Research Concerning the Influences Related to the Perforated Hole Diameters in Long Pipes

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Abstract.The purpose of this paper is to highlight the influence of the dimensional characteristics and mechanical strength characteristics of the pipe material on the diameter of the perforated holes in these long pipes, to maintain the stability of the pipe shape in the perforated area. The research aimed to establish the maximum limit dimensions of holes that can be made in long round pipes with thin walls, through perforating by cold plastic deformation in air, using only a punch applied to on the outside of the pipe, for a particular case of pipe clamping. Following the research, the mathematical relations between the maximum diameters of the holes that can be obtained in round pipes, in correlation with the dimensional characteristics and the mechanical resistance of the material, are presented. The characteristics taken into account are the outer diameter of the pipes, the thickness of the pipe wall, and the permissible resistance to rupture of the part material. In the conclusions, it is specified that the determined mathematical relations allow the construction of variation diagrams and the determination of the maximum possible diameters, for other dimensional characteristics of pipes and for other mechanical strength characteristics of different materials.

Keywords: Long pipes, perforation, punch, diameters, materials, plastic deformation, permissible strength.

1. Introduction

To make the holes in the long tubular parts, several processing processes are used, [1], [2], [3], [4], [5]: perforation by cold plastic deformation, laser perforation, hydro-perforation, thermal erosion perforation, ultrasonic perforation.

One of the procedures used to make the holes in tubular parts is the perforation by cold plastic deformation in the air environment, with associated edges, a punch applied on to the outside of the pipe and the cutting plate inserted on the inside of the pipe. This variant of perforation by cold plastic deformation, with associated edges is applied only for the holes located at the ends of the long pipes. This variant with associated edges is avoided for making holes arranged along parts such as long pipes with thin walls, because there is no convenient solution to insert a cutting plate on the inside of the pipe in the area of the hole.

The execution of cold plastic deformation, in the air environment, of the holes arranged along the length of the pipe is used less frequently, in which case only a secure cut is used, the punch applied from the outside of the pipe, without the cutting plate on the inside of the pipe. Such holes made with only one edge, the punch, can be made in good condition only for pipes with sufficiently high rigidity, so that the pipe does not deform under the action of the punch.

In the present paper, the influence of the pipe diameter, pipe wall thickness, and the material characteristics on the maximum diameter of the holes and the rigidity of the pipe were investigated.

2. Research hypothesis

The study of the perforation process of long tubular parts, with a singular edge with a punch, is based on the following considerations and recommendations:

- the perforation is accomplished by cold plastic deformation in an air environment, with a singular edge of a punch type;
- a clamping device according to figure 1 is used, thus the part is placed on a plate with a flat surface, the side walls in contact with the part;
- a punch guide plate is used;
- the workpiece is a hold for a length of 80 mm, centered towards the hole to be made.

Figure 1 shows schematically, in this section, the process of making holes by punching applied from the outside of the pipe and the device proposed for use in this case.

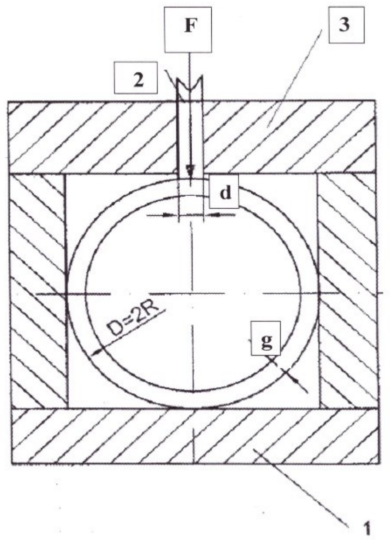

Figure 1. Device for clamping the tubular pipe in the hole area.

The notations are:
1 - the lower plate of the clamping device of the pipe;
2 - the punching punch;
3 – the upper plate of the clamping device and the punch guide;
F - punch actuation force;
D - outer diameter of the pipe;
g - the thickness of the pipe wall;
d – the hole diameter / the punch diameter.

