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Evaluation of the sensitivity of springback to various process parameters of aluminum alloy sheet with different heat treatment conditions

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A B S T R A C T

The forming steps by permanent deformation controlled by the tools generate a distribution of stresses inside the material which directly depends on the work hardening properties of the latter. The change in boundary conditions following the removal of the tools imposes the material to redistribute the stresses in the sections in a manner compatible with the new boundary conditions. This new distribution necessarily operates by local elastic deformations that result globally in a general change of shape called springback. This geometrical deviation can be minimized by the meticulous focus of the tools, but it cannot generally be completely annihilated due to the influence of several parameters. For this reason, the study of the influence of the different technological factors and physico-metallurgical parameters on the springback for the different metals is very important to design and properly realize forming tools. The main objective of this work is to find solutions to problems encountered in sheet metal forming such as the problem of springback. Our work has two essential purposes: the first is summarized in an experimental study based on theoretical analyses. To this end, much effort is made to add a new design of parts for a U-type stretch-bending device and adapt it to a tensile testing machine. This design has the advantage of modifying and assembling all parameters affecting springback at the same time and also of carrying out several forming processes on the same device. The second goal is the experimental and numerical prediction of springback, and the study of the effect of various stretch-bending process parameters such as punch velocity, the orientation of the sheet (anisotropy), hold time and punch-die clearance on springback behavior under heat treatment of aluminum alloy sheets with three different rolling directions (0°,45°,90°). A finite element (FE) model of stretch-bending has been established by utilizing ABAQUS/CAE software. From this analysis, it can be concluded that the springback is affected by the anisotropy of the sheet and the heat treatment in the stretch-bending process. The obtained experimental results were compared with the numerical simulations found in good agreement.

1. Introduction

In sheet metal forming processes, springback is a major problem. It is an elastic recovery of internal stresses, after releasing the tool. Its quantification and elimination are necessary. However, springback is sensitive to many factors. These factors are related, on one hand, to the shaping process and, on the other hand, to the sheet itself. Numerous works have been proposed in the literature to characterize the springback of thin sheets. Cho et al. (2003) investigated the effect of some parameters such as punch and die corner radii, punch-die clearance, and coefficient of friction on spring-back in the U-die bending process using the finite element method (FEM). Tekaslan et al. (2006) have studied factors such as sheet

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thickness, holding time, and material that affect the springback through the experiment. Also, Vasudevan et al. (2011) investigated the influence of process parameters such as coating thickness, the orientation of the sheet, punch radius, die radius, die opening, punch velocity, and punch travel on springback behavior during air bending of electrogalvanised steel sheet. It is found that the springback increases with increasing of all these parameters. Moreover Buang et al., (2015) conducted experiments in the air V-die free bending process of stainless steel sheet metal to study the effect of the die and punch radii on the springback. They conclude that springback decreases as die and punch radii decrease. Krinninger et al. (2016) presented experimental investigations on the free bending process of two steel materials, to study important parameters affecting the springback. They found that large bending radii in combination with large bending angles cause an enormous springback compared to small bending angles and radii, and the influence of the punch velocity should not be neglected in the design process of bending tools, otherwise, the required dimensional accuracy cannot be realized. Also Karaağaça (2017) by using the flexforming process for V-bending of AL1050-0 and AL5754-0 sheet metal materials is experimentally investigated the effects of forming pressure, die angle and holding time on the springback behavior, It was determined that die angle and holding time significantly influenced the springback. An experimental prediction of springback of aluminum-magnesium alloy 5083-H111 at cold and warm temperature has been proposed by Ozturk et al. (2009) to see the influence of temperature on the springback behavior, the results showed that the springback decreases with the increase of temperature. Also Sarikaya (2008) analyses the effect of heat treatment on springback in V-bending process of aluminum, both experimental and numerical methods are used. It is found that the amount of springback depends on heat treatment mode. Verma (2016) investigated the effect of warm forming process parameters on springback of three aluminum alloys. The results revealed that springback decreased when the temperature was increased from room temperature to 250°C. Wan-Nawang et al. (2015) carried out experimental studies on the effects of various parameters such as the thickness of the sheet, force applied, material rolling-direction, and holding time during the sheet-deformation on springback in bending of w-shaped micro sheet-metal parts. To evaluate the springback effect, Gite et al. (2016) presented a finite element analysis followed by experimental validation. Various parameters such as die valley angle, punch nose radius, depth of deformation, etc. are considered to evaluate the springback effect. Slota and Jurčišin (2012) showed an experimental and numerical prediction of springback in the v-bending process of anisotropic sheet metal. Experimental and numerical studies of the effects of significant parameters including sheet thickness, sheet anisotropy and punch tip radius on springback/springgo in U-die bending processes of three different sheet materials have been conducted by Shah et al. (2011). Younis and coworkers (2013) performed a numerical analysis to find the optimum parameters that reduce the springback in the U-die bending. The obtained results showed that the punch speed, the direction angle rolling, and the dwell time have a greater impact on spring back. Moreover Abed (2013) applied the Taguchi method to find the optimum bending parameters (punch speed, hold time and the orientation of material) to get the lowest springback on aluminum-silicon (Al-Si) alloy. The results show that the significant factor is the orientation of metal followed punch speed, and hold time. Additionally, Abed (2012) investigated the effect of hold time on the springback phenomenon in a V- dies bending process. Ahirwar and Jain (2017) examined the effect of different clearances between the punch and die on spring-back of steel sheet material with different thicknesses and variable blank holder force. It is observing that the springback increases when the clearance between punch and die increases. Lu and Huang (2012) have conducted experimental and numerical studies to investigate the effect of compressive pressure and punch radius on spring-back for aluminum alloy. It is shown that springback decreases as the ratio of the average pressure and tensile strength increases when the ratio is small; springback increases slightly as the radius of the punch increases from 8mm to 16mm. To find the optimum parameters that reduce the springback. Choudhury and Ghomi 2(014) studied the effect of various process parameters such as the bending angle, sheet thickness, material type, material texture, punch speed, punch holding time, sheet width, punch radius, lubrication, warm working, and repeat bending, on springback of an aluminum sheet in V-bending operation. The punch holding time, material type, and lubrication were found to be the most significant factors affecting springback.

