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Research Paper

EXPERIMENTAL ANALYSIS OF TUBE HYDROFORMING

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The Tube Hydroforming Process (THF) is a relatively complex manufacturing process; the performance of this process depends on various parameters like internal pressure, axial loading etc. and requires proper combination of part design, material selection and boundary conditions. Due to the complex nature of the process, the behaviour of this processes are studied experimentally. Current study involves experimental work on tube hydroforming. Study on various parameters of the tube hydroforming process to approach optimum process parameters. How different materials and process parameters influence the loading paths. The study was a part of a large investigation.

Keywords: Bulge forming, Tube hydroforming, Manufacturing process, Process parameter, Materials, Bulge height

INTRODUCTION

Tube hydroforming is one of the best processes to produce tubular components of different shapes, in this process the tubes are formed into the shapes of the dies by using internal pressure and axial force. There are so many applications of tube hydro forming in automobiles, aerospace, households, stationaries, etc., all types of ductile materials can be used for tube hydroforming process like aluminum, copper, brass, stainless steel, alloy steel etc. This process

includesmany difficulties such as loading variables, which is called design of loading paths and also internal pressure. If any variation in loading paths which leads to process failures such as buckling, wrinkling, bursting generally the fluid used for tube hydroforming process is water, there are somany advantages of hydroforming such as like weight reduction and high utilization of material strength and also stiffness. Initially the tube EN31of length 250 mm, diameter 57.15 mm and thickness 1.5 mm is placed between the dies and two plungers are used to enclose the ends of the tube to prevent leakage as well as to provide axial feeding of tubular material to maintain same thickness after deformation and a nozzle is provided to allow pressurized fluid

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into the tube from a hydraulic unit. Friction should be minimized while the formation of tube in THF. The friction is developed in between the tubular material and the die. If more friction is developed the axial force and internal pressure required is also high and at the same time we can't expect good formability, i.e., thickness and bulge height of tube.

In this current study analytical model for free bulge forming was proposed and it was shown that for $= 0.5$ where $= \frac{s_2}{s_1}$ so that we can obtain good correlation between experimental and analytical model was obtained. The tube formability can be increased and pressure can be decreased when $= -1$ is considered.

Figure schematic illustration of the tube end conditions during forming: 1) Freeforming, 2) Fixed end, 3) Forced end.

