International Journal of Mechanical and Industrial Engineering

Volume 1 | Issue 3 Article 11

January 2012

Present of Three-layered hydro-forming analysis of a new hybrid sandwich tubes using finite element method

J. Shahbazi Karami
Faculty of Mechanical Engineering, Shahid Rajaee Teacher Training University, Lavizan, Tehran, IRAN, Shahbazi.mech@gmail.com

K. Malekzadeh
Space research institute, 26th Kilometer of Expressway of Tehran-Karaj, Tehran, IRAN, K.Malekzadeh@gmail.com

G. Payganeh
Faculty of Mechanical Engineering, Shahid Rajaee Teacher Training University, Lavizan, Tehran, IRAN, G.Payganeh@gmail.com

Recommended Citation
Karami, J. Shahbazi; Malekzadeh, K.; and Payganeh, G. (2012) "Present of Three-layered hydro-forming analysis of a new hybrid sandwich tubes using finite element method," *International Journal of Mechanical and Industrial Engineering*: Vol. 1 : Iss. 3 , Article 11.
DOI: 10.47893/IJMIE.2012.1041
Available at: https://www.interscience.in/ijmie/vol1/iss3/11

Present of Three-layered hydro-forming analysis of a new hybrid sandwich tubes using finite element method

J. Shahbazi Karami[1], K. Malekzadeh[2], G. Payganeh[1]

[1] Faculty of Mechanical Engineering, Shahid Rajaee Teacher Training University, Lavizan, Tehran, IRAN
[2] Space research institute, 26th Kilometer of Expressway of Tehran-Karaj, Tehran, IRAN
E-mail: Shahbazi.mech@gmail.com

Abstract— ***Multi-layered tube hydro-forming is suitable to produce multi-layered joints to be used in special application in many industries. With using a middle layer of foam and making sandwich structures, tube bending strength increases when external loads are applied. Also because of the foam is high energy absorption, in the pipelines of major industries such as the nuclear, strength increases when natural disasters, especially earthquakes happen. In this paper for the first time, three-layered new sandwich tube (inner layer of copper, middle layer of aluminum foam and outer layer of annealed brass) hydro-forming processes were numerically simulated using finite element method by ABAQUS/Explicit 6.10. As the result of three-layered sandwich tube hydro-forming not reported in the literature, the results of this paper are compared with the latest experimental result of bi-layered tube hydro-forming find in literature by approaching the thickness of middle layer to zero. Finite element analysis shows that numerical and experimental results have a good agreement.***

Keywords— ***Tube hydro-forming, Finite element analysis, Multi-layered composite tubes, New sandwich hybrid tubes.***

I. Introduction

Tube hydro-forming (THF) is an advanced and unconventional metal forming technology growing fast in many industries. Internal pressure with or without axial compressive loads is used to deform the tubes to conform the shape of given die cavity.

According to the Fig. 1, tube hydro-forming process can be divided into four steps: (1) Placing the tube in the die cavity, (2) sealing and filling the tube with a fluid, (3) increasing the internal pressure and applying axial feed and (4) ejecting the hydro-formed part [1].

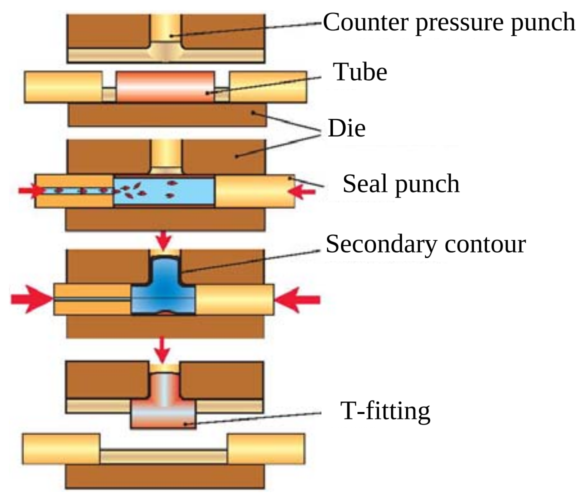


Fig.1. Tube hydro-forming steps [1]

When complex working environments mean that copper alloys cannot provide a heat exchange solution, it may be possible to use bimetallic tubing. Combined tubes can be produced with copper alloy, aluminum ,titanium, carbon or stainless steel combinations. Bimetallic tubing gives combined properties of heat exchange, strength and corrosion resistance that single tubes cannot provide [2].
The common application fields are heat exchangers for power plants (electric, nuclear, thermal and geothermal power plants), high corrosive systems (condensers, evaporators, sea water desalinations, fertilizing, urea systems, ammonia, gas and corrosive acids), chemical and

petrochemical industries, food processing and refrigeration industries [2].