This work aims to study the springback behavior of aluminum alloy sheets during the stretch-bending process with three different rolling directions (0°,45°,90°). The experimentation has done to analyze the influence of various parameters such as the orientation of the sheet, hold time, heat treatment, punch-die clearance, and punch velocity, on springback behavior. Both experimental and simulation methods are used.

2. Experimental investigation

2.1. Materials

Due to the property of lightweight, very high strength, and corrosion-resistant of the aluminum alloy, the latter has several uses in different fields and has considerable importance in many industries such as mechanical engineering, automotive, and aeronautics. The latter has been chosen as study materials. Aluminum alloy sheet (AL5086-H111) with a thickness of 0.8 mm was used in this study. The chemical composition of this aluminum alloy is shown in Table 1. The samples (sheets) are cut into rectangles in three different directions (0°, 45 °, 90 °) relative to the rolling direction.

Table 1. Chemical composition of the testing material (in wt.%)

Si	Fe	Cu	Mn	S	Ca	Mg	Al
0.534	**0.386**	**0.0228**	**0.172**	**0.0749**	**0.0868**	**3.72**	**95.0**

2.2. Tensile test

Tensile tests were conducted to determine the mechanical properties of materials (Table 2 and Table 3) which were prepared according to the ISO 6892-1:2009(E) standard. The specimens were produced by wire cutting A Zwick Roell tensile test machine was used for all the experimental work and this is shown in Fig.1. This machine has a load capacity of 50 kN. The cross-head velocity can be varied from 0.0005 to 180 mm/min. A dedicated computer, installed with specialist testing software, controls the machine functions, and captures the data required. One of the main aims of this study is to investigate the influence of heat treatment on springback, for this purpose half of the specimens used to carry out this work are underwent an annealing heat treatment. This treatment improves the mechanical properties of the material and relieves residual stresses, and it is ranging from 20°C to 200°C for 1 hour to show the influence of this heat treatment on the springback. In order to characterize the anisotropic behavior of the aluminum alloy sheet, uniaxial tension tests were conducted on samples with and without annealing heat treatment in the rolling direction (0°), transverse direction (90°) and at 45° from the rolling direction.

Fig.1. Zwick Roell tensile test machine used for testing

Table 2. Elastic mechanical properties

Density (g/cm3)	Young's modulus (GPa)	Poisson's ratio
2.70	71.7	0.31

Table 3. Uniaxial tension test results

Test condition	Yield strength (MPa)	Ultimate strength (MPa)	% Elongation	r value
0° – 20°C	136.8	260.8	21.9	0.71
45°– 20°C	135.4	262.4	25.7	0.99
90° – 20°C	138	275.4	20.2	0.69
0° – 100°C	146.4	250.2	27.8	0.60
45° – 100°C	134.7	244.8	29.4	0.87
90° – 100°C	139.6	242.3	21.8	0.62
0° – 200°C	117.2	149.3	36.75	0.58
45° – 200°C	113.6	138.6	39.5	0.82
90° – 200°C	112.8	139.0	34.7	0.60

2.3. Springback after stretch-bending

2.3.1. Experiment

To investigate the springback behavior of the present aluminum alloy sheets, the experimental tests are carried out by the adaptation and the developing of a stretching-bending device which is designed and manufactured in LPMMM laboratory, Setif, Algeria (Soualem, 2013; Soualem and Hakimi, 2018) by adding the new design of punch and die, and also by the use of a Starrett-type displacement comparator which has fixed on the die and brought into contact with the specimen to detect the least displacement, on the traction machine. The new punch and die design are shown schematically in Fig. 2. The blank sheet is the rectangular shape with a 10.0 mm width and 200.0 mm length, and the longitudinal direction is the rolling direction. The device is composed of a punch, die, and blank holder as seen in Fig. 3, and no lubricant was applied between tools and sheets. The punch moved down 10.0mm to 23.0mm with the punch velocity varied between 3.0mm/min and 180.0mm/min to observe springback deformation. The test specimen is also shown in Fig. 4.

