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Parametric Analysis of Tube during Bending Operation

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Abstract*: Bent tubes have a lot of various industrial applications. It is required for the transportation of fluids or gases. It also used as construction elements in all industries like car, aviation and shipbuilding industry, refrigeration and air conditioning technology, furniture industry. The objective of this paper is to understand the material deformation occurring during the bending of the tube bends and study the effect of parameters viz. bending radius, bending angle, springback on ovality of tube during bending operation. Tube undergoes certain deformation during the bending process which introduces various defects in the tube bends. This will lead the acceptability of tube bends for certain application. For better understanding the approximation of the defect it is necessary to reduce it at the manufacturing level itself. The testing uses different bending die to differ the bending radius and tests are performed at different bending angle. These whole data has been used to find the different defects and also to find the stress induced in the bends using FEA software package.

***Index Terms*: Circulatr Tube, Bending Radius, Spring Back, Ovality, Finite Element Method.**

I. INTRODUCTION

Tubes and its products are manufactured in various shapes having their applications in various sectors like automobile, aerospace, shipping, agriculture, furniture, ornaments etc. Hence there is more demand of tube in present time. The application ranges from simple and small household items to huge and sophisticated aerospace parts. Wherever tubes are used, accurate bend angle and uniform cross section are often desired. Generally steel and aluminium tubes are bent plastically by using tube bending machine. Compression, draw, ram, roll and press tube bending methods are used frequently in order to bend tubes to different angles and radii [6]. Rotary draw tube bending is the most flexible bending method among above type mentioned. It is used immensely in industry on account of its easy tooling and low cost. Rotary tube bending machine is used in this work. If the bending stress induced during tube bending exceed strength limit of material, then tube undergoes considerable distortion, wrinkling, springback, ovality, variation in wall thickness and finally failure due to fracture. This article gives effect of bending radius, bending angle and springback on ovality of tube during bending operation. Here different bending radius and bending angle to see effect on cross section with help of FEA software ANSYS. T. C. Michael et al. [1,2,3] performed experimentation on the effect on cross-section behavior under effect of internal pressure with Finite Element Method (FEA) analysis which is one of the important criteria to evaluate the acceptability of tube bends with shape irregularities. The same author [1] has also discussed about FEA models analysis of original section, elliptical & semielliptical section in term of a flow chart where increased the ovality and thinning/thickening with 5% in each analysis to generate the idea about how is the cross section changing with % change in the input i.e. ovality and thinning and thickening. The same author [2] has analyzed the same analysis by keeping the material and internal pressure constant and varying the bending radius of the tube, so that there will be change in ovality and percentage thinning / thickening and they determine the relation between allowable internal pressure for the tube bend & allowable stress intensity. Agrwal R. [6] studied various defects during bending which can be analyzed using FEA simulations of tube bends for different angle of bending. L. Sozen et.al. [4] performed an analytical study on relation between curvatures of the tube and cross sectional deformation. Plastic deformation in the bent part of the tube and elastic deformation in the pressure die area were represented as the two main reasons of the spring back occurrence. This study explained how to justify, select and implement the tube bending method on commercial level. Mohammed Noorul Hussain [7] described stress occurring in tube bending parts to make the design sturdy enough and to investigate the stress distribution in the tube to reduce the defects. This is useful for stress analysis of bending section. Boyle and Spence [8] showed that idealized bisymmetric (oval or elliptical) cross-section stress analysis of arbitrary small deviations from circularity. This is helpful for FEA analysis of cross section of tube. V.N. Shlyannikov [9] described effect of creep and fatigue on tube bends shape imperfection. FEA analysis is used to find internal pressure, operation time and shape imperfection of tube bend. It is useful reference for FEA analysis of tube bend under static loading. Jyhwen Wang [10] investigated the in-plane distortion and thickness variation occurs during tube bending. *Analytical* models explained to predict cross-sectional distortion and thickness change of tubes under various loading conditions are useful for this research approach. H. Ousji et.al. [11] showed parametric study of shock tube experimentation. The purpose of this study is reflected in pressure and impulse generated at a laboratory scale at tube end in terms of the tube length, the tube diameter, the explosive mass, and the stand-off distance.

