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STRESS STATE AND SPRING BACK IN V-BENDING OPERATIONS

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ABSTRACT

Bending is one of the most common metal forming technology and it can be applied not only in sheet metal forming but also in forming of wires, rods, strips, pipes and bars. However, in car production, ship building and home appliance manufacturing sheet metal bending is most widely employed. One of the most significant sheet metal bending operations is V – Die bending. This process consists of two phases: air bending and coining. At the end of the operation punch moves to the upper position. After unloading, due to elastic recovery, so called "spring-back" or "spring-forward" phenomena occurs.

Current paper elaborates negative spring back ("spring forward") and stress state in the deformation zone in V – Die bending operations of sheet metal of different thicknesses and different steel materials. Reasons for spring back phenomena have been clarified. Experimental investigation has been carried out as well as the measurement of workpiece bend angle after deformation. For stress analysis within the deformation zone numerical simulation was used. Bending operation has been conducted at Sack&Kiesselbach hydraulic press and angle measurement at Carl Zeiss CONTURA G2 RDS coordinate measuring machine. For FEM simulation Simufact Forming software was applied.

Key words*: Spring - back, stress state, bending*

1.0 INTRODUCTION

One of the most widely applied metal forming operation is bending. Materials with various cross–sections can be processed by this technology: sheet metal, bars, rods, pipes, wires. However, bending of sheet metal is most frequently used in industrial practice, first of all in car and ship building industry. There are different types of metal bending operations such as air bending, V – and U – die bending, roll bending, roll forming, press brake forming. Comprehensive review with theoretical background of most significant bending operations can be found in [1], [2]. Different aspects of bending have been elaborated in a number of papers.

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In [3] authors give extensive review of the possible computer application in sheet metal bending operations. They considered a number of segments related to the multi – sequences bending processes such as bend modeling, bend sequences, tool selection and optimization as well as ergonomic aspects of sheet metal forming. Special focus has been placed on collision detection between the punch and bent material. A newly developed reduced integration solid – shell element in the field of sheet metal forming is presented in [4]. By using the developed procedure, deep drawing and spring – back occurrence have been analyzed. Results were verified by experiment. V – Bending process of steel sheet and impact of die - geometry and process conditions on final bending results is explored in [2]. Numerical analysis and experimental investigation have been performed. Influence of every investigated parameter has been presented and analyzed.

In [5] authors investigated influence of process variables, such as punch and die radius, punch width and speed, friction coefficient, on punch load and on final shape of billets after unloading in V – die bending process. As a result it was found that with increasing punch radius and speed, punch load increases. Also it was concluded that punch load increases as lubrication decreases.

Experimental determination of spring – back in V bending was presented in [6]. Spring – back was determined for six different bending angles. An analytical model for prediction of spring back after V – bending is presented in [7]. In [8] application of finite element method in springback prediction of V bending process is emloyed.

Present paper elaborates experimental investigation of sheet metal V – bending operation. Different materials and thicknesses have been considered. Focus of the investigation has been placed on spring – back phenomena. Also, stress state in the deformation zone of the sheet workpiece has been determined and analyzed by numerical method.

2.0 SPRING - BACK PHENOMENA

After plastic bending, unloading takes place and punch removes from the workpiece to the initial position. Final shape of the workpiece after unloading differs from the punch /dies configuration in closed position. Occurrence of this difference is called “spring back”. In fig. 1 bent material is shown in two positions: a) bent and closed in the die (angle α_i) and b) after unloading (angle α_f). As it can be seen, after unloading bend angle is smaller than when being closed in the die ($\alpha_i > \alpha_f$).

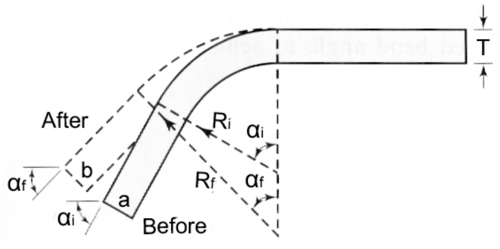


Fig.1 - Ilustration of spring – back phenomena [2]

Springback characterization is expressed by springback ratio (factor) K:

