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The Experimental and Numerical Investigation on the Springback Behavior in Free Bending Process

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Abstract: *Spring back is one of the key parameters in bending process. After the bending operation, the material under pressure is highly likely to return to its previous status due to the release of the applied forming force, which is known as 'spring back.' The precision of the forming operation is of prime significance for the final production of goods in industry. Therefore, the present study aimed to examine the effects of some parameters (die radius, punch velocity, sheet width and bending axis orientation) on the behavior of spring back in free bending process. The experiments were conducted on steel sheets with the dimensions 12cm×12cm which are extensively used in automotive industry. The results of the present study revealed that there was a direct relationship between springback and each of die radius, punch velocity, sheet width, and orientation of the bending axis orientation.*

Keywords: *Springback, Punch, Die, Bending*

INTRODUCTION

Sheet metal forming refers to various processes used to convert metal sheets into different shapes (Assikin Khakis et al., 2016). Permanent deformations take place when the maximum elasticity limit of is exceeded in the structure of a material. However, this is not the final scenario since, after the bending operation, the material under pressure is highly likely to return to its previous status due to the release of the applied forming force, which is known as 'spring back' (Suchy, 2006). Besides, because springback is known as a negative factor in the eyes of customers, it is of the essence. Hence, the precision of the bending process plays a major role in the quality of the end product. With the arrival of new material and the parts with complex geometries, the role of precise bending has become more apparent. However, the results of practical experience have it that springback is significantly affected by the dimensions and shapes of the applied dies or punches. Moreover, the size of the plasticized area created by the bending process is determined by the forming radius of the applied punches and dies. Not to mention, the die radius should also be selected in proportion to the material thickness, following the r/t ratio guidelines (Suchy, 2006). In Figure 1, the most commonly recommended dimensions of bending tools are shown (Suchy, 2006). The space between the punch and die, which varies according to the material thickness, is another significant factor that impact upon the outcome of the bending operation. This gap is usually adjusted within the range of t-1.2 t. Another contributing factor which affects the forming process is the forming speed, as a result of which heat and greater material hardening are observed on the one hand, and resulting in time- and cost-efficient bending operations on the other hand. So, the optimization of bending parameters can be studied from two aspects. The first aspect is accuracy of the bending process and meeting the customer requirements, and the second

one is its cost effectiveness aspect (Krinninger et al., 2016). In the present study, the samples were fixed between a holder and a die and were then shaped using the punch movement. In Figure 1, the schematic diagram of the bending process is shown.
For this type pf bend allowance, the following formula is used (Suchy, 2006):

$$BA=C(r+t/5)$$

Where r and t denote the bend radius and material thickness, respectively. Further, C represents a constant, which depends on the bending angle. For example, C measures 1.5708 for 90° bends. In addition, the bend allowance is used to calculate the total length of the article as follows:

$$L_{total}=BA+A+B$$

The parameters that can be impact on springback fit into three categories: geometric, material and process (Krinninger et al., 2016). The first category can be caused by sheet width, sheet thickness and bending angle. As for the second category, it can be expressed that springback can be greatly influenced by properties such as Young's modulus, yield strength, tensile strength, and strain hardening coefficient. For instance, higher yield and tensile strength, lower Young's modulus and a higher strain hardening coefficient can lead to a rise in the springback (Krinninger et al., 2016).
The process parameters include some factors, such as the rate of forming. In a study performed by Krinning et al. (2016), the effects of punch velocity on springback were investigated. In their study, the springbacks of micro-alloyed steel HX260LAD and stainless steel 1.4310 were investigated, and a model was developed for correction factors (Krinninger et al., 2016). In another study done by Dilip Kumar et al. (2014), the springback of aluminum sheet during L-bending was investigated, and it was concluded that there was a direct relationship between springback and forming rate. The springback of sheet metal components was predicted by Nasrollahi and Arezoo (2012) using holes on the bending area. In another study conducted by Assikin khamis et al. In two separate studies performed by Prior (1994) and Finn et al. (1995), explicit-implicit solvers were employed to simulate the bending process and springback effects, respectively. In another study conducted by Wang et al. (2016), a model with variable friction was employed for steels enjoying high stretching features.

Material

The experiments were conducted on steel sheets with the dimensions 12cm×12cm which are extensively used in automotive industry. According to ASTM E415-1 (2006), a yield strength of 190 Mpa and a tensile strength of 290 Mpa with a strain value higher than 42% were obtained. The chemical composition of the material is described in Table 1.