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The graphic representation developed estimate the tube geometry and the explosive mass necessary to generate a given couple of pressure–impulse at the tube end. These experimental techniques are very useful to complete this research article. E. Daxin et.al. [12] showed deformed analysis for circular tube in terms of stress distribution and wall thinning calculations. Here, Rotary draw bending is a CNC tube bending process is used. Axial force without no external drawing forced is taken for analysis. This article guide to stress analysis in current research article

II. TUBE BENDING

When tube undergoes bending, the outer surface of the tube is subjected to tensile stress whereas inner surface of the tube are subjected to compressive stress.

2.1 Cross- Section Distributions

There is tendency of surface at both the ends to move towards the neutral axis. The outer surface of tube tends to move towards the neutral plane to reduce the tensile elongation.

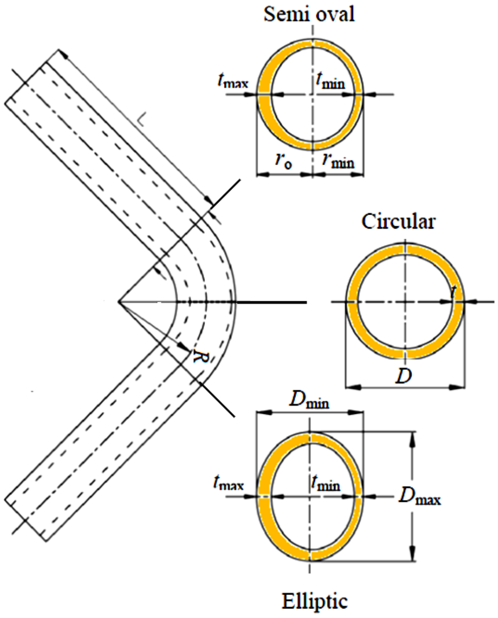

Fig. 1 Tube Bend with Attached Straight Tube Showing Ovality

This results in the cross-section of the tube being no longer circular, instead of that it’s become oval or elliptical which is as shown in Fig. 1. [1] Various terms used in tube bending are given below.

2.1.1. Ovality (Elliptic)

The degree of ovality (C_o) is determined by the difference between the major and minor diameters divided by the nominal diameter of the tube. When expressed in percentage form, Equation (1), it corresponds to percentage ovality [3].

$$C_0 = \left(\frac{D_{max} - D_{min}}{D}\right) \times 100$$

(1)

where D_{max} is maximum diameter of tube in mm, D_{min} is minimum diameter of tube in mm and mean diameter D is

$$D = \frac{D_{max} + D_{min}}{2}$$

2.1.2. Ovality (Semi oval)

The degree of ovality (C_o) for semi oval cross section is determined by the difference between the nominal outside and minor radii divided by the nominal outside radius of the tube [3]. It is expressed in percentage form as in Equation (2).

$$C_0 = \left(\frac{r_0 - r_{min}}{r_0}\right) \times 100$$

(2)

where r_o nominal outside radius of tube in mm, r_{min} is minimum radius in semi oval cross section in mm and r mean radius of tube in mm

2.1.3. Thinning

Thinning (C_t) which occurs at extrados of the tube bend, is defined as the ratio of the difference between the nominal thickness and the minimum thickness to the nominal thickness of the tube bend and is expressed in percentage [3] as given in Equation (3).

$$C_0 = \left(\frac{t - t_{min}}{t}\right) \times 100 \quad (3)$$

where t original thickness of tube in mm, t_{min} is minimum thickness of tube in mm

2.1.4. Thickening

Thickening (C_{th}) occurs at intrados and is defined as the difference between the maximum thickness and the nominal thickness divided by the nominal thickness of the tube bend [3]. The percentage thickening is given in Equation (4).