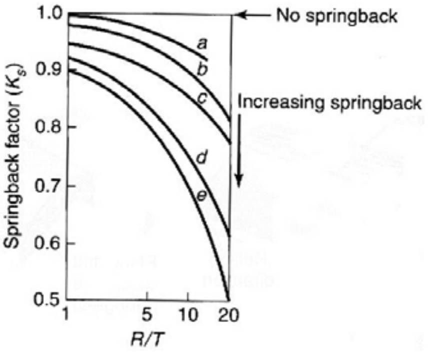
$$K = \frac{\alpha_f}{\alpha_i} \tag{1}$$

α_f – bend angle after unloading
α_i – bend angle - workpiece is closed in the die

From (1) is evident that in case K = 1 there is no spring back ($\alpha_i = \alpha_f$) and in case K = 0 complete elastic recovery of the bent material takes place ($\alpha_f = 0$).

In the diagram (Fig. 2) springback factor K is given for different materials, as a function of material thickness and final bend radius (R). From this diagram it can be concluded that materials with higher hardness characterize lower factor K and vice versa.

Occurrence of spring back and negative springback phenomenon is very complex to predict, as it depends on a number of parameters such as material properties (elasticity, yield stress, hardening properties), bending load, material thickness, die geometry, etc.



a – 2024-0 and 7075-0 aluminum

b – austenitic stainless steels

c – 2024-T aluminum

d – ¼- hard austenitic stainless steels

e – ½- hard to full – hard austenitic stainless steels

R/T – radius / thickness ratio

Fig.2 *- Spring – back faktor K for various materials [2]*

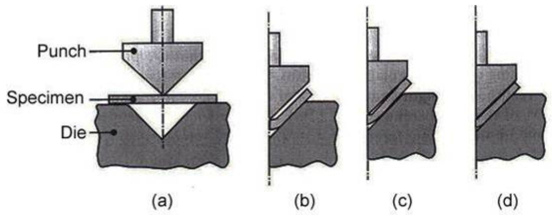


Fig.3 *- Schematic illustration of stages in bending by V – dies [2]*

In V-bending operation so called “negative spring back” can occur. This means that bend angle becomes smaller then angle after unloading ($\alpha_i<\alpha_f$) - according to Fig.1. This phenomenon can be explained by following consideration: V-bending consists of two distinct phases, air (free) bending and coining (Fig. 3). In the phase “c” the arms (ends) of the material which were free in the phases “a” and “b” touch the punch which bends them outward. This continues to the end of the process. As a result of this, unloading material will spring back inwardly.

3.0 EXPERIMENTAL INVESTIGATION

Experimental work was conducted in Laboratory for Technology of Plasticity, Faculty of Technical Science, Novi Sad. V – die bending was performed on Sack&Kiesselbach hydraulic press with 6,3MN rated force. Workpieces were sheet plates made from three different steel materials. Experiment was conducted in 3 series. For each series different steel materials, FePO1 (Č0146), X6Cr17 (Č4174), BRM2 (Č7680) and sheet thicknesses were applied. For series 1 and 2 thickness was 0.8mm, 1mm and 1.25mm. For series 3 thickness was 0.6mm, 0.9mm and 1.2mm. Two workpieces of each material and sheet thickness are used for experimental investigation. No lubricant was applied.

Table 1: Sheet samples used in experiment

Series	***Material***	***Workpiece***	***Dimensions of sheet plate [mm]***	***Thickness [mm]***
Series 1	FeP01 (Č0146)	A-0.8	100x58	0.8
		A-1	100x58	1
		A-1.25	100x58	1.25
Series 2	X6Cr17 (Č4174)	B-0.8	100x58	0.8
		B-1	100x58	1
		B-1.25	100x58	1.25
Series 3	BRM2 (Č7680)	C-0.6	100x58	0.6
		C-0.9	100x58	0.9
		C-1.2	100x58	1.2

