TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 65, Issue III, September, 2022

DESIGNING A FLATTENING, PUNCHING AND TRIMMING DEVICE FOR STEEL TUBES

Emanuela POP

Abstract: *This paper presents the design of a device for flattening, trimming, and punching circular or rectangular profile steel tubes on a hydraulic press. The device was adapted to the available machinery and to the parts to be manufactured in order to satisfy the requirements imposed by the company. Using the relations found in literature, the flattening, trimming, and punching loads were calculated. The results were used in order to validate the design and dimensioning process using Finite Element Analysis in the Solidworks Simulation module.*

Key words: *steel tube, flattening, punching, FEA.*

1. INTRODUCTION

The current project theme was chosen in collaboration with the company S.C. Sere Transilvania S.A. It was presented to the author as an abstract concept, as the idea of merging several operations (the flattening, punching, and trimming of a steel tube using a hydraulic press) into a single device (tool set) in order to increase productivity.

The company that issued the design project manufactures modular greenhouses, storage spaces, car ports, etc. using steel tube structures and polymeric materials.

Research into the matter concluded that no commercially available solutions for this issue currently exist. Some working prototypes of similar concepts were found (in the form of videos) along with a few cases of small-scale implementations in small foreign companies. However, none of them were able to provide a solution that could be implemented in the company. Therefore, the need for a custom-made device arose. The design process for this device is the subject of this paper.

Although the design itself was left to the choice of the author, some specific requests that it had to fulfill were issued by the company. Firstly, the proposed solution had to offer an obvious increase in productivity compared to the one currently implemented. Secondly, it had to be economically justifiable taking the size of the company and the volume of production into account. Therefore, the device had to be usable with the existent machinery. Naturally, another requirement was for the new solution to enable the manufacturing of the same types of parts with the same level of accuracy as the current setup (or better).

This paper aims to present the design process of a device that allows the flattening, punching, and trimming of steel tubes (Φ28 mm, Φ33 mm and 40x20 mm) using an 80-ton hydraulic press.

2. THE STATE OF THE ART

2.1 General notions regarding steel tube structures

Steel tube (or pipe) structures are structures built out of structural steel tubes, used most frequently in warehouses, greenhouses, storage spaces etc. The steel tubes used are made of steel with certain standardized mechanical and chemical properties. They are usually galvanized for proper corrosion resistance.

The structures are most frequently assembled by welding or using connector fittings (as in Fig.

Received: 25.07.22; **Similarities**: 11.08.22: **Reviewed**: 22.08./11.08.22: **Accepted**:17.09.22.

1) and fasteners (nuts, bolts, washers, rivets etc.).

Fig.1. Connector fittings [1]

One method for assembling steel tubes involves the use of connector fittings shaped to accommodate the shape of the tube (Fig. 2). The main advantage of this type of connector is that it minimizes the number of operations that must be executed on the tubes. The tubes must be cut to size, then the holes for the rivets or bolts must be drilled (Fig. 3).

Fig. 2. Assembly using connector fittings adapted to the shape of the tubes [1] [2]

The cost of this type of fittings can get quite high. Therefore, when possible, the steel tubes will be processed to obtain the proper shapes necessary for assembly and to minimize the number of connectors necessary.

The main operations that need to be performed of steel tubes used in steel tube structures are different types of symmetrical (center) and non-symmetrical flattening, necking, bending, trimming, and punching. This study will focus mainly on the symmetrical flattening, trimming, and punching operations of steel tubes using tools mounted on presses.

2.2 Types of machine presses currently in use

For the purposes of this study, and to better clarify the type of equipment used, the following classifications of machine presses will be used.

First of all, presses can be classified according to their power source into the manual, mechanical, hydraulic, pneumatic or a hybrid between some of the previous types (e. g., hydro-pneumatic). [3]

Secondly, one can classify presses according to their number of rams/slides, into the following categories: single action press, double action press or triple action press.

Fig. 3. Flattening operations performed on steel tubes [4]

The design presented in this study will be adapted for use on a Geka Hydracrop 80 Universal Ironworker hydraulic press (Fig. 4).

Fig. 4. The Geka Hydracrop 80 Universal Ironworker hydraulic press [5]

2.3 Flattening

As can be observed in Fig. 5, the flattening process uses two die halves, one mounted to the machine’s table, and the other mounted to the ram. The end of the pipe is placed between the two die halves and is flattened when the press starts its descending motion, applying force unto the upper die half.

