A numerical study of the effect of geometrical factors on bi-layered tube hydroforming

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Abstract:

Tube hydroforming is one type of unconventional metal forming process in which high fluid pressure and axial feed are used to deform a tube blank in the desired shape.

Bi-layered tube hydroforming is suitable to produce bi-layered joints which can be used in special applications such as aerospace, oil production, and nuclear power plants.

In this work a finite element study was performed using ANSYS LS-DYNA to investigate the effect of geometrical factors (Tube length, Initial thickness, and Corner radius) on bi-layered tube hydroforming of X branch. Bulge height, Von mises stresses, and thickness distribution were studied for the hydroformed part. Suggestions were made to increase formability of process by adjusting geometrical factors.

Optimization was performed to get minimum thickness reduction for a specific design.

Keywords:

Tube hydroforming, Bi-layered, ANSYS LS-DYNA, Geometrical factors

1 Introduction

Tube hydroforming is a process of forming closed section; hollow parts with different cross sections by applying an internal hydraulic pressure in conjunction with end axial feed to a straight or preformed tube.

It is a relatively new technology among metal forming processes, which has been developed for a few years and is now being widely used for manufacture of tubular parts of different configurations. The main application of this method was found in automotive, aerospace and household applications industry. In early 1939 Grey et al [1] established a tube hydroforming to manufacture seamless metal T and X branches, he tried to avoid the rupture of the tube by controlling the pressure and the axial force. A number of research works have been reported in the literature in recent years on the hydroforming process. Since 1996 Dohman and Hartel [2] had found that it is essential to have knowledge of the avoidance of failure cases as well as of the behavior of the tube in the tool under the compressive stress and forces that are exerted by the machine. They suggested employing appropriate computation procedures within the framework of a model, applying simplifying assumptions, while the implementation of the process control necessitates numerical control of the process action of axial force and internal pressure. After that Lang , Wang, Kang, Yuan, Zhang, Danchert, and Nielsen [3] had suggested using finite elements method to increase existing knowledge about this process. P.Ray and Mac Donald [4] had used LS-DYNA to analyse X and T branch tube hydroforming process.

Compared with conventional metal forming processes, tube hydroforming has the merits of a reduction in work piece cost, tool cost and product weight. Also, it can improve structural stability and increase strength and stiffness of the formed parts. Furthermore, THF offers many advantages including fine thickness distribution, fewer secondary operation and suitability for complex geometries.

Multi-layer composite tubular joints are suitable for a number of special applications [5]. These joints offer essential advantages for radiator connections compensating spring back forces thus making the installation easier. Industrial applications can be found in the area of compressed air supply lines, ship building and aerospace industries. Multi-layered systems are also suitable for chemical use in special environments. Another important application is The bimetallic CRA-lined pipe [6], which has a liner pipe made of corrosion-resistant-alloy (CRA) and an outer pipe made of low-cost steel, has been utilized in oil production, nuclear power plants and refining industry increasingly.

In this work a finite element study was performed using ANSYS LS-DYNA pre-processor and LS-DYNA solver to investigate the effect of geometrical factors (Tube length, Initial thickness, and Corner radius) on bi-layered tube hydroforming of X branch. Bulge height, Von mises stresses, and thickness distribution were studied for the hydroformed part.

LS-DYNA was used due to its support to the dynamic non-linear problems. Using LS-DYNA we could set up advanced contact and analyze large deformations and instabilities.

Suggestions were made to increase formability of process by adjusting geometrical factors.

2 Finite element study

Bi –layered tube hydroforming was simulated using finite element method; a tube of 60 mm length and 24 mm outer diameter was hydroformed in X branch die. Outer layer was made from Brass with a 1 mm thickness, while the inner one consists of Copper with a 0.9 mm thickness.

2.1 Finite element model

The finite element models were built in four parts: (a) outer tube, (a) inner tube, (c) rigid die and, (d) taper rigid plunger using ANSYS/LS-DYNA pre-processor. By taking advantage of symmetry, 1/8th of the X-branch was modeled. The nodes at the symmetric edges were restrained in the appropriate directions while the nodes attached to tube end were kept free for all degrees of freedom.

The two layers were modeled using thin shell elements with fully integrated advanced formulation with shell thickness change option activated. Although the computation cost for fully integrated element is relatively high, but it avoids warping and hourglassing deformation modes during the course of the FE simulation. Each layer consists of 720 quadrilateral mapped meshed elements.

