TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 68, Issue Special I, May, 2025

DESIGN AND MANUFACTURE OF A PIPE-CLAMPING DEVICE FOR EXPERIMENTAL ANALYSIS OF LONG THIN-WALLED-TUBULAR PARTS

Dinu Iacob POIANĂ, Mircea Dorin VASILESCU, Sergiu Valentin GĂLĂȚANU, Ioana IONEL

Abstract: *The aim of the paper is to carry out experimental verifications regarding the elasto-plastic deformation of round, thin-walled pipes. The paper has two goals. The first goal was to create a clamping device for long pipes. The second goal was to carry out specific experiments with this device, which would verify the calculation relation obtained in a previous theoretical research. The paper presents aspects related to the design and manufacture of the device. The experiments carried out are also presented, through which the elasto-plastic deformation that occurs when processing holes in long, thin-walled pipes was highlighted, and compared to the theoretical relation previously established. The conclusions presented confirm the achievement of the proposed goals, through 100% original contribution.*
Keywords: *Long pipes, thin-walled parts, elastic and plastic deformation, holes processing, pipe clamping devices.*

1. INTRODUCTION

In a previous research, the processing of long thin pipes was studied through cold plastic deformation procedures, and the interdependence relations between the main characteristic sizes of the processing of long thin pipes were established. [1], [2], [3]. In the present paper, the aim was to verify some relationships established in the previous activity, to validate the results obtained through theoretical research and mathematical modelling previously realized. In the future, one will follow the ways in which the present device can be improved and supplemented with other variants of pipe clamping devices, for the verification of more interdependence relations determined by theoretical research.

There are many cases in the industry when certain holes are required to be processed into pieces such as long pipes with thin walls. Quite often the process of making holes by cold plastic perforation is used. When processing holes in long pipes with thin walls, technological problems arise that affect the quality of these holes if the holes are located at a distance from the last part of the pipe [1].

Examples of such long thin-walled-tubular parts are found in the automotive and aeronautics fields (see Fig. 1, Fig. 2) [1], and also in various other industries for example for manufacturing storage shelves (Fig. 3) [2].

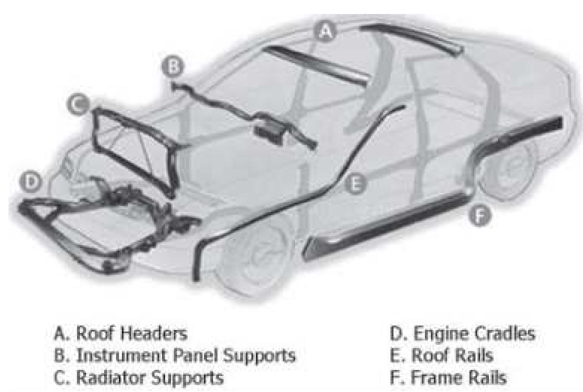


Fig. 1. Long tubular parts in the cars [1].

The technological problems that may arise are determined mainly by the quality of the holes obtained through various processing processes:

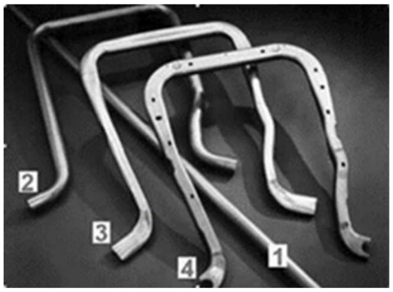


Fig. 2. Radiator supports for the cars [1].

Fig. 3. Long pipes storage rack components [2].

Drilling,
- Perforation in air environment,
- Electro erosion,
- Circular cutting with laser beam or jet/ plasma arc,
- Thermo-erosion [3],
- Hydro perforation.[4].

These processes are permanently in the attention of manufacturers worldwide. From the analysis of the mentioned procedures for the realization of holes in the tubular elements, more special problems with the perforation process arise, which can be solved with the help of stands. This process applied in the processing industries is suitable, having certain advantages:
- small processing time,
- the lack of heating of the material, without producing internal stresses after processing. But it has a disadvantage, as along, the pipe cannot be used for perforation of an ordinary two-edge stent meaning the punch and the cutting board, because one cannot insert a cutting board in the middle of the pipe. In such a case, only one nozzle can be used, meaning a punch, to perforate the pipe from the outside, for holes positioned away from the ends of the pipe.