$$C_0 = \left(\frac{t_{max} - t}{t}\right) \times 100 \quad (4)$$

where t_{max} is maximum thickness of tube in mm

2.1.5. Springback

After the bending process is complete and the tooling has been withdrawn the bent tube tends to regain its original shape due to the elastic nature of the tube material. That does not get the exact angle of bent. This is called springback or the elastic recovery of the tube. During the bending process internal stresses are developed in the tube and upon unloading, the internal stresses do not vanish completely. After bending the extrados is subjected to residual tensile stress and the intrados is subjected to residual compressive stress. These residual stresses produce a net internal bending moment which causes springback. The tube continues to spring back until the internal bending moment drops to zero. The springback is given in Equation (5).

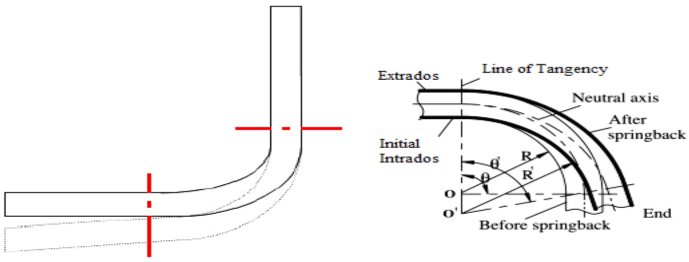

Fig. 2 Springback

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Springback = Bending Angle After Unloading - Bending Angle After Loading

The springback angle depends on the bend angle, tube material, tube size, mandrel, machine and tooling. In actual practice the amount of springback is calculated and the tube is over bent by that amount. The springback in tube at section of tube is as given in Fig. 2.

2.2 Objective of Research

During tube bending process, the cross section of bent tube becomes non circular. It gives thickening at intrados, thining at extrados and also creates springback. The acceptability of tube bends is based on induced level of these shape imperfections. Thus ovality, thickness variations and springback are imperfections considered here as problem statement. It is observed that thinning and ovality are to be taken into account together to decide the acceptability of tube bend. The more oval or deformed sections can lead to rejection of tube bends. If the reasons of imperfections are identified, then reduce defects in bending by providing proper suggestions which will result in reducing production cost and increase in profit.

III. TESTING AND OBSERVATION

Rotary draw tube bending is most useful and flexible bending machine among other types of tube bending. It has high quality and variety of tool options. Here, Rotary tube bending machine having capacity maximum 10-12 mm diameter tube size with Ultimate Tensile Strength (UTS) of 45-60 kg/mm^2 is used for tube bending. The machine has bending radius (R) range up to 15-125 mm. Bending radius is changed by changing the bending disk as per requirement and some other necessary arrangement have to be made [13] for getting different bend angle, manually stop the machine at respective angle.

3.1 Input Data

The testing data used is as follows:

- Bending Machine : Rotary tube bending machine
- Tube : Aluminium tube having diameter 10 mm
- Bending Pulleys: Bending radius 30 mm and 40 mm.

3.2 Procedure

Cold bending process is used for tube bending operation with maximum speed of 10 r.p.m. (5-6 r.p.m. normally). The Aluminium tubes are used for the bending process having different bending radius as 30 mm and 40 mm using two different die on the tube bending machine.

