Applied Mechanics and Materials
ISSN: 1662-7482, Vol. 787, pp 296-300
doi:10.4028/www.scientific.net/AMM.787.296

Submitted: 2015-02-07
Revised: 2015-04-27
Accepted: 2015-04-28
Online: 2015-08-28

Performance analysis of thin shell bends under high pressure and temperature

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Keywords: Pipe bends, ovality, thickening, thinning

Abstract

Around 70% of the cost in piping industry is spent in the pipe manufacturing with optimum design of pipes without defects. Research on design of pipes has gained importance from the last decade. There are numerous methods being developed to improve the efficiency of piping units considering various parameters. The pipe tends to flatten when they are forced to bend, this geometrical changes has a significant role in the acceptability criteria of pipes. It is necessary to bend pipes in order to transmit liquid or gas from one place to other place. In this work special attention is given to pipe bends because of high stress concentration due to various loading conditions. From several kinds of piping systems, process piping systems are chosen for analysis since pipes used here transport important and hazardous materials. Damage to such piping system can cause serious loss to economy and human lives. The geometrical imperfection associated with bending of pipes is ovality. This degree of ovality determines the acceptance of pipes. Thickening and thinning effects cause additional problems like large plastic deformation and loss of flexibility respectively. Hence estimation of the 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.

Introduction

Piping Systems: Piping systems are like arteries and veins. They carry the lifeblood of modern civilization. In a modern city they transport water from the sources of water supply to the points of distribution; convey waste from residential and commercial buildings and other civic facilities to the treatment facility or the point of discharge. Yun Jae Kim and Chang Sik Oh[1] found out approximate solutions for pipe bends under combined internal pressure and bending. Izumi Nakamura and Akihito Otani[4] found that pressurized piping used for an extended period may develop degradations such as wall thinning or cracks due to aging. Neilson and Wood[7] presented a comparison on plastic limit collapse loads from experimental in plane bending tests on three 90 degree single un reinforced mitred pipe bends with the results from various 3D solid finite element models. Veerappan and Shanmugam [2] discussed the stresses introduced in pipe bends with different ovalities and thinning for a particular internal pressure. Christo Michael et al. [3] made a comparison between pipe bends with assumed cross sections, namely elliptic and semi oval to include ovality along with wall thinning. Yun-Jae Kim and Chang Sik-Oh [5] analyzed the effects of attached straight pipes on finite element limit analysis for pipe bends. Yun-Jae Kim and Young-Il Kim [6] proposed plastic loads (limit load and twice-elastic-slope (TES) plastic load) for pipe bends with circumferential through-wall and part-through surface cracks under in-plane bending, based on three-dimensional FE limit analyses. Man Gyun Na and Jin Weon Kim [8] addressed the collapse moment due to wall-thinned defects and estimated through fuzzy model identification. The developed fuzzy models have been applied to the numerical data obtained by the finite element analysis

Process Piping Materials

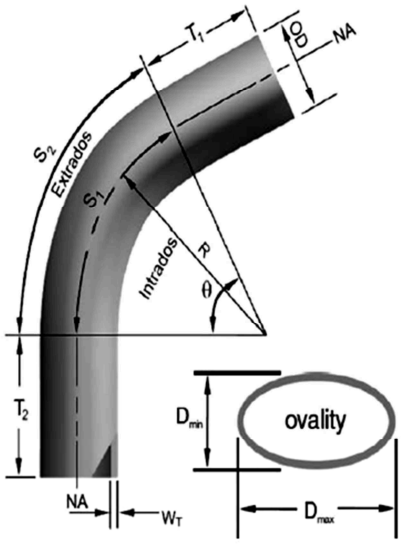
The language of materials can be complicated. During discussions with material specialists, one often has the feeling of visiting a foreign country. Nevertheless, efficient use of B31.3 requires some basic comprehension of Code layout and materials technology, especially material classification systems and material specifications.

Generic Designations

Classification of materials by generic designation involves the grouping of materials into broad categories according to certain attributes such as general composition, mechanical properties, product form or end use. There are no precise rules governing which attributes to apply in defining material groups and the level of detail afforded the classification system depends largely on the level of detail needed to communicate specific ideas.

