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Quality of the hydroformed tubular parts

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Abstract: In this paper the authors shows hydroforming of tubular parts. Also it presents the technology of the hydroforming of the tubular parts. It is presented some experimental research compared with the prediction of the numerical simulation of this process. There are presented also the mechanical parameters of the material which are used in the field of the deforming process.

Introduction

Hydroforming is a manufacturing process which uses hydraulic pressures for deforming same tubular parts, or same sheet parts. The tubular hydroforming method is frequently used to make complex parts at the structure of automotive and also in the other sector of manufacturing (aeronautical parts, industrial parts) [1]. At this method one of the most important facts is the coordination of the internal pressure with movement of the axial plunger. With this method we must obtained the parts without defects, such as bursting and wrinkling. This method is a cold deforming process, and we can obtain the form that we want by one single operation [2]. Hydroforming technology has gained increased interest in the world because of its many advantages and because it follows the development of the corresponding technologies. Many research works have been carried out, and a series of special seminars and symposiums have been organized around the world [3–5]. Before the process of hydroforming, the tubs can make same bending operation on that part.

Fig. 1. Exhaust parts produced by hydroforming [6]

In the use of the hydroforming, in industrial production, Germany is one of the forerunners. In 1993, the Daimler-Benz Corporation built its first tube hydroforming production line. Same product of the hydroforming we can see in figure 1. Through the last decades, it has been discovered that it is expensive and time consuming to design for hydroforming processes as well as conventional forming processes using trial and error. The application of numerical simulation for the hydroforming process helped engineers to efficiently improve the process development avoiding the cost and limitations of compiling a database of real world parts. Finite element analysis allows an inexpensive study of arbitrary combinations of input parameters including design parameters and process conditions to be investigated. Explicit finite element codes were proved to have much better capabilities to handle such kind of nonlinear behavior exhibited by the metal forming process and

provide a better understanding of the plastic deformation mechanism over implicit finite element analysis [7-8]. Similar to other forming processes, development of forming limit diagrams (FLD)[9] enabled designers and manufacturers to determine process limitations and to estimate the forming characteristics of the tube as an essential task in tube hydroforming. The obtained FLDs can be used to optimize the hydroforming tool geometries and also to develop criterion for material failure.
‘‘Open-die’’ hydroforming is one of the most popular methods used to obtain FLD for circular tubes of various materials [10–14].

Principle of hydroforming tubs

Figure 2 presents the process of hydroforming tubular parts. Figure 2,a presents the tubular parts which are introduced in the mold and its initial form; figure 2,b presents closed mold, also in this step the plunger is fixed on the part and a hydraulic liquid it is pumped whit the same pressure. Figure 2,c presents the open mold to get the pieces hydroformed. During the hydroforming process the material is swollen by increasing internal pressure, with two plungers acting at the ends of the tube.

