Effect of Loading Path on the Stress Distribution and Wrinkling in X-Branch Type Tube Hydroforming

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***Abstract* - In this study a novel analytical model to analyze the stress state and wrinkling in the X-branch bulging tube during the hydroforming process is presented using ANSYS LSdyna. The effect of applying load path on the forming process is considered and the deformation of the process was illustrated. It was shown that hydroforming to cause deformed tube effect by the loading path of internal pressure and axial feeding is existed. Two loading paths are investigated to observe its effect on the stress distribution and wrinkling. It can be concluded that the compressive stress in one dimension, deformed the tube element without thinning and tearing when the axial force is applied to the tube as well as the internal pressure. Also it's concluded that the load path 2 is more efficient than the load path 1, i.e. that the feed load is applied separately at the beginning of the bulging process to a certain value then the internal pressure is applied which is more efficient from applying ramp pressure with feed.**

Keywords: Loading path, Tube hydroforming, ANSYS-LSdyna, Bulging, X- Branch, wrinkling.

Symbols

$\dot{\varepsilon}$	Strain rate
C and P	Cowper-Symonds strain rate parameters
ε_e	elastic strain to yield
ε_{eff}^{P}	Effective plastic strain
k	strength coefficient
n	hardening coefficient

1. INTRODUCTION

The hydroforming process is done by applying high internal pressure towards the inner tube's wall to force it to take the final die's profile [1]. The axial load on both of clamped ends of tube is applied to enhance the material's flow via the cavity of the die. The hydraulic oil works as bulging tool instead of a rigid tool, i.e. no direct solid to solid contact between bulging tool and work piece and that leads to reduce friction with tube material. The process becomes complex in applying internal pressure with axial compression ends load on tube. The loading path means that axial movement of the two punches applied to generate sufficient axial compression load to reduce the tube length with hydraulic oil subjected to compression which generate the internal pressure against tube wall, and then plotted the relation between the punch movement and internal pressure. This relation can't be considered as a standard relation because it depends on tube dimensions especially wall thickness and material. The difficulty of controlling both internal and axial load may develop several types of defects in hydroformed tubes like bursting, wrinkling and buckling. Shijian *et al*., (2006) [2], studied the expanded tube experimentally and simulation was done to observe the wrinkling effect on the distribution of thickness in tube hydroforming using the load path curve as shown in Fig.1.

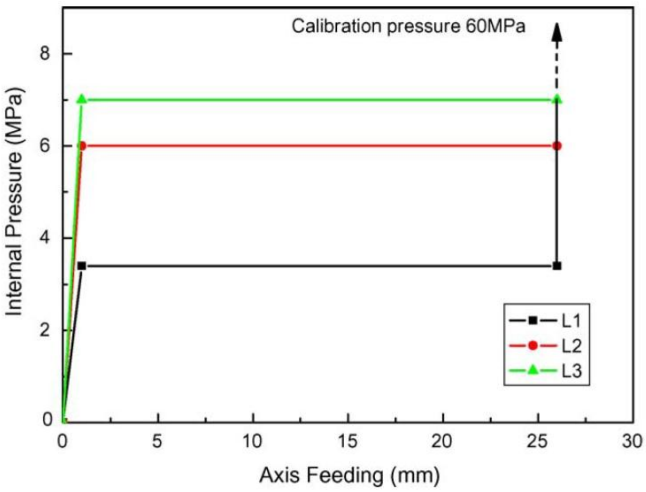

Fig.1 Loading paths [2]

Shuhui *et al*., (2009)[3], studied the tube's bulge processes of the die with trapezoid-sectional profile which through finite element method using different loading path as shown in Fig.2.

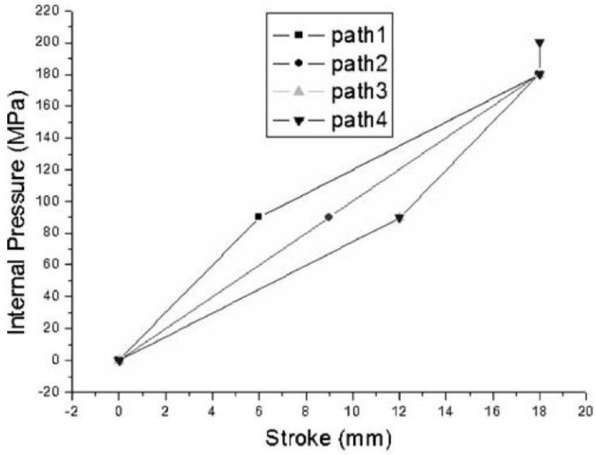

Fig.2 Loading Paths [3]

Honggang *et al.*, (2010) [4], studied the optimization of the loading path to the die with square cross section profile during the hydroforming process

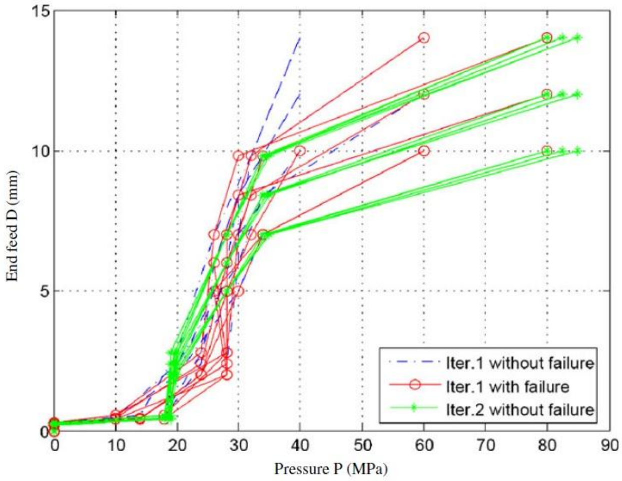

Fig.3 load paths [4]

Majid *et al*.,(2010) [5] presented the simulation of the new die of stepped tube and filling of the die's cavity was illustrated , The finite element method is done via ABAQUS, the curve of the pressure-displacement that's used in the finite element analysis and experimental shown in Fig.(4).

