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ANALYSIS OF THE FACTORS HAVING INFLUENCE ON THE QUALITY OF BENT TUBULAR PARTS BY FINITE ELEMENT SIMULATION OF THE FORMING PROCESS

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Abstract: *The paper presents a finite element model for the numerical simulation of the press bending of tubular parts. The finite element model is developed using the commercial code ABAQUS. The paper also presents the results of the simulation for different bending angles. Cold bending of metallic tubes is a very important production method, due to the fact that tubular parts are widely used in a variety of industrial products, such as automobiles, aircrafts, air conditioning equipment, air compressors, exhausting systems, fluid lines, etc.*
The objective of this paper is to study the change of the wall thickness using the finite element simulation. With this aim in view, a finite element model for the simulation of the press bending of tubes is developed. With the help of this finite element model, the influence of the bending angle on the change of the wall thickness is analyzed, both in the case of bending with internal pressure and in the case without pressure.
The results show that the bending angle has a strong influence on the change of the wall thickness. It is also noticeable that smaller bending angles cause more important variations of the wall thickness. The change of the wall thickness can be reduced by applying an internal pressure on the tube surface during the bending process.
Key words: *metal forming, tubular parts, bending, finite element simulation*

1. INTRODUCTION

The main technological problems in the bending of tubular parts are the modification and ovality of the wall thickness. In the outside region, the tube is subjected to tensile stress and the wall becomes thinner, while in the inside region, the compressive stress causes a thickening of the wall. In the previous works [1], the authors have developed a finite element model for the simulation of the bending process. This finite element approach can be used to optimize the product, the tooling design and the process parameters. There are a few bibliographic sources that report the use of the finite element simulation for the study of the tube bending. The finite element model, developed in ABAQUS/Explicit, has been used to study the influence of the bending radius on the wall change both in the case of using a mandrel and in the case of free bending. The paper [2] presents the simulation results on pre-bending and hydroforming process that are used to manufacture an automotive part.

2. PRINCIPLE OF PRESS BENDING

The device used in this manufacturing process consists of rolls 2 and 3 which are fixed on the plate of a press, while the roll 1 is attached to the ram of the same press (Fig 1). The tube 4 is placed on rolls 2 and 3, as the roll 1 moves vertically on the pipe causing it to deform. The bending radius, as well as the bending angle are controlled using the dimensional parameters x and h. The distance between rolls 2 and 3 can be adjusted by moving the rolls horizontally. The three rolls are placed on a surface with a channel that comes into contact with the tube. The channel dimensions are adapted to the diameter of the tube.
The most important advantage of this procedure consists in the fact that different bending radii can be produced without changing the rolls, because the bending radius of the tubular part is not dependent on the radius of the roll, but on the reciprocal position of the rolls (defined by the dimensional parameters x and h).

The only disadvantage of this procedure is the fact that the bending radius is determined indirectly using the parameters h and x, and it is a little more difficult to adjust.

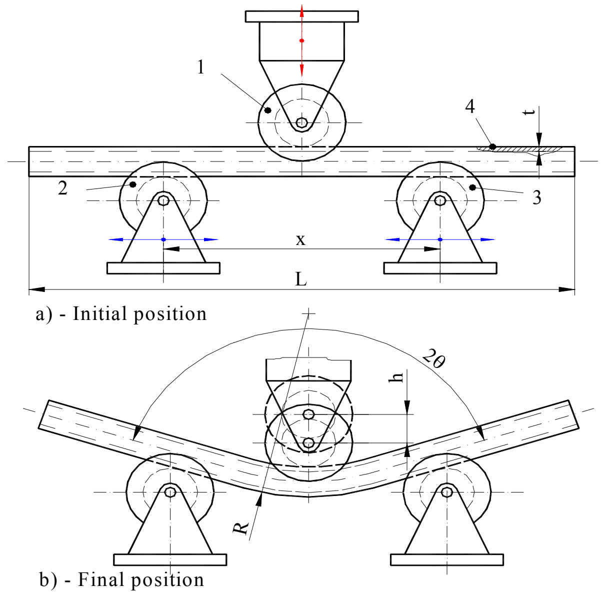

Fig.1. Principle of press bending
1 - upper roll; 2, 3 - lower rolls; 4 – tube; 2θ - bending angle; h – stroke of the upper roll during the bending process; R – bending radius

3. FINITE ELEMENT MODELING OF THE PRESS BENDING

A finite element model of the press bending has been developed using ABAQUS/CAE as shown in Figure 2. The tube has been modeled as a 3D deformable part made of an elastic-plastic material. The tools have been modeled as 3D discrete rigid bodies. Shell finite elements (S4R) have been used for meshing the tube median surface.