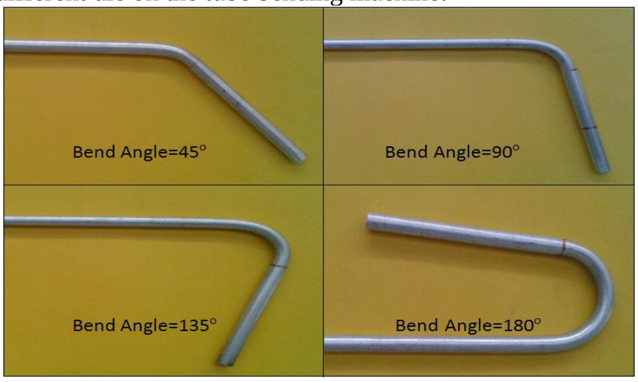

Fig. 3 Tube Bends For Different Angle For Bending Radius 30mm

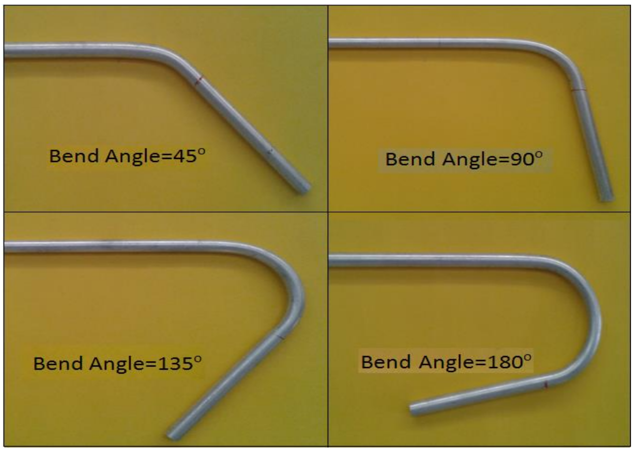

Fig. 4 Tube Bends For Different Angle For Bending Radius 40mm

The deformed tubes as shown in Fig. 3 and 4 are used further to calculate spring back, ovality using stress analysis. The spring back angles are given in Table 1.

Table 1. Spring Back Angle

R (mm)	Bend Angle (^{0})	Measured Angle (^{0})	Spring Back Angle (^{0})
30	45	44	1
	90	79	11
	135	119	16
	180	172	8
40	45	44	1
	90	80	10
	135	121	14
	180	173	7

3.3 Ovality Measurement

The magnitudes of shape imperfections obtained from trial reports, the tube manufacturing industries decide either accept or reject tube bends. The tubes are cut at the bend where the deformation is more for ovality, percentage thinning and thickening.

Then take impression of the cut section of tube on graph paper for measurement. Then thinning, ovality measurements are made from these impressions and based on the magnitude of these imperfections the tube bend is accepted or rejected. Fig. 5 shows impressions of ovality measurement for bending radius 30 mm. Similar procedure is used for ovality measurement for bending radius 40mm. The impressions of cross section were first scanned and the image was converted into an AutoCAD drawing file. Then an actual dimension got from this process is used in ANSYS analysis.

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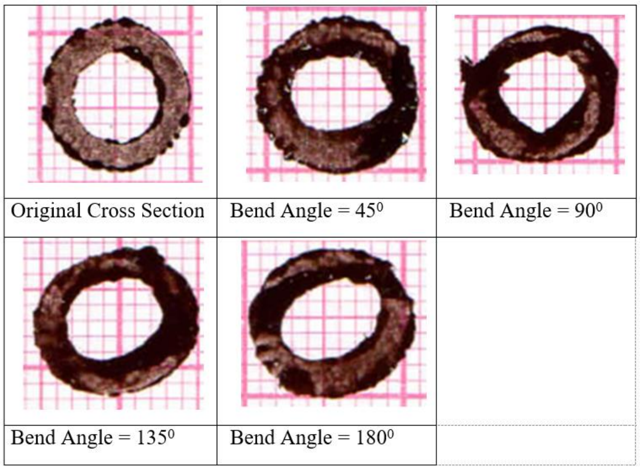

Fig. 5 Deformed Section of Tube Bended on 30 mm Bending Radius

3.1.1. Ovality for Bending Radius 30 mm

Cold bending process is used for tube bending operation with maximum speed of 10 r.p.m. (5-6 r.p.m. normally). The Aluminium tubes are used for the bending process, having different bending radius 30 mm and 40 mm using two different die on the tube bending machine.

