DESIGN OF THE TOOL FOR PRESSING OF TARPAULIN GROMMETS

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This paper deals with a design and a shape optimization of a tool that combines punching of a tarpaulin with the tarpaulin grommet pressing in one operation. The tarpaulin grommet 0.5 mm thick with a diameter of 10 mm is made of DX51D+Z275MAC steel. The designed tool and its main shape dimensions are verified by using a numerical simulation in an ANSYS Workbench software and subsequently also by a practical experiment, i.e. verification and debugging functionality in cooperation with H + D kovo company.

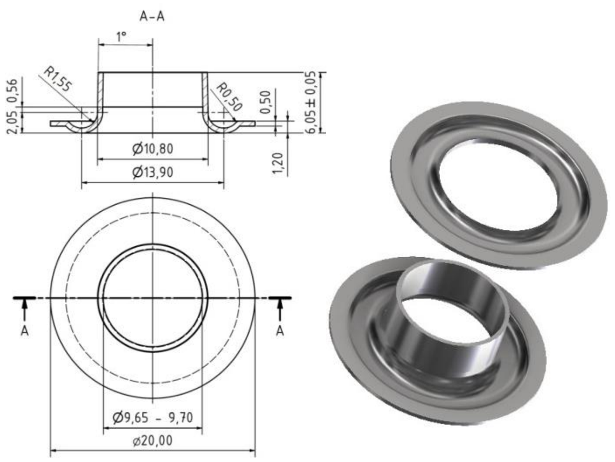
KEYWORDS

tarpaulin grommet, expanding, punching, ANSYS Workbench, numeric simulation, DX51D+Z275MAC steel

1 INTRODUCTION

Tarpaulin grommets are used together with tarp washers to reinforce of holes in fabrics and textiles. Steel sheets are commonly used for their production. In some cases, plastic parts can be used. Tarpaulin grommets are made in several shapes and dimensional variations.

In this case, application of circular grommet for strengthening of PVC coated fabric holes is solved. The shape and basic dimensions of the solved part are shown in Fig. 1a. 3D models of the tarpaulin grommet and the washer is shown in Fig. 1b. [Hudecek 2017]



a) basic dimensions b) 3D model

Figure 1. Manufactured part [Hudecek 2017]

DX51D+Z275MAC steel (1.0917) is used as the grommet and the washer material. It is low carbon steel for cold forming, which is hot coated by a zinc. Basic mechanical characteristics and chemical composition of this steel are shown in Tab. 1 and Tab. 2. [Hudecek 2017]

Yield strength	$R_{p0.2}$	[MPa]	272
Ultimate strength	R_m	[MPa]	331
Ductility	A_{80}	[%]	31

Table 1. Mechanical properties of DX51D+Z275MAC steel

%C	%Si	%Mn	%S	%P
0.045	0.006	0.203	0.008	0.014

Table 2. Chemical composition of DX51D+Z275MAC steel

For better description of material properties, standard tensile tests were conducted at room temperature under a constant strain rate of $5 \cdot 10^{-3}$ s^{-1} using a ZD 40 testing machine. A primary evaluation of recorded values was performed in M-TEST software. Five tensile tests were performed and then the results were averaged. Measured data were converted to the true stress – true (logarithmic) strain curve. In next, parameters of a Hollomon approximation were obtained which are necessary for other calculations. Hollomon approximation of the stress – strain curve is illustrated in Fig. 2.

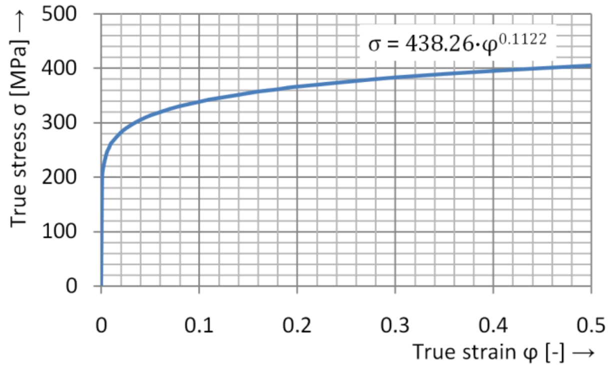


Figure 2. True stress – true strain curve of DX51D+Z275MAC steel

Grommets with washers are applied together on the PVC coated fabric. Main mechanical properties of the fabric are tabulated in Tab. 3.

