Journal of Applied and Computational Mechanics, Vol. 3, No. 3, (2017), 178-184
DOI: 10.22055/jacm.2017.21474.1102

Shahid Chamran University of Ahvaz

Journal of Applied and Computational Mechanics

Investigating the Ultrasonic Assistance in the Tube Hydroforming Process

Mehdi Zarei [1], Mahmood Farzin [2], Mohammad. Mashayekhi[3]

[1] Department of Mechanical Engineering, Tarbiat Modares University
Tehran 14115-111, Iran, mehdi.zarei@modares.ac.ir

[2] Department of Mechanical Engineering, Isfahan University of Technology
Isfahan 84156-83111, farzin@cc.iut.ac.ir

[3] Department of Mechanical Engineering, Isfahan University of Technology
Isfahan 84156-83111, mashayekhi@cc.iut.ac.ir

Received March 09 2017; Revised April 03 2017; Accepted for publication May 05 2017.
Corresponding author: Mehdi Zarei, mehdi.zarei@modares.ac.ir

Abstract

The purpose of introducing ultrasonic vibrations in the tube hydroforming process is to create more formability by obtaining a lower corner radius, improve thickness distribution of the wall and provide good tribological conditions at the tube and the die interface. Vibrations imposed on the die create alternating gaps which improve the formability in the tube hydroforming process in the presence of ultrasonic vibrations. Therefore, we attempted to understand the processing mechanism of the ultrasonic tube hydroforming in the square die using the finite element method. Abaqus software was used in these simulations and the die was considered as a deformable element.

Keywords: Tube hydroforming, Ultrasonic oscillations, Finite element method, Square die.

1. Introduction

The tube hydroforming is a manufacturing process which applies a high internal pressure and an axial feed to expand the tube to desired shapes. The major benefits include part consolidation, weight reduction, fewer secondary operations, and tighter tolerances. Murkawa and Jin [1] decreased the forming force using the axial and radial ultrasonic vibration in wire drawing operations. Hayashi et al. [2] investigated the ultrasonic vibration in the wire drawing process using the finite element method. They obtained a good agreement between the results obtained experimentally and those achieved by FEM. The FEM quantitative analysis revealed the dependence of the reduction of drawing speed on the amplitude. Moreover, the FEM quantitative analysis clarified changes in the stress distribution in wires and showed that when the direction of vibration is in the radial direction of wire, the maximum stress value decreases. Akbari Mousavi et al. [3] traced the influence of the ultrasonic vibration in an extrusion process. They showed that the extrusion force reduces with the axial ultrasonic vibrations. The reason was attributed to the reduction of the friction force between the die shoulder and material. Their results revealed that the material flow stress and the extrusion force were reduced by using the ultrasonic oscillations. In addition, they found that using the ultrasonic vibrations has no important effect on the equivalent plastic strain of the material. Huang et al. [4] employed the ultrasonic upsetting in order to accommodate the large compression loads and the need to obtain a constant vibration amplitude and uniformity throughout the forming process. The experimental data for plasticine cylinders revealed that employing a short longitudinal ultrasonic pulse to the die decreases the mean forming force during upsetting. Jimma et al. [5] conducted a numerically experimental study for a vibratory deep drawing. They showed that vibration of the blank-holder or the die in the thickness direction induced by a vibration in the radial direction contributes to the increase in the drawing ratio. In an attempt to improve formability, Mori et al. [6] considered the pulsating bulge tube hydroforming model in which the internal pressure varied sinusoidally.

Results from experiments and the finite element analysis showed a uniform expansion without local thinness. Bunget and Ngaile [7] performed experimental investigations on the tube hydroforming in the square die using the ultrasonic vibrations techniques. They showed that imposed vibrations on the die resulted in a smaller corner radius and less thinness as compared to the conventional tube hydroforming. Based on these results, it is thought that enhancement in formability could be obtained by inducing ultrasonic vibrations on tube hydroforming dies. In this paper, simulation of the ultrasonic tube hydroforming for the square die was considered. The effect of the friction coefficient and loading paths were studied by using the finite element method.