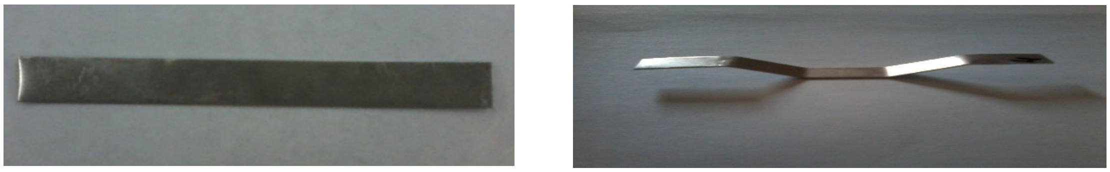
(a) (b)

Fig. 2. Schematic design of (a) punch and (b) die

Fig. 3. Picture of the experimental stretch-bending device

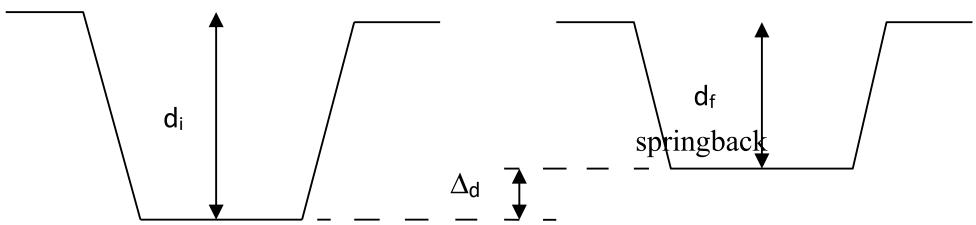
2.3.2. Springback measurement

The springback Δd is measured as a function of the drawing depth d_i (Ouakdi et al. 2012). The principle consists in measuring the depths at each stage (loading and unloading) i.e. the value Δd is given by the difference between d_i and d_f as shown in Fig.5. ($\Delta d = d_i - d_f$)



(a) (b)

Fig. 4. Specimen: (a) before and (b) after deformation

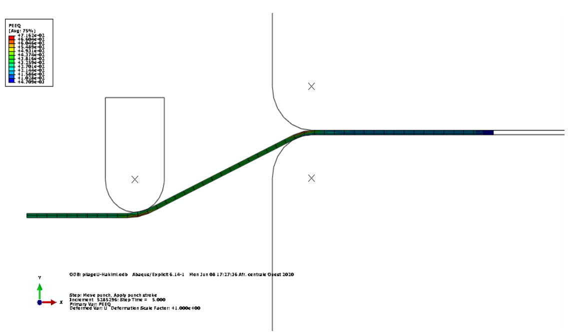


Final form of specimen before unloading final form of specimen after unloading

Fig. 5. Springback measurement.

2.3.3. FE simulation

For numerical modeling to be operational, it is necessary to choose a high-performance simulation tool such as the finite element code. The numerical simulation of the stretch-bending process (dynamic analysis) is performed by using a finite element code ABAQUS\Explicit, while the springback analysis (static analysis) is simulated in ABAQUS\Standard.



(a) (b)

Fig. 6. Simulation of : (a) stretch bending process and (b) Stress distribution in the blank sheet before tooling removal

The obtained results for the springback have been compared with experimental results. The simulation was carried out at different hold times, clearance between punch and die, the orientation of the sheet and velocity with different heat treatment, and without heat treatment. To give the mechanical properties of the material, different tensile tests with and without heat treatment are performed. The important dimensions are: blank 220×20×0.8 mm, die radii = 8 mm, punch radii= 6 mm, clearance between die and punch varied between 9 to 26 mm, blank holder force = 10kN. Linear quadrilateral elements of type

CPE4R with 5 integration points are employed to model the deformable body (blank), and the kinematic method is employed to treat the contact between tools and blank. Due to the symmetry, the numerical analysis of the stretch-bending process was performed by using only half of the 2D numerical model to reduce the computational time. The model is shown in Fig. 6.

3. RESULTS AND DISCUSSIONS

3.1. Effect of the punch velocity

The influence of punch velocity on springback value is studied in this part. In the finite element simulations and the experiment, the punch velocity is varied from 3, 20,100, and 180mm /min, respectively. The obtained results through simulations and experiments of influence of punch velocity to springback of aluminum alloy were shown in Fig. 7 and Fig. 8, respectively.