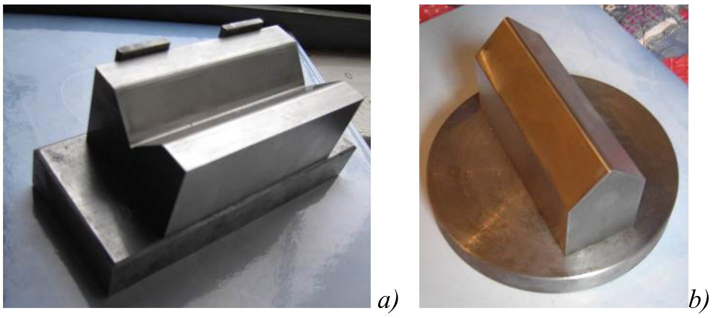


Fig.4 *- Bending die (a) and punch (b) used in experiment*

Table 2: Dimensions of bending die and punch

	Angle [º]	***Radius [mm]***
Punch	89º58'	2.8921
Bending die	89º58'	5.3735

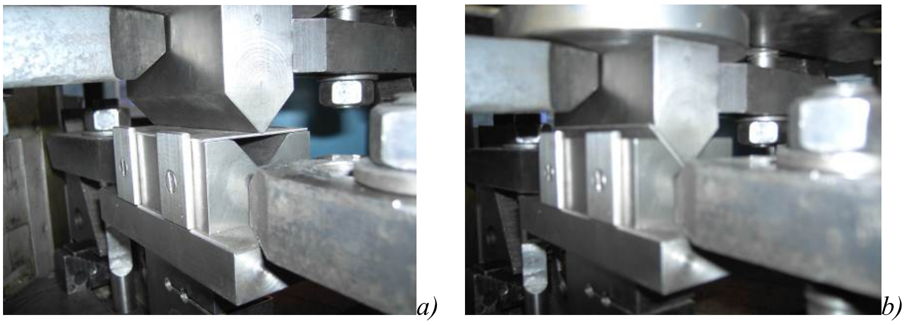


Fig.5 *- Beginning (a) and end (b) of the process*

Die and punch used in experiment are shown in Fig. 4, and dies with workpiece (plate) in initial and final position are depicted in Fig. 5. In table 2 dimension of die and punch are given.

In Fig. 6 sheet plates after deformation are shown. For each series one deformed workpiece is presented.

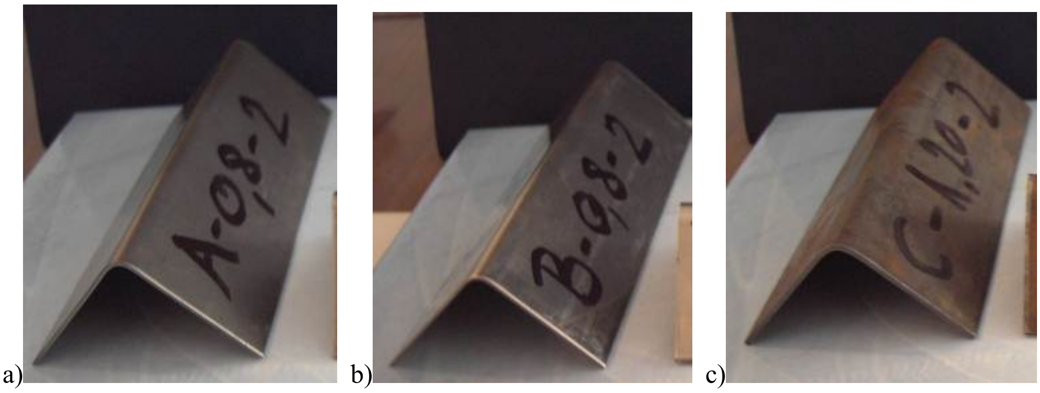


Fig.6 *- Sheet plates series 1 (a), series 2 (b) and series 3 (c) after deformation*

4.0 ANGLE MEASURMENT

Angle measurement was conducted on Carl Zeiss CONTURA G2 RDS coordinate measuring machine in Metrology Laboratory at Faculty of Technical Science, Novi Sad.

According to new generation of geometrical product specification (GPS), angle between features (two planes) was measured by the method that is in accordance with the directly tolerated angle dimension [9]. Directly tolerated angle dimensions are the difference between the maximum and the minimum permitted angular size. In this case, angle with nominal value of 89º58' was measured and deviation from the nominal value is shown in angular dimensions. Coordinate measuring machine (CMM) is used for measuring of real angle between planes, as mentioned above, (Fig. 7). The measurement was carried out in strictly controlled laboratory conditions.

***Fig.7** - Angle measurement*

Maximum permissible error for size measurement (MPE_E) of this CMM is $1.9 + L/330 \mu m$. Coordinate metrology use probing system which detects points on the surface of the workpiece. These points are used to reconstruct features. Result of the measuring angle depends on the orientations of the planes in relation to the workpiece coordination system. The factors which influence the orientation of the considered planes are: sampling strategy – sampling size and sample point locations, evaluation strategy and form deviations. The selected sampling strategy is most important strategy since it enables to make valid inferences regarding dimensions of a workpiece.

