Association of Metallurgical Engineers of Serbia
AMES

Scientific paper
UDC: 621.774.6

EXPERIMENTAL INVESTIGATION OF NON-UNIFORM DEFORMATION IN TUBE HYDROFORMING

Miroslav Plančak[1*], Karl Kuzman[2], Dragiša Vilotić[1], Tomaž Pepeljnjak[2], Igor Kačmarčik[1], Dejan Movrin[1]

[1]*Faculty of Technical Sciences, Trg Dositeja Obradovića 6, Novi Sad, Serbia*
[2]*University Ljubljana, Strojniska fakulteta, Askerceva 6, Ljubljana, Slovenia*

Received 13.05.2011
Accepted 17.06.2011

Abstract

The main characteristic of tube hydroforming is ability to produce a variety of complex hollow shapes of different size and materials, which have favorable weight to stiffness ratio. It is possible to extend the application field of tube hydroforming by integrating other technologies such as piercing, bending etc.

One of the significant influential factors in this process is friction which occurs during deformation between tube outer wall and die inner wall. Friction has impact on material flow, required axial force and quality of the final product.

This paper describes experimental investigation of non-uniform deformation of tube wall thickness. Network of circular grid was inscribed at outer wall surface of the tube which made possible to obtain amount of local deformation. Wall thickness along the tube length was measured by special device.

Key words: tube hydroforming, friction, wall thickness, non-uniformity

Introduction

Tube hydroforming is a relatively new technology of metal forming which makes it possible to manufacture hollow components of different shapes and sizes, from different materials. Due to its numerous advantages tube hydroforming finds its application in automotive industry, in manufacturing of various complex components (structural parts, pipe line elements, sanitary appliance etc.). In Fig. 1 some products made by tube hydroforming are shown: rear axle component of the car, sanitary appliances and exhaust part.

[*] Corresponding author: Miroslav Plančak, plancak@uns.ac.rs

It is essential to apply proper combination of inner pressure and axial force during the process. Too high axial force and low pressure cause wrinkling and too low force and too high pressure lead to bursting of the tube.

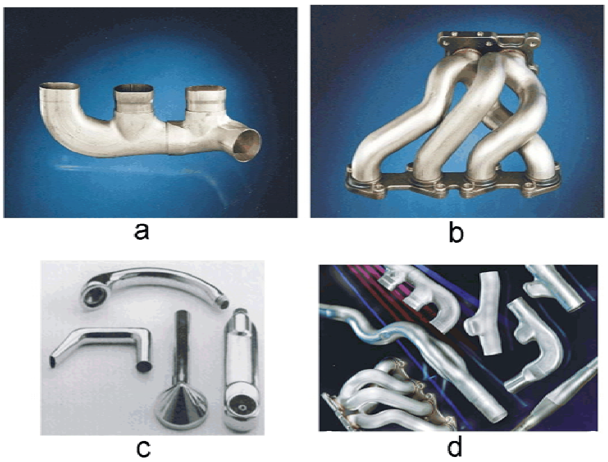

Fig. 1. Components made by tube hydroforming

In tube hydroforming tube is closed in the die and subjected to the simultaneous action of axial force and inner pressure (Fig. 2). In this way tube is plastically deformed, following the contour (shape) of the die in which it is closed.

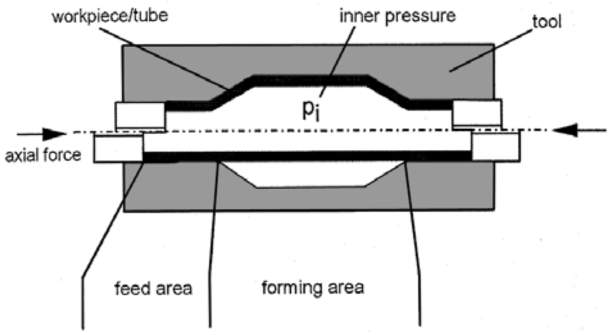

Fig. 2. Tube hydroforming

Friction, which occurs at the interface between tube and die, plays a significant role in the process as it affects material flow, required axial force and quality of the product.

One of the main indicators of the quality in tube hydroforming is (in) homogeneity of the wall thickness along the produced component.

This paper presents experimental investigation carried out to get insight into the non-uniform deformation, i.e. thickening of the component wall during hydroforming.