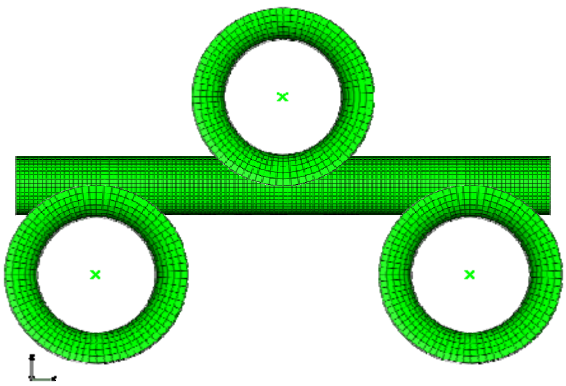

Fig.2. Finite element model of the press bending

The material of the tube is copper 99,9 and aluminum Al 99,5 . The mechanical properties of these materials have been determined by tensile tests performed on straight tubular specimens. The stress level was derived from the axial load force and the instantaneous geometry of the tube section.

Figures 3 and 4 present a comparison between the stress-strain curves obtained by testing heat treated and non treated specimens. As one may notice by analyzing these diagrams, as well as the values listed in Table 1, the heat treatment has very favorable effects on the formability of the aluminum and copper tubes.

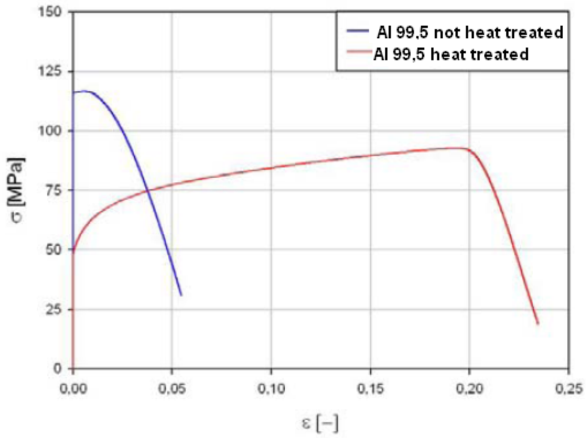

Fig.3. Stress-strain curves for aluminum Al 99.5

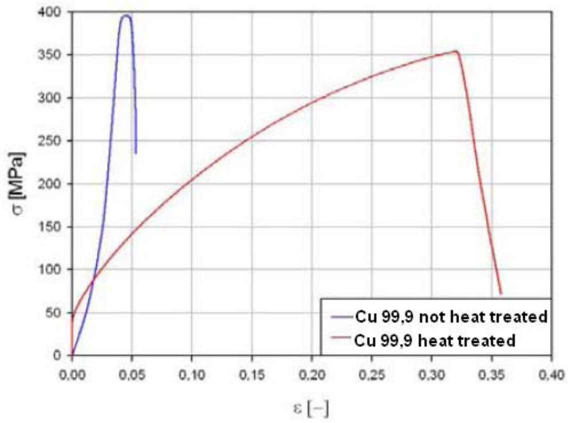

Fig.4. Stress-strain curves for copper Cu 99.9

Tabel1

Results of the tensile tests (case of the heat treated specimens)

Material	Al 99.5	Cu 99.9
Tensile strength R_m	77,1 MPa	232,7 MPa
Conventional yield stress $R_{p0,2}$	58,9 MPa	52MPa
Percent elongation under maximum load A_g	13,5%	32,7%
Total elongation under maximum load A_{gt}	18,7%	38,4%

4. RESULTS OF THE FINITE ELEMENT SIMULATION

Figure 5 presents the distribution of the wall thickness of aluminum Al 99.5 tubes bent at the angle $2\theta = 15^{o}$ and diameter 35 mm without internal pressure.

