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In-service life estimation of damaged gas pipelines: Full-scale experiments and finite element analyses

Guillaume Burgaud[1], Remi Batisse[2], Stephane Hertz-Clemens[2], Georges Cailletaud[1], Yazid Madi[1] and Gilles Rousselier[1]

[1]Centre des Matériaux, MINES ParisTech, CNRS UMR 7633, BP. 87, 91003 Evry, France
[2]GDF SUEZ, 93211 La Plaine Saint Denis, France

Abstract. Statistical analysis reveals that mechanical damage is the first cause of incidents on gas transmission pipelines. They can be created by third party activities such as excavator tooth impact or by interaction between the pipe and rocks. To manage the damaged pipeline safely without useless cost, there is a need to investigate the mechanical behaviour of dented pipelines under a varying internal pressure. The purpose of this study is to characterize the stress and strain field around defects in pipes submitted to cyclic pressure loadings in order to estimate their residual lifetime. Full 3D finite element analyses of the denting process followed by cyclic loading are performed. Full-scale experiments on dented sections are planned.

1. Identification of the material parameters

A series of specimens are machined in pipes from field in order to characterize the mechanical behavior. They include, smooth tensile bars, plane strain specimens and low cycle fatigue specimens. To describe the indentation process, smooth tensile bars and plane strain specimens were tested with a monotonous loading. Low cycle fatigue specimens are then used to obtain the cyclic behavior. Due to the production process of spirally welded steel pipes, the supposed anisotropy of the material was tested by testing smooth tensile bars in eight different directions defined by the angle θ with respect to the rolling direction ($\theta = -26°, 0°, 16°, 32°, 48°, 64°, 77°, 90°$). Results showed a classical orthotropic behavior. Plane strain tests generated stress states that are close to the loading of a pipe under pressure. They give us information on the yield function which lies between Mises' and Tresca's. Low cycle fatigue specimens were tested after various preloading levels ($\varepsilon = -2\%$, 0%, 4%, 6%, 8%) with two strain range ($\Delta\varepsilon = 1\%$, 2%) to evaluate the influence of pre-loadings on fatigue life. Results showed that a prestrain ε increases the subsequent fatigue life for $0 > \varepsilon > 8\%$. Barlat's criterion [1, 2] is used to account for orthotropic behavior. It introduces a stress deviator modified by a six component matrix. Three kinematic hardenings variables were also needed to describe both the cyclic behavior of low cycle fatigue specimens and mechanical response for monotonous tests made on smooth tensile bars and plane strain specimens [3]. The model is able to reproduce the difference between rolling and transverse direction in monotonic tests (Fig. 1) and the subsequent cyclic behavior after preloading (Fig. 2).

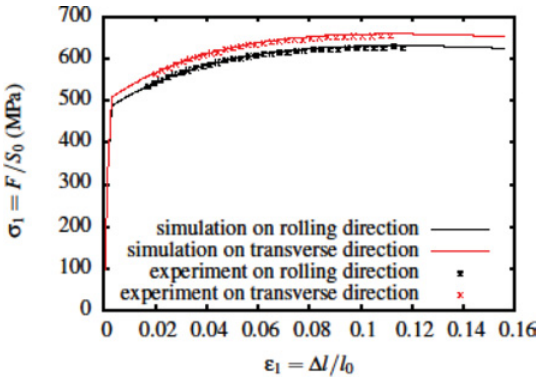

Figure 1. Comparison between tests and simulation for rolling and transverse directions.

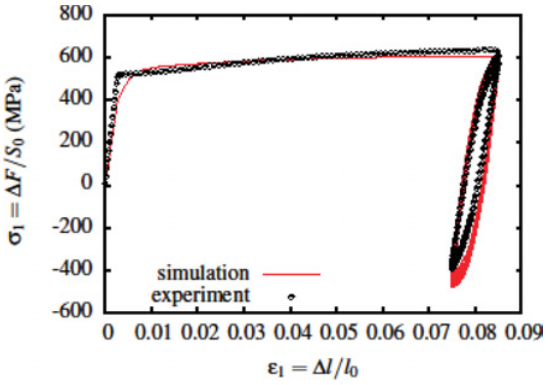

Figure 2. Monotonic and subsequent cyclic loading in the rolling direction.

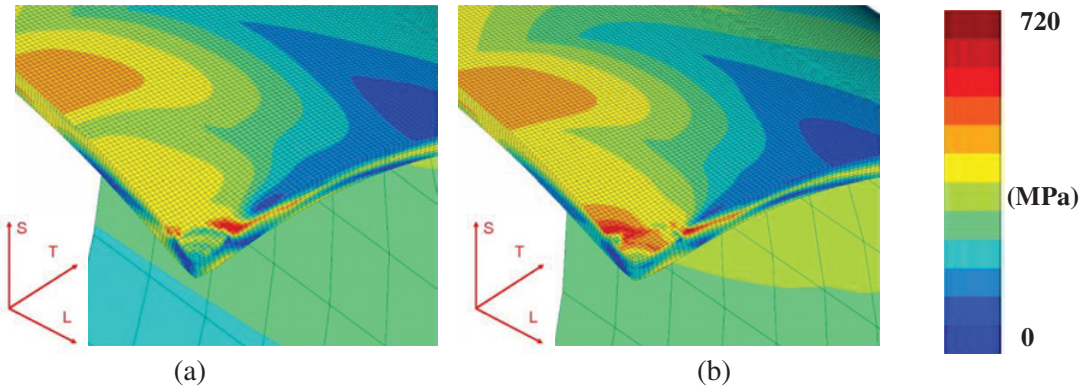

Figure 3. Von Mises stress contour illustrating the residual stress field after unloading: (a) sphere, (b) dome.

2. Finite element analyses

The current mesh of the tube, which nominal diameter is 1160 mm and thickness is 15 mm, introduces quadratic hexahedral elements, the size of which is 2 mm × 2 mm × 2 mm around the dented area. Larger elements are used for the rest of the tube. Their role is to correctly describe the global structural response in bending. The tube is reduced to a quarter due to symmetry conditions. It is maintained along the bottom line and the symmetry planes. A meshed indentor is pushed on the pipe, the indentation depth ranges are between 10 mm and 100 mm. Calculations were performed with two different shapes of indenters, a sphere (diameter 30 mm) and a dome (diameter 55 mm). The current results shows that the sphere produces more plastic strain and residual stresses than the dome (Fig. 3). The purpose of the study is to predict the influence of denting on the residual fatigue life for two cyclic pressure levels that are selected to be the minimum and maximum pressure gas pipes are usually submitted to. The life prediction models are sensitive to the mean stress and the stress amplitude [4]. The influence of prestrain and residual stress is also taken into account.

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