2. The process of the ultrasonic tube hydroforming in the square die

In the conventional tube hydroforming process (THF), the die is fixed. In the ultrasonic tube hydroforming (UTHF), the die is vibrated during the process. The internal pressure is ramped linearly to the maximum pressure for 30 seconds. The ultrasonic vibration is applied to the die system for the last 20 seconds. An example of the pressure loading path has been shown in Fig 1. The modal analysis was used to observe the die vibration and the possible useful effects on the forming process. The result appeared to be uniform gaps on all sides of the square section with a frequency of 20454Hz. The position of the maximum in the middle contributed to a better flow of the material, thus enhancement in the formability (see Fig. 2). The configurations of the tube and die before and after the expansion process in a square die are shown in Fig. 3. At the beginning of the process, the tube was in contact with the die in only four points. As the internal pressure increased, the tube expanded and the wall came in contact with the die. The die vibrated with a very high frequency in the ultrasonic domain. During the oscillation process, the contact between the tube and the die was minimized, the die was separated from the tube and a gap was created between die and tube. The contact and separation were repeated during the process, resulting in decreasing the corner radius due to reducing the friction forces. Experiments were carried out to investigate the effects of the ultrasonic oscillations on the tube hydroforming process. In the following figures and table, the classical process is noted by ‘non uo’, and ‘uo’ which represents the process where ultrasonic oscillations are used. The experimental set-up was used to conduct the test with and without oscillations proposed for two levels of internal pressure by Bunget and Ngaile (2008). The measurements of the corner radius of the ultrasonic tube hydroforming showed lower corner radius. This was the result of more expansion of the tube material which denoted an improvement in the formability vibrations.

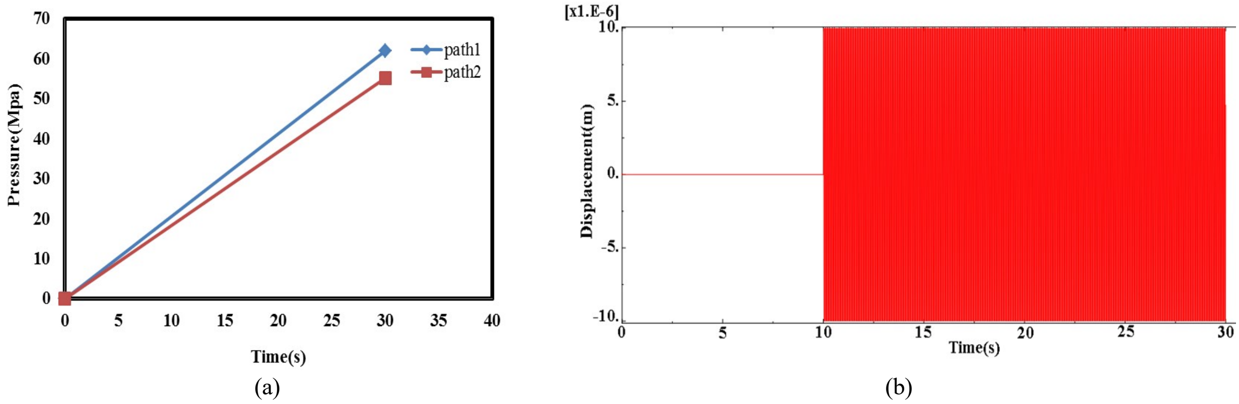

Fig. 1. Loading path: (a) Pressure path (b) Ultrasonic vibrations

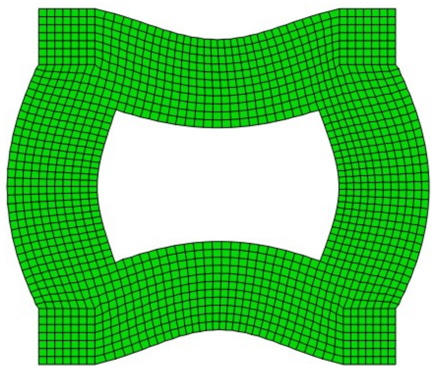

Fig. 2. Modal analysis and uniform gaps on all sides of the square section.

