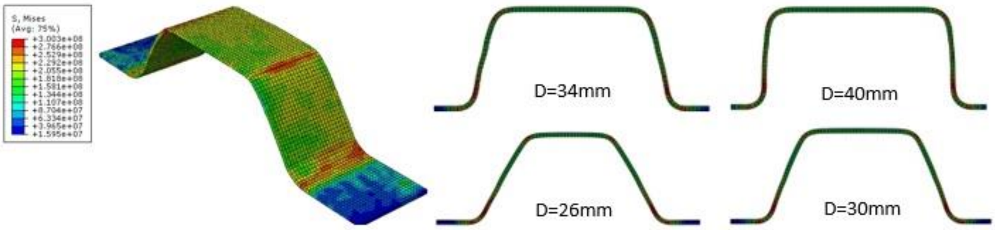

Fig. 8. The different pin distance: R_P=6 mm, R_d=6 mm and BHF=9 kN.

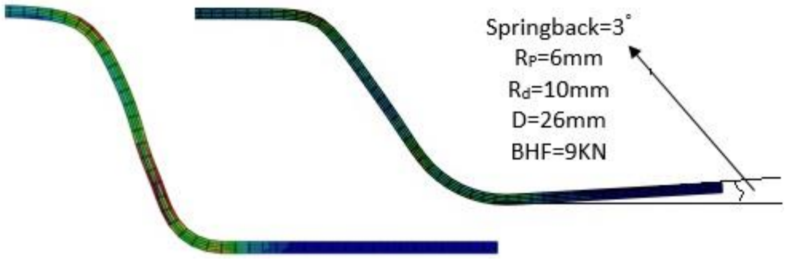

Fig. 9. The Springback: R_P=6mm, R_d=10mm and BHF=9 kN Springback.

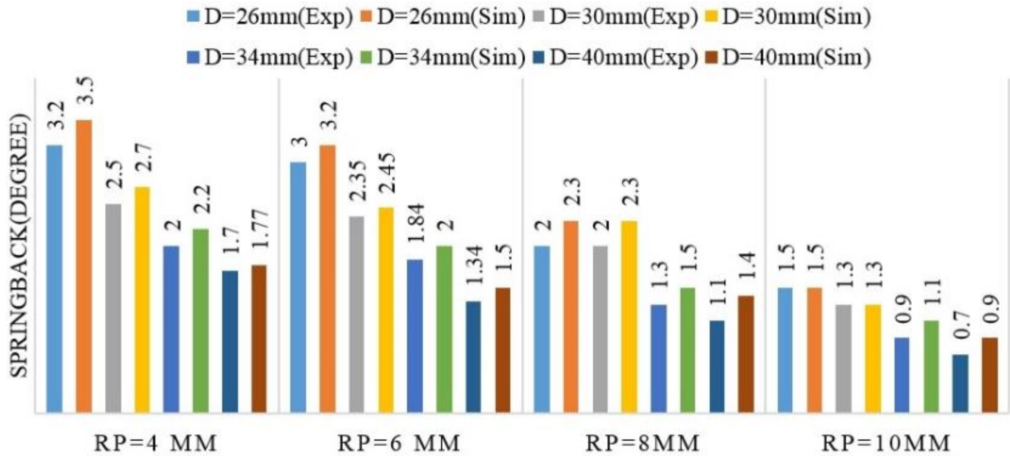

Fig. 10. The springback for different R_P and D, R_d= 10 mm, BHF=9 kN and h = 20 mm.

It should be acknowledged that increasing the holder load caused the sprignback to decrease while it is seen that, according to Fig. 7, for a constant amount of the holder's load, an upsurge in the pin radius made the springback decrease. the springback for a different amounts of the pin radius is illustrated in Fig. 11. As previously mentioned, the minimum amount of the springback was seen in the pin radius of 10.

