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Review paper

Fabricating by elastomeric tools: A review of development in Iran

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Abstract

In recent years, most industries such as the aerospace, automotive, and others have been pushed to methods for reducing costs. One of these methods is the Rubber Pad Forming (RPF) process, which has been given more attention as a low-cost method than conventional methods. In RPF, unlike conventional methods which mainly use metals as tools, one of the tools will be made of elastic pads. The RPF process has attracted the attention of many researchers around the world. Researchers from Iran started their work in this field around 2001 and subsequently published several remarkable articles. The first published Iranian study of the RPF process dates back to 2003, indicating that the use of flexible tools has a history of two decades in Iran. However, in the last decade, the number of published Iranian articles in the RPF process field and the introduction of new methods based on RPF and its simulation has increased. This review article aims to outline Iran's involvement in the RPF process, and it emphasizes that Iranian researchers predominantly contribute to the RPF process through simulation, experimental endeavors, and the introduction of innovative methods utilizing flexible tools.

1. Introduction

Since the 1930s, flexible tools have been utilized industrially in the forming, this process is used to produce parts from sheets and tubes. According to the Web of ScienceTM website, about 200 researchers from more than 38 countries participated in developing elastomeric tools in various ways. Although the first use of elastomeric tools dates back to 1872 (but the first patent was in 1938) [1], this method has been used among Iranian researchers since 2003 [2]. Contrary to the late start of Rubber Pad Forming (RPF) research in Iran, based on the total number of articles published in this field (about 161 articles), Iran is now ranked 4th in the world, 3rd in Asia, and 1st in the Middle East (see the Web of ScienceTM). Studies show that Iranian researchers have published about 9 % of all articles in this field. It should be noted that research in the field of Rubber-Pad Forming is still in progress worldwide [3–6].

By applying pressure in this process, the rubber transfers pressure to the sheet or tube and shapes it according to the die cavity. The imposition of hydrostatic pressure in this process is similar to the hydroforming process. However, the challenges in the hydroforming process, including problems related to sealing and leakage of high-pressure fluid, as well as the high cost of hydraulic equipment [1] have caused the RPF process considered a competitor for the hydroforming process. Currently, the RPF process can be used to produce sheet and tube parts from various alloys such as copper, aluminum, steel, etc. An elastic interface is used instead of fluid in the rubber pad forming process, eliminating sealing problems. Also, in this process, good results can be achieved if the friction between the surface of the part and the surface of the rubber is controlled. Other advantages of the RPF process can be the point that this process is an economical and clean process due to no need for complex machines and the entrance and outlet oil from the part. Fig. 1 shows a schematic of the RPF process for sheets and tubes.

In addition to using the rubber pad forming process for the items mentioned, Iranian researchers have combined elastomeric tools with other methods to improve and optimize them, which will be mentioned in this article.

1.1. Elastomers and hyperelastic models

Elastomers (or rubber materials) have been used for nearly 150 years as engineering materials that have elastic behavior after deformation under pressure or tension i.e., return to their original shape by removing the load under ideal conditions. High strength under dynamic or static stresses, good abrasion resistance, impermeability to air and water, and resistance to chemicals are other properties of elastomers. Natural rubber, styrene-butadiene rubber, silicone rubber, and polyurethanes are elastomers used in RPF processes.

In large deformations of elastomers, hyperelastic nonlinear models approximate the relationship between stress and strain. In general, the behavior of a hyperelastic material can be expressed as a strain energy function in polynomial form as follows [1].

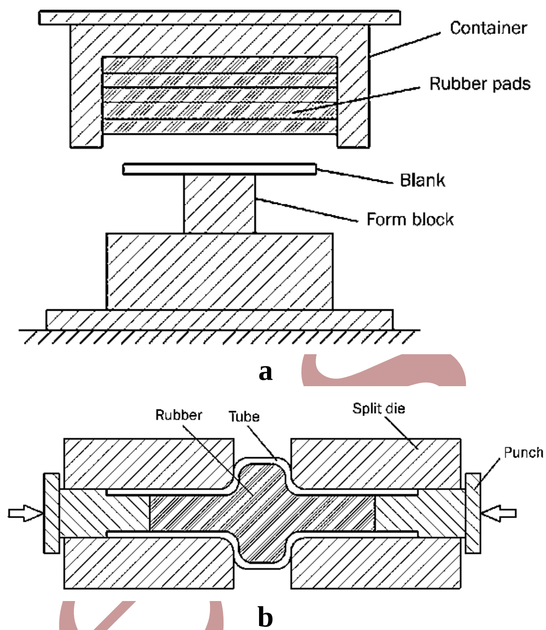

Fig. 1. Schematic of the rubber pad forming (RPF) process; a) sheet metal forming, b) tube forming [1]