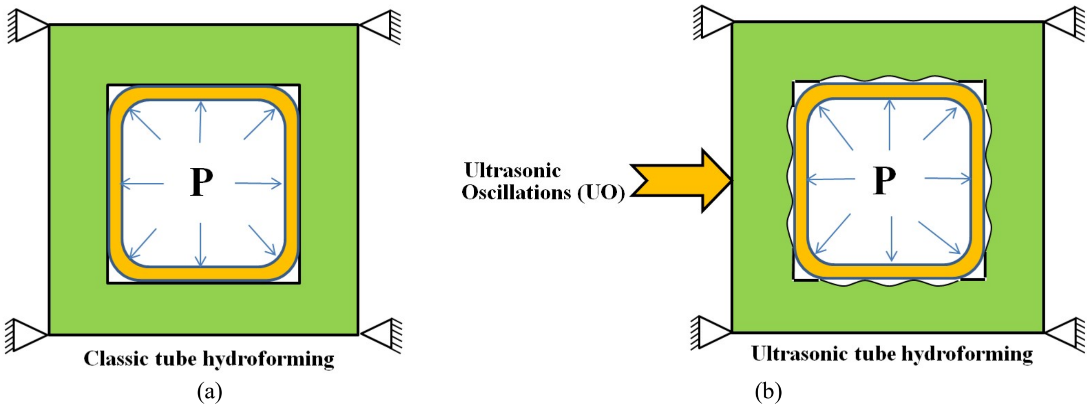

Fig. 3. (a) Classical tube hydroforming (THF), and (b) Ultrasonic tube hydroforming (UTHF)

Table 1. Conditions used in the finite element simulation of the tube.

Young's modulus (GPa)	117
Poisson's ratio	0.33
Yield stress (MPa)	220
Flow stress (MPa)	$560\,\varepsilon^{0.46}$
Coefficient of friction	0.02
Outer diameter of tube (mm)	35
Thickness of tube (mm)	1.6
Density(kg/m^3)	7800

Table 2. Conditions used in the finite element simulation of the die.

Young's modulus (GPa)	210
Poisson's ratio	0.3
Density(kg/m^3)	7800

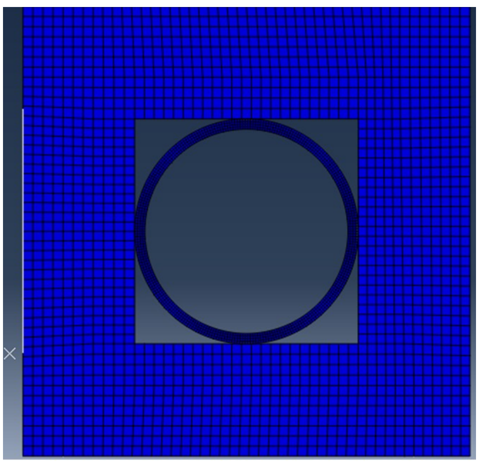

Fig. 4. Typical model used in the simulations

3. FEM simulation of the ultrasonic tube hydroforming

The simulations were performed through the finite element method. Due to its planar form, a plain strain modeling was performed. The quadratic planar elements with 8 nodes were used to mesh the die and the tube, respectively. The mesh independency also was performed in these investigations. The reported result confirmed that 1000 elements for the tube and 1424 elements for the die were needed to achieve the mesh independency. The tube material was assumed as the annealed copper of 122 alloy. The conditions used in the simulations of the tube and the die are summarized in Table 1 and Table 2. The tube was considered to behave as an elastic-plastic and the square die was considered to behave as deformable one. The contact area between the transducer and the die was considered 38 mm. The model used in these simulations is shown in Fig. 4. The tube was in contact with the closed die at four points. All boundary conditions in the sides of the corner as is depicted in Fig. 4 were clamped. The ultrasonic excitations were conducted by horizontal displacement which was imposed on the die. The amplitude and the frequency of the imposed vibrations were 10μm and 20454 Hz, respectively. To validate the simulation results, a comparison was made between simulation and experiment results by [7] (See Table 3, Fig. 5). It can be seen in Fig. 5 that ultrasonic vibrations result in the lower corner radius. This implies that ultrasonic vibrations increase the forming capability of the tube hydroforming process and decrease the friction between the die and the tube.