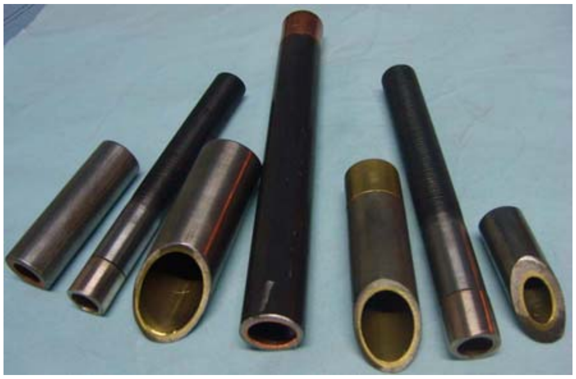


Fig. 2. Some types of bi-layered tubes [2]

The idea of three-layer sandwich tubes for the first time in the world will be discussed in this paper. Obviously if we can succeed, in most of the heat tubes that heat loss should not be occurred, also the outer layer must be metallic, this technique can be used. In this paper, three-layered tube (inner layer of copper, middle layer of aluminum foam and outer layer of annealed brass) hydro-forming was discussed. It's purpose is to use a metal foam middle layer. This layer may play two important roles:

1. It is plays the role of thermal insulation between the inner and outer layers. In transmission lines with the high temperature prevents heat loss.
2. With using a middle layer of foam and making sandwich structures, tube bending strength increases against external loads. Also because of the foam has high energy absorption property, the environmental induced energy can be damped when natural disasters occur, especially in earthquake events in the pipelines of major industries such as the nuclear industries.

Wang et al [4] improved hydraulic expansion device for manufacturing CRA-lined pipe. In order to form a complex desired shape such as T or X branch, Islam et al [5] carried out hydro-forming of a multi-layer tubes experimentally and numerically(Finite element simulation).
Alaswad et al [6] studied the hydro-forming process of pipes, experimentally and numerically using new model for bulge height, thickness reduction, and wrinkle height as a function of geometrical factors. Single and bi-layered tube hydro-forming processes were numerically simulated using the finite element method by Olabi et al [7].

In this paper, hydro-forming process of three-layered composite sandwich tubes, were numerically simulated with finite element method by ABAQUS/Explicit 6.10. The three layered composite sandwich tube forming phenomena is presented at the first time in this paper.

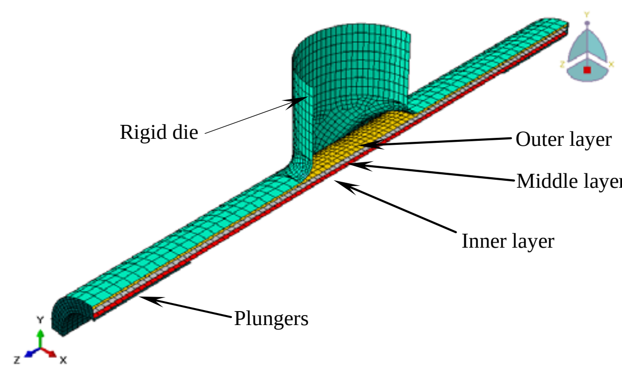
II. Finite Element Modeling

A finite element model was created for three-layered tube hydro-forming using ABAQUS/Explicit 6.10. All of layers were numerically hydroformed in X-branch die with a die corner radius of 3 mm using different settings of loading paths. Dimensions and materials of tubes, are shown and listed in Table 1.

Table 1
Mechanical properties and dimensions of three layers [3, 6]

Properties	Outer layer	Middle layer	Inner layer
Materials	Annealed brass	Aluminum foam	Copper
Density (g/cm^3)	8.80	0.27	8.98
Elastic modulus (GPa)	100	0.102	105
Poisson's ratio	0.33	0.33	0.33
Yield stress (MPa)	980	1.2	220
Outer diameter (mm)	24	22	20
Thickness (mm)	1	1	0.85

Note that the length of all tubes is equal to 120 mm and the tubes material is assumed homogeneous. The finite element model was built in five parts: (1) outer tube, (2) middle tube, (3) inner tube, (4) rigid die, and (5) plungers using ABAQUS software. By taking advantage of symmetry, a ¼ of the X-branch tube was modeled (Fig. 3).