Figure 1: Tube and Die Setup

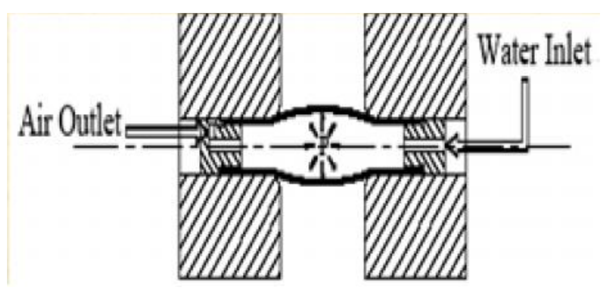


Figure 2: Tube Subjected to Axial Force

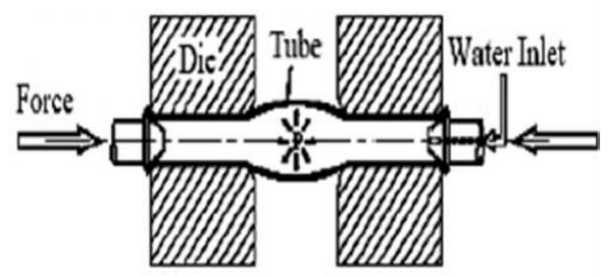


Figure 3: Tube After Bulging

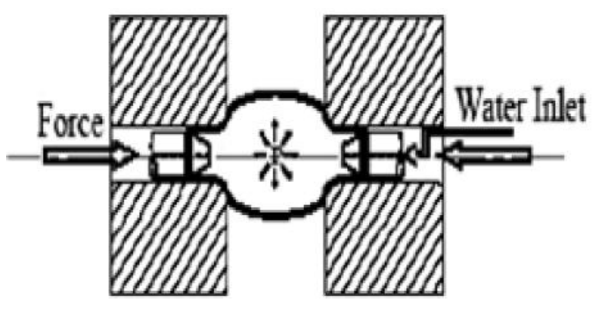
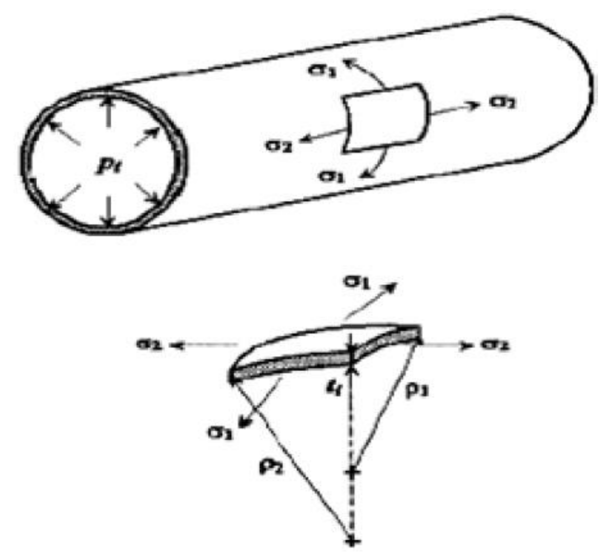


Figure 4: Stresses Acting at the Middle of the Tube on an Element



Analytical model for free bulge forming was proposed and it was shown that when $= 0.5$ $(\pounds_2/\pounds_1)$, good correlation between experimental and analytical model can be obtained.

ANALYTICAL SOLUTION

Assume when a tube is subjected to an internal pressure (P_i) at the middle of the tube for an element, the below equilibrium can be written

$$\frac{\sigma_1}{\rho_1}+\frac{\sigma_2}{\rho_2}=\frac{P_i}{t_i} \quad ...(1)$$

Von misses yield criterion (plane stresses) and equivalent strain can written as:

$$\pm = (1 - \sim + \sim_2)^{1/2} \pm_1 \quad ...(2)$$

$$£ = (4(1 + \quad + \quad_2)/3)^{1/2} £1 \quad ...(3)$$

where

$$\sim = \frac{\pm_2}{\pm_1} \quad ...(4)$$

and

$$= £_2 / £_1 \quad ...(5)$$

The radial and tangential strains $£_2$ and $£_1$ can be written as

$$£_1 = \ln\left(\frac{°_1}{°_0}\right) \quad ...(6)$$

$$£_2 = \ln\left(\frac{t_i}{t_0}\right) \quad ...(7)$$

where $°_0$ and $°_1$ is initial and final tube wall thickness and t_i is instantaneous tube wall thickness

LEVY-MISSES FLOW RULE YIELDS

$$\sim = (2 \quad + 1)/(2 + \quad) \quad ...(8)$$

(OR)

$$= (2\sim - 1)/(2 - \sim) \quad ...(9)$$

Combining Equations (1, 2 and 4) gives

$$Pi = \frac{\pm t_i}{(1 - \sim + \sim^2)}\left(\frac{1}{°_1} + \frac{\sim}{°_2}\right) \quad ...(10)$$

At the interface between elastic and plastic deformation we can assume that

$$°_1 = d0 - t0/2 \quad ...(11)$$

$$°_2 = \infty \quad ...(12)$$

$$t_i = t_0 \quad ...(13)$$

Yielding strength of a material $\pm y$

$$\pm = \pm y \quad ...(14)$$

where $d0$ is the outer diameter of the tube and $t0$ is the initial thickness of tube

$$(P_i)_y = \pm_y \frac{2t_0}{(d_0 - t_0)(1 - \sim + \sim^2)^{1/2}} \quad ...(15)$$

If $\sim = 1$

$$(P_i)_y = \pm_y \frac{2t_0}{(d_0 - t_0)} \quad ...(16)$$

Plastic Deformation

Assume that the tube expands as shown in below Figure ©. This assumption means $°_2 = \infty$