$$W = \sum_{i+j=1}^{N} c_{ij} J_1^i J_2^i + \sum_{i=1}^{N} \frac{1}{D_i} J_3^{2i} \qquad (1)$$

where c_{ij} and D_i are the constants of material and J is the invariant of the deformation tensor. Models such as Arruda-Boyce, Mooney-Rivlin, Neo-Hookean, Ogden, polynomial, reduced polynomial, Yeoh, and Van der Waals are used to illustrate this function [1]. The selection of the appropriate model depends on various factors, including the application type, strain rate, and the availability of necessary data derived from uniaxial and biaxial pressure tests. Table 1 displays the elastomers employed by Iranian researchers as flexible tools, accompanied by their corresponding hyperelastic nonlinear models. According to Table 1, it can be said that most Iranian researchers have chosen polyurethane as a flexible tool, which is a logical choice due to the properties of polyurethane compared to other elastomers (such as high wear resistance and load-bearing capacity).

Considering the types of hyperelastic functions mentioned in the previous section, it seems that the finite element (FE) modeling of the RPF process has a certain complexity. On the other hand, in commercial software, these different functions exist for modeling hyperelastic materials. Research by Iranian researchers has shown that most of them have used ABAQUS commercial software and the Mooney-Rivlin model for elastomer modeling (see Table 1). In modeling elastomer with the Mooney-Rivlin model, we are faced with two coefficients C_{01} and C_{10}, which accurate calculation of these coefficients is one of the influential factors in increasing the accuracy of the simulation results. Sedighi et al. [7] have presented how to calculate these coefficients using the experimental results of the stress-strain curve obtained from the polyurethane compression test.

2. Elastomeric tools

In contemporary efforts to curb greenhouse gas emissions and minimize fuel consumption, significant emphasis is placed on reducing the weight of vehicles. This is achieved by substituting solid components with lightweight tubes and sheets. Consequently, the adoption of advanced sheet and tube forming techniques has seen widespread development. In conventional methods, a set of rigid dies is used for imposing the desired plastic deformation on raw material. So, requiring different dies to produce parts with various geometric shapes, and designing and fabricating new dies has a high time and cost. As a result, to reduce design and construction costs, the development of flexible tooling methods can be considered as a suitable solution. In recent years, many innovations have been made by various researchers to increase forming process flexibility, and Iranian researchers are no exception.

Table 1. Elastomers used in research of Iranian researchers

Specimen	Rubber	Hardness (shore A)	Process	Exp./ Theo./ Num.	Hyperelastic models	Year	Ref.
Sheet	PU	70	Bending	Exp.	----	2011	[8]
	PU	---	Deep drawing	Exp.	----	2017	[9]
	PU	----	Free bulging	Num.	Mooney-Rivlin	2017	[10]
	PU	----	Continuous roll bending	Theo. & Exp.	Linear elasticity formulation	2011-2012	[11–13]
	PU	80	Deep drawing using a multi-point forming process with elastomer Pads	Exp. & Num.	Mooney-Rivlin	2013	[14]
	PU	85	Rubber pad forming	Exp. & Num.	Mooney-Rivlin	2015-2017	[15–22]
	PU	90	Rubber pad forming (tailor welded sheets)	Num. & Exp.	Mooney-Rivlin	2012	[23]
	PU	40, 55, 65, 90	Semi-stamp rubber forming	Exp.	----	2017	[24, 25]
	PU	70	Rubber pad forming	Num. & Exp.	Mooney-Rivlin	2017	[26]
	NR	61	Rubber pad forming	Num. & Exp.	Mooney-Rivlin	2013	[27]
	PU	75	Deep drawing	Num.	Mooney-Rivlin	2018	[28]
	PU	90	Rubber pad-constrained groove pressing (RP-CGP) process	Num. & Exp.	Mooney-Rivlin	2012	[29]
	PVC & PU	----	Rubber pad forming	Exp. & Theo.	-----	2016	[30]
Tube	PU	85	Free bulging & cam-shaped tube	Exp. & Num.	Mooney-Rivlin	2017, 2018	[31, 32]
	SBR	70	Bulging	Exp. & Num.	Mooney-Rivlin	2010	[33]
	PU	85	Free bulging	Num.	Mooney-Rivlin	2015-2016	[34–36]

2.1. Sheet forming with elastomeric tools

One of the flexible tools applications has been used in the research of Bagheri et al. [8], which investigated the effect of bending length and die radius on springback in 135° bending using an elastomeric tool. This type of bending is used in the first stage of the hemming process in the automotive industry. The traditional method requires two stages for 135° bending (bending 90° and then bending 45°). They observed that this type of bending could be performed in one bending step using an elastomeric tool with a hardness of 70 Shore A (see Fig. 2).