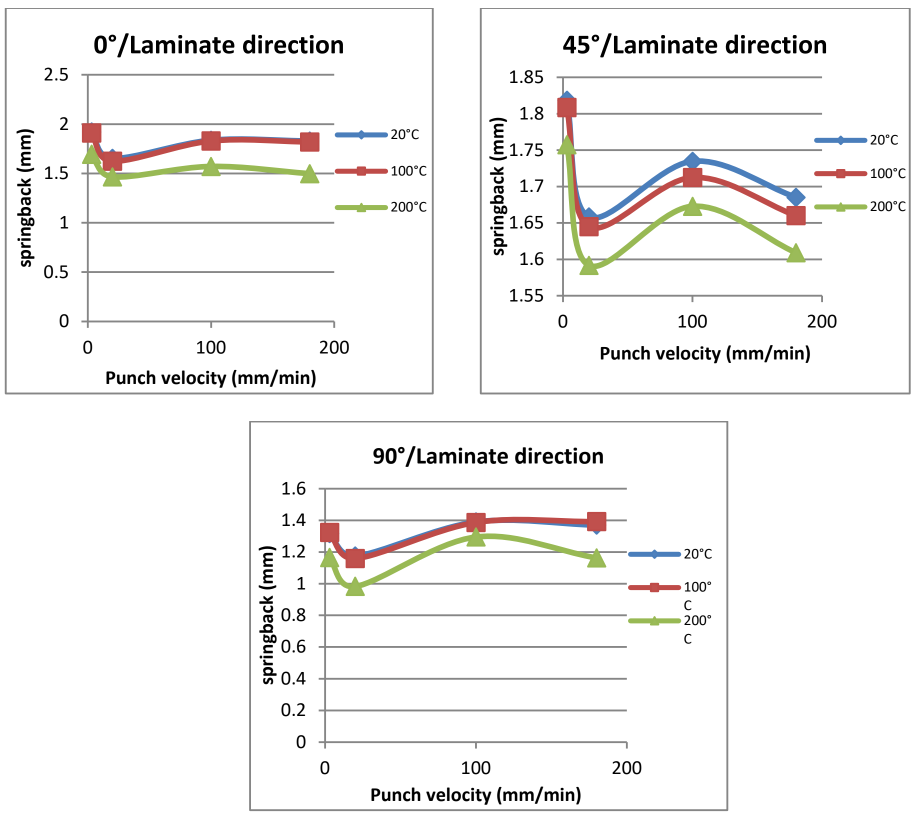
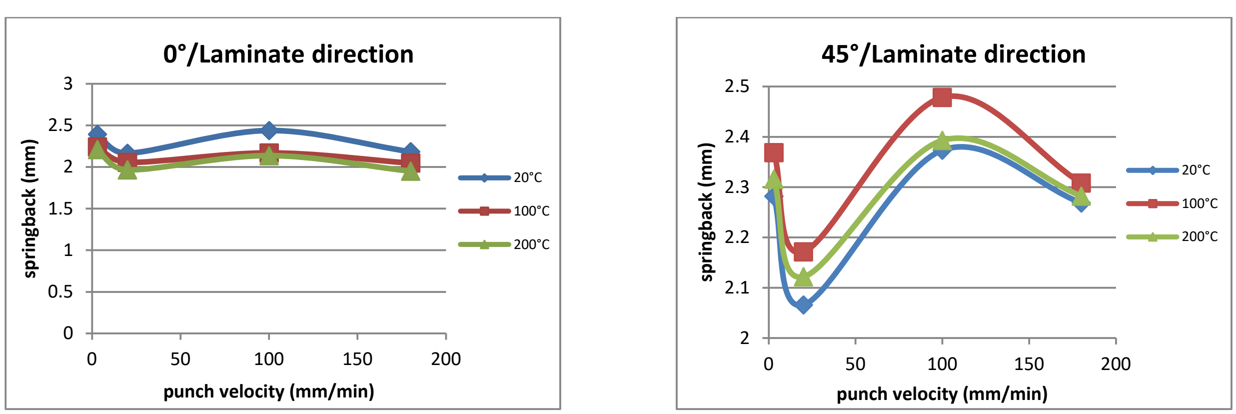


Fig. 7. Numerical results of springback versus punch velocity for different rolling directions and different annealing temperatures.



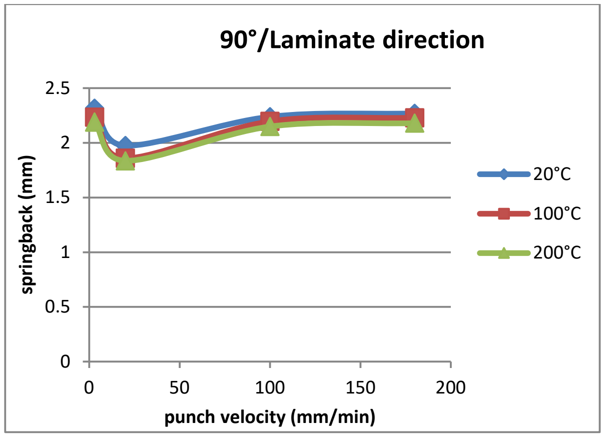


Fig. 8. Experimental results of springback versus punch velocity for different rolling directions and different annealing temperatures

Indeed, it can be observed that the springback value does not change much as the punch velocity increases and decreases as the annealing temperature increases, and this for all the values of punch velocity. Also, it is observed that the springback values are about the same at 20° and 100° and decreased beyond 200° (Ozturk et al. 2009). It is noted that the punch velocity has a limited effect on the springback for the three directions relative to the rolling direction respectively 0°, 45 °,90 °, This may be due to the small punch velocity (Liu et al. 2018). Thus, in the following, we will use the same punch velocity.

