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Numerical Analysis of Elastic Stress Due to Internal Pressure in Elbow Pipe

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ABSTRACT

A thick-walled 90° elbow pipe is of particular interest due to its frequent usage in industrial systems such as chemical processing plants and petroleum refineries. Elastic stress analysis of thick walled pipe elbows using finite element computer software, such as ABAQUS was investigated. The current study shows that the stress level is influenced by the effects of the ratios of bend radius to pipe mean radius (R/r_m) and mean radius to wall thickness (r_m/t) and value of internal pressure. The investigation is limited to include the elastic stresses due to internal pressure and stress variation which was found to be similar to that of a theoretical study reported in the literature. The stress along a thick-walled 90° elbow pipe with the increase in the inner radius, thickness and pressure increases the stress. Based on the variance analysis, the predictive models in this study are believed to produce values of the elastic stress of a thick-walled 90° elbow pipes close to those readings recorded numerically with a 96.5% confident interval.

Introduction

In the power, chemical and various other industries where piping systems are used, the structural integrity and cost of pipelines are of major concern. Piping systems are composed of various components such as straight pipes, elbows or curved pipes, branch connections, flanges etc. Elbows are commonly regarded as critical components in a piping system since they are not only help to change the pipe line orientation, but also increase the flexibility of the piping system, However elbows can be subjected to severe thermal, seismic, pressure, and other mechanical loads, and for this reason an increasing amount of attention has been given to their analysis to determine the collapse load to ensure that it is not reached since, a small increase of the load will cause large deformation, which may cause the entire piping system to undergo excessive deformation or deflection [1].For thin-walled elbows under internal pressure, an analytical elastic stress solution was derived by Goodall [2] (see also Miller [3]), from which a limit pressure solution was derived. Regarding limit pressures, the authors and co-workers [4], [5], [6], [7] and [8] recently performed extensive three-dimensional (3-D) finite element (FE) limit analyses based on an elastic-perfectly plastic material to refine the analytical limit pressure solution proposed by Goodall [1]. This paper structured as follows: In section II, investigated to represent the finite element analysis. In Section III, investigated a theoretical model to represent the finite element program ABAQUS. In Section IV, the results of numerical simulation have been simulated and discussed. Finally, the conclusion of current work is reported in section V.

Finite element analysis

Analytically, may be considered as sections a thick-walled a 90° elbow. They are basically defined by a bend radius R, a cross section radius r, wall- thickness t, ϕ as the coordinate in the circumferential direction of an elbow, and arc angle a as shown in Figure 1. Important non-dimensional variables related to the bend and pipe geometries are (R/r_m) and (r_m/t) for systematic analysis.

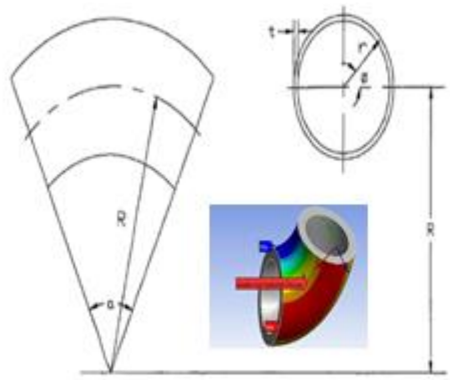

Figure 1. Illustration of a curved pipe

Where θ denotes the angular coordinate along the circumference (Figure 1), varying from $\theta =$ 0 at the extrados to $\theta = \pi$ at the intrados. In this paper, systematic elastic finite element (FE) analysis is performed to determine the elastic stress distribution in a thick-walled a 90° elbow under internal pressure based on wall thickness, inner radius and bend radius .The determination of stress distribution is to be obtained by conducting systematic use of simulation program named ABAQUS that use FEM for the analysis of elastic stress.

The general purpose FE programme ABAQUS [8] was used. The materials were assumed to be isotropic elastic with Young's modulus E and Poisson's ratio ν. Although values of E=193.74 GPa and ν=0.2642 were used, following the measured response of type 304 stainless steel at room temperature, as reported by Sobel and Newman (1979) throughout this study [9]. A quarter models were used considering symmetry. To reduce the computing time, twenty-node iso-parametric quadratic brick elements with reduced integration (C3D20R within ABAQUS) were used. Figure 2 depicts a typical FE mesh, employed in the present work. Four elements were used through the thickness, and the number of elements and nodes is 30,200 and 208,425, respectively. Internal pressure was applied as a distributed load to the inner surface of the FE model, together

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with an axial tension equivalent to the internal pressure to simulate a closed end.

