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Effect of Cross- Rolling on Mechanical Properties and Spring - Back of Aluminum 6061 Alloy

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ABSTRACT

The Cross-Rolling (CR) process is a severe plastic deformation technique that was used to roll aluminum alloy 6061. However, this process is accompanied by many disadvantages, such as spring back due to elastic recovery. This research aims to investigate the effect of cross-rolling on the spring back phenomenon by examining the main parameters that affect the forming process. Two different routes of cross-rolling were used: the first route, called two-step cross-rolling (TSCR), and the second, multi-step cross-rolling (MSCR), were employed to achieve high deformation and superior mechanical properties. The samples were bent using the V-bending process at three different speeds (5, 10, and 15 mm/min). The results showed that the rolling route and the change in cutting direction led to increased plastic deformation, thus increasing the spring-back factor. The type of route and cutting direction significantly impacted both the maximum load and the springback results.

1. Introduction

In recent years, sheet forming has grown in significance in industrial production. Finding a simpler method for mass production is essential. Cross rolling can reduce the directional dependence of many features of the rolled plate [1]. The cross-rolling process is effective to randomize lattice orientation distributions. Comparing conventional cold rolling and cross-rolling processes, cross rolling accelerates brass-type texture evolution of aluminum alloys, which is favorable for improving formability.

Furthermore, for cross-rolling process is severe plastic deformation, high stored energy realized in the materials, which can be seeds for granular and small sized grains by recrystallization at annealing states. As a result, plastic anisotropy is effectively suppressed by the cross-rolling process, offering great flexibility in manufacturing components [2, 3]. The sample is rotated 90 degrees around the normal direction (ND) on the rolling plane. The stages of cross rolling are not standardized [4]. Cross-rolling can affect the properties of a material; these include changes in residual stress distribution and plastic anisotropy, micro structural alterations, and changes in crystallographic texture [5-7]. Shin et al. created a sheet SPD method in 2002 using alternate pressing with grooved and flat dies. The constrained groove pressing process involves recurrent shear deformation under plane strain deformation conditions [8].

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But in 2014, K. Rahimi Meaghan investigated severely distorted commercially pure aluminum sheets produced via limited groove pressing that are then cross-rolled. The evolution of grain size and dislocation density during rolling was examined by applying Williamson-Hall analysis to the X-ray diffraction patterns of the deformed samples. These findings and observations from optical microscopy demonstrate that direct or cross-rolling of limited groove-pressed aluminum can result in elongated, small grains[9].CHANDAN MONDAL and A.K. SINGH described microstructure and texture development in an Al-Zn-Mg-Cu-Zr-based 7010 aluminum alloy during various hot cross-rolling processing modes.

In manufacturing vehicle, ship, and home appliance structural stamping parts, bending is one of the most popular metal forming techniques. (V-Die) bending is considered one of the most significant sheet metal bending procedures[10]. The most significant sheet metal bending process (SMB) is V-bending, which creates a V-shape and consists of two sub-processes: air bending in the first and coining in the second, where the punch entirely sets into the die[11]. According to M. Krinninger's research, the spring-back diminishes as punch velocity rises [12].According to M. Bakhshi-Jooybari's research, one of the most critical aspects of sheet metal forming processes is elastic recovery during unloading, also known as spring-back. This phenomenon leads to geometric alterations in the final product, affecting bend angles and curvature. This study conducted tests and numerical simulations to examine the impacts of key parameters on spring-back in U-die and V-die bending of CK67 anisotropic steel sheet.

Additionally, results from the finite element simulation and the experiment were compared [13]. Adil.S. Studied the impact of orientation and pre-tension on the distribution of stresses utilizing the finite element method and software ANSYS 19. The pre-tension in each rolling direction is set at 55% of the total strain. The findings demonstrate that the rolling direction significantly influences stress distribution and values before and after applying a 55% pre-tension. Although stresses distribute predictably in three directions, there is a significant variation in the stresses at 0, 45, and 90 degrees [14]. The current study aims to investigate the mechanical characteristics and spring-back of aluminum after subjecting it to cross-rolling in different directions and with varying cross-rolling punch velocities.

2. Experimental Method

2.1. Initial Setting

Three primary components comprise the experimental works; the first deals with the type of material sheet and how cross rolling with pseudo-cross rolling, also known as two-step cross rolling (TSCR), is constructed. Building and assembling some tools and equipment required for experiments with bending and forming make up the second portion. The methods and software used to measure the strain distributions and spring-back over the products are all included in the final section.