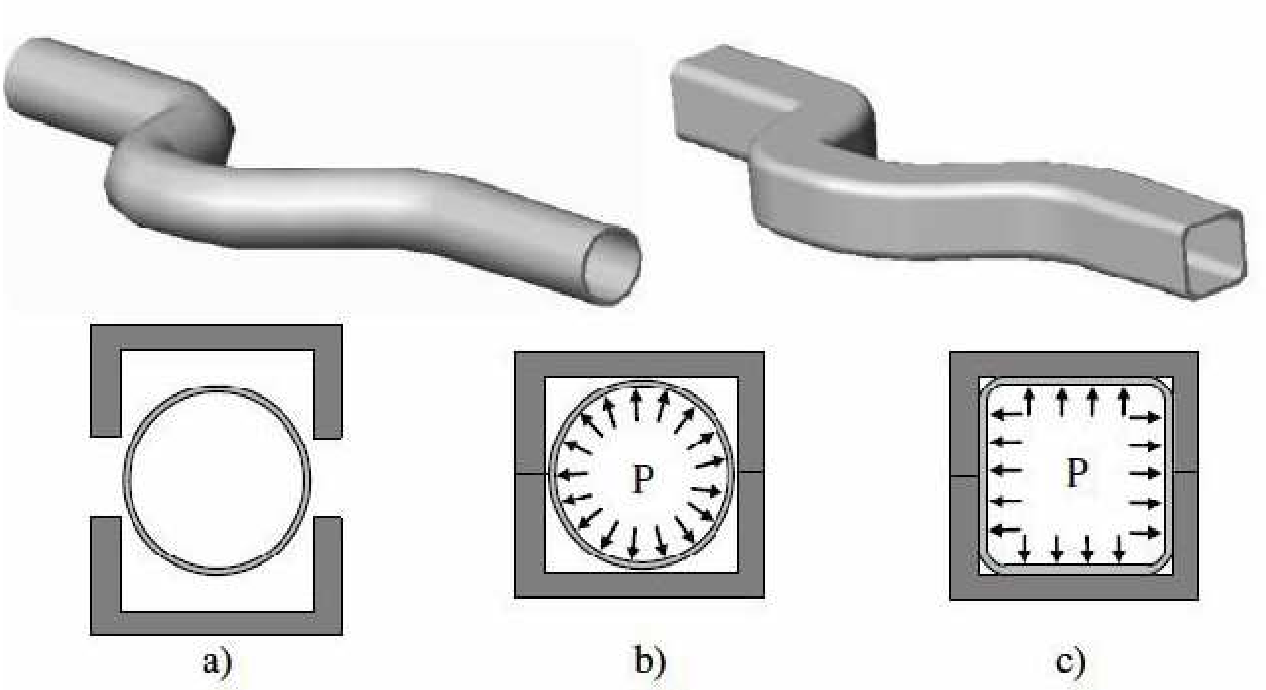

Fig. 2. Principle of the hydroforming tub

Plungers are pressing the ends of tube by introducing a fluid under pressure through holes of plunger, and deform the material of the tub.

Experimental research

Research methodology is primarily aimed at establishing mathematical model of the phenomenon (or process), being also studied as a method of research.
The method of research, will determined the order of the experiments, the measuring tools, how the measurement and observation systems are interconnected, and finally, how to store the data for the next interpretations. In this experiment, it is used experimental stands, which are constructed based on a research methodology, and the data will be processed directly, by using the computer software. This data will allow the foundation of some conclusions which can be used in technological practice. The number of the measurements is very important for the accurate results of the research. Theoretically, as the number of the measurements for the same phase of the research, is highest, the final conclusion is much closed with the experimental results.

For experimental research were used tube made from copper material, such as Cu 99,9 – EN 1057 Ed. These tubes were obtained by cold drawing process; this method is common to manufacture tubular parts, which are used more frequently in installations.
Tensile strength, yield strength, chemical composition and variation in wall thickness are properties that influence the hydroforming process parameters and characteristics of hydroformed parts.
Due to the manufacturing process of the shooting tubes, the hardening exponent "n" decreases by 10 – 20 [%] and uniform elongation is being decreased with a value of 2 – 4 [%], as compared with the same material properties sheet [14], [15]. For these reasons the made measurements will be made directly on material of the tube which are hydroformed, and significantly influences the manufacturing process.

Mechanical testing

To obtain properties of the material, the samples were uniaxial tensile strength tested along the tube axis direction. The properties obtained experimentally showed good concordance with the deformations of the wall thickness obtained by numerical simulation of the hydroforming process. Tensile strength testing is standardized by EN 10002-1:1995 and EN 10002-2:1995, which shows the shapes and dimensions of specimens, test conditions and yield determination. Figure 3 presents the specimen dimensions given by standard EN 10002-1:1995.

