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Research Article

Investigation on the ultrasonic tube hydroforming in the bulging process using Finite element method

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Abstract. In ultrasonic tube hydroforming, the tube is hydro formed while the ultrasonic vibration is applied to the die. Prior studies provide experimental proof that ultrasonic tube hydroforming reduces corner radius, improves lubrication and uniform thickness. Use of ultrasonic vibration can decrease friction at the tube-die interface. Few attempts have been made to analyze the wire drawing while the ultrasonic vibrations were also applied during the processes. A detailed analysis and understanding of the mechanism of improvement is not possible with conventional experimental observation because the ultrasonic vibration processing phenomenon occurs at high speed. Therefore, we attempt to understand the processing mechanism of ultrasonic tube hydroforming using the finite element method (FEM).ABAQUS was used for the FEM. Forming force and formability in tube hydroforming analyzed. From these studies, we quantitatively clarified the mechanism of improved formability characteristics, such as decreased forming load and increasing bulging diameter.

Keywords: Tube hydroforming, Ultrasonic oscillation, Finite element method, Bulging process.

1. Introduction

The tube hydroforming is a forming process in which by applying controlled pressure and axial feed. The shape of the tube material is changed to the desired shape. During the conventional bulging process, because of high, pressure, friction between the work piece and the die prevent the material flow.so high friction created in the contact area causes more thinning between die and tube interface. Therefore it is not possible to apply further pressure to achieve more formability in bulging diameter because tube will be bursted. Improving lubrication condition, which just decreases the sliding friction coefficient, cannot be effective significantly at high pressures on the formability. Few attempts have been reported in the literature on the application of the ultrasonic vibrations in the metal forming processes. In a typical tube hydroforming process, the pressure is applied internally, where water-oil emulsion is used as a pressure medium [1, 2]. Applications of tube hydroforming can be found in the automotive, the aircraft industries and in the manufacturing of components for sanitary use. Automotive applications can be seen in exhaust parts, camshafts, radiator frames, front and rear axles, engine cradles, crank-shafts, seat frames, body parts and space frame [3, 4]. Representative household applications are piping components and fittings [5]. Some of the advantages of the tube hydroforming in comparison with conventional stamping technology are: part consolidation, weight reduction, higher part quality, fewer secondary operations, reduced dimensional variations, reduced scrap, less springback, and improved structural strength and stiffness. But this process has also some drawbacks, such as slow cycle time, expensive equipment and lack of extensive knowledge base for process and tool design [3-5]. In order to increase the implementation of this technology in the stamping industry, some issues need to be addressed: the preparation of the tubes (material selection and quality of the incoming tube) preform design and production method, application of computer simulations, selection of effective lubricants and enhancement of the tribological performance, and improvement of the formability of the tube. The deformation at the corner was investigated by using finite element methods to simulate the tube hydroforming process for different corner radii [6]. The simulation results showed that friction between the tube and the die hinders the metal flowing into the die corner. Therefore, improving lubrication conditions will results in a uniform deformation. They also found that the smaller the corner radius to be formed, the easier the thinning occurs at the transition segment. They further analyze the thinning at the transition corner, where the effect of the friction on the state of stress was investigated; proving once more that an improvement in the lubrication conditions will result in a uniform thickness distribution and will delay the occurrence of instability. The effect of the ratio of wall thickness to the corner radius was also investigated. They concluded that when the ratio is greater than 0.5, the difference in the yielding conditions between the straight side and the corner is significant and results in excessive thinning The thickness variation and corner filling in tube hydroforming was also investigated by Kridli et al [7], where the effects of material properties and die geometry on the selection of the hydroforming process parameters were examined. The frictional conditions have a significant influence on the tube hydroforming processes. Due to high contact pressures and large contact surfaces, high friction forces between the tube and the die will result. These forces will affect not only the process