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FEA Simulation analysis of tube hydroforming process using DEFORM-3D

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Abstract

Tube hydro-forming (THF) one of the attractive forming process for the production of hollow tubes. number of applications of THF are known in the automotive and aerospace industry where more intricate geometries formed from tubes and extrusions. They are characterized by the use of tubes, thus allowing an extended different variety of shapes. Now a day, the automotive industry is showing interest in THF. The benefits of THF can, for instance, be combined with the high strength of extra high strength steels, which are usually less formable, to produce structural automotive components which exhibit lower weight and improved service performance. Design and production of tubular components require knowledge about tube material behaviour and tribological effects during hydro-forming and how the hydro-forming operation itself should be controlled.

The THF 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 behaviour of the process will be done in the simulation study. The simulation model will be prepared and analyzed by FEM tool DEFORM-3D. The main object of the proposed study is to examine the influence of various factors like friction between the dies and tube blank, axial plunger feeding and internal pressure on bulge height and thickness variations by using DEFORM-3D solver.

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1. Introduction

THF is a one of unconventional forming process in Automotive and aerospace industry to produce hallow shapes with complex geometries by using axial force and internal pressure. To manufacture any tubular products by tube hydroforming , a tube is placed in a suitable die, to conform the shape of the die cavity the pressure may be applied axially by using the cylinder arrangement. This hydroforming process enables the significant reductions in Product cost, tool cost and material wastage when compared with the conventional process.

This process has the advantages over the conventional manufacturing such as (1) Reduced weight, (2) Uniform thickness of wall (3) reduction in tool cost (4) more structural strength and stiffness (5) reduced number of secondary operations (6) improved dimensional accuracy (7) less scrap rate

The process steps of tube hydroforming are shown in Figure 1. A tube blank is inserted in between two half dies, the shape of the die cavity corresponds to the external shape of the produced part. These two half dies separated in longitudinal direction, dies are closed by hydraulic load, and the two ends of the tube are sealed by axial punches. The minimum loads required to sealing of the tube ends is at least less than equal to the force resulted from the product of internal area of the tube and internal pressure. But if the forming process needs, the axial load may be increased to highest possible value. During the process the pressure may be increased till the tube comes in contact with the inner surface of the Die Cavity. In comparison with the other theoretical methods, the FEM has more advantages in solving general problems with complex shapes of the formed parts. Because of the criticality involved in T- shaped bends, it is considered for this study, to analyse the forming behaviour by using the explicit solver of DEFORM-3D.

Nomenclature

d_0	Initial diameter of the tube
D_0	Outer diameter of the tube
D_i	Internal diameter of the tube
t_0	Initial thickness of tube
P_i	Internal pressure

2. Working principle:

Fig. 1 will give good idea about the principle for THF. A tube is inserted in die cavity, where shape and dimension of the die cavity corresponds to the external shape of the produced part.

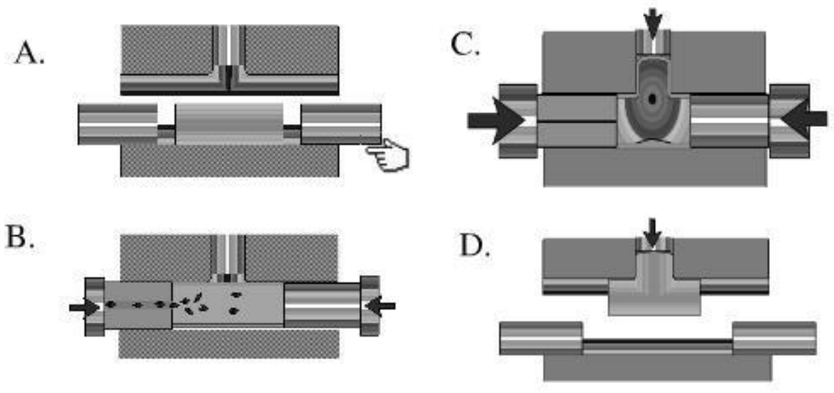

Fig. (1). Tube hydroforming process steps

There are two stages in tube hydro-forming, One is free forming; this stage ends when tool contact is made with the tube while it is expanding during the process and second stage named calibration starts as soon as tool making contact with the tool. In the calibration stage, the tube is forced to conform to the inner contour of the tool by an internal pressure. No additional material is fed into the expansion zone by the axial cylinders.