Table 3. Results of simulations and the experiment by Boungte & Ngaile

Process type	Forming pressure		Corner radius(mm)	
	psi	Mpa	Boungte&Ngaile	Present
Conventional	8000	55.2	7.8	8.2
THF	9000	62	6.75	7.1
Ultrasonic	8000	55.2	7.2	7.5
Vibration THF	9000	62	6.4	6.65

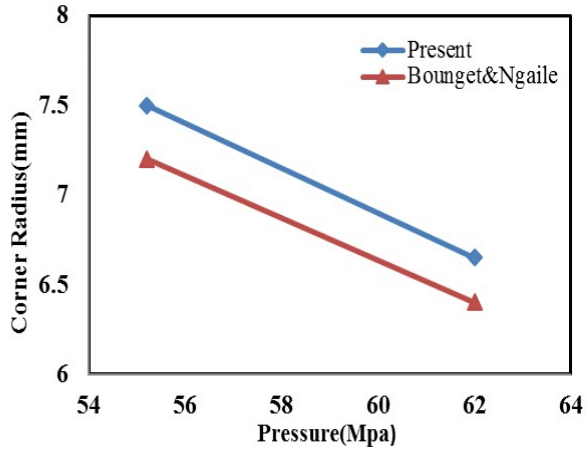

Fig.5. Comparison between simulations and the experiment results of the ultrasonic tube hydroforming for the square die

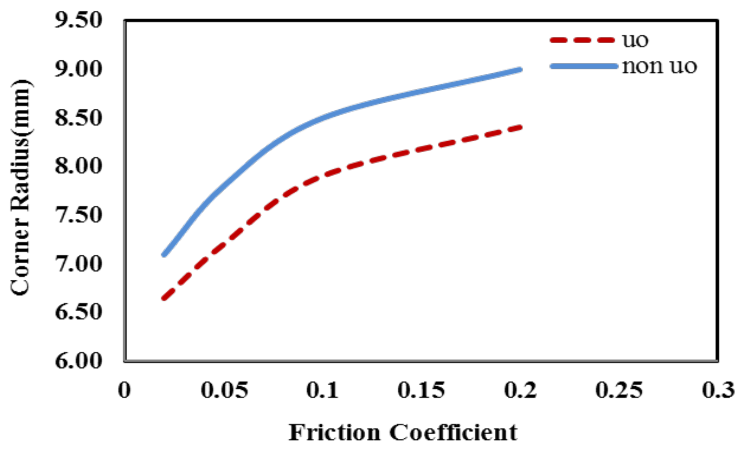

Fig. 6. Influence of the ultrasonic oscillations on the corner radius for various friction coefficients

4 Results and discussion

4.1. The effects of the friction coefficient on the corner radius

The friction conditions at the tube and the die interface have a significant influence on the quality of the final product. The simulation results showed that the corner radius obtained from the conventional tube hydroforming process was dependent on the friction coefficient. Fig.6 shows the corner radius attained when ultrasonic oscillations are used. The friction coefficients varied and the corner radii were determined for both ultrasonic and non-ultrasonic cases. A smaller corner radius achieved when the vibration was used. This matter was attributed to this fact that the effective coefficient of friction in the ultrasonic tube hydroforming is smaller than the original coefficient of friction in the conventional tube hydroforming because of alternating gaps and the decreased contact between the tube and the die.

4.2 The effects of the loading paths on the corner radius

The tube hydroforming is a complex process involving the interaction of many variables such as loading paths, material formability, and tribological conditions. Two pressure levels were used in the simulations, 55.2Mpa and 62Mpa psi. Fig. 7 shows the variations of the corner radius with increasing pressure. It can be seen that by increasing the pressure, the reduction in the corner radius decreases subsequently. The reduction in corner radius for path1 obtained as 6.3% and for path 2 obtained as 8.6%.