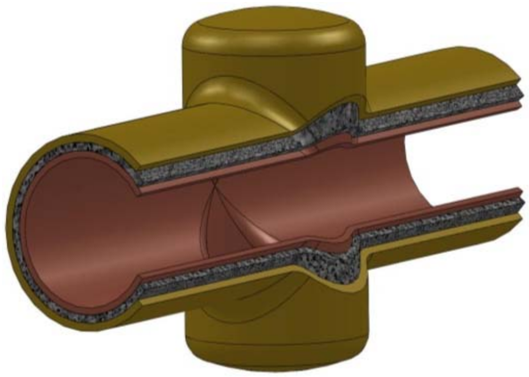


Fig. 3. Simulation of three-layered tube hydro-forming

The nodes at the symmetric edges were restrained in the appropriate directions while the nodes attached to the tubes end were kept free along x, y and z axes. The die was constrained along x, y and z axes. The plungers are free along the z axis and is constrained along x and y axes, because it was allowed to move along the tube length [6]. Because the stress changes in direction of thickness is not considered, the three layers were modeled using thin shell elements S4R type**.**

A mesh convergence study was carried out to minimize mesh refinement effect on the accuracy of the numerical results (Fig. 4).

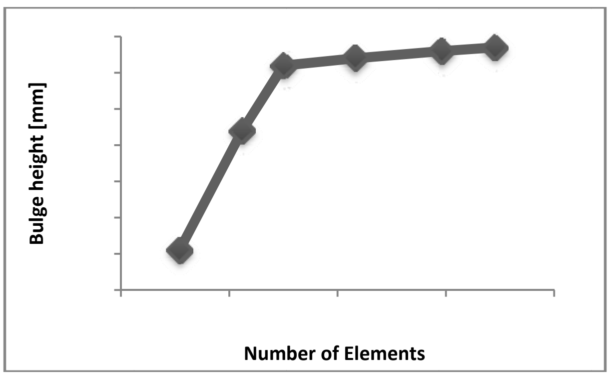


Fig. 4. Effect of number of elements on outer layer bulge height

The number of elements intended for outer, middle and inner tubes respectively is 1500, 1400 and 1300 quadrilateral mapped meshed elements. The rigid die and the plunger were not fully modeled and only the surfaces in contact with the layers were modeled with R3D4 elements type. The interfaces between the outer, middle and inner layers, outer layer and die, all layers and the plungers, were modeled with an advanced automatic surface-to-surface contact algorithm with penalty method. Coefficients of friction of 0.57 between the all layers and 0.15 between the outer layer, die and plungers was considered in numerical simulation [5].

III. VERIFICATION

As the result of three-layered sandwich tube hydro-forming not reported in the literature, the results of this paper are compared with experimental result of bi-layered tube hydro-forming find in literature by approaching the thickness of middle layer to zero [6]. The loading path (internal pressure and axial feed) is used according to Fig. 5a, 5b and 5c.

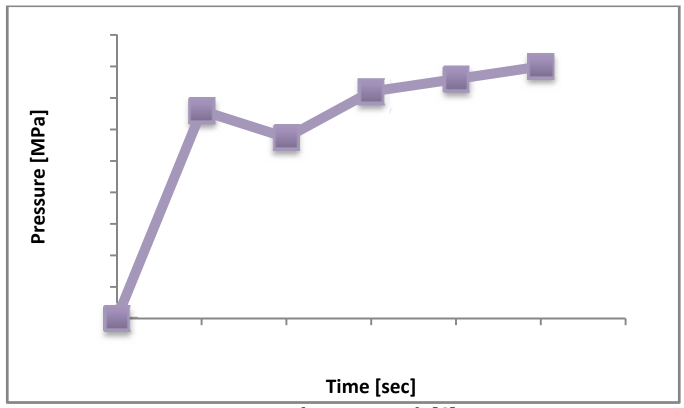


Fig. 5a. Used pressure Path [6]