So that $\frac{\pm_1}{°_1} + \frac{\pm_2}{°_2} = \frac{p_i}{t_i}$

$$\frac{\pm_1}{°_1} = \frac{p_i}{t_i} \quad ...(17)$$

Combining

$$°_1 = (d_i - t_i)/2$$

Combining Equations (2) and (16) gives

$$p_i = \frac{2t_i \pm}{(d_i - t_i)(1 - \sim + \sim^2)^{1/2}} \quad ...(18)$$

If $\pm = k(£n)$ ...(19)

Combining eq. © and ® with eq. ®, we get

$$P_i = \frac{2t_i k £_1^n}{(d_i - t_i)\sqrt{1 - \sim + \sim^2}}\left(\sqrt{4(1 + \quad + \quad^2/3)}\right)^n \quad ...(20)$$

Sub.

$$£_1 = \ln\frac{°_1}{°_0} = \ln\frac{(d_i - t_i)}{(d_0 - t_0)} \quad ...(21)$$

Equation (9) into Equation (20) yields

$$p_i = \frac{2t_i}{(d_i - t_i)} k \left(\frac{2}{2} - \sim \right)^n \left(\sqrt{1 - \sim + \sim^2} \right)^{n-1} \left(\ln \frac{d_i - t_i}{d_0 - t_0} \right) \quad ...(22)$$

Assume now that:

$$£_1 + £_2 + £_3 = 0 \quad ...(23)$$

Combining Equations (5), (7) and (24) we get

$$t_i = t_0 \left(\frac{d_i}{d_0} \right)^{-(1+ \ )} \quad ...(24)$$

Fracture strain can be denoted as:

$$£_f = (1 + r)^n \quad ...(25)$$

Fracture strain in hydroforming can be written as

$$£_{1_f} = \frac{(1+r)n - \sqrt{\frac{4}{3}} \ln\left(1 + \frac{t_0}{d_0}\right)}{\left(\frac{4}{3}(1 + \quad + \quad ^2)\right)^{1/2}} \quad ...(26)$$

Combining Equation (6) and (24) yields

$$d_{fr} \cong \frac{d_0 e \left(2n - \sqrt{\frac{4}{3}} \ln\left(1 + \frac{t_0}{d_0}\right) \right)}{\left(\frac{4}{3(1 + \quad + \quad ^2)} \right)^{1/2}} \quad ...(27)$$

where d_{fr} is the tube outer diameter at fracture and t_{fr} is the tube wall thickness at fracture.

Note: d_{fr} and t_{fr} yield the diameter and wall thickness at the middle of expansion zone.

EXPERIMENTAL PROCEDURES

Material Selection

The material selected for experimental procedure is En-31, its composition is given in Table 1, the outside diameter of the tube (D) is 57.15 mm and wall thickness (t) is 1.5 mm, length is 250 mm.

Table 1: Chemical Composition of En-31

EN-31	C	mn	si	s	ni	mo	p	cr
	1.08	0.53	0.25	0.015	0.33	0.06	0.022	1.46

Material Properties

The tensile properties for the En-31 parent metal and mixed material specimens are shown in Table 2, the tubular material is initially tested from the surface defects and then experiment was conducted for better output results.

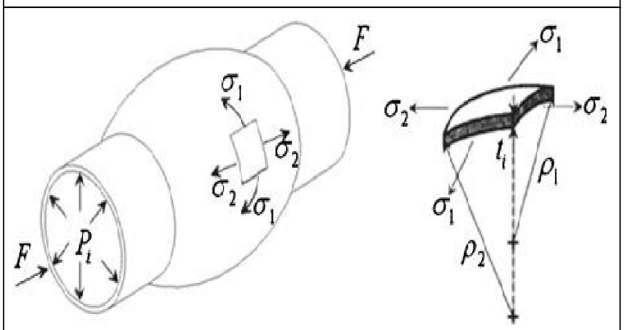
Table 2: Mechanical Properties of En-31

Density (Kg/m^3)	7.8
Tensile strength (N/mm^2)	750
Yield strength (N/mm^2)	450
Modulus of elasticity (N/mm^2)	215000

Experimental Approach

In this study, all the set of experiments were conducted on tube hydroforming machine and the type of hydroforming is free buldge hydroforming, it is carried out experimentally concentrating mainly on some parameters like pressure, axial feeding, time and finally friction that has been generated between tube and

Figure 5: Stresses Acting at the Middle of the Tube



die.The maximum allowable working pressure of the machineis 200 MPa and the maximum allowable axial force is 1,000 kN.