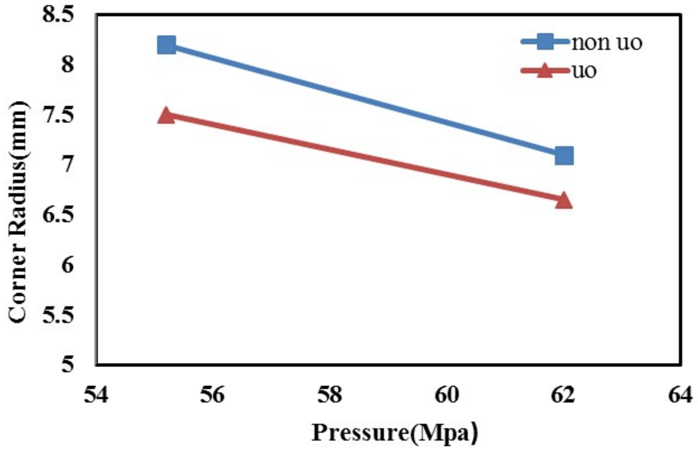

Fig. 7. The effect of loading path on the corner radius

4.3 The effects of the ultrasonic oscillations on the thickness distribution

The parameter of thickness also was studied in this simulation. In the ultrasonic process, the vibration imposed on the die resulted in alternating gaps at the die and the tube interface. The gaps' opening and closing after each oscillation, the more uniform thickness and the less thinness as well as the corner radius indicate improvement of the formability of the material. Fig. 8 shows the variations of the thickness for the diameter of the tube=35mm, the friction coefficient μ= 0.02 and the loading path 1 along the path OA (see Fig. 9) for both ultrasonic and non-ultrasonic cases. A smaller effect was observed in this case. It can be seen that the superimposing ultrasonic oscillation improves the thickness distribution.

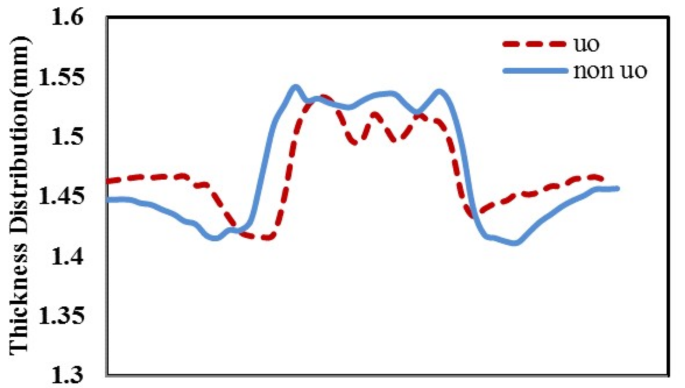

Fig. 8. The effect of ultrasonic vibrations on the thickness variations

4.4 The effects of ultrasonic oscillations on the stress distribution

Fig.10 illustrates the state of stress in an element considered in the contact zone for both conventional and ultrasonic tube hydroformings. While imposing ultrasonic oscillations on the die, the element between the die and the tube has two states of stress: when the die contacts with the tube and when the die is separated from the tube.

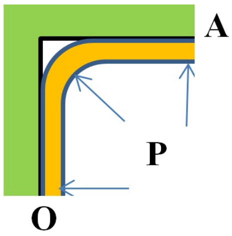

Fig. 9. The path OA for variation of thickness

Therefore, superposition of the two states of stress is lower than the state of stress in the conventional tube hydroforming. The influence of the ultrasonic oscillations on the stress distribution is shown in Fig. 11 where the diameter of the tube is 35mm; the friction coefficient μ is 0.02 and the loading path is1.

