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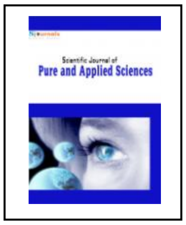

Original article

Computer aided modeling and simulation of hydroforming on tubular engineering products

J.Z. Li[a]
[a] *University of Bridgeport, Bridgeport, CT 06604, USA.*

[*] Corresponding author; University of Bridgeport, Bridgeport, CT 06604, USA.

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ABSTRACT

Hydroforming processes have been widely applied in many different industrial fields including aerospace, automotive, and modern plastics for weight-reduction and strength enhancement. Hydroforming on tubular products is better than the process of welding tubular assemblies from stampings including increased strength, reduction of work applied to the unit weight, decreased processing and tool costs, improved structural stability, less secondary operation, enhanced stiffness, and more uniform in product thickness. Although the hydroforming becomes popular manufacturing methodology, few researches have been done to study the hydroforming mechanism through computational modeling and simulation. This paper focuses on the study of hydroforming process and mechanism based on computer-aided modeling (FEA) and prototype testing to determine the material behaviors in hydroforming process. The objective of this research is to verify the effects of major manufacturing parameters on hydroforming processes. The computational analysis and prototype testing indicate that some factors including applied internal pressure path and compressive axial loading play important roles in hydroforming deformation. Both computer-aided modeling and prototyping experiment show close results which verifies the credibility of this research and analytic methodology.

1. Introduction

The conventional forming processes make components by welding parts together after multiple stamping processes. For example, it requires pressing up to six channel sections and joining parts by spot welding to manufacture typical chassis component, but it can be simply made by hydroforming as a single part (Altan et al., 2006). Hydroforming is a production process in which the fluid pressure is applied to form the ductile materials into desired geometrical features (Yang, 2008). Hydroforming on tubular products is an advanced manufacturing technology in metal forming processes. The major industrial applications include aircraft, automotive, and many household appliances (Fiorentino et al., 2010). The hydroforming process can make larger deformations than by traditional stamping or deep drawing and lead reduction in unit weight (Ghosh and Deshmukh, 2010). Hydroforming has been widely used in metal forming processes in the last decade of twenty century due to the advances in high pressurized hydraulic systems and improvement in machine fixtures/tools (Yang and Ngaile, 2010). Currently the industrial enterprises are aiming at the optimizing processes leading reduced product weight, increase material rigidity, and enhanced manufacturing stability (Bunget, 2011). All these improvements require alternative solutions to revaluate the traditional engineering design methods, existing manufacturing techniques, and proper product material (Ngaile and Kilinzo, 2011). Comparing to the conventional forming methods, hydroforming has remarkable technical function and economical potential in forming the materials (Ngaile and Welch, 2011). The tube hydroforming can manufacture a wide range of complex hollow components by applying high liquid pressure. The hydroforming system usually consists of forming tool/die, hydraulic press, and liquid pressure intensifier (Marcos and Salguero, 2012). By using hydroforming technology, many complex designs are possible with increased ration of strength to unit weight, reduction in number of subcomponent, higher material stability (Wu and Xie, 2012).

2. The hydroforming engineering system

The prototyped hydroforming system is shown in Fig.1. The processing sequences of hydroforming include: (1). Tubular product is placed in the die with designated geometrical shape. (2). Tubular product ends are sealed by blocking punches and die is closed by hydraulic press. (3). High pressure fluid is fed into tube as liquid mandrel to keep tube from collapsing and excessive surface deformation/wrinkling. (4). Axial force is applied at the tube by end caps to keep tubular wall from unexpected thinning while make desired part formation. The tubular product material becomes yielding under high pressure and flow into forming die to acquire the desired geometrical shape. (5). High pressure is then released with die opened and formed product is ejected from die.

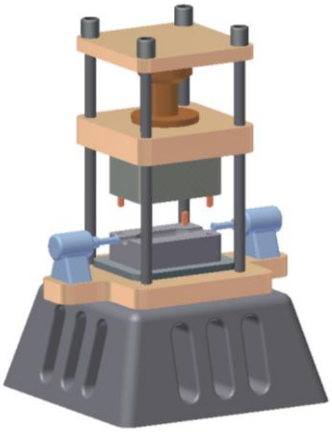

Fig. 1. Prototyped hydroforming system.

