ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering
ISSN: 1584 - 2665

THE FEM SIMULATION OF TUBE HYDROFORMING (THF) OF THE SUPER ALLOY

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ABSTRACT:
Tube hydro-forming process consists of a combined loading of compression forces as well as an internal pressure in order to obtain tubular components with different cross-sections. The process can be divided into two stages: free forming and calibration. The part of the hydro-forming operation, in which the tube expands without tool contact, is called free forming. Calibration starts as soon as tool contact is established. Tube hydro-forming offers many advantages in terms of better structural integrity of the product, production cost reduction, material saving, reduction in the number of joining processes and product reliability improvement. The failures encountered in tube hydro-forming are: buckling, Wrinkling, Fracture (bursting). The axial forces acting on the tube ends must exceed a certain level to prevent leakage. This limit is also known as sealing. The deformation during hydro-forming comprises elastic and a plastic portion. The limit at which yielding occurs is, therefore, of great importance. Once these limits (wrinkling, fracture, yielding and sealing) are determined, the working range can be established. This working range is dependent upon both tube material and tool parameters.
The objective of the present work is to explain in detail the factors influencing the wall thickness distribution of the hydro-formed tube by means of FEM simulation and experimental work. The process model involves simple hydro-forming of a T-shaped tube from a circular tube by internal pressure with additional compressive load applying simultaneously. As the factors, coefficient of friction, n-value and anisotropic parameter r-value are considered in FEM simulation. Experiment using an Inconel625 tube (ASTM / ASME SB 443 UNS 6625), is carried out to verify the validity of simulation results.
KEYWORDS:
Tube hydro-forming, T-shape tube, Wall thickness, FEM simulation

1. INTRODUCTION

The new process of tube hydro-forming (THF) has gradually come into use over the last half decade for manufacturing aircraft and automobile components. Using the THF process, manufacturers are able to produce parts of complex shape which are lighter and have fewer welds than those using alternative metal forming techniques. Advantages of hydro-forming include reduced tooling cost, reduced finishing cost on formed parts, excellent material utilization, fewer operations and improved part quality. There have been numerous studies on the tube hydro-forming process. Fuchizawa S [1] and Manabe K et al [2] in their research work has found the influences of material properties, strain hardening exponent and plastic anisotropy and additional compressive stress on free bulge forming. The forming pressure required to produce a desired part using the tube-hydro-forming process was investigated by Fuh-Kuo Chen et al [3]. The relationship between hydraulic pressure, outer corner radius of the deformed tube, tube thickness and tube yield stress was established based on a proposed theoretical model. Kawn et al. [4] has done series of simulations on hydraulic expansion, axial feeding and the counterforce of the tubes using the program DEFORM-3D. Zang et al. [5] used finite element method in the field of bulge hydro forming process to investigate the effect of the loading path on the forming result and obtained a reasonable range of the loading path in tube bulge hydro-forming process.

In summary, the research work performed so far account for a quantum of work done in the prediction of loading path using numerical, analytical procedures with the limitation that the theories developed, may be validated in the real time experimentation. Also many of the researches were restricted towards loading path determination; the important aspect of process parameter estimation was not explored in detail. In this work, the FEM simulation is used to investigate the hydroforming process of a T-shape tube. A series of FEM simulations on free bulging and axial feeding is carried out using the explicit finite element code HyperForm. The influences of the factors, coefficient of friction, n-value and anisotropic parameter r-value, strength coefficient is examined. Experimental results using nickel based super alloy Inconel625 are found to be in good agreement with FEM simulation results.

2. TUBE HYDROFORMING

The principle of tube hydro-forming is shown in Figure 1. The tube is first filled with a fluid, after which the tool is closed. The tube is then forced to adopt the inner contour of the tool by application of an internal pressure and two axial forces. In some cases, the tube is formed by the increasing internal pressure only. This means that the axial cylinders do not feed more material into the expansion zone. There are also cases in which the axial cylinders push more material into the expansion zone. In these cases, the tube is formed under the simultaneous action of the internal pressure and the axial forces.

