PROCEEDINGS OF SPIE

SPIEDigitalLibrary.org/conference-proceedings-of-spie

Numerical study of the of ultrasonic vibration in deep drawing process of circular sections with rubber die

M. Sheykholeslami, S. Cinquemani, S. Mazdak

M. Sheykholeslami, S. Cinquemani, S. Mazdak, "Numerical study of the of ultrasonic vibration in deep drawing process of circular sections with rubber die," Proc. SPIE 10595, Active and Passive Smart Structures and Integrated Systems XII, 1059539 (15 March 2018); doi: 10.1117/12.2292642

Event: SPIE Smart Structures and Materials + Nondestructive Evaluation and Health Monitoring, 2018, Denver, Colorado, United States

NUMERICAL STUDY OF THE OF ULTRASONIC VIBRATION IN DEEP DRAWING PROCESS OF CIRCULAR SECTIONS WITH RUBBER DIE

M. Sheykholeslami[1*], S. Cinquemani[2], S.Mazdak[3]

1- Department of Mechanical Engineering, Faculty of Engineering, Arak University Arak 38156-8-8349, Iran

2- Departmento of Mechanical Engineering, Politecnico di Milano, via La Masa 1, 20156 Milan, Italy.

3- Department of Mechanical Engineering, Faculty of Engineering, Tafresh University,Tafresh, Iran

ABSTRACT

Deep drawing is a practical process to create shell metal parts. In this process punch draw sheet metal into die cavity. Punch and die must be changed for part with new geometry leading to high costs and time waste. To overcome this problem, in the last years the use of rubber die has become more and more widespread. This technique requires the use of ultrasonic vibration that helps to reduce friction between punch and die and then the risk of thinning. In this paper a numerical study, based on finite element method, of the deep drawing process of circular sections with rubber die assisted by ultrasonic vibration is presented. An in depth analysis on the effects of amplitude and frequency of ultrasonic vibration is carried out. Results show that by increasing amplitude and frequency of ultrasonic vibration, limits on the forming force can be profitably increased, ensuring a better execution of the process.

Keywords: Ultrasonic vibration, rubber die

1- INTRODUCTION

Deep drawing process is a widely used forming process to produce a large variety of products. In this process, design and manufacture of die (punch and matrix) are time and cost demanding. Every change in the product (dimension shape, etc.) leads to a new design of the die, especially for matrix that is the more complex part. The use of soft die can reduce the need of changing matrix and therefore cuts down the process costs. Despite of this benefit, this kind of matrix leads to an increased friction between the matrix and the work piece and then to an increase in the required forming force. If the forming force results to be too high, the risk of die damaging and sheet rupture becomes high. An effective way to overcome these limitations is to reduce friction between parts by using ultrasonic vibrations. In this paper, the effects of ultrasonic vibration on soft matrix deep drawing die will be investigated numerically.

There are several reports for soft die deep drawing and most important parameters of this process. Brawn et. al in 1995 [1] presented experimental study for using rubber matrix in forming aluminum sheets. In their report, thickness distribution was reported together with the effects of main parameters for producing flawless products. Hassan et.al in 2002 [2] experimentally studied circular deep drawing of thin aluminum sheets. In this study, a polyurethane ring was used as soft matrix. The effects of polyurethane parameters were

Active and Passive Smart Structures and Integrated Systems XII, edited by Alper Erturk, Jae-Hung Han,
Proc. of SPIE Vol. 10595, 1059539 · © 2018 SPIE · CCC code: 0277-786X/18/$18 · doi: 10.1117/12.2292642