Table 2 presents the research conducted in the field of sheet forming using elastomeric tools in recent years in Iran. This Table indicates the interest of Iranian researchers in this field.

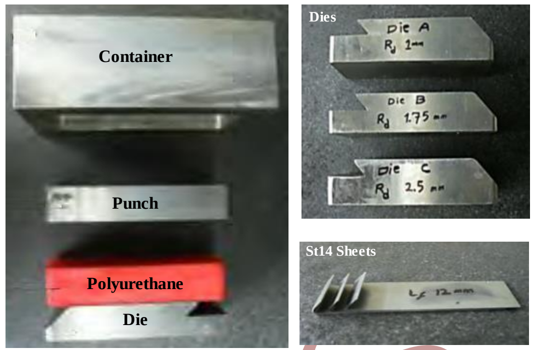

Fig. 2. Set-up of 135° bending die with the flexible tool as well as dies and bent sheets [8]

Table 2. Research conducted in Iran on sheet forming with elastomeric tools

Sheet (thickness)	Process	Target	Exp./ Theo./ Num.	Conclusion	Year	Ref.
St14 (0.6 mm)	Bending	Investigation of the influence of flange length and die radius on spring-back (SB)	Exp.	SB will be increased when the die radius increases and the flange length decreases	2011	[8]
Steel plate (1 mm)	Continuous roll bending	Elastic and plastic analysis	Theo. & Exp.	Equations solved analytically for elastic & plastic bending. Also, investigation effects of the process parameters	2011	[11–13]
AA2024 (1 mm)	Multi-point forming	Investigation of deep drawing using a multi-point forming process	Num. & Exp.	Multi-point forming with RP can be used as an effective and economic method for producing production	2012	[14]
Prue AL	RP-CGP	Investigation of rubber pad-constrained groove pressing process	Num. & Exp.	Significant increase in mechanical properties, but the ductility was reduced. Die with a larger groove angle better to grain refinement and mechanical properties but decreased uniformity of strain	2012	[29]
AL (1 mm)	Rubber pad forming	Study of parameters affecting metal forming using rubber pads, on parts with the radius of curvature	Num. & Exp.	Analyzed the effect of variables such as curvature radius, sheet and rubber thickness, rubber hardness, lubrication condition, springback	2013	[27]
AA6061-T6 (0.5 - 1.5 mm)	Rubber pad forming	Formability investigation of tailor welded blanks (TWB)	Num. & Exp.	Comparing conventional and RPF processes shows that using RPF causes a reduction in formability	2014	[23]
SS316 (0.1 mm)	Rubber pad forming	Lubricant effect on depth filling of metallic bipolar plates (MBP) with concave and convex patterns	Exp.	Polypropylene nylon will be the best alternative for the production of BP due to its high tensile strength and low thickness	2015	[15]
SS316 (0.1 mm)	Rubber pad forming	Dimensional accuracy of metallic bipolar plate's microchannel	Num. & Exp.	By increases in punch load, hardness, and thickness of the	2015	[17]