Table 1. The Chemical Composition of the Material

Element	C	Si	Mn	P	S	Cu	Ni	Cr
St12	0.1	0.01	0.16	0.013	0.004	0.007	0.006	0.01

Experimental Set-up

Testing Device and Tool Set-up

To perform the tests, a heavy duty hydraulic press was utilized. Moreover, various forces and speeds could be created in the machine through changes in the hydraulic pressure. To this end, a solenoid and a digital indicator were embedded in the machine in such a way that the moving jaw of the press moved at the set speed throughout the course.

To study the effects of different parameters on bending condition, a die with various radii and punches was developed. To this end, the die, punch and holder must be made of solid materials with good machining capabilities. So, steel VCN150 was used for this purpose Figure 2). In the present research, various dies with different radii were applied. In figure 2, a schematic view of the condition of the test is shown. As it can be seen, the sheet is tightly attached between the holder and the die using two screws, and the punch moves downwards at a predetermined speed and bends the sheet. Several dies were built for various bending conditions. The bending was performed in such a way that the sheets were placed at Zero and 90 angles in relation to the axis of the punching machine. Not to mention, the said angles were determined considering the direction of cutting samples. In other words, the samples were cut in two right-angle directions.

Figure 2: A schematic view of dies and how the test is done

To cut the edges of components, the RAXER Water Jet Cutter was used. The cutter sprinkles the mixture of water and abrasive materials at a speed of 900m/s. The samples were cut in two perpendicular directions, called bending axis orientation, with three different widths (see Figure 12). As shown in Figure 2, the holder and die were connected to each other using two screws and a sheet was placed between them. It should be noted that the friction force varied through loosening and tightening the two screws. In Table 2, the parameters of the applied material are shown.

Table 2. The Parameters of the Applied Material

Components	St12	St12
Thickness (mm)	0.06	0.06
Length (mm)	120	120
Bending orientation axis (degree)	0	90

To check the springback of the samples, grid papers were used, and the results were compared with those of ABQUS Simulation.

ABAQUS Simulation

Numerical simulation is widely used in designing products. ABAQUS is one of the adaptable finite element software that can be used to both homogenous and nonhomogeneous model structures (Chen and Liu, 1997). In this investigation, the ABAQUS Software was used for two purposes: obtaining the proper domains of punch velocity, clearance, bending force, coefficient of friction and comparing the results of experimental and simulation tests between stress and strain (Nasrollahi and Arezo, 2012). One of the most important factors in metal forming simulation is the relationship between stress and strain. The Duplicate ASTM E415-1 longitudinal tensile samples were tested for metal sheets (st12) in Razi Library. The results of tensile test, explained in section2 of the present study, were used in software simulation. To this end, a geometric model was designed for punch, holder, die and blank, the analyses were performed using ABAQUS. In Table 3, the process and response variables are shown. In fact, the response variables were evaluated through changing the process variables using the ABAQUS Software. For example, the proper value of clearance measured 1 mm.

Table 3. The Parameters in the ABAQS Software

Variable Parameters		Symbol	Unit
Process Variable	Velocity	V	m/s
	Clearance	C	Mm
	Holder force	F	N
	coefficient of friction	μ	-
Response Variable	Springback	θ	Deg
	Thickness	t	mm
	Stress	σ	MPa