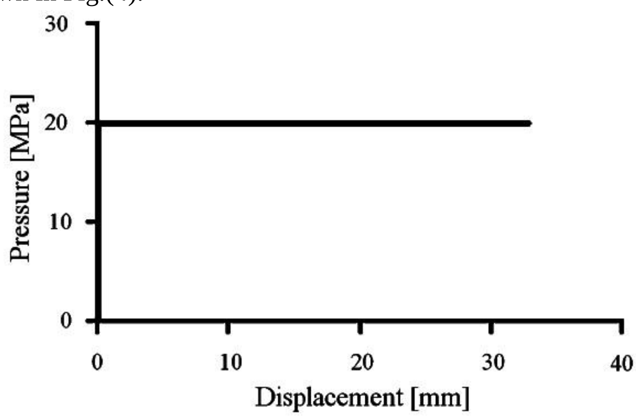

Fig.4 Pressure- displacement curve [5]

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Many researchers illustrated that the load path is an important parameter in the tube bulging process (i.e. expansion of tube, distribution of wall thickness, wrinkling etc.). hence in this paper, the effects of alternative load applying method on the expansion part characteristics. The finite element analysis is used to analyze X-branch type tube hydroforming via Ansys-LSdyna to observe the stresses and wrinkling behavior during forming process using different path loads.

2. ANSYS- LSDYNA MODEL

2.1 Geometric Model

Fig.5 shows the profile and sizes of the model used in the finite element analysis.

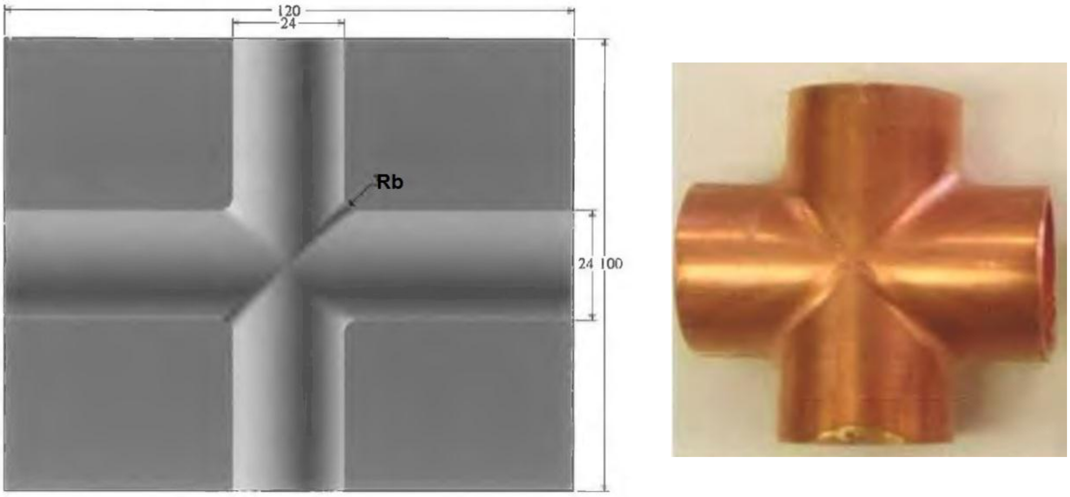

Fig.5 X-branch die and product [6]

The copper tube is annealed before bulging , with 120mm length, 24mm outer diameter and (0.8, 0.9 , 1 , 1.1, 1.2, 1.6, 1.8)mm wall thickness and Fillet radius Rb is (1.5, 3, 5)mm, with mechanical properties- modulus of elasticity = 119.86GPa, Yield strength = 0.116 GPa, Poisson's ratio = 0.31 and Density = 8900Kg/m^3. Fig.(6) shows the Ansys model. one-eighth of X-branch is modeled due to symmetry of the tube

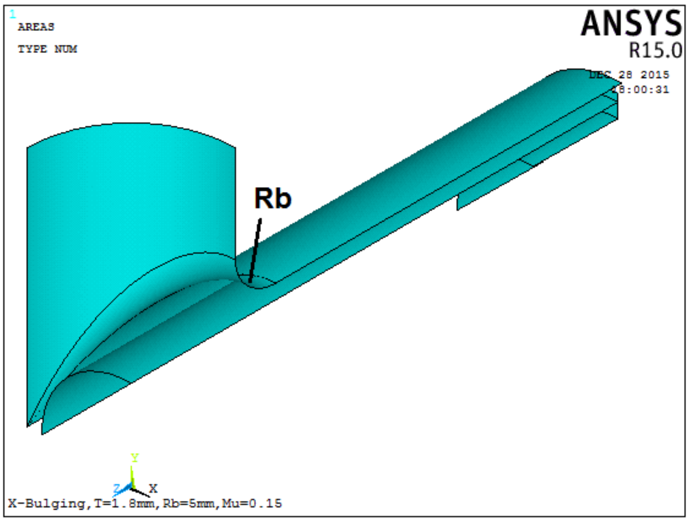

Fig.6 Ansys model

The tube blank was meshed by element SHELL163 as shown in Fig.7. It has 12 degrees of freedom at each node translations, accelerations, and velocities in the x, y, and z directions and rotations about the x, y, and z-axes. This element has 4-node and is used in dynamic stage. The formulation of fully-integrated Belytschko-Tsay shell element is used by setting KEYOPT(1) = 12 on [7]. The die represented as Master, and defined as a very rigid body and the tube blank material represented as a Slave. The contact interface between die and the deformed material is represented by Automatic contact with its option (ASSC, AG, ASS2D, ANTS, ASTS) . Automatic surface to surface (ASTS) contact type is used in this paper.

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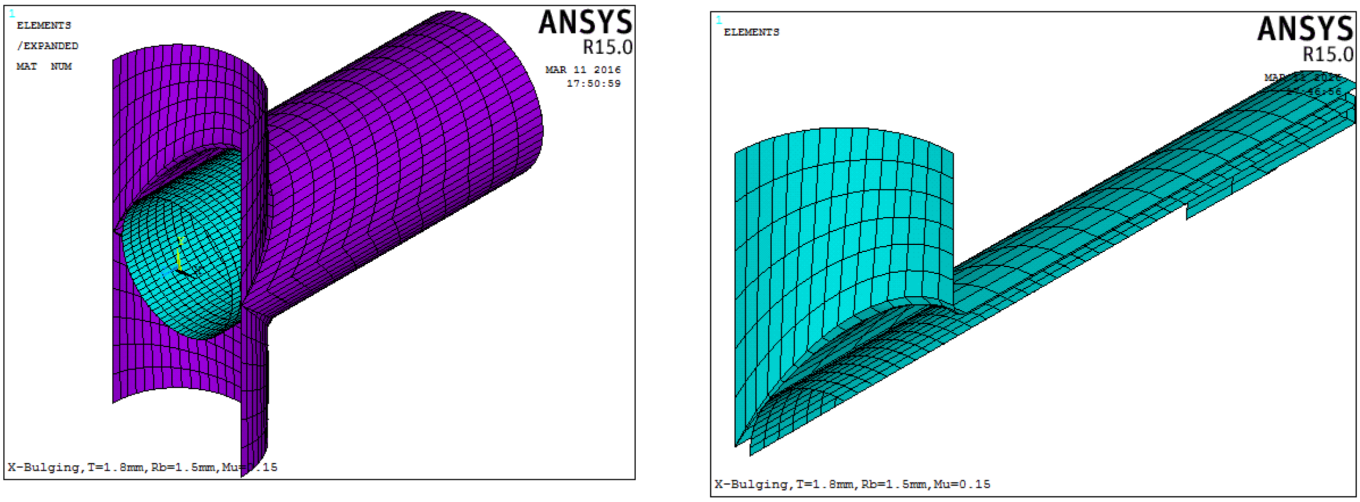