				rubber layer the dimensional accuracy increase		
SS316 (0.1 mm)	Rubber pad forming	Study of the die patterns in RPF process for the production of metallic bipolar plates	Exp.	In an equal magnitude of force, a die with a convex pattern shows more depth of filling.	2015	[18]
GI & Al (0.6 to 1.5 mm)	Rubber pad forming	Teflon-pad forming on circular metal blanks using a concave die	Exp.	When groove width of the die enhances, bending radius of A part of blank that is over the groove increases; so, the forming load decreases.	2015	[30]
SS316 (0.1 mm)	Rubber pad forming	Effect of rubber layers thickness on forming of bipolar plate's microchannel	Num. & Exp.	With increasing punch load and thickness of the rubber layer, the channel depth and filling percentage increased	2016	[16]
SS316 (0.1 mm)	Rubber pad forming	Integration of FEM & DOE for the investigation of critical factors in the RP forming of MBP for PEM fuel cells	Num. & Exp.	Nou-uniform thickness distribution and damage reach maximum values at the corners of channels. The critical parameters are the outer corner radius, draft angle, and friction coefficient	2016	[26]
SS316 (0.1 mm)	Rubber pad forming	Manufacturing metallic bipolar plate (MBP) fuel cells	Exp.	The convex die would create a deeper channel. Increases in forces rise filling depth of channels. The best possible version of BP in both convex and concave models formed.	2016	[22]
GI & Al (0.6, 1.1 & 1.5 mm)	Rubber pad forming	Shaping process of circular metal blanks into quasi-cup	Exp. & Theo.	A direct relationship between the forming energy and flow stress of the blanks. Also, the forming energy of a blank with PVC is higher than polyurethane; and the probability of wrinkling decreases when used PVC	2016	[30]
SS316 (0.1 mm)	Rubber pad forming	Investigation of die clearance in RPF of metallic bipolar plates	Num. & Exp.	By increasing the depth of bipolar plate channels, using die sets with lower clearance are better due to the increasing the rubber pad life	2017	[20]
AA1050 (1 mm)	Conical deep drawing	Investigation of different friction conditions	Exp.	The depth and the rupture location are different according to the type of lubricant	2017	[9]
PMMA (3 mm)	Free bulging	Improving the optical quality of poly methyl methacrylate (PMMA)	Num.	Produced the sheet with uniform thickness distribution	2017	[10]
SS316 (0.1 mm)	Rubber pad forming	Investigation of fracture in bipolar plate's micro channels	Exp.	The new method was successful to prevent from fracture and formability increased by machining the rubber pad	2017	[24]
SS316 (0.1 mm)	Semi-stamp rubber forming	Fabrication of metallic bipolar plates in PEM fuel cell	Exp.	The developed model could be a feasible technique for fabricating metallic bipolar plates	2017	[25]
Cu	Deep drawing	Study of the ultrasonic vibration in deep drawing process of circular section with rubber die	Num.	Increasing A & F of ultrasonic vibration can profitably increase limits on the forming force and ensure better execution of the process	2018	[28]
SS316 (0.1 mm)	Rubber pad forming	Investigation of failure during RPF of metallic bipolar plates	Num. & Exp.	Investigate the onset of fracture in different conditions. To achieve 100 % filling percentage, draft angle, corner radius, and the ratio of w/h	2020	[21]

				should be set to 15°, 0.2 mm, and 1.6, respectively		
SS316 (0.1 mm)	Rubber pad forming	Investigated parameters (punch force, hardness, the thickness of the rubber layer, wrinkling, etc.) in the fabrication of metallic bipolar plates	Num. & Exp.	Rubber blank holder reduces the wrinkles around the bipolar plate. exist a direct relationship between the channel depth and the applied force (to achieve a greater channel depth, the applied force and the rubber hardness should be increased accordingly).	2023	[37–39]
TWBs (0.2-0.4 mm)	Rubber pad forming	Simulation and investigation effects of friction, sheets thickness (composed of the Tailor Welded Blanks), and the force applied on the maximum displacement of the weld line	Num.	Increasing sheet thickness enhances the blank holding forces applied, reducing friction between the TWB & punch, and reducing the maximum amount of weld line displacement. In addition, enhancing the thickness ratio of TWBs raises the maximum weld line displacement.	2022	[40]
SS316 (0.1 mm)	Rubber pad forming	Study the effect of the rubber layer on the manufacture of the metallic bipolar plate	Exp.	The channel maximum depth decreases with enhancing the rubber hardness. On the other hand, with a large reduction in the rubber layer's hardness, it would be difficult to provide the pressure for applying the plastic deformation on the sheet metal.	2022	[41]

In one of the research mentioned in Table 2 improving the quality optical of Poly Methyl Methacrylate (PMMA) sheets using rubber pad forming has been investigated by Rezaei et al [10]. The flatness of the workpiece surface and the absence of distortion, as well as the shear strain distribution, are factors that affect the quality of transparent polymer products. The image of the objects would be clearer if the thickness distribution in the PMMA sheet was more uniform. On the other hand, shear strain indicates the sheet layers' movement on each other during deformation, and less movement of these layers on each other causes less light refraction or deviation. consequently, the image deviation behind the workpiece decreases [42]. For this reason, a product with good optical quality can be achieved if the thickness distribution and shear strain of the workpiece can be controlled. Their idea to control the distribution of thickness and strain in the sheet is to use the RPF method. For this purpose, a rubber (polycarbonate (PC)) with properties close to the sheet is placed under it, and during forming, air pressure is applied to the rubber instead of the sheet. As the set-up cools and the air pressure stops, the rubber returns to its original shape, but the sheet retains its final shape due to plastic deformation. In the RPF method, the whole surface of the sheet and the rubber are in contact with each other from the beginning, and the deformation is done uniformly. Fig. 3 illustrates the final cross-section of the PMMA sheet produced and the set-up forming, as well as the profile resulting from the RPF process simulation with different sections of rubber.

