Springback Analysis in Bending of V-Section Using Deformable Die

Jalil J. Shukur [1], Waqass S. Khudhir [2], Mohanad Qusay Abbood[3]

Authors affiliations:

1) Production Engineering and Metallurgy Department, University of Technology -Iraq, Baghdad, Iraq.
Jalil.J.Shukur@uotechnology.edu.iq

2) Production Engineering and Metallurgy Department, University of Technology -Iraq, Baghdad, Iraq.
waqass.s.khudhir@uotechnology.edu.iq

3) Production Engineering and Metallurgy Department, University of Technology -Iraq, Baghdad, Iraq.
Mohanad.q.abbood@uotechnology.edu.iq

With the development of manufacturing techniques, the demands have increased on tools with flexible components that can produce parts with different shapes and sizes only by replacing the rigid part of these tools, since the flexible part can match the required geometry. This study is focused on effects of rubber hardness and sheet thickness on the springback developed on the produced parts. Silicone rubber with three hardness (40,60 ,80) Shore A hardness scale was used. The material of workpiece was Aluminum (3003) with three different thicknesses of (0.8,1,1.2) mm and three holding time of (0,10,20) seconds. The results demonstrate that, the springback decreases with any increase in the rubber hardness or sheet thickness. In addition, the holding time showed a significant effect only with a harder rubber.

Keywords: Flexible Die Forming, Rubber Pad forming, Numerical Simulation.

<div dir="rtl">

تحليل الرجوعية في عملية الحني باستخدام قالب مرن

جليل جبار شكر، وقاص سعد خضير، محند قصي عبود

الخلاصة:

مع تطور تقنيات التصنيع، زادت الطلبات على الأدوات ذات المكونات المرنة التي يمكنها إنتاج أجزاء بأشكال وأحجام مختلفة فقط عن طريق استبدال الجزء الصلب من هذه الأدوات، حيث يمكن أن يتطابق الجزء المرن مع الاجزاء المطلوبة. تركز هذه الدراسة على تأثيرات صلابة المطاط وسمك الصفيحة على الرجوعية على الأجزاء المنتجة. مطاط السيليكون بثلاث صلابة (٤٠، ٦٠، ٨٠) تم استخدامه. كانت مادة الشغل من الألمنيوم (٣٠٠٣) بثلاث سماكات مختلفة (٠,٨,١,١,٢) ملم وثلاث زمن تثبيت (٠،١٠،٢٠) ثانية. تظهر النتائجُ أن الرجوعية تتناقص مع أي زيادة في صلابة المطاط أو سماكة الصفيحة. بالإضافة إلى ذلك، أظهر زمن تثبيت تأثيرًا كبيرًا فقط مع المطاط الأكثر صلابة.

</div>

1. Introduction

Sheet metal forming operations are widely utilized to manufacture complicated portions and contain a set of requisite processes, similar stretching, bending, blanking and stamping. Bending is a simple operation that is widely utilized in industrial productions [1]. Through the forming operation, generality blanks undergo a combination of unbending, bending, reverse bending and stretching. This operation can also be completed utilizing rubber tools, and an assortment of figures that are difficult to bend using traditional systems is possible with a flexible pad [2]. Rubber-pad forming is a multipurpose metal production operation that is utilized in commercial parameters such as, rubber hardness, curvature radius, rubber pad thickness, sheet thickness, spring back phenomena, and lubrication condition have

aerospace, military, and automotive applications. This operation is well suitable for prototyping and manufacturing of small numbers of sheet metal parts [3,4].