parameters but also the quality of the component, such as the wall-thickness distribution. Therefore, it is important to decrease the friction and its negative influence in tube hydroforming by utilizing textured tubes [8]. The textured surfaces contain 'pockets' that will facilitate the mechanical entrapment of the lubricant. The effect of the trapped and pressurized lubricant is that the lubrication regime will be micro plasto-hydrostatic as the internal pressure increase, necking or fracture will take place. The thinning usually occurs in the transition zone between the corner and the linear zone .An improvement in formability will result in an increase in the quality of the part, so more uniform strain and thickness distribution. The concept of dual-pressure tube hydroforming as a way to enhance formability was introduced by Jain et al [9]. In dual pressure process a more favorable state of stress is achieved. In an attempt to increase formability Mori et al. [10] proposed the pulsating bulge tube hydroforming model, in which the internal pressure varies sinusoidally. Results from experiments and finite element analysis showed a uniform expansion without local thinning. Smith et al. [11] introduced the concept of double-sided high-pressure tube hydroforming process. This process employs both internal and external pressures exerted on the tube. The presence of the external pressure will result in an increase of compressive radial stress as compared to the process with internal pressure only, thereby increasing formability. Finite element method was used to investigate the concept for plane-strain tubular sections and the results were promising. Greater corner filling, thus greater formability was achieved when the external pressure was applied, and a larger pressure difference resulted in a larger effect. Based on previous research, it is well established that ultrasonic oscillations have useful effects on the forming process, such as improvement in the tribological conditions and reduction in the forming load [12]. Murakawa and Jin [13] reduced the forming force using axial and radial ultrasonic vibration in wire drawing operations. Hayashi et al. [14] analyzed ultrasonic vibration wire drawing process using the FEM.A good agreement was obtained between the results achieved experimentally and those computed by the FEM. Siegert and Ulmer15] investigated tube and wire drawing processes using ultrasonic waves. Using the ultrasonic vibrations caused to reduce the forming force the flow stress, the friction between the die and work piece. Better surface finish with close tolerances was also obtained. Huang et al [16, 17]. The effect of the oscillation of the internal pressure on the formability and shape accuracy of the products in the pulsating hydroforming process of T-shaped tubes has been examined using a dynamic explicit finite element code [18].Method to improve the die corner radius in box shaped tube hydroforming by both controlling the wrinkling and oscillating the internal pressure has been proposed [19]. Zarei et al applied ultrasonic vibration on the square die during the tube hydroforming process using the finite element method. They showed that the ulatrasonic vibrations have significant effect on the stress distribution and thickness distribution filling corner radii [20]. In addition to the above mentioned advantages, imposing of the ultrasonic oscillations on the tube hydroforming process will result in pressure differential and change the local state of stress. The surface conditions are related with the changing of the frictional conditions at the die specimen interface. The kinematics of sliding varies and the friction force when superimposing the ultrasonic oscillations reverses the direction for every period of oscillations. Due to this friction force reversal, the friction force will oppose the forming process only during a half of the oscillations, and it will help during the other half. The result will be a decrease in forming load So because of widespread using the ultrasonic vibration for decreasing the friction between die and tube interface we utilized these vibration in the bulging process to investigation ultrasonic assistance in formability and increasing bulging diameter.

2. Mechanism of the ultrasonic tube hydro forming in the bulging process

In the conventional tube hydro forming process (THF), the die is stationary while the tube is in the die.in the ultrasonic tube hydro forming (UTHF), the die is ultrasonically vibrated along axial direction during the process. The pressure was ramped linearly from zero to the maximum pressure. Ultrasonic vibration was applied to the upper die system at the axial direction and the lower die was fixed. An example of a pressure loading path and direction of ultrasonic oscillation has been shown in figure (1). The tube was compressed from one end by feeding punch and other end was fixed. To validate simulation results, experiments carried out to investigate the effects of the ultrasonic oscillations on the square die. The experimental set-up used to conduct test vibration in metal forming has been discussed for many years.