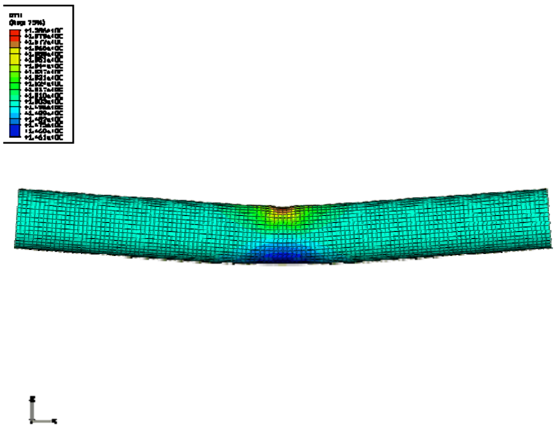

Fig.5. Distribution of wall thickness at the angle $2\theta = 15^{o}$ without internal pressure for Al 99.5

Figure 6 presents the distribution of the wall thickness of aluminum Al 99.5 tube bent at the angle $2\theta = 15^{o}$ and diameter 35 mm in the presence of an internal pressure.

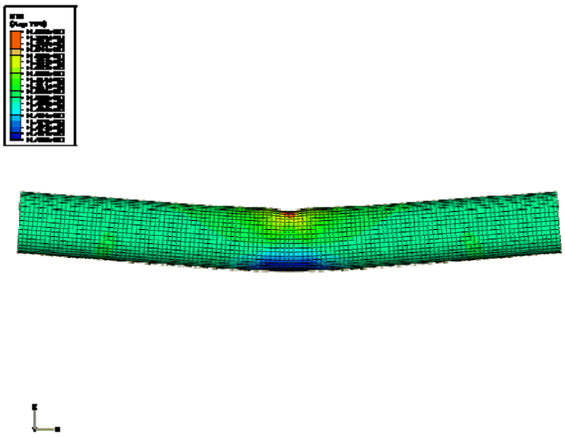

Fig.6. Distribution of wall thickness at the angle $2\theta = 15^{o}$ with internal pressure for Al 99.5

One may notice that in the case of Figure 5 the thickness of the wall varies between 1,461 mm and 1,586 mm, while, in the case of Figure 6, the variation is limited to the range 1,462 mm ÷ 1,560 mm. The initial wall thickness in the case of Al 99,5 is 1,5 mm.

Figure 7 shows the distribution of the wall thickness of aluminum Al 99.5 tubes bent at the angle $2\theta = 45^{o}$ and diameter 35 mm without internal pressure.

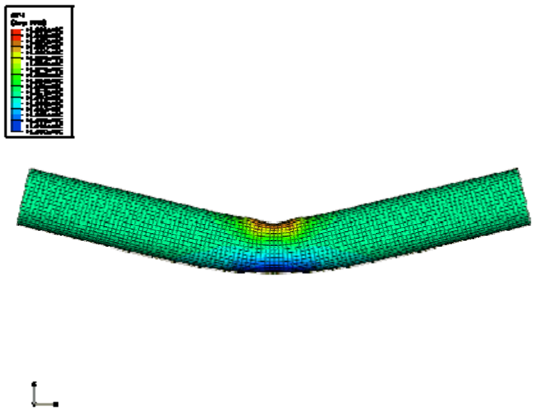

Fig.7. Distribution of wall thickness at the angle $2\theta = 45^{o}$ without internal pressure for Al 99.5

Figure 8 shows the distribution of the wall thickness of aluminum Al 99.5 tubes bent at the angle $2\theta = 45^{o}$ and diameter 35 mm, in the presence of an internal pressure.

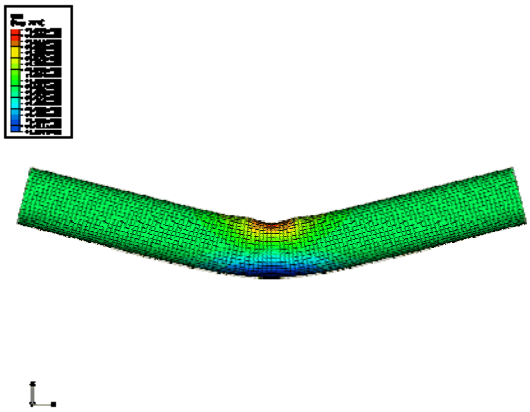

Fig.8. Distribution of wall thickness at the angle $2\theta = 45^{o}$ with internal pressure for Al 99.5

One may notice that in the case of Figure 7 the thickness of the wall varies between 1,405 mm and 1,681 mm, while in the case of Figure 8, the variation is limited to the range 1,397 mm ÷ 1,644 mm.