presented concluding that using soft die in thin sheet forming gives more benefits than traditional techniques. Linfa Peng et. al in 2009 [3] reported numerical and experimental study of soft punch deep drawing of St304 U-shaped microchannel sheets. Polyurethane material was used for the punch. They showed that hardness of rubber was considerably effective on the quality of the final product. Liu et.al in 2010 [4] used soft die deep drawing to produce concave and convex products. They showed that highest drawing ratio could be obtained in convex shape. Ramazani et.al in in 2012 [5] used a new friction model, based on local contact condition, to analyze the process. Their results showed better prediction than Coulomb frictional model. Irthiea et. al in 2014 [6] reported numerical and experimental study on deep drawing of a St304 foil with soft die. In this paper, a special technique was used consisting in letting an initial gap between blank holder and adjustable ring. Optimum gap has been reported in this paper. They showed that the depth of drawing could be increased by using this approach. Irthiea et. al in 2017 [7] studied micro forming of aluminum with soft die numerically and experimentally. In their work, using initial gap technique, the effect of rubber parameters, initial blank diameter and size scale on the quality of final products were studied. They showed that by decreasing compressibility of rubber, maximum attainable depth of products is decreased.

Regarding to literature, there is a common challenge in soft die deep drawing. Applying ultrasonic vibration during deep drawing process can be suitable solution for this challenge. In this paper, a numerical analysis has been carried out to evaluate the effects of ultrasonic vibration during soft die deep drawing process. Abaqus finite element commercial software has been used for this purpose. Effects of vibration amplitude and frequency on forming force and forming limit have been studied. Deep drawing process has been done on circular copper sheet with rubber matrix. Results show that ultrasonic vibration allows to a considerable increase in forming limit and to a better distribution of material of the final product.

2- MATERIAL AND METHOD.

2-1 Process Plan

Deep drawing is a sheet metal forming process in which a sheet metal blank is radially drawn into a forming die by the mechanical action of a punch.[1] It is thus a shape transformation process with material retention. The process is considered "deep" drawing when the depth of the drawn part exceeds its diameter. This is achieved by redrawing the part through a series of dies. The flange region (sheet metal in the die shoulder area) experiences a radial drawing stress and a tangential compressive stress due to the material retention property. Figure 1 shows a schematic view of deep drawing tools. Circular sheet has been made of brass. Punch has been made of steel and soft matrix has been made of rubber. Fixed blank holder has been used in order to satisfy ultrasonic vibration frequency response.

The total drawing load consists of the ideal forming load and an additional component to compensate for friction in the contacting areas of the flange region and bending forces as well as unbending forces at the die radius. The forming load is transferred from the punch radius through the drawn part wall into the deformation region (sheet metal flange)

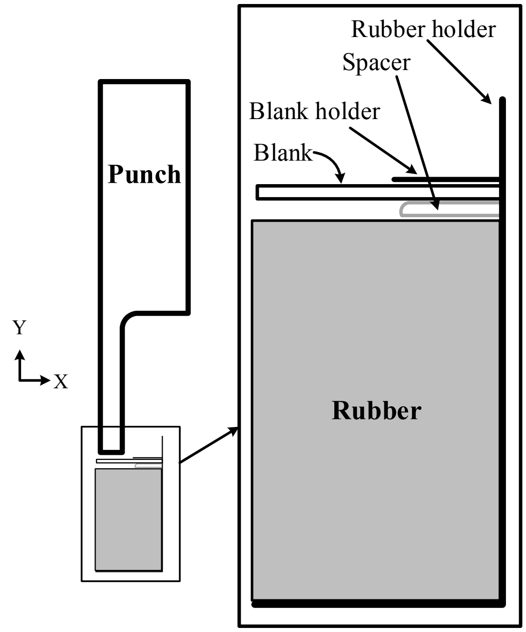

Figure 1 - Schematic view of deep drawing tools.

Ultrasonic vibration is exerted longitudinally on punch. To reach the highest performance, the ultrasonic frequency has to be set equal to the first resonance frequency of the punch. This allow to have the highest amplitude of vibration and to avoid the presence of anti-nodes. Punch radius has been designed to be less than a quarter of the wave length. This condition allows to minimize lateral waves, according to [8]. Figure 2 shows the main geometrical parameters of the punch while Table 1 collects the dimensions of the three punches used in this research.