Inhomogeneity of the wall thickness in the tube hydroforming

During hydroforming process, initially constant wall thickness of the tube changes along the tube length. In this way final component may have different wall thickness at different locations. This unfavourable feature occurs due to friction between tube and die during the process. Explanation of this phenomenon is given in Fig. 3: tube (1) is closed in the die-container (2) and subjected to the inner pressure "p_i" as well as to the axial forces F_{so} and F_{su}. Upper punch (3) moves downward, shortening the tube, while bottom punch (4) is fixed. In this situation two kinds of deformation can take place. If there is no friction between the tube and the die wall (theoretical case, $\mu = 0$) the die wall deforms uniformly, i.e. the wall thickness is constant along the tube height. In reality, however, friction force at the interface always occurs and, consequently, a non-homogeneous deformation of the wall thickness takes place. The biggest wall thickening takes place at the side of movable punch and lowest at the side of fixed punch (die bottom).

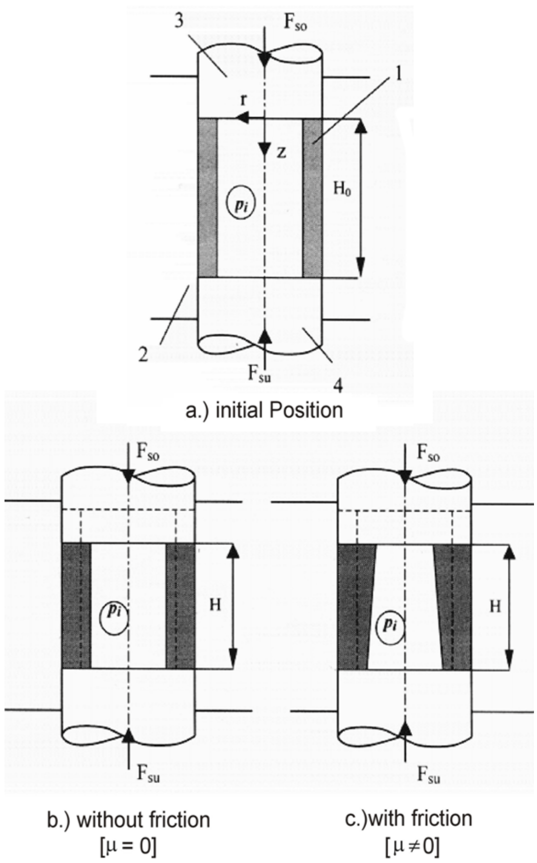

Fig. 3. Tube hydroforming without friction (b) and with friction (c)

Based upon presented consideration analytical method for determination of friction coefficient in tube hydroforming has been developed which makes it possible to obtain "μ" by measuring the deformed tube and by known material properties. More details related to this subject can be found in [1].

In Fig.4 force distribution is given as well as the relevant geometrical data.

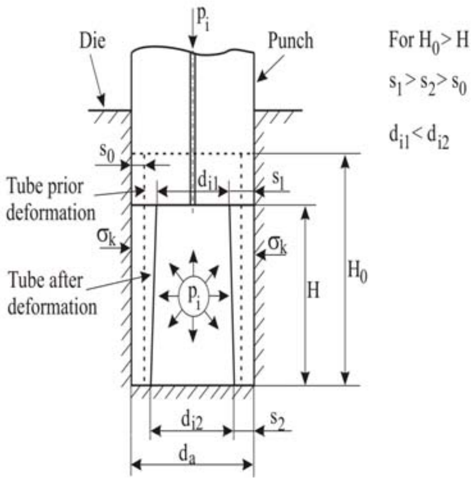

Fig. 4. Forces in tube hydroforming

Experimental investigation

For the experiment special tooling was made (Fig. 5). The tube was uniformly lubricated at the outher surface with molycote spray and placed into the die. Movable punch acts at the left side end of the tube while right end of the tube is supported by fixed punch. In this way upsetting of the tube, which simulates tube hydroforming process, is realized.

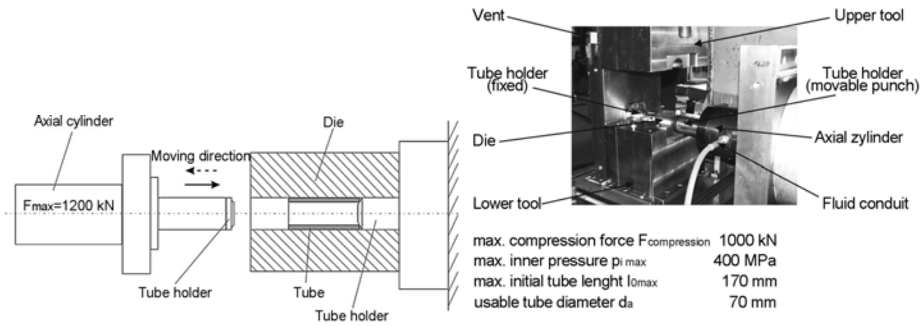

Fig. 5. Experimental tooling – scheme and photo

Experimental data:

- material: St34-2
- initial tube length: 130 mm
- final tube length: 108,4mm
- outer tube diameter: 70mm
- initial wall thickness: 3mm
- Lubrication: molycote spray

Tube hydroforming experiments were conducted on a hydraulic SPS press of 800kN (Fig. 6).