In case of perforation of the pipe only with a punch, the problem of deformation of the pipe in the processing area of the hole can occur, by losing the stability of the pipe profile in the section where the hole is made. Because of this, other technological processes are used, different from single punch punching. These can be achieved either by local heating of the processing area (laser, plasma, thermo-erosion) [3], or others that generate a high processing time (electro-erosion processing), or require a high-cost device (hydro drilling processing) [4].

In recent years, concerns of researchers around the world, regarding the problems of using long tubes arrised [5], [6], [7].

An intensively studied problem concerns is the hydroforming process of tubular parts, and many research results have appeared in the specialized literature regarding the use of hydroforming in numerous industries [8], [9], [10], [11]. Also studies have been carried out using the Finite Element Method for research on hydroforming of long tubular parts [12].

2. RESEARCH DATA

2.1 Initial data

The research focused on designing and manufacturing a device that would allow the realization of holes in any area along a long pipe, under conditions of quality improvement, using the process of perforation with a single punch in air environment.

As an early point of research in the present article, certain results obtained in previous research were considered. In previous theoretical research, the single-punch perforation process was studied in terms of the influence of the type of device used, in three variants of clamping-fixing devices for round pipes [13], [14]. One applied the technique with a single edge of the action point outside the pipe.

For theoretical research, the Castigliano method was used to determine interdependence relations through theoretical calculations regarding punching with single punchin air medium. The theoretical results were obtained regarding the modification of the type of device used for processing holes by perforating pipes in the air environment.

For each type of device, a calculation formula was obtained to determine in which cases holes can be achieved by perforation in the air environment so as not to lose the stability of the pipe in the section where the hole is made. The relationship was determined for each type of pipe clamping device in the hole execution area to calculate the maximum diameters of the holes that can be executed so that the pipe does not lose its stability.

Through these calculation, relationships for the diameters of the holes made in pipes, depending on the external pipe diameter, the thickness of the pipe wall, and the strength of the pipe material were determined.

One of the types of devices considered in theoretical research is shown in Figure 4 and the computational relationship determined by theoretical research [6, 7] is shown further, in form of the relationship (1).

The calculation relation for the diameters of the holes that must be made along a long thin-walled pipe, for clamping the pipe with the type 1 device [12], [13], is presented below:

$$d \leq \frac{lg}{1{,}91\pi R}\frac{\sigma_{ai}}{\sigma_r} \qquad (1)$$

where:
d is the maximum diameter of the hole to be executed, in mm.
l - length of pipe clamping device in mm.
g- the thickness of the pipe wall, in mm.
R- radius corresponding to the external diameter of the pipe in a cross section, in mm.
σ_{ai}-permissible bending strength of the pipe material, in MPa.
σ_r-the breaking strength of the pipe material, in MPa.

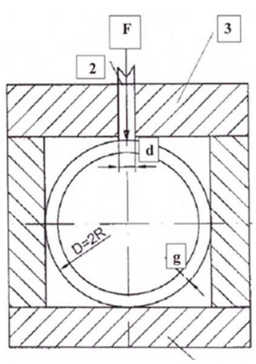


Fig. 4. Type 1 clamping device, according to [13], [14].

2.2 Considerations on experimental research

It was considered that the verification of theoretical results can be done by comparing some values determined by the calculation relations with corresponding values obtained by practical determinations. Thus, one proposed to determine the force values that can affect the stability of the pipe in the section where the hole is made. From the calculation relationship (1) it can be determined the increase of the deformation force at perforation and can be compared with the force size determined by practical measurements.

3. DEVICE ASSEMBLY CONCEPT

3.1 Design of the device

In this paper it was proposed to design and make a device that would allow the verification of theoretical results obtained in theoretical research in case of execution of holes in any area along a long pipe, as good quality as possible, by the procedure of perforation with single punch in air environment.

For this purpose, two devices have been designed and designed that comply withthe shape of the Type 1 device in Figure 4, allowing their use for a wide range of thin round pipes with external diameters from Ø15 mm to Ø60 mm.