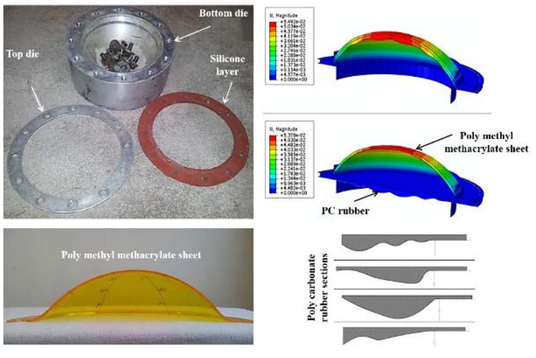

Fig. 3. Simulation, the different cross-sections of rubber, the die components, and the cross-section of the final product obtained from the free bulging process of the PMMA sheet with elastomeric tools [10]

As shown in this Figure, the upper surface of the rubber is smooth and polished and is ideally in direct contact with the sheet, but the lower surface is designed with variable thickness in different places. It seems that to reduce or increase the sheet thickness at one point, it is possible to use a change in the rubber thickness at the same point [10].

2.2. Tube forming with elastomeric tools

Industrial parts production from metal tubes to increase the strength-to-weight ratio of structures and significantly reduce vehicle fuel consumption, production of integrated parts, and increasing surface quality has led researchers to advanced forming processes with flexible dies (fluid or rubber). At present, the forming research team at the Shahrood University of Technology in Iran, led by Gerdooei, is conducting the most comprehensive research on tube forming using elastomeric tools. The experimental and numerical free bulging process of SS 304 seam-welded tube using a polyurethane elastic pad and the comparison of this process with the hydroforming (HF) process is an example of the research done by this team [43, 44]. They used of Forming Limit Diagram (FLD) ductile damage criterion at finite element method (FEM), and by comparing the strain of sound points on the strain plane in both processes, it found that the points were significantly higher than the FLD curve of the tube hydroforming process. This comparison shows that the tube forming limit has increased in the RPF process (Fig. 4) due to an enhancement in contact pressure. Investigating the factors affecting the tube bulging process with elastomeric tools [35] and the feasibility of producing a hollow cam-shaped tube using elastomeric tools [32] are other research of this team. Table 3 shows the research conducted on tube forming by using a rubber pad by Iranian researchers.

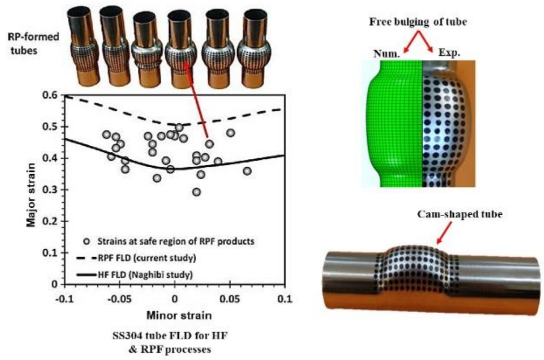

Fig. 4. The FLD of SS 304 tube of HF and RPF processes, as well as expanded tubes with elastomeric tool freely [44] and cam-shaped [32]

An overview of the published articles in Iran on tube and sheet forming using flexible tools reveals that the research conducted in the field is predominantly focused on sheet forming, accounting for 79%, while tube forming comprises 21% (refer to Fig. 5). Based on Fig. 5, it is evident that a significant portion of research by Iranian scholars is concentrated on integrating modeling and experimental works. This correlation may be attributed to the section dedicated to validating published results, a prerequisite for article publication. On the other hand, easy access to a wide range of commercial software (due to the lack of an international copyright agreement in Iran) and the lack of costs can also be effective. It can be said that in recent years, the allocation of funds for experimental research work has made Iranian researchers more interested in this direction.

3. Results and discussion

3.1. Elastomeric tools in the development of other processes

In recent years, numerous innovations have been introduced by various researchers to enhance the flexibility of forming processes. Iranian researchers have contributed to this effort by utilizing elastomeric tools to develop processes. Some of the notable research in this regard includes:

Table 3. Summary of research conducted in Iran for tube forming with elastomeric tools