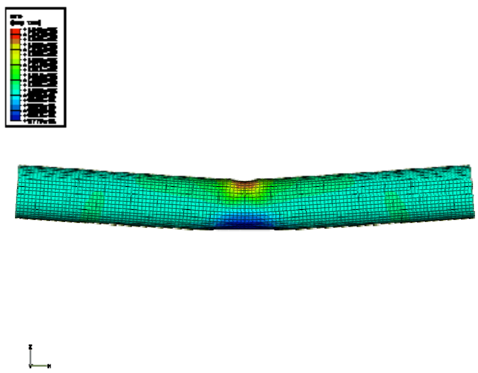

Fig.9. Distribution of wall thickness at the angle$2\theta = 15^{o}$ without internal pressure for Cu 99.9

Figure 9 presents the distribution of the wall thickness of copper Cu 99.9 tubes bent at the angle 2θ = 15° and diameter 35 mm without internal pressure.

Figure 10 shows the distribution of the wall thickness of copper Cu 99.9 tubes bent at the angle 2θ = 15° and diameter 35 mm in the presence of an internal pressure.

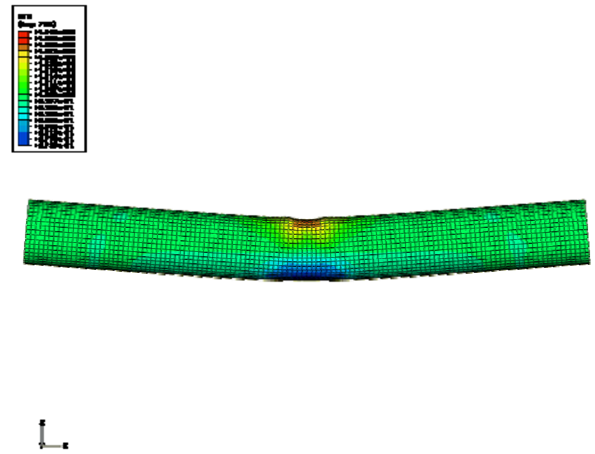

Fig.10. Distribution of wall thickness at the angle 2θ=15° with internal pressure for Cu 99.9

One may notice on these diagrams that in the case of Figure 9 the thickness of the wall varies between 0,973 mm 1,040 mm, while in the case of Figure 10 the variation is limited to the range 0,977 mm ÷ 1,046 mm. The initial wall thickness in the case of Cu 99,9 is 1,0 mm.

Figure 11 presents the distribution of the wall thickness of copper Cu 99.9 tubes bent at the angle 2θ = 45° and diameter 35 mm without internal pressure.

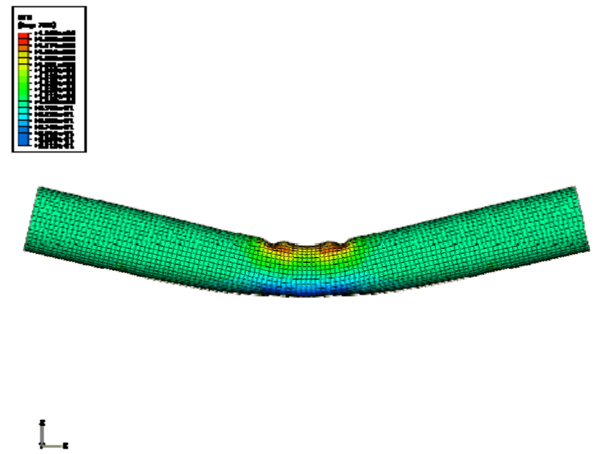

Fig.11. Distribution of wall thickness at the angle 2θ=45° without internal pressure for Cu 99.9

Figure 12 presents the distribution of the wall thickness of copper Cu 99.9 tubes bent at the angle 2θ = 15° and diameter 35 mm in the presence of an internal pressure.