2.2. Material Type

The present study used aluminum alloy sheets (Aluminum 6061) with dimensions of (70 x 70) mm and an initial thickness of 3.1 mm. Table 1 contains the sheet's chemical composition. The chemical composition test was carried out using a spectrometer device.

Table 1: Chemical composition of Aluminum alloy 6061 (% of mass).

Element	Comp.	Iso
Al	96.7	95.8
Fe	0.62	Max.
Si	0.5	0.4-0.8
Mg	0.8	0.8-1.2
Mn	0.13	Max 0.15
Cu	0.9	0.15-0.4
Ti	0.12	Max.

2.3. Tensile Test

Testing the properties of the alloy is essential before initiating the deformation process. The objective of the examination is to assess the material's response to various loads, including Young's modulus, yield stress, hardness, toughness, and material strength, among others. Tensile specimens were manufactured following the ASTM standard, and Figure 1 displays the dimensions of the specimen.A tensile test was conducted using a computerized universal testing machine (WDW-200E) with a capacity of 200 kN. The stress-strain curves are shown in Figure 2.The mechanical properties of 6061 Aluminum Alloy are summarized in Table 2.

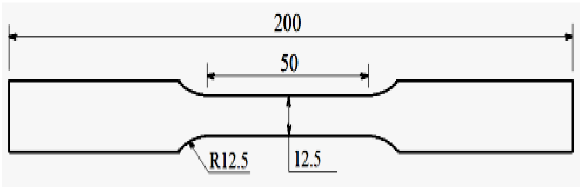


Figure (1): Dimensions of the tensile test specimen following E8M and ASTM standards.

Table2: Mechanical properties of aluminum alloy 6061.

Property	Value
Young's modulus (E)	69000 MPa (N/mm^2)
Yield strength (*YS*)	275 MPa
Ultimate tensile strength (*Su*)	310 Mpa
Elongation	12%
Poisson's ratio (υ)	0.33

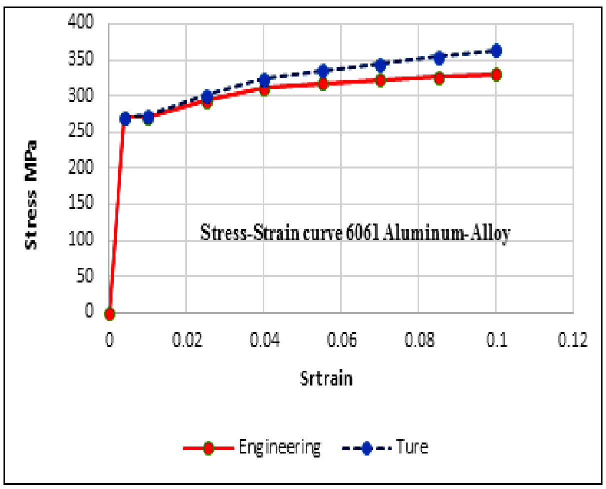


Figure (2): The stress-strain curves from the tensile test machine

2.4. Cross Rolling

A real cross-rolling operation consists of several small rolling passes made at right angles to one another. It is possible to express the ideal nature of this process as a plane deformation in each pass, with orthorhombic symmetry. It is possible to consider each two successive passes together as a deformation step combined with symmetry if the deformation of each pass is minimal. Therefore, compared to real cross-rolling, a pseudo cross-rolling or clock-rolling method involving two finite deformation stages in two mutually perpendicular directions produces different outcomes. As shown in Figure 3(a), during multi-step cross-rolling (MSCR), after achieving 50% of the total reductions, the rolling direction changes. The second method is transfer cross-rolling (TSCR), often called real cross-rolling, in which the direction is altered following each pass, as depicted in Figure 3(b).

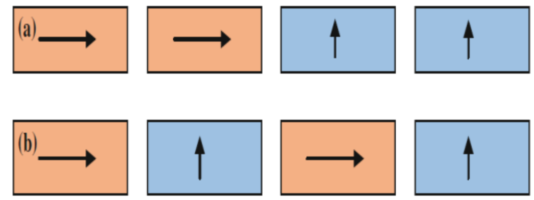


Figure (3): Cross-rolling sequences, including (a) the two-step cross-rolling (TSCR) and (b) the multi-step cross-rolling (MSCR). [1]

The substructure created by the previous deformation path is altered when changing the roll direction or deformation path, thereby affecting the texture of the deformation. As seen in Figure 4, cross-rolling results in rolled products with mechanical properties that are generally uniform throughout.