Table 2. Bending Radius 30 mm

θ (^{0})	D_{max}(mm)	D_{min}(mm)	t_{max}(mm)	t_{min}(mm)	C_0 %	C_{th} %	C_t %
45	9.8	9.3	2.2	1.58	05.2	10	21
90	10.0	8.7	2.3	1.52	13.9	18	24
135	10.02	8.9	2.5	1.48	11.8	25	26
180	10.1	8.4	2.8	1.38	18.3	40	31

3.1.2. Ovality for Bending Radius 40mm

The similar procedure used for ovality measurement of bending radius 40 mm which is used in bending radius 30 mm.

Table 3. Bending Radius 40 mm

θ (^{0})	D_{max}(mm)	D_{min}(mm)	t_{max}(mm)	t_{min}(mm)	C_0 %	C_{th} %	C_t %
45	9.8	9.3	2.08	1.7	5.24	4	15
90	10.0	9.23	2.1	1.68	8.008	5	16
135	10.02	9.20	2.2	1.6	10.31	10	20
180	10.4	9.16	2.46	1.58	12.68	23	21

Then the data obtained from the measurement of tube section having bending radius 30 mm is used to calculate parameters as maximum diameter, minimum diameter, maximum thickness and minimum thickness of tube given in Table 3.

IV. FINITE ELEMENT ANALYSIS

Finite element analysis (FEA) has been widely used in recent years for solving various engineering problems. Numerical solutions to even very complicated stress problems can now be obtained routinely using FEA. There are various software available in market which performs FEA analysis. The FEA simulation and analysis ease the complication of problem and reflect the true nature of material behavior especially in case of stress problem. Any problem can be solved in three basic steps as pre-processing, analysis and post-processing. This article gives a FEA simulation in ANSYS software to predict the thickness distribution, effective stress throughout the cross section and cross section distortion of the tube obtained from cross section of tested tube during the bending process. The results obtained from the FEA simulation is used to conclude discussion about parametric analysis of tube. This analysis is based on some assumption such as, cross-section of tube after bending is oval (elliptical or semi-elliptical) and tube bends are symmetric about vertical axis through the centre of bend and considered the axisymmetric structure of cross-section of tube for analysis. The tube material used for analysis is aluminium alloy 6061which having mechanical properties are given in Table 4[14].

Table 4. Mechanical properties of aluminium alloy 6061

Property	Value
Material	Aluminium alloy 6061
Modulus of Elasticity (GPa)	70*
Poisson ratio	0.346*
Tensile Yield Strength (MPa)	276*
Ultimate Tensile Strength (MPa)	310*
Ultimate Bearing strength (MPa)	607*

Keeping these points in mind, plane element designated as PLANE183 is used for modeling tube cross section after bend. This is 8-node or 6-nodes with a higher order two degrees of freedom at each node (translations in the nodal x and y directions) as shown in Fig. 6. The element may be used as a plane element or as an axisymmetric element [16]. Here, PLANE183 is used as axisymmetric element for analysis of cross section of tube as shown in Fig. 5. AR. Veerappan et al. [16] carried stress analysis results for assumed and actual pipe bend. It is predicted that the assumed and actual pipe bend cross sections after stress analysis are not comparable. Hence in this article the actual cross sections of tube bend are taken for FEA analysis which is shown in Fig. 5. For analysis purpose first calculate the pressure exerted by bending die on outer surface of tube with the help of known parameter like type of bending machine, relation between torque and speed of bending shaft.