Fig.7 Mesh of X-branch tube

2.2 Power Law Plasticity Model

In this work the constitutive equation of the elasto plastic with strain rate depended plasticity is used including the Cowper-Symonds multiplier to account for strain rate [8]:

$$\sigma_Y = \left[1 + \left(\frac{\dot{\varepsilon}}{C}\right)^{\frac{1}{P}}\right] k\left[\varepsilon_e + \varepsilon_{eff}^{P}\right]^n \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Using TB, PLAW,,,,2 to model the equation (1) in LS-dyna to represent the behavior of the material plastic zone , and it's data setting using TBDATA command as follows:

TBDATA, 1, k (strength coefficient)
TBDATA, 2, n (hardening coefficient)
TBDATA, 3, C (strain rate parameter)
TBDATA, 4, P (strain rate parameter)

2.3 Loading Path

The boundary conditions of the model represented by constraining the degree of freedom (displacement, velocity and acceleration) are fixed except in the direction of the axial punch, which is moving along the Z-axis towards the center of the tube. The load in this paper is applied as internal forming pressure and end axial feed as function of time. Two loading paths are used in this study (internal forming pressure vs. end axial feed) for X-branch tube as shown in Fig.8 and Fig.9, which are function of time (0,0.75, 1.5, 2.25, 3)sec.

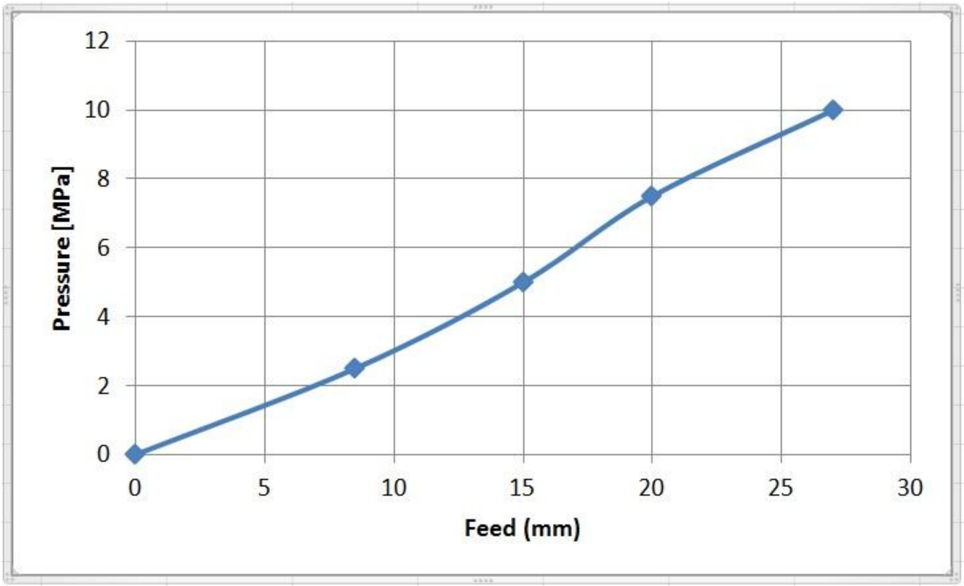

Fig.8 Load Path -1-

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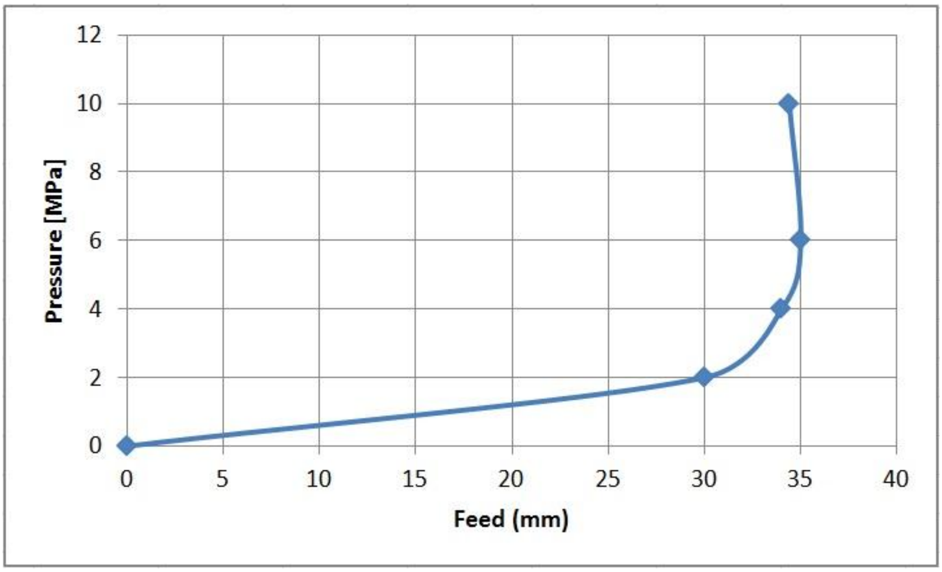

Fig.9 Load Path -2-

3. TUBES HYDROFORMING DEFECTS

The important parameters in the bulging process are the internal pressure and the axial loading. In order to control on the tubes hydroforming defect these two parameters have to be optimized. Fig.10 shows the types of defects which might happen in tube hydroforming process:

a) *Buckling*: due to increase in the axial compressive displacement.
b) *Wrinkling*: due to increase an axial loading or internal pressure.
c) *Bursting*: due to thinning of the tube's wall thickness or due to insufficient axial loading [7].
d) *Pinching:* This occurs due to the squeezing action of the tube between the upper and lower die. This causes local damage[10].