In practice, most often, stoppers and guide plates are also used to ensure proper flattening along the correct length of the pipe (see Fig.6). When the ram reaches the lower end of its stroke, the flattened pipe will be forced to be in alignment with the guide plates, while the stopper does not allow the pipe to advance too far, extending past the die halves.

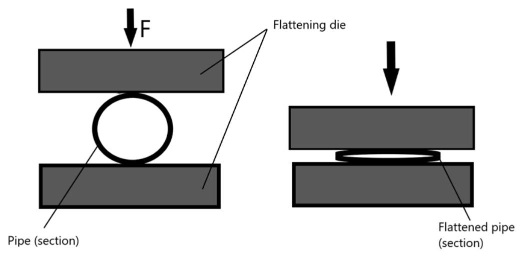


Fig. 5. Flattening – working principle

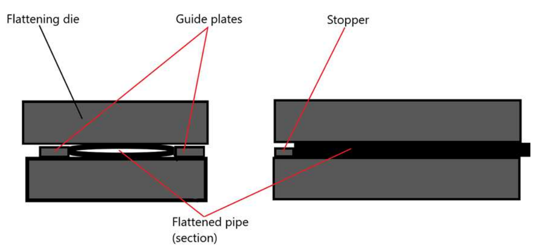


Fig. 6. – Flattening using stoppers and guide plates

2.4 Trimming

Trimming the ends of flattened pipes uses the same principle as open shearing (see Fig. 7) wherein the workpiece (flattened pipe, in this case) is placed unto a die, and a punch, actuated with a force F, generates the shearing force necessary to cut the material. The punch and die will be shaped according to the necessary final shape of the part. For proper shearing, a clearance is necessary between the punch and the die. [6]

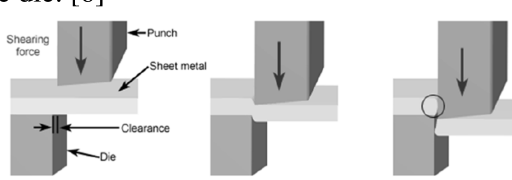


Fig. 7. Working principle for trimming [6]

2.5 Punching

During the punching process, the workpiece is placed unto a die and a punching force acts upon a punch in order to create a hole (see Fig.8). The size and shape of the hole are generated by the size and shape of the punch and of the die's hole. For the generated hole to be accurate, a clearance is needed between the punch and the die. [6] In the case of this study, the workpiece will be the flattened end of a steel tube.

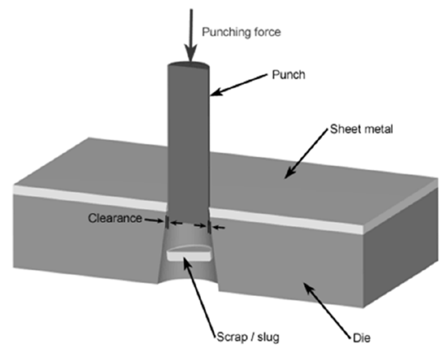


Fig. 8. Working principle for punching [6]

This section will focus on the study of the solutions that are currently in use, that allow performing flattening, trimming, and punching on steel tubes of different diameters. More accurately, the focus will be on the different combinations of tools (die sets) through which these operations can be performed.

Firstly, there is the possibility of using a different die set for each operation and each tube diameter. So, for example, if two tube sizes must be processed, six die sets will be needed (2 sizes x 3 operations). This scenario is only feasible for cases when high part accuracy is needed and efficiency is not paramount, or for large scale production using one workplace for each tool.

Secondly, one can use adjustable tools for each operation, in which case each operation requires one die set that can be adjusted to accommodate different tube diameters.

Thirdly, there is the possibility of using combined, non-adjustable tools. This means using a single tool for all three operations but having to use one such combined tool for each tube diameter.

Finally, an adjustable combined die set could be designed. Such a die set should be able to perform all the necessary operations on different size steel tubes, in one or more stages. An important requirement would be designing the set in such a way as to make it as easily adjustable as possible, all the while maintaining the proper level of accuracy required by the user. This study will further focus on designing such a die set.

Currently, the company uses a Geka Hydracrop 80 Universal Ironworker hydraulic press. The press uses two hydraulic cylinders, one on each end, therefore having two work areas and five workplaces, though only two workplaces can be used simultaneously. One end makes a shearing motion and includes four workplaces: sheet metal shearing, square and round bar shearing, angle shearing and flattening.

Fig. 9. The punching tool set (removed from the assembly)

The other end (working area) only includes one workplace: for trimming and punching. It uses a set of punches, including a hole punch and a trimming punch (Fig. 9). The set is fixed to the press cylinder using bolts. The part (flattened tube) is placed on the die (Fig. 10), which has a set of holes in accordance with the punch set. The active plate is fixed to the press body.