Yield strength	$R_{p0.2}$	[MPa]	35
Ultimate strength	R_m	[MPa]	65
Ductility	A_{80}	[%]	80

Table 3. Mechanical properties of PVC coated fabric [Hudecek 2017]

2 PRODUCTION AND APPLICATION TECHNOLOGY

Tarpaulin grommets are produced in a progressive tool that performs several shaping operations in one tool stroke (blanking, deep drawing, punching, trimming). After blanking operation, the basic circular shape is formed according to the schema in Fig. 3.

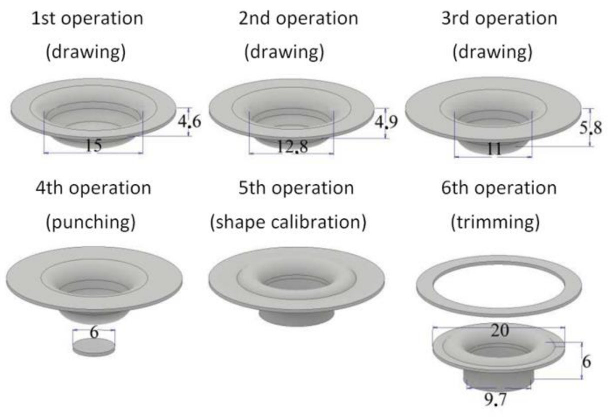


Figure 3. Manufacturing process of the grommet [Hudecek 2017]

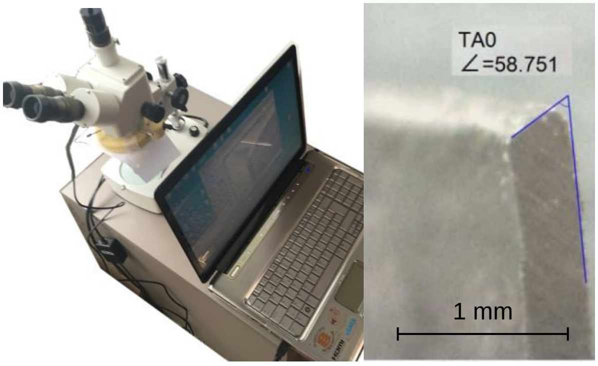
Application of tarpaulin grommets is possible in several ways. One possible way is a punching of the tarpaulin separately, thereby a hole for the grommet pressing is created. In a second operation, pressing of the grommet is realized. However, this method is lengthy. Therefore, it is preferable to combine above mentioned steps into a single operation. For this purpose, special tools are needed. For a successful application of tarpaulin grommets by using this approach, punching and curling parameters have to be solved firstly.

During designing of the tool, it is necessary to focus on the force parameters, among other things, i.e. the punch force and the curling force.

2.1 *Tarpaulin Punching Operation*

Due to specific manufacturing process of the tarpaulin grommet, it is possible to use the grommet to punch the tarpaulin. As a part of the study of the tarpaulin punching process, it is necessary to focus on the appearance and the geometry of the grommet edge that occurs during the grommet manufacturing process in the fourth operation, see Fig. 3. This edge will have a function of the punching tool.

For determination of the grommet edge appearance, SSM-3E stereo microscope equipped with USB camera was used, see Fig. 4.



a) SSM-3E microscope b) snapshot of the edge

Figure 4- Microscopic detection of the grommet edge [Hudecek 2017]

The tarpaulin punching process is shown schematically in Fig. 5. The total thickness of the punched material is 1 mm. For textiles up to 3 mm thick, a punch clearance was determined by [Finda 2003] as 0.04 mm. A theoretical value of the maximal punching force is then solved by well-known equation:

$$F_p = n_s \cdot L \cdot s_{0T} \cdot 0.77 \cdot R_m \qquad (1)$$

$$F_p = 1.33 \cdot 30.41 \cdot 1 \cdot 0.77 \cdot 65 = 1\,978.62\ \mathrm{N} \qquad (2)$$

where n_s is the tool wear coefficient, L is the cutting length, s_{0T} is the initial thickness of the tarpaulin and R_m is the ultimate strength of the tarpaulin.