a) buckling b)wrinkling c) bursting

Fig.10 Tubes hydroforming defects

4. THEORETICAL CONSIDERATION OF TUBE WALL THICKNESS

Consider a force balance on a circular element of radius ρ near the pole (Fig.11) [11-12]. The radius r of this element is $r = \rho\,\Delta\theta$. The vertical component of the force acting on the circumference of this element is $2\pi r t\sigma\,\Delta\theta = 2\pi t\rho\sigma\Delta\theta^2$. This is balanced by the force of the oil, $\pi r^2 P = \pi(\rho\Delta\theta)^2 P$. Equating, $2\pi t\rho\sigma\Delta\theta^2 = \pi(\rho\Delta\theta)^2 P$ or

$\sigma = P\rho/(2t)$ …………………………………… (2)

The radial strain, ε_r , can be used to find the thickness,

$t = t_o \exp(-2\varepsilon_r)$ ……………………………….. (3)

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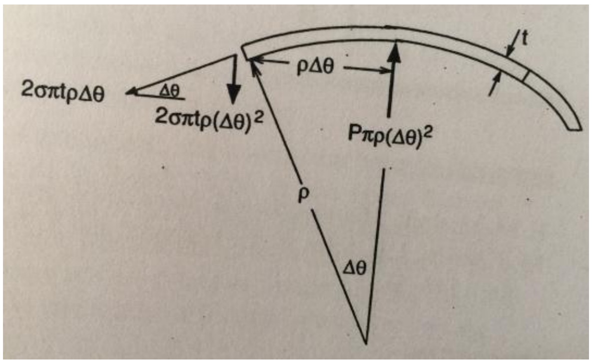


Fig.11 Force balance in hydraulic bulging[11]

5. RESULTS AND DISCUSSION

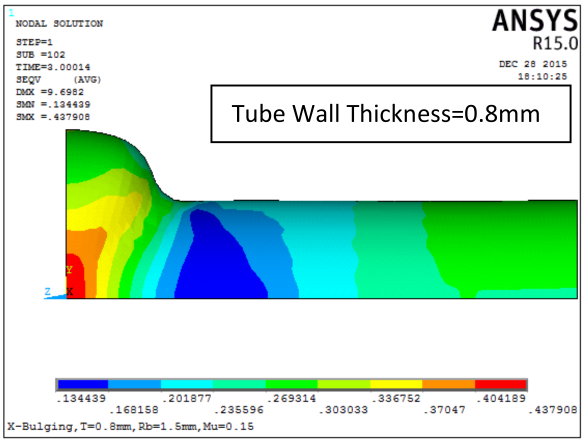
Much higher strains are possible in a hydraulic bulge process than other forming process, so the effective stress-strain relations can be evaluated at higher strains. In this work the wrinkle waves and thickness distribution in the hydroforming tube is controlled using finite element method. A three dimensional model is simulated via, ANSYS-LS-DYNA. It was found that the results from FEM can be used effectively for modeling of the main process parameters .Combined internal pressure and independent axial feeding as predicted numerically. In this work the effects of Rd and tube wall thickness and loading path are studied. For each load path the parameters Rb and thickness of tube are changed with constant coefficient of friction $\mu = 0.15$. Tables(1) and (2) illustrate the equivalent stress of the X-branch tube bulging for different values of thickness (0.8, 0.9, 1, 1.1, 1.2, and 1.4) mm with three different value of Rb for loading path-1- and -2- respectively. Figs.(12),(13) and (14) shown the distribution of stresses for both cases of loading path and with different tube wall thickness.

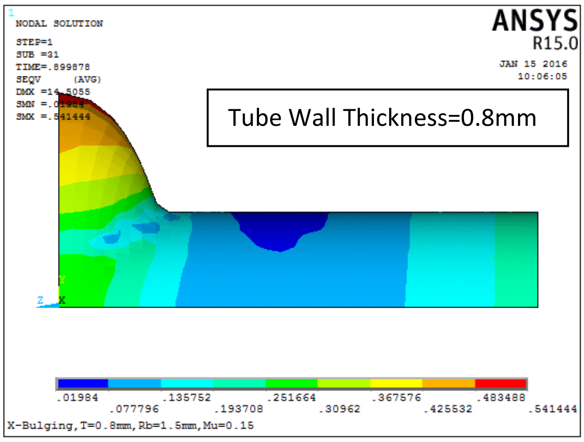
Table:1 Equivalent stress of X-branch tube due to load path-1-

Thickness of tube [mm]	Equivalent Stress [MPa]		
	R_b=1.5 mm	R_b=3 mm	R_b=5 mm
0.8	0.437908	0.425968	0.410528
0.9	0.427197	0.419977	0.405606
1	0.418877	0.412757	0.400804
1.1	0.409837	0.405849	0.397147
1.2	0.402769	0.401118	0.392145
1.6	***0.33574***	***0.35283***	***0.396586***
1.8	***0.403343***	***0.525588***	***0.615124***

Table:2 Equivalent stress of X-branch tube due to load path-2-

Thickness of tube [mm]	Equivalent Stress [MPa]		
	R_b=1.5 mm	R_b=3 mm	R_b=5 mm
0.8	0.541444	0.579557	0.599117
0.9	0.560028	0.555694	0.606191
1	0.445095	0.432901	0.553287
1.1	0.441743	0.431721	0.418098
1.2	0.436835	0.429221	0.415753
1.6	0.384245	0.412507	0.383404
1.8	***0.509516***	***0.506771***	***0.386508***





(a)

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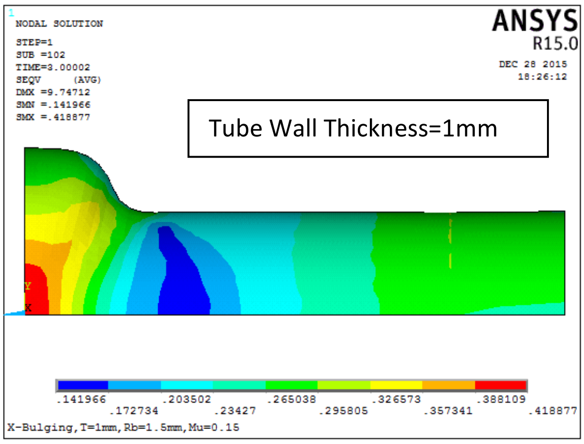