3.2. Effect of the punch-die clearance

Fig. 9 and Fig. 10 illustrate the relation between the punch-die clearance and springback for the three different directions of the sheet.

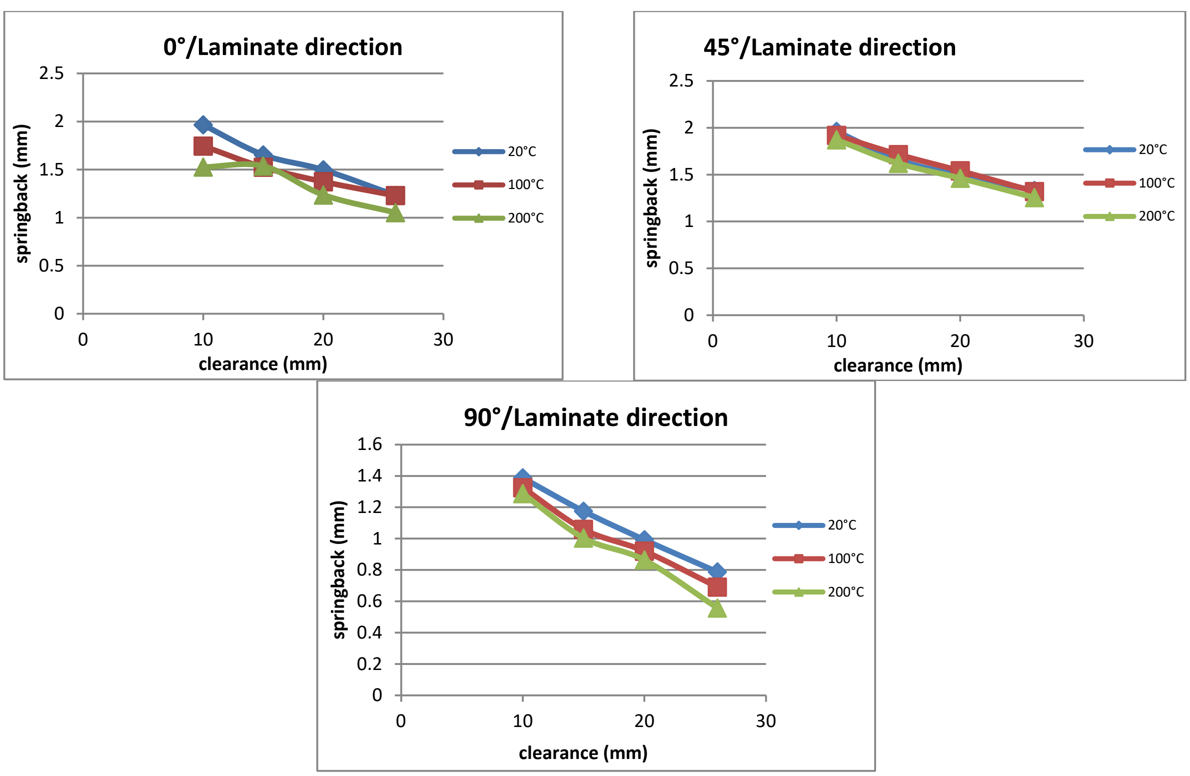


Fig. 9. Numerical results of springback versus die-punch clearance for different rolling directions and different annealing temperatures

It shows that the springback value is maximal in the direction 0°, and it decreases for the directions 45° and 90°. This variation may be due to the variation in the mechanical characteristics (Young's modulus, yield strength, and mechanical strength in general) of the specimen in all three directions. These findings are corroborated by the results of the tensile test (see Table 3), which showed that Young's modulus increases in the 90°, 45°and 0° directions respectively, and as indicated in the theory and previous work (Carbonnière, 2009; Ragai et al., 2005), the increase in Young's modulus causes a decrease in springback. The increase in the curves can be explained by the fact that the clearance has increased, the plastic deformation becomes more important and consequently, the springback will be decreased. Additionally, it can be noticed that with increasing the temperature, the amount of springback is decreased. The simulation and experiment results show that the difference between them is acceptable.