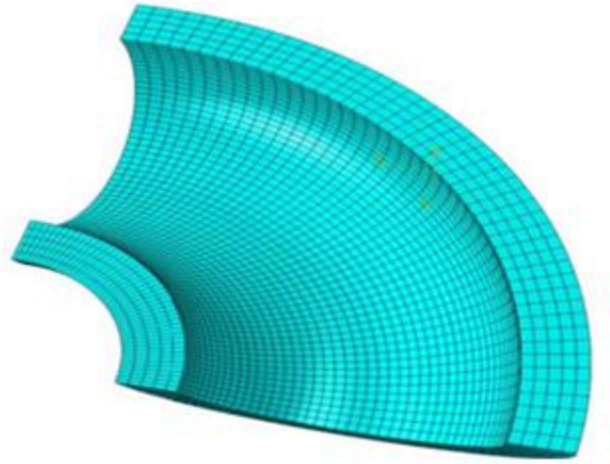

Figure 2. Typical finite element mesh of an elbow

The Finite element Models

The finite element program ABAQUS used to models the plane 90° elbows pipe in this paper. Table 1 shows completed information to start for the computer simulation of all 27 models these dimensions were extracted from practical dimensions of pipe line that are widely used in the industries and coded in the international engineering standards. The assumed pressure on that elbows we 10, 30, 60 Mpa.

Results and Discussion

In this work, the results for the simulation it was concluded that ABAQUS is a powerful tool in analyzing a thick-walled 90° elbow pipes. Results obtained using a shell element give results for wall thickness results that are very close to previously published data. A number of parameters affect the results, including bend radius R, a cross section radius r, wall- thickness t and internal pressure P. The maximum Von-Mises Stress in a curved tube under internal pressure occurs at the intrados. For a given radius ratio (R/^{r}m), the Max.Von-Mises Stress, has been found to increase with increasing curvature of the elbow pipe, i.e. with decreasing values of R. Larger stresses have also been observed with decreasing radius ratio (R/^{r}m). Taking an example of our simulation result shown in Figure 3 represented by elbow15.

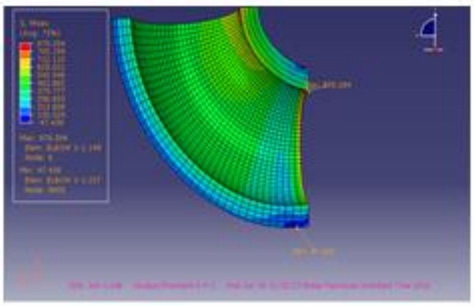

Figure 3. Stress distributions for pressurized 90° elbow pipe

The result of maximum von-Misses stress obtained from the software simulation ABAQUS, are given in Table 2 for the value of internal pressure p=10,30,60 Mpa.for more illustration about these results (maximum von-Misses stress) ,figure 4 described the increasing in a bend radius leads to decreasing in von-misses stresses when the inner radius and thickness were constant (25mm,5mm) ,also observed increasing in stresses when increasing internal pressure with presence same above conditions.figure 5 ,6 explained the affecting of changing in inner radius of tube (40mm,50mm) leads to improved the stresses values .figure 7 showes the increasing in thickness (10mm) on the modelation curves between stresses and bend radius .figure 8,9 illustruted the affecting of inner radius on the relation between stesses and bend radius at constant thickness (10mm) also observed the stresses value were beter for each increasing in thickness.figuer 10 discusse the increasing in thickness (15mm) leads to decreasing stresses vlues . the best improvement for stresses were cleared in figure 11,12 .

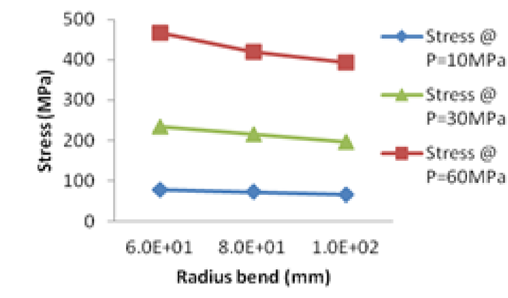

Fig.(4): Von-Misses stresses & radius bend when the thickness (5mm) and inner radius (25mm) are constant

