Extended Abstract with Poster

Study on Tube Hydroforming Process using Finite Element Analysis and Experimental Validation

A. Baheri, Yucheng Liu

Department of Mechanical Engineering
University of Louisiana at Lafayette

M. Hedayati

Department of Mechanical Engineering
Kashan University, Iran

Extended Abstract

At present, tube hydroforming process has drawn increasing attention from automotive, aerospace, and shipbuilding industries because of its unique advantages over the traditional forming process. For example, it is well known that the hydroforming process can effectively reduce the overall weight of the formed part as well as the number of steps required for making complex shapes. Hence, such process keeps the tooling costs and the component production costs low. The tube hydroforming process is mainly used to make tubular products with varying cross-sectional shape along their longitudinal direction. During the process, a tube is first placed in the closed cavity of a forming die. After sealing both ends of the tube, the hydraulic fluid is then injected into the tube and the tube is formed according to the shape of the die cavity.

This study investigates the effects of material properties and frictional parameters on a hydroforming process that includes performing and crushing. The effects of flow formulation in analytical analysis of the tube hydroforming process are also discussed.

The tube material used for this study is stainless steel SUS304. The material's flow stress is defined through a power law of its equivalent strain, $\bar{\sigma} = K\bar{\varepsilon}^n$, where K = 1452MPa is the strength coefficient and n = 0.6 the strain-hardening exponent. Other properties of SUS 304 include: Young's modulus E = 200GPa, Poisson's ratio ν = 0.3, and density ρ = 7800kg/m^3. Material's anisotropy in longitudinal and hoop directions is evaluated through incremental ratios as:

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$$r_x = \frac{d\,\varepsilon_{22}}{d\,\varepsilon_{33}} \quad , \quad r_y = \frac{d\,\varepsilon_{11}}{d\,\varepsilon_{33}} \tag{1}$$

The geometric dimensions of the tube are: outer diameter D_o = 94mm, wall thickness t = 1.28mm. The distance that side dies move during the performing step is 17mm, the distance in which upper dies move down is 17mm. The radius of the side die is 15mm, the length of the upper die is 90mm, and its width is 60mm. Fig. 1 sketches the configuration of the tooling.

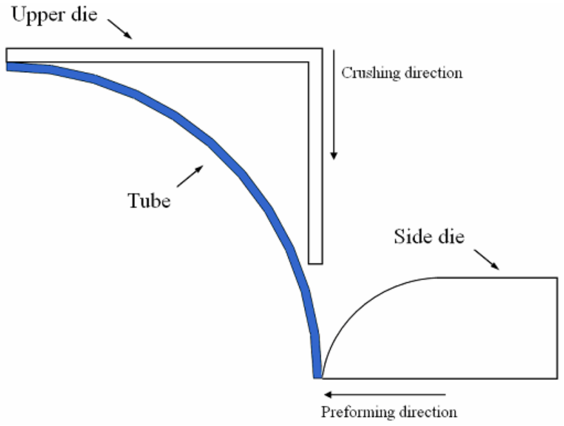

Figure 1. Configurations of the tube and dies

Pressurization curve during the expansion and crushing in this hydroforming process is displayed in Fig. 2.

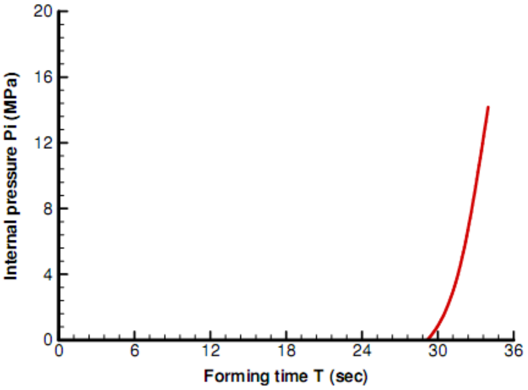

Figure 2. Pressurization curve during expansion and crushing processes

In the entire process, the first time period is from 0 to 17 seconds corresponds to the movement of the side dies during the performing step, and the second time period is from 17 to 34 seconds refers to the movement of the upper dies during the crushing step. The velocities of the side and upper dies are set to be 1mm/s, therefore the distances that both dies move during the performing and crushing steps can be precisely controlled at 17mm when the two time periods are set as 17s.