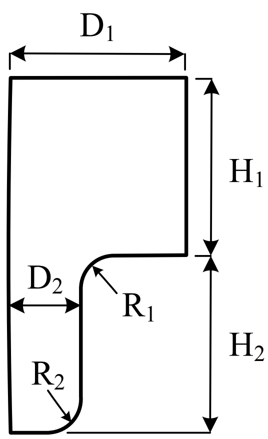

Fig.2. Punch and its parametrical dimensions

Punch	Frequency (Hz)	D_1 (mm)	D_2 (mm)	H_1 (mm)	H_2 (mm)	R_1 (mm)	R_2 (mm)
1	20050	20	5	105	61.1	2	1
2	29640	20	5	63	41	2	1
3	39135	20	5	50	30	2	1

Table.1. Dimensions of designed punches.

Eigenmodes and eigen frequencies of the three tested punches are calculated by finite element analysis and results are shown in Fig. 3.

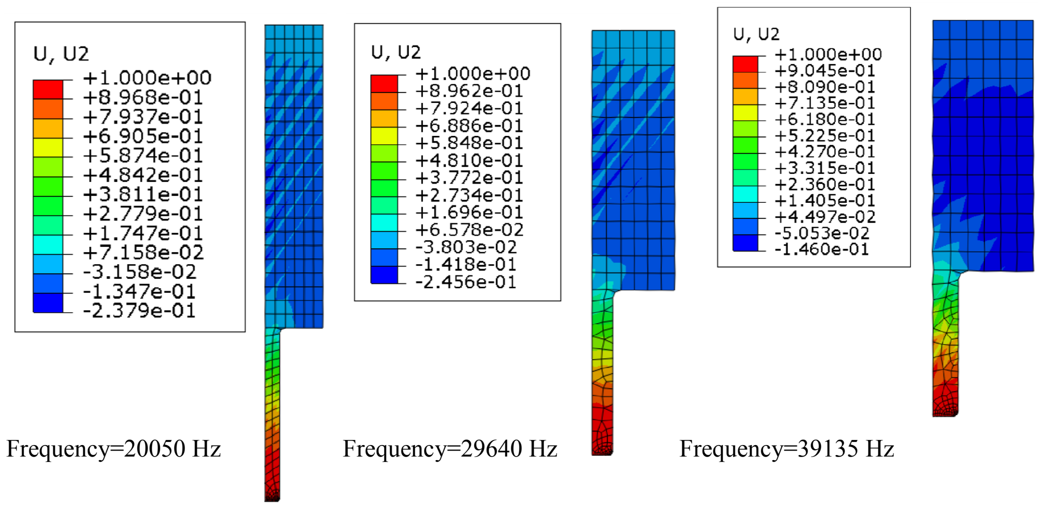

Fig.3. Resonance frequency and mode shape of punches.

2-2 Numerical Model

Abaqus commercial software has been used to finite element simulation. As it is shown in Fig.1, the geometry of the model is considered as axis-symmetric and a quarter model has been considered for simulation in order to decrease execution time. Simulation has been done in dynamic implicit module. As previously discussed, the model consists of punch, sheet, blank holder, rubber holder and spacer. In this process, fixed blank holder has been used in order to provide enough space for rubber deformation.

Table.2 shows material properties of punch and blank and Table.3 depict material properties in rubber. Rubber properties are obtained exploiting Hyper elastic Mooney Rivilin model [7].

Table.2. Material properties of sheet and punch.

Part	Young modulus(GPa)	Poisson's ratio	Density $\left(kg/_{m\text{^}3}\right)$	Yield Stress(MPa)	K(MPa)	N
Punch	200	0.29	7800	-		
Blank	97	0.33	8940	45.7	297.8	0.4574

Table.3. Material properties of rubber [7].