The interfaces between the two layers, outer layer and die, the both layers and the plunger, were modeled with an advanced automatic surface-to-surface contact algorithm with an elastic coulomb friction law, with a coefficient of friction of 0.57 between the two layers and 0.15 in the rest of contacts, exponential decay coefficient of 0.5, calculated viscous damping friction coefficient of 0.067 and viscous damping coefficient of 20. Another kind of contact parameter was defined with single surface contact entity. This was defined on the two layers in case there is formation of wrinkle due to excessive axial feed, in which case this contact definition will take care of self-surface contact due to wrinkling or buckling.

A power law plasticity model was used for the simulation of the two layers. The material plastic flow properties (engineering stress–strain data) were obtained using a uniaxial tensile test of flatened part of the tubes used for the experiment. For the simulation true stress–strain data were used, which was calculated from the engineering stress–strain data and power law plasticity models were fitted to the true stress–strain curve.

The rigid die and the plunger were not fully modeled, only the surfaces in contact with the layers were modeled with 3D thin shell elements. The material properties used were of EN21 hardened tool steel for both die and plunger. Although the die and the plunger were assumed to be rigid, realistic material properties were defined because these values are used by the LS-DYNA code for calculation of the contact friction and stiffness. The die was constrained for all degrees of freedom and the taper end plunger was constrained for all degrees of freedom except for Z-translation i.e. it was allowed to move along the axial length of the tube.

Internal pressure was applied on the inner surface of inner layer, which press the outer layer to form the bulge. Pressure was applied using the pressure advanced path as it gives the best formability [7] like "Figure 1", while axial feed supposed to be linear with time (constant velocity V=2.33 mm/sec).

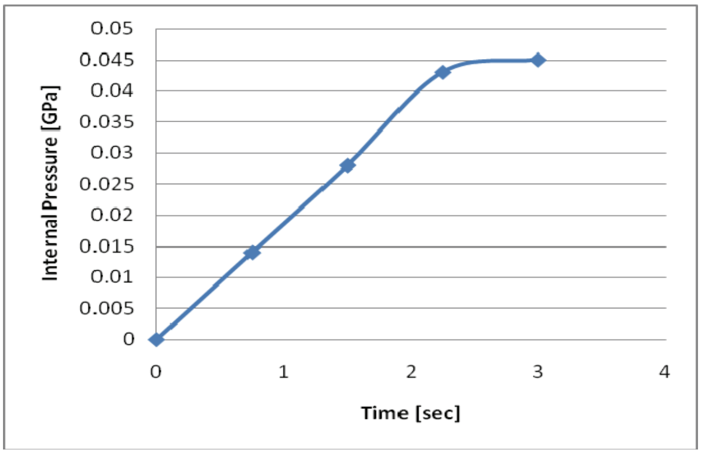

Figure 1: Pressure loading path of the model

Bulge height of the hydroformed part is 5.14 mm, while maximum von mises stresses is 37.24 MPa which is well below the ultimate stresses for both materials, see "Figure 2"

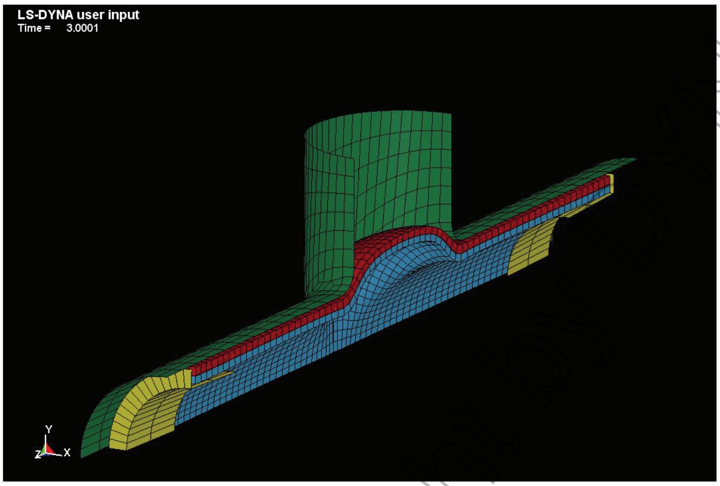

Figure 2: 1/4th of the X-branch tube hydroformed

2.2 Experimental validation of the model

The model has been verified by comparing it with the experiment which has been done by Islam [5], both have the same materials and dimension. Only loading path has changed in the model to fit the experimental one in “Figure 3”

The branch height of the formed X branch in the experiment was 3.5 mm, while the resultant one from the finite element study is 3.52 mm which means that results are so closed and the syudied model is validated.

