Finite Element Analysis Of Composite Elbow Subjected To Combined Bending Moment And Internal Pressure

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ABSTRACT

Pipe bends are considered the critical components of a piping system. When an elbow or pipe bend is subjected to bending load, pipe bend's cross-section tends to deform significantly both in and out of its own plane. This shell-type behaviour, characteristic of pipe bends are mainly due to their curved geometry, accounts for their greater flexibility. This flexibility is accompanied by stresses and strains that are much higher than those present in a straight pipe of the same size and material, under the same loading conditions. Hence, for the purpose of designing and qualifying a pipeline structurally, it is useful to have a reliable estimate of their load-carrying capacity, along with a deep understanding of their structural behaviour until instability, under different and combined loading conditions.

The primary goal of this research is to study the elastic behaviour of pipe bends, under in-plane moment loading. It is also required to study the effects of internal pressure. The finite element method is used, throughout the present work, to model and analyse the pipe elbow subjected toInternal pressure varying from 0% to 40% of the yield pressure in increments of 20%. The results of these analyses are presented in the form of load deflection plots.

The analysis work has been extended to the above stated component made up of Graphite-epoxy composite. The identical boundary conditions have been considered. The behaviour of the composite elbow under the varying loading conditions is believed to be good compared to the conventional one. The work helps towards the potential replacement of the conventional one with the new proposed elbow.

INTRODUCTION

Large pipelines are most commonly found in petroleum rigs, refineries, factories producing chemicals and pharmaceuticals, and in power plants.

Pipes are very often used to carry substances that, by virtue of their pressure, temperature, physical and chemical characteristics, can have serious negative effects on health, property and the environment, if released into the atmosphere. Examples of such substances include steam, oil and chlorine gas.

Stresses in the piping systems are developed due to dynamic loads, of seismic origin or generated by a defective attached device (e.g. pump or compressor), and thermal loads, which cause different pipe segments to expand, also create stresses within the piping system. In general, dynamic and thermal loads are more important, and more complex to deal with. Hence, it is vitalthat some means or mechanism, for relieving these stresses, be present in the design of a piping system, to avoid overloads which might in turn lead to failure of a pipe segment, or cause damage to an attached device, vessel or support.

Because of increased flexibility in pipe bends, they are forced to accommodate large displacements arising from the differential thermal movements. However, care must be taken so that deformations of the bend remain predominantly elastic. Otherwise, the resistance to deformation may decrease rapidly leading to the failure of the system. It is, therefore, important to know its limit load

At the limit load, the deformation of the elbow increases without significant increase in load. Different studies had earlier been carried out to evaluate the limit loads of elbows.

It has been known for a long time, that the flexural rigidity of pipe bends is smaller than that of a straight pipe of the same material and dimensions. This added flexibility embrace a shell-type behaviour that is not displayed significantly by straight pipes, which tend to behave like beams instead of shells. Because of this characteristic behaviour, the bend's cross-section abandons its original roundness, turning into an oval shape. In addition, the bend's initially plane cross-section tends to deform out of its own plane, which also provides some additional flexibility. These two deformation patterns are termed "ovalization" and "warping", respectively.

For this reason, pipe bends are considered the critical components in the piping system, and hence it is necessary, to be able to predict their response accurately, and to have a deep understanding of their elastic-plastic behaviour under different types of loads.

In addition to experimental investigations, several attempts have been made using analytical and numerical approaches, to gain a deeper understanding of the problem, based on which safer and more reliable design codes and practices can be formulated and adopted.

The simplest loading configuration is when the pipe bend is loaded in its own plane, either in the opening or closing direction; i.e. the load tends to reduce or increase the curvature of the bend's centre line, respectively. Due to its simplicity, most of the work previously done in this area was focused on this specific case, extending it to include internal pressure effects and/or end-constraints.

Objectives of the Study

1. To carry out Experimental investigation for the 90 degree elbow.
2. To carry out finite element analysis for the 90 degree elbow of made of graphite/epoxy composite (cross ply).
3. Comparison of results with that of steel elbow.

Methodology

The parametric study was made on the 90 degree elbow specimen by using the FEA software and validation of the result by using the experimental investigation on the above stated specimen. The extended work is also carried out for the elbow made of Graphite-epoxy composite material, the behaviour of the component under different loading conditions were studied.