Polyurethane rubber	Hardness Shore A(°)	C10(MPa)	C01(MPa)	D1	Poisson's ratio
	75	0.942999882	0.310333528	0.000779341	0.499399

Regarding to axis-symmetrical model, all degrees of freedom in rubber holder have been fixed. In all mating parts, surface to surface contact has been defined. Coefficient of friction has been set on 0.05 [9]. Upper surface of punch has been fixed on x and θ_z directions. For superposing punch speed and ultrasonic vibration on punch, special user subroutine (DISP user subroutine) has been used. Before punch and sheet contacts, punch displacement has been fixed. After punch and sheet contacts, displacement of punch has been calculated from Eq.1. In Eq.1, punch speed has been fixed on 8 m/s.

$$y = -8t - A\sin(\omega t) \qquad (1)$$

where, t is time, A and ω are amplitude and circular frequency of ultrasonic vibration respectively. Blank holder and spacer have been fixed on x and θ_z directions. Along y directions, sheets can move upward. Upward movement of sheets can occur once the contact between sheets and rubber is obtained. Element properties are shown in Table.4. In selecting size of element, mesh independent criteria has been considered. Hyper element was activate for modeling rubber. In modal analysis, 2^{nd} degree element has been selected in order to avoid analysis diverge.

Table.3. Element properties.

Part name	Element	Used method and properties element
Blank	CAX4R	A 4-node bilinear axisymmetric quadrilateral, reduced integration, hourglass control.
Punch (Harmonic and modal analysis)	CAX4R	A 4-node bilinear axisymmetric quadrilateral, hourglass control, reduced integration
Blank Holder, spacing, Rubber holder	Analytic al rigid	
Rubber	CAX6M H	A 6-node modified quadratic axisymmetric triangle, hybrid with linear pressure

3- RESULTS AND DISCUSSION

Figure 4 shows the Von-Mises stress distribution in brass sheet and rubber during the forming process. As it is noticed, as the sheet is surrounded by the rubber matrix, the formability of edges can be greatly improved.

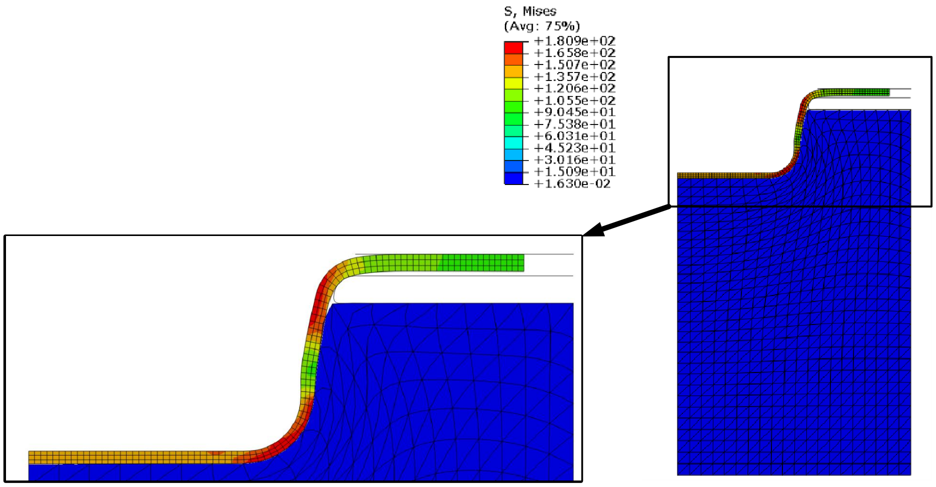

Fig.4 . Von Mises's stress distribution

The effect of ultrasonic vibration on punch force in deep drawing process is depicted in Fig. 5. The dashed line refers to traditional deep drawing, while the solid one relates to the ultrasonic vibration aided approach. As can be clearly noticed in the first technique, due to the high friction between surfaces, there is a significant limit to the punch displacement due to the higher force needed to perform the operation. In this condition the risk of die damaging and sheet rupture becomes high. The use of ultrasonic vibration has beneficial effects allowing a reduction of friction and providing the so called "acoustic-softening phenomena" (Blaha effect). In this case the force exerted by the punch is about 30% less than in traditional deep drawing process, thus allowing an higher deformation of the sheet (about +60%).