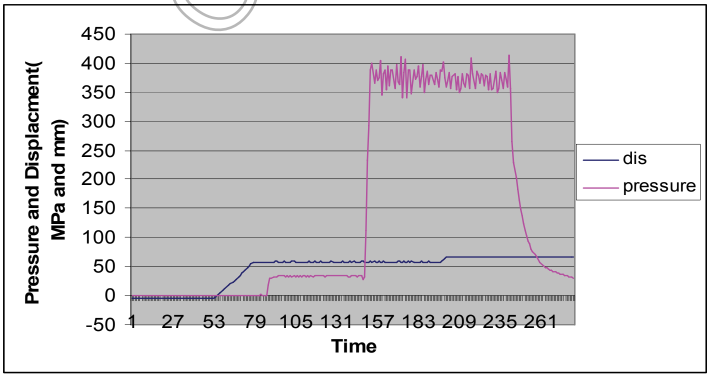

Figure 3: Loading profile on the hydroforming machine [5]

2.3 Study of the effect of geometrical factors

The component geometry as well as its die geometry affect the tube hydroforming formability. In this study the effect of geometrical parameters a.) initial tube length, b.) initial thickness and, c.) die corner radius on the hydroformed part was analysed using finite element model which has been built in (2.1)

2.3.1 Effect of initial tube length

Based on the model studied in (1.1) simulations were conducted with total tube lengths ranging from 80mm to 160mm, and the maximum expanasion, von mises stresses, and thickness reduction were studied. The results show as in“Figure 4“ that hydroforming of a longer tube will result in shorter bulge height and less von mises stresses. This can be explained by considering the effect of friction on the process. Tubes with a longer length have bigger contact surface, and becuase of this they are subjected to bigger friction forces which resist the forming.
Because of the same reason it has been found that thickness reduction is becoming more with longer tubes, but it turnes to decrease around the value: 120 mm because of the small bulges formed after this value.

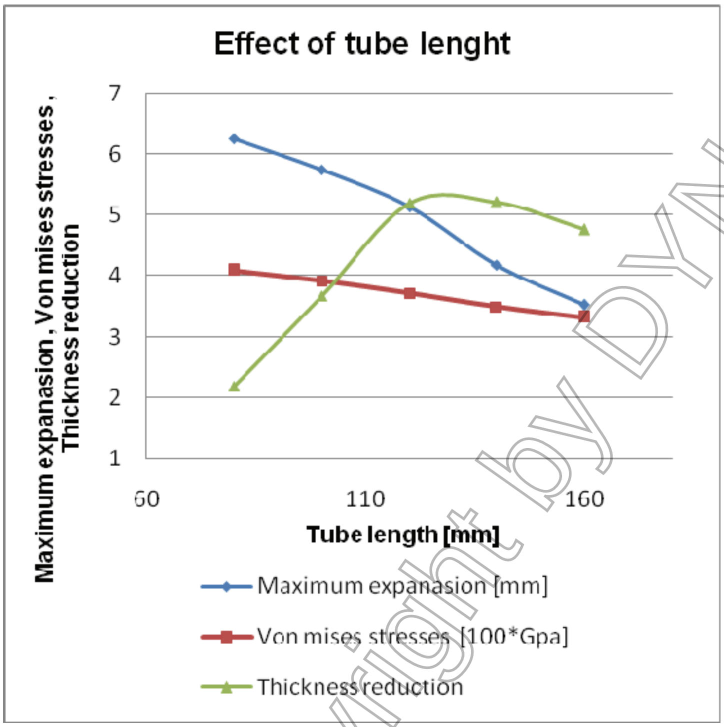

Figure 4: Effect of tube length on hydroformed part

However it is concluded that tube length should be selected judiciously.