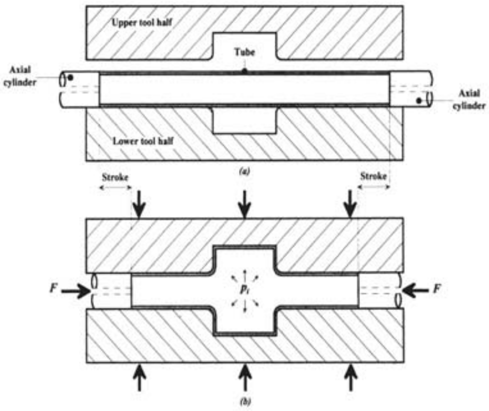

Figure 1. Schematic of the tube hydro-forming

2.1. FEM Simulation

The non-linear explicit FEM commercial code HYPERFORM 9.0 with RADIOSS script as the solver is used for analysis of the hydro-forming process of tubes. Figure 2 shows the CAD model with lower and upper die with tubular blank which is used for FEM simulation. The meshing parameters are given in Table 1 and Table 2 indicates the process parameters of the T-shape tube hydroforming. For the tubular blank, isotropic and anisotropic elasto-plastic materials obeying power hardening law are used as material models:

$$\sigma_t = k\,\varepsilon^{\,n} \qquad (1)$$

where σ_t is the true stress, k is the strength co efficient, ε is the true strain and n is the strain hardening co efficient. Figure 3 shows the FEM model.

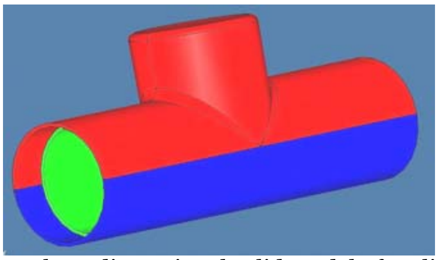
Figure 2. Three dimensional solid model of tooling and tubular blank

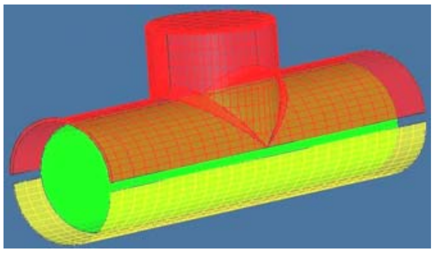
Figure 3. FEM model

Table 1. Meshing parameters

Category	Tube	Upper die	Lower die
Element	Shell	Rigid	Rigid
Mesh shape	Quad	Mixed	Mixed
Adaptability	Adaptive mesh		

Table 2. Process conditions used in fem simulation

Parameters			
Strain hardening coefficient (n-value)	0.1	0.2	0.3
Plastic anisotropy (R-value)	0.5	1	3
Friction coefficient (μ-value)	0.06	0.1	0.15

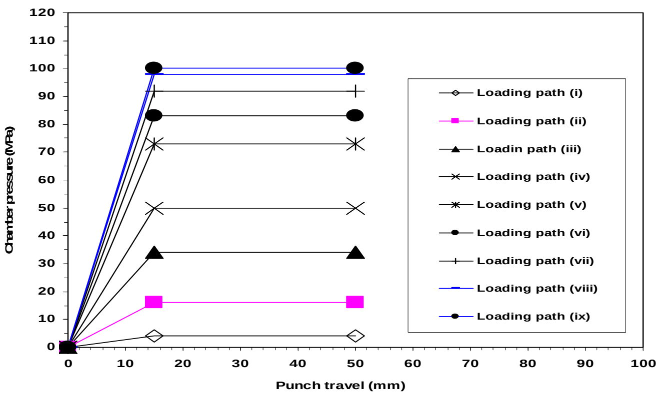

Figure 4. Various loading paths used in fem simulation

The loading paths used in the FEM simulation of the tube hydro-forming are shown in Figure 4. The maximum internal pressure of loading (i) to (xi) are 4, 16, 34, 50, 73, 83, 92, 98, 100 MPa respectively.

3. RESULTS OF FEM SIMULATION

The influences of the process conditions on the formed tube are discussed as follows:

3.1 Plastic anisotropy (R-value)

The effect of plastic anisotropy value is given in Figure 5 and Figure 6. The higher values of R marked with better metal flow and hence more amount of strain both in the linear and the radial direction. Also when R value increases, more bulging is the result. The deformed shape obtained for various values if plastic anisotropy is given in Figure 7. The higher value of plastic anisotropy results in good deformation.