Fig. 6. Hydraulic press SPS of 800kN

Table 1. Tube geometry prior and after deformation

	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5
	d_o	d_1	φ_z	s_1, wall thickness	$\Delta s = s_1 - s_0$
1.	5,176	/	/	3,43	0,43
2.	5,105	4,584	10,76	3,4	0,4
3.	5,100	4,552	11,36	3,35	0,35
4.	5,094	4,435	13,8	3,50	0,5
5.	5,103	4,491	12,7	3,48	0,48
6.	5,137	4,460	14,13	3,49	0,49
7.	5,130	4,501	13,08	3,49	0,49
8.	5,168	4,505	13,73	3,49	0,49
9.	5,192	4,513	14,01	3,50	0,50
10.	5,214	4,497	14,79	3,50	0,50
11.	5,140	4,403	15,47	3,50	0,50
12.	5,257	4,382	18,2	3,50	0,50
13.	5,301	4,365	19,42	3,50	0,50
14.	5,210	4,406	16,76	3,51	0,51
15.	5,244	4,392	17,73	3,51	0,51
16.	5,279	4,375	18,78	3,52	0,52
17.	5,229	4,383	17,65	3,52	0,52
18.	5,294	4,398	18,54	3,53	0,53
19.	5,266	4,352	19,06	3,54	0,54
20.	5,132	4,328	17,03	3,54	0,54
21.	5,235	4,318	19,25	3,47	0,47
22.	5,085	4,397	14,54	3,34	0,34

Prior to deformation outer surface of the tube was marked by circular mesh which was created by electrochemical procedure. Due to some inaccuracy during this procedure of marking initial diameters of every circle slightly differs. In the first column of Table 1, initial diameter of every circle in vertical direction is given. Circle number 1 is located at the fixed end and circle number 22 at the movable end of the tube (Fig. 7).

After deformation deformed tube was taken out of the die, needed geometrical data (wall thickness distribution and corresponding tube heights) were measured by Zeiss 3D Coordinate device.

In column 2 circle diameters in vertical direction after deformation are given.

Based upon known (measured) circle diameters prior and after deformation corresponding values of φz are calculated and shown in column 3 for every vertical position of the tube. Wall thickness along the tube which was measured by ultrasound instrument is given in column 4. Finally, column 5 shows difference between initial and final wall thickness at given location of tube (thickening of the wall) .

In Fig. 8. marked tube prior and after deformation is given.

Obtained results – distribution of tube wall thickness along the tube after deformation – for different friction conditions are given in form of a diagram in Fig. 9.