Figure 5 shows the device designed for clamping and fastening round pipes with external diameters between Ø 15 mm and Ø 30 mm.

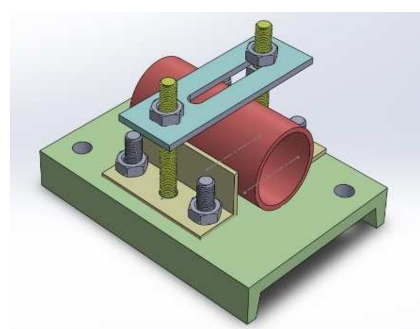


Fig. 5. Clamping device for external diameter pipe between Ø 15 mm and Ø 30 mm.

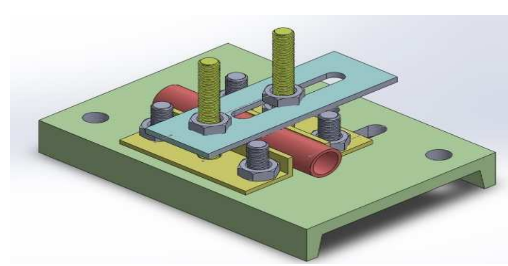


Fig. 6. Pipe clamping device for diameter pipe between Ø 30 mm and Ø 60 mm.

Figure 6 illustrates the device designed for clamping and fastening round pipes with diameters between Ø 30 mm and Ø 60 mm.

3.2 Manufacturing of pipe clamping device

Based on the model designed in SolidWorks, a device has been executed that has the characteristics of the design model. For this purpose, two devices were built, according to the project executed in SolidWorks, to be able to satisfy a wider range of pipes, with external diameters ranging from Ø15 mm to Ø60 mm, according to the design model.

Figure 7 shows the manufactured device and shows the principal components of the manufactured device, namely:

- a base plate noted 1, on which the tube to be studied is placed.
- two side parts noted 2, pipe clamping.
- a top plate noted 3, fixing the pipe at the top.

6 M10 screws and 10 M10 nuts.

4. APPLIED RESEARCH

4.1 Theoretical considerations

From the relation (2) the relation (3) results:

$$\pi d g \sigma_r \leq \frac{l g^2 \sigma_{ai}}{1{,}91 R} \qquad (2)$$

The following relations are considered further:

$$F_d = \pi d g \sigma_r \qquad (3)$$

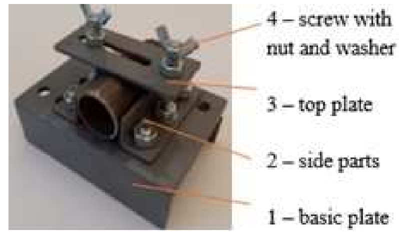
$$R = \frac{D_{ext}}{2} \qquad (4)$$

Then, through replacements of the relations (3) and (4) into relation (2), the relation (5) becomes:

$$F_d \leq \frac{2 l g^2 \sigma_{ai}}{1{,}91 D_{ext}} \qquad (5)$$

where:

F_d is the deformation force of the pipe in the pressing area, in MPa,
l - length of pipe clamping device in mm,
g- the thickness of the pipe wall, in mm,
D_{ext} - external diameter of the pipe, in mm,
σ_{ai} - permissible bending strength of the pipe material, in MPa.



a) pipe clamping device with external diameter Ø30 mm ÷ Ø60 mm highlighting its components.

b) the base plate of the device.

c) side clamping parts.

d) the upper plate of the device.

Fig.7. The device made and components of the pipe clamping device with the external diameter Ø30 mm ÷ Ø60 mm.

Based on the relation (5), calculations were achieved for the thickness of the pipe wall between 0,5 mm and 6 mm, for an allowable resistance to the coating of 150 MPa, and for the external diameter of the pipes of D_{ext} = 15, 20, 25, 30, 35, 40, 45, 50, 55, 60 mm. It was considered the length of the pipe clamping device l= 80 mm, the results obtained from the calculations are centralized in Table 1, for each value of the external diameter.

Table 1

Variation of the deformation force according to the pipe wall thickness for each value of the external diameter.