This hydroforming system can be applied to make many different formed parts. This paper analyzes the hydroforming process in making hollow sectional parts. The hydroforming system mainly consists of hydraulic press, hydraulic actuators, and upper/lower dies. Figs. 2 and 3 display the detail views of top and bottom die setups.

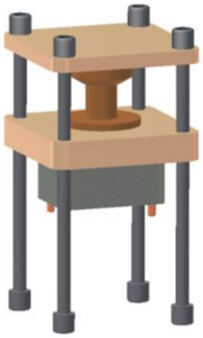

Fig. 2. Top die setup.

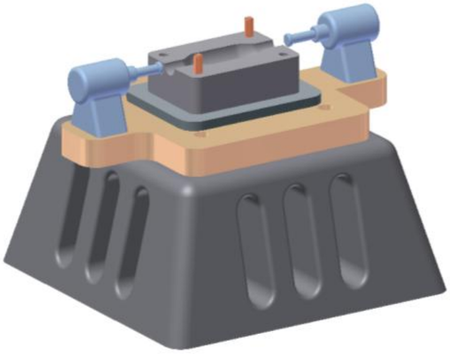

Fig. 3. Bottom die setup.

The tube to be formed is put in lower die that is mounted in the fixture and two hydraulic actuators are installed at two sides of bottom die to provide feeding and axial force. The upper die is mounted to the press to provide high clamping force while die is closed.

3. Computer-aided modeling and simulation

It is important to understand the hydroforming mechanism to improve forming process and quality. It is difficult to understand forming process once dies are close and so far there are few researches showing the mechanism of hydroforming process. This paper studies and analyzes the forming process through computer-aided modeling and simulation. The prototype testing has also been performed to verify the results from computational simulation. Fig.4 shows one tubular product made by hydroforming process.

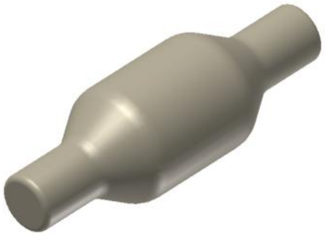

Fig. 4. Tubular product manufactured by hydroforming process.

The pressure loading path is defined that, if wrinkle appears in tubular wall, the internal pressure needs to be increased to eliminate these defects. In computer-aided simulation and analysis, the initial internal pressure is increased up to the pressure before causing material yield while a moderate axial feeding stroke is generated by hydraulic actuators at both ends to seal two ends. The axial stroke is then continuously increased at both ends of tubular product while the internal liquid pressure is maintained at a specific pressure. If wrinkles are detected, the internal pressure will be increased while axial feeding stroke is temporarily halted until internal pressure is increased to the burst pressure. The hydroforming process continues until product is formed with no defect. Another important fact is that, under final constant pressure, the geometrical shape in a formed product, such as corners and edges, changes based on the material stiffness and strength. Because of this situation, the internal pressure is continuously increased at the final forming stage until working products burst.

The product being formed is high strength steel with following parameters:

1. OD of tubular product: 35 mm
2. Length of tubular product: 300 mm
3. Wall thickness: 6 mm
4. Modulus of elasticity: 200 GPa
5. Yield strength: 350 Mpa
6. Tensile strength: 475 Mpa
7. Permitted elongation: 30%

The results from computer-aided modeling and simulation are shown in Figs. 5-8. Among these figures, Fig.5 displays the deformation profile in tubular product, Fig.6 shows the pressure profile in tubular product, Fig.7 represents deformed tubular product under maximum hydraulic pressure, and Fig.8 depicts the stress profile in tubular product during hydroforming process.