EXPERIMENTAL STUDY ON 90 DEGREE STEEL ELBOWS

In this section, the behaviour of a pipe bend under in-plane loading, obtained from a finite element analysis, is compared to its behaviour, under similar conditions, obtained experimentally. The purpose of this comparison is to verify that the code used in ANSYS, and its shell element in fact simulate the real behaviour of pipe bends accurately, and that they have been used adequately in the modelling and analysis of the problem, throughout this study.

Fabrication of experimental setup

A standard size stainless steel elbow is used, which is having a diameter of 65mm, bend radius of 110 mm and a thickness of 2 mm. For the loading condition a straight pipe segments of same material is welded at either sides as shown in figure 2. For fixing the setup a base plate having 10 mm thickness of mild steel is welded at one end of pipe and for loading the other end is clamped. This hole set up is mounted on Universal Testing Machine with T-bolts.

A strain gauges are mounted for measure the strain and a dial Gauge is fixed to measure the vertical deflection. This is shown in Figure 2.

Fig 2: Pipe elbow with strain gauges

Experimental procedure

In this static test experiment was done without internal pressure due to some experimental constraint. A gradual in plane loading of elbow is done by increasing the loading valve of the UTM. Specimen was loaded with an external force of sufficient magnitude to produce predominantly elastic response. The magnitude of the load varies from 0 to 500N with an incremental load of 50N. The dial indicators readings were the primary source for response determination and the end deflection in the study, and the strain gauge data were used for measurement of strains at the elbow.

During this elbow response such as deflection and strains are measured through dial indicator and strain meter. The results of Strain versus load and load versus deflection are obtained by experiment and FEM are plotted as shown in figure 3(a)and 3(b) respectively. From the figure 3(b) it seems that the end deflection of the elbow increases with increase in the load. The results obtained from the FE analysis are closer to the experimental results. Hence the system is validated.

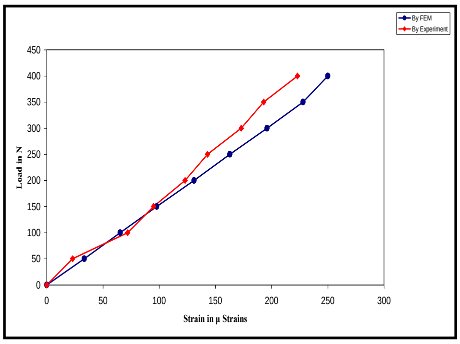

Fig.3(a) Load versus Strain of the 90 degree steel elbow

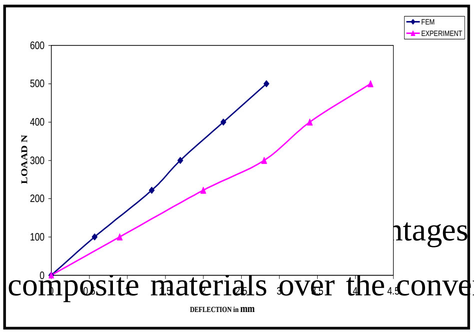

Fig . 3(b) Load versus Maximum deflection of the 90 degree steel elbow

...ntages of the composite materials over the conventional materials the study has been extended to analysis of elbow made of graphite/epoxy material.

The mechanical properties of the 0/90 cross ply graphite/epoxy composite material are given in Table 1.

Table 1: Material properties of Composite

	Property	Value
Young's modulus	E_{11}	181.00 GPa
	E_{22}	7.24 GPa
	E_{33}	7.24 GPa
Poisson's ratio	ν_1	0 .3
	ν_2	0 .36
	ν_{31}	0 .3
Torsional rigidity	G_{12}	3.62 GPa
	G_{23}	3.62 GPa
	G_{31}	3.62 GPa

Validation and convergence checks considering Pinched Cylinder problem

To ascertain the capability of the elements for use in pipe analysis, a thorough convergence and validation checks is carried out by comparing the results with standard problem available in literature.

Pinched cylinder is a standard problem found in literature for the analysis of shells. Hence the same is considered for the validation check of the present element used for the analysis of the elbow pipe. The geometry and material properties of the pinched cylinder are given below. A straight cylinder which is having length to wall thickness ratio (L/R) =2, supported at the ends by shear diaphragms. The material properties are as follows,

1. Isotropic material

   $E=2\times10^5$ MPa ; $\nu = 0.3$

2. Graphite/epoxy

$$\frac{E_{11}}{E_{22}} = 25, \frac{G_{11}}{G_{22}} = \frac{G_{31}}{G_{22}} = 0.5$$

$$\frac{G_{23}}{E_{22}} = 0.2, \upsilon_{12} = 0.3, k = 0.8333$$

A typical pinched cylinder is as shown in the Figure 4.