Pipe wall thickness g (mm)	1 D ext = 15 mm F_d (N)	2 D ext = 20 mm F_d (N)	3 D ext = 25 mm F_d (N)	4 D ext = 30 mm F_d (N)	5 D ext = 35 mm F_d (N)	6 D ext = 40 mm F_d (N)	7 D ext = 45 mm F_d (N)	8 D ext = 50 mm F_d (N)	9 D ext = 55 mm F_d (N)	10 D ext = 60 mm F_d (N)
0.5	209.4	157.1	125.7	104.7	89.8	78.5	69.8	62.8	57.1	52.4
1.0	837.7	628.3	502.6	418.8	359.0	314.1	279.2	251.3	228.5	209.4
1.5	1884.8	1413.6	1130.9	942.4	807.8	706.8	628.3	565.4	514.0	471.2
2.0	3350.8	2513.1	2010.5	1675.39	1436.1	1256.5	1116.9	1005.2	913.9	837.7
2.5	5235.6	3926.7	3141.4	2617.8	2243.8	1963.4	1745.2	1570.7	1427.9	1308.9
3.0	7539.3	5654.5	4523.6	3769.6	3231.1	2827.2	2513.1	2261.8	2056.2	1884.8
3.5	10261.8	7696.3	6157.1	5130.9	4397.9	3848.2	3420.6	3078.5	2798.7	2565.4
4.0	13403.1	10052.4	8041.9	6701.6	5744.2	5026.2	4467.7	4020.9	3655.4	3350.8
4.5	16963.4	12722.5	10178.0	8481.7	7270.0	6361.3	5654.5	5089.0	4626.4	4240.8
5.0	20942.4	15706.8	12565.4	10471.2	8975.3	7853.4	6980.8	6282.7	5711.6	5235.6
5.5	25340.3	19005.2	15204.2	12670.2	10860.1	9502.6	8446.8	7602.1	6911.0	6335.1
6.0	30157.1	22617.8	18094.2	15078.5	12924.5	11308.9	10052.4	9047.1	8224.7	7539.3

By correlating with the data in Table 1, the diagram in Figure 8 was obtained**.**

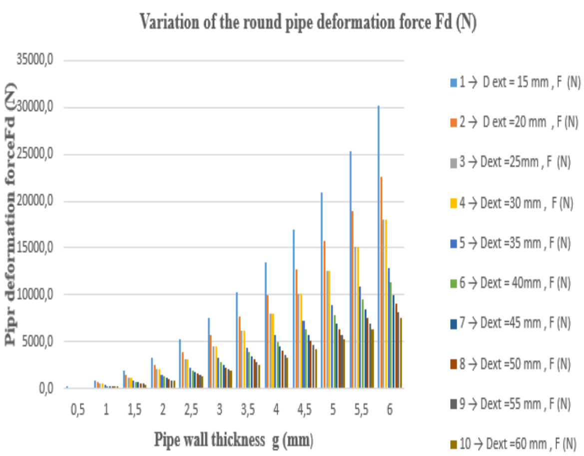


Fig. 8. Variation of the deformation force depending on the pipe wall thickness, for each value of the external diameter.

4.2 Experimental research

In order to carry out the experimental research one used the traction/compressive materials test machine type A009-TC100 series 06N/1 with a nominal load of 100 kN. This testing device has one drive force measurement system, controlled by computer.

The test machine consists of a robust two-column frame in which a mobile cross member is mounted. The machine control unit, UDI 16/4 allows the control of the test machine via a computer (PC) and the TCSoft2004Plus software. In Figure 9 the test machine used in experiments is shown.

Fig. 9. UDI 16/4 Compression test Machine with soft TCSoft2004Plus.

The experiment was performed for a round steel pipe with D_{ext} = Ø33 mm, wall thickness g = 2 mm, σ_{ai} = 150 MPa.

Figure 10 shows how the device was placed with the pipe fixed in it and how to apply the punch with a 4 mm ball at the top of the punch. The device was used without the top plate.

For this type of pipe, the value of the deformation force of the respective pipe was calculated according to the calculation relationship (5).

Fig. 10. Fastening the pipe in the clamping device and applying the punch to the pipe.

The result is presented in Table 2.