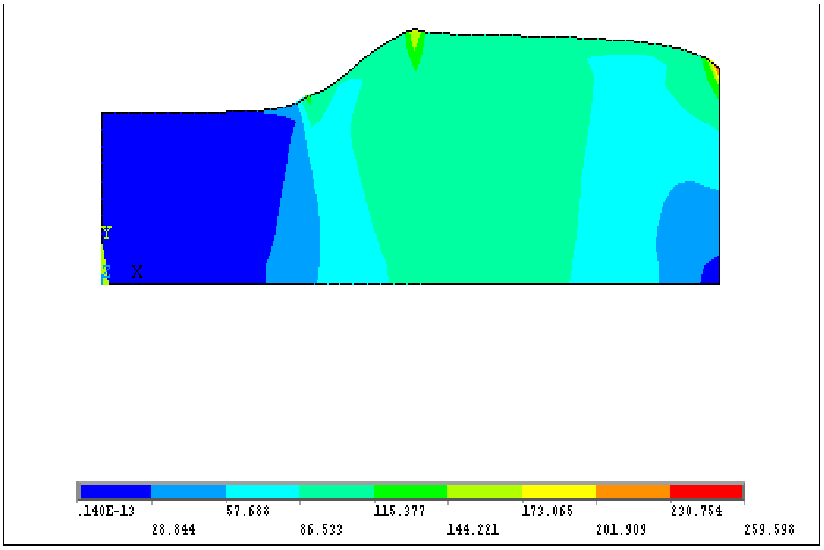

Fig. 5. Deformation profile in tubular product
Modal solution
Step=1; sub =1; time=1; seqv = (avg); dmx=.752362; smn = .140e-10; smx = 259.598

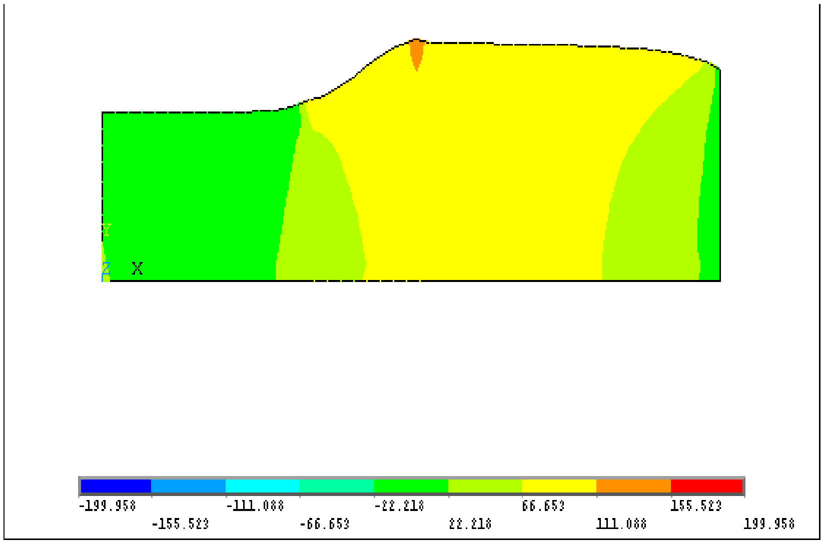

Fig. 6. Pressure profile in tubular product
Modal solution
Step=1; sub =1; time=1; sy = (avg); rsys=0; dmx=.087448; smn = -40.253; smx = 155.523

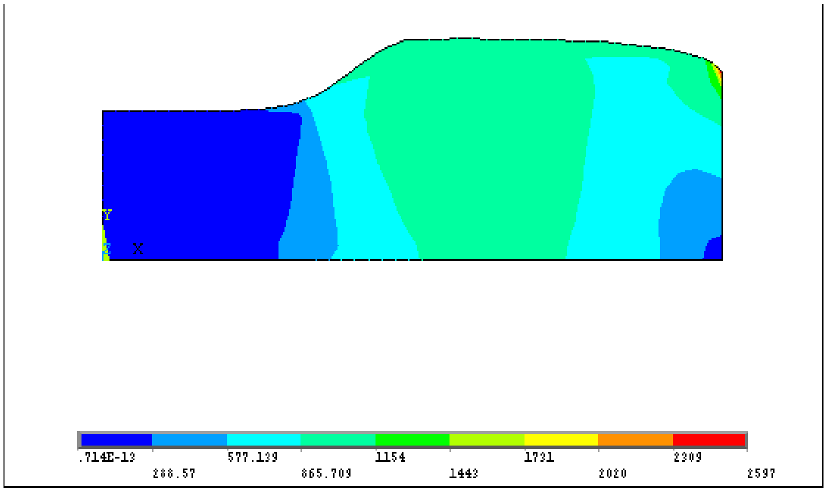

Fig. 7. Deformation under maximum pressure
Modal solution
STEP=1; SUB =1; TIME=1; SEQV = (AVG); DMX=.752362; SMN = .714e-10; SMX = 2597