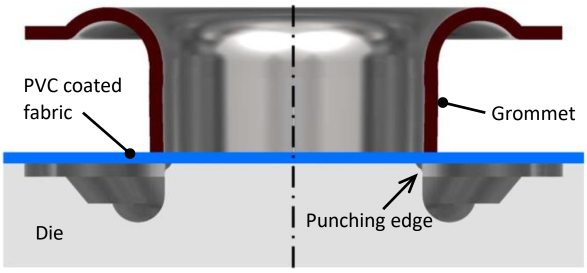


Figure 5. Punching process

2.2 *Curling Operation*

The design of the curling tool is based on the desired dimensions of the resulting joint, i.e. D_z = 13.65 mm and V_z = 3.8 mm, see Fig. 6.

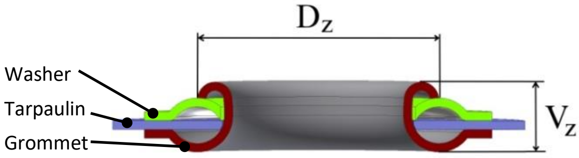


Figure 6. Resulting joint of the pressed tarpaulin grommet

The curling operation is schematically shown in Fig. 7. The curling radius was chosen as r = 1 mm. Based on this value, the working punch diameter D_v = 13.64 mm was determined.

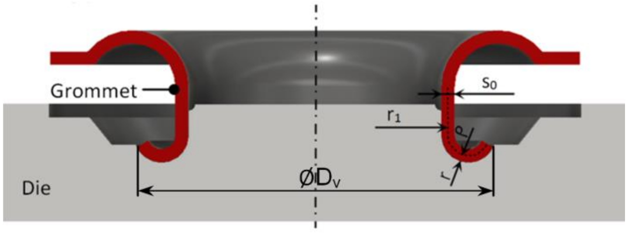


Figure 7. Geometric parameters the curling process

Literature [Daw-Kwei 2014] gives a theoretical determination of the curling force by the equation:

$$F_c = 2 \cdot \pi \cdot C \cdot s_0 \left(\frac{2}{\sqrt{3}}\right)^{1+n} \cdot \left\{ \frac{r_1}{2+n} \cdot \frac{1}{\rho^n} \cdot \left(\frac{s_0}{2}\right)^{1+n} + \rho \cdot \mu \cdot \left(\frac{\rho}{r_1}\right)^n \cdot \left(1 - \frac{n \cdot \pi}{4}\right) + \left(\frac{\rho}{r_1}\right)^n \cdot \left[\rho \cdot \left(1 - \frac{n}{2}\right) + \rho \cdot \left(1 + \frac{n \cdot \rho}{2 \cdot \rho}\right)\right] \right\} \qquad (3)$$

where C is the material constant, n is the strain hardening exponent, s_0 is the initial wall thickness of the curled part, r_1 is the die radius, ρ is the mean value of the curled radius and μ is the friction coefficient.

After substituting, the equation passes into the shape:

$$F_c = 2 \cdot \pi \cdot 373.3 \cdot 0.5 \left(\frac{2}{\sqrt{3}}\right)^{1+0.081} \cdot \left\{ \frac{5.83}{2+0.081} \cdot \frac{1}{0.75^{0.081}} \cdot \left(\frac{0.5}{2}\right)^{1+0.081} \cdot \left(\frac{2 \cdot e^{-0.15 \cdot \frac{\pi}{2}}}{0.75} \cdot \frac{1 - e^{-0.15 \cdot \frac{\pi}{2}}}{0.75} \right) + 0.75 \cdot 0.15 \cdot \left(\frac{0.75}{5.83}\right)^{0.081} \cdot \left(1 - \frac{0.081 \cdot \pi}{4}\right) + \left(\frac{0.75}{5.83}\right)^{0.081} \cdot \left[0.75 \cdot \left(1 - \frac{0.081}{2}\right) + 0.75 \cdot \left(1 + \frac{0.081 \cdot 0.75}{2 \cdot 0.75}\right)\right] \right\} = 2\,612.1\mathrm{N} \qquad (4)$$