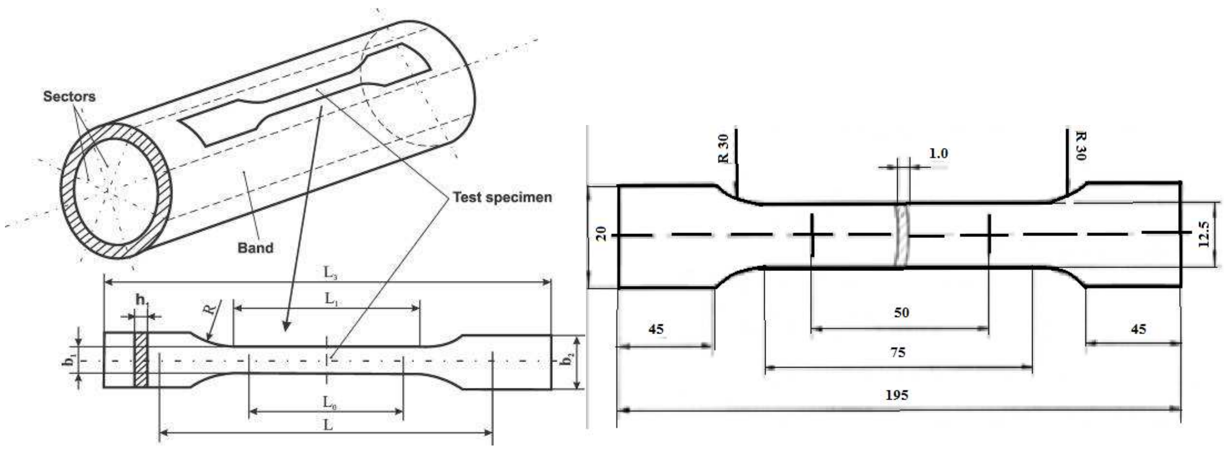

Fig.3 Tensile test specimens according to SR EN 10002-1:1995

Tensile test specimens were cut from the tube diameter Ø 35 mm in the longitudinal direction without affecting the characteristics of the material. They were cut on water-jet cutting machine OMAX 2626 from the Technical University of Cluj-Napoca, as shown in figure 4.

Fig. 4. Water-jet cutting machine OMAX 2626 and different phases of the process

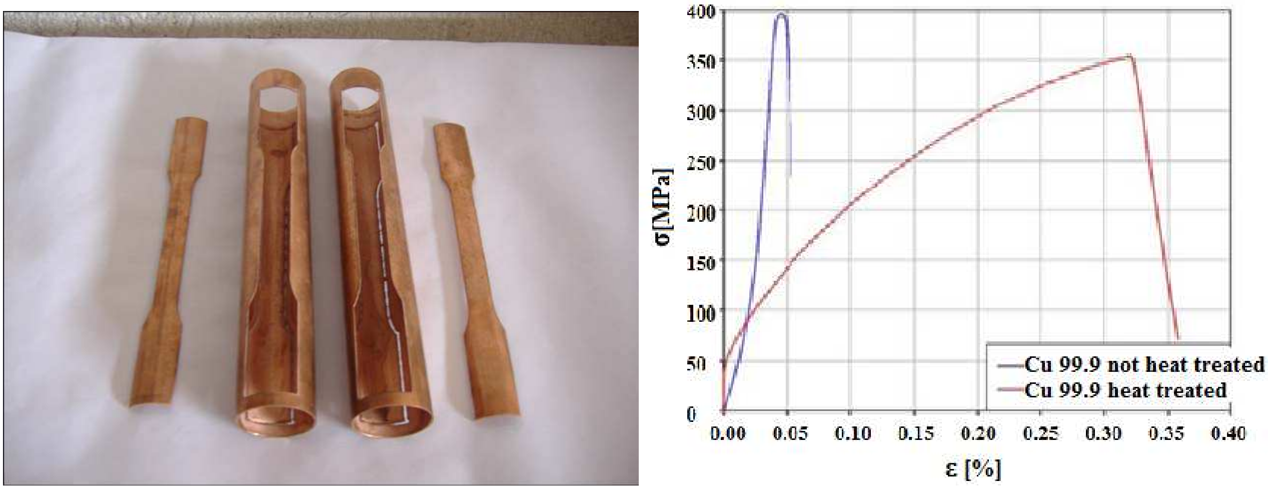

Fig. 5. Stress-strain curves for cooper material and tensile strength testing results

Uniaxial tensile strength testing consists in applying a tensile force on a specimen until fracture, in order to determine the mechanical properties characteristics. Figure 5 presents the stress-strain curves in the case of heat treated cooper material and in the case of cooper material without any heat treatment applied. Also it is show some tensile testing obtained for cooper material (the case of Cu 99,9 – EN 1057 Ed).