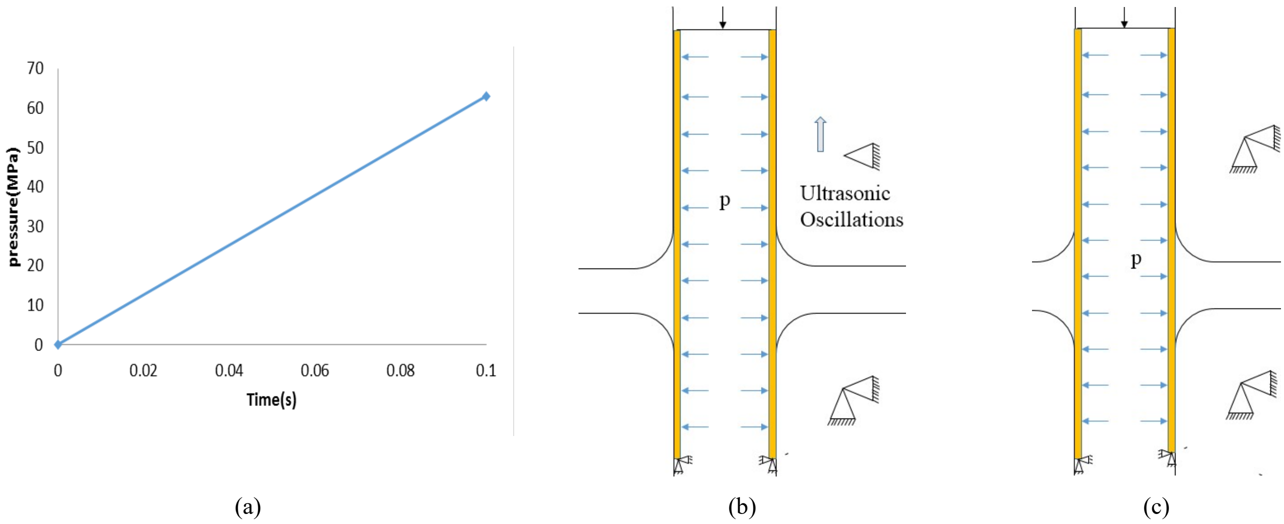


Fig. 1. Loading path**:** a**)** pressure path b) ultrasonic vibration c) classical bulging process

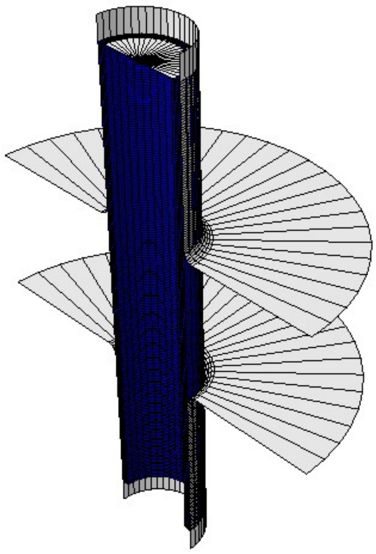


Fig. 2. Typical model used in the simulations

The experiments investigations conducted by previous researchers emphasized the effects of superimposing the ultrasonic oscillations on the forming processes, such as: considerable reduction in the friction force. The surface effects are related with changing of the frictional conditions at the die specimen interface. The kinematics of sliding varies and the friction force when superimposing the ultrasonic oscillations reverses the direction for every period of oscillations. Due to this friction force reversal, the friction force will oppose the forming process only a half of the oscillation will help during the other half. The result will be a decrease in forming load (see figure 3).

