

Plastic Hardening Models and Fatigue Life Simulation of Pipe Line Wrinkle Bend

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ABSTRACT: Pipeline elbows and bends are very important parts in a pipeline system. These are curved parts with high flexibility and are acted upon by higher stresses and strains in comparison with the other pipe components. So these parts are critical components in a piping system. Here presents a numerical simulation of effect of plastic hardening models on the stress, strain and fatigue life of a pipe line wrinkle bend which is under operating pressure and cyclic bending moment. The numerical simulation will give accurate result if and only if the material's plastic hardening response and the mechanical behaviors such as Baushinger effect, strain ratcheting etc. are considered properly. The isotropic, kinematic and combined isotropic and kinematic hardening models are applied to the wrinkle bend, which are under cyclic in-plane bending and constant internal pressure to simulate the stress and strain using ABAQUS software. The most appropriate plastic hardening model is selected from the FEA result. Fatigue life is also calculated with obtained result using certain fatigue models which are used generally in pipeline industry.

KEYWORDS: pipe line elbow, wrinkle bend, hardening model, Bausching effect, strain ratcheting, low cycle fatigue

I. INTRODUCTION AND LITERATURE REVIEW

Wrinkle bends are used in large diameter pipeline systems. They may exhibit huge stresses because of changes in internal pressure and temperature deviations. These changes of loading on the bend is resulted in considerable variations of level of stress. This problem is introduced by the additional effect of stress concentration on the inner surface of the small local bends. The evaluation of stresses in a wrinkle bend can be carried out in a similar manner that is used to determine the stresses in bellows convolutions used in the gas ducting of power stations. N W Murray formulated expressions for the bending stresses in a wrinkle bend. A study about inelastic wrinkling and collapse of tubes under combined bending and internal pressure has carried out by Limanm [1]. He carried out a systematic series of experiments involving bending of SS-321 tubes with $D/t = 52$ under internal pressure. Bending leads to ovalization of the pipe cross section but internal pressure tends to reduce it and at the same time, expansion is taken place. Following some plastic deformation, small amplitude axial wrinkles forms in the compressed side. The wrinkles are benign in starting so that their amplitude increases little amount with the curvature. At a certain point, the value of the wrinkle starts increasing, following localization in the form of an outward bulge along with the failure of the structure. It is found that internal pressure will considerably stabilize the part by lowering localization and failure. If the ductility is not sufficient, the part will get fail before the bulging collapse condition is reached. Also, the pipe must be free of imperfections.

The analysis of wrinkling in pipe bending has been a challenging subject. The analytical solution can provide a global view in terms of the general tendency and the effect of individual parameters on the onset of wrinkling and can be achieved in an almost negligible computational time and Wang and Cao [7] made a study on the wrinkling limit in the tube bending. The analysis of a curved tube can be characterized as buckling of a sheet with double curvatures.

N. Baaskaran [2] has done an experimental investigation of effects of wrinkling in pipe lines. The importance of the structural property of the steel pipe gets lowered due to the failure of pipes when it is subjected to continuous loading. They proposed to calculate the post-wrinkling behaviour and its effect on structural property of wrinkled pipeline acted upon by axial loads along with the application of internal pressure.

The structural behavior of mechanically lined pipes under bending loading is investigated by Daniel Vasilikis, Spyros A. Karamanos [3] motivated by its use in offshore pipeline applications. In this situation the pipeline is subjected to significant bending deformation in the presence of external pressure so that, significant stresses develop in the pipeline wall, associated with excessive cross-sectional ovalization and possible local buckling. Numerical results they obtained indicate that separation between the outer and the liner pipe occurs at the compression zone (detachment), leading to liner buckling in the form of wrinkling. Results from three-dimensional analysis in both elastic and steel lined pipes indicate that a first bifurcation occurs at curvature that leads to a uniform wrinkling pattern, associated with small values of detachment and of buckle wave height. Subsequently, a second bifurcation occurs at a bending curvature, which is higher than the value associated with larger values of wrinkling amplitude and can be

considered as the wrinkling limit state of liner failure due to bending. Also liner pre-stressing due to the manufacturing process has a beneficial effect

Holliday and Clyne[6] outline an integrated approach applied to a pipeline to demonstrate the acceptability of non-compliant wrinkles. They applied the codified strain assessment of dents to wrinkles. The fatigue simulation described as part of this study mainly considers cyclic plastic loading according to pressure history data. But, another failure mode of wrinkles is high-strain low-cycle fatigue, a mechanism which is commonly challenging to simulate.