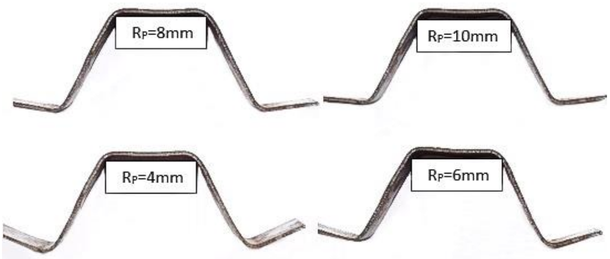

Fig. 11. The springback rate for different of R_P, R_d=6 mm, BHF= 9 kN and h=20 mm.

In this study, the role of the springback and its corresponding effect has been scrutinized. It is seen that the variation of the springback is attributed to some parameters including Rd, Rp, D, and BHF. Furthermore, in order to prognosticate the springback, the multi-choices regression model has been utilized based on MATLAB 2015 software. The input numbers are the mentioned parameters as, Rd, Rp, D, and BHF and the outcome Is the springback, thereby the below equation has been calculated. It should be mentioned that the mean square error, MSE, and the correlation coefficient are 0.185 and 0.959, respectively. Table 6 shows the calculated spring back from the Formula and simulation. For this purpose, different values of Rd, Rp, D, and BHF were used and springback was obtained based on formula and simulation. The results showed that the formula calculated the values very accurately.

$$springback = -0.02043 \times BHF - 0.15374 \times D - 0.26184 \times R_p + 0.024042 \times R_d + 8.2636 \quad (1)$$

Table 6. Springback comparison between results of formula and simulation

BHF	D	R_p	R_d	Springback (Formula)	Springback(simulation)	Error
11	36	8	5	0.53	0.59	10.16949
5.1	26	4	7	3.28	3.61	9.141274
6.3	35	9	6	0.54	0.62	12.90323
7.8	29	7	9	2.02	2.14	5.607477
10	33	5	8	1.86	2.02	7.920792
4.8	31	11	7	0.67	0.71	5.633803
9.5	30	6	5	2.01	2.13	5.633803

4. Conclusion

The springback is a negative phenomenon that occurs in bending processes. In this study, the effect of some parameters on springback were investigated. The tests were done based on experimental and simulation methods. The results of numerical simulation demonstrated that the stretching height for St12 Sheet was about 20 mm, and the von Mises yield was in the range of 289 to 556 MPa. As the diameter of the pin increased, the shaping force, which was around 15-27 kN for a 4-10 mm radius, decreased. With the increase of BHF and the radius of the pins, there was a drop in springback phenomenon. The results of experimental tests revealed that the sheets experienced wrinkles in the form of M shapes for torques of T>36 N.m. When the pin diameter and the die radius increased and BHF measured at 6 kN, the springback was almost zero. With the increase of pin spacing, the springback decreased, and for R_P=10 mm, it was near zero.

5. References

[1] A. Adelkhani, H. Ebrahim, M. M. Attar, The Experimental and Numerical Study of the Effects of welding Angle on Forming Multilayered Sheets in U-Bending Operations, *Journal of Mechanical Science and Technology*, 34 (2020) 239-244.

[2] D. K. Leu, A simplified approach for distinguishing between spring-bach and spring-go in free U-die bending process of SPFC 440 sheets, *Materials & Design*, 94 (2016) 314-321.

[3] S. K. Panthi, N. Ramakrishnan, A. Meraj, S. S. Shambhavi, M. D. Goel, Finite element analysis of sheet metal bending process to predict the springback, *Materials & Design*, 31(2010) 657-662.

[4] M. Samuel, Experimental and numerical prediction of springback and side wall curl in U-bending of anisotropic sheet metals, *The Journal of Materials Processing Technology*, 105 (2000) 382-393.

[5] Z. Q. Jiang, H. Yang, M. Zhan, X. D. Xu, G. J. Li, coupling effects of material properties and bending angle on the springback angle of titanium alloy tube during numerically controlled bending, *Materials & Design*, 30 (2010) 846-850.

[6] K. Mori, K. Aktia, Y. Abe, springback behavior in bending of Ultra-high-strength steel sheets using CNC servo press Abe, *The International Journal of Machine Tools and Manufactur*, 47(2007) 321-325.