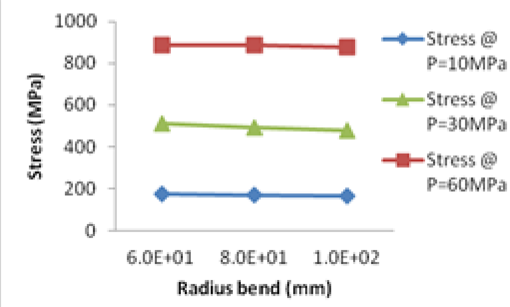

Fig.(5): Von-Misses stresses & raduis bend when the thickness (5mm) and inner radius (40mm) are constant

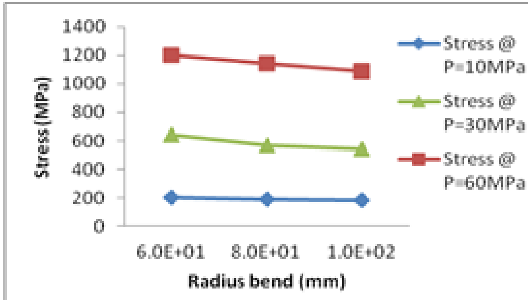

Fig.(6): Von-Misses stresses & raduis bend when the thickness (5mm) and inner radius (50mm) are constant

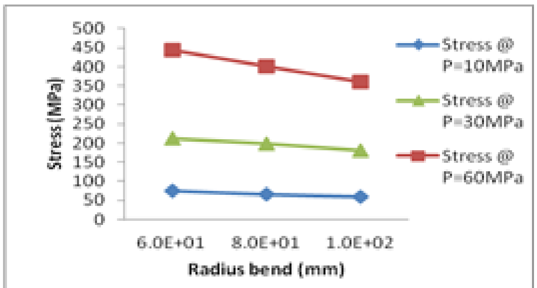

Fig.(7): Von-Misses stresses & raduis bend when the thickness (10mm) and inner radius (25mm) are constant

Table 1. Dimension of Elbow Pipes Used in This Study

Model No.	t mm)	r mm	R mm	Model No.	t mm	r mm	R mm
ELB1	5	25	60	ELB15	10	40	100
ELB2	5	25	80	ELB16	10	50	70
ELB 3	5	25	100	ELB17	10	50	80
ELB 4	5	40	60	ELB18	10	50	100
ELB 5	5	40	80	ELB19	15	25	60
ELB 6	5	40	100	ELB 20	15	25	80
ELB 7	5	50	60	ELB 21	15	25	100
ELB 8	5	50	80	ELB 22	15	40	60
ELB 9	5	50	100	ELB 23	15	40	80
ELB 10	10	25	60	ELB 24	15	40	100
ELB 11	10	25	80	ELB 25	15	50	80
ELB 12	10	25	100	ELB 26	15	50	90
ELB13	10	40	60	ELB 27	15	50	100
ELB14	10	40	80				

Table 2. Stress results with pressure of (p) =10, 30, 60 MPa using ABAQUS

No.	Max. Stress P=10MPa	Max. Stress P=30MPa	Max. Stress P=60MPa	No.	Max. Stress P=10MPa	Max. Stress P=30MPa	Max. Stress P=60MPa
1	78.139	234.4	468.1	15	93.788	289.56	562.7
2	71.562	214.6	420	16	102.5	310.3	612.5
3	65.44	196.3	394.12	17	93.66	289.11	593.66
4	171.173	513.5	888.9	18	84.07	252.98	554.42
5	167.55	493.5	885.1	19	45.162	135.48	270.97
6	165.6	478.8	878.284	20	44.163	132.18	264.063
7	203.33	640.1	1200	21	43.483	130.44	258
8	189.011	567.1`	1139.9	22	83.186	199.70	499.134
9	181.836	545.5	1090.8	23	71.961	189.29	460.1
10	74.56	213.2	444	24	66.10	185.796	416.6
11	66.03	198.1	401.2	25	70.66	214.42	425.12
12	60.367	181.1	360.367	26	64.6	189.97	384
13	105.199	315.6	631.9	27	59.4	175.6	361.01
14	96.520	295.65	579.9				

Table 3. Summary of output

Regression Statistics	
Multiple R	0.98234935
R Square	0.965010245
Adjusted R Square	0.956845969
Standard Error	57.65780295
Observations	75

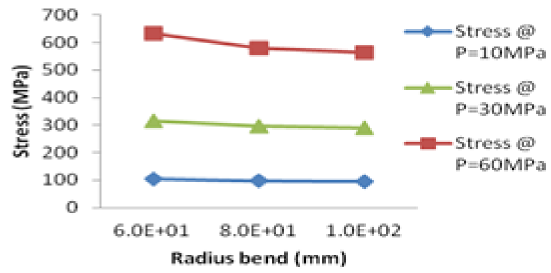

Fig.(8): Von-Misses stresses & radius bend when the thickness (10mm) and inner radius (40mm) are constant