II. RESEARCH METHODOLOGY

The pipe line wrinkle bend is firstly analyzed for the critical region, where large stresses and strains are acting, which in turn cracks initiation likely to take place after certain loading cycles. So the study is to be concentrated there more. As a next step elastic plastic FEA simulations have done in wrinkle bend in cyclic bending using ABAQUS with different hardening models and identified better model for accurate simulation. A fatigue life prediction is done after that by using Smith Watson Topper fatigue damage model with the use of result obtained from the later analysis.

While analyzing the wrinkle bend under combined loading of cyclic in plane bending and constant internal pressure, the thermal effect is not considered. The effect of seismic loading in a buried pipe line is incorporated in the analysis by applying an in plane bending. No any out of plane bending is also considered.

III. ANALYSIS OF WRINKLE BEND

Wrinkle bends are the bends which have outward directed folds in the intrados. These are present in large diameter pipe line systems and they are not so common now. But according to studies a significant number of existing pipe line systems contains these types of bends which have built years ago. So the study about the wrinkle bend is widely acceptable. According to Department of Transportation- US agency for ensuring the effective and safest transportation across the world, certain conditions and specifications are there for manufacturing a wrinkle bend. Those are as follows; (a) The bend must not have any sharp kinks (b) When measured along the crotch of the bend, the wrinkles must be at a distance of at least one pipe diameter (c) On pipe 16 inches (406 millimeters) or larger in diameter, the bend may not have a deflection of more than 1.5° for each wrinkle. (d) On pipe containing a longitudinal weld the longitudinal seam must be as near as practicable to the neutral axis of the bend. For the analysis on a wrinkle bend, obtained a solid model of wrinkle bend as shown in figure 1. The nominal diameter of straight pipe is taken as 406.4 mm (16 inch). The thickness of the pipes and elbow are 12.7mm (0.5 inch).



Figure 1 : Solid model of wrinkle bend

Murray [5] in his research found out the stress distribution along a wrinkle bend. He found out that the maximum stress is occurred at the top point of intrado when they are loaded with in plane cyclic bending and internal pressure. So for further analysis in the wrinkle bend this intrado point is taken as hot spot, where the analysis to be concentrated more. Detailed elastic plastic FEA simulation is done in a wrinkle bend with combined inplane cyclic loading and internal pressure. The material in consideration is X42 steel. Here the effect of plastic hardening mode is also evaluated. The analysis for stresses and strains are carried out with different plastic hardening models for each time.

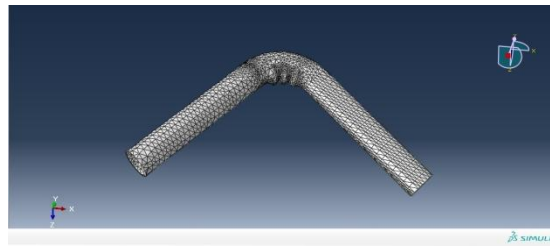
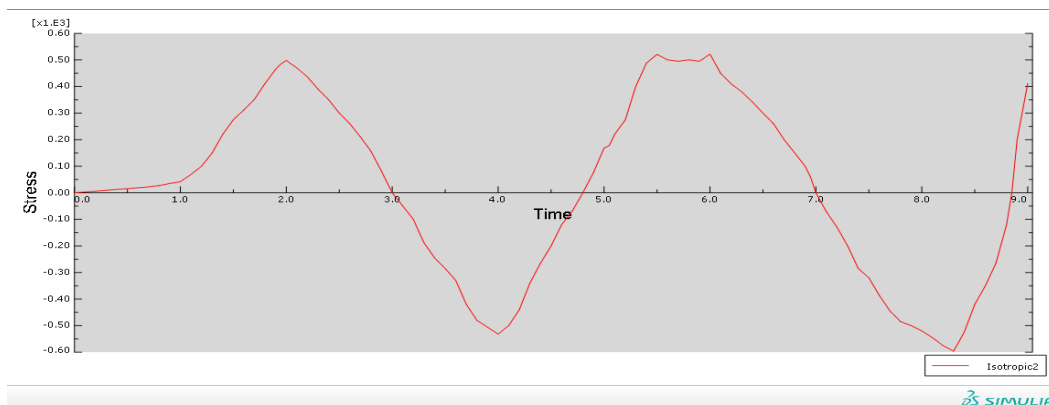


