

EFFECT OF GEOMETRIC PARAMETERS ON FORMABILITY AND STRAIN PATH DURING TUBE HYDRFORMING PROCESS

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Abstract. Forming limit diagram (FLD) is an important tool to measure the material's formability for metal forming processes. In order to successfully manufacture a component through tube hydroforming process it is very important to know the effect of material properties, process and geometrical parameters on the outcome of finished product. This can be obtained by running a finite element code which not only saves time and money but also gives a result with considerable accuracy. Therefore, in this paper the mutual effect of diameter as well as thickness has been studied. Firstly the finite element based prediction is carried out to assess the formability of seamless and welded tubes with varying thickness. Later on, effect of varying diameter and thickness on strain path is predicted using statistical based regression analysis. Finally, the mutual effect of varying material property alongwith varying thickness and diameter on constraint factor is studied.

Keywords: *Tube hydroforming; Strain path, Forming limit diagram, Finite element method*

1. Introduction

The increase emphasis on fuel consumption and reducing the carbon emission leads to an industrial demand for manufacturing lightweight component, tube hydroforming has become a widely employed manufacturing technique in automotive and aerospace sector [1]. Successfully manufacturing the component using tube hydroforming process requires optimised loading path and precise knowledge of the impact of material properties and tube geometry on any process [2]. Hence, the finite element method (FEM) has been widely used to predict the formability of tube hydroforming process and to optimise the process parameters [3]. The most widely used tool to assess the formability of a forming process is termed as "forming limit diagram" (FLD) and its concept is developed by Keeler and Beckofen [4]. Imaninejad et al.[5] has proposed the experimental methodology to generate strain path on either side of FLD by inducing different stress states as well as changing the geometrical condition to obtain FLD curve. Several researchers have since assessed the formability for different material and in one of our earlier work [6] FLD of the ERW steel tubes were drawn using the same methodology. Kang et al.[7] have studied the effect of tube diameter on hydroformability of bumper rail section and optimise the loading path to obtain the objective of reduce thinning rate. Liu et al. [8] have predicted the crack location of tailor welded tube with different thickness ratio as well as weld position.

This work deals with the prediction of the effect of varying thickness as well as diameter on the formability and strain path during tube hydroforming process. The comparisons were made with welded as well as seamless tubes to further study the impact of weld on forming characteristics.

2. Simulation Methodology

The tube hydroforming simulations were carried out on commercially available finite element based software PAM-STAMP-2G[®]. The simulation methodology used in this work is discussed in detail in the work done by Nikhare et al.[9]. In order to obtain biaxial strains, the elliptical bulge methodology proposed by Li et al.[10] is used. To predict the onset of necking, a thickness gradient criterion is used [11]. In the simulation, Hill's-1948 yield theory is used and flow stress characteristic is defined by Hollomon's law. All the simulations were carried



out with shell element having 1mm mesh size and same loading path. Weld size is modeled as 7.5mm as obtained in previous work [6]. The FEM model for tube hydroforming simulation is shown in figure 1.

3. Result and Discussion

3.1 Effect of thickness on FLD

The forming limit diagram for tubes of diameter =57.15 mm is plotted, as shown in figure 2, for seamless as well as welded tubes with varying thickness ($t=0.6\text{mm}$, 1.6mm , 2.6mm) and is based on the methodology discussed above.

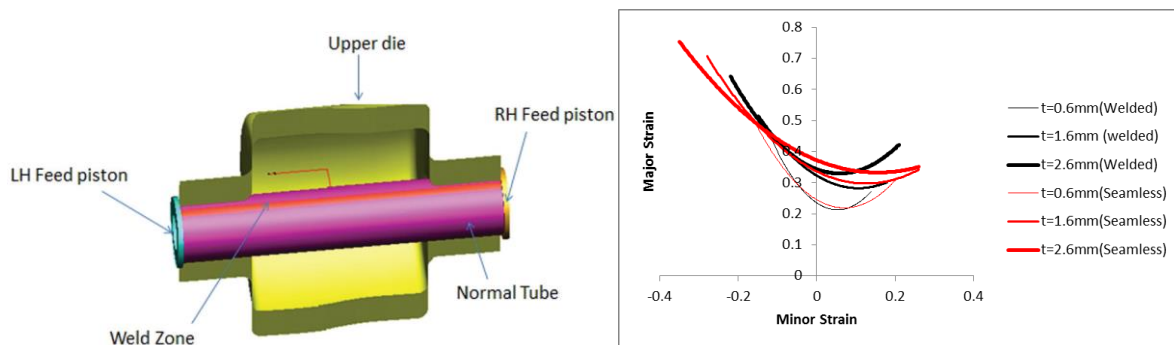


Fig.1 – CAD model for Tube hydroforming simulation

Fig.2 – Forming limit diagram for varying thickness

Table-1 The FLC_o and slope values at varying thickness for welded and seamless tubes

Tube type	Welded Tubes				Seamless Tubes			
Thickness	0.6mm	1.6mm	2.6mm	%change	0.6mm	1.6mm	2.6mm	%change
FLC _o	0.2312	0.2623	0.29	25	0.2424	0.30	0.317	32
FLC _L	-1.71	-1.56	-1.46	15	-1.64	-1.36	-1.11	32
FLC _R	0.24	0.26	0.36	50	0.28	0.18	0.125	55.3

The FLD obtained in figure 1 were linearly fitted by regression analysis to obtain the FLC_o as well as slope of drawing and stretching region and these values were tabulated in table 1. From the above table it can be concluded that weld zone affect the formability in the entire region viz: drawing, plane strain and stretching region. Furthermore with increasing thickness the formability is increase with around 20-30 % in LHS of FLD. It is possible that the RHS of FLD prediction is over predicted because of less no. of data points and hence more simulation is needed to be carried out with varying oval ratio to have more point and better fit to ascertain the accuracy of prediction for biaxial region.