Consequently, materials may be generically grouped according to very broad characteristics, for example metal or nonmetal, ferrous or nonferrous, cast or wrought. Alternatively, materials may be placed in more narrowly defined generic groups such as mild steel, 3XX series stainless steel etc. With piping materials, generic grouping based on alloy content is most popular. These groups usually reflect the primary alloy content and may include varying levels of complexity depending upon the extent to which one needs to communicate specific material needs.

Pipe Bend Features



R = Bend radius
q = Bend angle
T1, T2 = Tangent lengths
WT = Wall thickness
OD = Outside diameter
D_{max} = Major diameter
D_{min} = Minor diameter
Ovality = $(D_{max} - D_{min})/OD$
NA = Neutral Axis
Strain = $(S_2 - S_1)/S_1$
= $\{(R + 0.5OD) - R\}/S_1$

Fig1.Pipe bend features

Finite Element Analysis

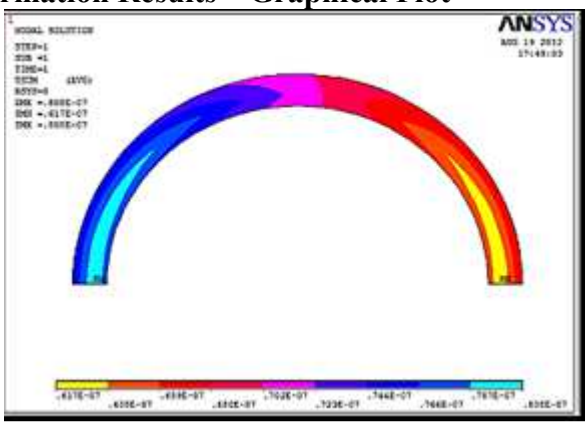
A structural analysis is performed on pipes made of Incoloy 800. This analysis is to be performed on pipes which are being bent by cold bending processes. The pipe bends are the areas of stress concentration due the shape imperfections formed as a result of bending and the thickening and thinning effects. Hence the cross section at the mid plane of the pipe bend is taken for analysis because the undesired effects are maximum at this region. The Nominal Outer Diameter for majority of pipes used in hydrogen reformer plants. For this case the schedule 40 standard is used for finding out the pipe wall thickness. 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 in the table below. These values are obtained from ASME 31.3 Process Piping Guide.

Table 1 Process parameters

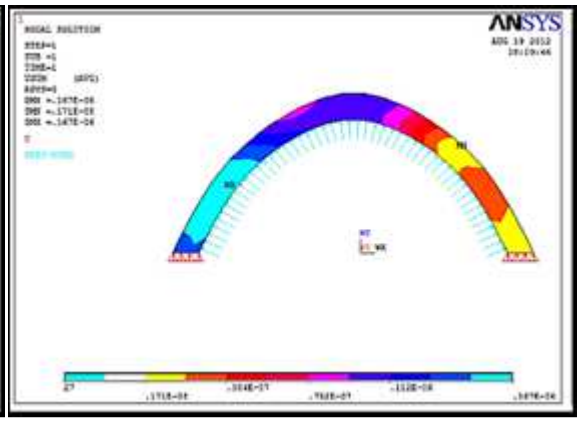
S.No	Pipe Parameters	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
1		Pipe Material			INCOLOY 800 ASTM B407		
2	Inner Diameter(max)	35.6	36.26	36.6	37.19	38.25	39.3
3	Inner Diameter(min)	35.6	34.14	33.8	32.97	31.92	30.86
4	Inner thickness (max)	3.56	3.66	3.7	3.916	4.1	4.27
5	Inner thickness (min)	3.56	3.46	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		

The modeled files are imported to ANSYS APDL 12.0. Only a half of the cross section is modeled since it is axis symmetric. The bend is assumed to have a bend angle of 90 degrees and the bend radius is taken as 250 mm. The temperature and pressure in the setup is assumed to be 100 degree centigrade and 27 Newtons per square millimeter. A fluid flow analysis is to be performed on the pipe (in this case the gases in hydrogen reformer plants). But since the failure nature of the pipe is being studied a structural analysis is required.The element type is selected as solid brick node and the number of elements is 352670 and the number of nodes is 660600 and the boundary condition is axis symmetric. The details of the analysis are listed below.