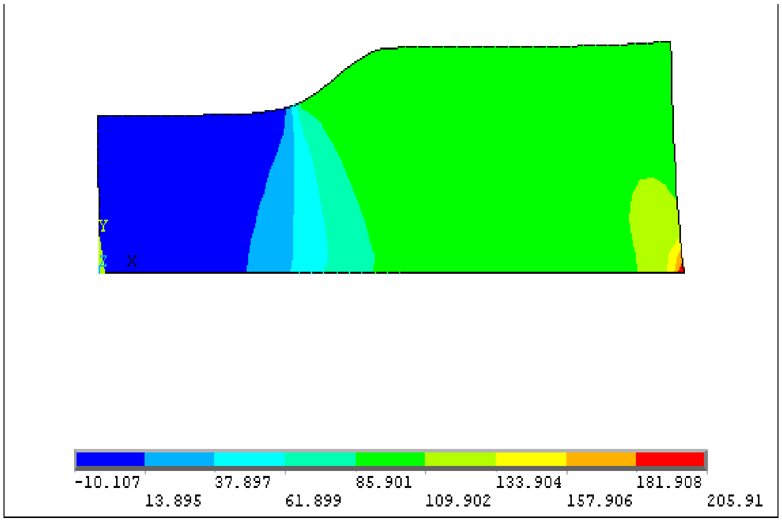

Fig. 8. Stress profile in tubular product
Modal solution
STEP=1; SUB =1; TIME=1; SY = (AVG); RSYS=0; DMX=.09658; SMN = -10.107; SMX = 205.91

The computer-aided modeling and simulation indicate that, when axial compressive force has been applied at both ends of tubular product to move material into volumetric expansive regions, the thickness of tubular wall in expansive regions is decreased. Axial force exerted by hydraulic actuators will extend the forming boundaries in tubular product material. Since the material allowable elongation is 30%, the deformation of deformed part must be controlled under this elongation limit. If the applied compressive force is too high, the formed part will experience the material fracture. Under compressive force of 350 KN, the product is fully formed with material deformation of 10.35 mm from deformation profile shown in Fig. 5 and stress of 385.38 Mpa from stress profile depicted in Fig.8. All these results indicate that, while fully form this alloy steel material with specified dimensions, the material deformation is within material allowable deformation limit and the stress value is under material tensile strength.

4. Prototype testing

The testing has been performed to compare the results from computer-aided simulation in this research. The original material stock of high strength alloy steel, with yield strength of 350 Mpa and tensile strength of 475 Mpa, is placed in this hydroforming system and the tubular samples are finally formed with dimensions of 35 mm in OD, 300 mm in length, and 6 mm in wall thickness under compressive force of 350 KN.

The prototype testing results are shown in Table 1.

Table 1

Prototype testing in hydroforming process

# of Test	Compressive force applied (KN)	Tubular product deformation (mm)	Stress in tubular product (MPa)
1	350	10.38	384.88
2	350	10.34	385.12
3	350	10.37	385.08
4	350	10.34	384.78
5	350	10.33	386.18
6	350	10.34	384.58
7	350	10.38	385.48
8	350	10.38	384.68
9	350	10.34	384.85
10	350	10.39	385.22
Average	350	10.36	385.08

Based on the prototype testing results, the average deformation and stress in tubular product during hydroforming process are 10.36 mm and 385.08 MPa. Comparing with computer-aided modeling results (deformation of 10.35 mm and stress of 385.38 MPa), both computational simulation and prototype testing show the close results of deformation and stress in completely formed tubular product. This validates the credibility of this research and computer-aided simulation methodology.

5. Conclusion

Hydroforming is an emerging and effective manufacturing technology applied in many industries, such as aerospace, automobile, aircraft, and many other consumer products. Comparing to conventional manufacturing processes, hydroforming has more advantages including increase in material strength/stiffness, reduction in ratio of work to unit weight, less secondary operation, decrease in tool cost, stabilized in material structure, and more evenly distributed wall thickness. In this research paper, the computer-aided modeling is constructed to simulate the hydroforming process on tubular product to determine loading path including axial force applied and internal pressure required to form the tubular product. The produced stress and deforming behavior during hydroforming of tubular product have been studied through computational simulation and sample testing. The results indicate that the loading path of axial force and internal pressure are the most important parameters required to be controlled in hydroforming manufacturing. Both computational simulation and sample testing show close results which verify the credibility of this research methodology. More sample testing will be planned for further validation of this hydroforming research.

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