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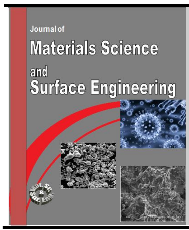

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Effects of Wrinkling in pipelines: An Experimental Investigation

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Abstract

Buried pipeline may be subjected to some forces results in deformations. The wrinkling in the walls of the pipes due to the strains and localized curvature subjected on the pipes. The prospect of the structural property of the pipe gets decreased due to the propagated bursting of pipes when it is subjected to continuous loading. This project was aimed to evaluate the post-wrinkling behaviour its impact on structural property of wrinkled pipeline subjected to axial loads combined along with internal pressurisation. The current work focuses on experimental studies and microstructure failure analyses. The present experimental work had been conducted on line pipes IS3601 in the developed test rig to predict and evaluate the load buckling behaviour due to the deformation in post wrinkling stage. The detailed assessment of telescopic wrinkle in consideration of stress-strain fields had been plotted. Metallurgical failure analysis had been carried out to study the formation of cracks due to wrinkling and elasto-plasto behaviour of pipes. Parametric studies were conducted to understand the effect of D/t, and internal pressure on pipe failure mode.

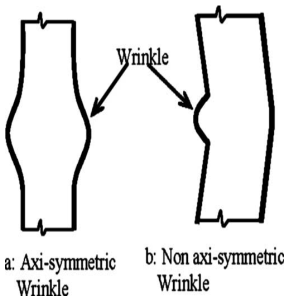
The work had been presented at an international conference ***Fatigue Durability India 2015****, 28-30th May 2015, JN TATA AUDITORIUM, Indian Institute of Science, Bangalore.*

Introduction

Pipe lines are used by many industries as the primary mode for transporting natural gas, crude oil, petroleum products and water. The most of these pipelines are exposed to harsh environment which run underground, also the pipe line behaviour should be mandatory for design engineers which can operate under all the potential adverse conditions[1].

Typical Wrinkle Shapes

The shape of the wrinkle is nearly axisymmetric if the wrinkle forms under internal pressure and concentric axial load only. However the shape of the wrinkle becomes non axisymmetric due to applications of internal pressure axial load and bending moment as shown in Fig.1.



Courtesy-ASCE (2008)

Figure: 1 Typical Wrinkle Shapes

Field observations of buried energy pipelines experiences indicate that the subsurface geotechnical movements along the walls exposed to thermal loads, can subjected to large forces and displacements on submerged pipelines results in strains, localized curvature, and transverse deformations in the walls of the pipes. Generally the local deformations of the pipe wall results in local buckling in the walls of pipes called "wrinkling "and the post buckling range of response and local buckles wrinkles in the pipe wall propagates under prolonged deformations. The wrinkling usually occurs under the combined implications of axial load, internal pressure, and with or without bending moment. The shape of the wrinkle is nearly axisymmetric if the wrinkle forms under internal pressure and axisymmetric axial load or deformation. However, the shape of the wrinkle becomes nonaxisymmetric if it forms due to the application of internal pressure, axial load, and bending moment or deformation.

A wrinkled pipeline may then be subjected to various load combinations and load hysteresis such as monotonically increasing axisymmetric or nonaxisymmetric deformations, monotonically increasing shear deformations, and cyclic axisymmetric or nonaxisymmetric deformations. Extensive research has been carried out during the last decades to study the initiation and formation of wrinkles under various load and deformation conditions that buried pipelines experience in the field. Consequently, most of the current pipeline design standards and practices recommend various limit state design methods for energy pipelines based on noticeable cross-sectional deformation and formation of local buckling/wrinkling that corresponds to material strain of 0.5–2.0%. Since sufficient information on ultimate post wrinkling behaviour of pipelines is not yet available, the current pipeline design and maintenance standards do not allow such a wrinkled pipeline in the field be left unattended.

However, it has been suspected that current pipeline design and maintenance standards are conservative since the formation of a wrinkle in the field pipeline does not necessarily poses a threat to the integrity and/or safety of pipeline operations and simultaneously the recommendations had been made to satisfy the current pipeline limit state design norms and practices. The present findings by Das et al exhibits that the wrinkled pipeline is susceptible to fracture if subjected to fatigue load or displacement

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history. The present work was undertaken to study the failure condition and failure modes of wrinkle energy pipeline when subjected to monotonically increasing axisymmetric axial compressive deformation. A “failure” in this study refers to occurrence of rupture in the pipe wall and/or excessive cross-sectional deformation that jeopardizes the safe operation of a field pipeline. This study involved both experimental and numerical parametric investigations.