2.3 *Proposal of the Tool for Pressing of Tarpaulin Grommets*

The tool for piercing of the tarpaulin with the tarpaulin grommet pressing in one operation is composed of two main parts, see Fig 8. Upper and lower tool parts are clamped in the press work space by using bolts that press against the tool clamping surfaces. The upper part of the tool consists of a grommet holder with cavity in which a spring is inserted. During movement of the upper tool part, the grommet is attached to the mandrel until a contact between the mandrel face and the tarpaulin is reached. In the next movement, the mandrel spring is gradually compressed. This fact cause that the mandrel moves into the grommet holder cavity and a distance between the grommet and a bearing surface on the grommet holder is reduced until the grommet is wiped from the mandrel. Increasing pressure force is transmitted to the tarpaulin, below which the die is located. At the forehead of the die, there is an undercut that eventually centers the grommet against the punching edge on the die. Further movement of the upper part of the tool causes the punching process and the edge of the grommet reaches the area of the die radius where it expands, i.e. curling operation is performed.

As soon as the edge of the grommet reaches the tarpaulin, the washer is compressed and the tarpaulin is clamped between opposite pressing surfaces of the grommet and the washer. The tool concept is designed for manual feeding and stretching of the tarpaulin during the pressing process. In the next configuration, it is possible to add an outer blank holder to keep the tarpaulin be stretched.

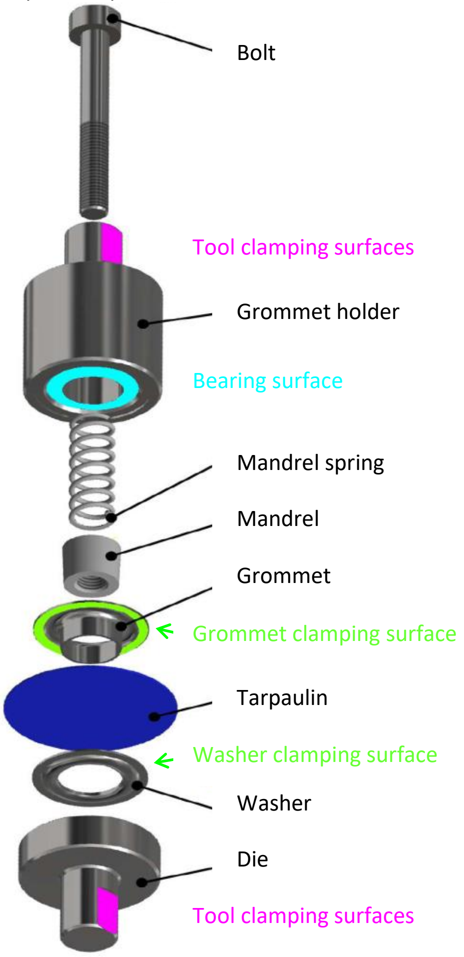


Figure 8. *Tool for pressing of tarpaulin grommets* [Hudecek 2017]

3 VERIFICATION BY USING NUMERICAL SIMULATION

For verification of the tool functionality and the stress – strain analysis of the tarpaulin grommet during the pressing process, finite element analysis was performed in the ANSYS software.

3.1 Geometrical Model

It is important to note, that the simplified geometrical model was used. It is based on an axisymmetric model and therefore the FEM analysis can be solved in 2D space, see Fig. 9.