Table 1. Results of the tensile tests (case of the heat treated specimens)

Material	Cu 99.9 heat treated	
Tensile strength R_m	232,7	[MPa]
Conventional yield strength $R_{p0,2}$	52	[MPa]
Percent elongation under maximum load A_g	32,7	[%]
Total elongation under maximum load A_{gt}	38.4	[%]

In table 1 there are presented the main characteristics of the tensile strength tests performed in the case of heat treated cooper material. These characteristics were determined before hydroforming process and help us to perform further on the numerical simulation of the process.

Mold of hydroforming

The aims of hydroforming process were the deformability analysis of the tube and the changes of the wall thickness in the case of hydroformed parts. For this, it was necessary to design and manufacture a hydroforming mold.

The hydroforming mold is composed by following parts (figure 6):

1- Tubular sample. This was make by cooper material (Cu 99,9), taken from tubular part with outer diameter of Ø35 [mm] and a length of 5000 [mm]. The wall thickness was 1 mm.
2- Sealing parts, was made by tubular silicone with length of 20 [mm] and inside diameter of Ø22mm; outside diameter was Ø33 [mm].
3- Mobile plunger was made by OLC 45 material. Inside of the plunger, a hole for the hydraulic oil has been designed and manufactured.
4- Fix plunger was made by OLC 45 material. This item has the role of lining-up and guiding the hydroforming mold.
5- The two parts of the mold was made by OL 37 material, having the dimensions 300 x 160 x 40 [mm]. These two parts of the mold were milled on a CNC Machine.