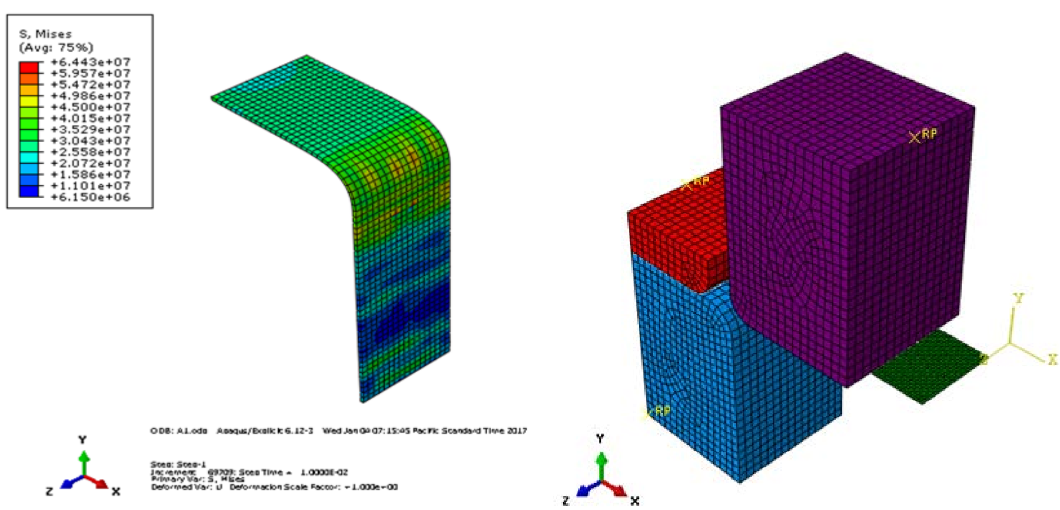

Figure 3: ABAQUS simulation

Experimental Design

In Table 4, the variable parameters applied in the present study are shown.

Table 4: the variable parameters applied in the present study

material	Cutting direction or Txture (degree)	Die radius or RD(mm)	Punch radius or RP (mm)	Sample width or w(mm)	Punch velocity or V(mm/s)	Clearance OR C (mm)
	0	2	8	10	10	1
	0	4	8	20	50	1.5
	0	6	8	30	100	2
St12	0	8	8		150	
	90	2	8	10	10	1
	90	4	8	20	50	1.5
	90	6	8	30	100	2
	90	8	8		150	

Findings and Discussion

In Figure 4, in which both simulation and experimental results are presented, the effects of punch velocity on springback with clearance of 1 mm and die radius of 4 mm for 10- and 20-mm widths are shown. The results revealed that a rise in speed velocity resulted in a drop in strain rate and bending stress. So, after unloading, the residual stress decreased significantly. The results also showed that a rise in punch velocity and width of parts led to the decrease of springback. When the bending operation started, the edges of samples bulged due to the material displacement in the boundary zone (Krinninger et al., 2016). The results of experimental investigations indicate that the bulges of samples with different widths are similar and have no significant effects o