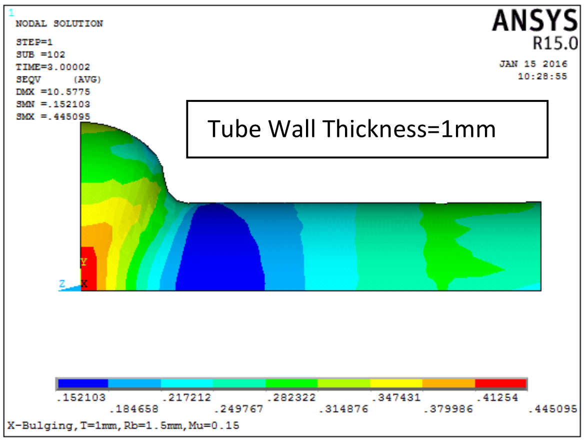

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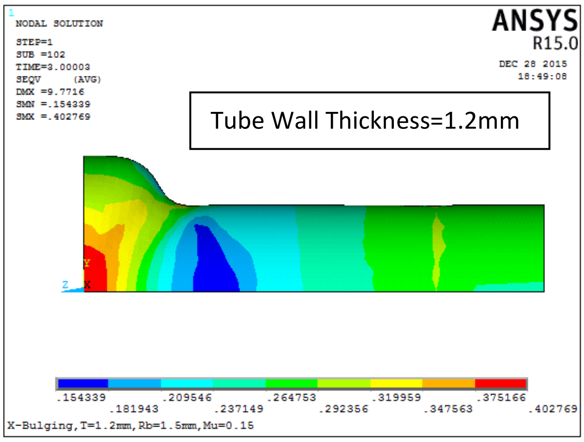

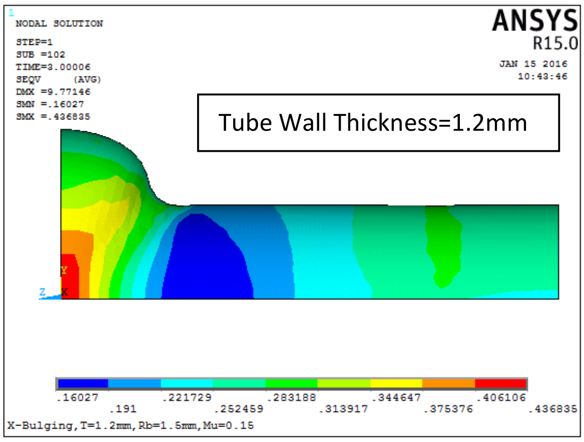

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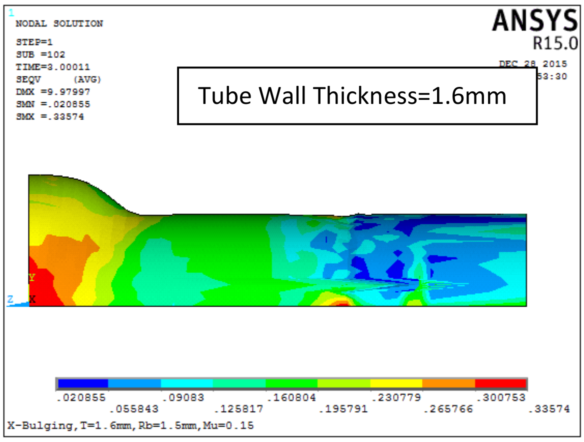
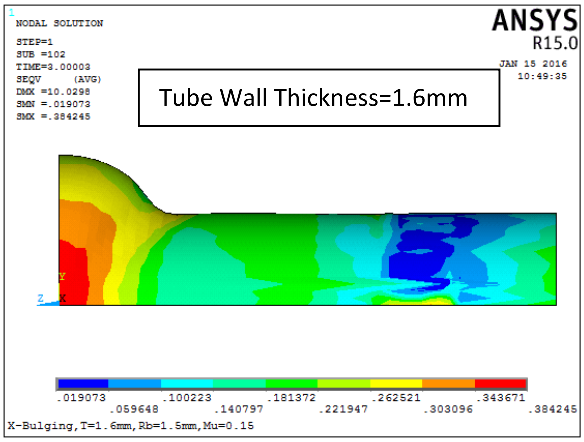
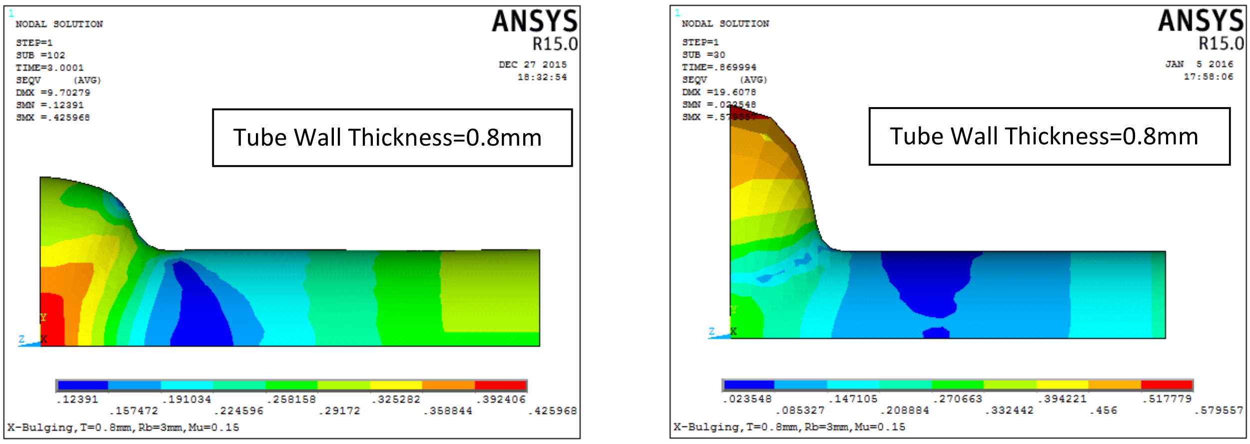