There are numerous studies reported in the literature that are focused on the scope of rubber-pad forming process. One of the successful attempts was reported by **Mahshidifar, A., and Vafaeesefat, A.** [2013] [5], In this paper, the active parameters in the rubber pad forming methods on parts having curvature radius have been studied experimentally as well as using the finite element methods. Natural rubber of Shore Hardness 61(SHORE A) and blanks of aluminum with a curvature radius were used. The influence of

been investigated. Furthermore, the cited factors have different influences on the portion quality. **Chen, et al** [2014] [6] has studied, the wrinkling with

a perpendicular experimental design by contract flanging in the rubber forming process. Four influence factors were investigated including the (forming pressure, die fillet radius, the flange length and die radius) were investigated. The alloys used as blanks were (2024-T3, 7075-O, 2024-O). The wrinkling had a huge influence on those factors. The strength of the altered materials agree well with the range of wrinkling. Numerical simulation can predicts wrinkling. While **Sun, et al** [7] has observed that the beginning of wrinkling delays causes high forming velocity and the wrinkles height and width have considerable effect on the rubber hardness. On the contrary, spreading of wrinkles is less affected by rubber hardness. **Halkaci, et al [**2016] [8] have noted that the simulation of a rubber pad forming process requires a considerable processing time. However, this problem can be minimized by using the 2D axisymmetric approach in the LS-DYNA explicit finite element software. Inconel 625 and DX56D galvanized sheet metal blanks were used with the support of four rubber pads. a 50% reduction in the CPU time in 2D analyses. **Subbaramaiah, et al** [2016] [9], In this paper investigated using a rubber pad forming for formability of Glass reinforced aluminum (GLARE). The numerical and experimental analyses are then presented for a hat-shaped GLARE forming process. The explicit finite element analysis has proved that the evaluation of the GLARE formability to be costly. A fast active tool to develop and design the forming process. **Mahmut et al** [2017] [10] investigated numerically and experimentally a miniature forming with flexible die. workpiece on Dome shape made of aluminum 1100 H14 and flexible material is polyurethane rubber with two different hardness values (60A and 80A Shore) were used. The results illustrated that tearing was prevented in conventional forming by using the flexible die. The forming of mesoscale parts is viable in this process without extreme weakening. Additionally, the harder polyurethane is better than the softer counterpart in achieving the desired final geometry. **Koubaa, et al [**2017] [11], to investigate the influence of rubber on the capability of forming a numerical study that simulated and discussed flexible bulge and hydroforming forming processes has been conducted. Blanks made out of aluminum. The authors also recommended the use of polyurethane rubber as a flexible medium to decrease thinning and enhance forming capability. The influence of rubber shore and friction on thickness distribution is studied. It was shown that various friction coefficients cause the difference in thickness thinning regions. **Abbas, et al** [2018] [12], finite element analysis has been adopted in a Commercial software (ABAQUS/CAE). was positioned under and above the rubber (MAT27) (90A) steel (CK45) with thickness (0.5) mm. Will include this analysis specifying and finding the chief effecting factors to determine and estimate the suitable geometry design. Results are effects of changing the rubber thickness on stress generation are less than the influence of altering the radius.

2.Fundemental Definition
2.1 Springback
During bending the load is applied to bend the part in the expected shape. The bending tool bends the metal into a certain angle with a given bend radius. After bending, when the tool is removed, there is a dimensional change of the bent part as illustrated in Figure (1). Widening the angle and increasing the radius is referred to as springback [13]. The amount of springback can be defined either by anon-dimensional springback ratio (Ks) [14], which represents the ratio between the final bending angle θ_f and the loading bending angle θ_i.

$$Ks = \frac{\theta_f}{\theta_i} \qquad \qquad \text{.... (1)}$$

While the springback angle is the difference between the final bending angle θ_f and the loading bending angle θ_i.

$$\Delta\theta = \theta_f - \theta_i \qquad \qquad \text{....(2)}$$

The springback ratio can also be defined in terms of the bending radius as

$$\frac{R_i}{R_f} = 4\left[\frac{R_i \sigma_y}{Et}\right]^3 - 3\left[\frac{R_i \sigma_y}{Et}\right] + 1 \qquad \text{.... (3)}$$

Where R_i represents the radius in the loading state, R_f is the final radius, t is the sheet thickness, σ_y is the Yield stress and E is the modulus of elasticity.