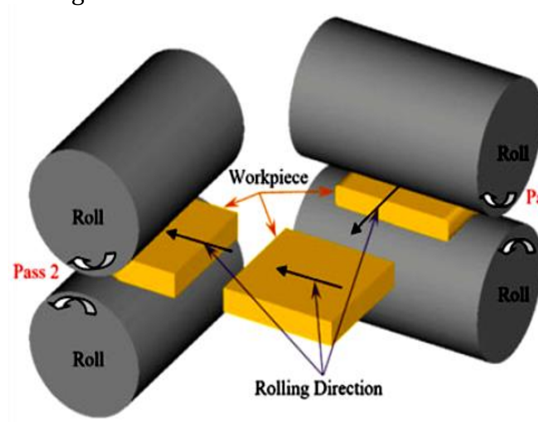


Figure (4): Cross rolling arrangement in a rolling mill[1]

Samples cut in two directions, longitudinal and transversal, concerning the direction in which it rolled to measure the spring back, as illustrated in Figure (5).

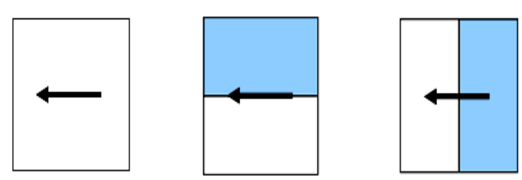
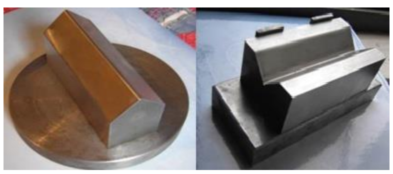


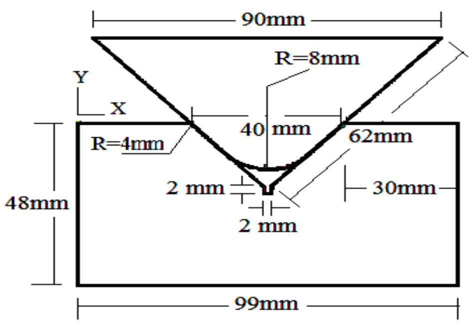
Figure (5): The direction cut for cross rolling specimen

2.5. Bending test

Steel CK45 was used to manufacture a 90° semi-closed V-bending tool, consisting of two pieces of punch and die, designed and produced to standard specifications. The first part is the open-type lower die with a 90° bottom bend. It has the shape of a parallelogram measuring (108 x 100 x 48) mm, a bending depth of approximately (19) mm, and an opening die of (40) mm. The upper die, also known as the punch, is the second component and features a 90° angle, as shown in Figure 6(a & b).All V-bends are performed with a constant load of 100 kN. Three experiments are conducted for each type of root, cutting direction, and punch speed (5, 10, 15) mm/min.



(a)



(b)

Figure (6): (a &b) Shape and dimensions of die and Punch

The bend angles are measured three times for each parameter, and the resultant spring-back angle for each parameter is obtained by averaging the spring-back values from the three experiments.

2.5.1. Spring-back measured

After mounting the die and punch on the press, the plate placed on the die opening before the punch brought into contact with the plate and the load is applied. The load is raised, the punch is taken out, and the plate is drawn out of the die opening. The workpiece's outer radius decreases due to a change in the bending angle. It is possible to calculate the difference between the sheet angle and the punch angle. This is called the spring back, as depicted in Figure (7). The spring-back angle is measured using a tool equipped with a universal bevel protractor and a magnifying glass to read angles precisely on sample features, as shown in Figure (8).

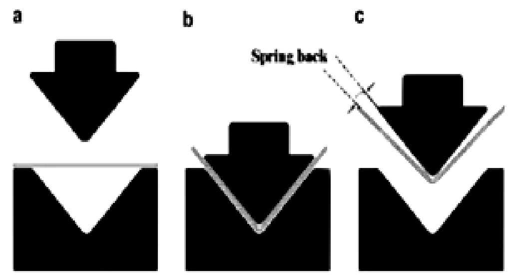
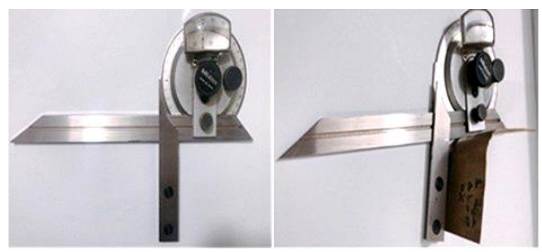


Figure (7): Illustration the spring back in V- die.