Figure 2: finite element mesh for wrinkle bend

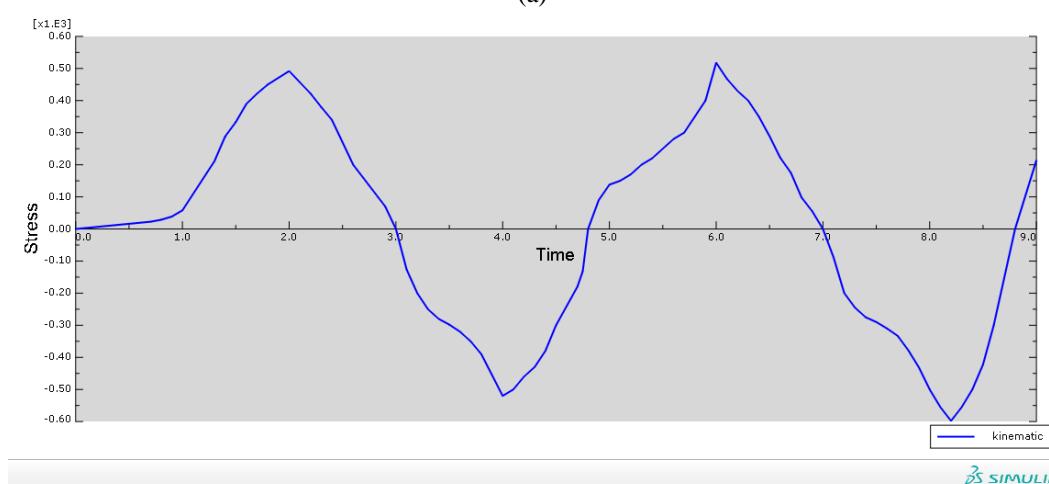
IV. ANALYSIS OF WRINKLE BEND WITH HARDENING MODELS

A wrinkle bend with combined loading of cyclic in plane bending and internal pressure is analyzed. The hot spot is selected as the upper point of the wrinkle present in the intrado region. The variations of axial strain and axial stress are obtained and it is shown in fig 4.1 and. The trend of the variation of the axial stress and strain with the loading time is same as we observed in the case of elbow. But the stress and strain range values are larger compared to the elbow. This may be due to the stress concentration in the wrinkle. In the wrinkle bend also the plastic hardening models have less effect on the stress values and a significant effect on the strain value.

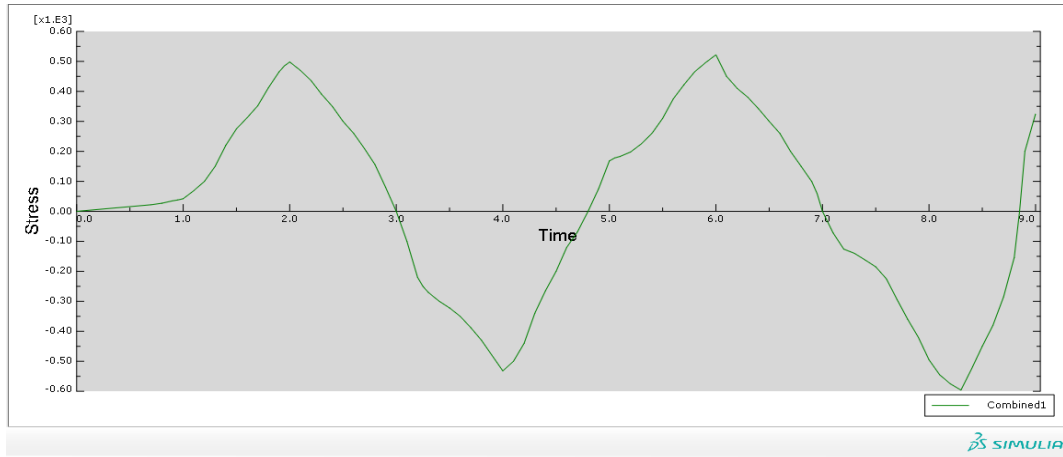
The stress - strain curve at the hot spot of the wrinkle bend is extracted and analyzed. Figure 4.2 shows the stress - strain curve of the wrinkle bend. The isotropic, kinematic and combined model predicts smallest largest and intermediate stress strain loop. The compressive strain is found to be increasing as the loading cycle increases.