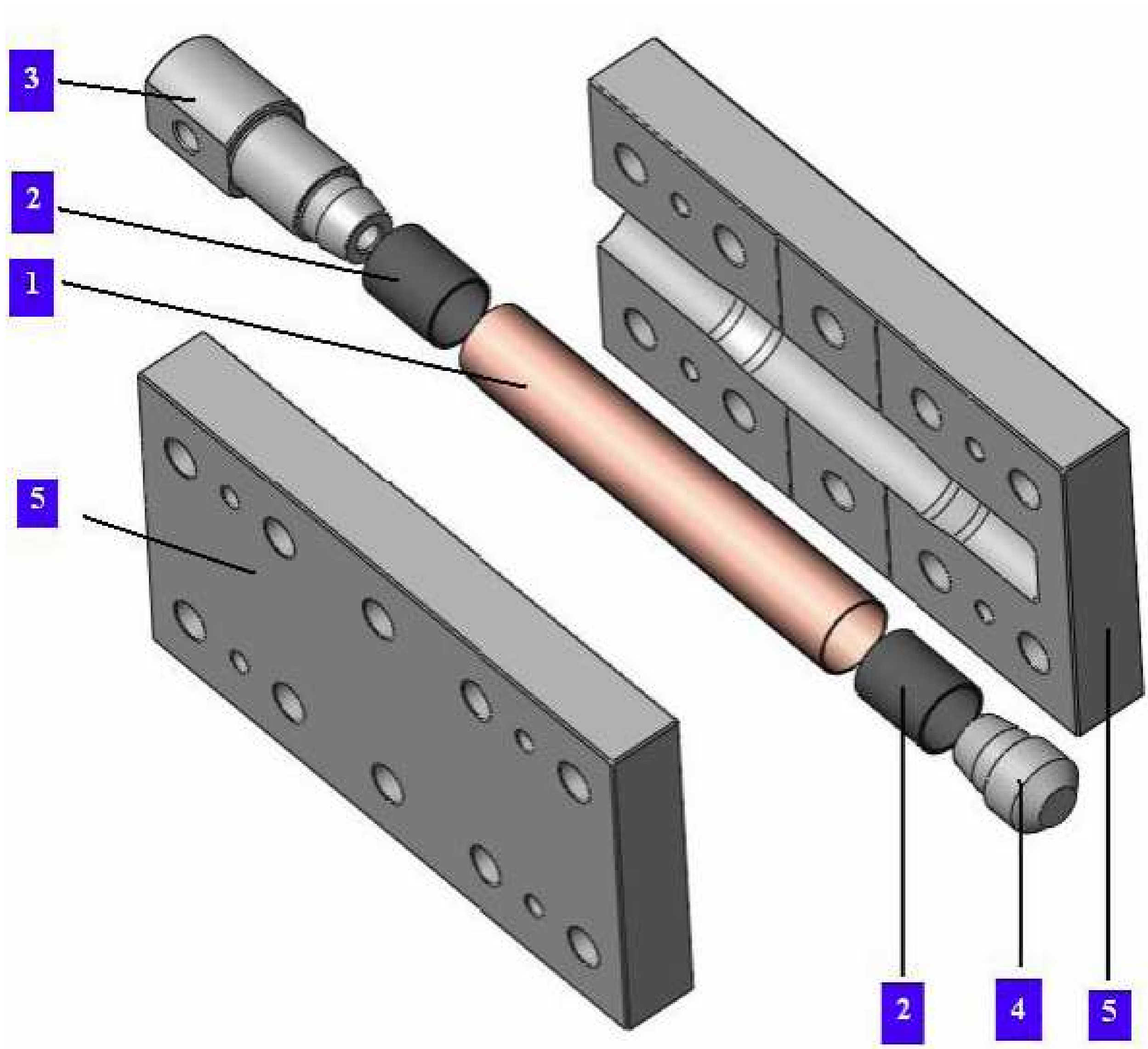

Fig. 6. Mold of the hydroforming tub

Stand of hydroforming

Experiments of hydroformed tubes from copper material were made at the Technical University of Cluj-Napoca, in the laboratory of the Manufacturing Engineering Department.
In these made experiments, it was used the stand of hydroforming presented in Figure 7, consisting in the following elements:

1- Mold of hydroforming;
2- High pressure hydraulic pomp;
3- Tensile strength testing Machine Tinius Olsen, with nominal force of 100 [kN].

In order to perform the hydroforming processes, the copper tubes were divided to the corresponding length, calculated using the inside of the hydroforming mold. After dividing, the tubes were trimmed and cleaned in order to be easily mounted in the mold. Before the hydroforming, the samples were heat treated in order to have good deformation characteristics.
Combining was performed between tubular specimen and fixed, mobile plunger, using sealing elements by pressing. On the internal surface of the mold there was manually applied a layer of lubricant (hydraulic oil H46 EP), in order to reduce the friction between specimen and the internal surfaces of the mold. This assembly, made by fixed, mobile plunger, tubular specimen, sealing elements was introduced inside of the mold.