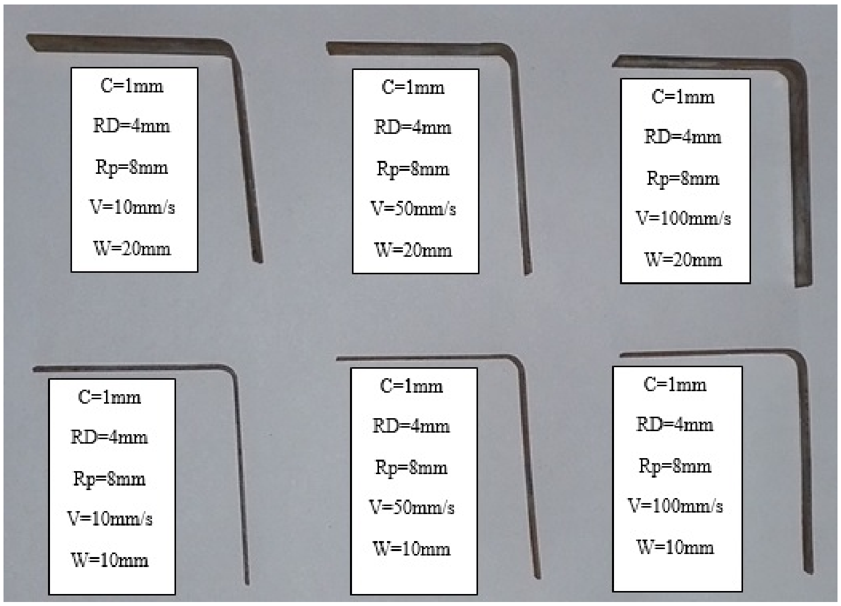

Figure 4: springback for different speeds and widths

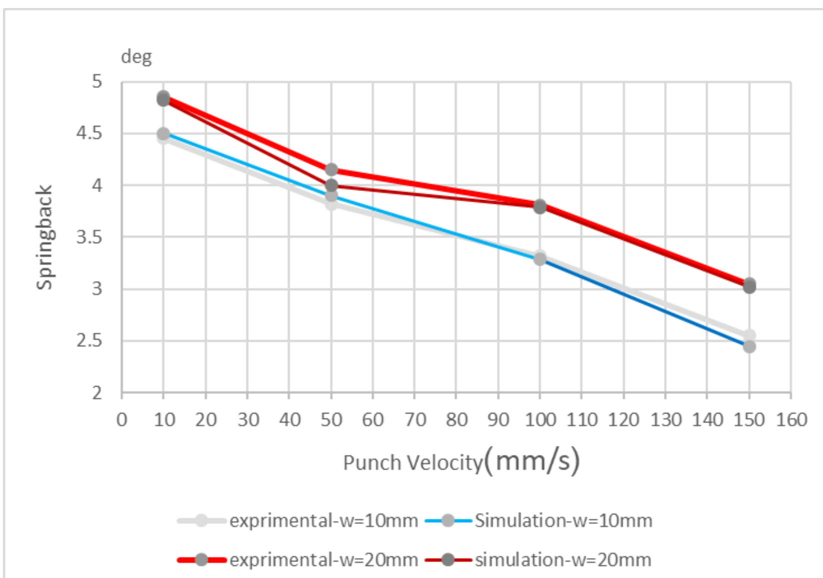

Figure 5: springback at different speed

In Figure 3, the effects of bending orientation on springback with clearance of 1 mm, die radius of 4 mm and punch velocity of 50 mm/s for 10, 20, and 30-mm widths are shown. The results indicated that changing the direction of bending from 0 to 90 led to a rise in the springback because of the orientation of the molecular bonds.

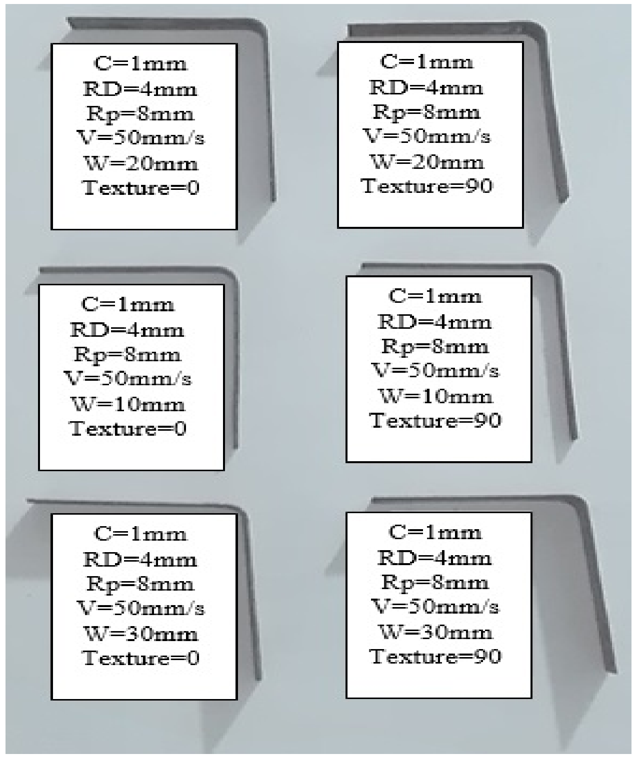

Figure 6: springback for zero and 90 cutting direction

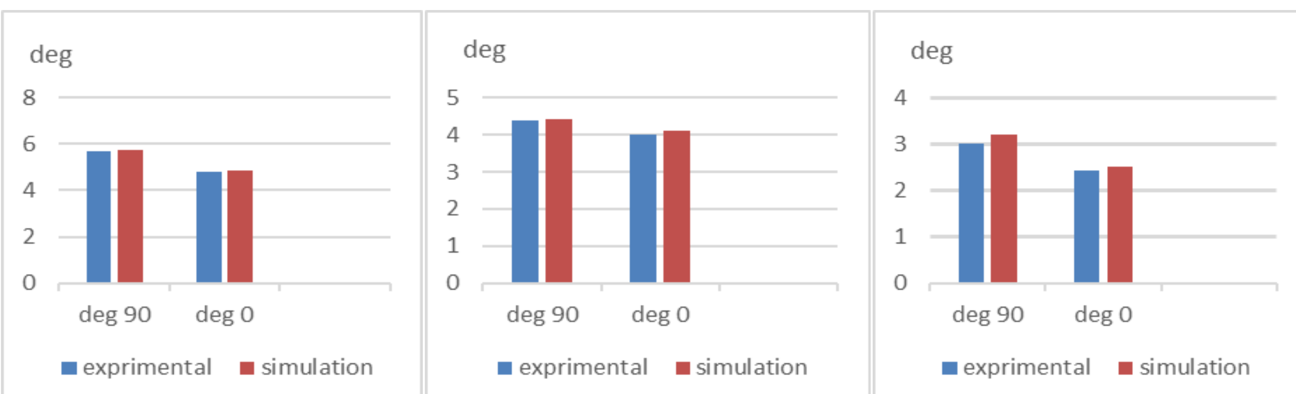

Figure 7: The springback when Rp=8 mm, RD=4 mm, C=1 mm, V=50 $^{mm}/_{s}$(left W=10, middle W=20 and right W=30 mm)