(a)

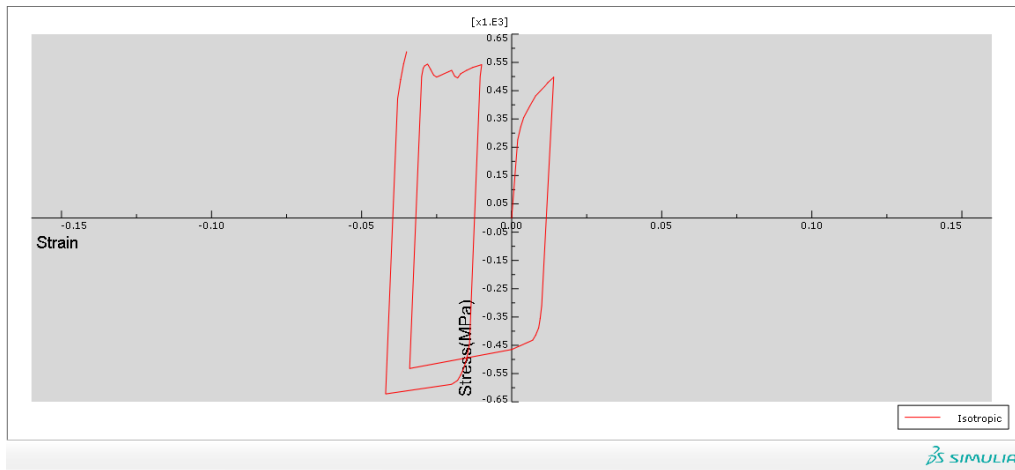


(b)

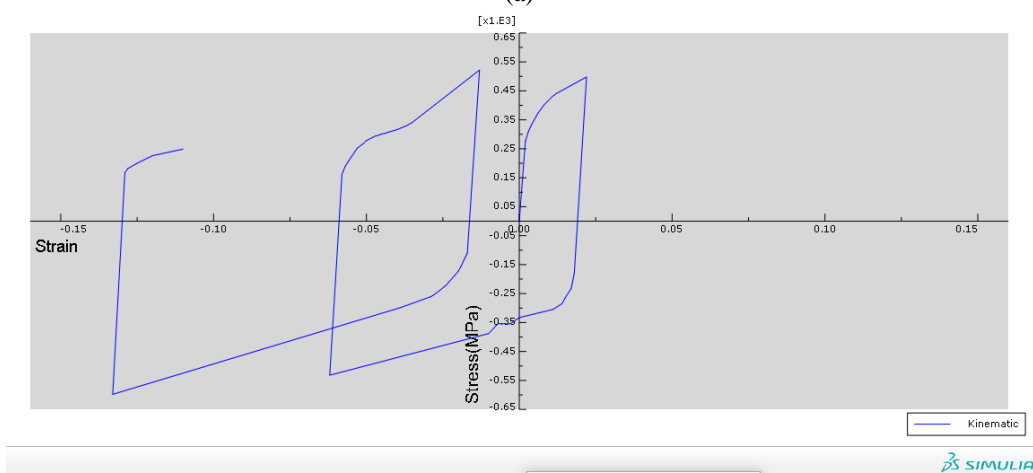


(c)

Figure 4.1: Stress response of the wrinkle bend in the analysis at the hot spot with (a) isotropic (b) kinematic and (c) combined hardening model.