2.3.2 Effect of die corner radius

Simulations were conducted using the same model with changing the die radius from 1 mm to 5 mm, and the effect of this change on the maximum expanasion, effective stresses, and thickness reduction of the hydroformed part was studied.
From the results shown in “Figure 5“ we can conclude that with a bigger die radius, forming will be easier and so maximum expanasion and effective stresses will be more. Thickness reduction increases as well becuase of the increasing in expanasion, only we can find thickness reduction at the value of R=4 mm is slightly lower than its in R=3 mm because of the small increase of expanasion between these two values in spite of increasing of die corner radius and making material flow easier which will improve thickness vriation at this point.

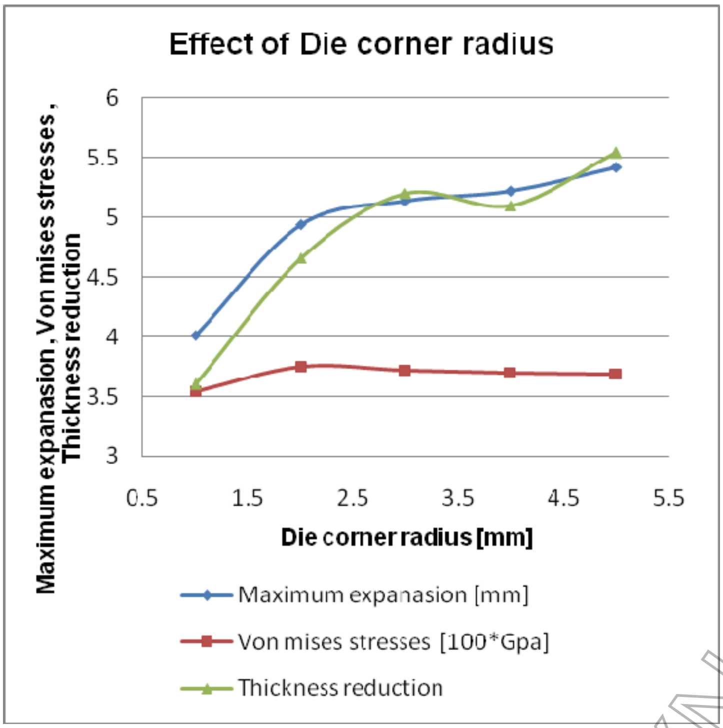

Figure 5: Effect of die corner radius on hydroformed part

Actually increasing die corner radius will result in better parameters but it may not be possible because of geometrical design reasons.

2.3.3 Effect of initial tube wall thickness

Entire initial tube thickness was varried from 1.5 mm to 2.3 mm to study the effect of initial thickness on the hydroformed part. Thickness change has been adjusted to keep the percentage between the thickness of the both layers same (1/0.9).
From "Figure 6" it has been found that all of maximum expansion, effective stresses, and thickness reduction decrease when using thicker tubes because thicker material show more resistance to the forming, so initial thickness should be selected juidiciously depending upon the expansion needed in the final shape while keeping thickness reduction in accepted levels.

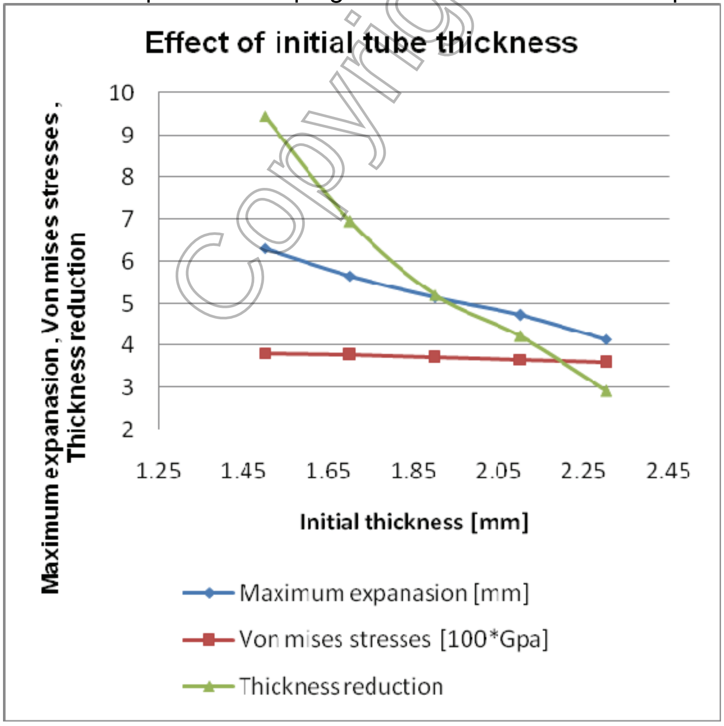

Figure 6: Effect of initial tube thickness on hydroformed part

2.3.4 Discussion

1- It is known that maximum expansion gives a good description of the process formability, but it should be noticed that it may not be equal to the maximum bulge height in bi-layered tube hydroforming because in general we can see that the maximum expanasion takes place in inner layer, while bulge height is calculated considering the outer layer. Normally it is a very small diffrence between the two values because of thickness reduction in the outer layer.