It is Wrinkles are formed during free forming at the intake regions of the expansion zone, if the pure-shear path is selected shown in Fig. 3. These wrinkles are straightened out during calibration.

As shown in Fig. 3, during free forming, in pure shear, great amount of material is forced into the forming zone. More material in the expansion zone at the start of calibration process, thinning of wall may become less. To control the wall thinning, the loading path during free forming lies between the uniaxial tension path and the pure-shear path (Fig. 3). The main objective of process design in tube hydroforming is to find out the loading path; thereby the wall thinning is controlled without any risk of wrinkling or fracture.

3. Finite element method for THF

Finite element analysis is being used to simulate hydroforming process which enables to study various process parameters. FEA packages, such as LS-DYNA, PAMSTAMP, ABAQUS, DEFORM, etc. are successfully used for THF. The simulation process indicates necessary modifications in tool design for THF. Aiming at reducing the time for THF process the necessary codes and techniques are being developed. The simulation technique iterates the appropriate inputs of internal pressure and axial feeds, which assures the fracture and wrinkle free parts. FEA correlating with experimental validation helped to understand the process. As the experimental validation of the process is expensive, the finite element simulation helps to derive the process parameters, even for the geometrically complex parts during product design and development. T-branch components are considered for this paper, the related loading paths and subsequent processes are simulated.