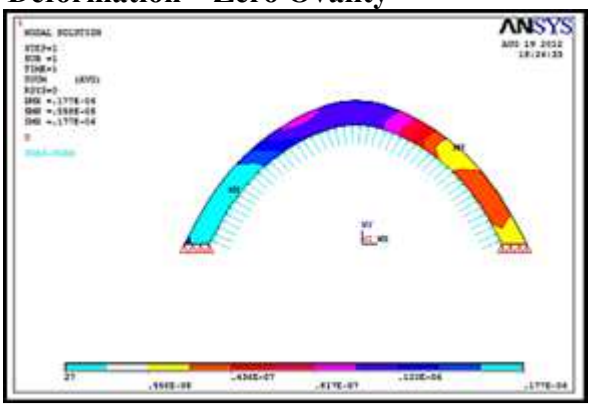
Deformation Results – Graphical Plot



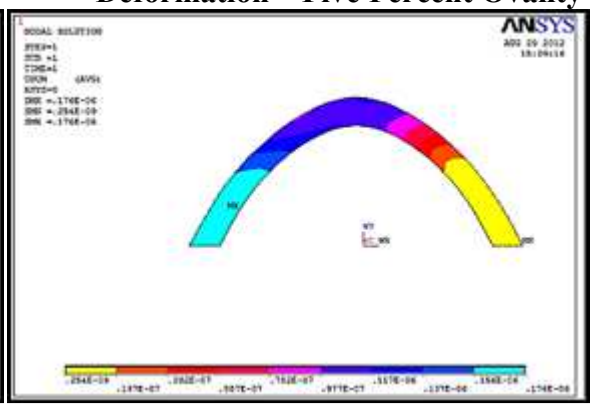
Deformation – Zero Ovality



Deformation – Five Percent Ovality



Deformation – Eight Percentage Ovality



Deformation – Ten Percentage Ovality

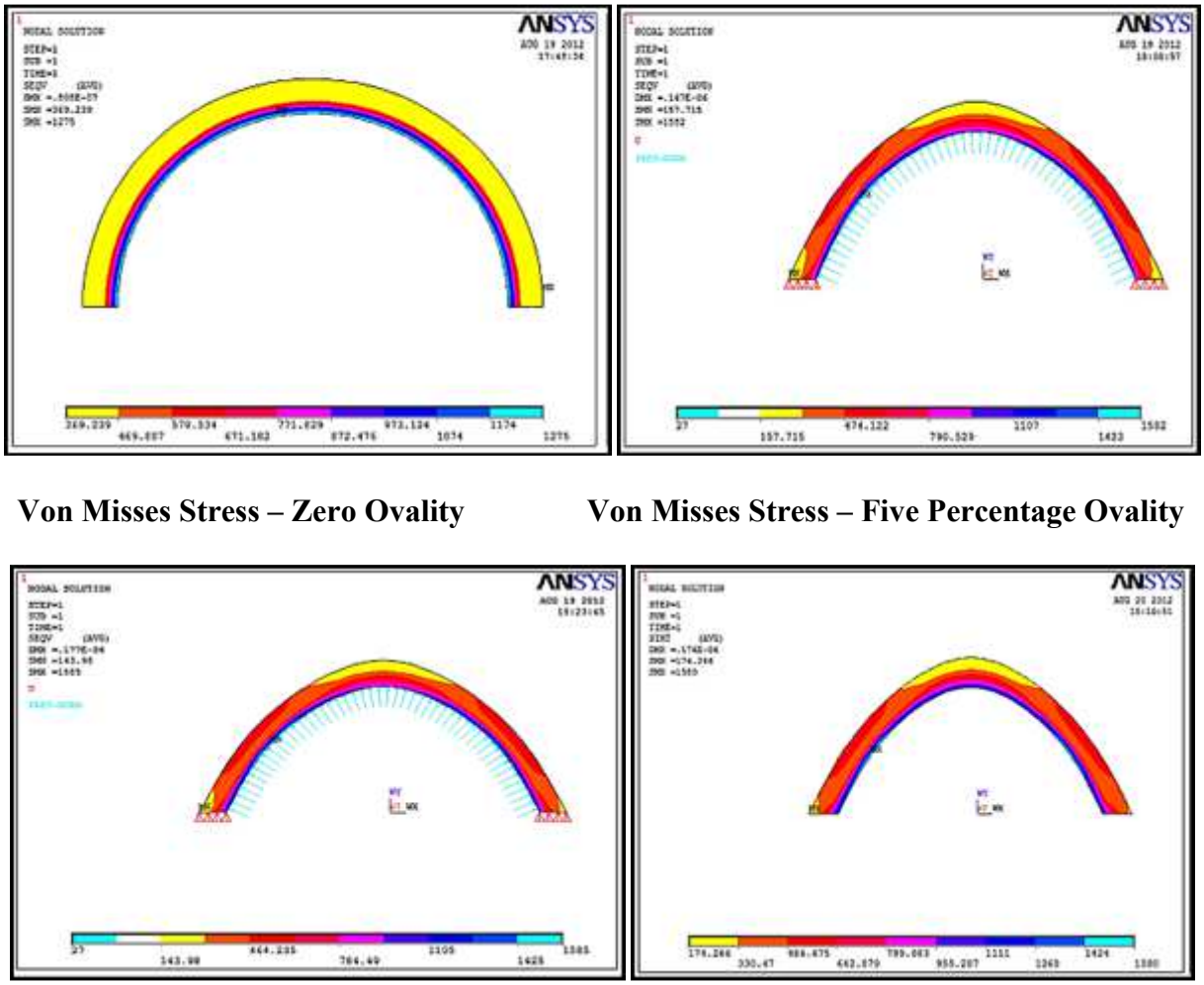
Fig.2. Deformation results

Inference – Structural Analysis

Deformation: The deformation is maximum for the maximum percentage ovality. 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.

Stress Intensity: The stress intensity has high 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.

Von Misses Stress – Graphical Plot



Von Misses Stress – Zero Ovality **Von Misses Stress – Five Percentage Ovality**

Von Misses Stress – Eight Percentage Ovality Von Misses Stress – Ten Percentage Ovality

Fig.3. Von Misses Stress results

Von Misses Stress : 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*