Tube (thickness)	Process	Target	Exp./ Num.	Conclusion	Year	Ref.
St37 (2 mm)	Bulging	Local contraction of the tube for assembly in the vehicle structure	Exp. & Num.	The RPF can be used to connect tubes/pipes with different materials	2010	[33]
SS304 (0/75 mm)	Free bulging	Study of friction in free bulging	Exp. & Num.	The intact parts formed using nylon lubricant (between tube & rubber) and drawing oil (between tube & die)	2015	[34]
SS304 (0/75 mm)	Free bulging	Investigation of effective Parameters & presentation of the optimal values	Num.	Significant parameters are the friction (between tube & rubber), rubber height, punch displacement, and tube axial feeding	2016	[35]
AA1050 (1 mm)	Free bulging	Investigation of aluminum tube bulging on different loading curves	Exp.	Different loading curves were applied by changing the initial tube length & constant length for the urethane rod. Can product sound parts by varying length of tubes and changing the onset of applying axial feeding	2016	[36]
SS304 (0/75 mm)	Free bulging	Study on formability; A comparison between HF & RPF	Exp. & Num.	Due to friction in RPF versus HF, the formability of the tube meaningfully improved	2017	[31]
SS304 (0/75 mm)	Bulging	Produce the cam-shaped tube using RPF versus HF	Exp. & Num.	Using HF versus RPF easier fill the small radius of the die	2017	[32]
C12200 Cu (0.75 mm)	Bulging	Study various parameters on the process of T-shaped bulging	Exp. & Num.	the friction coefficient between die and the tube decreases and as the die corner radius increases, the longer branch could be formed.	2017	[45]

A) Elastomeric tools in multi-point forming

In the multi-point forming process, the pins operate independently, allowing for easy adjustment. By controlling the height of the pins, it becomes possible to generate continuous surfaces with varying curvatures. Using the above technology, the production time of a particular product is significantly reduced, due to the lack of need to design and manufacture a new die, as well as the simplicity and high-speed reform at the multi-point forming dies. Vafaei et al. [14] have investigated the feasibility of the multi-point forming method in deep drawing of AA2024 parts with elastomeric tools. They examined the effect of parameters such as pin diameter and elastomer layer thickness on the thickness distribution and dimensional accuracy of the produced parts. Also, they compared the results obtained from the FE simulation and experiments (Fig. 6). As depicted in the figure, the concentrated force generated by each pin during operation leads to the formation of the most prevalent defect in the multi-point forming process, known as the indentation defect. To prevent this defect, the polyurethane layer has been used as a flexible interface between the sheet and pins surfaces. The final product exhibits excellent surface quality, with no observable indentation defects in both simulation and experimental results. Additionally, based on Fig. 6, the strain levels are reduced, and a more uniform strain distribution is achieved in the product compared to the formed sample without using a polyurethane layer. According to the results, the multi-point forming process can be used as an efficient and economical method to produce various types of parts with different shapes with just one die.

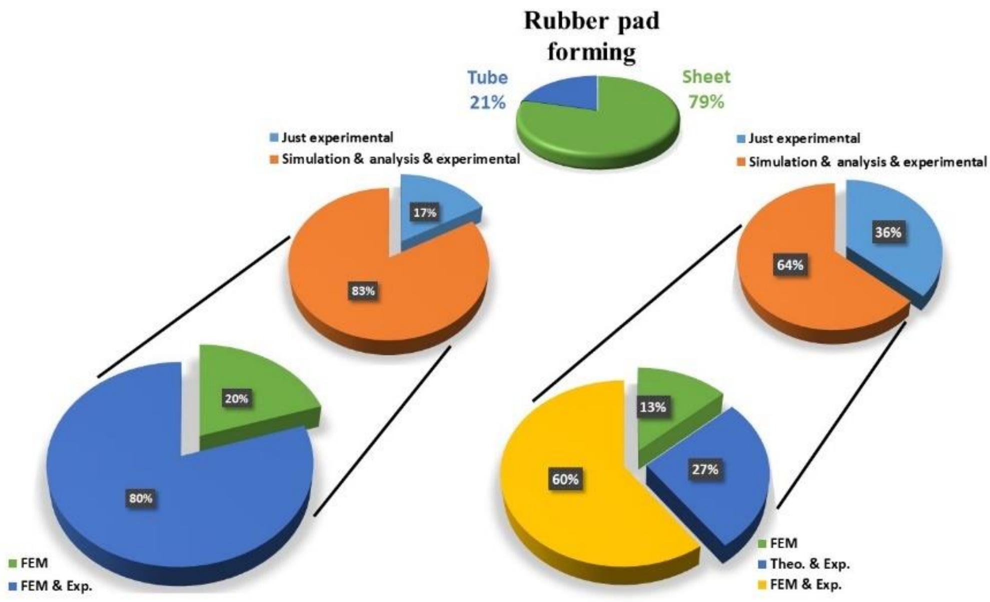

Fig. 5. The general division of published research on RPF in Iran, along with the distribution of experimental, numerical, and theoretical methods in each category