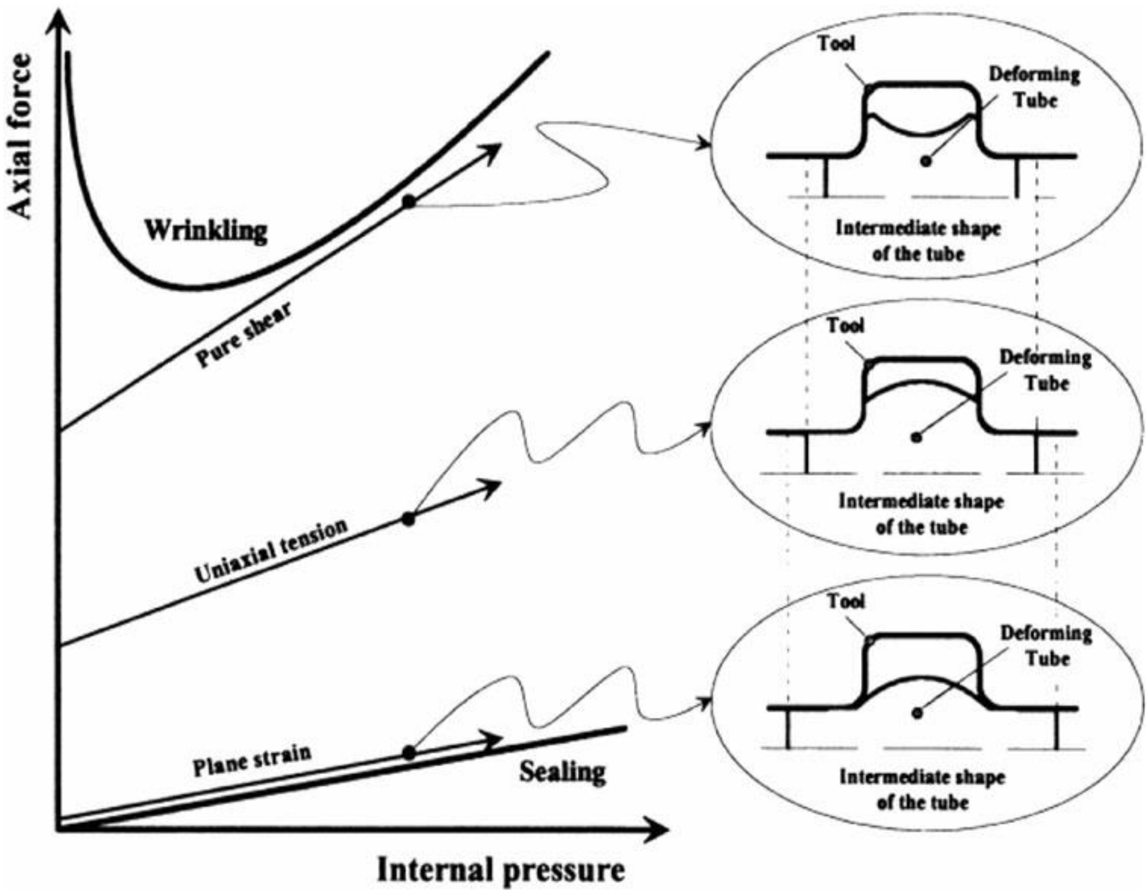

Fig. 2. loading path in THF

In order to carry out the THF simulation, the metal forming system for the selected geometry of the product is simulated as a first step i.e. need to design, draft and develop the computer models of the deformation system and the metal forming process as well. The format of the developed model must be supported by the solver. The deformation system which includes the physical, mathematical and numerical model must be simulated by using the related models. The physical model resembles the real engineering problem which satisfies the theories of physics. The mathematical model satisfies the related mathematical equations and the sequential order of the FEM analysis. The element types, mesh density and process parameters described by the numerical model. The process parameters considered along with tolerances, error bounds, iteration specifications and convergence criteria. These models along with the relevant parameters are uploaded to the solver as input. There are four steps in finite element based computer aided engineering simulation process i.e. Pre-Processing, Simulation and analysis, Post-Processing and Results & Analysis. After completion of the simulation run, the calculated results need to be evaluated and analyzed. If the results are not satisfactory, modify the metal forming system by varying the parameters such as design of Part, tooling, Process and selection of material and perform the next iteration. These iterations are performed till the specifications matches with the design requirements.

3.1. Solid Modeling:

The Solid Models of (a) Specimen, (b) half die, (c) axial plunges and (d) counter plunger are built with dimensions are given below in table using Auto CAD, and models are converted into .stl file as the format should be support by the solver.

The tubular specimen is modeled as shown in the Fig.(3) and the dimension of the tube is given in Table. 1. The die, axial plunger and Counter plunger are shown in Fig. 6. Two halves of the T- shaped Dies are modeled with the dimensions as mentioned in table 2.