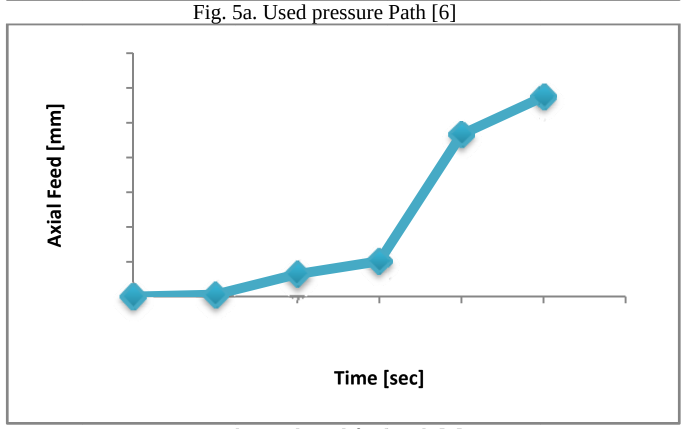


Fig. 5b. Used axial feed Path [6]

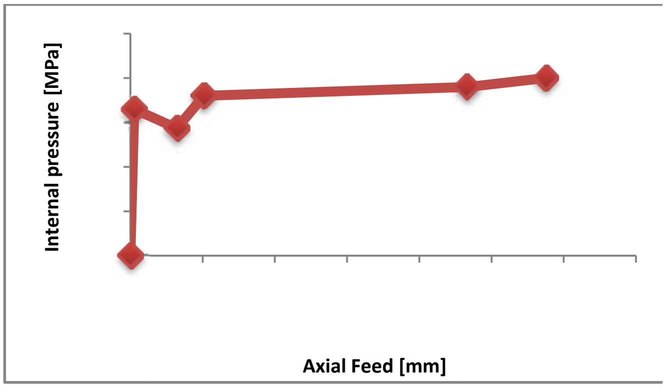


Fig. 5c. Used loading path [6]

For the validation of this study, the thickness of middle layer (aluminum foam core) reduced to zero in some stages, to achieve bi-layered tube hydro-forming. The results of this simulation are shown in Fig. 6. Figure 6 shows, that the conveging of magnitude of bulge height to experimental measured magnitude (7.88 mm) of it [6] is good.

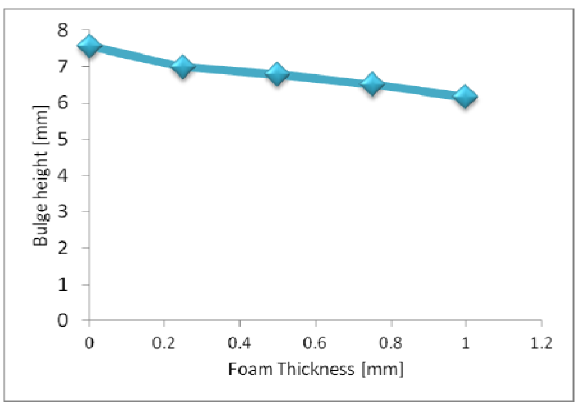


Fig. 6. Effect of middle layer thickness on bulge height

Verification with experimental results for the two major parameters, i.e. the bulge height and thickness reduction was shown in Table 2.

Table 2
Experimental and numerical result

Result types	Experi mental [6]	Numerical [6]	Present simulation	Error with experi mental (%)	Error with numerical (%)
Branch height (mm)	7.88	8.44	7.548	4.2	10.5
Thickness reduction (%)	14.06	15.25	15.17	7.9	0.5

As can be seen, present numerical simulation, were good agreement and acceptable error (Average %6 with experiment and numerical in [6]).

IV. Loading Paths Type

This section reviews some important parameters. In order to achieve a good quality of final product, the parameter of loading path (relation between internal pressure and axial feed) is very important.

In this case, different loading paths types were applied on created model and the process of formability under each applied loading path was investigated. One of the factors which significantly influence the process formability is the loading path type selection which determines the relationship of the internal pressure and the axial feed during the process. Applied loading paths which are shown in figure 7, can be categorized in three types. First type which is loading path (D) represents a linear relationship between the internal pressure and axial feed.

Loading paths (E, F and G) are classified as pressure advanced type in which the hydraulic pressure is raised to a certain magnitude in advance of the axial pushing, while (A, B and C) stand for the loading paths which insure a big increase of the axial feeding in advance of the internal pressure [7].