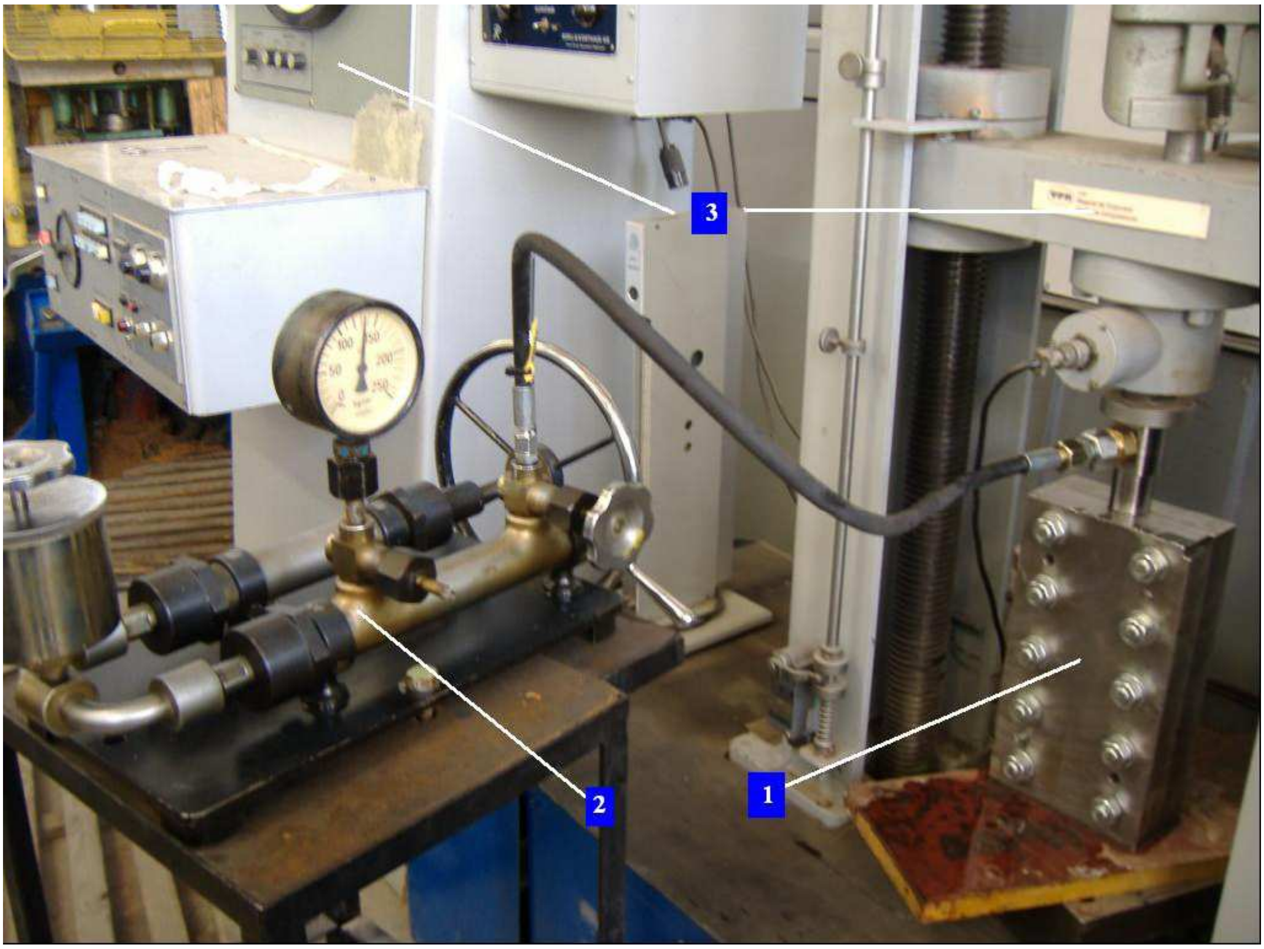

Fig. 7 The stand of hydroforming tubes

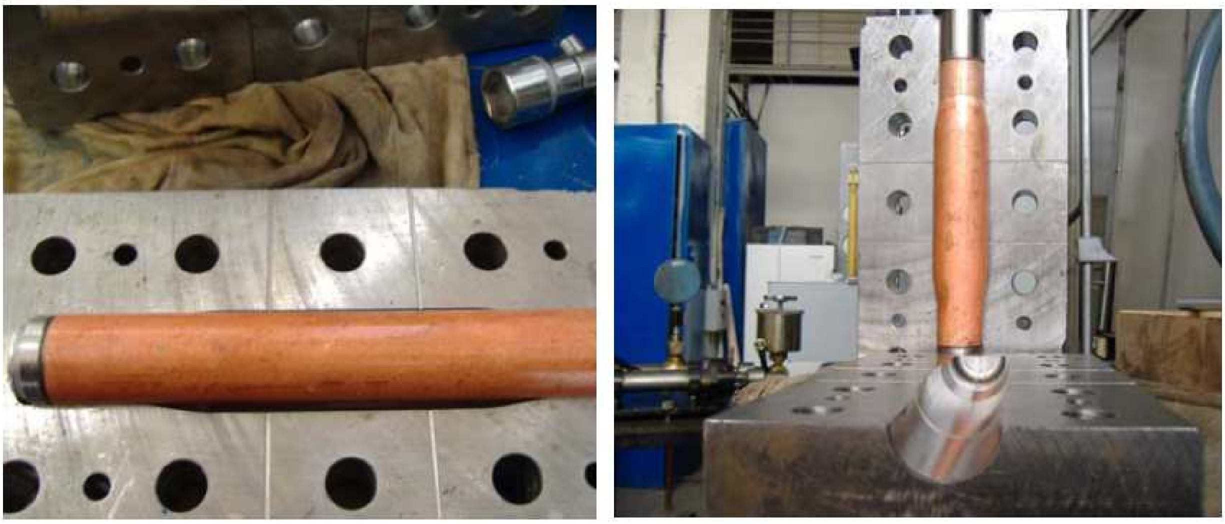

Fig. 8. The Hydroforming Process –inside of the mold

Fig. 9. Tubular specimen before and after hydroforming

Figure 9 presents some tubular specimens from cooper material that was hydroformed using the experimental stand.