Table 1. Dimension of the tube

Item	Dimensions (mm)
L	120 ± 0.5
D_i	21.4 ± 0.1
D_0	24 ±0.1
t_0	1.30 ± 0.05

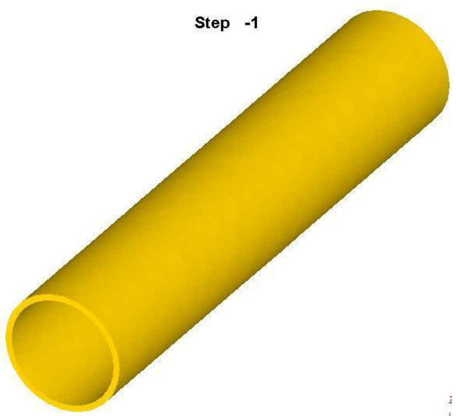

Fig. 3. Solid model of tube blank

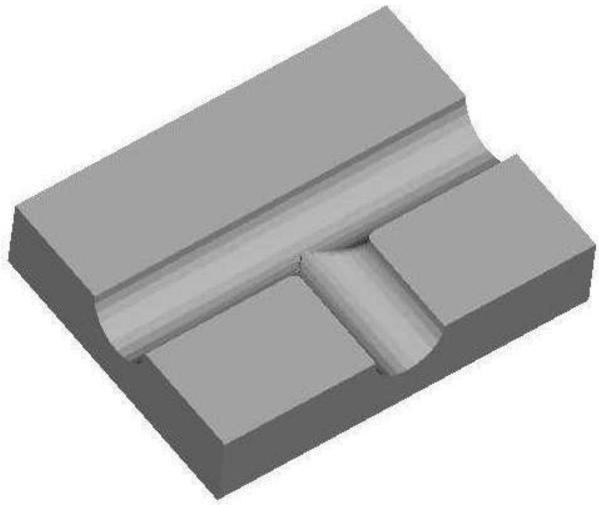

Fig. 4 Solid model of half die

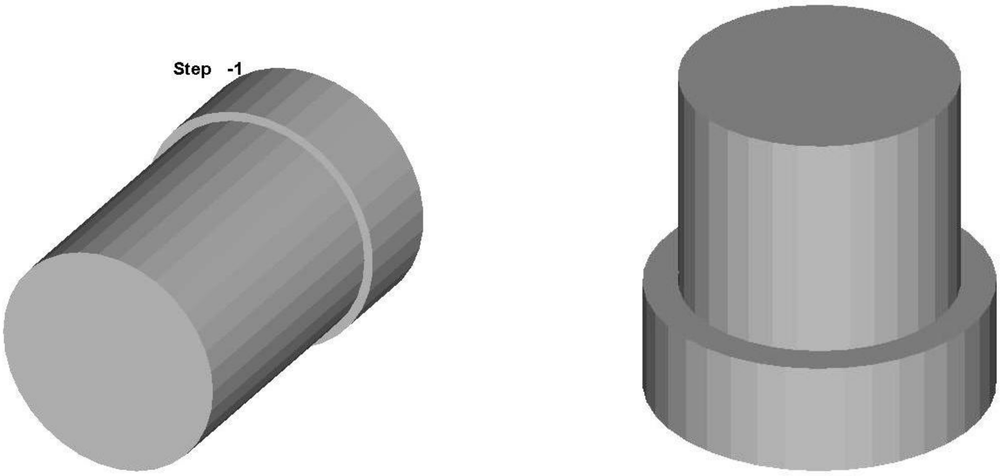

Fig. 5 (a) the axial plunger; (b) counter plunger

Table 2. Dimension of the die

Item	Dimensions (mm)
Length of the die (in tube axis)	120
Width	100
Corner radius	3
Tube cavity radius	12
Counter radius	12

The solid model of the die is shown in fig. 5.various dimension of the die are listed in below table. 2. The radius of the Axial and Counter die are equal to the tube cavity radius. The solid models of Axial and counter dies are shown in Figs. (a) and (b) respectively.

Fig.6. will give an idea of THF process and arrangement of all components together to perform the tube hydroforming process.

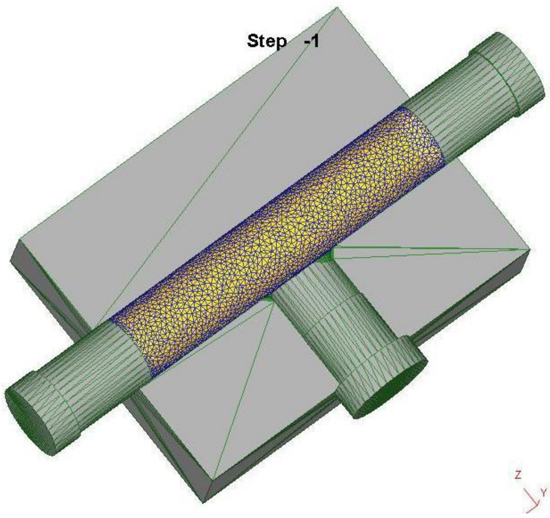

Fig. 6. Tube hydrofming – setup of dies and tube

Table 3. Properties of Inconel-718

Item	-
Density (g/cm³)	8.2
Melting point (° C)	1260-1340
Hardness (HB)	≤363
Tensile strength (MPa)	965
% of Elongation	30
Yield strength (MPa)	550

DEFORM3D 6.2 has been used to carry out the CAE simulation and analysis. The designed standard steps are followed and generated results are saved to a specific location. The work material considered is Inconel-718 as it has number of applications. The properties of the tube material are given in the table.3. Tool steel dies are considered for solid modeling and carried out the simulation study. The rigid die and rigid plunger are considered for the modeling. The steel is considered for die and plunger as well. The deformed tube is meshed with 20,986 tetrahedral elements.