Table 1: comparison between result of simulation and experiment for a square die

Process type	Forming pressure		Corner radius[mm]	
	[psi]	[Mpa]	[21]	Present(FEM)
classic THF	8000	55.2	7.8	7
	9000	62	6.75	5.9
Ultrasonic tub Hydroforming UTHF	8000	55.2	7.2	6.2
	9000	62	6.4	5.5

3. Simulation of ultrasonic tube hydroforming

The simulations were performed with Abacus explicit code. Due to symmetric, axisymmetric modeling was performed. The tube material was assumed to be annealed copper alloy 122 tubing with E=117GPa*,* ν=0.33 and ρ=7800 Kg/m^3 .The tube was considered to behave elasto-plastic and the die was considered to behave as rigid body. The quadratic axisymmetric elements with 8 nodes have been used to mesh the tube, respectively. Mesh independency also performed in these investigations. Reported result confirmed that 1500 elements for tube is need for obtaining mesh independency. The material stress-strain relations were supposed to obey the flow rule of $\sigma = 510\varepsilon^{0.12}$ Mpa. The Die diameter was assumed 40mm and thickness of tube was assumed 3mm. friction factor was considered μ =0.02 for all contact surfaces. A constant punch speed of 15mm/s was used in simulations. The amplitude and frequency of the vibrations used were 10 μm and 20 KHz, respectively. The model used in these has been shown in figure (2).since the simulation ultrasonic vibrations in tube hydroforming for bulging process never has been done and just for a square die has been performed, so to validate present simulation first time validation of simulation for a square die with experimental results [21] was done and when validation was performed correctly then simulation of bulging process under imposed ultrasonic vibration was performed. It can be seen ultrasonic tube hydro forming result in lower forming load. This implies that ultrasonic vibrations increased forming capability of the tube hydroforming and decreased friction forces.

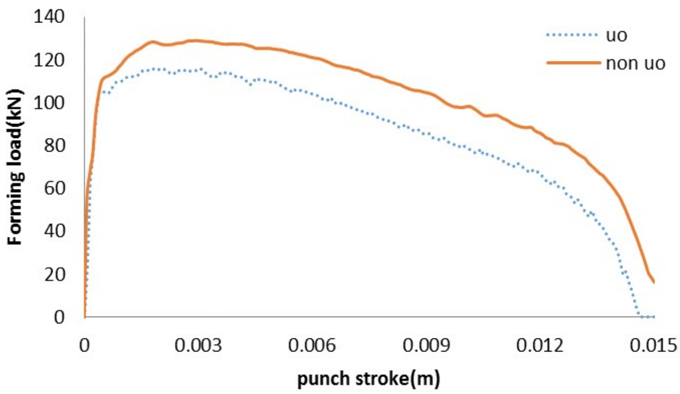


Fig. 3. Forming load comparison between THF and UTHF

4. Results and discussion

4.1 effect of the fluctuation amplitude on the forming load and formability

The simulation results showed that, forming load obtained from the ultrasonic tube hydroforming process was depending on vibration amplitude (see table 1 and figure 2) and ultrasonic vibration decreases forming load 20%. Figure 4 shows the variations of the forming load by increasing amplitude. This figure shows the effect of the amplitude on the forming load for two different amplitude 10, 50 μm. For the cases where amplitude was increased, the FEM analysis did not predict more reduction in the forming load. Because during the feeding tube no more reduction in friction obtained. The ultrasonic vibration also effects on the bulging diameter. It can be seen from figure 5 with increasing amplitude of vibration, the bulging diameter increases.