3. The state of stress and solving indetermination

Because the holes in the round pipe are made by a plastic deformation process, at the moment of impact of the punch on the round pipe, the tensions appear in the workpiece. When the sheer force appears, this one causes the rupture and detachment of the material subjected to the perforation process.

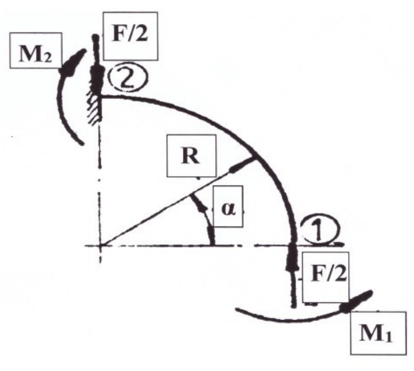

Figure 2. The balance diagram of the forces and moments that appear in the process, in a cross section through the pipe.

The tensions that appear in the material are determined at the moment of the action of the punch on the piece. The part must not deform under the action of the punch. This tension can be determined based on known issues in the strength of materials, using analytical computational relationships and constructing equilibrium schemes of the forces and moments that appear for the considered case.

Figure 2 shows the specific schemes of the strength of the materials taken into account for this case studied, with the forces and moments that appear [6].

4. Mathematical considerations. Interdependent relationships

The mathematical relations between the maximum diameters of the holes that can be obtained in round pipes, depending on the dimensional characteristics of the pipes and the mechanical resistance of the material For the present case in the study of the perforation process for parts of the type of long pipes, we chose the Alberto Castigliano method, which is one of the energetic methods widely used in the study of cold plastic deformation processes.

The Castigliano theorem is applied to solve the indeterminacy of the diagram in figure 2. In section 1, the zero rotation is considered and the relation is obtained

$$\phi_1 = \frac{\partial u}{\partial M_1} = \frac{1}{EI}\int M_i \frac{\partial Mi}{\partial M_1} ds = 0 \tag{1}$$

The bending moment in zone 1-2 will have the expression:

$$\mathrm{M}_{1-2} = \mathrm{M}_1 + \frac{\mathrm{F}}{2}\mathrm{R}(1-\cos\alpha) \tag{2}$$

Where, F is the punching force.

Replacing relation (2) in relation (1) results:

$$\int_0^{\frac{\pi}{2}} \left[M_1 + \frac{F}{2} R(1-\cos\alpha) \right] R \cdot d\alpha = 0 \tag{3}$$

After integration you get:

$$M_1 = -0.18 F \cdot R \tag{4}$$

The expressions of the efforts in a certain cross section are:

$$\left.\begin{aligned} \mathrm{N}_{1-2} &= -\frac{\mathrm{F}}{2}\cos\alpha \\ \mathrm{T}_{1-2} &= -\frac{\mathrm{F}}{2}\sin\alpha \\ M_{1-2} &= (0.32 - 0.5\cos\alpha) F \cdot R \end{aligned}\right\} \tag{5}$$

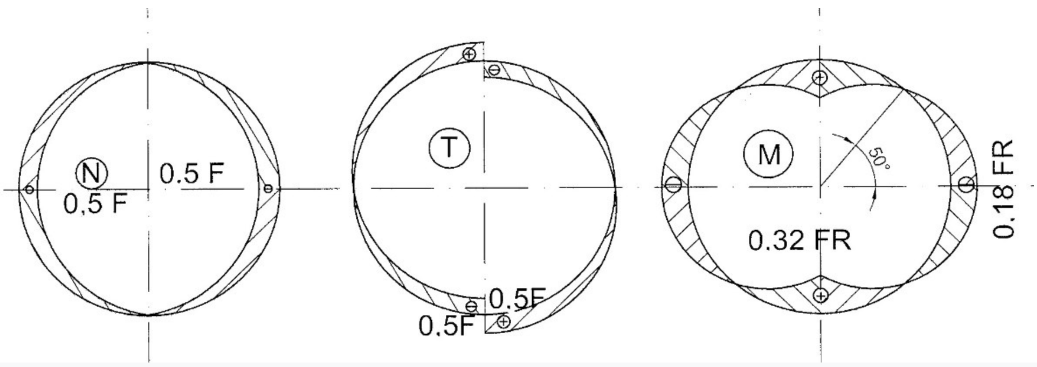

Figure 3. Effort diagrams with de forces and the moments that appear.