The T-shaped dies are modeled; a tube with 20,986 tetrahedral mapped meshed elements is selected and inserted in between two dies. At the end of the tube two axial plungers are arrange to provide the axial load on the two ends of the tube to feed the material into the forming zone. The interfaces between the tube and dies are modeled with interference positioning option with an elastic coulomb friction law, with a coefficient of friction as 0.5 between the tube and upper, lower die. Contact boundary conditions of dies and plungers are also specified auto automatically.

Simulations have been conducted with different boundary condition, the initial boundary condition are calculated by using theatrical equations to study and analyze the effects of process parameters such as contact friction, internal pressure and axial loading on the process behaviour and thickness variation.

Internal pressure at yielding is calculated by

$$(P_i)_y = \sigma_y \frac{2t_0}{(D_0 - t_0)}$$

Maximum internal pressure can be calculated by

$$(P_i)_b = \sigma_u \frac{4t_0}{(D_0 - t_0)}$$

To study the effect of contact friction on maximum branch height and thickness variation of the tube, the friction is varied from 0.1 to 0.25 and internal pressure and axial load are kept constant. Similarly the effects of pressure and axial movement on the tube branch height and thickness variation could be studied by varying the pressure from 20 to 290 MPa and axial movement varied from 0.5 to 3.0 mm/s respectively.

4. Results and discussions

After providing all boundary condition, the simulator have been completed various simulation steps by DEFORM-3D explicit solver. The effect of various parameters like friction, internal pressure and axial load on the branch height has studied by the post processor of DEFORM-3D. Fig. 7 show the tube after deform .

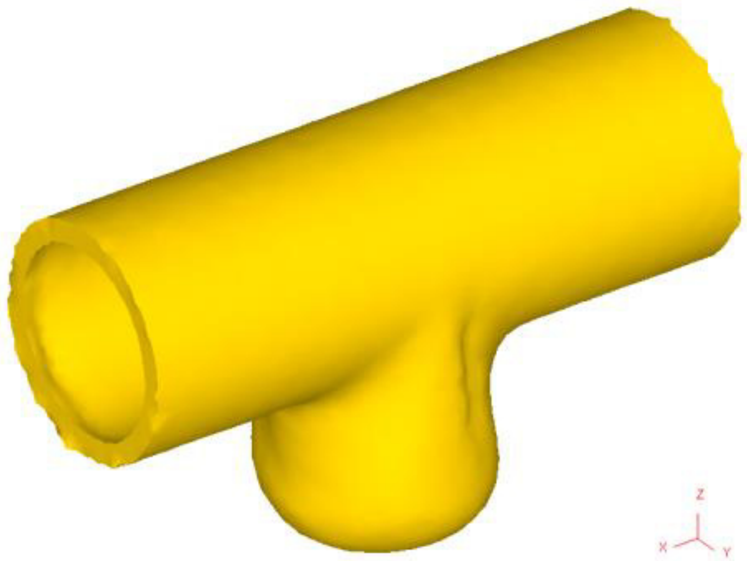

Fig. 7. Tube- after deform

4.1. Branch Height

Simulation have been conducted with different condition (different process parameters) to study the effect of various parameter on bulge height and thickness at maximum bulge point.

4.1.1 Effect of friction on bulge height:

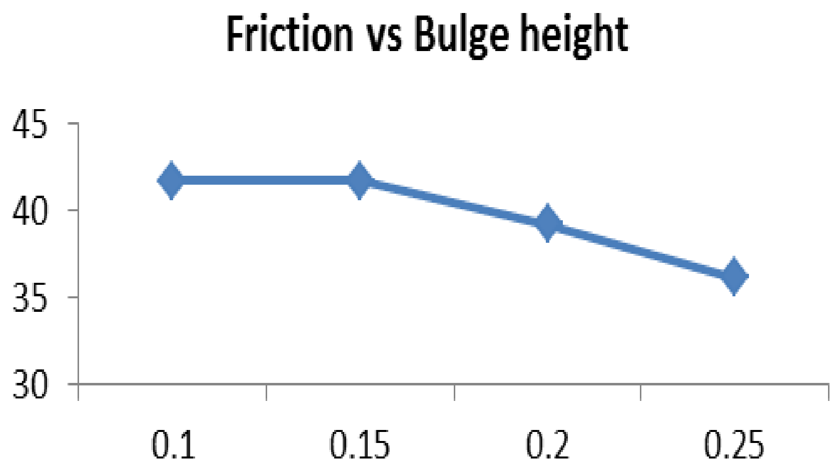

Fig. 8. Effect of friction on bulge height

It observed that friction affects the bulge height from the above figure fig. 8. While increasing the friction co-efficient it restricts the maximum bulge height. In present study, it is verified with different friction and observe that decrement in the bulge height because of the material is not feed properly in to the forming zone.