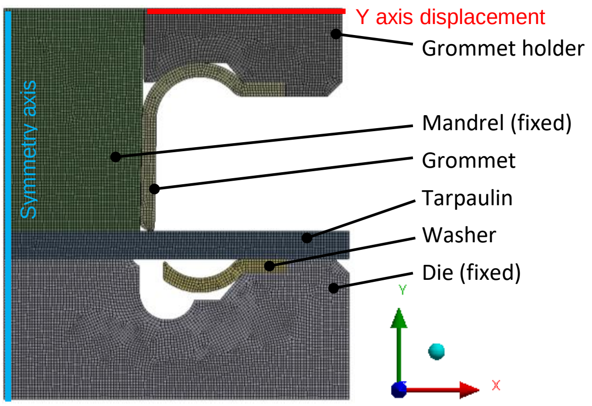


Figure 9. *Geometrical model of the FEM analysis*

3.2 Material Model

Material propperties of the grommet were entered to the simulation according to the uniaxial tensile test data, see Fig. 2 with a density value of 7850 kg · m^{-3}. The tarpaulin material model was based on [Ambroziak 2014] and [Pargana 2014]. Whereas the simplified 2D geometry is considered, an isotropic material model was used. Stress – strain curve of the tarpaulin is shown in Fig. 10. A maximum equivalent strain value of 0.22 was chosen as the criterion of failure. A friction coefficient was set to 0.15.

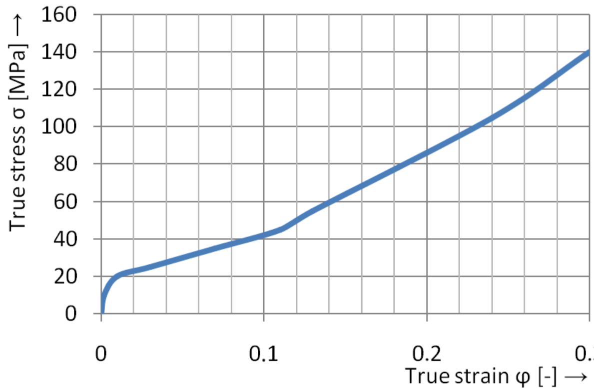


Figure 10. True stress – true strain curve of the tarpaulin

3.3 Results

Primarily, the FEM simulation gives overview of the grommet deformation during the curling process. In Fig. 11, there is the strain analysis of the grommet pressing operation.

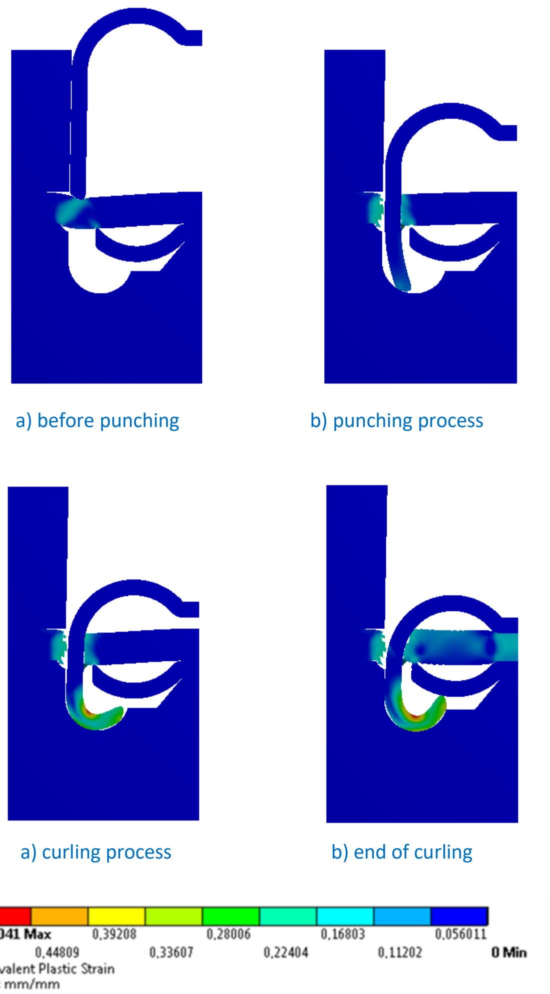


Figure 11. Effective strain *analysis*

4 IMPLEMENTATION AND EXPERIMENT

Based on above mentioned analyzes, the prototype of the tool was manufactured and tested. Fig. 12 shows the upper and the lower parts of the tool.

