International Journal of Modern Trends in Engineering and Research
www.ijmter.com
e-ISSN No.:2349-9745, Date: 2-4 July, 2015

Analytical Study of Hydraulic Forming Process

Vaibhav E. Kothawade[1], Sachin P. Kakade[2] , Sachin B. Mahale[3]

[1] *Department of Mechanical Engineering, MET's BKC IOE, vaibhavkothawade4@gmail.com*
[2] *Department of Mechanical Engineering, MET's BKC IOE, sachinkakade2107@gmail.com*
[3]*Department of Mechanical Engineering, MET's BKC IOT- P, sachin4549@gmail.com*

Abstract — The effect of forming pressure required to form a tube using the tube-hydro forming process is studied in the present study. The relationship between hydraulic pressure, outer corner radius of the deformed tube, tube thickness and tube yield stress is studied with the help of proposed theoretical model. In the theoretical model, the material hardening property was taken into consideration. The predicted values from the theoretical model are plotted on the graph to overview the nature of effect of pressure on outer corner radius.

Key words: - Hydraulic forming, hydraulic pressure, outer corner radius, tube thickness, tube yield stress

I. INTRODUCTION

The increasing demand for lighter and safer products is the key challenge for many of the manufacturers. A significant development of unconventional procedure processing has brought up by the market demands for the rapid part changes in automotive industry, whereas economic and market demands couldn't be satisfied with the conventional method of automotive part manufacturing. Almost all recent technological processes are based on utilization of the unconventional procedure of metal processing with plastic forming. It is significant that about 10% of manufacturing in automotive industry includes fluid plastic forming of a tube. The demands are corresponding to the techno-economic justification and hydro forming process utilization [2].

The sheet metal hydro forming is a younger technology which presents, in comparison with tubes, the advantage of allowing a material draw-in from the flange area, reducing in this way the stretching component and thus increasing the forming capability. However, the process complexity grows also significantly, since the process parameters have to be optimized for each specific case. The application of sheet hydro forming to complex body structures has a great potential, concerning both weight and cost aspect. Hydro forming uses fluid pressure applied to a tubular or sheet metal blank to form it into the desired component shape. The most commonly used materials in hydro forming include the various grades of steel. These grades of steel are used extensively because they exhibit good fatigue properties, high energy absorption, and reasonable resistance to corrosion. Hydro forming is a cost-effective way of shaping ductile metals such as aluminum, brass, low alloy steels, stainless steel into lightweight, structurally stiff and strong pieces. One of the largest applications of hydro forming is the automotive industry, which makes use of the complex shapes possible by hydro forming to produce stronger, lighter, and more rigid unibody structures for vehicles. This technique is particularly popular with the high-end sports car industry and is also frequently employed in the shaping of aluminum tubes for bicycle frames. Hydro forming is a specialized type of die forming that uses a high pressure hydraulic fluid to press room temperature working material into a die. Hydro forming allows complex shapes with

@IJMTER-2015, All rights Reserved

concavities to be formed, which would be difficult or impossible with standard solid die stamping. Hydro formed parts can often be made with a higher stiffness-to-weight ratio and at a lower per unit cost than traditional stamped or stamped and welded parts [3].

II. TUBE HYDROFORMING

Tubular hydro forming begins with the placement of either straight tubes, or more commonly preformed tubes, into the die. Sealing punches within the die close off the tube ends as fluid pressurization begins. The three surfaces of a tube that can act as sealing surfaces include:

1) The outside diameter of the tube 2) The inside diameter of the tube 3) The end surface of the tube

During forming, a combination of increasing internal fluid pressure and a simultaneous axial pressing on the tube ends by the sealing punches cause the tubular material to flow into the contours of the die.