4.1.2. Effect of axial movement on bulge height:

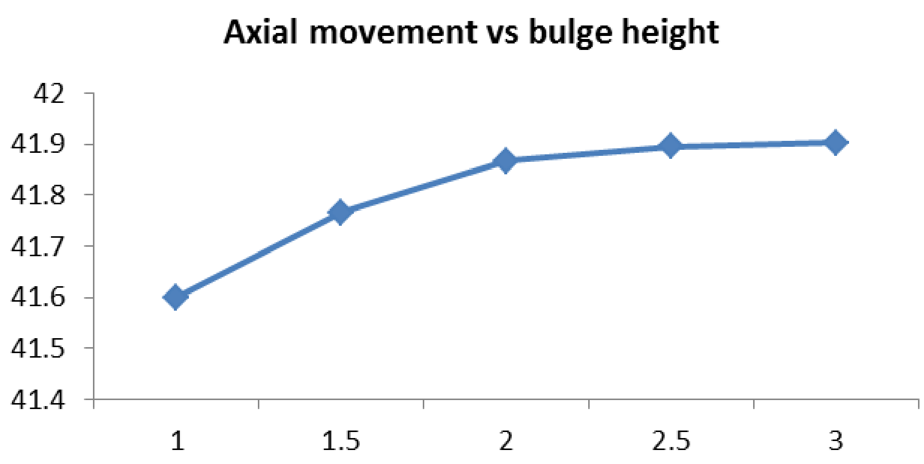

Fig. 9. Effect of axial movement on bulge height

While increasing the axial movement, there are more loads on the ends of the tube, because of this reason there is more material feed into the forming zone. Bulge height is increased while increasing the axial movement because sufficient material fed into the forming zone.

4.1.3. Effect of pressure on bulge height:

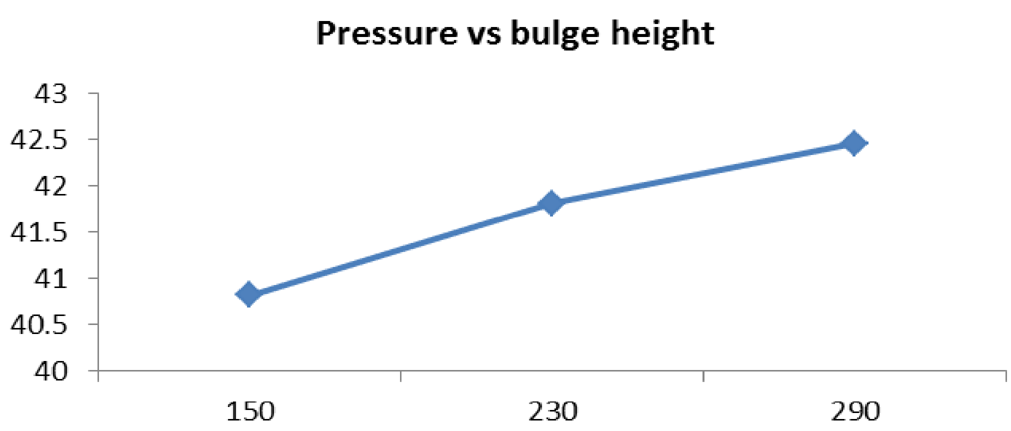

Fig. 10. Effect of internal pressure on bulge height

Internal pressure is one of the important parameter to achieve maximum bulge. Bulge height increases while increasing internal pressure. If bulge pressure exceeds the limit, tube failure like bursting make taken place. To achieve the maximum bulge height requires the maximum internal pressure.