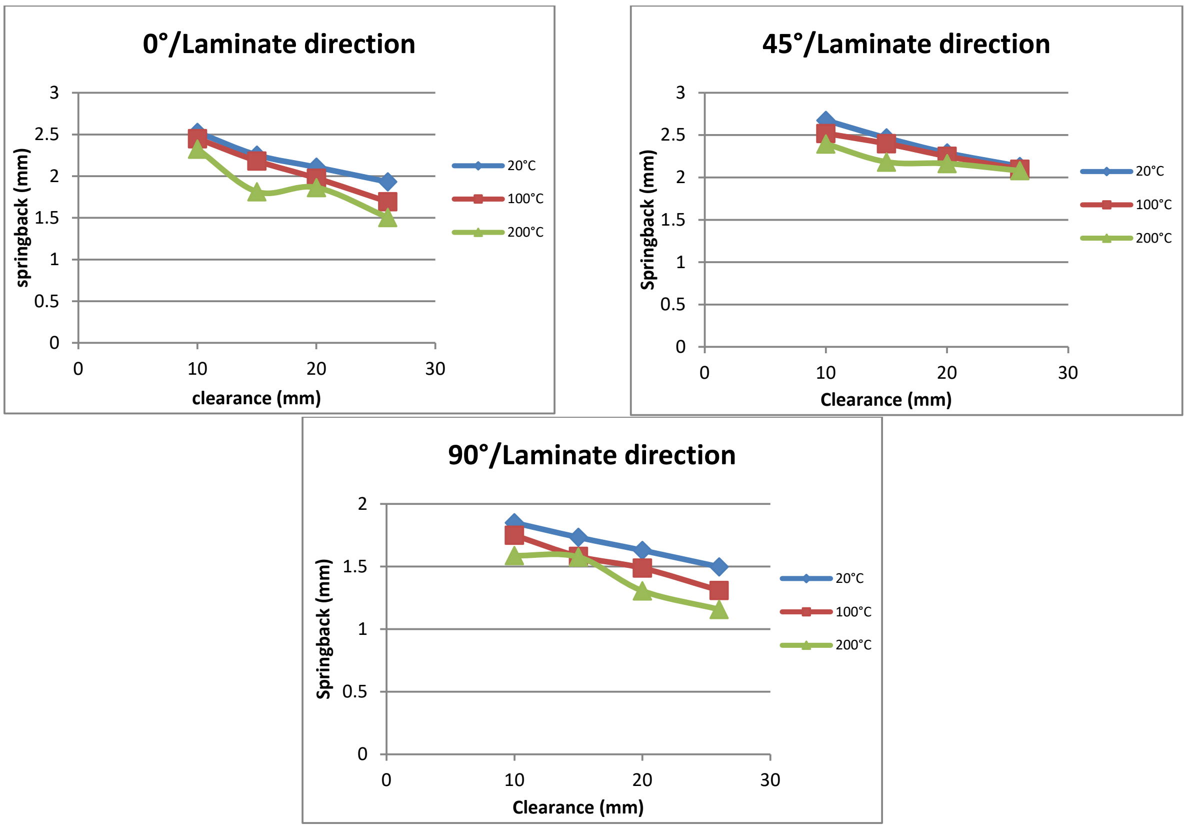


Fig. 10. Experimental results of springback versus die-punch clearance for different rolling directions and different annealing temperatures

3.3. Effect of the hold time

To investigate the effect of the hold time on springback value, different values of hold time are used (the 30s, 1min, 3min, 5min, 10min, and 20min). Fig. 11 and Fig. 12 demonstrate the relationship of sheep between hold time and springback. The general appearance of the curves reveals that there is an important fall to the point where the springback takes a minimum value with a holding time of 20 min in all the rolling directions. It may be concluded that while the hold time increasing, the springback decreased. As may be seen, this effect is due to the relaxation of material and that proved by previous studies (Younis et al., 2013; Abed, 2013). It is shown that in Figs. 11 and 12, FEM results are in good accordance with the experiment results.