3.Experimental Work
3.1 Material Characterization
Aluminum (3003) alloy sheets have been used with different thickness (0.8, 1, 1.2) mm. In addition, an optical emission spectrometer has been utilized to analyze the chemical composition of this used material in order to check the manufacture certificate as shown in table (1).
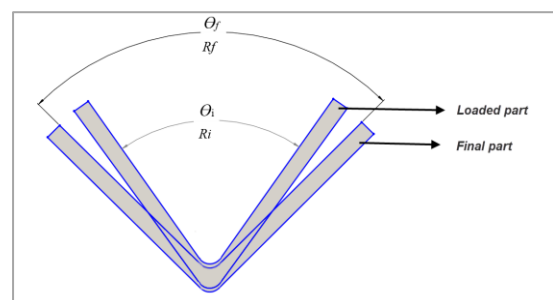

Figure (1): Springback of bending part.

To identify the mechanical properties of Aluminum (3003), the uniaxial tensile test has been performed. Therefore, the standard tensile specimens have been cut from the original sheets with 50 mm gauge length and 12.5-gauge width according to the ASTM-E8M specifications. The wire electric discharge machining process was used, where these specimens have been tested on the universal tensile

machine with model (WDW-200E) at initial strain rate $0.6 \times 10^{-3} s^{-1}$ until fracture occurring. The tensile test could be repeated for each thickness of sheets to find the average values of some mechanical properties from the obtained flow curve, the tensile tests as follows, the modulus of elasticity of 71 GPa, Poisson's ratio of 0.3, the measured offset yield stress 64 MPa, and the total elongation is 28%. While the forming die has made from silicone rubber with three hardness (40,60 ,80). The hardness of rubber has measured by Shore A test according to ASTM-D2240 standard using Durometer device.

Table (1): Chemical Composition of (AL-3003).

Si%	Fe%	Cu%	Mn%	Zn%	Others%	Al%
0.6	0.7	0.12	1.13	0.09	0.2	Remain

3.2 Bending test

Bending experiments have been performed to produce V sectional bended parts on the test machine (WDW-200E), which has a maximum capacity of 200KN. The bending operations have been carried out on the initial blanks which have dimensions of 30mm × 100mm and cut through the rolling direction of the low carbon steel sheets with three different thicknesses of (0.8, 1, 1.2) mm. The upper punch with an angle of 90° and a nose radius of 2mm has been designed and manufactured from Ck45 which have been used in this study. Rubber pad die (flexible die) has been prepared by cutting to the block shape having dimensions of 50mm × 120mm ×X 50mm.Besides, Silicon rubber has been chosen to be the material for the rubber pad. In order to investigate the effect of hardness of rubber, three types of hardness (40, 60, 80) shore A have been utilized in this study. It has been ascertaining of the rubber hardness by using the shore test to examine the hardness of the rubber pad used. Figure (2) presents schematic representation with detailed dimensions of the bending rigid punch and rubber deformable die. On the other hand, figure (3) demonstrates the photographic representation of punch(a), rubber (b) and produced V-section parts shown figure (3). Table (2) summarizes the process parameters and its levels to be studied experimentally and numerically in this research. While Figure (4) demonstrates some of produced parts.

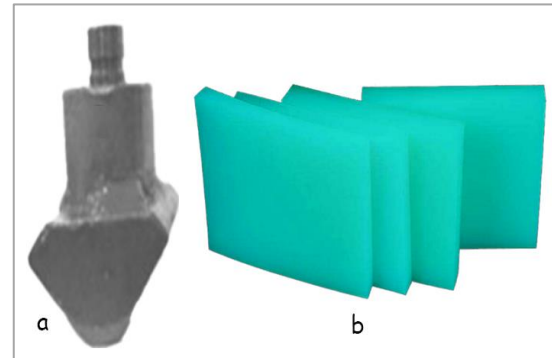**Figure (2):** The flexible bending operation: the schematic dimensions of the tool set.

Figure (3): Experimental tool and produced parts.

Figure (4): V-section produced parts.