4.2. Thickness variation:

The main advantage of tube hydroforming process is, it is possible to achieve uniform thickness of the tube after deform to particular shape by controlling the loading path (controlling the axial load and internal pressure). Present study is given good clarification how the thickness may vary with the various input parameters.

4.2.1 Effect of friction on thickness:

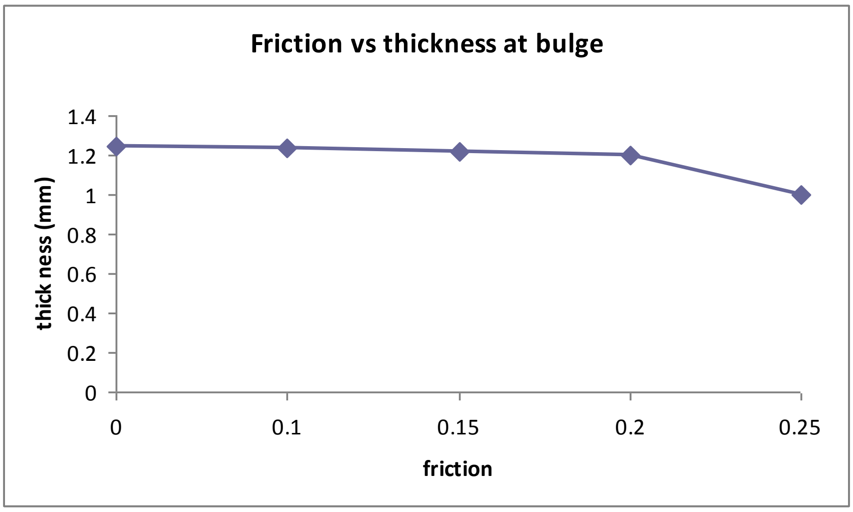

Fig. 11. Effect of friction on thickness

Fig. 11. Shows how the friction effects the thickness of the tube at maximum bulge point. By increasing the friction, the thickness of the tube at bulge point decreasing. This is because of sufficient material is not supplied to the forming zone. Friction decreases the flow of material to the forming zone.