Tubular hydro forming is generally divided into three operating techniques:

1) Low-Pressure Hydro forming uses fluid pressures of 12,000 PSI/828 bar or less. Cycle time is less than with other hydro forming methods, but components must be designed carefully to form properly using the lower fluid pressures.
2) High-Pressure Hydro forming uses fluid pressures ranging from 20,000 to100, 000 PSI/1,379 to 6,895 bar. The exact amount of pressure needed is dependent upon several factors such as material yield strength, tube wall thickness and the inside radius of the sharpest cross-sectional corner. When the tube is expanded by high pressure within the die cavity, material thickness may vary throughout the part. Additionally, larger presses are needed for high-pressure hydro forming and the higher operating pressures can result in longer cycle times.
3) Pressure Sequence Hydro forming utilizes the closing action of the hydraulic press to assist in the hydro forming of the blank. The blank is first placed in the die cavity and the die is partially closed, partly deforming the tube. Low-pressurized fluid is then pumped into the blank allowing it to resist compression. The die starts to close again with the desired low-pressure maintained while part cross section reduces. Once the die is fully closed, high pressure is applied to the fluid, forcing the blank material into the corner recesses of the die cavity with no wall thinning. Maximum pressure for pressure sequence hydro forming is typically under 10,000 PSI/690 bar [4].

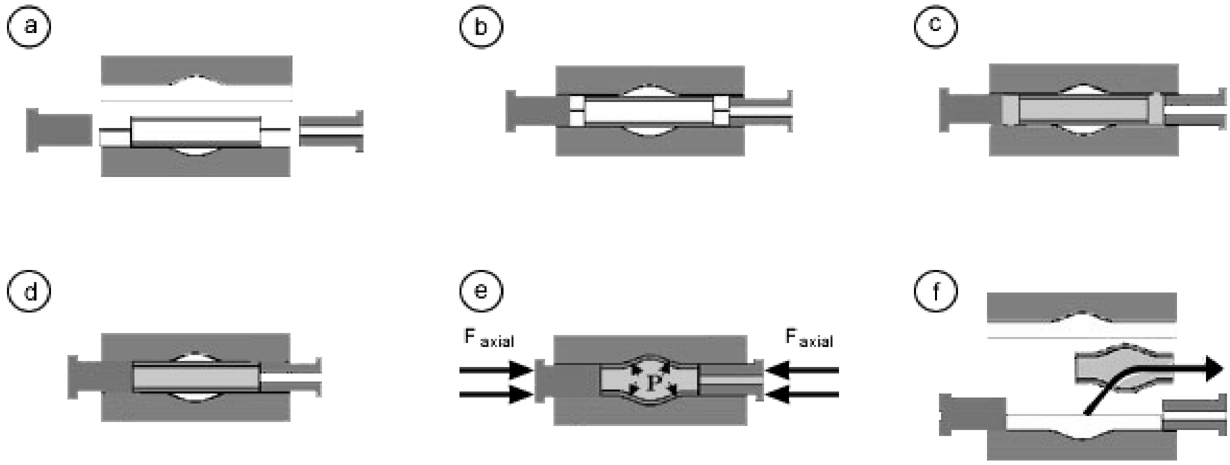


Figure 1: - Procedure in Tube Hydro forming

@IJMTER-2015, All rights Reserved

III. ANALYTICAL MODEL

In order to simplify the analysis, a long, straight hydro formed part was considered, and the part shape can be formed by expansion alone without the need of axial feed. Thus, a state of plane strain deformation can be assumed in the theoretical model. In the analysis, the following assumptions are made:

1) The tube is homogeneous and isotropic.

2) The elastic deformation is negligible and the tube is considered as rigid-plastic.

With the required internal hydraulic pressure calculated by the proposed theoretical model, the die-closing force exerted by the press can be predicted by carrying out a simple analysis Both the theoretical model and the simple analysis are depicted in the following.Inner Noise – is the type of variation from specification, which can be described as between product noise, which remains in the piece-to-piece, variation after the general mean level conforms to specification. The major concern of dimensional accuracy in a hydro formed part is the formation of an edge corner to a desired radius. It is known that the hydraulic pressure required in a tube hydro forming process to manufacture a structural part depends on the minimum corner radius in the part shape. Therefore, a formability study of the tube material is essential to the tube-hydro forming design. The formability analysis of tube hydro forming may include the relationship between hydraulic pressure, outer corner radius of the deformed tube, tube thickness and tube yield stress. The press tonnage required to hold the tube in place while it is internally pressurized, which is called die closing force, is also very important in the tube-hydro forming design. An empirical formula for predicting the pressure to form a corner radius is proposed. However, the author points out that the predicted pressure is an upper- bound value and is generally significantly higher than the actual pressure required. In the present study, a theoretical model was proposed to construct the above-mentioned relationship and calculate the die-closing force. Two different finite element codes were employed to validate the proposed theoretical model. A comparison is subsequently made between the predicted values and the finite element simulation results [1].