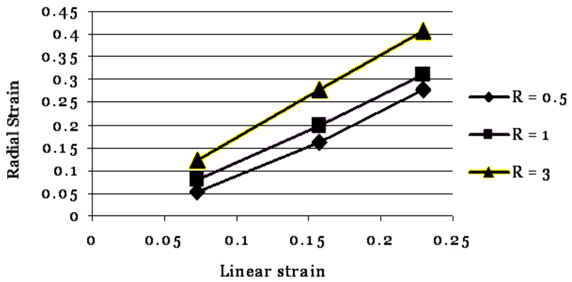

Figure 5. Effect of r-value on linear and radial strain

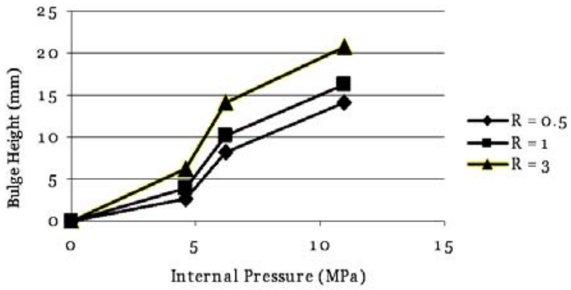

Figure 6. Effect of r-value on internal pressure and bulge height

3.2 Strain hardening coefficient (n-value)

The formability of a tubular material is closely related to n-value. Figure 8 shows the effect of n value on radial strain–axial strain relation. Even when tubular blanks with various n values were used in the operation, no significant differences in the linear strain for the same hydro-forming profile observed. But for higher n values, the strains obtained are larger. The influence of n values on the deformed shape is given in Figure 9.

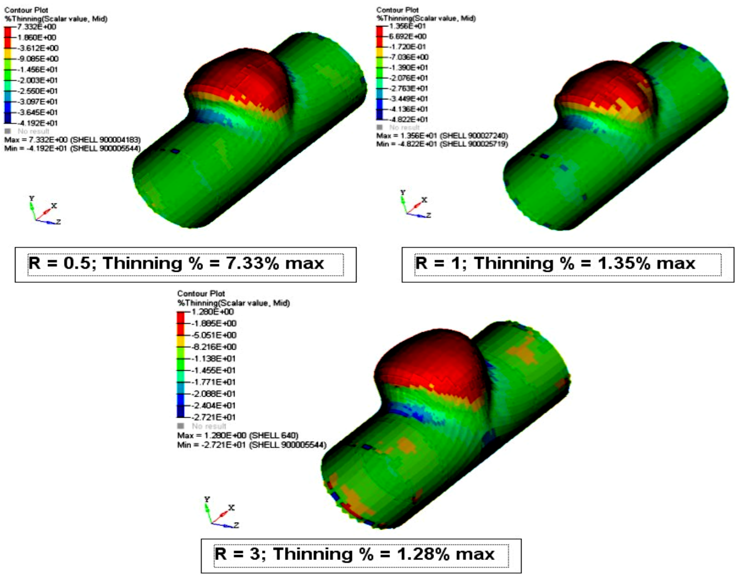

Figure 7. Effect of r-value on percentage thinning

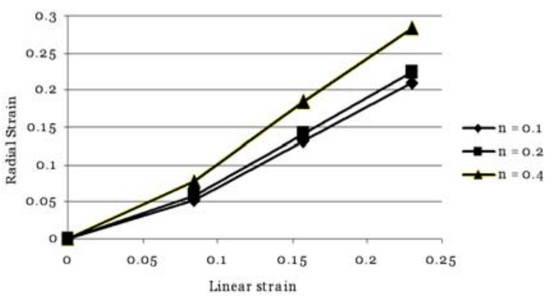

Figure 8. Effect of n-value on linear and radial strain

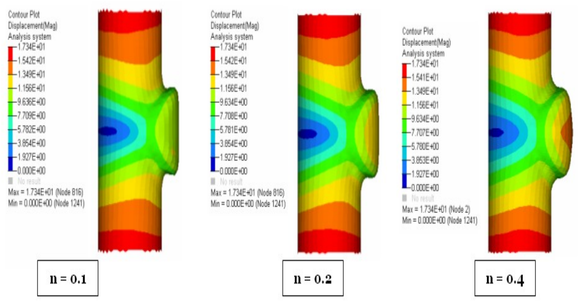

Figure 9. Effect of n-value on deformed shape

3.3 Friction coefficient (μ-value)

The influence of μ-value on the bulge height, linear and radial strain was found to be negligible for the given set of conditions in FEM simulation (Figure 10 and Figure 11). But this may not hold true in the actual experimentation.