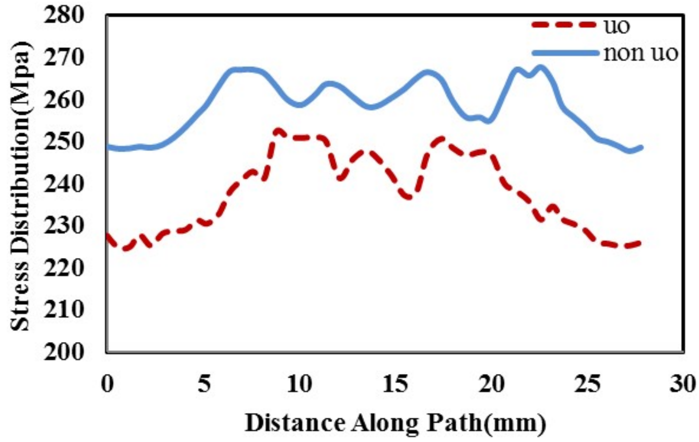

Fig. 10. Influence of the ultrasonic oscillations on the stress distribution

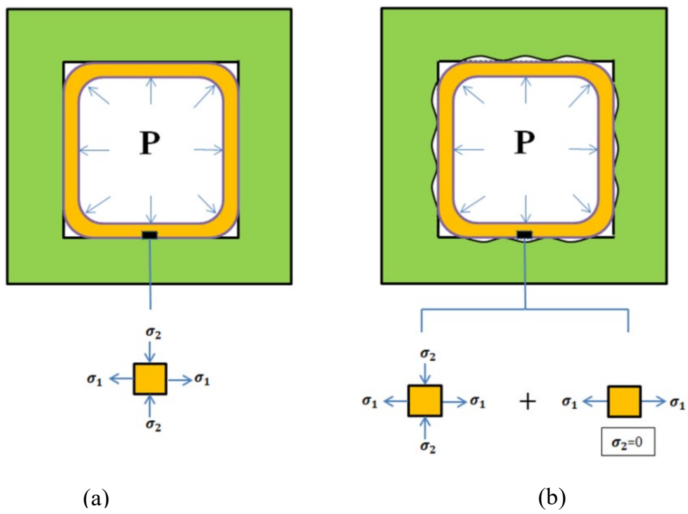

Fig. 11. stress components (a) Classical and (b) ultrasonic tube hydroforming process (square-shape)

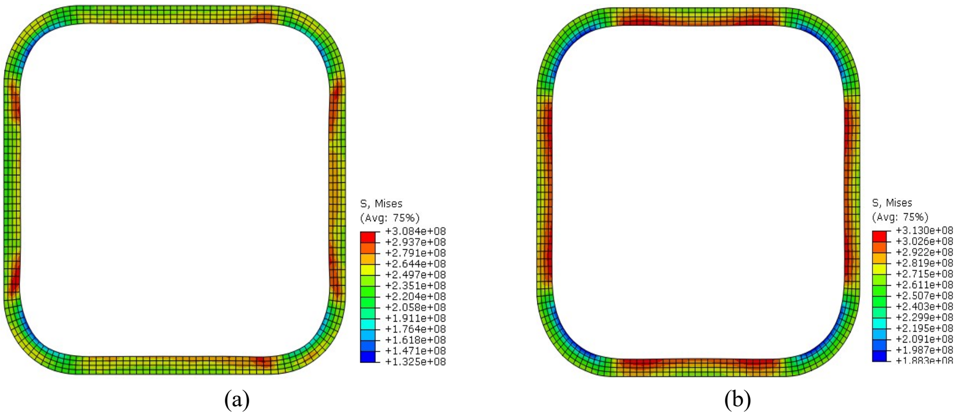

Fig. 12. Typical von-misses stress distribution for (a) the ultrasonic tube hydroforming (b) the conventional tube hydroforming

5. Conclusions

Simulation of the ultrasonic assistance in the tube hydroforming for a square die was performed using the finite element method. The following conclusions were drawn:

1) The corner radius was reduced by applying the ultrasonic vibrations, the die was separated from the tube, and a gap was created between the die and the tube. The contacts and separations were repeated during the process and resulted in the corner radius due to the reduction of the friction force.

2) By increasing the pressure, the reduction in the corner radius was subsequently decreased.

3) The ultrasonic oscillations resulted in more uniform thickness distribution, less thinness, thus more expansion.

4) The use of ultrasonic oscillations resulted in reduced distributed stresses even though the difference was not very large.

References

[1] M. Murakawa, M. Jin, "The utility of radially and ultrasonically vibrated dies in the wire drawing process", *J. Mater. Process. Techno.* pp. 113, 81-86, 2007.

[2] M. Hayashi , M. Jin, S. Thipprakmas, M. Murakawa, J. C. Hung,Y. C. Tsai, C. H. Hung, "Simulation of ultrasonic-vibration drawing using the finite element method (FEM)", *J. Mater. Process. Technol.* 140, pp.30-35, 2003.

[3] S. A. A. Akbari-Mousavi, H. Feizi, R. Madoliat, "Investigations on the effects of ultrasonic vibrations in the extrusion process", *J. Mater. Process. Technol.* pp. 187–188, 2007.

[4] Z. Huang, M. Lucas, M. J. Adams, "Influence of ultrasonics on upsetting of a model paste", *J. Ultra.* 48, pp. 40-43-48, 2002.

[5] T. Jimma, Y. Kasuga, N. Iwaki, O. Miyazawa, E. Mori, K. Ito, H. Hatano, "An application of ultrasonic vibration to. The deep drawing process", *J. Mater. Process. Technol.* 80–81, 406–412, 1998.

[6] K. Mori, T. Maeno, S. Maki, "Mechanism of improvement of formability in pulsating hydroforming of tubes", *Int. J. Mach. Tool. Manuf.* 47, pp. 978-984, 2007.

[7] C. Bunget, G. Ngaile, "Mechanics of Ultrasonic Tube Hydroforming", 2008.