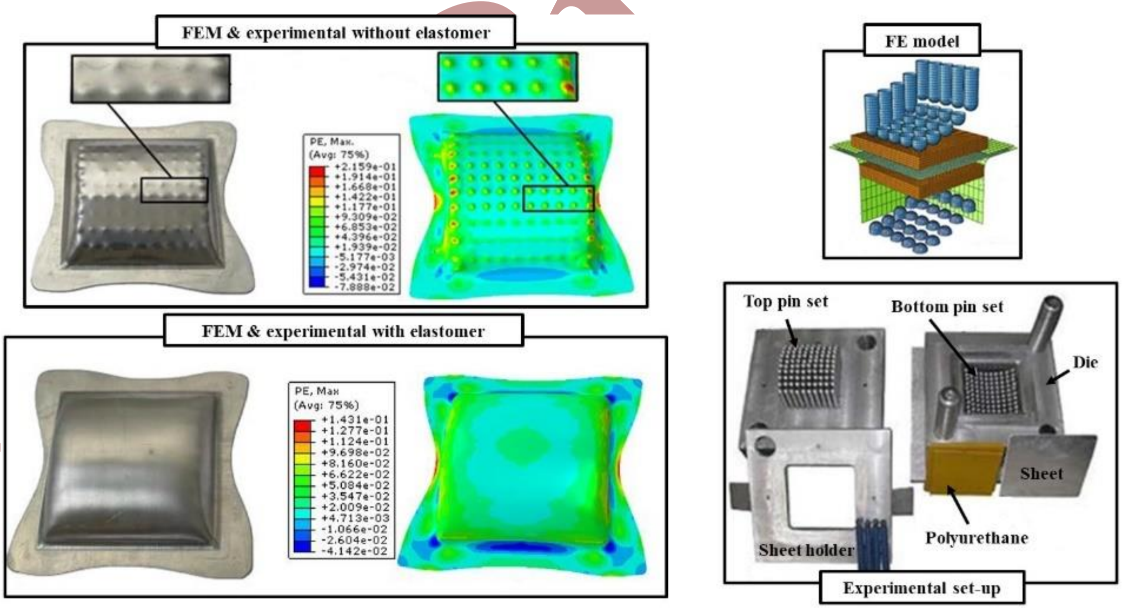

Fig. 6. Deep drawing of AA2024 under multi-point forming process with and without elastomeric tool as well as the set-up [14]

B) Elastomeric tools in the ECAP process

Due to the tendency of industry towards materials with a high strength-to-weight ratio, various methods of severe plastic deformation have been proposed to refine the materials and increase their strength. Iranian researchers have done a lot of research in this field [46]. On the other hand, the proposed techniques for tubular samples (such as Spin Extrusion (SE) and High-

Pressure Tube Twisting (HPTT) processes) have high complexity and cost. So, Iranian researchers have proposed a new method based on equipment simplicity and low cost to produce microstructured tubular specimens. In this method, they performed the equal channel angular pressing (ECAP) process on the tube by inserting a flexible elastomeric rod inside it under different conditions (see Fig. 7) [47–49]. The copper tubes with the flexible polyurethane rubber rod inside them successfully ECAPed up to four passes in different routes in the die with a 90° channel angle. Hardness measurements in the tubes show that the amount of hardness in them has increased, and the grain size has decreased by about 70% after four passes. However, by measuring the thickness at different points of the tubes, no change is observed. The impact of varying tube thicknesses on the effective strain, uniformity of strain distribution, and other parameters has been studied and detailed in references [40-42].

C) Rubber pad tube straining (RPTS)

The thin-walled structures are widely used due to the very high strength-to-weight ratio and the ability to absorb extraordinary energy. Lightweight and volume, availability, and cost-effectiveness are the advantages that have led to research on using these tubes to optimize energy absorption properties. Due to the need for tubes with a high strength-to-weight ratio in the industry, efforts have been made to produce them using the plastic deformation method. An Iranian researcher has proposed a novel method to address the question of whether it is possible to subject a specimen to severe deformation from another direction while keeping it fixed, aiming to eliminate defects and distortions caused by surface contact. The objective is also to achieve higher shear strains compared to previous methods. This innovative approach involves strengthening the tube using a central solid mandrel and rubber, as illustrated in Fig. 8 [50]. As shown in Fig. 8, the tube is retained by a cylindrical rubber, and a mandrel with a convex part in the center inserts into the tube. As a result, the initial diameter of the tube increases, and then, as the mandrel goes down, the tube returns to its original dimensions by rubber pressure. The results indicate that an effective plastic strain of approximately one can be achieved after a single process pass.
Additionally, the strain distribution demonstrates good homogeneity along the tube's thickness and length. It is also observed that the yield and ultimate stresses of aluminum tubes have increased from the initial values of 80 and 128 MPa to approximately 172 and 182 MPa, respectively. Also, Vickers hardness increased from 44 to 55 HV (for more detailed information, refer to reference [50]).

