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PERFORMANCE ANALYSIS OF STEEL PIPE BENDS

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ABSTRACT

Research on design of pipes has gained importance from the last decade. The pipe tends to flatten when they are forced to bend and this geometrical change has a significant role in the pipe design. It is necessary to bend pipes in order to transmit liquid or gas from one place to other. In the present study, special attention has been given to pipe bends with high stress concentration due to different loading conditions. Thus the process piping systems has been chosen for the analysis as they were used to transport hazardous materials. The damage to such piping system can cause serious loss to economy and human lives. The geometrical imperfection associated with bending of pipes is ovality and the degree of ovality determines the acceptance of pipes. Thickening and thinning effect causes additional problems like large plastic deformation and loss of flexibility respectively and hence the estimation of best degree of ovality is required. In this work effect of ovality is estimated by taking the internal fluid pressure and in-plane bending moment into account. The optimum percentage of ovality which is desired for pipes has been estimated. The cross section of the pipes at the mid plane of the pipe bend is modeled with different percentages of ovality (six models) and structural analysis is performed. Based on the results (Deformation, Von Mises Stress and Stress Intensity) an optimum percentage of ovality is found out. In the present study the results are evaluated and compared for three factors deformation, stress intensity and percentage of ovality in the pipe bends.

Key words: Pipe bends, Imperfection, Ovality, Analysis.

INTRODUCTION

Around 70% of cost spent in piping industry is on pipe manufacture with optimum design of pipes without defects. Pipe bends are the most critical region in pipes since they obstruct and deviate the fluid flow. Thinning and Ovality are commonly observed irregularities in pipe bends which induce higher stress than perfectly circular cross section (A. R. Veerapan & S. Shanmugam, 2010). Piping Industries transport fluids at very high temperatures and pressures which add an extra load on weak spots (bends). Pipe bends are

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subjected to high levels of stress concentration and inappropriate design would lead to failure. The pressurized piping used for an extended period may develop degradations such as wall thinning or cracks due to aging (Izumi Nakamura & Akihito Otani 2011).

Sophisticated piping systems are used to process and carry hazardous substances. The pipelines carry crude oil from oil wells to tank farms for storage or to refineries for processing. The bending load has been applied reduced the bend angle and in turn the resulting cross section ovalisation lead to recognize weakening mechanism (Neilson and Wood 2010). The design, construction, operation, and maintenance of various piping systems involve understanding of piping fundamentals, materials, generic and specific design considerations, fabrication, installation, examination, testing and inspection requirements. Reasonable life predictions can be obtained based on steady state peak stresses compared with the life predictions obtained with creep damage modeling (Yun-Jae Kim & Chang Sik-Oh 2005).

Analysis of pipe bends

Steam reforming is the most widespread process for the generation of hydrogen-rich synthesis gas from light carbohydrates. The device in which hydrogen is extracted is called a reformer. The feed materials natural gas, liquid gas or naphtha is endothermically converted with water steam into synthesis gas in catalytic tube reactors. Process heat as well as flue gas are used for the steam generation. The pipe lines are subjected to very high loads. Hence the pipes are made out of high cost alloys. The pipes used in these plants are generally formed using bending. These pipes have shape imperfections and hence inherit many problems. The material used here is Incoloy800 which is high cost material and the hazardous nature of the plant necessitates the need for optimum design of pipes. The INCOLOY 800 series of alloys, invented by the Special Metals Corporation Group of Companies, is the result of years of monitoring and maintaining the ultimate chemical properties for high-temperature strength and resistance to oxidation, carburization and other types of high-temperature corrosion.

A structural analysis is performed on pipes made of Incoloy 800. This analysis is to be performed on pipes which are being bent by cold bending processes. The pipe bends are the areas of stress concentration due the shape imperfections formed as a result of bending and the thickening and thinning effects. Hence the cross section at the mid plane of the pipe bend is taken for analysis as the undesired effects were maximum at this region. Six different models of cross sections with the varying ovalities are being modeled using Pro E Wildfire 5.0. The values and the parameters used for analysis are mentioned. These values are obtained from ASME 31.3 Process Piping Guide. In the past, FEA has been performed to study the effect of cross section approximation on the behavior of pipe bends with shape imperfections under internal pressure. Finite element analyses were performed on a cross sections and the hoop stress induced due to internal fluid pressure load was obtained for models (Christo Michael et al., 2011).

The CAD models are imported to ANSYS APDL 12 and only a half of the cross section is modeled since it is axis symmetric. Solid Brick Node Elements has been chosen for the element type and Axis symmetric boundary condition has been carried out. The bend is assumed to have a bend angle of 90º and the bend radius is taken as 250 mm. The temperature and pressure in the setup is assumed to be 100ºC and 27 N/mm^2. The Table 1 presents the details of the dimension in the pipes used for modeling. The internal fluid pressure exerted by the fluid is applied as pressure on the inner wall of the pipe. Both the end of the pipe's cross section is fixed (all DOF arrested). Then an edge pressure equal to the internal pressure of the fluid is applied on half of the cross section to indicate the extrados region.