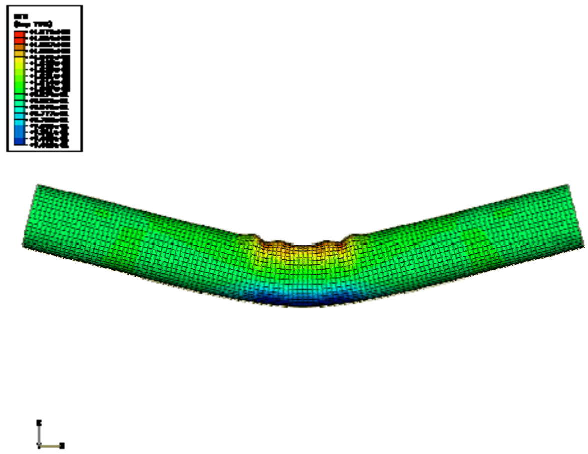

Fig.12. Distribution of wall thickness at the angle 2θ=45° with internal pressure for Cu 99.9

One may notice on these diagrams that in the case of Figure 11 the thickness of the wall varies between 0,951 mm and 1,089 mm, while in the case of Figure 12 the variation is limited to the range 0,942 mm ÷ 1,088 mm. The initial wall thickness in the case of Cu 99,9 is 1,0.

The finite element simulation also allows the evaluation of the ovality developed during the bending process. Figure 13 presents a comparison of the ovality at the level of the critical section for aluminum Al 99,5 tubes bent at different angles.

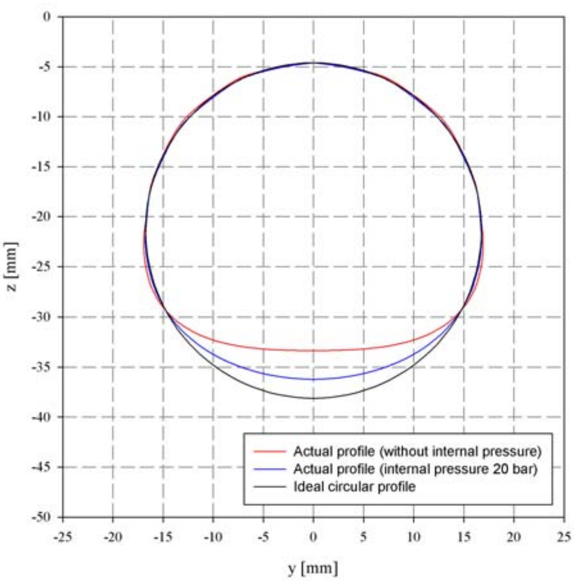

Fig.13. Cross-section ovality of a bent tube of aluminum Al99.5

Figure 14 presents a comparison of the ovality at the level of the critical section for copper Cu99,9 tubes bent at different angles.

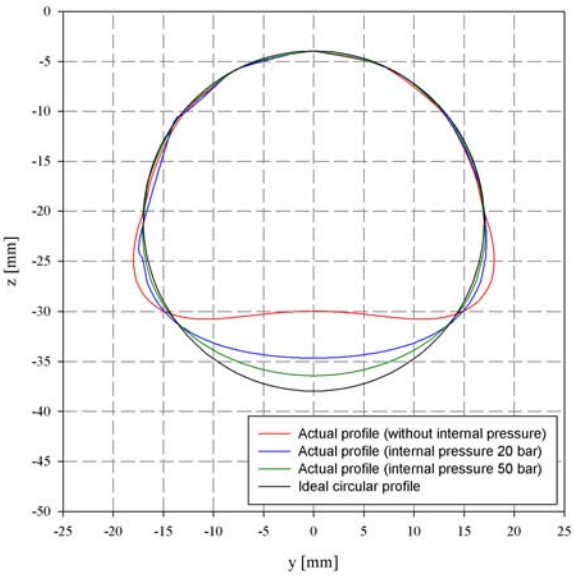

Fig.14. Cross-section ovality of a bent tube of copper Cu99,9

The ovality has the same characteristics for both materials. In general, the more severe the bending is, the higher must be the internal pressure in order to reduce the amplitude of this defect.

Because of the non-uniform plastic deformation in the bending process, the wall thickness around the cross-section of the bent tube decreases in the tension zone and increases in the compression zone. The plastic strains increase with the severity of bending. The wall thinning which occurs reduces the formability of the bent tubes. Hence, it is important to investigate the thickness strain distributions after the bending process in order to evaluate and predict its formability.

Figure 15 presents the distribution of the equivalent plastic strain of aluminum Al 99,5 tubes bent at the angle of 45^0.