Table 2

Value of the deformation force on the round steel pipe with D_{ext}= Ø33 mm and g = 2 mm.

Pipe wall thickness g (mm)	Deformation force for Dext = 33 mm F_d (N)
2	1523.08

The calculation proofs that the pipe does not deform at forces below the value resulting from the calculation, i.e. 1.5 kN.¶

To test experimentally whether the plastic deformation of the pipe occurs only at pressing forces greater than 1.5 kN, three experiments were conducted on the same steel pipe with D_{ext} = Ø33 mm, and the thickness of the pipe wall g = 2 mm,

For the first experiment, the machine was adjusted for a maximum force of 1.49 kN and for a maximum displacement of 2 mm of the punch trapped in the car's bows. The movement speed of the pointer has been adjusted to 10 mm per minute. The diagram obtained by the software of the car is shown in Figure 11.

The machine indicated a 0.49 mm punch tip displacement. But since the pipe examination after the experiment was observed only a trace of scratches on the pipe, the conclusion is that only a small deformation occurred in the elastic field and the pipe recovered after removal from the device.

The resulting diagram in this case is shown in Figure 11.

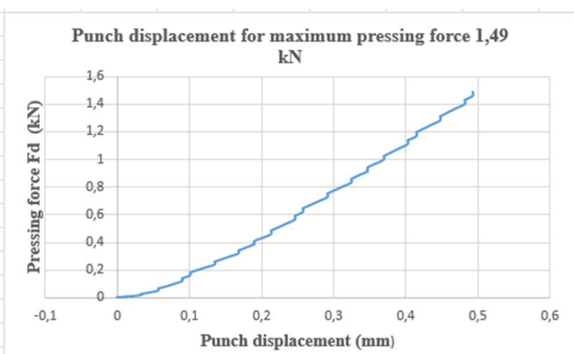


Fig. 11. The punch displacement under the action of the maximum force 1.49 kN.

The second experiment was achieved for a maximum of 1 kN. The movement speed of the punch has also been adjusted to 10 mm per minute. The machine indicated a 0.39 mm punch tip shift and resulted in only a small punch mark in the form of a scratch on the pipe surface. The resulting data is presented in Figure 12.

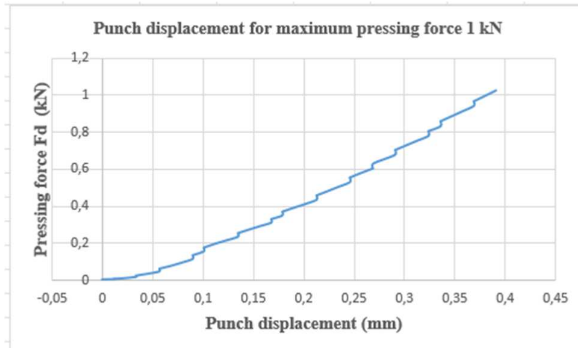


Fig. 12. The punch displacement under the action of the maximum force 1 kN.

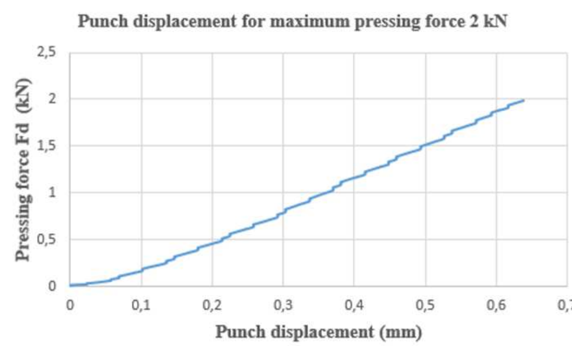


Fig. 13. The punch displacement under the action of the maximum force 2 kN.

The third experiment was realized for a machine-adjusted force of 2 kN. The movement speed of the punch has also been adjusted to 10 mm per minute. Following the S0a experiment, one noticed a more visible trace on the pipes. The machine indicated a 0.64 mm punch movement. A slight plastic deformation of the pipe occurred in the push area of the punch. The resulting diagram is shown in Figure 13.

