MODELLING AND SIMULATION OF T SHAPED TUBE HYDROFORMING PROCESS

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Abstract

Tube Hydroforming is a process of forming closed-section, hollow parts with different cross-sections by applying combined internal hydraulic forming pressure and end axial compressive loads or feeds to force a tubular blank to conform to the shape of a given die cavity. It is one of the most advanced metal forming processes and is ideal for producing seamless, lightweight, near net shape components.. This innovative manufacturing process offers several advantages over conventional manufacturing processes such as part consolidation, weight reduction and lower tooling and process cost. To increase the implementation of this technology in different manufacturing industries, dramatic improvements for hydroformed part design and process development are imperative. The current design and development of tube Hydroforming processes is plagued with long design and prototyping lead times of the component.

The tube Hydroforming process is a relatively complex manufacturing process; the performance of this process depends on various factors and requires proper combination of part design, material selection and boundary conditions. Due to the complex nature of the process, the best method to study the behavior of the process is by using numerical techniques and advanced explicit finite element (FE) codes. In this work-branch components were formed using a tube Hydroforming In this work, T-branch components were formed using a tube Hydroforming. the processes were simulated using ANSYS AUTODYN explicit FEcode using the same experimental boundary, loading conditions and the simulation results were compared with the Commercial available component.

Keywords: Hydroforming Process, Tube Hydroforming Process, Finite Element Modeling (FEM), Deformation behaviour, Friction.

1. Introduction

Form complex shapes. Tubes are formed into the desired shapes using internal pressure usually obtained by various means using hydraulics, viscous media, elastomers, polyurethane, etc. and axial compressive loads simultaneously to force a tubular blank to conform to the shape of a given die cavity. Compared with conventional metal forming processes, tube Hydroforming has the merits of a reduction in work piece cost, tool cost and product weight. Furthermore, it can improve structural stability and increase strength and stiffness of the formed parts. THF also offers many other advantages including fine thickness distribution, the requirement for fewer secondary operations and suitability for complex geometries.

The main application of this method has been found in manufacturing of reflectors, household appliances as well as components in the hygiene, aerospace, automotive and aircraft industries. Examples of the use of Hydroforming in the automotive industry include exhaust parts, camshafts, radiator frames, front and rear axles, engine cradles, crankshafts, seat frames, body parts and space frame.

2. Tube Hydroforming

Tube Hydroforming is one of the most popular unconventional metal forming processes which is widely used to form various tubular components. By this process, tubes are formed into different shapes using internal pressure and axial compressive loads simultaneously to force a tubular blank to conform to the shape of a given die cavity. Tube Hydroforming is one of the unconventional metal forming processes which is widely used in order to form complex shapes. Tube Hydroforming (THF) has been called by many other names such as:

- Bulge forming of tubes (BFT)
- Liquid bulge forming (LBF)
- Hydraulic pressure forming (HPF)
- Internal high pressure forming (IHPF)
- Unconventional Tee Forming (UTF), depending on the time and country in which it was used.

Establishment of process goes back to 1939 when Grey et al. investigated manufacturing of seamless copper fittings with T protrusions using a combination of internal pressure and axial load. The investigation was considered as a US patent in the 1940, which gave an indication of the coming period of tube Hydroforming

2.1. Tube Hydroforming Setup.

Design of the THF system is of special importance since high hydraulic pressures and complex shaped parts involved.

The system needed for THF consists of the followings:

- Presses or clamping devices for closing the dies,
- Tooling,
- Pressure system; intensifier,
- Hydraulic cylinders and punches; for sealing the tube and move the material,
- Process control systems; computers, data acquisition, transducers, etc.

2.2. Principle of Tube Hydroforming

The principle of tube Hydroforming is shown in Fig 1.The tubular blank is firstly placed between the two die halves and then filled with high-pressure liquid through holes in the plungers to remove any air bubbles trapped inside. The tube is then forced to adopt the inner contour of the tool by application of internal pressure (via high pressure liquid) and two axial forces (via plungers) simultaneously. In many cases, internal pressure can be transmitted via an elastomers (e.g. rubber or polyurethane), or a soft metal (e.g. lead) [9] or limited applications, the tube can be formed by the increasing internal pressure only. This means that the axial plungers do not feed more material into the expansion zone. However, the axial forces acting on the tube ends must exceed a certain level to prevent leakage. This limit is known as sealing [4].