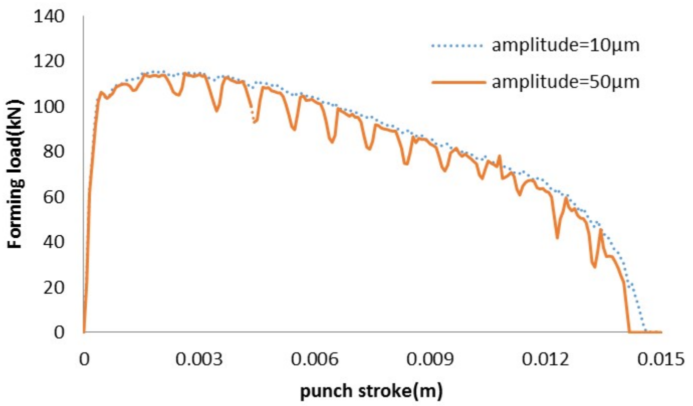


Fig. 4. Comparison of the forming load for two amplitudes

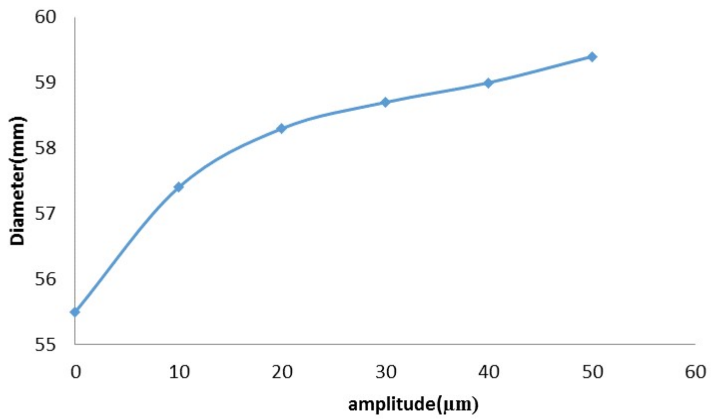


Fig. 5. Effect of fluctuation amplitude on the bulging

4.2 Effects of frequency of vibrations on the forming load

Simulations results showed that increasing the frequency was given rise to increasing bulging diameter in comparison. (See figure 6). Figure 7 shows the variations of the forming load by increasing frequency. This figure shows the effect of the frequency on the forming load for two different frequencies 10 KHz and 40KHz.for the cases where the vibrations of frequency increased; the FEM analysis did not predict more reduction in the forming load. Because during the feeding no more reduction in friction obtained. The von misses stress distribution for two different frequencies 10,40KHz were shown in figure 8.