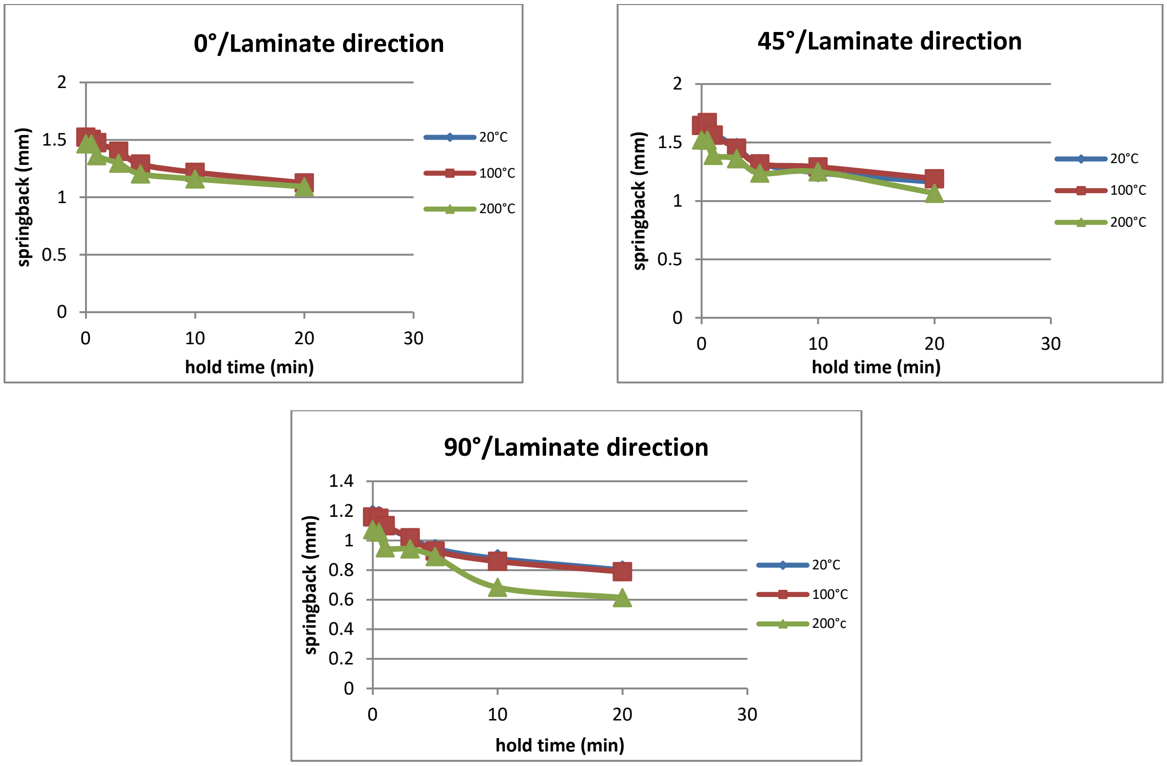


Fig. 11. Numerical results of the effect of the hold time on the springback for different rolling directions and different annealing temperatures

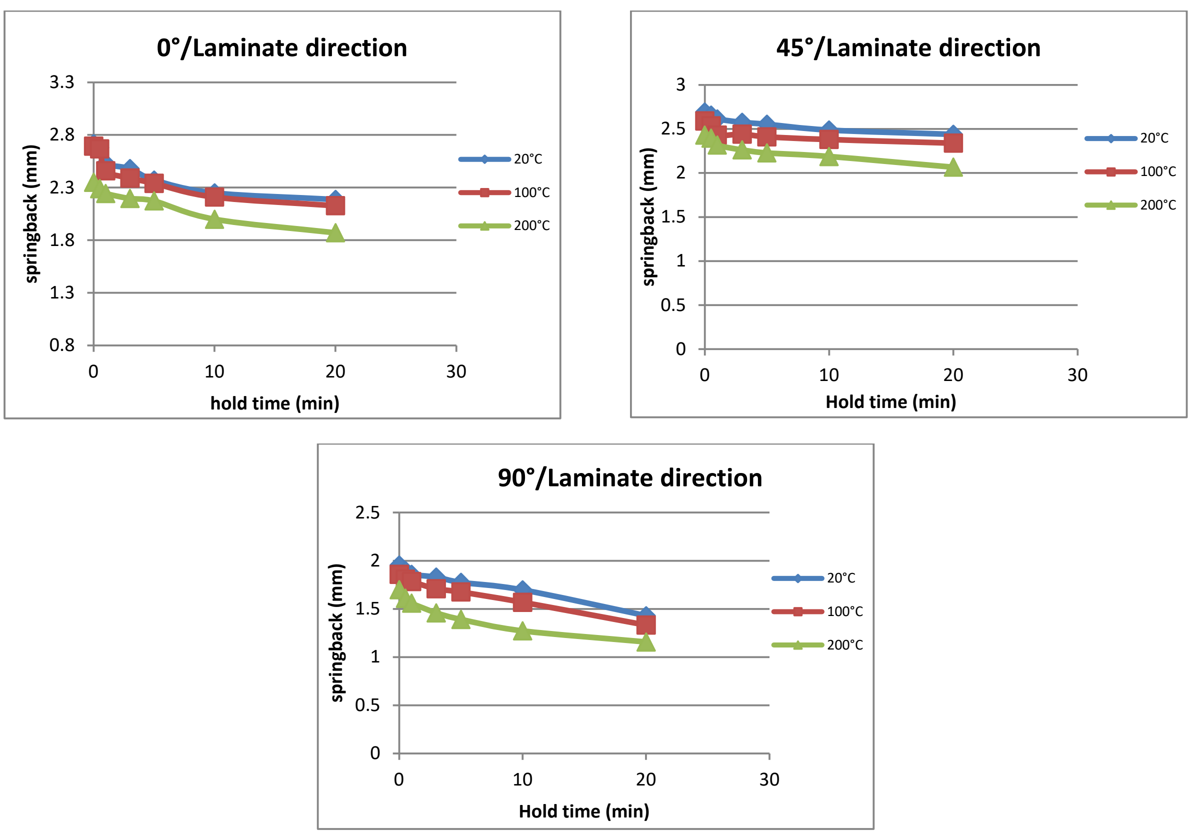


Fig. 12. Experimental results of the effect of the hold time on the springback for different rolling directions and different annealing temperatures

4. Conclusion

In order to measure the springback, many parameters are considered (such as, mean orientation of the sheet or anisotropy, punch velocity, clearance between punch and die, hold time, and heat treatment. The main conclusions, which can be made from the present study are:

-For the anisotropy of the springback where the specimens are cut through three different directions of rolling: 0°,45°,90° of laminated direction. Under this test, the springback decreases differently under these three directions. Thus, the anisotropy has a greater impact on springback.

- Meanwhile, punch velocity is a significant parameter, but it is necessary to take higher values to see their influence on the springback.
- Increase the punch-die clearance causes a increase in the springback value.
- Increasing the hold time causes a decrease in the springback value.
- It may be concluded that also the temperature has a greater impact on springback. Indeed, when the temperature increases, the springback is decreased.