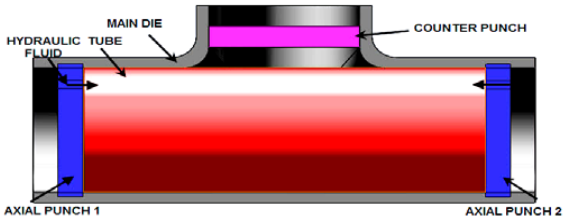
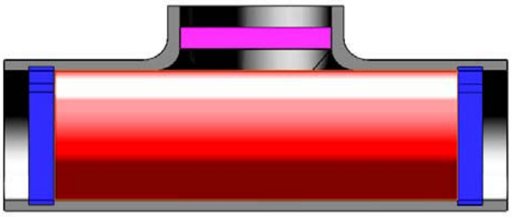
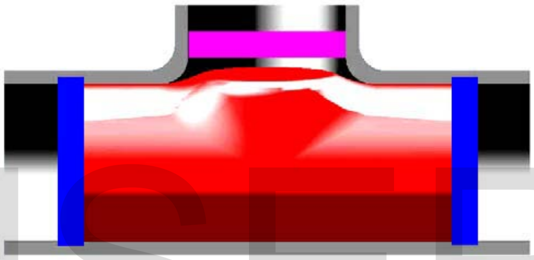


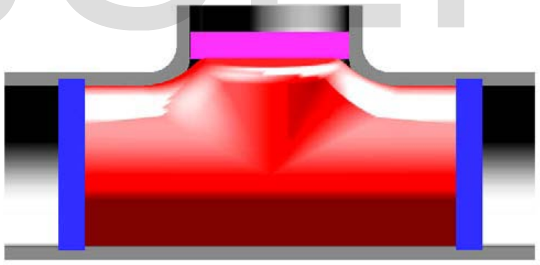
Figure 1. Schematic diagram of Tube Hydroforming System



(a) Initial setup



(b)Intermediate stage



(c)Final Stage

Figure 2. Various Stages during Tube Hydroforming Process

The overall success of Hydroforming product heavily depends on the incoming tubular material properties. Material properties such as composition, weld type, yield and tensile strength, ductility, anisotropy must be determined for tubes [3,5]. Some of the important characteristics tubular materials for quality THF applications are high and uniform elongation, high strain-hardening exponent and low anisotropy [7]. There are certain limitations on the degree of deformation achievable in tube Hydroforming (THF) process such that parts with desired specifications (like expansions) may not be formed without any defects. THF process defects can be grouped as wrinkling, buckling and bursting (Necking, Fracture) [11,13].

Aluminum has poor drawing capability with conventional forming processes. But with hydroforming process its formability can be increased by 30-40%.The higher draw ratio of sheet hydro formed aluminum makes it a replacing element to steel sheets as it has same strength with light weight. In order to develop double-T shape joint, aluminum can be material with hydroforming process. So in this report, Aluminum tube is used for forming double T joint with THF process [8].

The Tube Hydroforming process parameters, viz., die geometry, internal fillet angle at corners, internal hydraulic pressure variation, velocity of pistons, and temperature greatly influence the final microstructure and thus the properties of the final product. In this investigation pure aluminum is processed by THF process and studied the formability of aluminum

3. Literature Review.

The history of hydroforming process is not very old. Its application in automobile sector field began in Europe and North America and has been showing rapid expansion in these countries. In Japan, on the other hand, the application of Hydroforming Process to the manufacture of car components began in 1999. THF process has been in practical industrial use only more than a decade, the development of the techniques and establishment of the theory started in 1940s. Manufacturing of seamless copper fittings with T branches was investigated using internal pressure and axial load by Grey et al [14].

Davis tested tubes of medium carbon steel under internal pressure and tensile axial load in order to determine their yield and fracture characteristics [15]. Experimental and numerical studies were conducted to find the bursting pressure of thick-walled cylinders by Faupel, Crossland and Dietmann during 1950s and 1960s [16].

In1960s, experimental and theoretical investigations on instability of thin- walled cylinders were performed by many researchers at different countries [17]. Fundamental investigations on thin-and thick-walled cylinders helped theoretical improvements in THF operations. Use of hydrostatic pressure in metal forming processes, in particular, for bulging of tubular parts was first reported by Fuchs [18]. In this paper, he reported experimental studies on expansion and flanging of copper tubes using hydraulic pressure.

Ogura and Ueda [19] presented their experimental results on THF of Tee shapes from low and medium carbon steel. Different configurations and number of Tee protrusions were formed using internal pressure and axial compressive loading. Al-Qureshi and his team [20] performed bulging and piercing experiments of different materials including copper, steel and aluminium using polyurethane to provide internal pressure [21]. They did not report use of axial loading in their experiments.