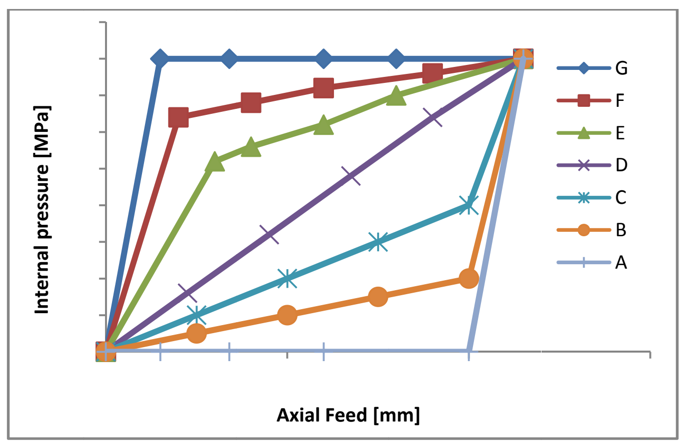
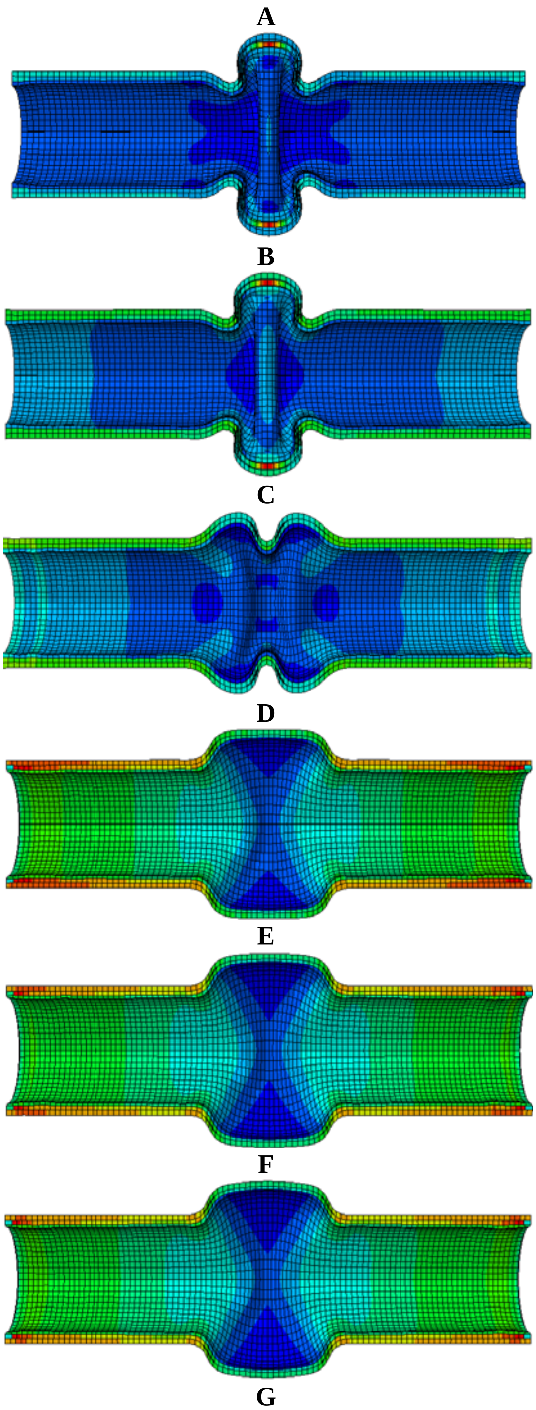


Fig. 7. Applied loading paths

This seven loading paths can be applied in simulation and the result by applying each loading path were shown in figure 8.



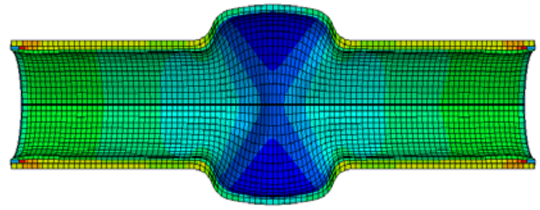


Fig. 8. Hydro-formed parts under different loading paths

V. Bulge Height

Bulge height in different loading paths is shown in Fig. 9. Along loading paths of A, B and C, because of the high axial feed and low internal pressure, the wrinkling was happened. As along the loading path of D, the linear relationship has between the internal pressure and axial feed, the branch has not a good shape and the height is too low. Loading path of G has the highest bulge height without the wrinkling.