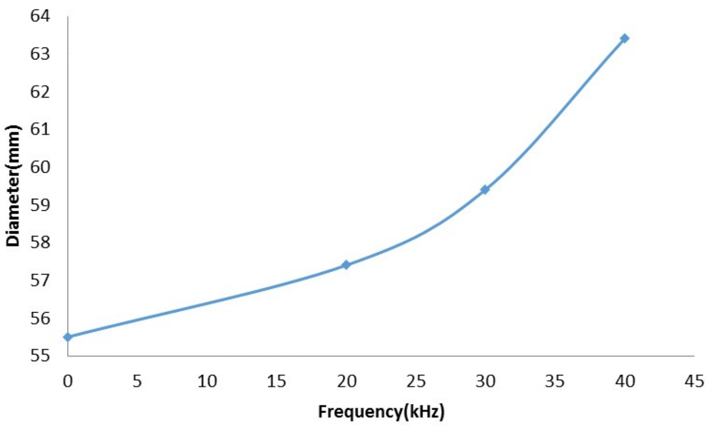


Fig. 6. Effect of frequency vibration on the bulging

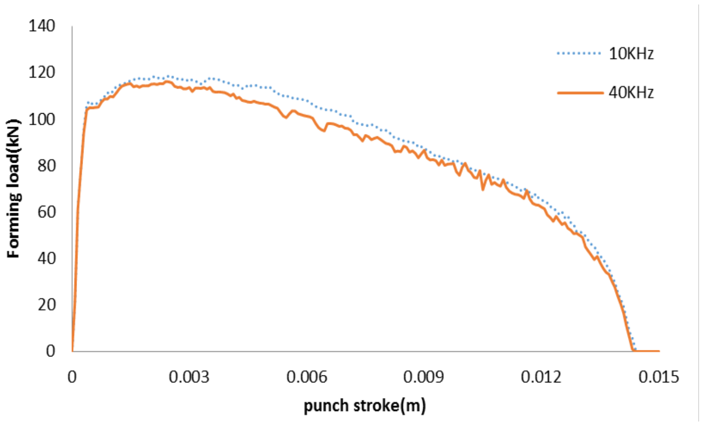
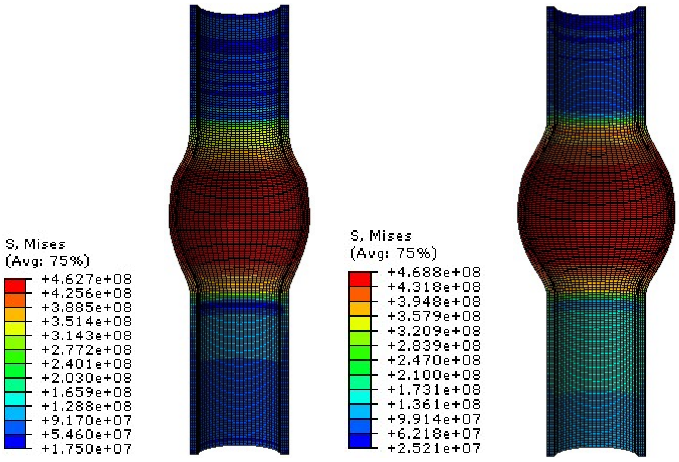


Fig. 7. Variations of forming load with the frequencies for 10,40KHz



(a) (b)

Fig. 8. Typical von-misses stress distributions for the two different frequencies a) 10 KHz b) 40 KHz

4.3 Effects of the friction on the formability

The frictional conditions have a significant influence on the tube hydroforming processes. Due to high contact pressures and large contact surfaces, high friction forces between the tube and the die will result. These forces will affect not only the process parameters but also the quality of the component, such as the wall-thickness distribution. Investigation was also conducted to consider the effects of the friction on the ultrasonic tube hydroforming. The friction presents the quality of Lubrication during and its effect on the formability in the ultrasonic tube hydro forming. Figure 9 shows the friction effects on the bulging diameter. It was predictable that by increasing amount of friction the bulging diameter is decreased because friction increases forming load. But by applying ultrasonic oscillations, forming load was decreased.

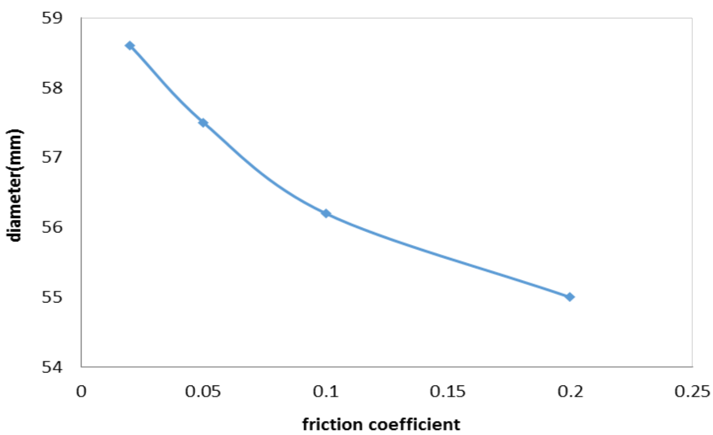


Fig. 9. Effect of friction vibration on the bulging diameter

5. Conclusions

In this paper, the new method of applying ultrasonic oscillations to the bulging process has been proposed. The aim of applying the vibrations is to improve conditions between die/tube interface and decrease forming load. A simulation first was carried out for square die. After validation the simulation also was carried out for bulging process. The following conclusion could be drawn:

1) The forming load can be reduced by applying the ultrasonic vibrations if the ultrasonic vibrations applied in the axial direction. Applying vibrations was found to have effect on the increasing bulging diameter.

2) A larger reduction in forming load could not be obtained by either increasing frequency or increasing frequency or increasing amplitude of vibrations.

3) Friction has significant effect on the formability and decrease bulging diameter.

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