This working setup has a series of disadvantages. First of all, the flattening phase and the punching and trimming phase are done at different workplaces, which significantly limits productivity, since the parts must be flattened, then transported to the other workplace for the operation to be finished.

Secondly, using this setup, both work areas of the press are occupied by a single operation. Since the shearing area includes 4 workplaces, freeing it up would make these workplaces available for other operations while the flattening, trimming, and punching take place.

Finally, the flattening is currently done using a shearing motion. This is not ideal, as the two flattening blocks are not parallel. Therefore, the tube is never truly flattened; one end of the flattened area will always be flatter than the other. This situation is exaggerated in Fig. 11 for easier understanding.

Fig. 10. The die (removed from the assembly)

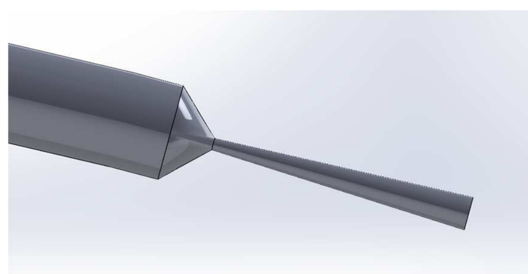


Fig. 11. The flattened area is flatter at one end than at the other

The design in this study will focus on eliminating these disadvantages by combining the tooling used for all three phases (flattening, punching, and trimming) into a single die set.

3. DESIGNING THE DEVICE

3.1 Dimensioning the flattening blocks

The flattening phase of the process is done with the help of two flattening blocks (two halves of a flattening die): an lower package and an upper package. The lower package must incorporate the guide plates and stopper. Therefore, the parts were designed as seen in Fig. 12.

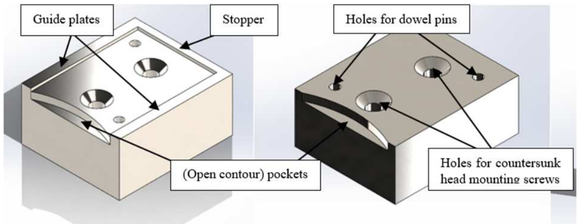


Fig. 12. The flattening packages, lower (left), upper (right)

The blocks have holes for countersunk head mounting screws (two in each block) as well as for dowel pins (two in each block) for the correct positioning of the blocks in the assembly. Two open contour pockets were added to enable the device to manufacture parts with the appropriate shape (see Fig. 13). These pockets were dimensioned in accordance with those present in the flattening blocks used in the current setup.

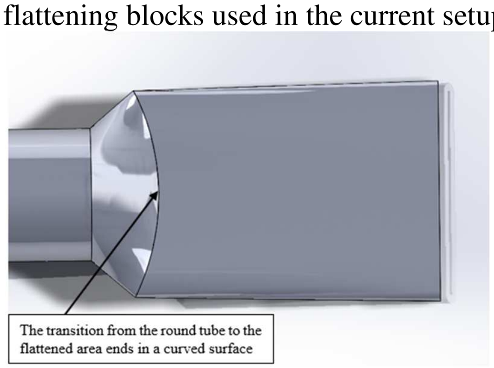


Fig. 13. The shape of the flattened end of the parts to be manufactured

The blocks are subjected to compression and very little wear. Therefore, the chosen material is C45U. It provides adequate toughness and compressive strength and can be hardened to 50-55 HRC, which is appropriate for bending tools of this shape. After machining, the blocks will be quenched in water, then tempered to 50-55 HRC. [7]

The distance between the guide plates and the length of the blocks have been chosen in accordance with the dimensions of the flattened end of the tubes, as they are produced by the company and to ISO 8492, which states that the width (w) of the platens used for flattening tubes should be at least 1.6 times the diameter of the tube (Dmax), [8], [9], [10], [11]as follows:

$$w \geq 1{,}6 \times Dmax = 1{,}6 \times 33 \quad (1)$$

$$w \geq 52{,}8\ mm \quad (2)$$

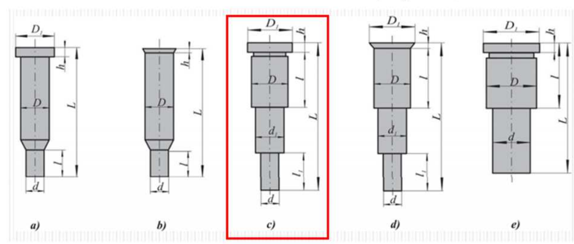
Because the device must also be able to flatten rectangular tubes (40x20mm), the adopted width will be equal to the maximum possible width of the flattened rectangular tube:

$$w = 40 + 2 \times \left(\frac{20}{2}\right) = 60\ mm \quad (3)$$

The width and height of the guide plates and stopper were chosen constructively, as was the total height of each block.