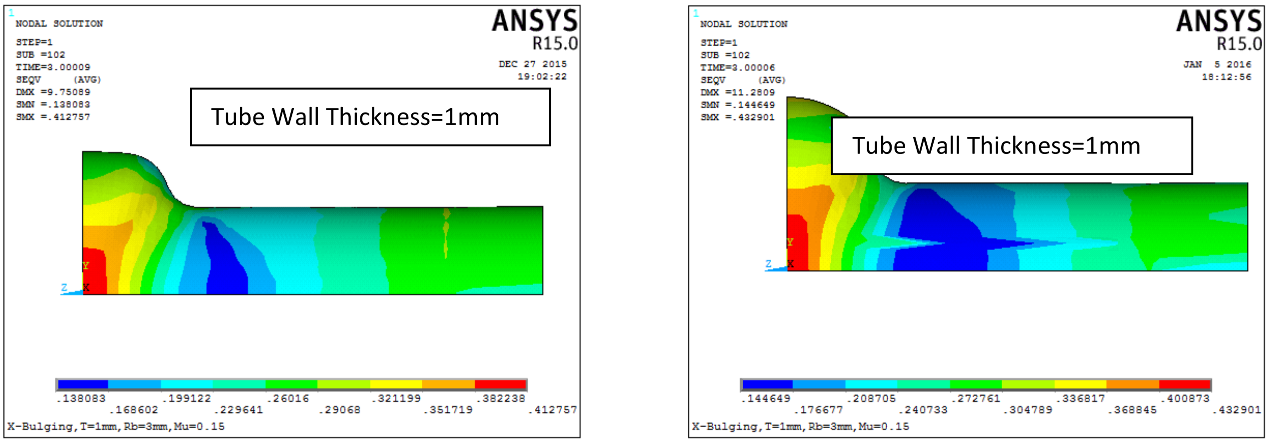
(d)

Loading path -1- Loading path -2-

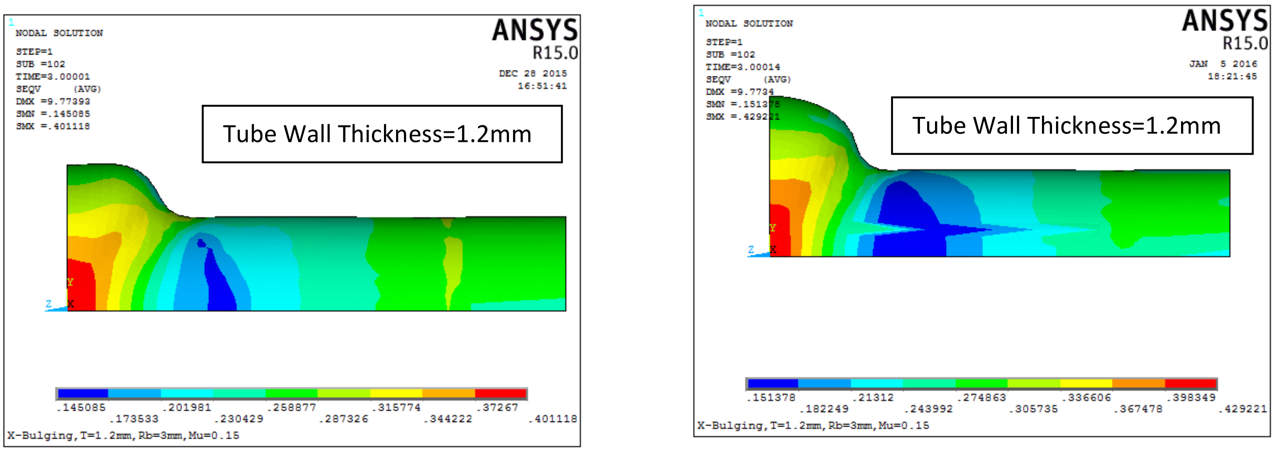
Fig.12 Equivalent Stress (Von Mises stress) of X-branch tube at Rd=1.5 mm


ANSYS
R15.0
Tube Wall Thickness=0.8mm
X-Bulging,T=0.8mm,Rb=3mm,Mu=0.15
ANSYS
R15.0
Tube Wall Thickness=0.8mm
X-Bulging,T=0.8mm,Rb=3mm,Mu=0.15

(a)


ANSYS
R15.0
Tube Wall Thickness=1mm
X-Bulging,T=1mm,Rb=3mm,Mu=0.15
ANSYS
R15.0
Tube Wall Thickness=1mm
X-Bulging,T=1mm,Rb=3mm,Mu=0.15

(b)


ANSYS
R15.0
Tube Wall Thickness=1.2mm
X-Bulging,T=1.2mm,Rb=3mm,Mu=0.15
ANSYS
R15.0
Tube Wall Thickness=1.2mm
X-Bulging,T=1.2mm,Rb=3mm,Mu=0.15

(c)

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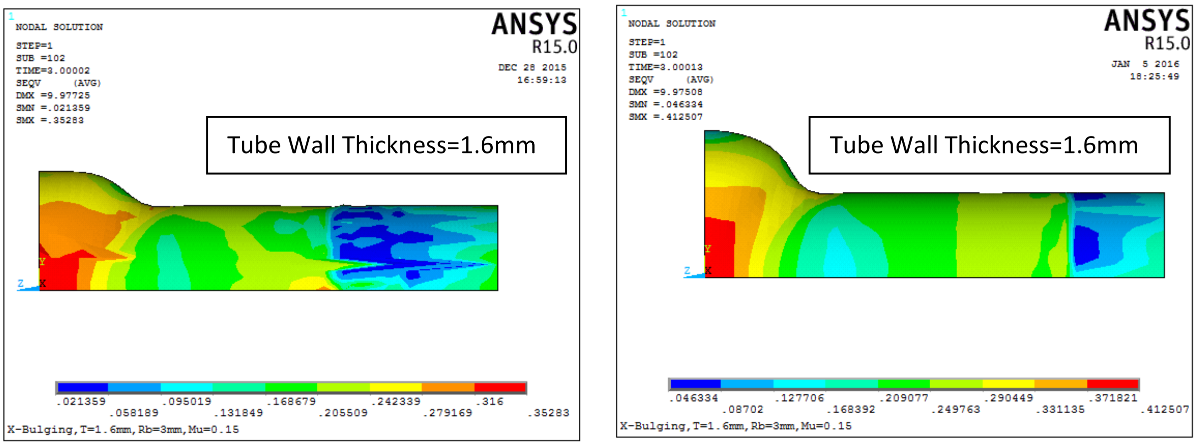
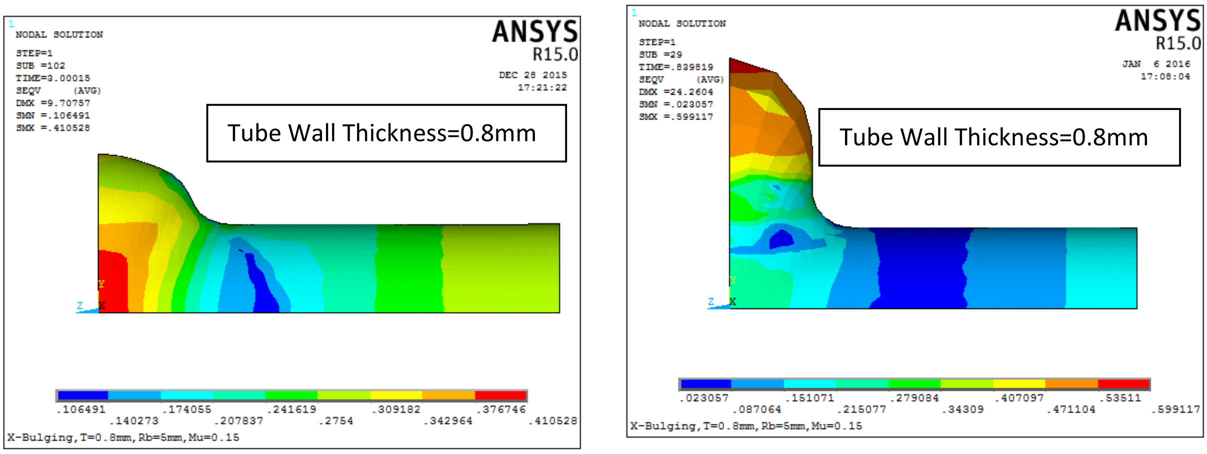