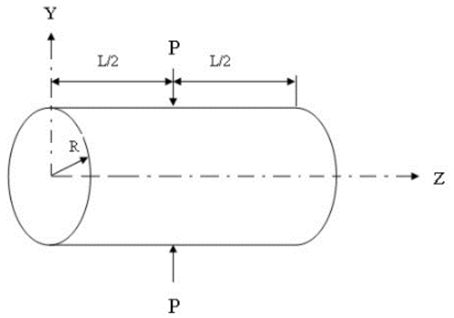

Figure 4 Geometry of Pinched cylinder

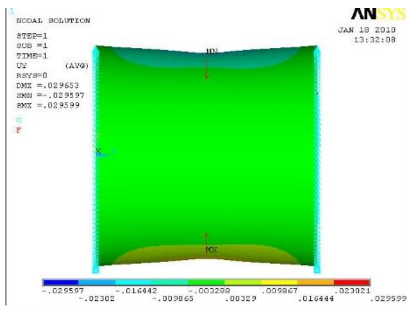

Figure 5 Deflection at the middle in

For this pinched cylinder the analysis was carried out by using shell elements (shell63, shell99) and the loading conditions are as shown in Figure 4. The magnitude load of 200N applied, the Y-component of deflection characteristics at the center of the cylinder is studied and Y-component of deflection is shown in Figure 5.6. The results obtained from this analysis are shown below.

The standard formula for determining the deflection, which is dimensionless quantity given by,

$$\overline{W_c} = \frac{E_{11} \times W_c \times t}{P}$$

Where $\overline{W_c}$ dimensionless quantity

E_{11} Modulus of elasticity

w_c Deflection at section c in mm

t Thickness of the cylinder

P Concentrated load in Newton

For this model $\overline{W_c}$ = -146.170 from [6]

From the above equation deflection at the loading point is computed and used for validation.

The results from analysis are compared with the published results [6] and are shown in the Table 2.The results are found be closer and above work is validated.

Table 2 Deflection $\overline{W_c}$ of a pinched Cylinder

Material used	Present $\overline{W_c}$	FROM [6]	% Difference
0/90	-133.94	-146.170	8.4
Isotropic	-12.1	-11.34	6

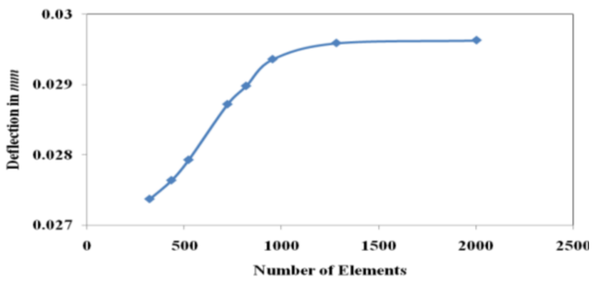

Figure 6 Convergence of the pinched cylinder results

The convergence of the solution, i.e. the influence of the number of elements on the convergence towards a common solution is as shown in the Figure 6, and it seems that the results are quite satisfactory.

6.4.1 Effect of Load on Stress and deflection of 90 degree elbow

The elbow is made up of Graphite/epoxy is studied under the similar loading and boundary condition. In the initial phase the fibre orientation is taken as 0/90 cross ply graphite/epoxy material of same thickness (t=3mm) and similar elbow geometry is used for the analysis. In this case also initially the analysis is carried out with zero internal pressure, and then the pressure is varied to 20% and 40% of the yield pressure. For 600N loading the Von-Mises stress distribution is shown in figure 7.