Experimental Tooling and Procedure

The experimental tooling is based on the concept of freehydroforming that was manufactured toimplement the tubebulge test shown in Figure 6. It is composed of an upper die, alower die, and two axial plungers. while free forming, thetube is subject to axial compressive force F and an internalpressure Pi. Figure 7 shows the simplified schematic ofexperimental tooling. The experimental procedure includes four stages: (1) Thetubes are prepared for the experiments. The tubes are cut intoproper length; (2) The tube is placed into the die, the dies areclamped properly and the axial plungers are pushed for sealing; (3) Axialcompressive force is applied with the correspondinginternal pressure under different linear strain paths to the tube until the tube has subjected to bursting; (4) Thedeformation of the tube surfaceclosely at the fracture point is measured for themajor strains e_1 and minor strains e_2. And the values ofthe true strain (£$_2$, £$_1$) are transformed.

Table 3: Analytical and Experimental Results

Max. Buldge Height (Analytical)	Max. Buldge Height (Experimental)	Pressure (MPa)	Buldge Height Error (%)
10.62	9.79	156.24	7.81
10.34	8.92	147.38	13.73
11.07	9.63	153.78	13
10.45	9.81	151.02	6.12
10.67	8.62	145.54	19.21
10.32	8.73	146.21	15.4
10.75	9.45	152.87	12.09
11.09	9.18	151.97	17.22

RESULTS AND DISSCUSION

Numerical Analysis Results

Bysolving Equations (23) and (24) simultaneously, maximum bulge height and thicknessvariation of the tube (in max bulge height position) can beobtained. The results such are obtained is compared with experimentaldata results. As shown, for = –0.5, a goodcorrelation between experimental

Figure 6: Test Specimen After Bulging

Figure 7: Test Specimen that are Subjected to Failure

results and analytical resultshas been achieved. It is also known that for $b = (-1)$, formability of tube is increased and lower internal pressure is needed for forming the tube and thickness variation will increase.

In order to investigate the effect of hardening coefficient (14) on the formability of the extruded tube, pressure assumed to be 156.24 MPa and the value of n were varied between 0.2-0.3 and the corresponding bulge heights were compared. The resulting tube expansion is shown in Figure 10 as shown, a larger hardening coefficient leads in a higher expansion. And also, for a given increment in 'n' a greater increase in formability was seen at higher 'n' value.

Influence of Friction

Friction is an important factor in the majority of forming operations. A low friction coefficient is often desirable for forming process. To study the effect of friction between the die and tube surfaces, a higher friction coefficient leads to a less expansion and huge thickness variation. In other words, we can say that decreasing the friction which reflects in an increase in the formability of tubes.