3.3 Springback Measuring

The bending process starts with the punch fixes on the upper part of the aforementioned press machine and the rubber pad die was placed on the base of the machine. The steel sheet blank is then introduced between the punch and the flexible pad (rubber die). After that, the punch moves downward to bend the sheet against the flexible die until required bending depth of 14mm is achieved. To examines the accuracy of the bended products, springback measurement is required, which is the difference between the bent angle of the manufactured part and the target angle, which is the punch angle 90° as a reference. It is worth it to mention the bended angles have been measured by a Mitutoyo 187-907 tool bevel protractor with a magnifying glass for reading highly precisely as presented in Figure (5).
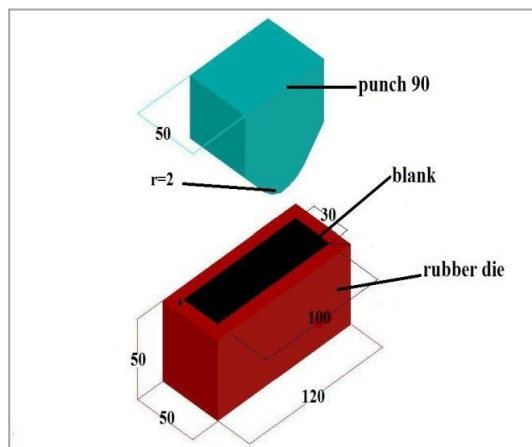
Figure (5): Measuring device Mitutoyo 187-907.

Table 2. Process parameters in experimental tests.

Process Parameters	Sheet Thickness (mm)	Rubber Hardness (Shore A)
Parameter Levels	0.8	40
	1	60
	1.2	80

4.Numerical Model Description

The numerical model has been created with the commercially available ANSYS 19.2 software, which allows users to define the blank and die (rubber pad) as a deformable part, while the punch is defined by rigid property, and it represents the only non-deformable part in the bending tool set. The modeling stages and its features is illustrated in following points:

1. The part geometry is created in SOLIDWORKS and the CAD file has exported to ANSYS mechanical.
2. The material definition has been applied to each part (rigid behavior for punch, nonlinear plastic model for sheet metal and hyperelastic model for rubber die).
3. The mapped mesh has been adopted to mesh the three parts, whereas a refinement is subjected to edge of punch with local mesh control as shown in Figure (6).
   4. Nonlinear Augmented Lagrange was used to define the contact behavior in punch-sheet interface with 0.1 friction factor and in sheet-rubber interface with 0.2 friction factor.
   5. A fixed support is applied to the bottom edge of rubber die while a frictionless support is used in both of the vertical edge of rubber die with modelling constraints demonstrated in Figure (6).
   6. The springback has measured after unloading by determine the angle between

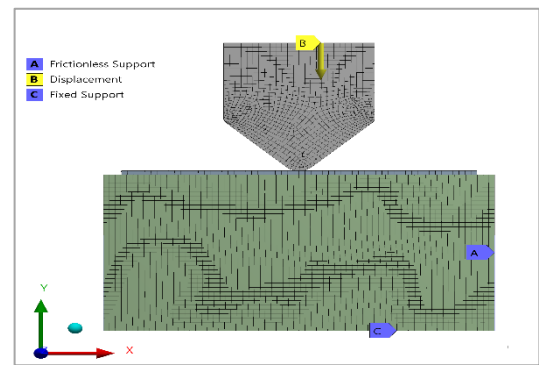two predefined nodes have equal distance from blank centre.

Figure (6): Meshing and boundary condition of numerical model.
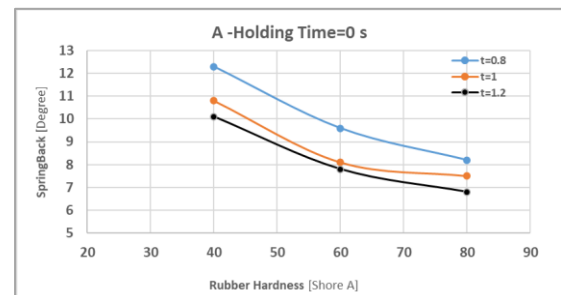
5.Results

The results of experimental and numerical studies have been evaluated in terms of the effects of rubber hardness, material thickness and holding time on the springback in V-bending process. The results obtained are discussed below:

5.1 Influence of Rubber Hardness on Springback

The amount of springback in the produced parts is linked to the magnitude of the bending pressure subjected by punch from upper side and die from bottom side since the rubber is deformed elastically. The rubber hardness is an important parameter as it controls the distribution of internal stress generated in sheet metal by progressive of forming process.