In 1970s, research on different aspects of bulge forming continued both experimentally and theoretically by various authors. New shapes, materials, different tooling configurations and new machine concepts were introduced, whereas the fundamentals remained the same. For illustration, instead of polyurethane, rubber and elastomer were used to provide internal pressure [21].

Limb and his team [22] performed THF of different materials with changing wall thickness. They reported that increasing the internal pressure gradually during the application of axial load gives the best results on thinning and complete filling. Thickening of tube wall at feeding zone was also mentioned due to the friction between tube and die surface.

Woo [23] reported experimental and analytical results for tubes bulged under internal pressure and axial compressive loading. He carried out a numerical study assuming that the entire length of the bulged tube was in tension, and thus, free bulging took place.

Limb et al. used oil as pressurizing medium in their experiments to investigate the forming of copper, aluminium, low carbon steel and brass Tee-shaped tubular parts. Results of lubricant and material evaluations were reported in terms of protrusion height attainable. Sauer et al. presented their theoretical and experimental work on necking criterion of bulged tubes. Assuming a constant ratio of hoop and longitudinal stresses in tube wall during expansion, numerical and experimental results were found to be in agreement. Effective strain at necking was also explained in terms of pre-strain, strain-hardening exponent and stress ratio.

Woo and Lua [24] described their experimental tooling for THF process, and presented a theoretical analysis of stresses and strains taking into account the anisotropy effect of the sheet metals in two separate papers. They utilized Hill's theory of plastic anisotropy in their work.

Starting from 1980s, researchers in Japan concentrated on determining the material properties and their effects on tube bulging operations. Manabe and Nishimura investigated influence of the strain hardening exponent and anisotropy on forming of tubes in hydraulic bulging and nosing processes [25]. They briefly presented the maximum internal pressure as a function of tube radius, thickness, strain hardening exponent, and strength coefficient assuming that there was no axial loading.

Manabe et al. [26] published their work on examination of deformation behavior and limits of forming for aluminium tubes under both internal pressure and axial force. Axial cylinders and internal pressure were controlled by a computer-control-system to obtain pre-defined stress ratio during their experiments. They utilized fundamental analysis of thin-walled cylinders in their predictions for internal pressure and axial force.

Fuchizawa [27] analyzed bulge forming of finite-length, thin-walled cylinders under internal pressure using incremental plasticity theory. He presented the influence of strain-hardening exponent on limits of bulge height. Internal pressure and maximum expansion radius were expressed in terms of length, diameter, strength coefficient (k) and strain-hardening exponent (n). He based his analysis on deformation theory and Hill's theory of plastic anisotropy.

Thiruvarudchelvan [28] and his team have worked on experimental and theoretical aspects of tube bulging process using both polyurethane and liquid as pressurizing medium Ueda presented forming of differential gear casings with hydroforming techniques after a series of experimentations in 1980s. Hashimi and his team investigated the bulge forming of axi-symmetric and asymmetric components via experiments, analytical techniques and FEA.

4. Finite element analysis of T-Shape Tube Hydroforming Process

The Double T-Shape Tube Hydroforming Process is simulated by using the commercial metal forming finite element code 'FORGE 2011'. The initial tube sample having 10 mm in external diameter, 1mm thickness and 50 mm in length, made of pure copper Al-99 is used. Our goal is to focus on the average equivalent strain obtained.In this investigation each geometrical combination with a particular velocity is studied under oil, low, medium and high friction conditions respectively. The punches moved with velocities 1mm/s in opposite directions. The counter punches remained fixed at 10mm from centerline so that proper material flow can be achieved at protrusion area. The internal pressure was varied linearly from 0 to 100 MPa during the process.

4.1 Arrangement for Double T-shape hydroforming process

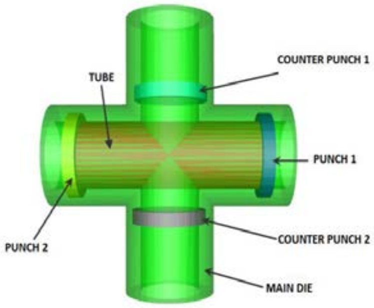


Figure.3 Schematic illustration T- shape Die.