Loading path -1- (d) Loading path -2-

Fig.13 Equivalent Stress (Von Mises stress) of X-branch tube at Rd=3 mm



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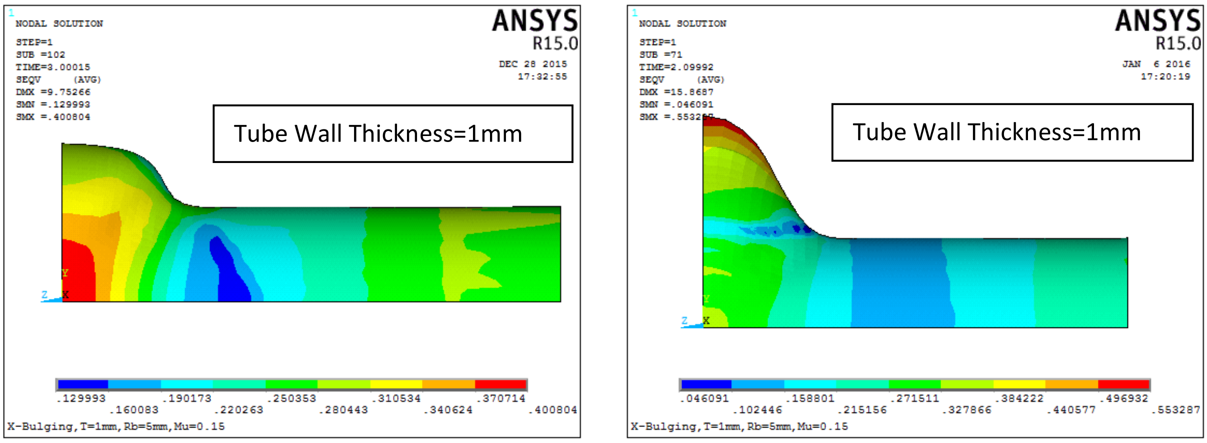

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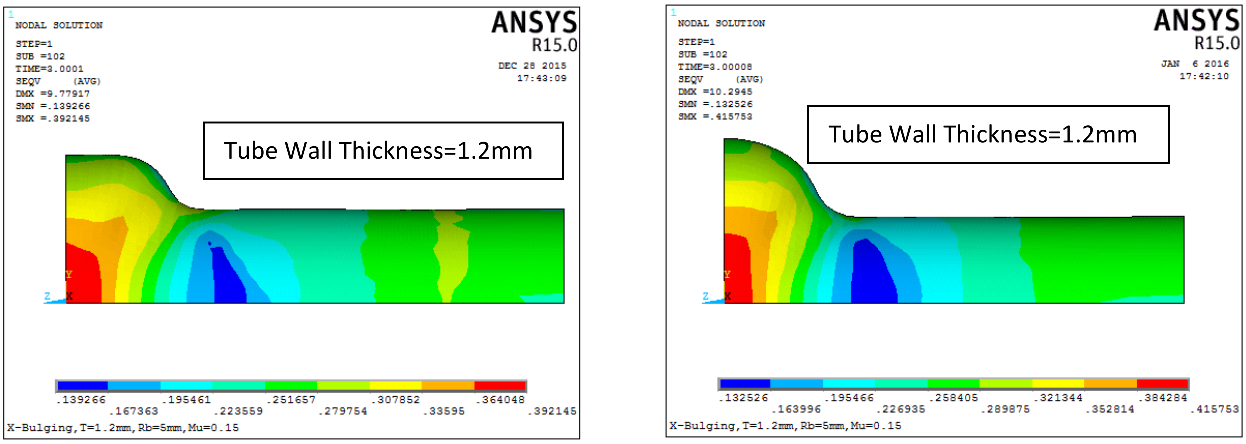

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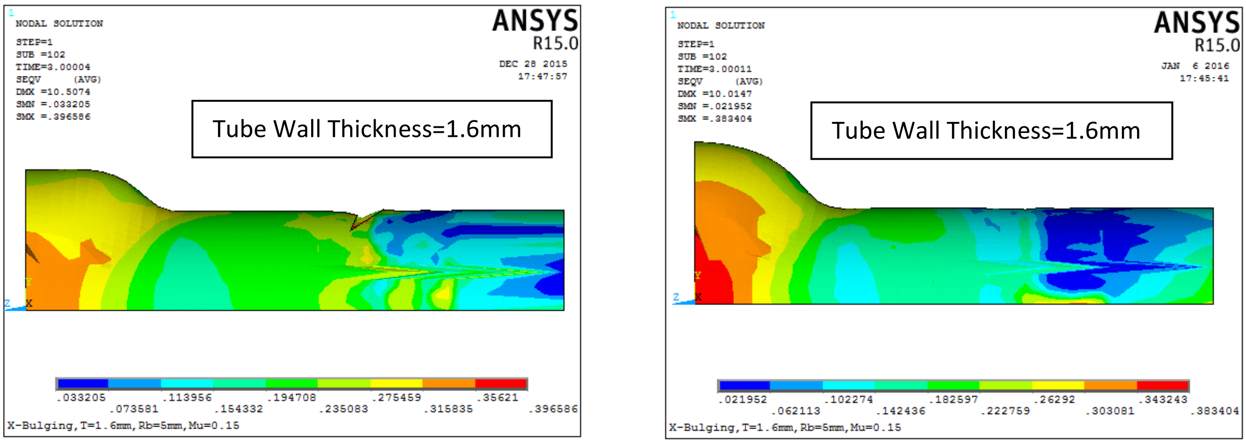
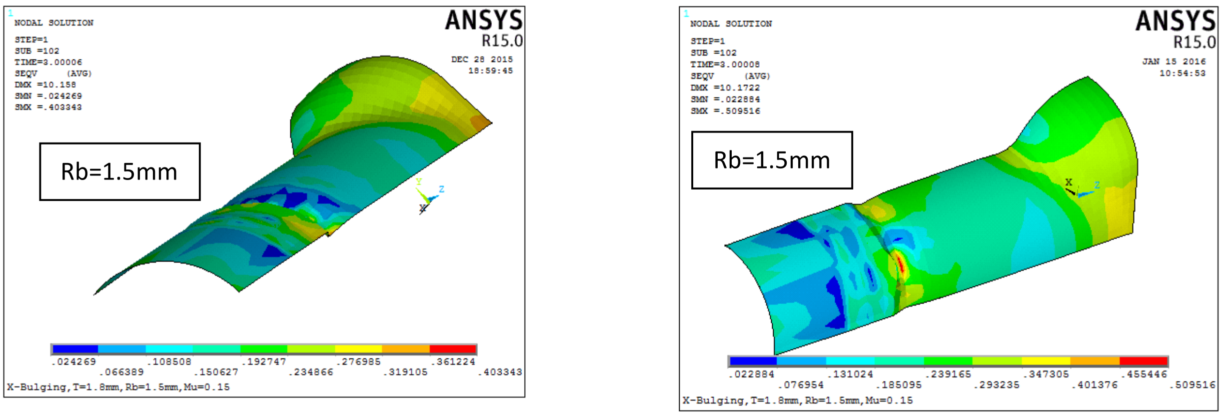