Springback decreases remarkably with any increase in rubber hardness as shown in Figure (7). Although the trend of decrease was more pronounced when rubber with high hardness is used. The reason behind that is due to the fact that the harder the rubber is, the more forming pressure that subjected by deformable die to enforce sheet metal to take shape of rigid punch. In other words, the rubber with hardness (especially rubber of 40 Shore A) means the springback rises significantly as a result of leak of support from rubber to downside of sheet.

The most obvious values of what was discussed in holding time 0 s, the largest springback 12.3° is appears when a rubber of 40 Shore A is used.
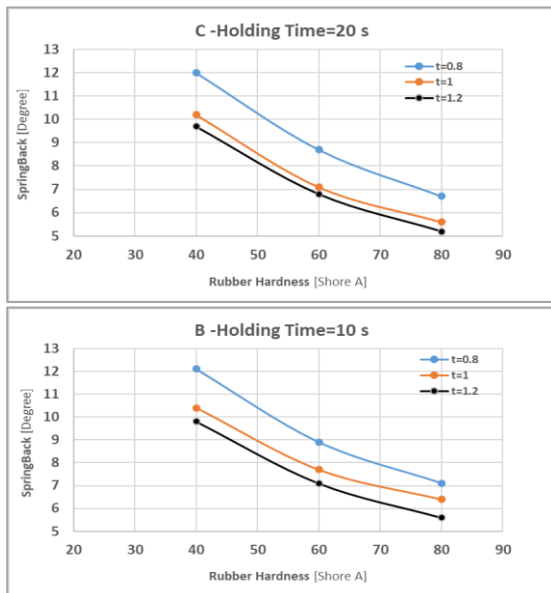
Figure (7): Effects of rubber hardness on springback (Experimental results).

5.2 Influence of Sheet Thickness on Springback

One of most influential factors on springback is part thickness as it is related to the ability of metal to recover elastic deformation as described in equation (3). The experimental and numerical results demonstrated that there is a significant difference in magnitude of springback when the sheet metal thickness is changed.

In general, the springback decreases with increase in sheet thickness. As an example, 19% decreases in springback have been achieved when the sheet thickness is increased from 0.8 mm to 1.2 mm as shown in Figure (7-A). On other hand there's a convergence in the results of 1mm and 1.2 mm thicknesses when compared with the results of 0.8 mm thickness. The variation in springback with any change in thickness resulting from the nature of compressive stresses in sheet metal upper layers and tensile stresses lower layer. Therefore, as the thickness of the used sheet increases, the effects of these stresses play important rule in controlling the elastic recover operation.

5.3 Influence of Holding Time on Springback

Often to reduce, or even eliminates the springback in the produced part holding time is used to prevent the part from elastic recover or maintain part in support between punch and die to reach a state where plastic deformation distributed uniformly in whole part. However, when deformable die is used the results demonstrated a minimal influence of holding time as compared with effect of using rigid tools in paper that reviewed in introduction.

The holding time is highly affected by sheet thickness and rubber hardness, where the percentage reduction in springback is 2.5% when a sheet thickness of 0.8 mm, die of 40 Shore A hardness and the holding time increased from 0 to 20 second. When a rubber of 40 Shore A hardness, sheet of 1.2 mm the percentage reduction in springback is 23.5% and holding time is increased from 0 to 20 second as demonstrated in Figure (7).

Table (3) presented the experimental results for all parameter level. While Table (4) shown the simulation results.

Table 3. Summarized of experimental result.

Holding time (s)	Rubber hardness (Shore A)	Springback (degree)		
		0.8mm	1mm	1.2 mm
0	40	12.3	10.8	10.1
	60	9.6	8.1	7.8
	80	8.2	7.5	6.8
10	40	12.1	10.4	9.8
	60	8.9	7.7	7.1
	80	7.1	6.4	5.6
20	40	12	10.2	9.7
	60	8.7	7.1	6.8
	80	6.7	5.6	5.2

Table 4. Summarized of simulation result.