Numerical Simulation

In order to describe the mechanical behavior of the tube, it was adopted an elastoplastic material model. This model describes the elastic deformation through standard linear Hooke law, the structure constructed mainly by using two material constants, such as: Young's modulus (E) and Poisson's ratio (ν).

Table 2 Mechanical Characteristics of cooper Cu 99,9

Elastic constants	E	$8.5 * 10^4$ N/mm^2
	ν	0.32
Constants of Hollomon's	K	365 N/mm^2
	n	0.185

In table 2 there are presented the values of the material constants witch defines the elastoplastic model from Cooper Cu99,9 material. All mechanical parameters from the table 2 correspond to the state of material after the heat treatment process.

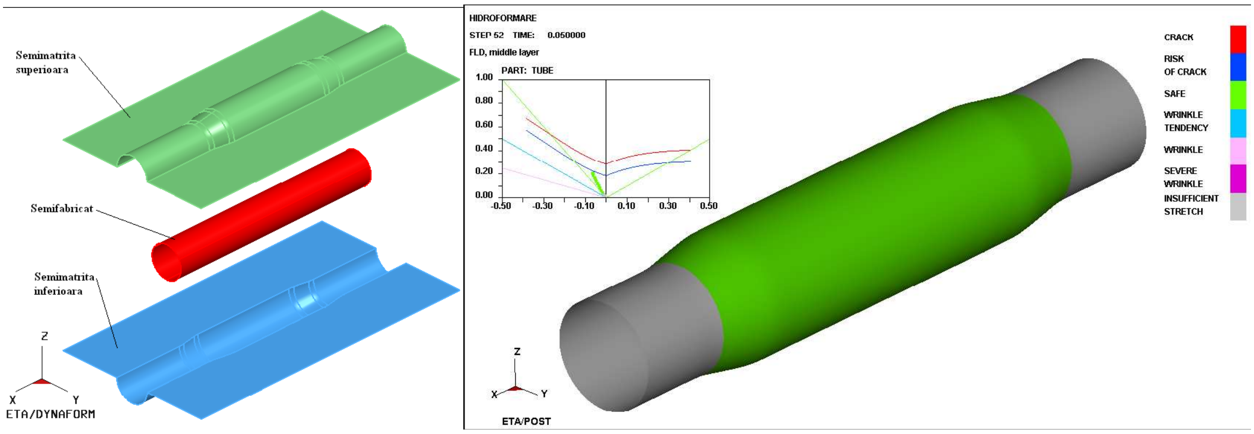

Fig. 10. The importance of the geometrical models of the tubular specimen made by DYNAFORM

The tubular sample and the active surfaces of the molds were designed by using the SolidWorks 2008 CAD program. The geometric representations of these items were transferred to the DYNAFORM FEA program, as ".IGES" files (figure 11).

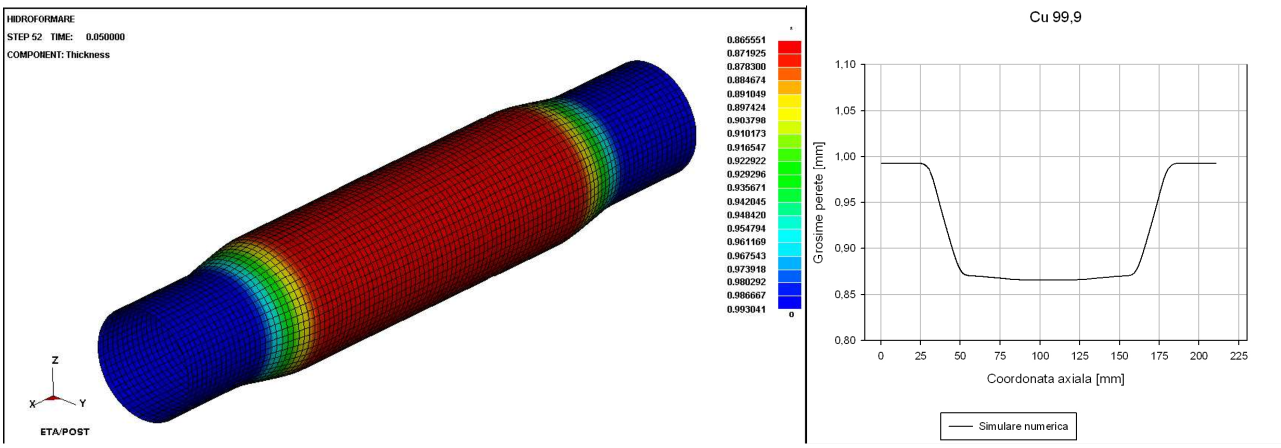

Fig. 11. The wall thickness axial variation of the hydroformed sample made by Cu 99,9 material