2- In studied cases it has been noticed that thickness reduction is bigger in the outer layer, while both of von mises stresses and expanasion are more in the inner layer. So we can suggest to make the outer layer thicker than the inner one and to design the inner layer to stand with bigger deformation and stresses.

2.4 Finite element optimization.

Based on the FE model studied in (1.1) the geometrical factors have been optimized using the same loading path to obtain X branch with a bulge height of 5 mm, while the objective is to minimize thickness reduction of the inner layer, taking in consideration that outer layer thickness of the final shape shouldnt be less than 0.9 mm.
Optimization was performed using sub-problem optimization method with the following parameters:

2.4.1 Design variables:

Tube length (L) varied from 55 to 65 mm, and die corner radius (R) in the range between 2 and 4 mm.

2.4.2 State variables:

Bulge height (Ymax) is 5 mm as a minimum as we can cut the bulge weather it is bigger, and the outer layer thickness (Othmin) can not be less than 0.9 mm due to protection of the inner layer. While keeping von mises stresses under well under the ultimate stresses.

2.4.3 Objective:

The objective is to obtain the minimum thickness reduction for the inner layer.

The following data was obtained:

	set 1	set 2	set 3	set 4	set 5
YMAX(SV)	5.0116	4.6208	5.1225	4.9333	5.3555
OTHMIN(SV)	0.94877	0.94909	0.94919	0.95053	0.95165
L (DV)	60	63.472	58.88	60.376	56.335
R (DV)	3	2.9144	3.3847	3.2358	3.8735
OBJECTIVE	2.9312	2.7956	2.1691	2.4793	1.8951
Feasibility	Feasible	Infeasible	Feasible	Infeasible	Feasible

	set 6	set 7	set 8	set 9	set 10
YMAX(SV)	5.1909	5.2883	4.9245	5.3724	5.3824
OTHMIN (SV)	0.96018	0.95592	0.95869	0.95161	0.95249
L (DV)	55.345	55.387	58.121	56.186	56.058
R (DV)	2.4378	3.446	2.3911	3.916	3.9593
OBJECTIVE	2.2829	2.098	2.3024	2.0071	1.9157
Feasibility	Feasible	Feasible	Infeasible	Feasible	Feasible

	set 11	set 12	set 13 *	set 14	set 15
YMAX(SV)	5.3812	5.3804	5.3065	5.2323	5.2925
OTHMIN (SV)	0.95253	0.95234	0.95205	0.951	0.9513
L (DV)	56.044	56.074	56.826	57.56	57.181
R (DV)	3.9696	3.9647	3.9616	3.9887	3.9866
OBJECTIVE	1.9382	1.9313	1.8297	1.8915	1.8731
Feasibility	Feasible	Feasible	Feasible	Feasible	Feasible

Table 1: Optimization study of geometrical factors affecting on tube hydroforming

15 cases were studied and it has been found that cases (2,4,8) are infeasible because bulge height is under 5 mm, while the best result met the case (13).

3 Conclusion

- Bi-layered tube hydroforming is suitable to produce bi-layered joints to be used in special applications such as aerospace, nuclear power plants and refining industry.
- In this work a finite element study was performed using ANSYS LS-DYNA to investigate the effect of geometrical factors (Tube length, Initial thickness, and Corner radius) on bi-layered tube hydroforming of X branch. Bulge height, Von mises stresses, and thickness distribution were studied for the hydroformed part.
- It has been concluded that shorter and thinner tubes with bigger die corner radius results in higher protrusion, but that could be accompanied with dangerous thinning for one of the layers or increasing of von mises stress over than the ultimate one. Optimization should be performed to obtain design variables which will make the best result.
- Based on the (2.3.4) it is preferred to make the outer layer thicker than the inner one and to design the inner layer to stand with bigger deformations and stresses.

4 Literature

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