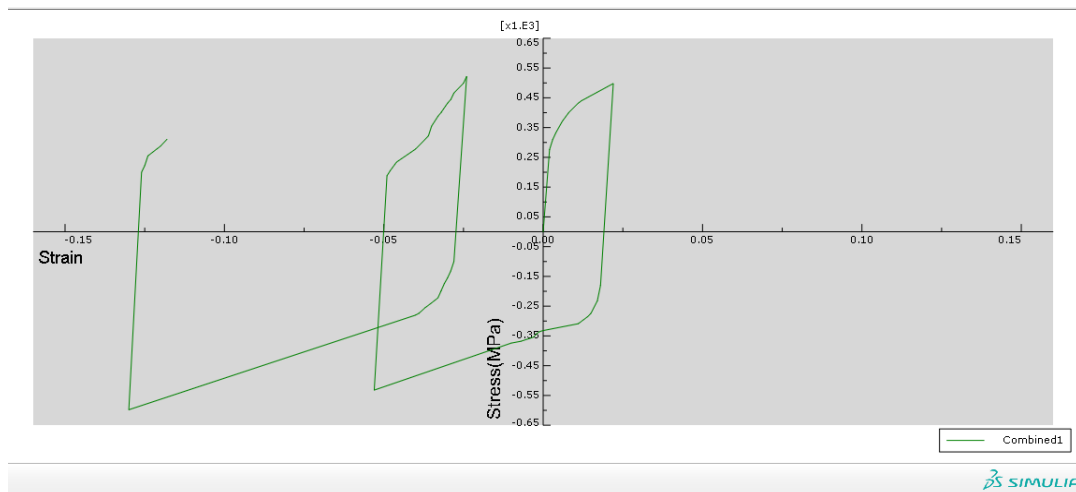


(a)



(b)

(c)



(C)

Figure 4.2: Stress - Strain curve at the hot spot for (a) isotropic (b) kinematic and (c) combined hardening model.

V. FATIGUE LIFE ANALYSIS OF PIPE LINE ELBOW AND WRINKLE BEND

The elbow and wrinkle bend may fail due to fatigue under cyclic loading. For predicting the fatigue life of these parts an appropriate fatigue parameter is needed. In the case of pipeline bends low cycle fatigue is taken place i.e. the failure will occur in comparatively lesser number of loading cycles. Also in each loading cycle it will be entered the plastic region of the material. In this type of circumstance, the common fatigue damage parameter used is Smith-Watson-Topper (SWT) damage parameter. This is an energy based parameter. The SWT parameter is given as,

$$D_f = \sigma_{max} \times \epsilon_{amp} \quad (5.1)$$

Based on a set of fatigue test data for various pipeline steels, a fatigue damage curve in reference to the SWT parameter is determined by

$$D_f = 6.895 [273(N_f)^{-1.02} + 2.1(N_f)^{-0.28}] \quad (5.2)$$

D_f is in MPa. If we are able to find the value of D_f we can find the fatigue life, N_f from the equation 5.2. For the wrinkle bend which are in combined loading of cyclic in plane bending and internal pressure, the maximum stress and the strain amplitude can be found out with the help of stress-strain diagram which was obtained from analysis. From figure the σ_{max} and ϵ_{amp} can be found out for each hardening model.

Fatigue life of wrinkle bend for three hardening model have found out. D_f value for the wrinkle bend for isotropic, kinematic and combined isotropic and kinematic hardening model are 6.65, 30.83 and 26.11 MPa respectively. The SWT model predicted fatigue lives for wrinkle bend as 172, 31 and 42 cycles respectively.

VI. RESULT AND CONCLUSION

A detailed elastic plastic FEA analysis is done in pipe line wrinkle bend. Studied the effect of various hardening models (i.e., isotropic, kinematic and combined isotropic and kinematic hardening model) on the simulation of stress and strain in these parts. A fatigue prediction is done on wrinkle bend under combined loading of cyclic bending moment and internal pressure utilizing the energy based fatigue damage model namely "Smith Watson Topper fatigue model". The conclusions which have arrived from the study are:

(a) The strain range predicted by isotropic, kinematic, and combined hardening models are smallest, largest and intermediate respectively. So we can conclude that the isotropic model underestimate and the kinematic hardening model overestimate the plastic strain. While the combined hardening model predict a reasonably accurate plastic strain value.

(b) From analyzing the graphical result obtained from the analysis it can be noted that, there is no considerable effect of plastic hardening models on the stress values. At the same time there is a significant effect of plastic hardening models on the strain values.



(c) The compressive strain acting on the bend under cyclic in plane bending and internal pressure increase with increase of loading cycles.

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