Table 3: Measurement results

Material	***Series***	***Workpiece***	***Angle [º]***
FeP01 (Č0146)	Series 1	A-0,8-1	89°49'
		A-0,8-2	89°26'
		A-1-1	88°49'
		A-1-2	88°02'
		A-1,25-1	89°35'
		A-1,25-2	89°49'
X6Cr17 (Č4174)	Series 2	B-0,8-1	88°40'
		B-0,8-2	88°58'
		B-1-1	88°01'
		B-1-2	88°03'
		B-1,25-1	89°37'
		B-1,25-2	88°51'
BRM2 (Č7680)	Series 3	C-0,6-1	89°19'
		C-0,6-2	89°21'
		C-0,9-1	89°44'
		C-0,9-2	89°37'
		C-1,2-1	89°57'
		C-1,2-2	89°24'

In order to obtain extracted presentation of the workpiece geometry, the sampling strategy consisted of 50 discrete measurement points are uniformly arranged on the workpiece surface. For obtaining associative geometry (perfect form) evaluative method of minimum zone (MZ) is used. Software analysis of two associative planes provides the real value of bending angle. Table 3 presents results of the angle measurement for all investigated cases.

5.0 STRESS STATE IN BENDING ZONE

For stress state determination numerical analysis was applied. SimufactForming V10 program package was used for that purpose. In Fig. 8 constellation of the specimens and tooling elements at the beginning and at the end of simulation is shown. Numerical analysis was employed for steel FeP01 (Č0146) specimens. Specimens with three different thicknesses were used. Dimensions of the specimens were equal to those in experiment (table 1, series 1).
Upper and lower dies used in simulation were set as rigid bodies. Press velocity was 0.1mm/s. The dies were modeled in CAD package SolidEdge V18 and then imported in to the SimufactForming program. Advancing Front Quad with 0.1mm size elements were applied. Friction coefficient in simulation was 0.15. Stress strain curve of the material FeP01 (Č0146) was:

$$\sigma = 198,5 + 394,26 \cdot \varphi^{0,407} \tag{2}$$

Comparative view of force – stroke diagram obtained in experiment and simulation, for three different sheet thicknesses is presented in Fig. 9. As it can be seen, in the end of the process, force obtained in simulation is higher than force obtained in experiment in case of bending sheet specimens with 0.8mm and 1mm thickness. In case of bending of specimens with 1.25mm thickness force occurred in the end of experiment is higher than force obtained in simulation.

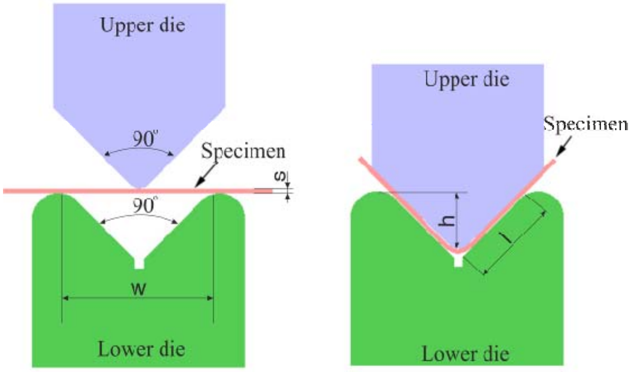
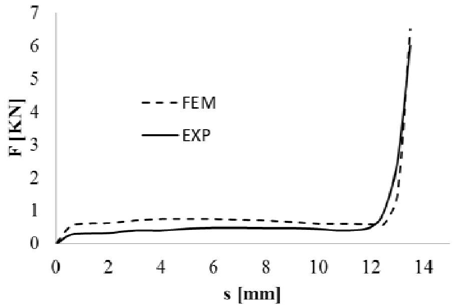
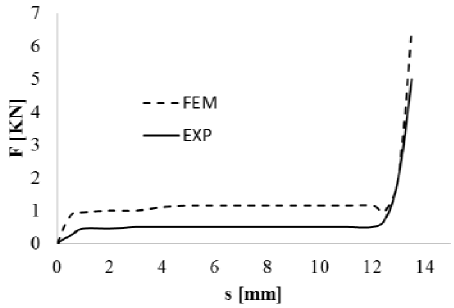