5. FINDINGS AND CONCLUSIONS

Following the experiment, one proved that:

1. The role of the device for performing the function of gripping and fixing long pipes was successfully tested.
2. The adjusted forces were 1, 1.49 and 2 kN, with a certain displacement of the punch (2 mm), and with a constant speed of the punch movement for pressing the pipe.
3. The pipe deformations under the action of the punch pressing were compared. It was found

that the limiting pressing force resulting from the theoretical research was correctly determined. Thus, at the forces of 1 kN and 1.49 kN which were below the calculated plastic deformation limit of the pipe (1.5 kN), according to the calculations, the pipe did not undergo plastic deformations but got only extremely small elastic deformations, which were no longer observed after the cessation of the pressing the pipe. At the pressing of 2 kN the pipe suffered a small plastic deformation. Therefore, one concludes that the value of the force of 1.5 kN, resulting from the theoretical calculations, was correctly determined with the relation (5).

Following the experiments, the drown conclusions are:

i) The aim of the paper was achieved because:

- a useful device for the proposed experimental activities has been designed and developed, and
- the proposed experimental activities were carried out in good conditions, being a contribution to the confirmation of the activities previously performed in the theoretical research.

ii) The device designed for the experimental part has been practically checked and allowed experiments to be carried out in very good conditions. It was confirmed that the design and manufacture of the device was correct and the desired and necessary measurements could be made to verify the results of the theoretical research.

iii) In the experiments performed, diagrams were obtained that allowed the interpretation of the results to clarify the previous theoretical aspects

iv) The comparison of experimental results with theoretical research data shows that theoretical research has established a correct interdependence between the parameters considered when establishing the relationships.

v) In the future, research will be possible on other variants of pipe clamping devices t, through various technological processes.

vi) The paper addresses an original solution.

6. REFERENCES

[1] Poiană, D.I., Ionel, I., *Study of modern perforation processes specific to the automotive industry*, IOP Conference Series: Materials Science and Engineering, Vol. 898, 012043, Sesiunea anuală de lucrări științifice - IMT Oradea 28-29 mai 2020, Oradea, România, IOP Conf. Ser.: Mater. Sci. Eng. 898 012043, DOI:10.1088/1757-899x/898/1/012043, 2020.

[2] *** Meta, *Sisteme de rafturi*, (2025), https://sistemederafturi.ro/catalogue/index.html?p=18, 2025, accessed 20.01.2025

[3] Shalamov, P., Pivtsaeva, M., Chvanova A, Shamguno A, *Use of combined tools to reduce axial force during thermal drilling,* Materials Today: Proceedings Volume 38, Part 4, 2021, pp. 1931-1935, https://doi.org/10.1016/j.matpr.2020.09.071, 2021

[4] Poiană, D.I., Ionel, I., Popa, M., Bordeașu, I, *Results concerning manufacturing of tubular car components using hydroforming and hydroperforation processes*, IOP Conference Series: Materials Science and Engineering, Vol.1220, Cea de-a XXXI-a ediție a Congresului Internațional SIAR de Inginerie a Automobilelor și Transporturilor "Automotive and Integrated Transport Systems" (AITS 2021), 28-30 octombrie 2021, Chișinău, Republica Moldova, IOP Conf.Ser.:Mater.Sci.Eng.1220 012038, DOI: 10.1088/1757899x/1220/1/012038, 2022.

[5] Lavrentiev, A.M., *Experimental studies of rotatory rolling of long thin-wall pipes,* Materials Science and Engineering IOP Conf. Ser.: Mater. Sci. Eng. 680 012002, 2019.

[6] Habtemariam, A. K., Könke, C., Zabel, V., Bianco, M. J., *Generalized Beam Theory formulation for thin-walled pipes with circular axis,* Institute of Structural Mechanics, Bauhaus-Universität Weimar, Marienstr. 15, 99421 Weimar, Germany, www.elsevier.com/locate/tws, Thin–Walled Structures 159 (2021) 107243, 2021.

[7] Brodnik, N.R., Muir, C., Tulshibagwale, N., Rossin, J., Echlin, M.P., Hamel, C.M., Kramer, S.L.B., Pollock, T.M., Kiser, J.D., Smith, C., et al., *Perspective: Machine learning in experimental solid mechanics.* J. Mech. Phys. Solids 2023, *173*, 105231, 2023.