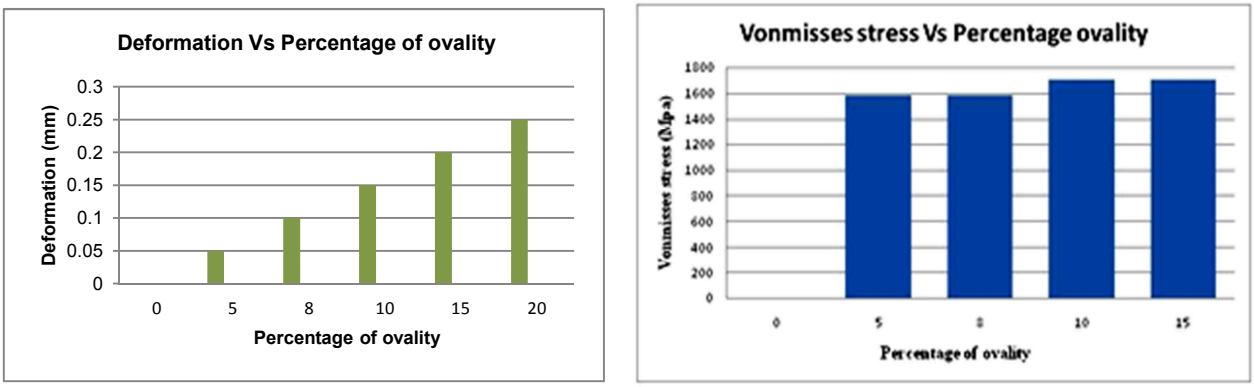


Fig.4.Comparison of Results

Results and Discussion

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 percentage ovality on the pipe bends produce the least amount of plastic deformations and optimum amount of stress. Further the different assemblies used in industries are modeled and were subjected to structural analysis so as to find out the bending assemblies that can produce pipe bends with least percentage of ovality. Further the magnitude of bending must be large enough for the stress intensity developed in the pipe. Out the different setups modeled the rotary draw bending setup provides the optimum amount of deformation and very high levels of stress intensity for a constant load applied. Further the percentage of ovality is very low and further the value is very close to the optimum value as identified from the analysis on pipe bends.

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