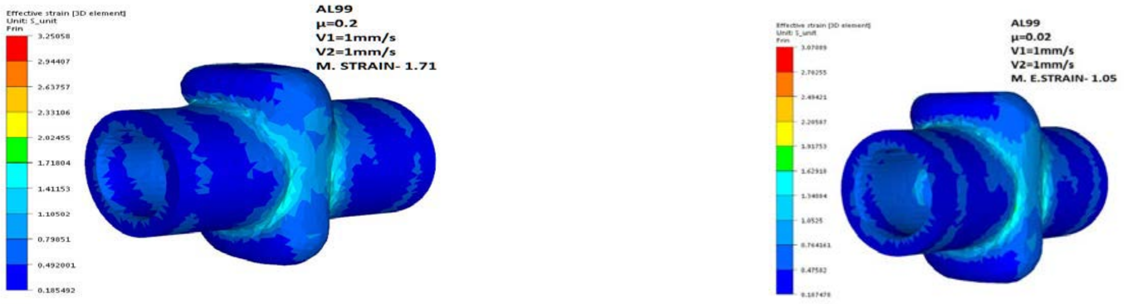
Tube Parameters

Figure 4. Tube Parameters

Table 1.Process Parameters for Double T-joint hydroforming process

Tube Type	*Circular*
Tube Dimension	Length=50mm External Diameter=10mm Tube Thickness=1mm
Tube Material	Aluminum (99% pure)
Temperature	Ambient (20°C)
Friction	High(μ = 0.2) Medium(μ=0.05) Low(μ=0.02) Oil(μ=0.01)
Press type	Hydraulic
Velocity Punch 1 Punch 2	1 mm/s
Counter Punches 1,2	Stationary

The equivalent strain contours during tube hydroforming process on Al99.97 under different friction conditions and ram velocity of 1mm/sec using FORGE are depicted in figure 5.

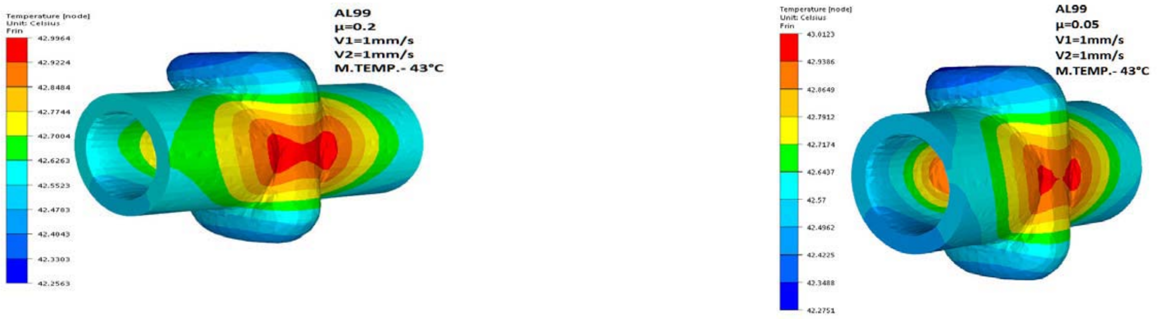


(a) High Friction (c).Low Friction

(b).Medium Friction (d) Under Oil Condition

Figure 5. Variation of strain during Double T-Shape THF process on Al99.97 under different friction conditions using FORGE

Figure6. indicated the variation of temperature over the tube during THF process. It is observed that with increase friction equivalent strain decreases for all considered friction values.



(a) High Friction *(b) Medium Friction*

(c) Low Friction *(d) Under Oil Condition*

Figure 6. Variation of temperature during Double T-Shape THF process on Al99.97 under different friction conditions using FORGE.

5. Conclusion

From the experiment it is concluded that under different friction conditions the equivalent strain generated in the Al billet increased tremendously with different rates. High strain is obtained with high friction and with decreasing friction strain gets reduced. Also the shape achieved also effected with friction conditions. The current FE study greatly helps to understand THF parameters to design experimental facilities. FEM analysis of double T-shape hydroforming process is done with Aluminum under different conditions of friction. The strain generated, and hence deformation achieve in the process is studied. The protrusion height achieved during the deformation process is also studied.