3.2 Dimensioning the active elements for punching and trimming

The hole punch was chosen according to literature, but they were adopted to fit the current case scenario. This decision will be validated using Finite Element Analysis later on. The adopted dimensions are [9]: d = 9,8mm; d1 = 12,5mm; D1 = 17mm; l1 = 21mm; D = 13mm; h = 3mm; l = 16mm; L = 45mm (fig.14).



d	L	l	d_1	D	D_1	l_1
5–7	40–70	25–30	7,5	8	12	10
7–9	40–80	25–35	9,5	10	14	10
9–12	40–80	25–35	12,5	13	17	12
12-15	40-80	30-35	15,5	16	20	14
15–18	40–80	30–35	19,5	20	24	15
18–21	40–80	30–35	21,5	22	27	16
21–26	40–80	30–35	23,5	24	30	18

Fig. 14. Choosing the appropriate shape and dimensions for the hole punch [9]

The chosen material is X210Cr12, as it is appropriate for punching and shearing and it can be heat treated in order to obtain the proper hardness [7]. As the maximum wall thickness of the tubes to be processed is 2mm, the thickness considered for choosing the appropriate punch material is 4mm.

After machining, the punch will be quenched and tempered to 58-62 HRC. This provides the proper hardness and wear resistance necessary.

The final shape of the punch may be seen in Fig. 15. A chamfer was added to the flange in order to avoid interference with the retention plate.

The trimming punch cannot be chosen according to a standard, as its shape needs to be customized to the shape of the part it needs to process.

Fig. 15. The final shape of the hole punch

Therefore, it was designed according to the technical drawing of the part (see Fig. 16), considering the following requirements:

- The punch also needs to act as the stopper in order to reduce the number of parts.
- The punch should be as easily and as cost-effectively replaceable as possible, as it is expected to wear out in time.

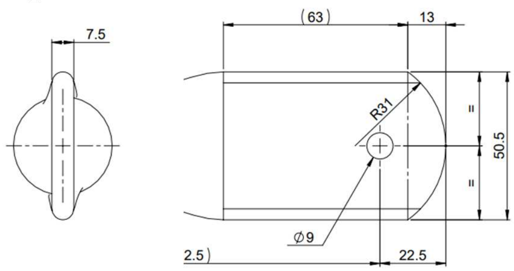


Fig. 16. The shape of the trimmed end of the flattened steel tube

Therefore, as may be seen in Fig. 17, the punch has been designed as a four-part subassembly. There is a punch body, which has a flange for mounting onto the punch retainer plate. The removable punch plate is mounted onto the punch body using two countersunk head screws. The screws were dimensioned constructively as M4x15mm. As the trimming punch has a rather complex geometry, having a removable plate lowers the maintenance costs, as the worn-out plate can be easily removed and replaced, and it is simpler and cheaper to produce.

As for the flattening blocks, the material chosen for the trimming punch body is C45U. It provides the proper hardness (after heat treatment) and compressive strength. After machining, it will be heat treated by quenching in water and tempering to a hardness of 50-55 HRC. [7]

Fig. 17. The trimming punch; left view (left), front view (middle) and custom view (right)

The removable punch plate will be made out of X210Cr12, and heat treated just like the hole punch, by quenching and tempering to 58-62 HRC. This provides the appropriate properties considering the material to be processed and its thickness.

The active plate was designed in accordance with the shape of the parts it needs to accommodate. The dimensions were chosen constructively (see Fig. 18) and validated later on using Finite Element Analysis.