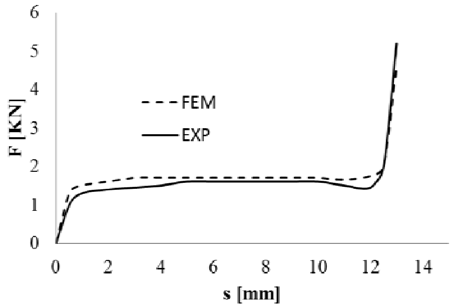
***Fig. 8** – Simulation process*



a) Thickness 0.8mm



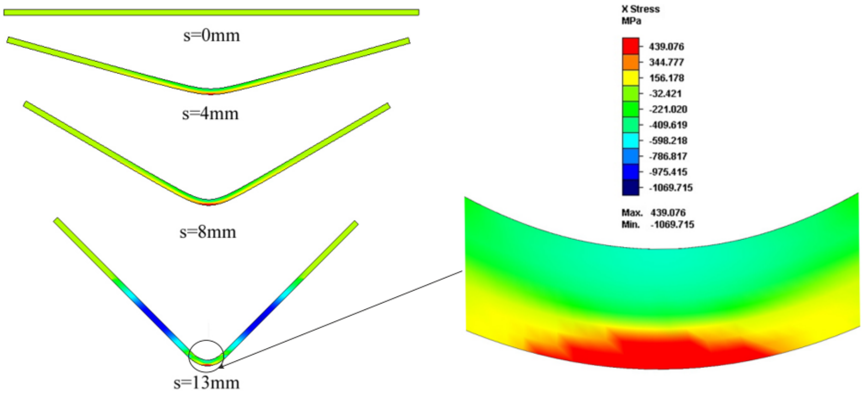
b) Thickness 1mm



c) Thickness 1.25mm

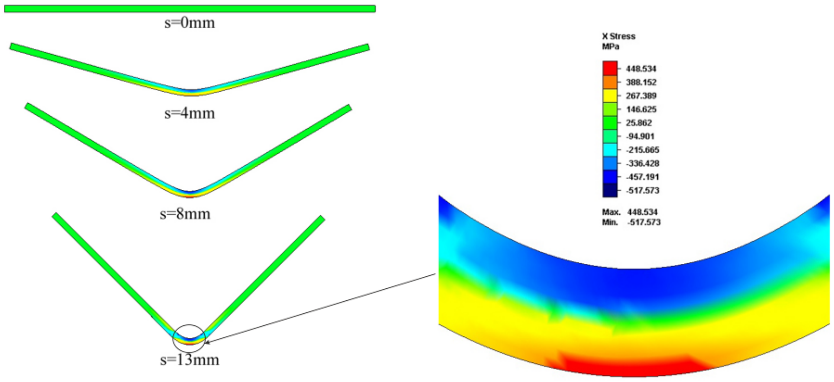
Fig.9 *– Force – stroke diagram*

In Fig. 10 bending process for three different types of sheet workpieces is presented. Fig. 10a presents workpiece shape in different bending phases of the process. Distribution of stress in bended zone trough complete intersection of workpieces is presented in Fig. 10b. At the inside surface of the specimen (contact surface between upper die and sheet specimen) negative (compressive) stresses occurred. Positive (tensile) stress appeared on the outer side of the specimen. Values of maximal tensile and compressive stresses in bending zone, depending on die stroke, are presented in Fig. 11.