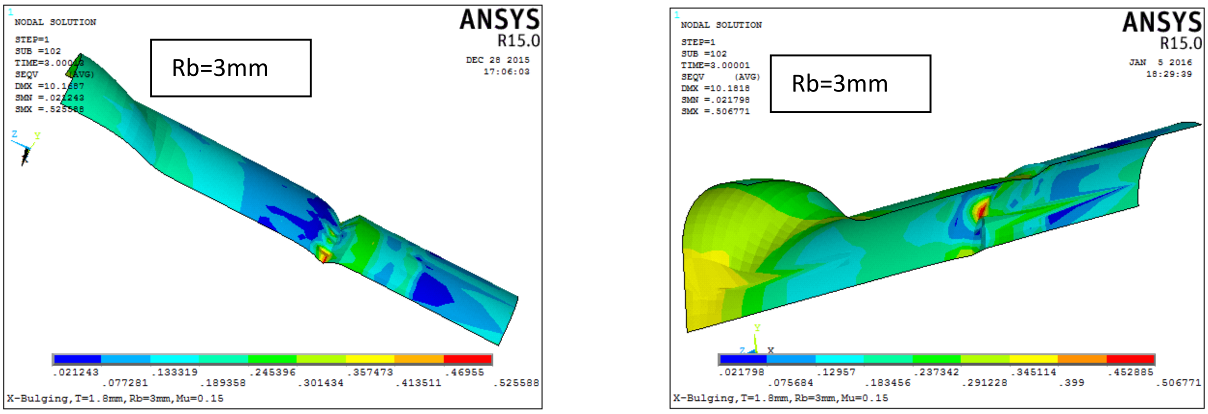
Loading path -1- (d) Loading path -2-

Fig.14 Equivalent Stress (Von Mises stress) of X-branch tube at Rd=5 mm

It can be seen from the figures that when the wall thickness is larger than 1.6mm, wrinkling occurs in all case. Fig.15 shows the equivalent Stress (Von Mises stress) of X-branch tube for Rd=1.5, 3, 5 mm with wall thickness=1.8mm.



(a)



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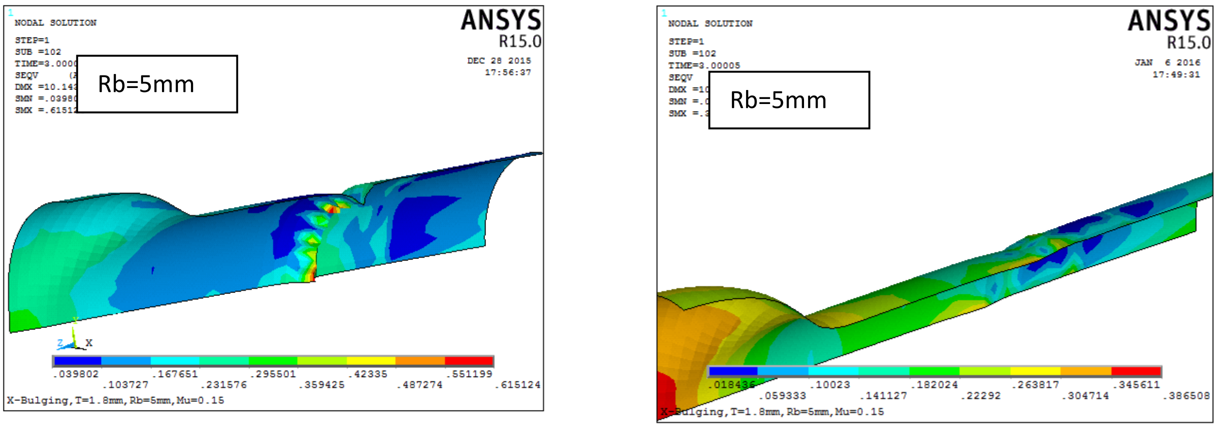

(c)

Loading path -1- Loading path -2-

Fig.15 Equivalent Stress (Von Mises stress) of X-branch tube for Rd=1.5, 3, 5 mm with wall thickness=1.8mm

6. CONCLUSION

Many pipe fittings are made by hydroforming process , where axial force applied to the tube in addition to the internal pressure; where a compressive stress in one dimension, is deforming the tube element without thinning and tearing when the axial force is applied to the tube as well as the internal pressure. Finite element via Ansys-LSdyna was used to examine these parameters, the finite element based loading paths can significantly reduce trial and error, enhance productivity and expand the tube hydroforming capability in forming complex parts. The test results also demonstrated that the reliability of the finite element based loading paths is highly dependent on the accuracy of the material properties of the blank and interface friction and forming pressures which can be reduced if controlled buckling under compressive forces is obtained. Also it is concluded that the load path 2 is more efficient than the load path 1, i.e. that the feed load is applied separately at the beginning of the bulging process to a certain value then applied the internal pressure which is more efficient than applying ramp pressure with feed.

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