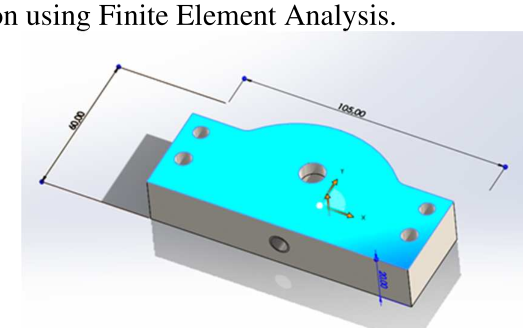


Fig. 18. The shape and outside dimensions of the active plate

The shape of the hole was chosen according to Fig. 19. The most proper shape is shape "a)", as it provides the best wear resistance and precision for the current application. [12]

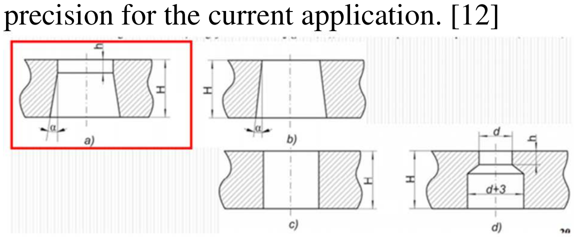


Fig. 19. Choosing the appropriate shape of the hole for the hole punch [12]

The dimensions of the hole were chosen as: h = 6mm, α = 0º30'

The other (passive) elements of the punching and trimming subassembly (the punch retainer plate, the part retainer plate and the evacuation block were dimensioned constructively.

3.3 Dimensioning the guide elements

The minimum guide pillar diameter considering the outside dimensions of the lower and upper plates is Φ25mm. In order to combat the lateral forces that result from the asymmetry of the cylinder on the press, the guide pillars have been oversized to Φ30mm and a four-pillar layout was chosen. This decision will be verified using Finite Element Analysis.

Considering the chosen dimension, the guide pillars were chosen from commercially available variants. In order to keep costs as low as possible, a simple standard guide pillar with sliding guide bushings was chosen. The length was chosen constructively as 160mm. The code of the chosen pillar is E5010/32x160.

The bushings were chosen according to the manufacturer [13, 14] according to the speed of the ram and the lateral force on the bushing. Since the press is hydraulic, and therefore, slow, and the lateral forces quite high, the simple steel sliding bushing was chosen. The longest available length outside the upper plate (56mm) was chosen in order to combat the lateral forces and to prevent accidents (the longer the bushing, the lower the risk of objects being trapped between the bushing and lower flattening block. The specific bushing model that fulfills these criteria is E 5124/30x35/56.

The manufacturer only provides one mounting system for the specific model of guide bushings that was chosen. The model number is E 5270/ 6/ 6.

4. VALIDATION OF THE DIMENSIONING PROCESS USING FINITE ELEMENT ANALYSIS

4.1 The calculation of the forces for flattening, trimming, and punching

First of all, in order to calculate the necessary forces, the properties for each material to be processed must be assessed. The calculations will be made for the material with the best properties, since the forces are highest for this material and the device must be dimensioned to withstand these forces.

The tubes processed by the company are made of the following types of galvanized steel: E260 and S355. By analyzing the materials properties, it was concluded that the material used for the calculations should be S355 because of its better mechanical properties.

For calculating the force necessary for flattening, the relevant property is the yield strength since tube flattening is a form of bending [15]. Based on [15], the calculations are as follows:

$$M_P = \frac{(\sigma_0 \times t^2)}{4} = 330\ Nmm \tag{4}$$

$$P_0 = \frac{(4M_P)}{R} = 80\ N \tag{5}$$

$$P_T = P_0 \times L_F = 6400\ N \tag{6}$$

$$P_{TA} = P \times k = 9600\ N \tag{7}$$

where MP – fully plastic bending moment [Nmm], σ_0- steel yield stress [N/mm^2], t- section modulus, P0 – initial collapse load of a tube of unit length [N], PT – total load considering the length of the flattened area of the tube [N], PTA – total adopted load, calculated using a safety factor “k” [N].

Conclusively, a flattening load of 9600 N was adopted and it will be used later on for running the Finite Element Analysis simulations.

The necessary loads for trimming and for punching are calculated in the same way, as they both work according to the principle of shearing. However, they will be calculated separately, as the two punches are of different lengths. This was done to ensure that they act successively on the part (rather than simultaneously) in order to reduce the necessary load. The calculations are presented below:

$$F_P = k \times L_P \times g \times \tau = 5389.96\ N \tag{8}$$

$$F_T = k \times L_T \times g \times \tau = 10158.72\ N \tag{9}$$

$$g = 2 \times t \tag{10}$$

where k – safety factor; k = 1.1…1.3 [9], LP – Length of the cutting path for the hole punch [mm], LT¬ – Length of the cutting path for the trimming punch[mm], g – The thickness of the material[mm], t – wall thickness of the steel tubes[mm], τ – shear strength of the material [N/mm^2].

4.2 Running Finite Element Analysis simulations on the parts

In this step, a simulation was run for each of the three phases of the manufacturing process in which the device is involved (flattening, trimming, and punching). The simulations were performed on the 3D model of the device using the Simulation addon for Solidworks (Solidworks Simulation).