4.2.2. Effect of axial movement on thickness:

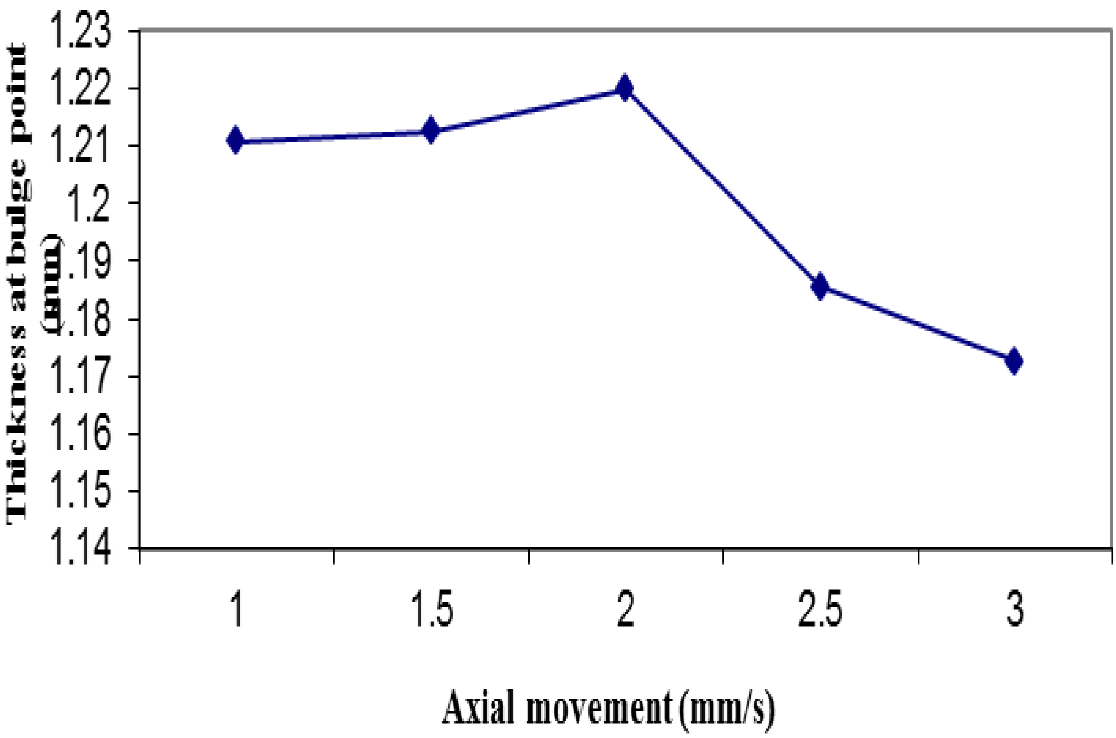

Fig. 12. Effect of axial movement on thickness

Axial movement influences the thickness of the tube. Here tube thickness increases with the increment of the axial load (axial movement). But axial movement after 2mm/sec, it is identified that there is a fold at the corner of the tube as shown in Fig. 13.

Fig. 13 folding at corners

The fold causes interruption of the material flow to the maximum bulge point; it results thinning of the tube at maximum bulge point. Until unless forming of the fold, the axial movement and the thickness of tube at maximum bulge point are proportional.

4.2.3. Effect of pressure on thickness:

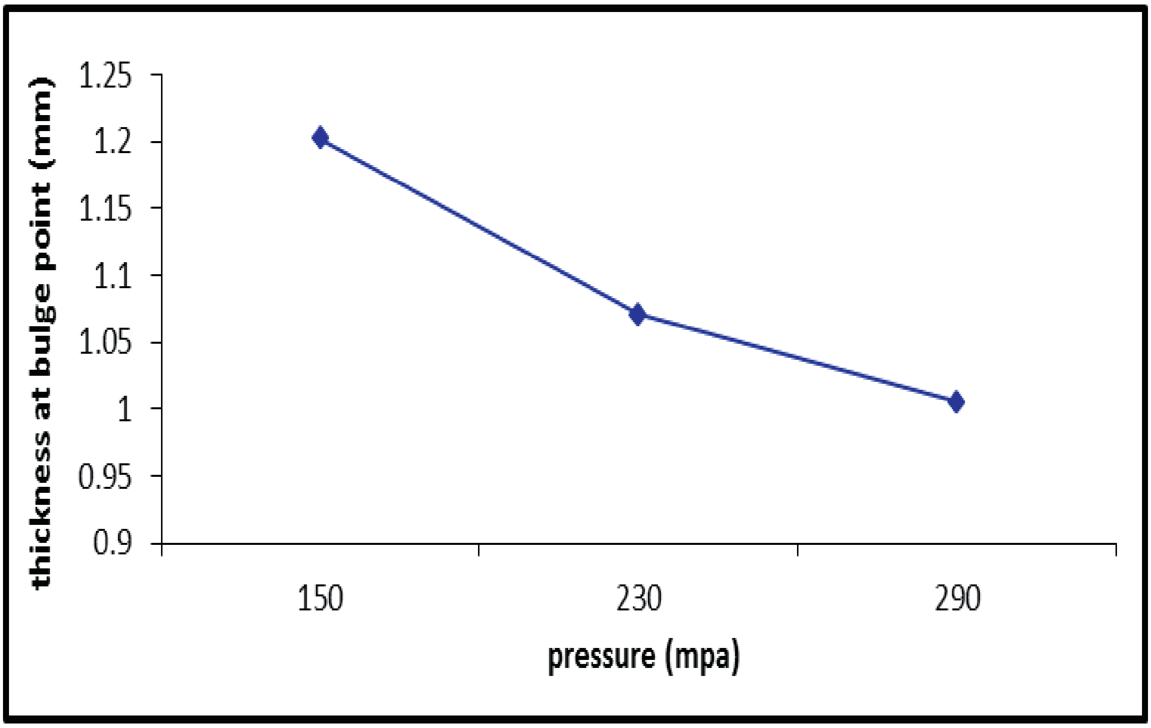

Fig.14. Effect of internal pressure on thickness

Internal pressure in the process of tube hydroforming is the parameter causes to expand the tube. Increasing internal pressure yields the thinning of the tube. In Fig.14, Pressure is observed that thinning of the tube with internal pressure increment.

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