Cross-sectional Deformation

Ovalization of a pipe cross-section occurs when a thin pipe undergoes curvature under flexural stresses. This phenomenon was described and studied by Gresnigt (1986).The hoop stresses in the neighbourhood of the extreme compression and tension fibers of a pipe subject to curvature have components that force the pipe wall at these regions to move towards the centroid of the pipe cross section. Gresnigt (1986) suggests limiting pipe out-of-roundness Or to 15%, where

$$O_t - \frac{D - D_s}{D}$$

The symbol D denotes the original outside diameter of the pipe and D_s is the smallest outside diameter of the deformed cross section. Price and Barnette (1987) adopted the same expression as a deformation limit state for buried pipelines. Price and Anderson(1991) suggested arbitrary limiting values for out-of-roundness (or ovalization) of 15%for unpressurized pipes and 6% for fully pressurized ones. Row et al. (1987) defined another limit on ovalization O_v expressed as

$$O_v = \frac{2(D_t - D_s)}{D_t + D_s}$$

Here Dt is the largest outside diameter of the deformed cross-section. They suggested limiting the magnitude of Ov to 7.5% for pipes subjected to deformation controlled loads where it can be demonstrated based upon detailed inelastic analyses that sectional collapse will not occur as a result of excessive deformation.

The pipe diameter differential D_d is a slightly different expression proposed by Zhou and Murray (1993), and defined as

$$D_d = \frac{D_t - D_s}{D}$$

Experimental Setup

As reported in the literature review, numerous experiments have been carried out in order to determine the structural response of steel pipes. Tests made on IS3601 pipe were performed to investigate pipeline behaviour under axial load, This project was, therefore, designed to investigate the failure of steel pipes under similar load and deformation conditions. The primary objective is to find and verify the loads and boundary conditions that can cause the telescopic wrinkle and rupture similar to what happened in the field pipeline (Fig.2 and 3).

Figure 2: Field Pipe

Figure 3: Field Pipe

Carbon Steel Chemical Composition

IS3601 (steel tubes for mechanical and general engineering purpose)

The chemical compositions of carbon steel specimen is given in Table **1**

Table 1: Chemical Compositions

Grade	C (%)	Mn (%)	P (%)	S (%)
M	0.16	1.20	0.04	0.04

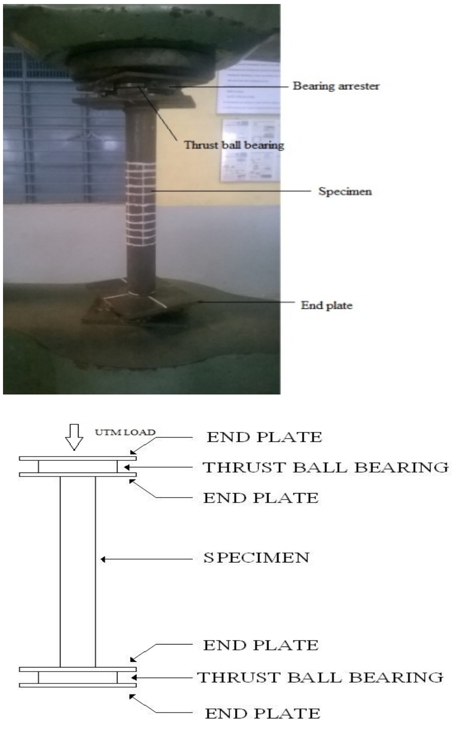

Figure 4: Experimental Setup

The concentric axi-symmetric axial compression load (P) was applied to the specimen through the vertical loading by universal testing machine (UTM) as shown in Fig.4. It was designed, manufactured, and used to control the rotation at two ends of the specimen along with special end condition (rotating head support). The end plates were 200 mm long × 160 mm wide × 10 mm thick. Two thrust ball bearings were used at the end plate support for rotation. With this setup an axial load is applied by using UTM up to wrinkle formation in the specimen as shown in Fig.4. The Fig.5

shows the non axisymmetric and post wrinkling behaviour of the wrinkled specimen.

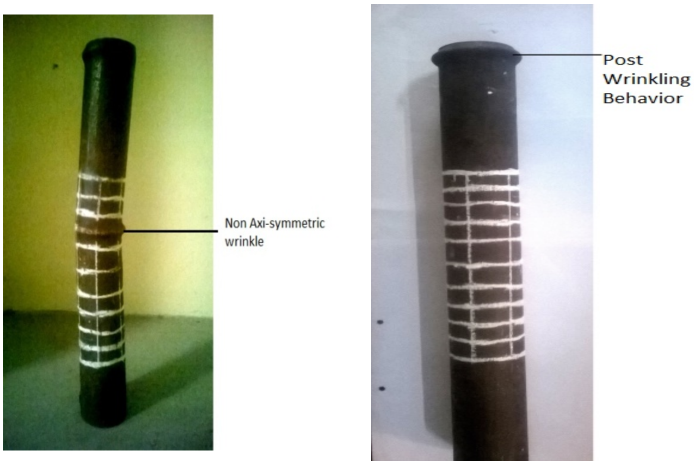

Figure 5: post wrinkling Behaviour (Axisymmetric)

Experimental Test Values

Table 2: Test Values

Specimen (No)	Length (mm)	ID (mm)	OD (mm)	Thickness (mm)	Ultimate Load (KN)
1	475	55.1	60.3	2.6	128.05
2	475	55.1	60.3	2.6	126.15

From this test values Table 2 shows that the specimen yields at a point and reaches its maximum load carrying capacity of ultimate load. After it reaches its ultimate load wrinkle become visible and further applying of load it decreases after it reaches its ultimate point. The tested specimen Fig.6 shows the two wrinkle formation of non axisymmetric wrinkling and post wrinkling behaviour.