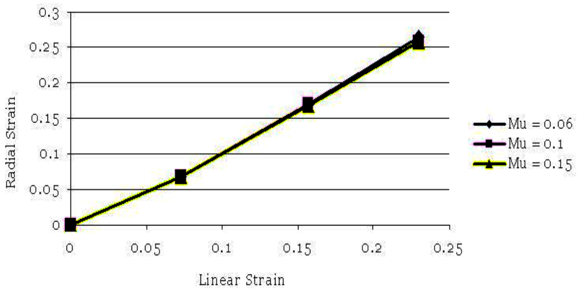

Figure 10. Effect of μ-value on linear and radial strain

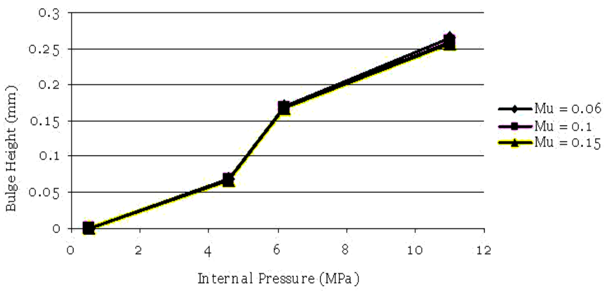

Figure 11. Effect of μ-value on bulge height

4. COMPARISON: FEM VS EXPERIMENTAL RESULTS

In order to confirm the validity of the FEM simulation results experiments involving tube hydro-forming of Inconel625, a nickel based super alloy, was performed. The material used is had an outer diameter of 50.8 mm and a thickness of 1 mm. In order to match with FEM simulation load profiles, internal pressure and axial feed values are applied manually. Figure 12 shows the influence of μ-value on deformed shapes. From the results, it is concluded that better lubrication results in large axial compression and the experimental results are in good agreement with FEM simulation. Figure 13 shows the comparison of thinning ratio Vs traverse distance from the tube centre between experimental and FEM results. The results confirm the fact that the thinning ratio tend to decrease up to a certain point from the bulge region and then starts to increase as the tube rims are approached.

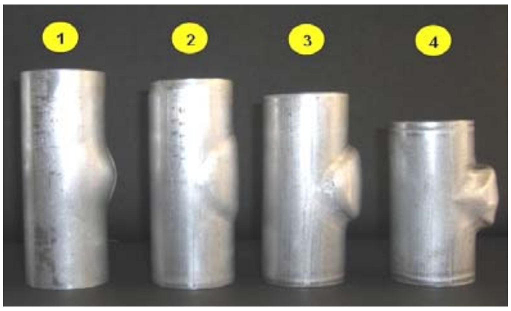

Figure 12. Effect of μ-value on deformed shape

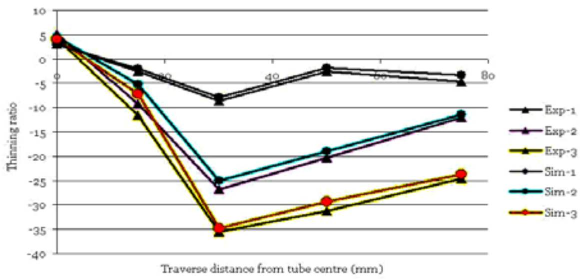

Figure 13. Comparison of thinning ratio vs traverse distance from the tube

5. CONCLUSIONS

The following conclusions are made from FEM simulation and verified by experimental work:

- In this work, a FEM procedure using commercial finite element code is developed to identify the optimum loading conditions for accomplishing the qualified hydro-formed parts. The same can be applicable for industrial T-tube production
- Tubular materials with high strain hardening coefficient, Low coefficient friction and plastic anisotropy value will results in uniform wall thickness of hydro-formed parts
- The thinning ratio tend to decrease up to a certain point from the bulge region and then starts to increase as the tube rims are approached
- Regarding the material factors, plastic anisotropy value plays an important role in tube hydro-forming of super alloy

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