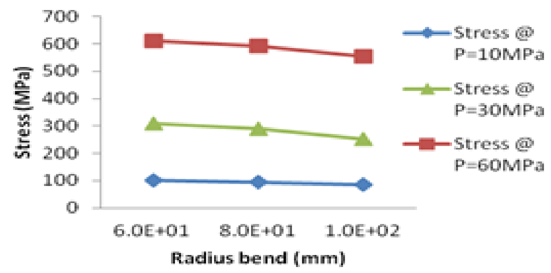

Fig.(9): Von-Misses stresses & radius bend when the thickness (10mm) and inner radius (50mm) are constant

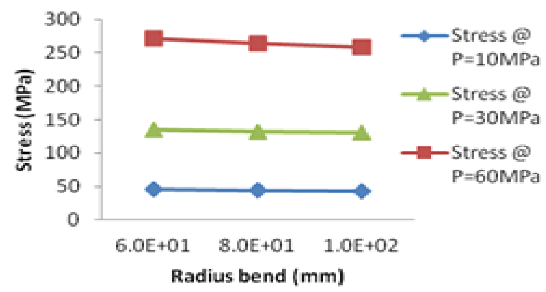

Fig.(10): Von-Misses stresses & radius bend when the thickness (15mm) and inner radius (25mm) are constant

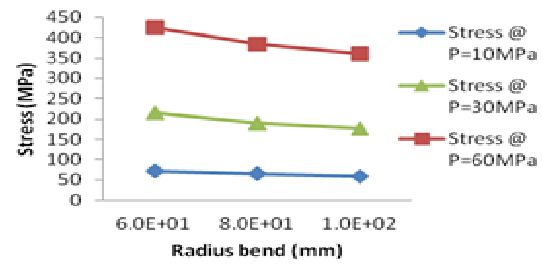

Fig.(12): Von-Misses stresses & radius bend when the thickness (15mm) and inner radius (25mm) are constant

Analysis of variance (ANOVA) methods are used to estimate the coefficients of the second order model equations, and to check for the significance effect. The empirical model was developed for each response which correlated the response with preparation variables by applying a second degree polynomial equation . This can be represented by following :

$$Y = b_0 + \Sigma_{i=1}^{n} b_i x_i + \left(\Sigma_{i=1}^{n} b_{ii} x_i\right)^2 + \Sigma_{i=1}^{n-1} \Sigma_{j=i+1}^{n} b_{ij} x_i x_{ij}$$

where,
Y = The predicted response
b0 = The constant coefficient
bi = The linear coefficients
bij = The interaction coefficients
bii = The quadratic coefficients respectively
xi, and xj = The coded values for thickness ,inner radius , bend radius ,and pressure.

The summary output is presented as follow in Table 3. Response surface methodology (RSM) resulted in empirical formula for stress in thick wall pipe elbows under internal pressure: STRESS = [-776.036 + 13.996* Thickness + 41.688 * Inner Radius - 1.596 * Bend Radius + 10.577* Pressure + 1.664* Thickness* Thickness-0.332* Inner Radius* Inner Radius + 0.024 *Bend Radius* Bend Radius+ 0.003 * Pressure* Pressure-1.318* Thickness* Inner Radius+ 0.013*Thickness*BendRadius+0.756*Thickness*Pressure0.057 *InnerRadius*BendRadius+0.267*InnerRadius*Pressure-0.044*Bend Radius*Pressure]. The most straightforward way to characterize the nature of the response surface is to examine a contour plot of the fitted model, if there are only two or three process variables.

Conclusion

In this paper, a simple and realistic FEM model for the stress analysis of a thick-walled 90° elbow pipe has been investigated use of simulation program named ABAQUS that use FEM for the analysis of elastic stress under effect of parameters priority such as wall thickness, inner radius, bend radius and effective internal pressure. The results obtained through finite element analysis have been used with the Analysis of variance (ANOVA) methods to estimate the coefficients of the second order model equations, and to check for the significance of each terming the model used Statistical analysis using MINITAB version 14 is performed for each of the four characteristics. Finally, it can be developing an empirical formula to predict the stress in thick wall pipe elbows which helps to evaluate the significance of the design parameters.

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