Holding time (s)	Rubber hardness (Shore A)	Springback (degree)		
		0.8mm	1mm	1.2 mm
0	40	12.9	11.9	11.2
	60	10.67	8.75	8.46
	80	8.3	7.7	7.1
10	40	13.4	11.34	10.7
	60	9.8	8.3	7.7
	80	7.8	7	5.9
20	40	13.6	11.2	10.6
	60	9.7	7.74	7.3
	80	7.35	5.9	5.41

5.4 Comparison between numerical and experimental results

Numerical simulation results showed the same trend as of the experimental results with good agreement in values of springback as shown in Figure (8). However, as is evident from results data in table 3 and 4 there was a clear difference between experimental and simulation results the greatest variation between simulation and experimental results are 11.7% when a sheet thickness of 0.8 mm, die of 40 Shore A hardness and the holding time 20 s.in the other hand the smallest variation between simulation and experimental results are 3.8% when a sheet thickness of 1.2 mm, die of 80 Shore A hardness and the holding time 20 s.

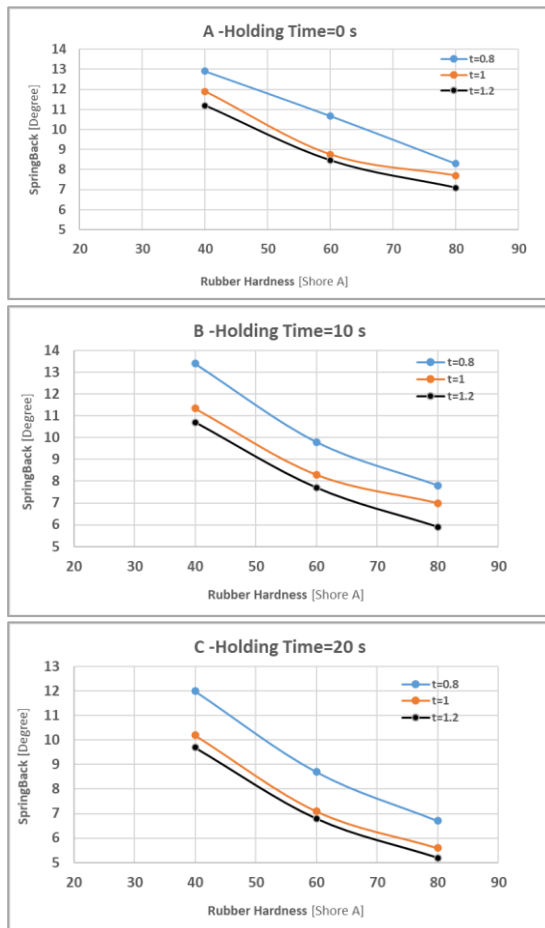While Figure (10) shows the distribution of deformation in sheet metal and deformable die.

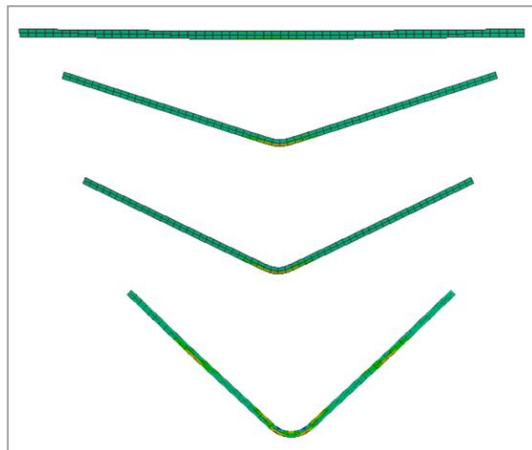**Figure (8):** Effect of rubber hardness on springback (Numerical results).

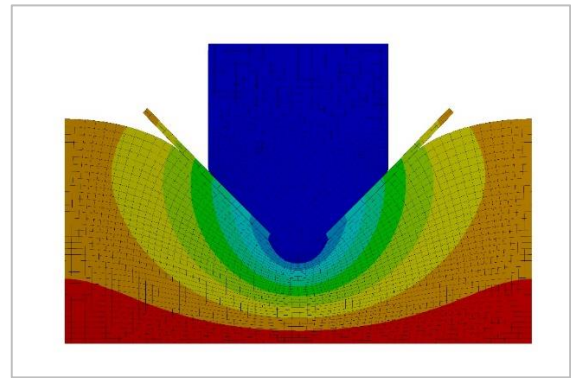**Figure (9):** Sequence of forming process in numerical simulation.