IV. ANALYTICAL STUDY

A rectangular cross section, as shown in Fig. 2, was adopted to define the dimensions of the tube thickness (t), inner corner radius (ri), and outer corner radius (ro). For simplicity, a corner of an arbitrary die cross section, as shown in Fig. 3, was used to construct the theoretical model. In order to further simplify the analysis, the configuration was made symmetric with respect to the y-axis so that only one half of the configuration is necessary to be considered for the analysis. For the deformed tube at any stage of hydro forming after die-closing, the tube apex which is not in contact with the die surface can be assumed as a circular arc with a uniform thickness, t, and a mean radius of curvature, $\bar{r}$, as shown by A–B in Fig. 3[1].

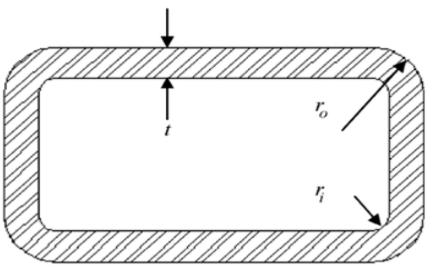


Figure 2:- Dimension of Rectangular Cross Section

Deformation caused by an increment of internal pressure only occurs over the circular arc, and the remaining portion of the tube that is already in contact with the die surface, such as *A–P* and *B–Q* shown in Fig. 3, remains as it is. Therefore, it may be convenient to use polar coordinates (r,θ) for the analysis of the incipient plastic deformation of the tube apex. Consider a differential element of the deformed tube at angle of θ, as shown in Fig. 3. The condition of force equilibrium in the r-direction results in

$$\frac{d\sigma r}{dr} - \frac{\sigma\theta - \sigma r}{r} = 0$$

where $\sigma\theta$ and σr are the hoop and radial stresses, respectively.
Since $\sigma\theta > \sigma r$ and σz is an intermediate stress in the plane strain condition, the Tresca yield criterion is given by $\sigma\theta - \sigma r = \sigma$
where σz is the axial stress and $\bar{\sigma}$ is the flow stress of the tube material. It is readily seen that the hydraulic pressure (p) required to cause the incipient yield of the tube apex is obtained by setting $\sigma r = -p$ at $r = ri$ and $\sigma r = 0$ at $r = ro$, resulting in

$$p = \sigma . \ln \frac{r0}{ri}$$

Rearranging Equation and taking exponential, we obtain the relationship between the outer corner radius of the deformed tube and the hydraulic pressure as

$$\frac{r0}{t} = \frac{1}{1 - e\wedge - (p/\sigma)} \quad \text{------- (1)}$$

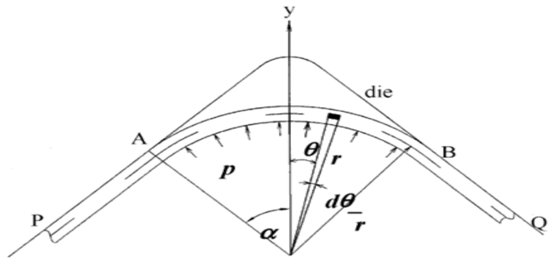
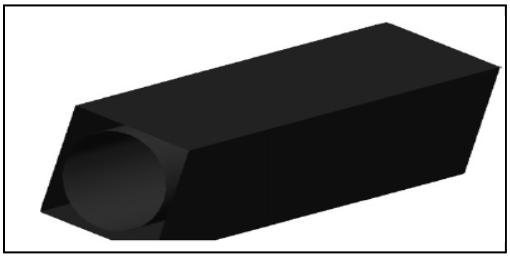