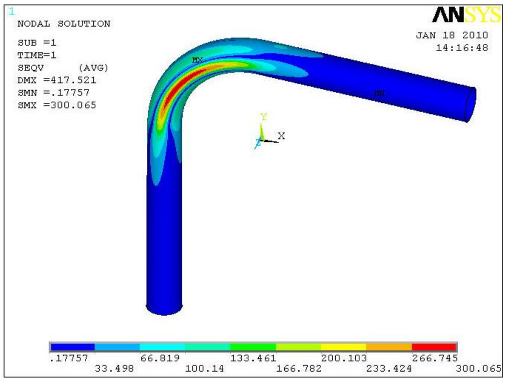

Figure 7 Von-mises stresses distribution in composite elbow

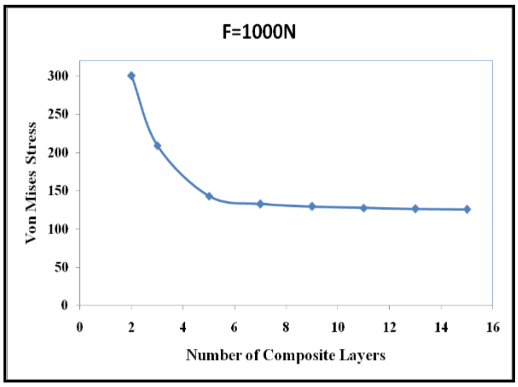

Fig 8 Von-Mises Stress v/s Number of Composite Layers

The variation of Von-Mises stress and deflection is studied by increasing the composite layers. Initially the number of layers are increased in the composite elbow keeping the layer thickness constant. In elbow system as layers increases the considerable amount of von mises stress reduces till certain number of layer (up to 10 number of layers) and after by increasing the layers, the slope of curve become flatten and not much reduction of stress and deflection is found. The graph, figure 8 shows variation of Von-Mises stress with respect to increment of layer in composite elbow.For 800N loading the Y-component of rotation of the elements in composite elbow is shown in figure 9.

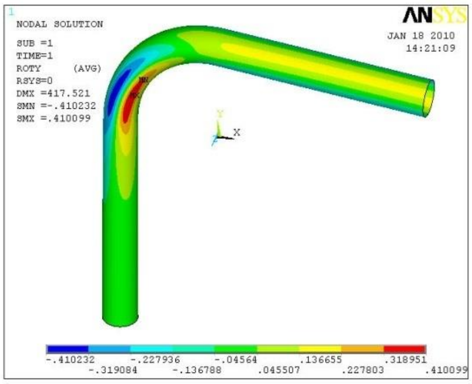

Figure 9 Y component of rotation in composite elbow

The maximum rotation of the elements in the composite elbow under incremental external bending load and internal pressure(0%, 20%, 40%P_y) results are obtained and represented in graph, shown in figure 10.

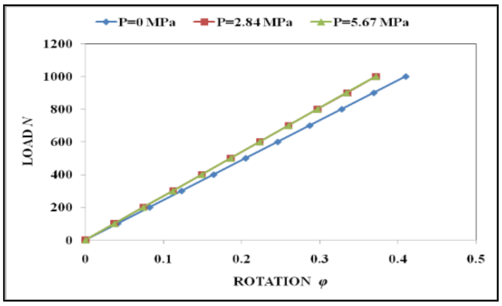

Figure 10 Load v/s Y-component Rotation of the composite elbow

Conclusions

In the present work a parametric study is made on elbow which is made of composite material, an orthotropic material where. Stresses and deflections are obtained by using FE package and results are compared with experimental procedure.

From the studies made the following conclusions can be made

1. Linear analysis of steel elbow reveals that the maximum stresses are obtained at 45° plane in the junction where vertical and horizontal pipe meet. Also unlike curved beams in which stresses are maximum in extreme fibres (top and bottom), the experiment and finite element analysis reveals that the stresses are found to be maximum in the fibres of side walls of the elbow.
2. Study of 90 degree elbows with and without internal pressure reveals that the pipes are more stiffer with the presence of internal pressure, as compared to pipes without internal pressure. Also, the stresses induced at critical cross-section are found to decrease with increase in internal pressure. This may be due to the fact that ovalization is reduced with the presence of internal pressure.
3. Non-linear analysis reveals that, the deflection and rotations obtained are slightly higher to that obtained in linear analysis for the same geometry and loading even in the elastic region.

4. The study of composite elbow reveals similar behavior as that of steel elbow, the variation of stress and deflection against load for two layered (0/90) Graphite/epoxy pipe bend are studied and load carrying capacity of the composite elbow is found to be slightly lesser than the steel elbow.
5. Experimental study on a steel elbow subjected to bending load (with zero internal pressure) reveals that, the value of strain and deflection obtained experimentally compares well with those obtained by finite element analysis.

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