3.2 Effect of varying diameter and thickness on strain path for welded tubes

In order to individually predict the impact of diameter and thickness of tube on strain path, 3 different set of diameter (i.e. 28.42, 42.7, 57.15 mm) were taken with three set of thickness. 9 simulations were carried out with tube being modeled with weld and the loading path is kept same in all the simulation so as to avoid its impact on the strain path. Strain paths were analysed based on strain ratio ($SR = \epsilon_{\text{minor}} / \epsilon_{\text{major}}$) as well as coefficient of determination ' R^2 ' obtained from regression analysis. $R^2=1$ fits a straight line showing no deformation heterogeneity whereas as the heterogeneity in deformation increases R^2 decreases. Thus severe strain localisation

indicates lesser R^2 value. The slope of strain path based on linear fit were obtained and tabulated below in table 2. Lesser the slope (in terms of negative value) more is the extent of drawability obtained for a given strain path.

Table-2 Strain path results for different dia. and thickness

Tube type	Welded Tubes		
Tube dia. and thickness	Strain Ratio= $\epsilon_{\text{minor}}/\epsilon_{\text{major}}$	R^2	Slope
$\phi 28.4 \times 0.6$	-0.17	0.89	-3.66
$\phi 28.4 \times 1.6$	-0.32	0.82	-1.72
$\phi 28.4 \times 2.6$	-0.36	0.78	-1.47
$\Phi 42.7 \times 0.6$	-0.27	0.96	-2.91
$\Phi 42.7 \times 1.6$	-0.34	0.84	-2.06
$\Phi 42.7 \times 2.6$	-0.35	0.80	-1.49
$\Phi 57.15 \times 0.6$	-0.22	0.96	-3.18
$\Phi 57.15 \times 1.6$	-0.29	0.92	-2.91
$\Phi 57.15 \times 2.6$	-0.35	0.82	-2.06

The FLD obtained in figure 1 were linearly fitted by regression analysis to obtain the FLCo as well as slope of drawing and stretching region and these values were tabulated in table 1. From the above table it can be concluded that weld zone affect the formability in the entire region viz: drawing, plane strain and stretching region. Furthermore with increasing thickness the formability is increase with around 20-30 % in LHS of FLD. It is possible that the RHS of FLD prediction is over predicted because of less no. of data points and hence more simulation is needed to be carried out with varying oval ratio to have more point and better fit to ascertain the accuracy of prediction for biaxial region.

3.3 Effect of material properties and thickness on strain distribution for welded tubes

The material properties used for this section is 0.12 and 0.187 for strain hardening exponent of base metal and 0.054 and 0.085 for weld metal. 'R' value for base metal is taken as 1.2 and 2.1 whereas for weld metal 'R' value is taken as 1. The tube diameter and thickness are taken as 28.42, 57.15 mm and 1.6, 2.6 mm respectively. The heterogeneity in thickness strain is termed as strain non-uniformity index (SNI) and the heterogeneity in surface strain distribution is termed as Constraint factor (CF), as shown in figure 3 and eqn.1, the combination of both is used for the purpose of decision making and process control [12]. The CF is defined as follows-

$$CF = \frac{[\epsilon_{2\text{peak}} - \epsilon_{2\text{pole}}]}{[\epsilon_{1\text{peak}} - \epsilon_{1\text{pole}}]} \dots\dots\dots (1)$$

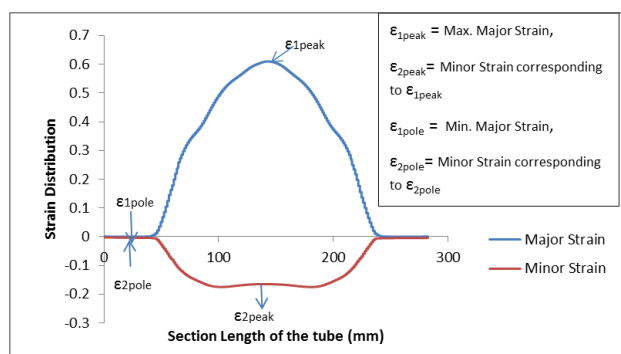


Fig. 3- Concept of Constrain Factor

Table-3 Results of ANOVA for Constraint Factor

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	0.072	4	0.018	11.94	0.0005
A-n	9.2E-003	1	9.2E-03	6.14	0.0307
B-r	0.039	1	0.039	25.71	0.0004
C-D	0.024	1	0.024	15.84	0.0022
D-T	8.1E-005	1	8.1E-05	0.054	0.8207

Predicted R-Squared = 0.6438

Adjusted R-Squared = 0.7447 .

The factors which are accepted after F-testing on the model at the significance level of 5% are revealed to be plastic anisotropy 'r' followed by tube diameter and strain hardening exponent 'n'. Therefore, in order to achieve higher formability in drawing region the plastic strain ratio should be higher resisting severity in thinning.

4. Conclusion

With increase in thickness the formability of the drawing region is increased upto 15-25 % in case of welded tube whereas for seamless tube the formability is increase to 32% in same region. This result can further be strengthened by observing the effect of strain path on increasing thickness which leads to lower negative slope and higher strain ratio indicating improvement in formability. For biaxial region the increase in formability is upto 50% with increasing thickness which is quite high therefore more simulations are needed to carry out with more combination of oval ratio to acquire more data points to ascertain the reliability of the finding above. Deformation heterogeneity is assessed by co-efficient of determination ' R^2 ' and the results shows that for higher diameter the deformation heterogeneity reduces. Finally the mutual impact of n, r, dia. and thickness is studied on CF and it was found that r value has the most significant effect followed by tube diameter.

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