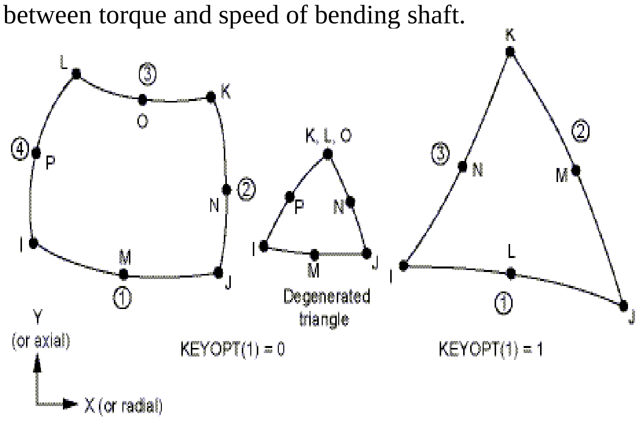

Fig. 6 PLANE183 Geometry

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The pressure applied in most of daily applications of aluminium tubes is in range of approximately 20 MPa to 50 MPa for tube diameter 80 mm to 40 mm. Hence here applied pressure of 30 MPa for R = 30 mm and 22 MPa for R = 40 mm radius of tube. Mesh generated for original section with the boundary condition for applied pressure 30 MPa is as shown in Fig. 7.

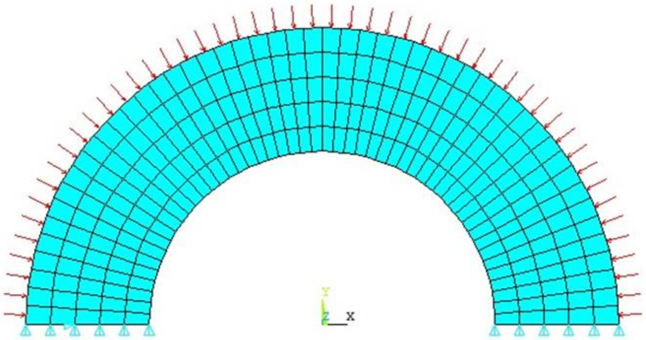


Fig. 7 Meshing of the Original Section with Boundary Conditions

Deformed section obtained from the application of pressure on original section of tube which is initial stage of bending is shown in Fig. 8.

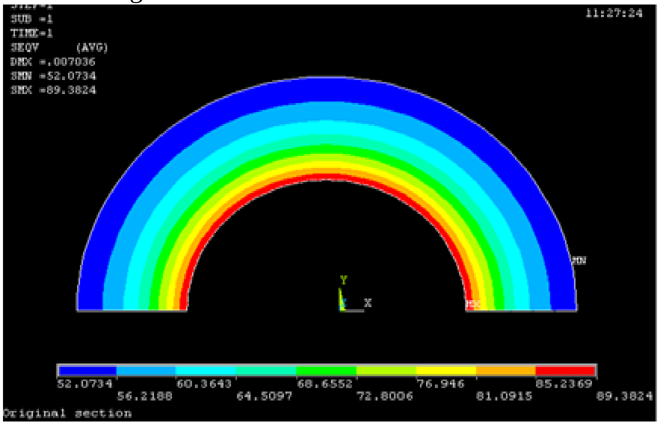


Fig. 8 Stress Induced at Initial Position of Tube Bends

The plots shown in Fig. 9 are obtained from FEA analysis of the tube bending at bending angle 45^0 to 180^0 for bending radius 40 mm. Similar type of results are obtained for bending radius 30 mm.

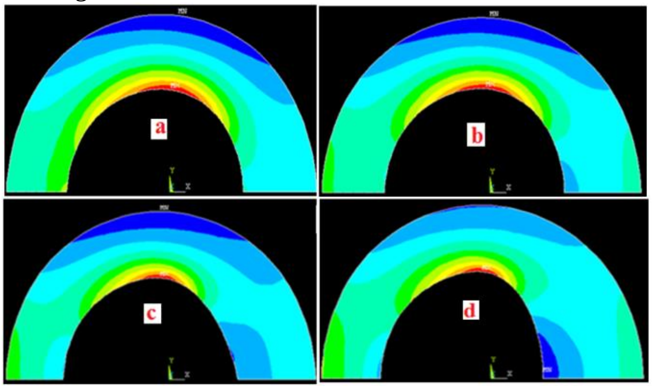


Fig. 9 Stress Induced During Bending for R= 40 mm at Bending Angles (a) 45^0 (b) 90^0 (c) 135^0 (d) 180^0

V. RESULTS AND DISSCUSSION

Geometrical, mechanical and forming parameters of analytical methods not give satisfactory results for bending angle, bending radius and springback predication on ovality. So a Finite Element method was used. The results and discussion about spring back, ovality, Hoop Stress and bending angle are given below.