References

1. Ahmetoglu M., Sutter K., Li X.J., and Altan T., "Tube hydroforming: current research, applications and need for training." *J Mater Process Technology* Vol. 98, pp 224–31, 2000.
2. Ahmed M., and Hashmi M. S. J.," Three dimensional finite element simulation of axi-symmetric tube bulging. *In: Proc pacific congress on manufacturing and management.* Brisbane, Australia, pp. 515–21, 1998.
3. Back C., Miyagawa M." The plastic deformation and strength of circular cylindrical shells under internal pressure and/or axial force (1st report, experiment)." *Trans Jpn Soc Mech Eng* Vol 32(235), pp.447–56, 1966
4. Birkert A., "Tool and part design for hydroforming."Proceedings of the International Conference on Hydroforming, Stuttgart, Germany, October 12-13, 1999.
5. Breckner M.," Hydraulic systems for hydroforming." *Proceedings of the International Conference on Hydroforming, Stuttgart, Germany,* October 12-13, 1999.
6. Chen F., Wang S., and Lin R. "A study of forming pressure in the tube hydroforming process." *J Mater Process Technology* 192–193, pp.404–409, 2007.
7. Fuchizawa S., “Influence of strain hardening exponent on the deformation of thin-walled tube of finite length subjected to hydrostatic external pressure.” *Adv. Technol. Plasticity,* vol.1, pp. 297–302, 1984.
8. Hama T., Ohkubo T., Kurisu K., Fujimoto H., and Takuda H.," Formability of tube hydroforming under various loading paths." *J Mater Process Technology* Vol. 177, pp.676–9, 2006.
9. Jeong K., Sang-Woo K., Hoon-Jae P., and Kang B. S., “A prediction of bursting failure in tube hydroforming process based on plastic instability”. *Int. J Adv. Manufacturing Technology* vol.27, pp.518–524, 2006.
10. Kang S. J., Kim H.K., Kang B. S. “Tube size effect on hydroforming formability” *J Mater Process Technology,* Vol. 160, pp 24–33, 2005.
11. Klaas F., "Innovations in high pressure hydroforming." *Proceedings of the Second International Conference on Innovations in Hydroforming Technology, Columbus, OH,* September 17, 1999.
12. Koç M., Allen T., Jiratheranat S., and Altan T. “The use of FEA and design of experiments to establish design guidelines for simple hydroformed parts” *Int. J Mach Tools Manufacturing,* Vol. 40, pp.2249–2266, 2000.
13. Altan T., Muammer Koc "Prediction of forming limits and parameters in the tube hydroforming process", *International Journal of Machine Tools & Manufacture* 42 pp.123–138, 2002.

14. Grey J. E., Devereaux A.P., Parker W.N.," Apparatus for making wrought metal T's", *US Patent 2,203,868 June (1939).*

15. Davis E.A.," Yield and fracture of medium-carbon steel under combined stress,."*J. Appl. Mech.*pp.13-24, 1945.

16. H. Dietmann, "The Flow behaviour of thick-walled cylinders under internal pressure." Bander Bleche Rohre 8(3), pp.143-149, 1967.

17. Woo D.M., "The analysis of axi-symmetric forming of sheet metal and the hydrostatic bulging process." *Int. J. Mech. Sci.* 6, pp. 303-317, 1964.

18. Fuchs F.J., "Hydrostatic pressure Ð its role in metal forming."Mech. Eng. pp. 34-40, 1966.

19. Ogura T and Ueda T. "Liquid bulge forming" *Metalwork Prod*, pp.73–81, 1968.

20. Al-Qureshi H.A., Mellor P.B., Garber S., "Application of polyurethane to the bulging and piercing of thin-walled tubes."*Proceedings of the Ninth International MTDR Conference, Birmingham, UK, pp. 319-338, 1968.*

21. Al-Qureshi H.A.," Comparison between the bulging of thin-walled tubes using rubber forming technique and hydraulic forming process." *Sheet Metal Ind.* pp.607 612, 1970.

22. Limb M.E., Chakrabarty J., Garber S., and Mellor P.B.," The forming of axi-symmetric and asymmetric components from tube." *In Proc 14th international MTDR conference, pp.* 799–805, 1973.

23. Woo D.M.," Tube-bulging under internal pressure and axial force." *J. Eng. Mater. Technol.* pp.219-223, 1973.

24. Woo D.M.," Development of a bulge forming process,." *Sheet Metal Ind.*, pp.623-625, 1978.

25. Manabe K., Nishimura H.," Influence of material properties in forming of tubes." *Bander Bleche Rohre 9,* 1983.

26. Manabe K., Mori S., Suzuki K., Nishimura H.," Bulge forming of thin-walled tubes by micro-computer controlled hydraulic press." *Adv. Technol. Plasticity* pp.279- 284, 1984.

27. Fuchizawa S., "Influence of strain hardening exponent on the deformation of thin-walled tube of finite length subjected to hydrostatic external pressure." *Adv. Technol. Plasticity*, vol.1, pp. 297–302, 1984.

28. Thiruvarudchelvan S.,"A theory for the bulging of aluminium tubes using urethane rod." *J. Eng. Technol.* 1989.