[8] Alaswad, A., Benyounis, K.Y., Olabi, A.G., *Tubehydroforming process: A reference guide,* Materials & Design, Volume 33, January 2012, pp. 328-339, 2012.
[9] Bell, C., Corney, J., Zuelli, N., Savings, D., *A state-of-the-art review of hydroforming technology.* Int. J. Mater. Form. 2020, 13, pp. 789–828, 2020.
[10] Reddy, P.V., Reddy, B.V., Ramulu, P.J., *Evolution of hydroforming technologies and its applications—A review,* J. Adv. Manuf. Syst. 2020, 19, pp. 737–780, 2020.
[11] Hartl, C., *Mechanics of hydroforming,* TH Köln - Faculty of Automotive Systems and Production, University of Applied Sciences, Cologne, Germany, pp. 71-109, https://doi.org/10.1016/B978-0-12-818232-1.00003-5, 2020.
[12] Cheng, L., Guo, H., Sun, L., Yang, C., Li, J., *Real-Time Simulation of Tube Hydroforming by Integrating Finite-Element Method and Machine Learning*, Journals JMMP, Volume 8, Issue 4 DOI: 10.3390/jmmp8040175, 2024.
[13] Poiană, D.I., Ionel, I., Drăghici, G., *Research concerning the influences related to the perforated hole diameters in long pipe*, IOP Conference Series: Materials Science and Engineering, Vol. 1235, Cea de-a 25-a ediție a Conferinței Internaționale IManEE 2021 (IMANEE 2021) 21-22/10/2021, IOP Conf. Ser.: Mater. Sci. Eng. 1235 012070, DOI:10.1088/1757-899x/1235/1/012070, 2022.
[14] Poiană, D.I., Ionel, I, Drăghici, G, *Research on the influence of the clamping devices on the size of the perforated holes in long round pipes*, IOP Conference Series:Earth and Environmental Science, Vol. 960, Conferința privind energia, mediul, economia și termodinamica (COFRET 2021) 14-16 octombrie 2021, București, România, IOP Conf. Ser.: Earth Environ. SCI. 960 012023, TWO:10.1088/17551315/960/1/012023, 2022.

Proiectarea și fabricarea unui dispozitiv de prindere a țevilor pentru analiza experimentală a pieselor tubulare lungi cu pereți subțiri

Scopul lucrării a fost de a realiza verificări experimentale referitoare la deformarea elasto-plastică a țevilor rotunde lungi cu pereți subțiri. Lucrarea a avut două ținte. Prima țintă a fost realizarea unui dispozitiv de prindere a țevilor lungi. A doua țintă a fost să se realizeze cu acest dispozitiv experimente specifice, care să verifice relațiile de calcul obținute într-o cercetare teoretică anterioară. În lucrare sunt prezentate aspecte legate de proiectarea și de confecționarea dispozitivului. Sunt prezentate de asemenea experimentele realizate, prin care s-a pus în evidență deformarea elasto-plastică ce apare la prelucrarea orificiilor în țevi lungi cu pereți subțiri, comparativ cu relațiile teoretice stabilite anterior. Concluziile prezentate la finalul lucrării confirmă atingerea țintelor propuse, prin contribuție originală 100%.

Cuvinte cheie: *Țevi lungi, piese cu pereți subțiri, deformări elastice și plastice, prelucrarea găurilor, dispozitive de prindere a țevilor.*

Dinu Iacob POIANĂ, PhD student, Politehnica University of Timișoara, Department for Mechanical Machinery, Equipment and Transportation, dinu.poiana@student.upt.ro.
Mircea Dorin VASILESCU, PhD, Professor, Politehnica University of Timișoara, Department for Mechanical Machinery, Equipment and Transportation, mircea.vasilescu@upt.ro, correspondent author.
Sergiu Valentin GALAȚANU, PhD**,** Associate Professor, Politehnica University of Timișoara, Department of Mechanics and Strength of Materials, sergiu.galatanu@upt.ro.
Ioana IONEL, PhD, Professor, Politehnica University of Timișoara, Department for Mechanical Machinery, Equipment and Transportation, ioana.ionel@upt.ro.