For the flattening phase, the load is placed on the two flattening blocks. The setup for the simulation only includes the blocks and a segment of flattened tube. This is sufficient for now, as the rest of the assembly will be verified later on.

The fixtures placed on the assembly are a fixed geometry on the bottom of the lower flattening block and two "roller/slider" fixtures on the left and the back faces of the upper package, in order to simulate the effect of the guide pillars on the stroke. The flattening load calculated previously was placed on the top surface of the upper package as a distributed load.

For the mesh, the finest control available by default was selected (see Fig. 20) because the parts are few and quite simple in geometry and the finer mesh leads to more accurate results.

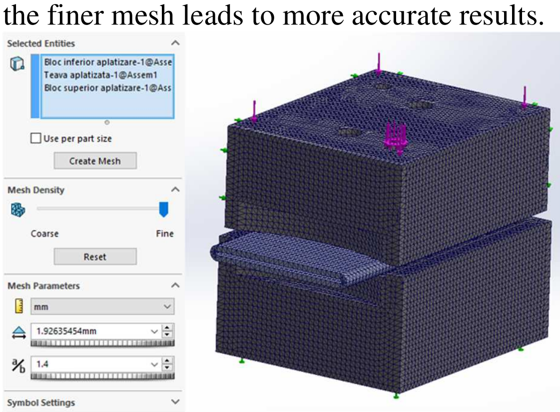


Fig. 20. The mesh settings used for the simulation

The results are presented in Fig 21. Although the deformation model for the tube is inaccurate, this is not relevant at the moment, as the stroke of the press will be limited to only allow the tube to be flattened to the thickness specified in the drawing. However, as it may be seen, the stress on the flattening blocks is absolutely negligible. Although this means that they are grossly oversized, the limitations imposed by the minimum width of the blocks and minimum height of the assembly does not require any further optimization.

To conclude, the results of the Finite Element Analysis simulation validate the dimensioning process for the flattening blocks. For the punching process, the only component that will be verified is the hole punch.

The fixtures used are all of the fixed geometry type. They were placed on all of the surfaces that come in contact with the punch retainer plate and with the pressure. Again, the finest mesh available by default was used in order to obtain accurate results.

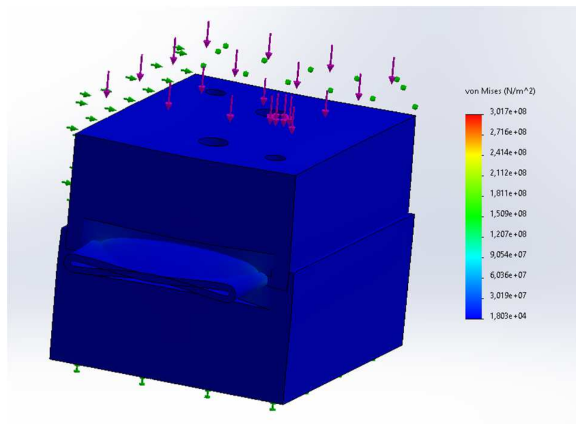


Fig. 21. The stress of the simulation of the flattening process

The results can be observed in Fig. 22. The results are satisfactory. The red spots along the line where the contact with the retainer plate ends can be dismissed as simulation anomalies. To conclude, the obtained results validate the dimensioning process for the hole punch.