Figure 8: Influence of Bulge Height and Pressure

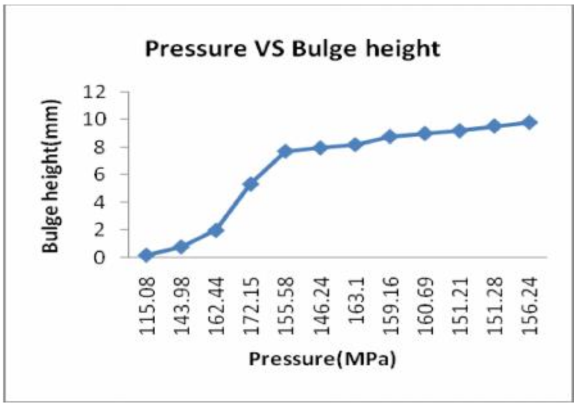


Figure 9: Bulge Height, Axial Movement w.r.t Time

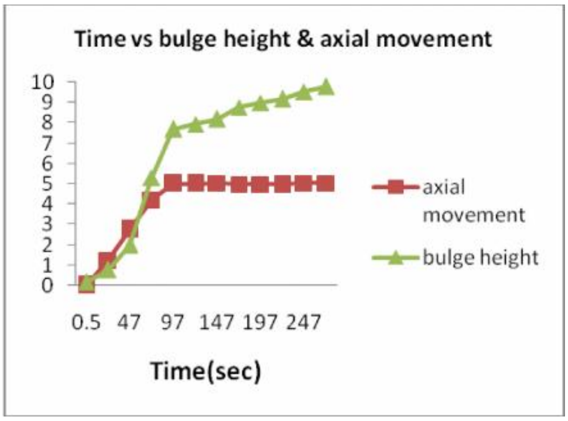


Figure 10: Axial Movement Illustrated with Pressure

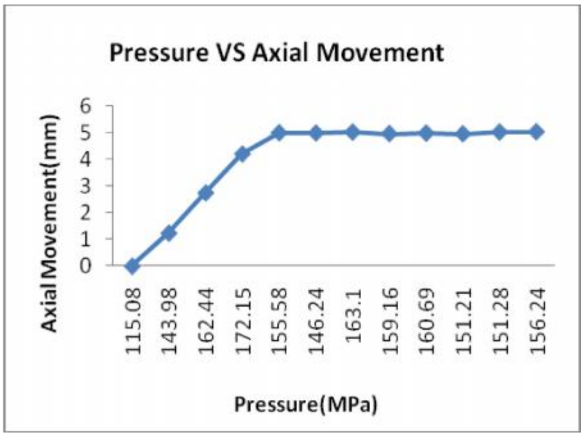
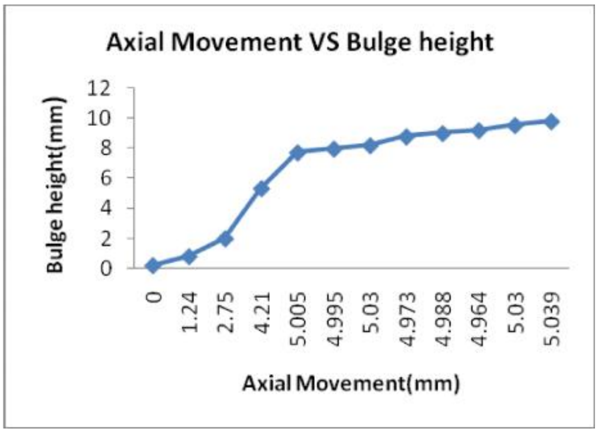


Figure 11: Variation of Bulge Height w.r.t Axial Movement



The above graph it is clear that by gradually increasing pressurethe bulge height goes on increasing upto 9.79 mm, the axial feeding of tubular material which reduces the friction between tube and die, also reduces the intake pressure and pushes the material in the bulging area of the tube.

CONCLUSION

As per the above experiment, experimental and theoretical analysis results and relevant discussions, the below conclusions are obtained: Strain hardening coefficient has the high influence on formability of the tube, so that for forming of materials with higher value of *n*, Lower internal pressure is needed, but change in thickness in these materials is higher than others with lower of *n*, if the friction between die walls and tube increase, it leads in renitent force on the contact surface of the tubular material, so maximum outer diameter decreases and thickness variation increases. As shown in this study, if tight tolerances are required on final hydroformed tube, spring back should be controlled in the process. With higher friction higher initial thickness, lower dieradius and lower yielding stress, tight tolerances can be obtained. Correlation could be achieved between experimental and numerical results. The oretical analysis showed that thin walled cylinder equations were suitable to solve tube hydroforming process. Lower internal pressure was needed to form if $b = -0.5$, there is a better correlation between experimental and analytical results.

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