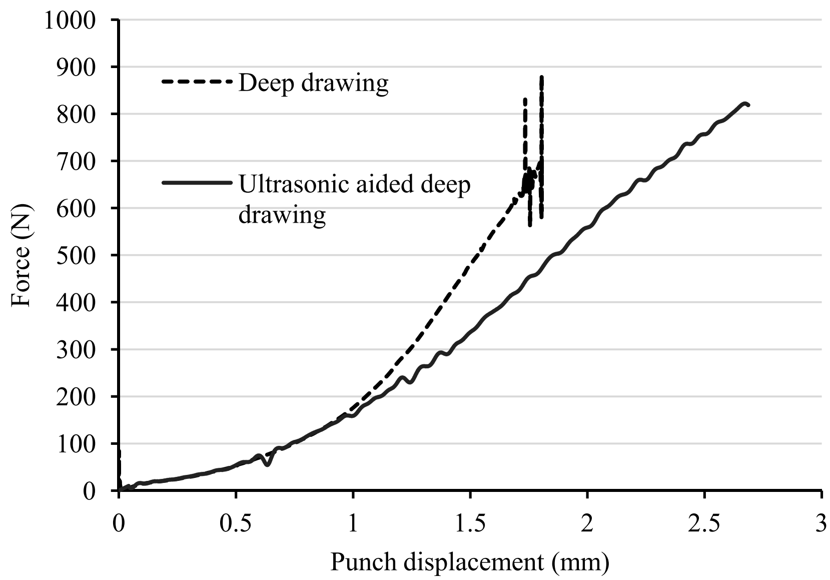

Fig.5 . Effect of ultrasonic vibration on punch force.

Figure 6 shows final deep drawing work piece for different vibrational frequencies and amplitudes. Changing frequency with same amplitude has not considerable effect on residual strain, while increasing the amplitude of ultrasonic vibration a significant benefit is noticed.

Considering *h* the drawing depth and *t* the minimum thickness of workpiece, it is interesting to estimate which is the maximum ratio h/t that is achievable for this technique. Figure 7 shows that ultrasonic vibration strongly increases the limit with respect to traditional technique and a strong relationship with the amplitude of vibration is noticed.