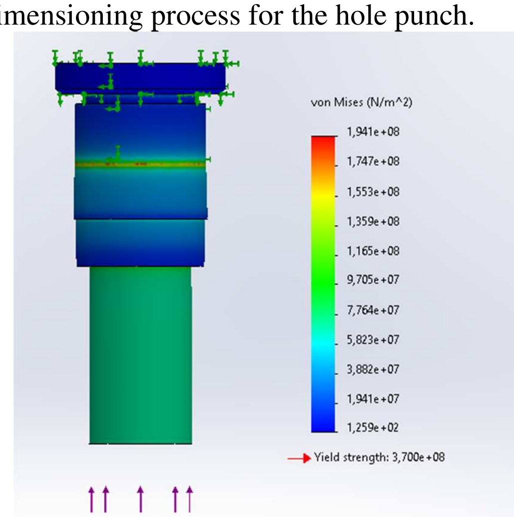


Fig. 22. The stress on the simulated punch

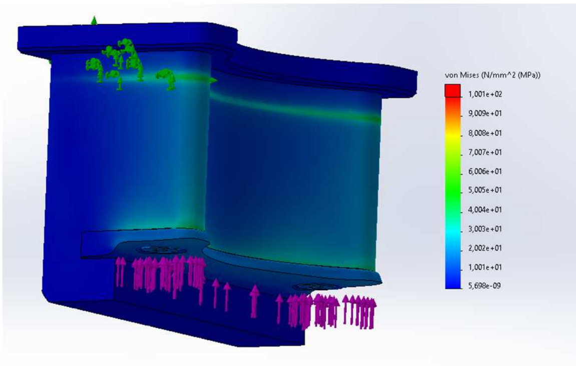


Fig. 23. The stress on the trimming punch subassembly

This simulation was run on the trimming punch subassembly, which includes the trimming punch, the trimming punch removable plate and the two mounting screws for the plate.

The load was placed on the face of the removable plate, but only in the area that will contact the part.

As may be seen in Fig. 23, the results of the simulation are satisfactory, validating the dimensioning process for the trimming punch.

The setup for verifying the active plate also includes the flattened end of a tube, as it is necessary for placing the loads (the loads are placed on top of the hole and outside the contour of the active plate).

The results of the simulation are presented in exploded view in Fig. 24, as the results shown for the flattened tube are irrelevant (and inaccurate) and would obscure the view of the active plate. The results shown for the active plate suggest adequate behavior of the component and validate the dimensioning process.

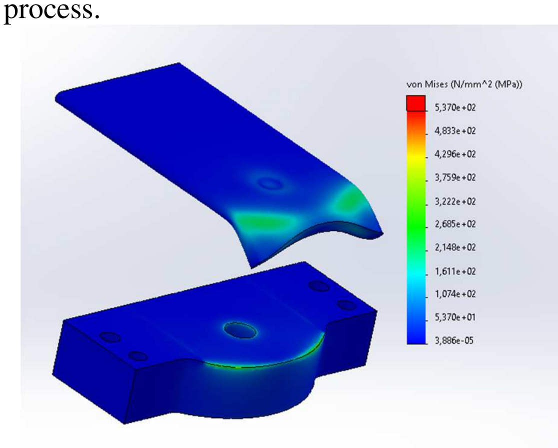


Fig. 24. The stress of the active plate simulation

A last step for the validation of the dimensioning process is to check the entire assembly. This was done using the maximum load the press can exert on the device. If the press reaches the bottom of its stroke without the stroke length being properly adjusted, the entire 80-ton load might be placed on the closed device. Therefore, ideally, the device should be able to withstand this load. The assembly was simulated in the fully closed position. The load was placed on the top surface of the part which connects the upper plate to the press' cylinder.

The results are shown in Fig. 25. They indicate that, theoretically, the device should be able to withstand the entire load of the press. Although this is fortunate, it is still highly inadvisable for this situation to occur as it might result in grave injuries.

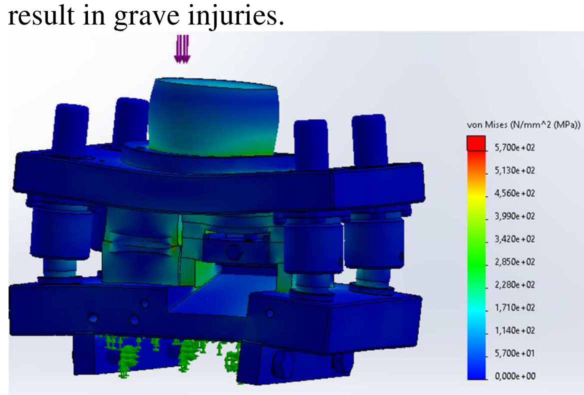


Fig. 25. The stress of the simulation ran on the device assembly

The research presented in this paper led to the design of a device for the flattening, trimming and punching of steel tubes. The final design it is presented in Fig. 26.

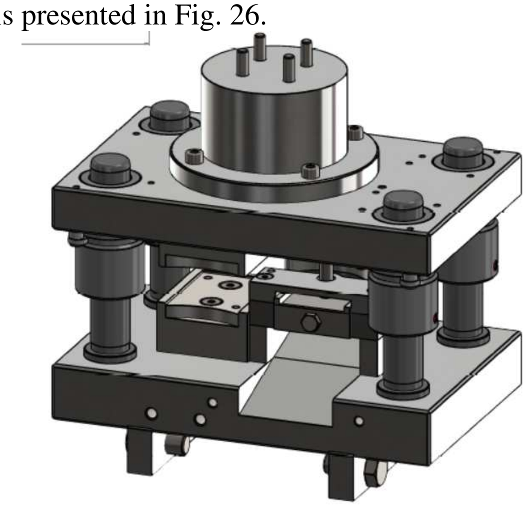


Fig. 26. The designed device

5. CONCLUSION

The device is to be implemented by the collaborating company for manufacturing parts of different diameters and lengths to be used for modular greenhouses, storage spaces, car ports etc. It should significantly improve productivity and also free up some workplaces that may be used for other tasks.