In Figure 5, the springback for different values of die radius are shown. In the present study, the results revealed that with a clearance of 1 mm, a punch speed of 50 mm/s and a bending orientation of zero degrees, springback was affected by various die radii. As can be seen in the figure 9, a rise in the die radius resulted in a rise in the plastic region and a rise in the zone for the material flow in the case of plastic. However, the same scenario led to a decrease in residual stresses and springback.

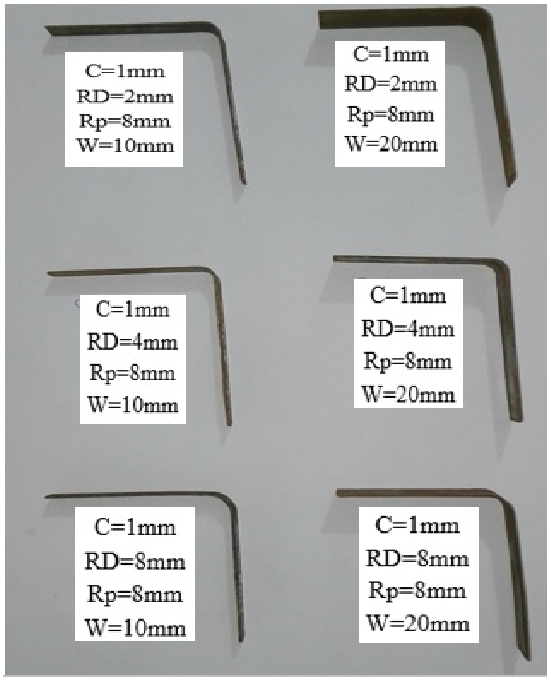

Figure 8: Springback for different die radii and widths

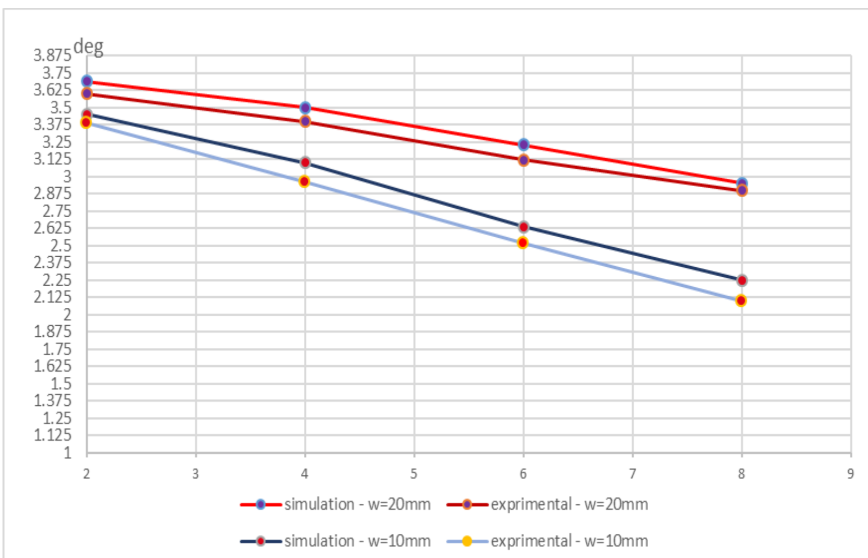

Figure 9: The Springback when Rp=8 mm, C=1 mm, V=50 $^{mm}/_{s}$, and cutting direction=0°

In Figure 6, the effects of die radius on bending stress are shown. In this figure, the stress of a punch radius of 8 mm, clearance of 1 mm and punch velocity of 10 mm/s for 10, 20 and 30-mm width is shown. The results revealed that increasing the die and punch radii led to the reduction of bending stress due to a rise in the bending area and a fall in the stress concentration. In Figure 7, the relationship between clearance and bending stress is shown. In this figure, the punch radius, die radius and punch velocity measured 8 mm, 4 mm and 10 mm/s, respectively. The result indicated that bending stress was reduced by a rise in the clearance, and the tension was increased by the shrinkage in this case.