5.1. Springback Curve

The springback curve gives relation between bending angle and springback angle. The spring back angle observed for bending radius 30 mm (R = 30 mm) and bending radius 40mm (R = 40 mm) having bending angle range from 0^0 to 180^0.

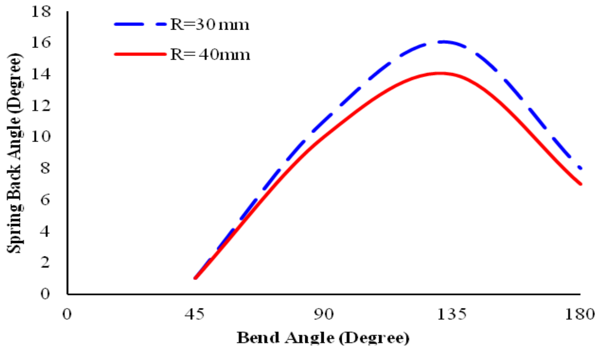


Fig. 10 Spring Back Curve

The springback curve plotted as shown in Fig. 10 by referring the values from Table 1. Springback curve shows that as spring back angle increases from 45^0 to 135^0 and then decreases upto 180^0. In the present work, it is observed that the springback angles were obtained for various bend angles and as bend angle increased the amount of springback is increased. Also it is observed that Springback increases with decrease bending radius.

5.2. Bending Angle vs Hoop Stress and Ovality

Hoop stress is the stress in a tube wall, acting circumferentially in a plan perpendicular to the longitudinal axis of the tube and produced by the pressure. Fig. 11 gives Hoop stress vs bending angle for bending radius R= 30 mm and bending radius R = 40 mm. As bending angle increases, hoop stress inside tube also increased. The hoop stress in bending radius 30 mm is more compared to bending radius 40 mm for the same bending angle. The graph shows higher hoop stress value at 180^0 as compared to other bend angles.

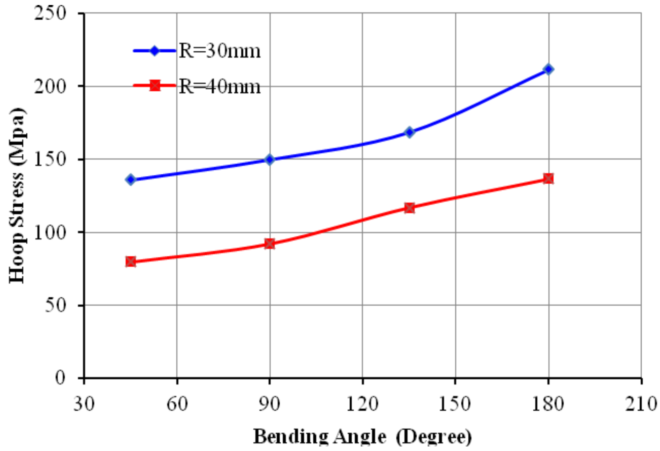


Fig. 11 Bending Angle vs Hoop Stress for Bending Radius R= 30 and R= 40

It is observed that as bending angle increases from 30 to 180 degree, ovality is also increased due to shape change in cross section of tube as shown in Fig. 12. The ovality in bending radius 30 mm is more compare to bending radius 40 mm for the same bending angle.