Research into the state of the art with regards to such a device led to the conclusion that currently, no commercially available solutions exist. Therefore, designing a device that uses standardized, commercially available components and also customizable components (that are designed using proper rules and principles found in literature) to suit the needs of the user is an important advancement for the industry. The designing and dimensioning process was validated using Finite Element Analysis. This also helped to evaluate whether any optimization was due.

While most of the parts proved to be significantly oversized, it was concluded that it would be superfluous to further optimize any of them. No optimization measures that can reduce the amount of material used or that can simplify the manufacturing process were found.

6. REFERENCES

[1] Roofscreen, https://www.roofscreen.com/portfolio/ photo-gallery.php. [Accessed 08.02.2021].

[2] Roofscreen, https://www.roofscreen.com /products/product-category.php?category= Steel_Tube_Fram ing_8 [Accessed 08.02.2021].

[3] D. BANABIC, *Course notes for the discipline Technology of Plastic Deformation Processes,* Cluj-Napoca: Technical University of Cluj-Napoca, 2021.

[4] Tubebending, http://www.tubebending.net/tubeflattening.html. [Accessed 08.02.2021]

[5] Geka, http://www.geka-ironworkers.com/universal-two-cylinder-punching-machines/hydracrop-80-150/[Accessed 08.02.2021].

[6] D. BANABIC, *Lecture notes*, Cluj-Napoca: Technical University of Cluj-Napoca, 2018.

[7] Deutsche Edelstahlwerke, *Selecting Materials for Punching and Forming Tools and the Heat Treatment thereof*, [Online]. https://www.dewstahl.com/fileadmin/files/dew-stahl.com/documents/Publikationen/Broschueren/072_DEW_Werkstoffauswahl_Kaltarbeit_GB.pdf [Accessed 28.06.2021].

[8] G. Y. X. L. Q. L. L. R. X. H. Y. W. Yao Wang, *Metal ductility evaluation by flattening test: The geometry dependence*, International Journal of Pressure Vessels and Piping, V. 170, 2019.

[9] N.C. Tang, *Plastic-deformation analysis in tube bending*, Int. J. Pres. Ves. Pip., 77 (2000), pp. 751-759.

[10] D. Munz, *Cross-sectional flattening of pipes subjected to bending,* Int. J. Pres. Ves. Pip., 10 (6) (1982), pp. 421-429.

[11] D. Mackenzie, J.T. Boyle, A simple pipe bend element for piping flexibility analysis, Int. J. Pres. Ves. Pip., 51 (1) (1992), pp. 85-106.

[12] M. Teodorescu, *Elemente de proiectare a ștanțelor și matrițelor*, București: EDP, 1977.

[13] Meusburger, *Selection guide*, https://ecom.meusburger.com/files/pdf/e/stanz_auswahlhilfe.pdf. [Accessed 29.06.2021].

[14] Meusburger, *Sliding guide bush, steel, with collar*, https://ecom.meusburger.com/files/pdf/e/e5124.pdf [Accessed 29.06.2021]

[15] https://www.makeitfrom.com/material-properties/EN-1.0045-S355JR-Non-Alloy-Steel [Accessed 30.06.2021].

PROIECTAREA UNUI DISPOZITIV PENTRU APLATIZAREA, GĂURIREA ȘI DECUPAREA ȚEVILOR DIN OȚEL

Rezumat: Această lucrare prezintă proiectarea unui dispozitiv pentru aplatizarea, tăierea și ștanțarea tuburilor de oțel cu profil circular sau dreptunghiular pe o presă hidraulică. Dispozitivul a fost adoptat la utilajele disponibile si la piesele de fabricat pentru a satisface cerintele impuse de firma. Folosind formulele întâlnite în mod obișnuit în literatură, au fost calculate sarcinile de aplatizare, tăiere și perforare. Rezultatele au fost utilizate pentru a valida procesul de proiectare și dimensionare utilizând Analiza Elementelor Finite în modulul Solidworks Simulation.

Emanuela, POP, Lecturer Eng., PhD, Technical University of Cluj-Napoca – Department of Design Engineering and Robotics, emanuela.pop@muri.utcluj.ro.