[7] A, Mkaddem, D. Saidane, Experimental approach and RSM procedure on the examination of springback in wiping-die bending process, *The Journal of Materials Processing Technology*, 189 (2007) 325-333.

[8] S. W. Lee, Y. T. Kim, A study on springback in the sheet metal flange drawing, *The Journal of Materials Processing Technology*, 187 (2007) 89-93.

[9] R. K. Verma, A. Halder, Effect of normal anisotropy on springback, *The Journal of Materials Processing Technology*, 190 (2007) 300-304.

[10] L. Papeleux, J. P. Ponthot, Finite element simulation of springback in sheet metal forming, *The Journal of Materials Processing Technology*, 125 (2002) 785-791.

[11] W. Liu, Y. Yang, Z. Xing, L. Zhao, Springback control of sheet metal forming based on the response-surface method and multi-objective genetic algorithm, *Materials Science and Engineering* A, 499 (2009) 325-328.

[12] S. W. Lee, D. Y, Yang, an assessment of numerical parameters influencing springback in explicit finite element analysis of sheet metal forming procrss, *The Journal of Materials Processing Technology*, 180 (1998) 60-67.

[13] G. Liu, Z. Lin, W, Xu, Y. Bao, Variable blank holder force in U-shaped part forming for eliminating springback error, *The Journal of Materials Processing Technology*, 120 (2002) 259-264.

[14] K. P. Li, W. P. Carden, R. H. Wagoner, Simulation of springback, *The International Journal of Mechanical Sciences*, 44 (2002) 103-122.

[15] D. K. Leu, A simplified approach for evaluating bendability and springback in plastic bending of anisotropic sheet metals, *Journal of Materials Processing Technology*, 66 (1997) 9-17.

[16] J. Yanagimoto, K. Oyamada, Mechanism of springback free bending of high stretch steel sheets under warm forming conditions, *Manufacturing Technology* 56(2007) 265-268.

[17] M. L. Garcia-Romeo, J. Ciurana, I. Ferrer, Springback determination of sheet metals in an air bending process based on an experimental work, *Journal of Materials Processing Technology*, 191 (2007) 174-177.

[18] T. Serkan, K. Suleyman, O. Fahrettin, The effect of material thickness and deformation speed on springback behavior for DP600 steel. *Advanced Materials Research*, 264 (2018) 636-645.

[19] X. Li, Y. Yang, Y. Wang, J. Bao, S. Li, Effect of material-hardening mode on the springback simulation accuracy of V-free bending, *Journal of Materials Processing Technology*, 123 (2002) 209-211.

[20] H. Y. Yu, Variation of elastic modulus during plastic deformation and its influence on springback, *Material & Design*, 30 (2009) 846-850.

[21] S. Jadhav, M. Schoiswohl, B. Buchmayr, Applications of finite element simulation in the development of advanced sheet metal forming processes. *BHM Berg-und Hüttenmännische Monatshefte*, 163 (2018) 109-118.

[22] S. Saravanan, M. Saravanan, D. Jeyasimman, Study on effect of springback on sheet metal bending using simulation methods, *International journal of mechanical and production*, 8 (2018) 923-932.

[23] V. Gautam, V. Manohar Raut, R. Kumar, Analytical prediction of springback in bending of tailor-welded blanks incorporating effect of anisotropy and welded zone properties, *Institution of Mechanical Engineering*, 4 (2015) 1-13.

[24] E.H. Ouakdi, R. Louahdi, D. khirani, L.Tabourot, Evaluation of springback under the effect of holding force and die radius in a stretch bending test, *Materials and design*, 35 (2012) 106-112.

[25] F. K. Chen, J. H. Liu, Analysis of equivalent model for the finite element simulation of a stamping process, *Journal of Machine Tools and Manufacture*, 37 (1997) 409-423.

[26] V. Nasrollahi, B. Arezo, Prediction of springback in sheet metal components with holes on the bending area, using experiments, *finite element and neural networks*, 36 (2012) 331-336.

[27] S. T. Atul, M. L. Babu, A review on effect of thinning, wrinkling and spring-back on deep drawing process, *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, *233* (2019) 1011-1036.