a) lower tool part b) upper tool part

Figure 12. Practical Realization of Pressing Tool [Hudecek 2017]

Testing of the proposed tool was carried out on the ZD 40 testing machine. By performing an experiment, the maximal value of the punching force was determined as 2 269.8 N and the required curling force was found as 3 545.2 N, see Fig. 13. If these results are compared with theoretically determined values, the curling force values significantly differ. This effect is mainly caused by the fact that the force does not decrease to the zero value after the punching, due to the resistance of the punched material. Furthermore, if the FEM analysis and experimental results are compared in Fig. 13, a fairly good agreement is reached, except calibration phase at the end of the pressing process, where the difference is approximately 1 000 N. For further refinement of the simulation, it would also be advisable to focus on biaxial tensile tests of formed steel, which more closely corresponds to the stress state during the curling operation.

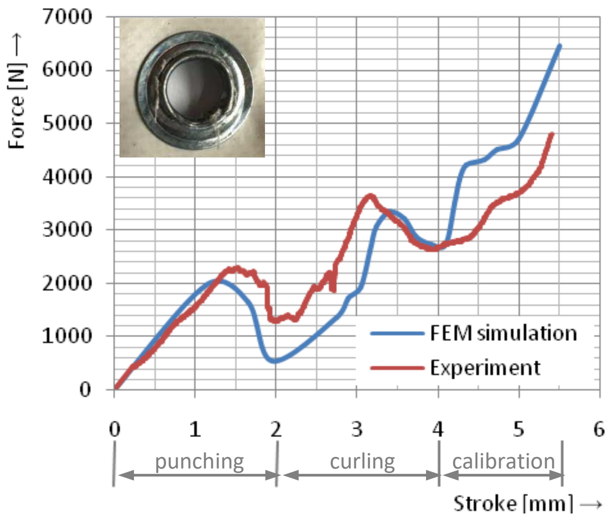


Figure 13. Force – stroke diagram

5 CONCLUSIONS

For the application of tarpaulin grommets for strengthening of PVC coated fabric holes in H + D kovo company, the tool design that combines punching of the tarpaulin with the tarpaulin grommet pressing in one operation were elaborated with support of the FEM analysis in the ANSYS Workbench software. After construction of the tool, its functionality was tested in the ZD 40 testing machine.

For the chosen tarpaulin grommet shape and dimensions, which is made of DX51D+Z275MAC steel, the tool was successfully validated and owns forming process was debugged. The comparison of the numerical simulation and the experiment was also carried out with fairly good degree of conformity.

REFERENCES

[Ambroziak 2014] Ambroziak, A. and Klosowski, P. Mechanical properties for preliminary design of structures made from PVC coated fabric. Construction and Building Materials, 2014, Vol.50, pp 74-81, ISSN 0950-0618

[Daw-Kwei 2014] Daw-Kwei, L. The curling characteristics of static inside-out inversion of metal tubes. International Journal of Machine Tools & Manufacture, 2000, Vol.40, pp 65-80, ISSN 0890-6955

[Finda 2003] Finda, L. and Haltuf, R. Academy of Forming: Cutting [online]. 17. 5. 2010. [2017-09-07]. Available from < http://www.mmspektrum.com/clanek/akademie-tvareni-strihani.html>

[Hudecek 2017] Hudecek, M. Tool Design for Pressing of the Tarp Grommets. Brno: Brno University of Technology, 2017

[Miller 2003] Miller, G. G. Tube Forming Processes: A Comprehensive Guide. Michigan: Society of Manufacturing Engineers, 2008. ISBN 978-0-872-63633-0

[Pargana 2014] Pargana, J. B. et al. Advanced material model for coated fabrics used in tensioned fabric structures. Engineering Structures, 2007, Vol.29, pp 1323-1336, ISSN 0141-0296

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