Vickers Hardness Readings Obtained on wrinkled Sections of pipe

Table 3: Hardness Test Values

Section (ID)	Readings (HV)	Average (mm)
Normal	189.4, 186.3, 188	188
Compression	209.5, 209.5, 206.8	208.6
Tension	181.2, 176.9, 176.2	178.1

The obtained hardness values of specimens are shown in Table 3. Compare to normal section of pipes the obtained values in non axisymmetric wrinkle region, in compression the hardness value is increased and in tension hardness value is decreased.

Metallographic Analysis

All the steel samples have been prepared for optical microscopy using standard metallographic practice. 50% HCL and 50% H_20 is used as etchant. Optical micrographs of steel sample at magnification 100X are shown in Fig.6, Fig.7, and Fig.8 respectively. Here white region also depicts ferrite and black region depicts pearlite. The average grain size has increased in various sections shown in Fig.8.

Preparation of specimen for microstructure inspection includes surface preparation by using different grade of silicon carbide sheet. The grades varies from E400, E600, P800, P1000, P1200, P1500, P2000 and P2500 respectively to prepare surface in specimen till it reaches the glass finish. The etching process is carried out after surface preparation in the prepared specimen and viewed under microscope for evaluation and inspection of microstructure. The obtained microstructure showed that the ferrite and pearlite grains were elongated after deformation.

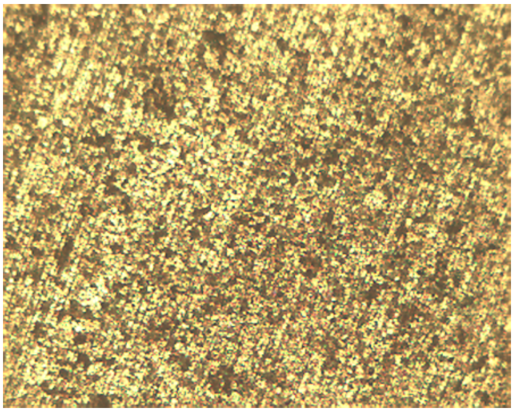

Figure 6: Normal section Microstructure

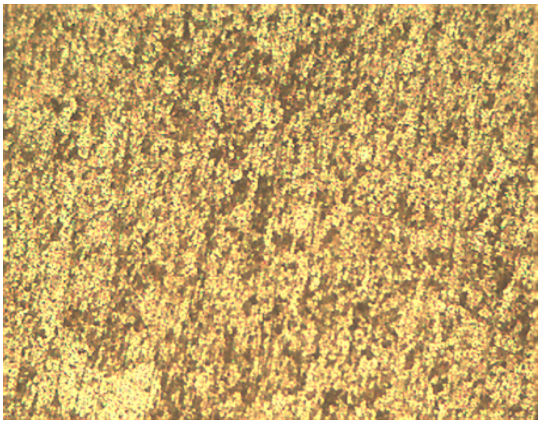

Figure 7: Compression section Microstructure

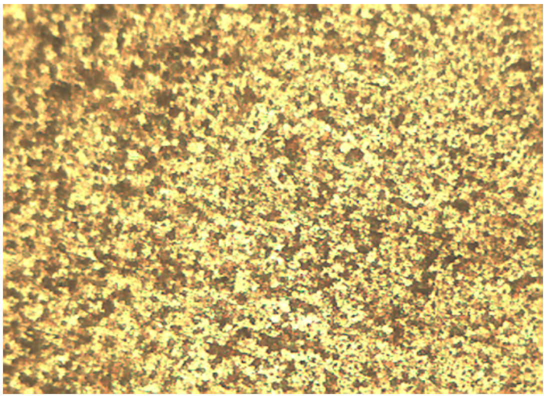

Figure 8: Tension section Microstructure

Conclusions

Wrinkled pipe subjected to monotonically increasing axial compression load as was applied in the test specimens is able to produce a deformed shape and a wrinkle that look like the one that occurred in field line pipe. The phenomenon of losing the structural stability in monotonic compressive loading. Compare to normal section (188HV) the hardness value is increased in compression (208.6HV) and decreased in tension section (178.1HV). Micro structural examination showed that the ferrite and pearlite grains were elongated after deformation.

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