(a) (b)

Figure (8): (a) measuring instrument (b) the instrument while gauging the sample's angle

The spring-back angle, which is defined as the difference between the final bending angle (f) and the initial bending angle (i), can be measured in order to reduce the effect of process factors on the profile's spring-back

$$\Delta\alpha = \alpha f - \alpha i \quad (1)$$

Suppose the ratio of the spring-back angle to the initial bending angle is not employed. In that case, the spring-back factor is calculated from the ratio of the final bending angle to the initial bending angle[15].

$$K = \alpha f / \alpha i \quad (2)$$

3. Results and Discussion

The primary cause of spring-back is attributed to Bauchinger's effect, which allows the material to follow different paths through loading and unloading cycles in the plastic zone, where each forming operation occurs. Therefore, nonlinear material properties that consider stress-strain interactions in the nonlinear regions are required to estimate or perform spring-back calculations. The angle of loading and unloading must differ for spring-back to become evident. For specimens with various deformation speeds, the predicted values of spring-back and the calculated values of the spring-back factor (Ks) are displayed in Table (3).

Table 3: bending angles under various conditions.

Types of rout	Direction of cut	Bending speed (mm / min)	Angle of Spring-back	Spring-back factor	Max. bending Load (KN)
Clock Rolling	Perpendicular to roll direction	5	17°	1.188	3.48
		10	19°	1.211	3.2
		15	20°	1.123	3.25
	transfer roll direction	5	15°	1.166	2.88
		10	16°	1.177	2.76
		15	16.5°	1.183	2.65
TSCR	Perpendicular to roll direction	5	14°	1.155	3.4
		10	17°	1.188	.25
		15	18°	1.197	3.16
	transfer roll direction	5	17°	1.188	2.95
		10	18°	1.2	2.72
		15	19°	1.123	2.88

Figure (9), (10), and (11) show the effect of bending speed on the spring-back factor for each clock rolling direction and TSCR at perpendicular, with the roll direction cut, respectively.Therefore, it is evident that the cutting direction has a positive relationship with the spring-back factor. This means that the spring-back factor increases under different circumstances due to increased dislocation density, which modifies the mechanical behavior. Rolling typically results in strain hardening, which is brought on by the formation and rearrangement of dislocation sub-structures in the material. Due to the creation of the plastic deformation zone and the extension of the elasticity zone, there is some elastic recovery after bending when the load is withdrawn. The bending speed significantly affects the spring-back outcome.

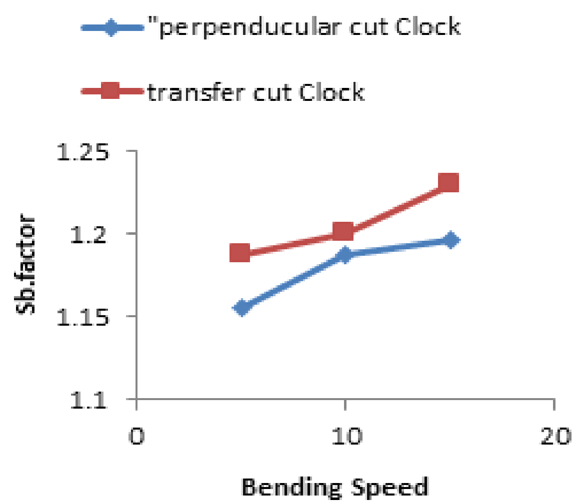


Figure (9): Shows the relationship between the spring back factor and the bending speed for a clock roll at various rolling cuts.

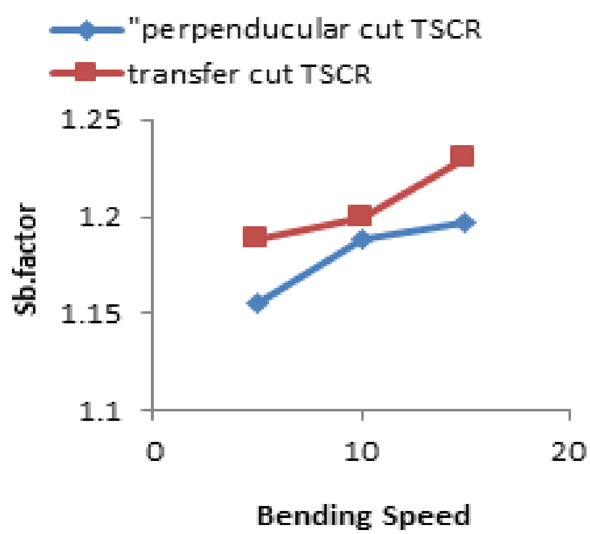


Figure (10): Shows the relationship between spring back factor and bending speed for TSCR rolls at various rolling cuts.