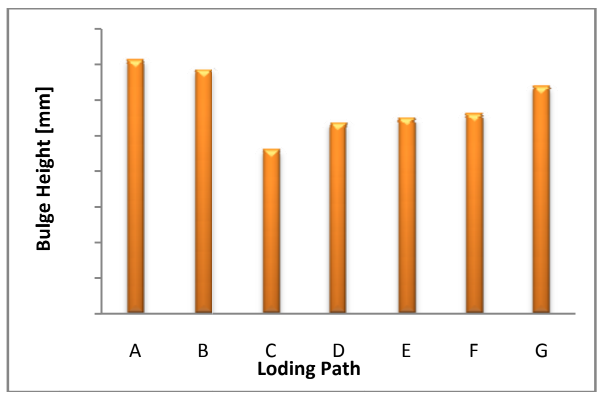


Fig. 9. Bulge height in different loading paths

VI. Thickness Reduction

In A, B and C loading path, that the axial feeding is in advance of the internal pressure, first tube flows into the die, then the pressure increases in the tube and this causes lower thickness reduction. But along E, F and G loading path that the internal pressure occurred in advance of the axial feed, because of higher reaction force between the tubes, higher friction forces can be occurred. Therefore parameter of thickness reduction could be increased. Along the loading path of G maximum thickness reduction was occurred.

Figure 10 shows the total thickness reduction of sandwich tube in different loading paths.

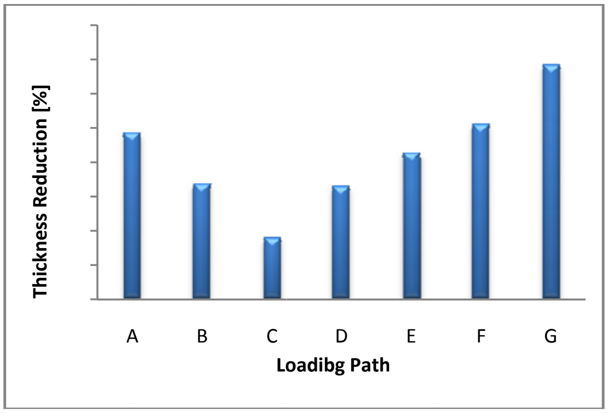


Fig. 10. Thickness reduction in different loading path

As it is clear from the chart, the biggest reduction in thickness is related to G loading path that used maximum internal pressure and has maximum bulge height.

The thickness distribution along the length of outer tube has been shown in figures 11. As can be seen in figure, the minimum magnitude of tube thickness is in the middle zone of tubes.

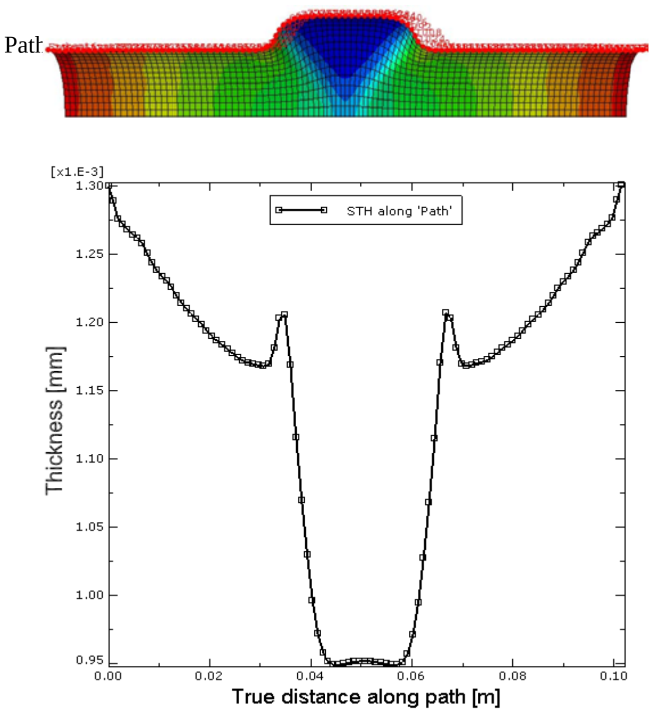


Fig. 11. Thickness distribution in outer tube

In the tube hydro-forming process, increase in thickness due to the axial feeding was happen.

The maximum thickness of three layered sandwich tube in each layer along different loading path, has shown in Fig. 12.