The stress diagrams are shown in figure 3. In critical section 2, efforts have values:

$$\left.\begin{aligned} N_2 &= 0 \\ T_2 &= -\frac{F}{2} \\ M_2 &= 0.32F \cdot R \end{aligned}\right\} \tag{6}$$

To determine the maximum value of the diameter of the holes that can be made by punching with a die without cutting plate, the condition of resistance to the compound stress of the part will be taken into account, on which the drilling force acts and the diagram in figure 3 is considered N, T and M_i.

In the critical section 2, the normal tension σ_2 will be:

$$\sigma_2 = \frac{N_2}{A} \pm \frac{M_2}{Wz} \le \sigma_{ai} \tag{7}$$

In which:

$$A = \lambda \cdot g \tag{8}$$

$$W_z = \frac{\lambda \cdot g^2}{6} \tag{9}$$

Where, λ is the length of the pipe corresponding to the deformation zone [mm]; g is the pipe wall thickness [mm]; σ_{ai} is the permissible bending strength of the pipe material [MPa].

For the perforation force F, the known relation is considered:

$$F = \pi \cdot d \cdot g \cdot \sigma_r \tag{10}$$

Where, d is the diameter of the perforated hole and σ_r is the breaking strength of the pipe material. By replacing (8), (9) and (10) in (7), relationship (11) is obtained:

$$d \le \frac{\lambda \cdot g}{1.91 \cdot \pi \cdot R} \cdot \frac{\sigma_{ai}}{\sigma_r} \text{, [mm]} \tag{11}$$

The deducted relations (11) can be verified in the future by experimental research by various other methods appropriate to the case studied, such as example, the finite element method (MEF), for example, using Solid Works and /or Forge7.

5. The variation curves of the maximum diameter of the holes based on the mathematical relations

Based on the relationship (11), the values were drawn up in table 1 and figure 4. Thus, one indicates the relations existing between the diameters of the perforated holes, the dimensional and material characteristics of the perforated part, in case the piece is placed on a device with a flat surface, according to figure 1.

Table 1. Results concerning calculated values for the diameters according to different wall thickness.

Pipe wall thickness g [mm]	D=15, Maximum diameter of the perforated hole d [mm]	D=20, Maximum diameter of the perforated hole d [mm]	D=25, Maximum diameter of the perforated hole d [mm]	D=30, Maximum diameter of the perforated hole d [mm]	D=40, Maximum diameter of the perforated hole d [mm]	D=60, Maximum diameter of the perforated hole d [mm]
0.5	0.4042	0.30315	0.24252	0.2021	0.15157	0.10105
1	0.8084	0.6063	0.48504	0.4042	0.30315	0.2021
1.5	1.2126	0.90945	0.72756	0.6063	0.45472	0.30315

2	1.6168	1.2126	0.97008	0.8084	0.6063	0.4042
2.5	2.021	1.51575	1.2126	1.0105	0.75787	0.50525
3	2.4252	1.8189	1.45512	1.2126	0.90945	0.6063
3.5	2.8294	2.12205	1.69764	1.4147	1.06102	0.70735
4	3.2336	2.4252	1.94016	1.6168	1.2126	0.8084
4.5	3.6378	2.72835	2.18268	1.8189	1.36417	0.90945
5	4.042	3.0315	2.4252	2.021	1.51575	1.0105
5.5	4.4462	3.33465	2.66772	2.2231	1.66732	1.11155
6	4.8504	3.6378	2.91024	2.4252	1.8189	1.2126
6.5	5.2546	3.94095	3.15276	2.6273	1.97047	1.31365
7	5.6588	4.2441	3.39528	2,8294	2.12205	1.4147

Figure 4 shows the corresponding curves for parts of the long pipe type, with the dimensional characteristics:

- Outer diameter of the parts of: D = 15, 20, 25, 30, 40, 60 mm,
- The wall thickness of the pipes for each diameter considered was g = 0.5 - 7 mm.