The movements of the dies are described as follows: in the performing step, the side dies move 17mm inwards during 17s and immediately move back to the original position at the end of the time period; at the same time the upper dies begin to perform the crushing operation at a total stroke of 17mm from 17s to 34s. As reflected in Fig. 1, the internal pressure of the tube appears at t = 29s, which means that the internal pressure does not appear during the performing (movement of the side dies) as well as the early stage of the crushing (from 17s to 29s). At t = 29s, when the upper dies move 12mm downwards, the internal pressure begins to be applied inside the tube and increase gradually while the upper dies continue to move down until the maximum stroke of 17mm is reached. The internal pressure is applied during the late stage of the crushing (after 29s till 34s) to prevent the performed tube from returning to its initial circular shape, thereby avoiding pinching of the tube between the upper and lower dies. The applied internal pressure will also flow the tube material into the corners of the dies as much as possible.

FEA software package ABAQUS is used to model the tube and simulate the hydroforming process. A linear 4-node element that uses reduced-integration (CPE4R with hourglass control) is used to model the tube. Fig. 3 shows the FE tube model is in contact with an upper die, which includes 705 elements and is meshed following the algorithm of advancing front.

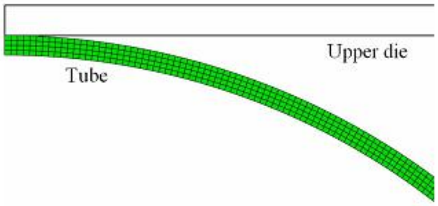

Figure 3. Finite element tube model

After implementing the flow formulation and applying appropriate boundary conditions, the presented FE model is used for numerical analysis through ABAQUS.

From the FEA results it can be observed that during the performing-crushing-hydroforming process, as the strain hardening component reduces, the strength coefficient and anisotropy in X direction increases, the material flows better through the die cavity and the relative thickness along the tube becomes more unified. The anisotropy in Y direction, however, has no obvious influence on the thickness distribution. As shown in Fig. 12, when the friction coefficient increases, the amount of material that flows into the die cavity decreases and the local thinning increases, hence the die filling also increases.

In this study, the effects of material properties and friction coefficient on a performing-crushing-hydroforming process are investigated. Important parameters discussed in this

study include the strain hardening component, strength coefficient, and anisotropic in X (longitudinal) and Y (hoop) directions. The effects of those parameters on the tube's thickness distribution and corner filling are revealed. Through the numerical simulation it is found that when the value of the strength coefficient increases or the value of strain hardening component decreases, the distribution of the thickness along the tube length is more uniformed and the radius of filling of the corner decreases. Also by increasing the value of anisotropy in X direction the magnitude of tube wall thinning is decreased while the radius of filling of the corner is decreased also. It should be noted that variation of anisotropy in Y direction doesn't have any sensible effect in the thickness distribution and die filling. As the friction between tube and die increases, the local thinning along the tube increases and the flow of material through die decreases also.

Afterwards, the effect of flow formulation in the analysis of tube hydroforming process is studied by comparing the results obtained from the flow formulation to those from the solid formulation. Flow formulation is implemented in a numerical code, SPID, for an axisymmetric bulge simulation. The simulation results are compared to those obtained from ABAQUS which uses the solid formulation. The comparison shows that the results from the flow formulation in the process that undergoes large plastic strain are in good agreement with those from the solid formulation, except that the stress values in the direction perpendicular to the direction of material flow are lower than those evaluated using the solid formulation. In general it can be concluded that the flow formulation is suitable for processes that experience large deformation. For other process where the large deformation is not involved, the flow formulation will lead to considerable errors, especially in predicting the stress distribution.

Keywords: tube hydroforming process, performing-crushing processes, flow formulation, solid formulation, finite element method, numerical simulation.

References

[1] Y.-M. Hwang and T. Altan, "Finite element analysis of tube hydroforming processes in a rectangular die", *Finite Elements in Analysis and Design*, 39(11), 2003, 1071-1082.

YUCHENG LIU
Dr. Yucheng Liu currently serves as an Assistant Professor of Mechanical Engineering at the University of Louisiana at Lafayette. His research interests include structural impact and crashworthiness, computer modeling and simulation, mechanical and machine design, alternative energy technologies, numeric solutions to engineering problems, and engineering software development. Dr. Liu is a registered Professional Engineer in Louisiana and holds active membership in ASEE, ASME, and SAE

ALI BAHERI
Ali Baheri is currently a Ph.D. student at the Department of Mechanical Engineering at the University of Louisiana at Lafayette. His research areas include input shaping control, robust control design and structural design.