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References

Abed, A. H. (2012). The Effect of Hold Time on the Spring Back Phenomenon in a V-Dies Bending Process. *Engineering and Technology Journal*, *30*(19).

Abed, A. H. (2013). Determination of the Optimal Spring-back Parameters using TAGUCHI Method. *Al-Qadisiyah Journal for Engineering Sciences*, *6*(1), 53-61.

Ahirwar, R. K., & Jain, A. K. (2017). Experimental study of wear in sheet metal during various forces. *International Journal of Research-GRANTHAALAYAH*, *5*(2), 162-167.

Buang, M. S., Abdullah, S. A., & Saedon, J. (2015). Effect of die and punch radius on springback of stainless steel sheet metal in the air V-die bending process. *Journal of Mechanical Engineering and Sciences*, *8*, 1322-1331.

Carbonnière, J. (2009). *Contribution à l'analyse du retour élastique en emboutissage* (Doctoral dissertation, Lyon, INSA).

Cho, J. R., Moon, S. J., Moon, Y. H., & Kang, S. S. (2003). Finite element investigation on spring-back characteristics in sheet metal U-bending process. *Journal of Materials Processing Technology*, *141*(1), 109-116.

Choudhury, I. A., & Ghomi, V. (2014). Springback reduction of aluminum sheet in V-bending dies. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, *228*(8), 917-926.

Gite, R.E., Phad, K.S., Bajaj, D.S. (2016). Springback effect analysis of bracket using finite element analysis. *International Advanced Research Journal in Science, Engineering and Technology*, *3*(1), 246-255.

Karaağaç, İ. (2017). The evaluation of process parameters on springback in V-bending using the flexforming process. *Materials Research*, *20*(5), 1291-1299.

Krinninger, M., Opritescu, D., Golle, R., & Volk, W. (2016). Experimental investigation of the influence of punch velocity on the springback behavior and the flat length in free bending. *Procedia Cirp*, *41*, 1066-1071.

Liu, Y., Wang, L., Zhu, B., Wang, Y., & Zhang, Y. (2018). Identification of two aluminum alloys and springback behaviors in cold bending. *Procedia Manufacturing*, *15*, 701-708.

Lu, H., & Huang, W. (2012). The Influence of compressive pressure in the thickness direction on spring-back for aluminum alloy. In *Advanced Materials Research* (Vol. 472, pp. 736-739). Trans Tech Publications Ltd.

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

Ozturk, F., Toros, S., Kilic, S., & Bas, M. H. (2009). Effects of cold and warm temperatures on springback of aluminium-magnesium alloy 5083-H111. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, *223*(4), 427-431.

Ragai, I., Lazim, D., & Nemes, J. A. (2005). Anisotropy and springback in draw-bending of stainless steel 410: experimental and numerical study. *Journal of Materials Processing Technology*, *166*(1), 116-127.

Sarıkaya, O. T. (2008). *Analysis of heat treatment effect on springback in v-bending* (Master's thesis).

Shah, J. R., Sharma, S. K., & Patel, B. C. (2011). Investigating Springback effect in U-Die Bending Process by varying different Parameters. In *Nirma University International Conference on Engineering. Institute of Technology, Nirma University, Ahmedabad* (pp. 1-6).

Slota, J., & Jurčišin, M. (2012). Experimental and Numerical Prediction of Springback in V-Bending of Anisotropic sheet metals for automotive industry. *Zeszyty Naukowe Politechniki Rzeszowskiej. Mechanika*, (84 [284], nr 3), 55-68.

Soualem, A. (2013). A Detailed Experimental Study of the Springback Anisotropy of Three Metals using the Stretching-Bending Process. *International Journal of Mechanical and Mechatronics Engineering*, *7*(1), 144-147.

Soualem, A., & Hakimi, S. (2018). Experimental Study and Prediction of the Springback under Heat Treatments for Anisotropic Sheet. *Experimental Techniques*, *42*(3), 253-260.

Tekaslan, Ö., Şeker, U., & Özdemir, A. (2006). Determining springback amount of steel sheet metal has 0.5 mm thickness in bending dies. *Materials & design*, *27*(3), 251-258.

Vasudevan, D., Srinivasan, R., & Padmanabhan, P. (2011). Effect of process parameters on springback behaviour during air bending of electrogalvanised steel sheet. *Journal of Zhejiang University-Science A*, *12*(3), 183-189.

Verma, R. (2016). *Effect of elevated temperature on mechanical behaviour and springback of aluminum alloy brazing sheets* (Master's thesis, University of Waterloo).

Wan-Nawang, W. A., Qin, Y., & Liu, X. (2015, August). An experimental study on the springback in bending of w-shaped micro sheet-metal parts. In *MATEC Web of Conferences* (Vol. 21).

Younis, K. M., Hamad, A., & Mansor, K. K. (2013). Study the optimization parameters for Spring back phenomena in U-die bending. *Engineering and Technology Journal*, *31*(9 Part (A) Engineering).