For the length of the device, one selected λ = 80 mm.

The characteristics of the material taken into account for the material used in automotive industry are: σ_r = 330 MPa and σ_{ai} = 150 MPa [2], [4], [7], [8].

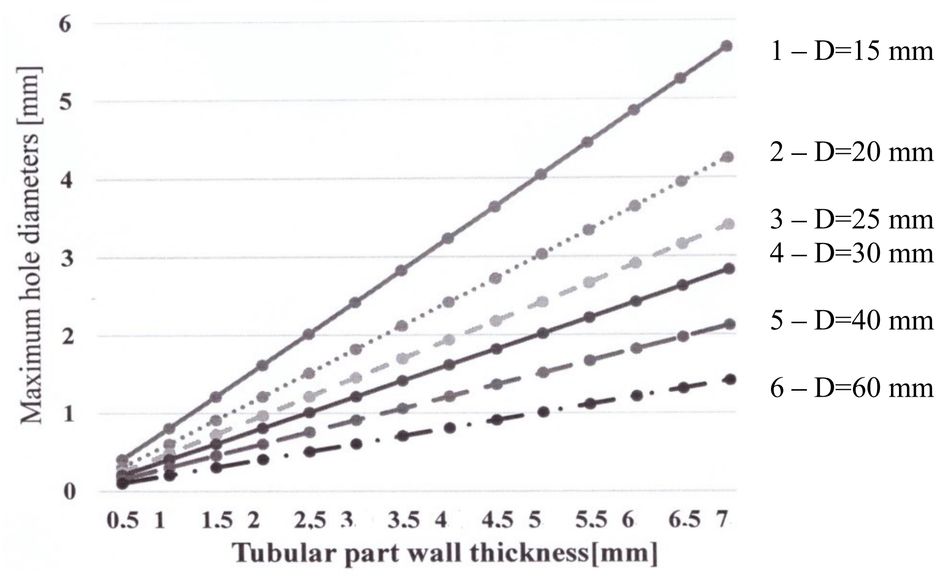

Figure 4. Variation curves of the maximum diameter of the perforated holes, depending on the dimensions of the parts, outer diameters, and the thickness of the wall, under the conditions of maintaining the rigidity of the part, in the area of the perforated hole.

By analyzing the diagram in figure 4, it is observed that for the pipes with a wall thickness of 1 mm, the following maximum punch diameter results:

- ϕ 0.8 mm → for the pipes with D = 15 mm,
- ϕ 0.6 mm → for the pipes with D = 20 mm,
- ϕ 0.4 mm → for the pipes with D = 25 mm,
- ϕ 0.4 mm → for the pipes with D = 30 mm,
- ϕ 0.3 mm → for the pipes with D = 40 mm,
- ϕ 0.1 mm → for the pipes with D = 60 mm

For the pipes with a wall thickness of 7 mm, the following maximum punch diameter results:
- ϕ 5.6 mm → for the pipes with D = 15 mm,
- ϕ 4.2 mm → for the pipes with D = 20 mm,
- ϕ 3.3 mm → for the pipes with D = 25 mm,
- ϕ 2.8 mm → for the pipes with D = 30 mm,
- ϕ 2.1 mm → for the pipes with D = 40 mm,
- ϕ 1.4 mm → for the pipes with D = 60 mm

6. Conclusions

The research scope is confirmed, because a general relationship was established, which allows the calculation of the maximum limits of the diameters for the perforated holes in round pipes, for different types and dimensions of material.

It was applied, for the case referring to the clamping part. It proofs the interdependence between:

- the diameter of the holes, respectively, the diameter of the punch, d;
- the outer diameter of the pipe, *D*;
- the pipe wall thickness, *g*;
- the characteristics of the material, σ_r and σ_{ai}.

Based on this relation (11), specific diagrams were deducted. They allow determining the maximum diameter of the holes, depending on the thickness of the pipe wall, for certain pipe diameters.

The determined relation (11) allows the construction of similar diagrams as well, for pipes with different outer diameters and for other types of materials, with different mechanical characteristics.

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