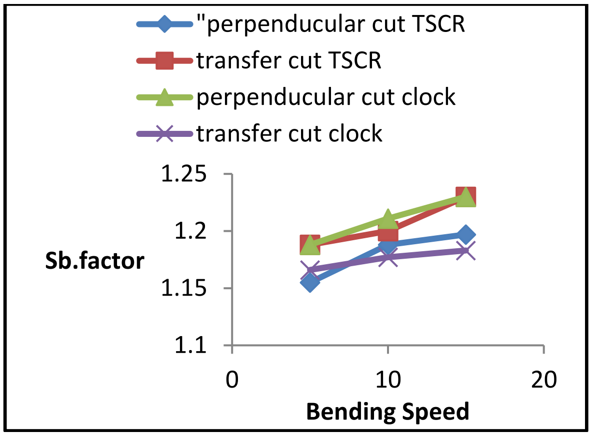


Figure (11): Showing the relationship between the spring back factor and the bending speed at various rolling passes and rolling cuts.

Figure (12), (13) and (11) show the effect of bending speed on max. bending load for each clock rolling direction and TSCR at perpendicular, with roll direction cut respectively. They significantly influence the material properties; this is consistent with source no. [16].It is proven that the maximum bending load reduces during the subsequent unloading, runback and dislocation annihilation create a drop in the mobile dislocation density. When the material is loaded again, the density of mobile dislocations increases, and new dislocation pile-ups develop. The growing dislocation density increases the potential for the formation of dislocation pile-ups near barriers. Additionally, the types of routes lead to a decrease in the isotropy of the material and a rearrangement of grain boundaries.

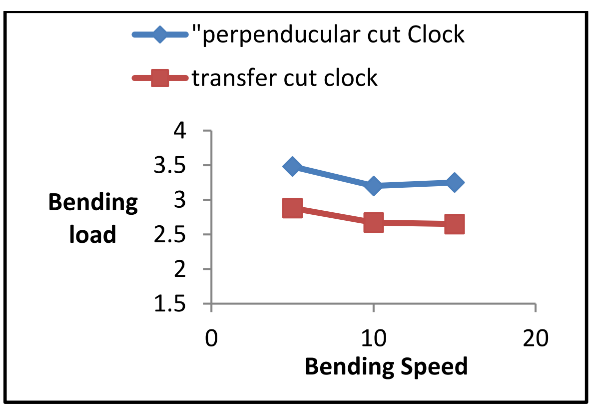


Figure (12): The relation between max. bending load and bending speed at different rolling cut for clock roll.

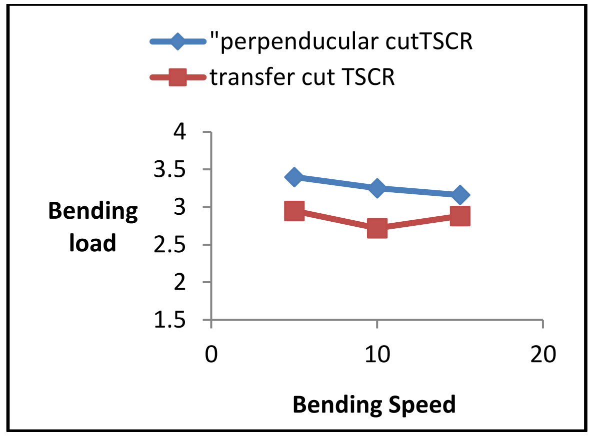


Figure (13): The relation between max. bending load and bending speed at different rolling cut For TSCR roll.

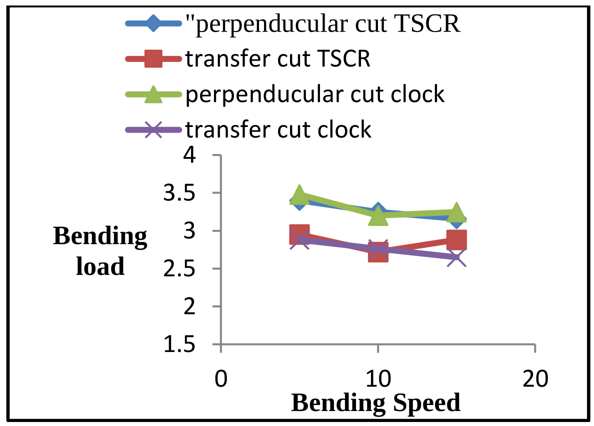


Figure (14): The relation between max. bending load and bending speed at different rolling cut and different rolling roots.