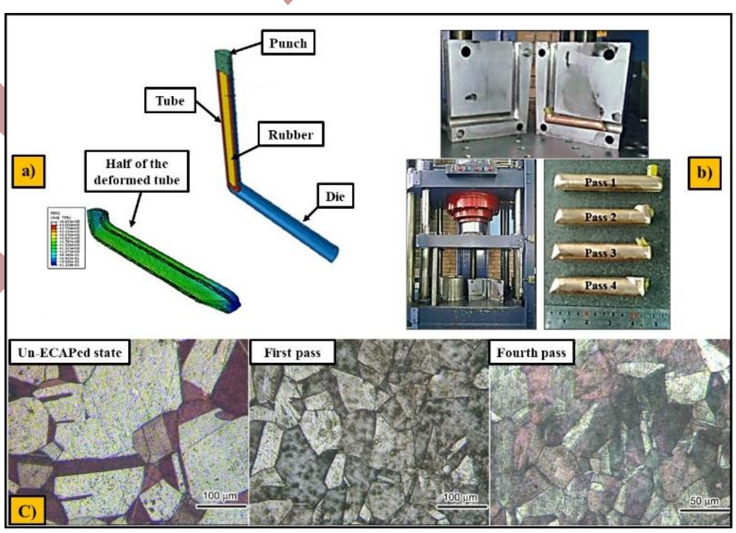

Fig. 7. a) The finite element model of the ECAP process with rubber rod; b) hydraulic presses, ECAP die, and ECAPed copper tubes with polyurethane rod inside them; c) microstructure of copper tube before, after one pass, and after 4 passes of ECAP with rubber rod [37- 39]

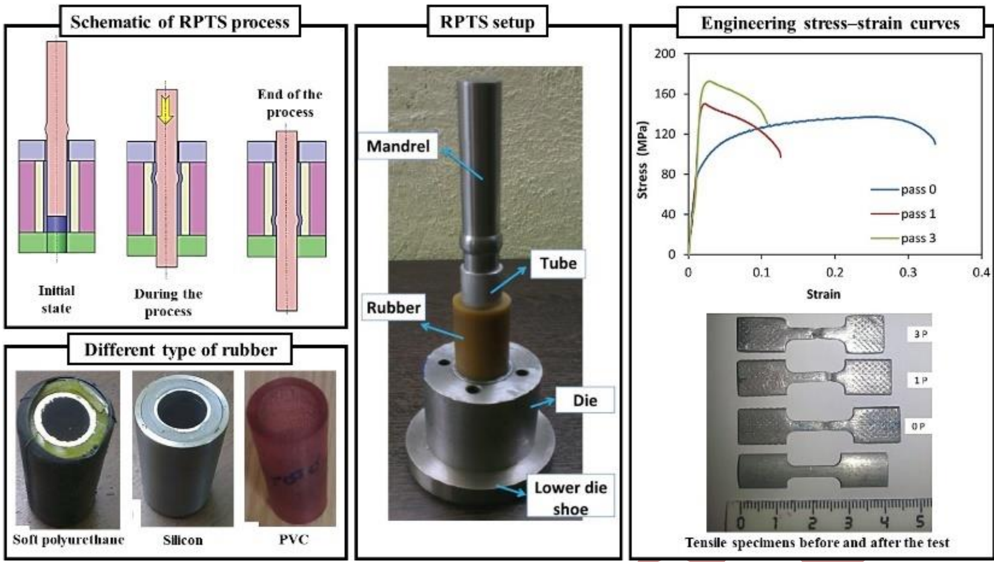

Fig. 8. Schematic of RPTS process as well as set-up forming, rubbers, and engineering stress-strain curve obtained from the tensile test before and after process [50]

4. Conclusions

One of the topics that Iranian researchers are interested in is the use of elastomeric tools in metal forming, both sheets and tubes. The first study on the Rubber Pad Forming (RPF) process in Iran was published in 2003. Subsequently, Iran's engagement in research on elastomeric tools has steadily expanded. A summary of the most important results of the current study is as follows.

- Iranian researchers have primarily contributed to the RPF process through simulation and experimental research, focusing on validating experimental works to enhance result accuracy.
- The subject matter of the published works indicates the substantial interest of Iranian researchers in incorporating elastomeric tools into industrial applications.
- Studies show that Iranian researchers, as residents of a developing country, seek to use elastomeric tools to develop other processes and even create new methods. Indeed, this will be accelerated if the research opportunities of Iranian researchers to cooperate with other countries improve, provide sufficient funding, and equip laboratories with advanced tools.

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