Figure (10): Deformation distribution along bended part and rubber die.

6.Conclusion

Experimental and numerical studies were conducted using rubber die materials. The findings obtained in this paper are indicated as following:

1. In the deformable die bending process, the springback is highly affected by rubber hardness, where was a direct proportion between springback and rubber hardness.
2. it was observed that a thinner sheet is associated with a larger springback magnitude. The springback in a sheet thickness of ٠٫٨mm differs considerably from that in the others two thickness used.
3. While there was a significant influence of holding time with high die hardness this influence diminishes with die of lowest hardness.

References

[1] Z. M. R. Maziar Ramezani, Rubber-pad forming processes: Technology and applications. Woodhead Publishing Ltd, 2012.

[2] QUADRINI, Fabrizio; SANTO, Loredana; SQUEO, Erica Anna. Flexible forming of thin aluminum alloy sheets. International Journal of Modern Manufacturing Technologies, 2010, 2.1: 79-84.

[3] M. Benisa, B. Babic, A. Grbovic, and Z. Stefanovic, "Computer-aided modeling of the rubber-pad forming process," vol. 46, no. 5, pp. 503–510, 2012.

[4] Jingwei Zhang, Sheng Ding, Jun Yanagimoto, "Bending properties of sandwich sheets with metallic face sheets and additively manufactured 3D CFRP lattice cores" vol. 300, 117437, 2022.

[5] Mahshidifar, A., & Vafaeesefat, A. (2013). Numerical and experimental study of parameters affecting metal forming using rubber pads, on parts with radius of curvature.

[6] L. Chen, H. Chen, Q. Wang, and Z. Li, "Studies on wrinkling and control method in rubber forming using aluminium sheet shrink flanging process," Mater. Des., vol. 65, pp. 505–510, 2015.

[7] Y. Sun, M. Wan, X. Wu, "Wrinkling prediction in rubber forming of Ti-15-3 alloy," Trans. Nonferrous Met. Soc. China, Vol. 23, pp. 3002– 3010, 2013.

[8] H. S. Halkaci, "2D Finite Element Analysis of Rubber Pad Forming Process" 2 ND Int. Conf. Sci. Ecol. Technol. 2D, no. January 2017, 2016.

[9] R. Subbaramaiah, S. Lim, G. Pearce "Rubber pad forming of glare cruciform using numerical and experimental analysis," Cooperative Research Centre for Advanced Composite Structures, Fishermans Bend, Australia, pp.1–11, 2016.

[10] Mahmut Tandogan and Omer Eyercioglu " Hardness Effect of Polyurethane Rubber on Mesoscale Rubber Pad Forming " International Advanced Research Journal in Science, Engineering and Technology Vol. 4, Issue 9, September 2017, pp. 95-105.

[11] Koubaa, Sana, et al. "Numerical investigation of the forming capability of bulge process by using rubber as a forming medium." The International Journal of Advanced Manufacturing Technology 92.5-8 (2017): 1839-1848.

[12] A. A. Abbas, M. A. Hussein, and M. M. Mohammad, "Design Parameters Estimation and Design Sensitivity Analysis in Manufacturing Process of Rubber Pad by Using Finite Element Technique," Int. J. Mech. Mechatronics Eng., vol. 18, no. 03, pp. 75–85, 2018.

[13] Cheng, C., Chen, H., Guo, J., Guo, X., & Shi, Y., "Investigation on the influence of mandrel on the forming quality of thin-walled tube during free bending process," In Journal of Manufacturing Processes (Vol. 72, pp. 215–226), 2021.

[14] T. You , Y. Pan and Y. Zhai, "Heat transfer in a U-bend pipe flow at supercritical pressure," Int. J. of Heat and Mass Transfer., vol. 191, ISSN 0017-9310. 75–85, 2022.