Figure 3:- A Corner Of An Arbitrary Die Cross Section

It is to be noted from Equation (1) that an exponentially proportional relationship exists between the hydraulic pressure required to expand the tube and the ratio of outer corner radius to the current thickness of the deformed tube, instead of the outer corner radius alone. Above Equations are applicable to a tube without work hardening behaviour. For tubes which work-harden, use of the stress–strain relations must be made to calculate the flow stress $\bar{\sigma}$. It is assumed that the tube work-hardens according to the stress–strain relations. Flow stress is calculated by,

$$\sigma = K(\varepsilon 0 + \varepsilon)0.238 \text{ (MPa)}.$$



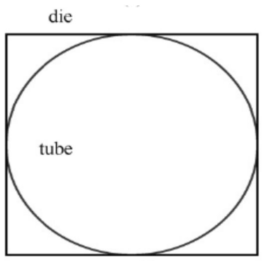


Figure 3:- Configuration of die opening angle

@IJMTER-2015, All rights Reserved

V. RESULTS AND DISCUSSIONS

The configuration with a 90◦ die opening angle, as shown in Figure.3, was used to determine the relationship between the hydraulic pressure and the outer corner radius. Since the deformed tube shape at die-closing is unpredictable, finite element simulations were conducted for tube shapes with different initial radii (R) ranging from 10 to 50mm in an increment of 10 mm. It is also seen in graph that the internal hydraulic pressure required to start the deformation for a tube with R = 10mm is about 80MPa. Below this pressure, the tube is almost rigid. The theoretical model that predicts the relationship between the hydraulic pressure and the corner radius of the tube to be deformed was analysed wit h analytical model [1].

Hydraulic pressure	Corner radius
80	11.8
70	13.34
60	16.39
50	18.26
40	22.56
30	29.74
20	44.11
10	87.21
5	90
0	90

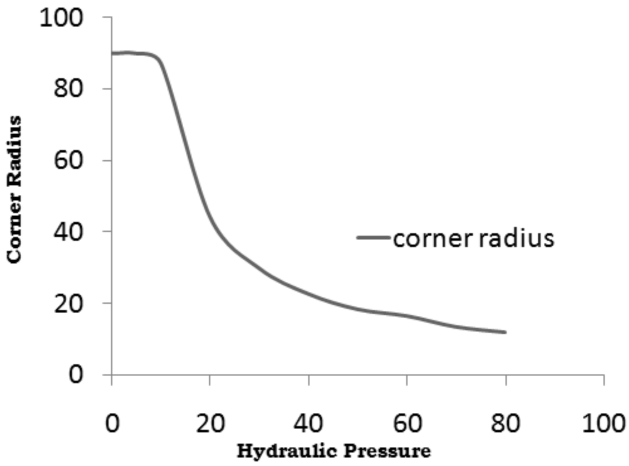


Figure 5:- Relation between Corner Radius and Hydraulic Pressure

VI. REFERENCES

[1] Fuh-Kuo Chen∗ , Shao-Jun Wang, Ray-Hau Lin, "A study of forming pressure in the tube-hydroforming""; Journal of Materials Processing Technology 192–193 (2007) 404–409

[2] FujunLiua,*, Jinyang Zhenga, Ping Xua, Mingze Xub, Guohui Zhu, "Forming mechanism of double-layered tubes by internal hydraulic expansion" International Journal of Pressure Vessels and Piping 81 (2004) 625–633

[3] Ho Changa,∗ , Tsing-Tshih Tsunga, Liang-Chia Chenb, Lee-Long Hana, "The manufacture of microwave plate reflector antennas by employing the improved super plasticity hydraulic forming method", Journal of Materials Processing Technology 160 (2005) 107–111

[4] Edina Karabegović1, Miran Brezočnik2, "Parameter Optimization of Tube Hydro forming" International Journal Of Computational Engineering Research (ijceronline.com) Vol. 2 Issue. 8

[5] M. Tolazzi, M. Geiger, Process parameters optimisation in sheet Hydro forming, Chair of Manufacturing Technology, University of Erlangen-Nuremberg, Egerlandstr. 11, D-91058 Erlangen, Germany

[6] U. Gather2, W. Homberg1, M. Kleiner1, Ch. Klimmek1, S. Kuhnt2, Parameter design for sheet metal hydro forming processes, Chair of Forming Technology, University of Dortmund, Germany; 2Chair of Mathematical Statistics and Industrial Applications, University of Dortmund, Germany

[7] Nader Abedrabbo*, Naeem Zafar*, Ron Averill*, Farhang Pourboghrat* and Ranny Sidhu‡, Optimization of a Tube Hydroforming Process, MI 48824 -1226 ‡ Red Cedar Technology, East Lansing, MI 48823

@IJMTER-2015, All rights Reserved