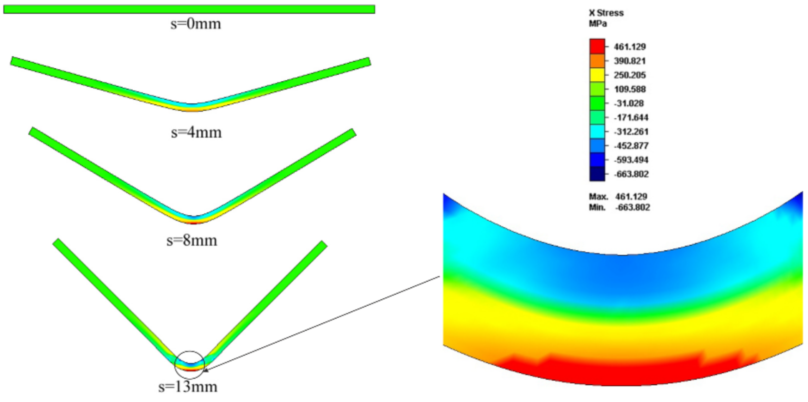
a) *b)*

Thickness 0.8mm



a) *b)*

Thickness 1mm



a) *b)*

Thickness 1.25mm

Fig.10 *– Stress distribution for three different sheet thicknesses*

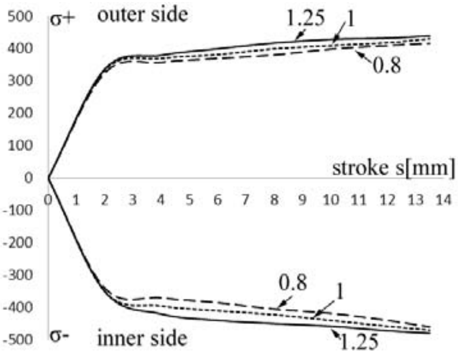


Fig. 11 *– Values of maximal tensile and compressive stresses in bending zone*

6.0 DISCUSSION AND CONCLUDING REMARKS

Elastic recovery (so called »spring back«) during unloading in sheet bending operations is one of the main features of this process and it has direct influence on the product accuracy. The knowledge of the spring back values is essential for die design and process planning.

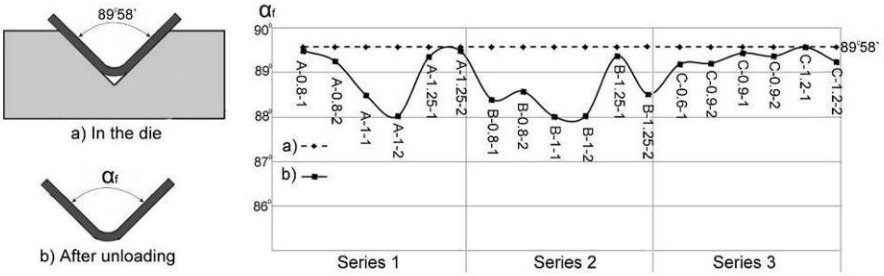


Fig.12 *- Measured angle values after unloading*

Current paper presents some preliminary results of the V- Die bending operation with the focus on spring back phenomena. Sheet plates of three different materials and thicknesses were applied. Punch angle and bending die angle were 89º58'. Object of investigation was to measure and analyze a spring back value which occurs in bending operations. Results are presented and shown in Fig. 12. It should be noted that angle denotation in Fig. 1 and Fig. 12 are contra wise (reversed).

Fig. 12 presents difference between punch and bending die angles (89º58`) and angle after unloading (α_f). It can be concluded that in all series, angle between two planes (arms) after unloading is smaller than angle of bending dies, which means that negative spring – back takes place. This difference is in the range from 1' to 1°57' and most noticeable for series 1 and 2. For series 3 (high steel specimens) smallest values of negative spring back were measured. Also, it can be concluded that sheet thickness does not affect spring – back significantly.

Stress distribution in bending zone for three different sheet thicknesses depending on die stroke is presented in Fig. 11. As it can be seen, there is no significant difference in values of stress for different sheet thicknesses.

ACKNOWLEDGEMENT

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NAPONSKO STANJE I ELASTICNO VRAĆANJE PRI SAVIJANJU LIMA V-ALATIMA

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REZIME

Savijanje je najčešće primenjivana operacija deformisanja i može se koristiti kako za savijanje lima tako i za savijanje žica, cevi, šipki. Međutim, u auto industriji i brodogradnji savijanje lima je najrasprostranjenije. Najznačajnija operacija savijanja je savijanje sa V alatima. Nakon izvršenog procesa savijana alat se vraća u početnu poziciju. Nakon rasterećenja, zbog pojave elastičnog vraćanja dolazi do pojave negativnog ili pozitivnog ugla elastičnog vraćanja.

U ovom radu je ispitivan negativni ugao vraćanja kao i naponsko stanje u slučaju savijanja lima različitih materijala i debljina V alatima. Obrazloženi su i razlozi negativnog ugla elastičnog vraćanja. Operacija savijanja je sprovedena na hidrauličnoj presi dok su merenja ugla savijanja izvršena na koordinatnoj mernoj mašini Carl Zeiss CONTURA G2 RDS. Za numeričku simulaciju je korišten program SimufactForming.