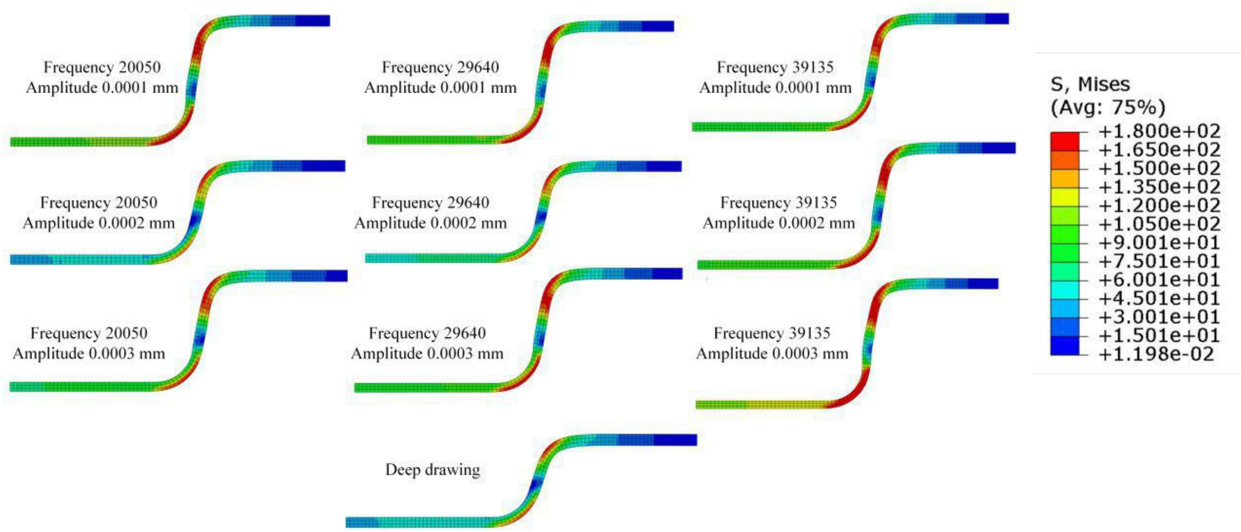

Fig.6 . Final end work piece in different deep drawing conditions.

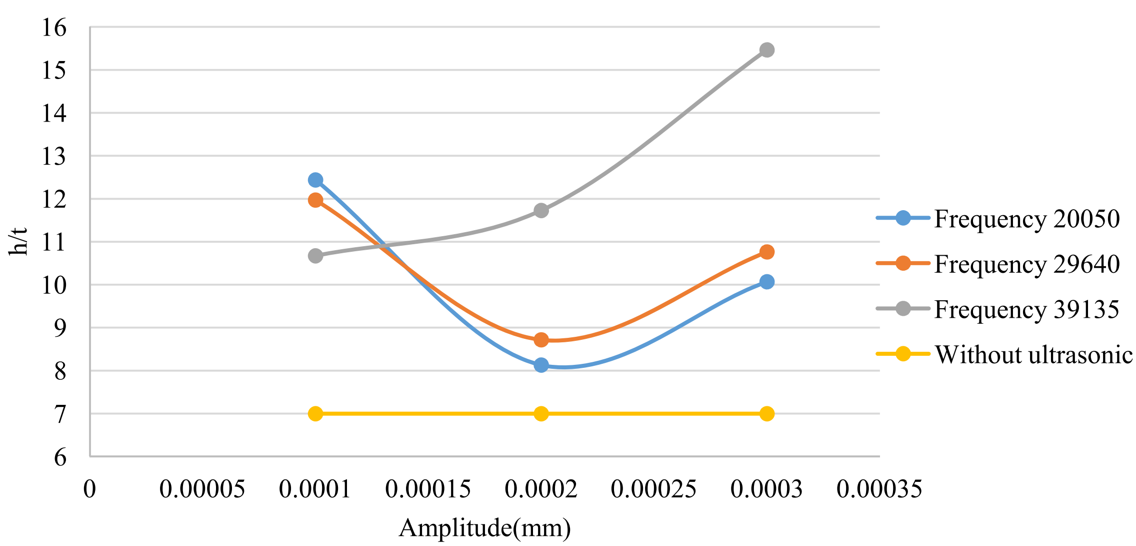

Fig.7 . Effect of ultrasonic vibration on h/t ratio.

Similar result can be obtained evaluating the minimum thickness of the workpiece that can be manufactured. Figure 7 shows the effects of amplitude and frequency of ultrasonic vibration on the minimum thickness of final work piece. As it can be predicted, because of increasing in drawing limit, best performance can be obtained for higher frequency and high amplitude.