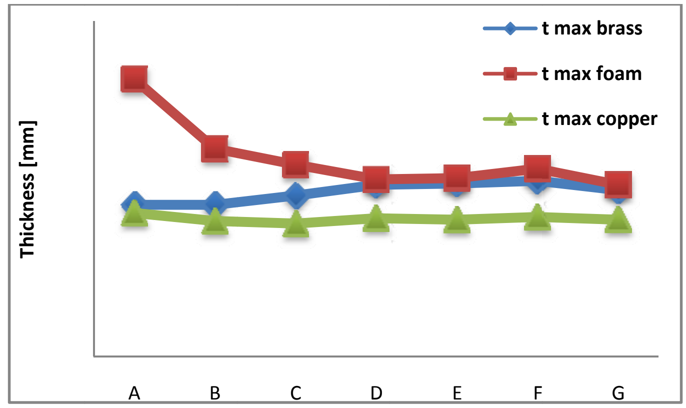


Fig. 12. Increase in tube thickness in different loading path

VII. STRESS

As can be seen in figure 13, maximum of the Von mises resultant stresses in outer tube have been shown in the end of the process. The maximum stress, must be lower than ultimate strength of tubes material.

Region of maximum and minimum stresses has been shown in Fig. 14. As can be seen in the figure, the region of maximum stress is clearly identified by red color.

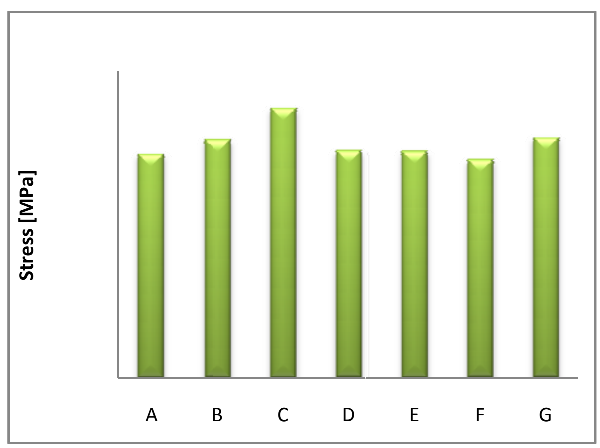


Fig. 13. Maximum stresses in outer tube

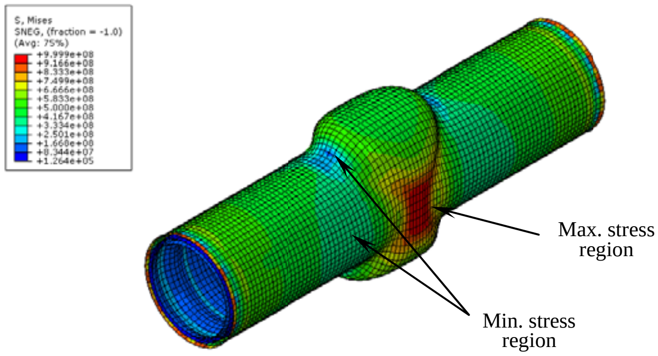


Fig. 14. Von mises stress distribution

The Von mises stress distribution along the length of outer tube, has been shown in figures 15.

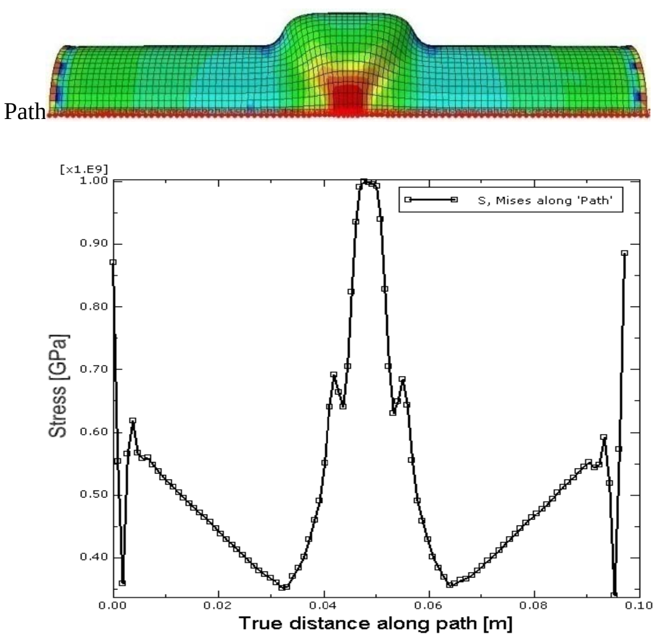


Fig. 15. Von mises stress distribution of outer tube

VIII. Friction

Friction has a great influence on the tube hydro-forming process. When the friction increases, axial feed can be more difficult and the bulge height decreases. Also increase of the friction coefficient will cause higher stresses in the tubes. The effect of friction coefficient on the bulge height has been shown in Fig. 16.