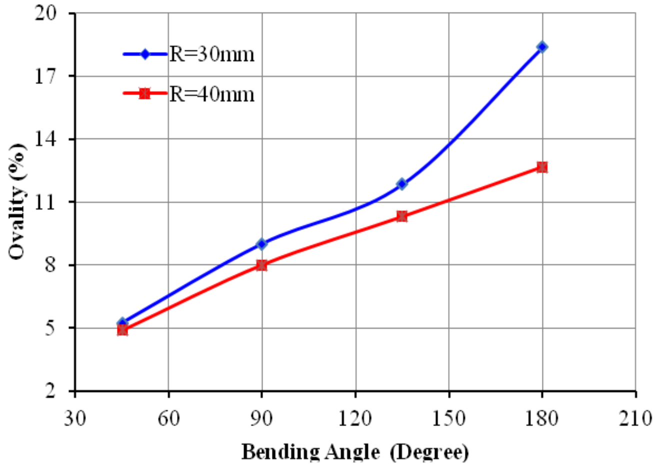
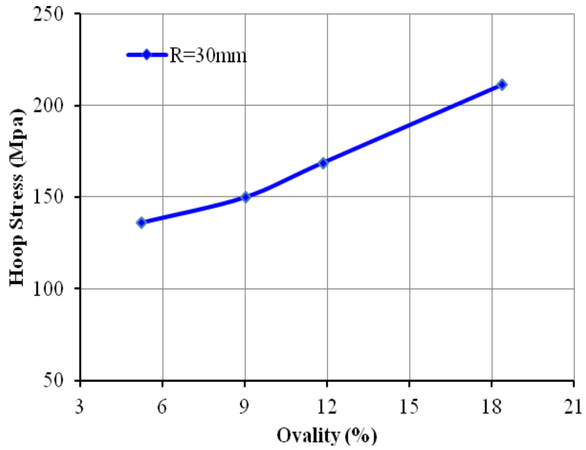


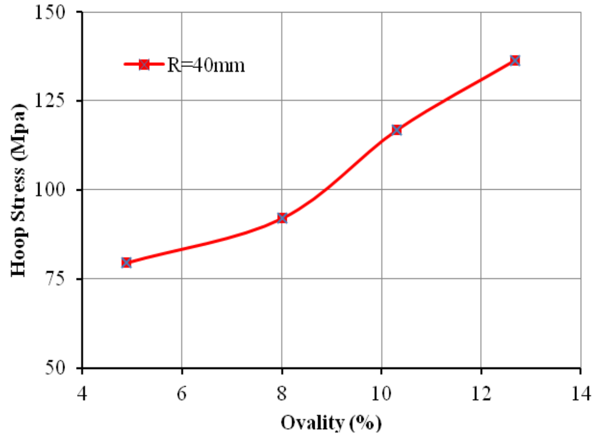
Fig. 12 Bending Angle vs Ovality for Bending Radius R= 30 and R= 40 mm

5.3. Hoop Stress vs Ovality

Fig. 6 shows various tube cross sections after bending. The effect of ovality on collapse loads of tube bend models with elliptic and semi oval cross sections increase with the increase in ovality. The FEA analysis software gives hoop stress data for bending radius 30 mm and 40 mm. Then this data is used to plot the graph of hoop stress vs ovality as shown in Fig. 13. These graphs gives information as ovality increase, hoop stress also increased. For bending radius 30 mm, hoop stress and ovality is more compare to bending radius 40mm.



(a) Bending Radius R= 30mm



(b) Bending Radius R= 40mm

Fig. 13 Hoop Stress vs Ovality

VI. CONCLUSION

This research work presents the effect of bending radius, spring back and different bending angle on the bend or deformed cross section of aluminium tube because it have low cost and widely used in various applications. The following specific conclusions are drawn based on results and observations made for the behavior of tube after bend:

- Stresses induced inside the tube bend increases with increase in bending angle and these are maximum at inner surface of the tubes.
- Stresses induced inside tube bend decreases with increase in bending radius.
- Spring back increases as the bend angle increases with constant bending radius due to elastic behaviour. But once it goes into plastic region its decreases since metal tends to stay deformed.
- The effect of ovality is significant, as the ovality is increased in range of 5% to 20% and its influence is more on elliptical cross section.
- Stress analysis carried out for the assumed and actual tube bend cross sections are not comparable. Hence the actual cross sections taken from stress analysis at different bend angle.

Thus above concluding remarks used in tube bending for better design and improve procedure in industry to accept or reject tube bends based on the shape imperfection.

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