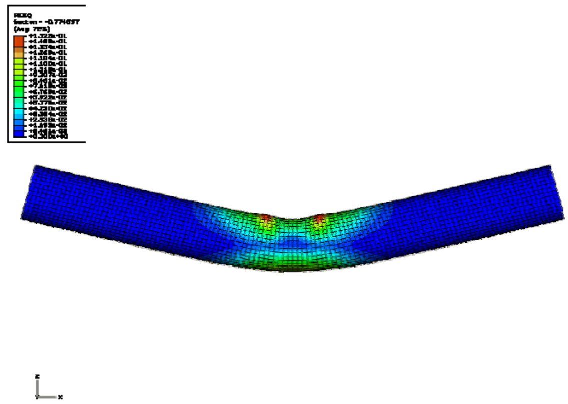

Fig.15. Plastic strain distribution of aluminum Al 99,5

Figure 16 presents the distribution of the same quantity in the case of copper Cu 99,9 tubes.

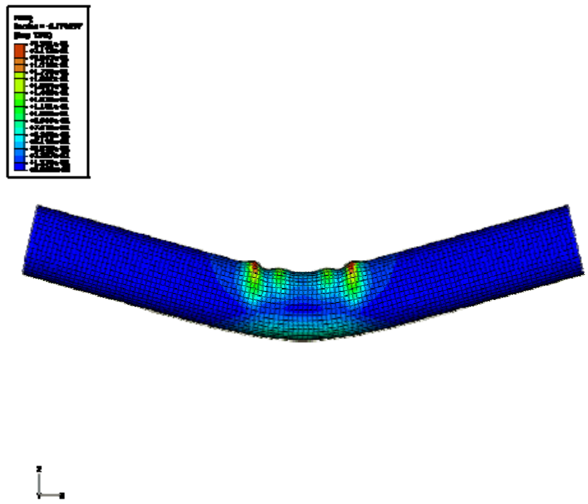

Fig.16. Plastic strain distribution of copper Cu 99,9

5. CONCLUSION

The tube bending is an important procedure frequently used before the hydroforming operations. Understanding the mechanical behavior of the material, the geometrical changes during the bending process, the influence of the forming parameters and their reciprocal relations allow the designers to obtain products and tooling designs in a better, faster and more reliable way.

The objective of this paper was to study the wall thickness change of bent tubes, using the finite element simulation. With this aim in view, a finite element model of the tube bending was developed. With the help of this finite element model, the influence of the bending angle on the wall thickness distribution has been studied, both in the case of bending with internal pressure and in the case non-assisted by pressure. The analysis has been focused on three values of the bending angles, namely 15, 30, 45^0.

The numerical results show that the bending angle has a strong influence on the wall thickness.

It has been also noticed that the difference between the maximum and minimum thickness of the tubular part can be diminished by applying an internal pressure during the bending operation.

6.ACKNOWLEDGMENT

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7. REFERENCES

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Analiza factorilor care influenteaza calitatea pieselor tubulare indoite cu ajutorul simulari numerice a procesului de deformare a tuburilor

Rezumat:*Lucrarea prezinta simularea numerica a procesului de indoire a epruvetelor tubulare. Aceasta simulare numerica a fost realizata cu ajutorul programului ABAQUS. Deasemenea in lucrare sunt prezentate rezultatele obtinute pentru indoiri de tuburi la diferite unghiuri.Indoirea la rece a tuburilor metalice este o metoda foarte importanta datorita faptului ca piesele tubular sunt utilizate pe scara larga si intr-o varietate foarte mare in industria de automobile, aviatica, in echipamente de aer conditionat, instalatii sanitare, precum si in industria bunurilor de larg consum. Obiectivul principal al acestei lucrari este de a studia modificarea grosimii peretelui cu ajutorul simularilor cu elemente finite. In acest scop am dezvoltat un model pentru indoirea tuburilor pe role, adaptabil pe echipamente universal. Cu ajutorul acestui model am studiat influenta unghiului de indoire asupra modificarii grosimi peretelui, precum si a ovalizari tubului, atat pentru cazul cand indoirea are loc cu presiune interioara sau fara presiune interioara.Rezultatele arata ca unghiul de indoire are o influenta puternica in modificarea grosimi peretelui, precum si a ovalizari.Deasemene in urma rezultatelor obtinute am ajuns la concluzia ca aplicarea unei presiuni interioare, are influente asupra grosimii peretelui.*

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