4. Conclusions

The phenomenon of spring back, arising from elastic recovery during sheet metal bending, is a crucial factor in industrial contexts. To predict and mitigate this effect, researchers utilized cross rolling techniques. The study outcomes revealed that the chosen route type substantially affects spring-back outcomes, intensifying the effect due to severe deformation in the rolling route. Additionally, the cutting direction markedly influences both spring-back and maximum load, underscoring its pivotal role in these phenomena. Lastly, regardless of the cutting direction, a rolling route consistently reduces the bending load, offering a promising solution for industrial applications.

References

[1] M. Rout, S. K. Pal and S. B. Singh. “A Metal Forming Process” VIII, 321 pp.171 , 2015.

[2] S. S. Lim, J. P. Hong “Study on Rolling Defects of Al-Mg Alloys with High Mg Content at Normal Rolling and Cross-Rolling Processes”, 2023. doi:10.20944/preprints202307.1095.v1

[3] G. Christina, B. Alexander, "Cross-rolling process for manufacturing lightweight hybrid components” Journal of Advanced Joining Processes vol. 3 100063, 2021.

[4] A. Bocker, H. Klein, H. J. Bunge “Development of cross-rolling textures in AIMn1” Hindawi Publishing Corporation Vol. 12 | Article ID 275912 12:155–174, 1990.

[5] S. Suwas, N. P. Gurao, “Development of microstructures and textures by cross rolling” Elsevier Reference Collection in Materials Science and Materials Engineering vol. 3, pp. 81-106, 2014.

[6] C. Mondal, A. K. Singh, A. K. Mukhopadhyay, K. Chattopadhyay, “Effects of different modes of hot cross-rolling in 7010 aluminum alloy” Metal Mater Trans A 44(6):2746–2763, 2013.

[7] S. Wronski, M. Wrobel, A. Baczmanski, Wierzbanowski K “Effects of cross-rolling On residual stress, texture and plastic anisotropy in f. c. c. and b. c. c. metals”. Mater Charact77:116–126, 2013.

[8] D.H. Shin, J.J. Park, Y.S. Kim, and K.T. Park, “Constrained Groove Pressing and Its Application to Grain Refinement of Aluminum” Mater.Sci. Eng. A, 328, p 98–103, 2002.

[9] K.RahimiMamaghani and M. Kazeminezhad “The Effect of Direct- and Cross-Rolling onMechanicalProperties and Microstructure of Severely Deformed Aluminum” JMEPEG, 23:115–124, 2014.

[10] C. MONDAL, A.K. SINGH “Effects of Different Modes of Hot Cross-Rolling in 7010 Aluminum Alloy ” Part I. EMTMMT volume 44A ,(2746-2763), 2013.

[11] A. Ivaniševic, M. Milutinovi, B. Štrbac and P. Skakun, “Stress state and spring back in v-bending,” J. Technol. Plast., vol. 39, no. 2, pp. 158–168, 2013.

[12] M.Krinninger, D. Opritescu, R. Golle and W. Volk, “Experimental Investigation of theinfluence of punch velocity on the spring-back behavior and the flat length in free bending,” Procedia CIRP, vol. 41, pp. 1066–1071, 2016.

[13] M.Bakhshi – Jooybari “The study of spring-back of CK67 steel sheet in V-die and U-die bending processes, journal of Material and design” Vol.30, issue7, pp(2410-2419) , 2007.

[14] Adil S. Jabber a, Aseel H. Abed b, Anwar H, zbon “Effect of Orientation and Pre-tension on Stresses Distribution on V-Die Bending Processes by Finite Element Method “Engineering and Technology Journal Vol. 38, Part A, No. 05, Pages636-648, 2020.

[15] Aseel hamad “The Effect of Hold Time on the Spring Back Phenomenon ina V- Dies Bending Process” Engineering and Technology Journal Vol.30, No.19, pp. (3384-3393), 2012.

[16] N. Nanu, and G. Brabie, “Analytical model for prediction of spring-back parameters in the case of U stretch–bending process as a function of stresses distribution in the sheet thickness” International Journal of Mechanical Sciences vol. 64 no.1, pp.11-21, 2012.