Table 1: Dimensions of pipes

S. No.	Pipe parameters	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
1	Pipe material	Incoloy 800 ASTM B407					
2	Inner diameter (max)	35.6	36.26	36.6	37.19	38.25	39.3
3	Inner diameter (min)	35.6	34.14	33.8	32.97	31.92	30.86
4	Inner thickness (max)	3.56	3.66	3.7	3.916	4.1	4.27
5	Inner thickness (min)	3.56	3.46	3.4	3.204	3.07	3.27
6	Outer diameter (max)	42.2	43.26	43.9	44.31	45.37	46.42
7	Outer diameter (min)	42.2	41.14	40.5	40.09	39.035	37.98
8	Bend radius	250 mm					
9	Bend angle	90 degrees					
10	Percent of ovality	0	5	8	10	15	20
11	Working pressure	27 N/mm^2					
12	Working temperature	100 degree centigrade					
13	Poisson ration	0.3					

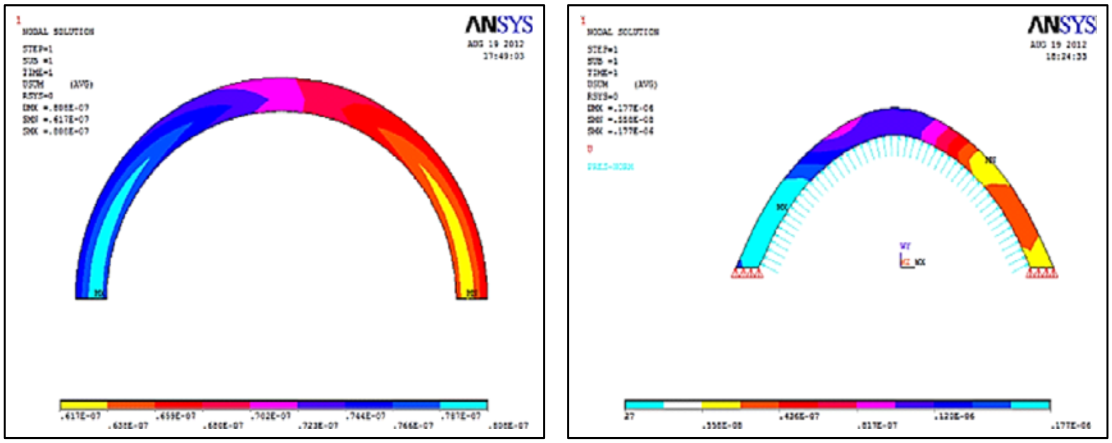

Fig. 1: Deformed pipe bend

RESULTS AND DISCUSSION

The Analysis has been carried out using ANSYS software and the results have been presented here. The Fig. 1 presents the deformed pipe bend of a model with Zero percentage ovality shown in the Table 1. The deformation is maximum (0.808 mm) for the zero percentage ovality. The deformation here refers to the permanent plastic deformation that occurs in a pipe line. The minimum deformation (0.167 mm) is observed at five percentage ovality. The deformation then goes on increasing with increase in percentage of ovality.

Table 2: Structural analysis results

% Ovality	Deformation (mm)	Total stress intensity (Mpa)	Von misses stress (Mpa)
0	0.808	961.93	1275
5	0.167	966.83	1582
8	0.177	961.93	1585
10	0.176	980.02	1580
15	0.258	929.31	1703
20	0.306	936.27	1700

The Table 2 presents the output of the ANSYS software for the analysis carried out. The deformation and the resultant stresses have been presented for pipe bends with different ovality. The stress intensity has no dependence on the percentage of ovality. The stress intensities are high on the inner surface of the pipe which is evident from the fact that this surface is exposed to the fluid pressure. The Von Misses Stress signifies the resultant of forces acting at a particular point. The Von Misses Stress is minimum at zero percentage ovality and then on its value increases with increase in ovality. From the above inferences the percentage of ovality, which gives the minimum plastic deformations at the pipe bend and minimum stresses induced is five percentage ovality.

CONCLUSION

Shape imperfections in the pipe bends were considered as the major problem. The pipe bends are analyzed with taking a particular application of hydrogen reformer. The pipes are modeled with different degrees of ovality and analyzed so as to identify the best one ovality level for long life of pipes. From the analysis it is found that five percent ovality on the pipe bends produce the least amount of plastic deformations and optimum amount of stress. This is due to the reason that the mandrels present inside the pipe prevents the pipe cross section at the bends to change into an elliptical one. Further the effect of thickening and thinning are also very low in this bending process. The optimum amount of ovality (5%) also fixes the optimum value of thickness at the extrados of the pipe after bending. Hence the pipe bends in process piping applications are analyzed for performance under hazardous applications. Thus in the present study the optimum percentage of ovality which is desired for pipes is estimated.

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