The measurements of the hydroformed tubs were made by using a 3D CYCLONE –RENISHAW Series 2 scanner. 3D Scanning is a well known method that it is used in order to get information on 2D or 3D surfaces that are difficult to be defined [16]. This machine has optical and mechanical sensors.

In order to study the variation of copper specimens size, there were performed hydroforming tests on specimens tube with the length of 220 [mm] and the thickness of 1 [mm]. There were made 9 hydroformed samples and the measurement was made in the cross area of the sample, as illustrated in figure 12.

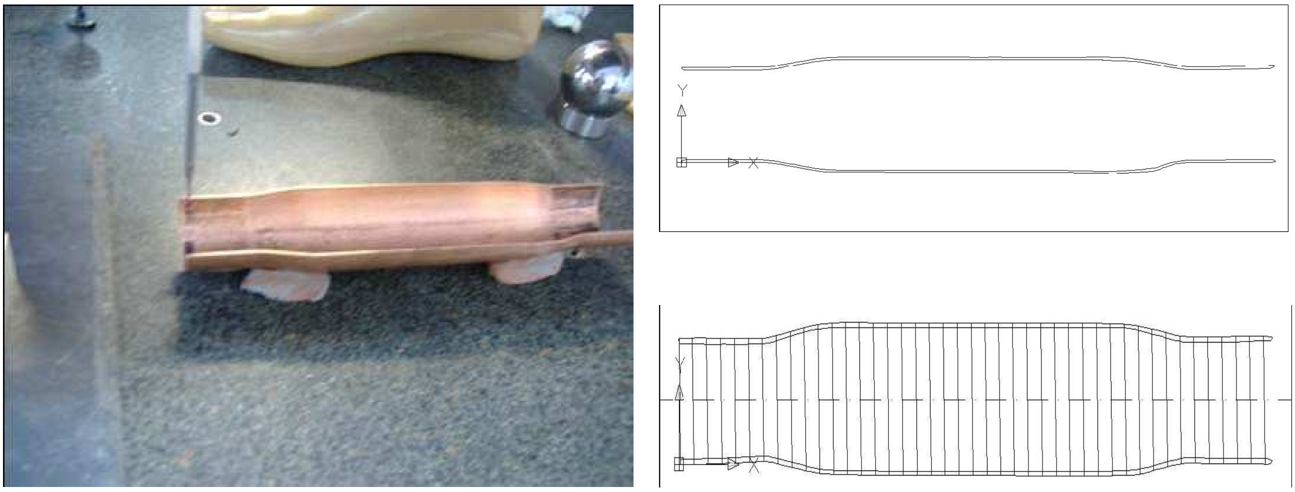

Fig.12 The measurement of the hydroformed tubular specimens

Conclusion

The made experiments were focused on aspects related to the quality of tubular parts obtained by the hydroforming processes. The laboratory research results that were obtained were used further on to calibrate the material model that was necessary for the simulation of the hydroforming process that has been performed and finally to validate the numerical results obtained by the FEA simulation. Experimental results showed a very strong influence treatment especially on Ag percent elongation and Agt total elongation, whose values have increased significantly.
The experimentally determined thickness distributions were compared with predictions obtained by finite element analysis performed using the DYNAFORM FEA program.
It can be concluded that there is a good concordance between the experimental obtained results and those obtained from numerical simulation.
Heat treatment is another factor that highly influences the quality of hydroformed tubes, preventing defects in the hydroforming process.
It is indicated to use hydraulic oil in order to reduce the friction between the work piece and mold for the hydroforming.
By the economical point of view, there are advantages as well coming by the fact that this device can be installed on any universal machine for cold pressing.

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