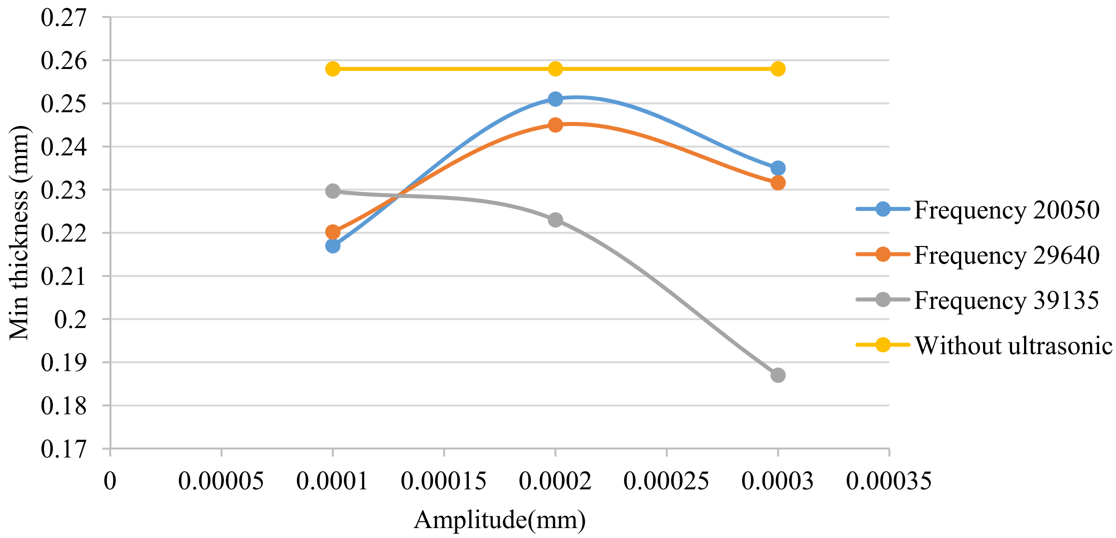

Fig.8 . Effect of ultrasonic vibration on minimum thickness.

4- CONCLUSION

In this paper, effect of ultrasonic vibration on soft die deep drawing process was numerically studied. In this work punch was made of steel and matrix was made of rubber. Brass sheet was formed due to deep drawing process. Three punches were designed to have resonance frequency approximately on 20, 30 and 40 kHz in order to study effect of vibrational frequency and amplitudes on this process. Results showed that a considerable decrease on forming forces were occurred because of applying ultrasonic vibration. By increasing amplitude and frequency drawing limit was increased too.

REFERENCE

[1] Browne, David J., and Emil Battikha. "Optimisation of aluminium sheet forming using a flexible die." Journal of materials processing technology 55.3-4 (1995): 218-223

[2] Hassan, M. A., N. Takakura, and K. Yamaguchi. "Friction aided deep drawing of sheet metals using polyurethane ring and auxiliary metal punch. Part 1: experimental observations on the deep drawing of aluminium thin sheets and foils." International journal of machine tools and manufacture 42.5 (2002): 625-631.

[3] Peng, Linfa, et al. "Investigation of micro/meso sheet soft punch stamping process–simulation and experiments." Materials & design 30.3 (2009): 783-790.

[4] Liu, Yanxiong, et al. "Studies of the deformation styles of the rubber-pad forming process used for manufacturing metallic bipolar plates." *Journal of Power Sources* 195.24 (2010): 8177-8184.

[5] Ramezani, Maziar, and Zaidi Mohd Ripin. "Analysis of deep drawing of sheet metal using the Marform process." The International Journal of Advanced Manufacturing Technology 59.5 (2012): 491-505.

[6] Irthiea, Ihsan, et al. "Experimental and numerical investigation on micro deep drawing process of stainless steel 304 foil using flexible tools." International Journal of Machine Tools and Manufacture 76 (2014): 21-33.

[7] Irthiea, Ihsan K., and Graham Green. "Evaluation of micro deep drawing technique using soft die-simulation and experiments." *The International Journal of Advanced Manufacturing Technology* 89.5-8 (2017): 2363-2374.

[8] Sheykholeslami, M. R., Hojjat, Y., Cinquemani, S., Ghodsi, M., & Karafi, M. (2016). An approach to design and fabrication of resonant giant magnetostrictive transducer. *Smart Structures and Systems*, *17*(2), 313-325.

[9] Golmakani, Hamid, et al. “Experimental and numerical investigation of the important parameters in deep drawing square sections two-layer sheet with rubber matrix.” Modares Mechanical Engineering, Vol. 16, No. 2, pp. 79-87, 2016 (in Persian)