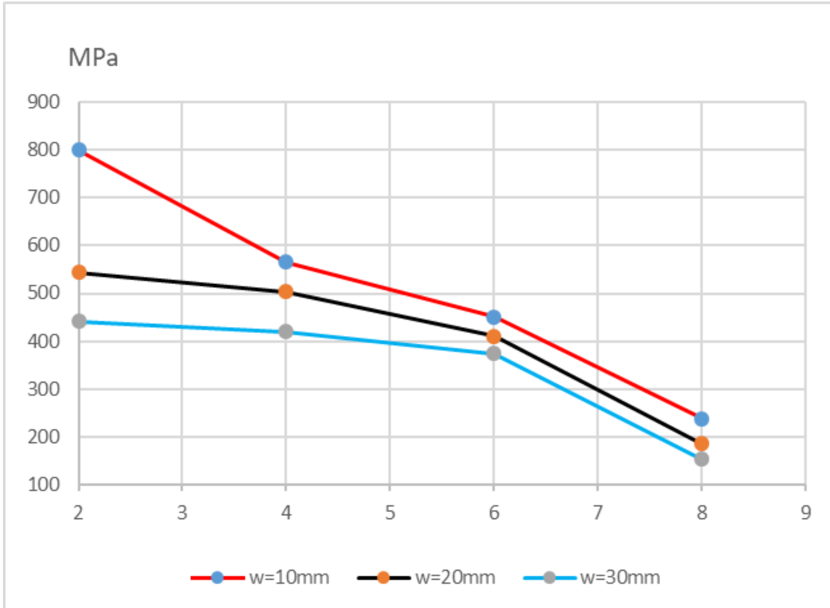

Figure 10: The effects of the radius of the template on the Tension in the Bending area when V=10 $^{mm}/_{s}$, Rp=8 mm, and C=1 mm

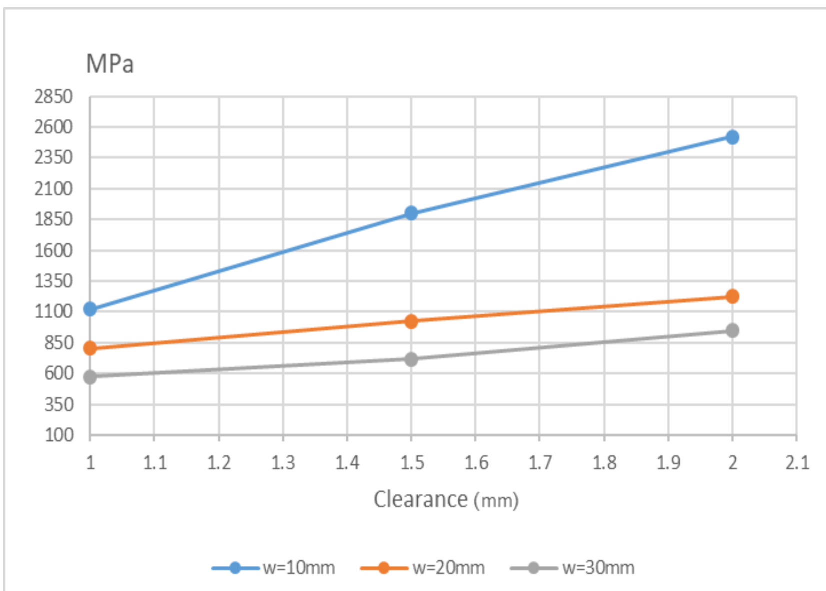

Figure 11: The effects of Clearance on the Tension in the Bending area when V=10 $^{mm}/_{s}$, Rp=8 mm, and RD=4 mm

Conclusion

In this experimental study, various samples and dies with different size were performed, whereby the springback of st12 steel sheets were examined. The results of the present study demonstrated that there was an inverse relationship between the springback and each of die radius, sample width and punch speed. Therefore, given the significant of speed punch in the bending design, this parameter should not be ignored because the accuracy of the final bending hinges upon the punch speed to a great extent.

Declarations

Availability of data and materials

The datasets generated during and or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The purpose of this article was to obtain a research credit to promote to associate professor.

Funding

Moreover, the article above has been extracted from the thesis of one of my master's students, and I, as his supervisor, incurred part of the costs.

Author's contributions

More to the point, data collection was done by the students and I personally translated and edited the required material.

Acknowledgments

Not applicable

Author's information

Furthermore, as a faculty member in the Department of Mechanics at Islamic Azad University of Kermanshah, I have supervised many theses about Springback.

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