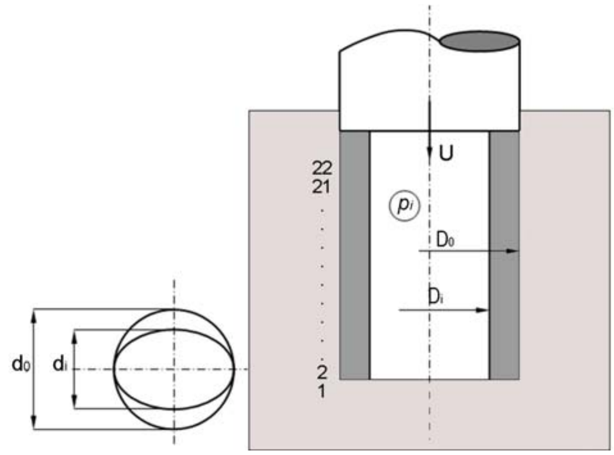

Fig. 7. Position of the marked circles at the tube outer surface

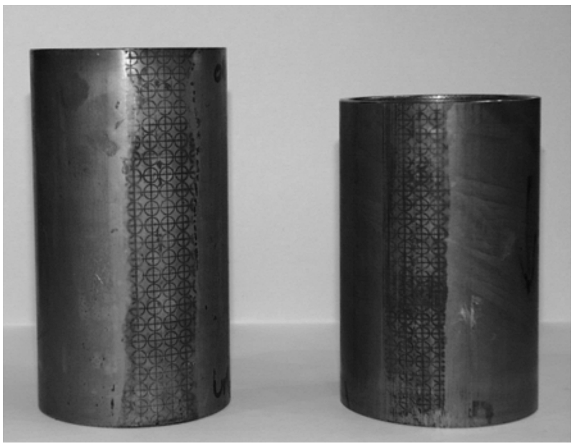

Fig. 8. Initial and deformed tube with circular mesh

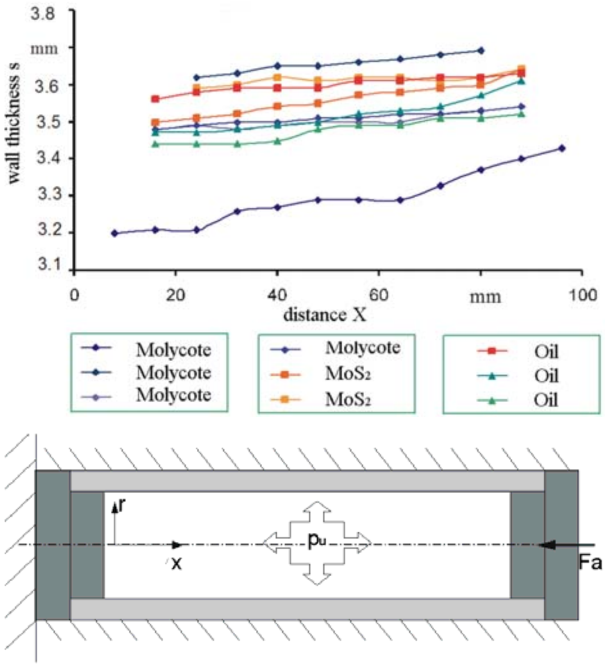

Fig. 9. Distribution of tube wall thickness along the tube after deformation

Horizontal coordinate indicates tube length and position of the fixed and movable punch and at vertical coordinate corresponding wall thickness is given.

Concluding remarks

Due to its advantages when compared with other technologies, tube hydroforming has found its application in various branches of industries. In the same time at many research laboratories worldwide investigation have been undertaken in order to improve and optimize characteristics of the process and quality of the components made by this technology.

One of the undesired features in tube hydroforming is non-uniform wall thickening which takes place during deformation. As a result of this, component with (unwanted) difference of wall thickness is produced.

Current paper illustrates experimental investigation which was carried out with the goal to determine phenomenon of non uniform wall thickening. For the experimental investigation special tooling was designed and made.

In order to obtain amount of local deformation of the tube wall, circular grid was placed at the outer tube wall. By comparing this grid prior to and after tube upsetting, axial deformation along the tube has been obtained. Thickness of the tube wall at corresponding locations was measured by Zeiss instrument.

Results had shown that initial wall thickness of 3mm increases during deformation to 3.54mm (18%). Maximum thickness is obtained at the side of movable punch and minimum at the side of fixed punch.

In further work on this subject different process parameters will be varied: inner pressure, tube dimensions (length, diameter, initial wall thickness), lubrication, punch velocity and material. Additionally, FE simulation will be applied.

Acknowledgement

Investigation presented in this paper has been part of EUREKA E!5005 Project.

References

[1] F. Vollertsen, M. Plancak: On possibilities for the determination of the coefficient of friction in hydroforming of tubes, Journal of Material Processing Technology, 125-126 (2002), 412-420.
[2] M. Plancak: Ein Beitrag zur Ermittlung der Reibzahl beim IHU-Rohrstauchen, Interner Bericht, Universität Paderborn, 2000.
[3] Ch. Hartl: Ein Beitrag zur Flexibilierung der Innenhochdruckumformung. Dissertation: Berichte aus der Fertigungstechnik, Verlag Shaker, Aachen 1995.
[4] M. Plancak, F. Vollertsen, J. Woitschig: Analysis, finite element simulation and experimental investigation of friction in tube hydroforming, Journal of materials processing technology, 170 (2005), 220-228.
[5] M. Plancak, F. Vollertsen: A contribution to determination the friction coefficient in hydroforming of tubes, Leaf Coppin, Tribotest journal, 2003 (9) 219 ISSN 1354-4063.
[6] M. Prier: Die Reibung als Einflussgrösse im Innenhochdruck-Umformprozess, Dissertation: Berichte aus Produktion und Umformtechnik, PtU, Universität Darmstadt, Band 46, Shaker Aachen 2000.
[7] K.N. Bogoyavlenskij, E. I. Serjakov: Hidravliceskaja formovka trojnikov i krestovin (Hydraulisches Formen von T und Kreuzstücken), Kuznjecnoe-Stampovocnoe Proizvodstvo (1972) 4, 22-25.
[8] A. Zarin, B. Sc. Thesis, University Novi Sad , FTN, 2001 (in Serbian).