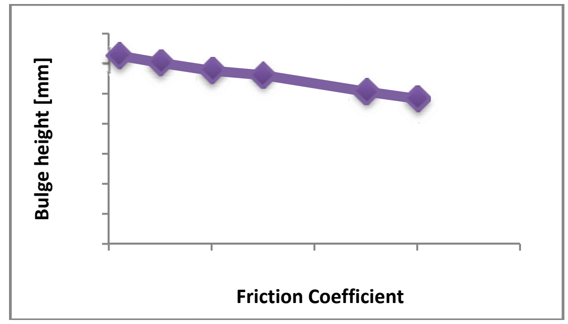


Fig. 16. Effect of friction coefficient on bulge height

The effect of friction coefficient on the von mises stress of outer tube has been shown in Fig. 17.

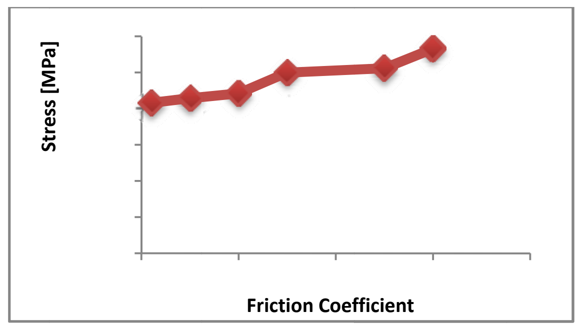


Fig. 17. Effect of friction coefficient on von mises stress

IX. Conclution

In this paper, hydro-forming process of three-layered composite sandwich tubes, were numerically simulated with finite element method by ABAQUS/Explicit 6.10. The three layered composite sandwich tube forming phenomena is presented at the first time in this paper.

We can use finite element simulation instead of try and error to reduce the cost and time of design and analysis of process. Other result includes:

- The loading path is most important input parameter that have most influence on the output parameters such as bulge height, thickness reduction and stresses.
- To achieve a successful technique and desired final part without bursting, wrinkling and buckling, the optimal loading path should be used.
- Thickness reduction dependent on some factors such as friction and loading path. One of the most important objectives of tube hydro-forming process is the producing of the parts with a

minimum thickness reduction and trying to keep the uniform thickness distribution of parts.

- In X-shape hydro-forming, the location of the minimum thickness and the maximum stress is in the middle zone of the tube.
- If coefficient of friction due to the use of proper lubricant be kept low, the bulge height increase and thickness distribution is uniform.

X. ACKNOWLEDGEMENTS

The authors wish to thanks professor G. Liaghat from Tarbiat Modares University of Tehran, R. Darvish, M.Soroush and O. Maghruri for their support.

XI. REFERENCES

[1] *Schuler, Metal Forming Handbook ,Springer, 1998*

[2] http://www.tubeco.com/bimetallic-tubing .asp

[3] http://www.ergaerospace.com/Aluminum-properties.html

[4] Xuesheng Wang, Peining Li, Ruzhu Wang, Study on hydro-forming technology of manufacturing bimetallic CRA-lined pipe , International Journal of Machine Tools and Manufacture, 2005, Volume 45, Issues 4-5, Pages 373-378.

[5] M.D. Islam, A.G. Olabi, M.S.J. Hashmi, Feasibility of multi-layered tubular components forming by hydro-forming and finite element simulation, Journal of Materials Processing Technology, 2006, Volume 174, Issues 1-3, Pages 394-398.

[6] A. Alaswad, A.G. Olabi, K.Y. Benyounis, Integration of finite element analysis and design of experiments to analysis the geometrical factors in bi-layered tube hydro-forming , Materials & Design, , 2011, Volume 32, Issue 2, Pages 838-850.

[7] Abed Alaswad, K.Y. Benyounis, A.G. Olabi, Finite element comparison of single and bi-layered tube hydro-forming processes, Simulation Modeling Practice and Theory, 2011,Volume 19, Issue 7, Pages 1584-1593.

◈◈◈