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The effect of soil load on fracture behaviour of three-layer polymer pipe for non-pressurised applications

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Abstract. Fracture behaviour of a three-layer polymer pipe subjected to nonhomogenous distribution of external pressure induced by soil embedding is studied in this paper. Both long term and additional short term loading is considered. Such loading induces tensile stresses in the inner pipe wall which can lead to crack initiation and further slow crack propagation. The material interface between a protective layer and the base pipe can contribute to crack deceleration and can prolong the residual lifetime of the pipe. The paper presents three-dimensional numerical analysis of a commercial three-layer pipe containing an internal semi-elliptical crack. The effect of soil load on the fracture behaviour of the cracked pipe is quantified and discussed.

Introduction

Besides offering low installation costs, plastic pipes are attractive for non-pressure applications due to high flow rates, adequate strength for earth loads and high chemical resistance [1]. To improve mechanical and physical properties of polymer pipes multilayer structuring are used. Often multilayer pipes consist from three different layers: inner layer (resistance against abrasion and slow crack growth), middle layer (improve stiffness of the pipe) and outer layer (resistance against external scratches and point loads). Therefore, usual composition of co-extruded pipes consists of a soft internal layer, stiff middle layer and again soft outer layer [2].

The lifetime of a modern polymer pipe is expected to reach up to 100 years in service. The long-term failure of the pipe is usually in a quasi-brittle mode in which the slow (creep) crack growth (SCG) occurs. Due to the small plastic zone in the vicinity of the crack tip in the SCG regime the linear elastic fracture mechanics can be applied. Therefore, the stress intensity factor can be used as a parameter controlling the crack growth in polymer pipes, see e.g. [3–6].

This paper focuses on fracture mechanics assessment of a multilayer polymer pipe containing internal semi-elliptical axially oriented crack. The pipe is loaded by non-homogenously distributed external pressure that can induce tensile stresses in the internal pipe wall. Such stresses can lead to crack initiation and further crack propagation. The aim of the paper is to perform a numerical study of the cracked pipe, find the critical location for crack initiation and estimate the failure behaviour of the buried pipe.

Numerical model

The pipe considered in this study is a commercially produced polymer pipe with an external diameter d = 400 mm and total pipe wall thickness s = 14.2 mm. The thicknesses of the layers were: external layer t_{out} = 0.8 mm, middle layer t_m = 10.8 mm and internal layer t_{in} = 2.6 mm. The

Young's modulus of specific layers were in the ratio (external:middle:internal) 2:3:1, all with Poisson's ratio 0.35.

The external loading of the pipe corresponds to Austrian standard ÖNORM B 5012 (Static calculation of buried pipelines for water supply and sewerage). Based on this standard the soil loading of the buried pipe can be decomposed into horizontal and vertical components, see Fig. 1. The loading components taking into account long term and short term loading together are $q_v = 0.1092$ MPa, $q_h = 0.0459$ MPa and $q_h^* = 0.0495$ MPa at peak, angles $\alpha_v = \alpha_h = 120$ deg.

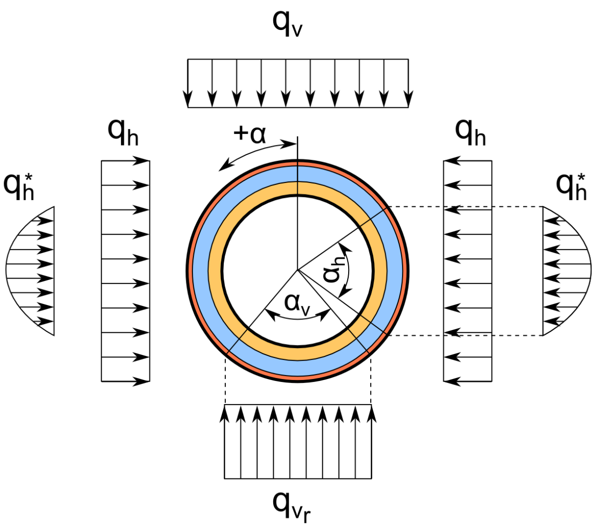

Fig. 1. Soil loading decomposition based on standard ÖNORM B 5012

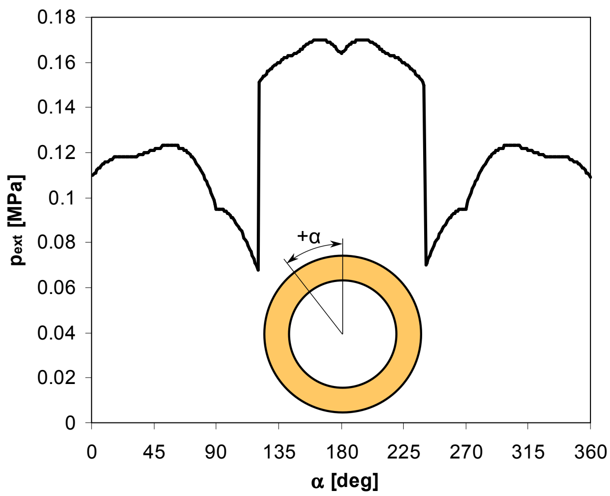

Fig. 2. Distribution of external pressure p_{ext} on the external pipe surface

The three-dimensional numerical model of the three layer pipe was developed in the commercial software ANSYS. Due to the existence of two planes of symmetry only one-quarter of the pipe was modelled. The typical model of the cracked pipe consisted of approx. 150 000 20-node isoparametrical elements. A semi-elliptical crack growing in axial direction from the internal pipe surface was modelled. The aspect ratio of the semi-elliptical crack front was taken from [5] in the following form:

$$b = a\left(-0.1936\left(\frac{a}{s}\right)^2 + 0.6628\left(\frac{a}{s}\right) + 1.0919\right) \quad (1)$$

where a is crack length and b is half-width of the surface crack on the internal pipe wall, see Fig. 3. The stress intensity factor was estimated in the deepest point of the crack using so called direct method [7,8].

Results

At first the pipe without a crack was analysed in order to find the critical location for the crack initiation. The distribution of the tangential stress along the internal and external pipe wall is shown in Fig. 4. The nonhomogenous nature of the tangential stress is a product of nonhomogenous distribution of the external pressure from soil.

The maximum value of the tangential stress at the internal pipe surface (2.15 MPa) can be found for the angle $\alpha = 180$ deg (bottom part of the pipe). Therefore, the most critical location for the internal crack initiation is $\alpha = 180$ deg. The tangential stress at the external surface has two maxima: $\alpha = 100$ deg and 260°deg where it reaches a value of 4.3 MPa. The through-wall distribution of the

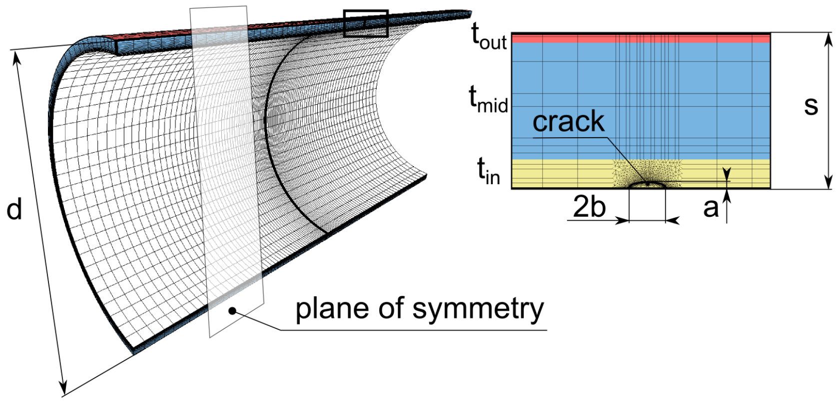

Fig. 3. Preview of FE model of the cracked three-layer pipe with semi-elliptical crack

tangential stress in the pipe wall is shown in Fig. 5 for two different locations corresponding to $\alpha = 0$ and 180 deg.

In the next step a semi-elliptical crack was introduced into the numerical model. The stress intensity factor was determined for the semi-elliptical crack front shape defined by the Eq. (1) and also compared with the straight crack front (aspect ratio $b/a = \infty$). Furthermore, the stress intensity factor of a homogenous pipe subjected to external pressure loading is shown in Fig. 6 to observe the influence of the layered nature of the pipe. Finally, the stress intensity factor values valid for the cracked homogenous pipe subjected to internal pressure loading, see [5] for more details, corresponding to the hoop stress of the same value as in the three-layer pipe at the internal pipe surface is also present. Resulting stress intensity factors are shown in Fig. 6. It can be seen that the layered nature of the pipe leads to significant decrease of the stress intensity factor in comparison to a homogenous pipe. Furthermore, by inspecting Fig. 5 the tangential stress significantly decreases in the internal layer up to the material interface between internal and middle layer. This fact has also positive impact on the fracture behaviour of the three-layer pipe subjected to soil loading. On the other hand if the crack will propagate in the sideway direction (higher ratio b/a) the stress intensity factor could be increased up to about 50% until it reaches the stress intensity factor valid for the straight crack front representing 2D solution.

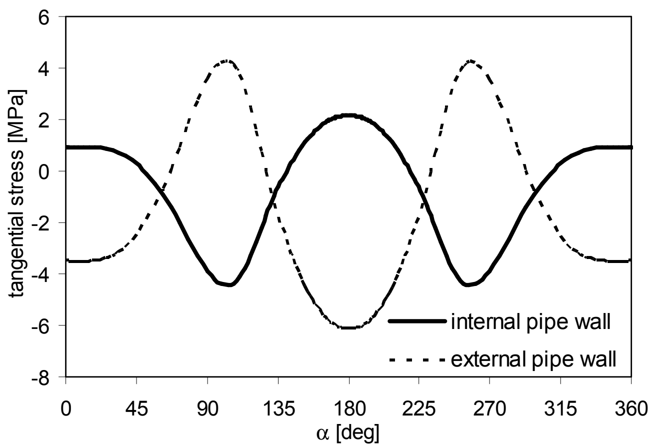

Fig. 4. Distribution of the tangential stress along the internal and the external pipe surface

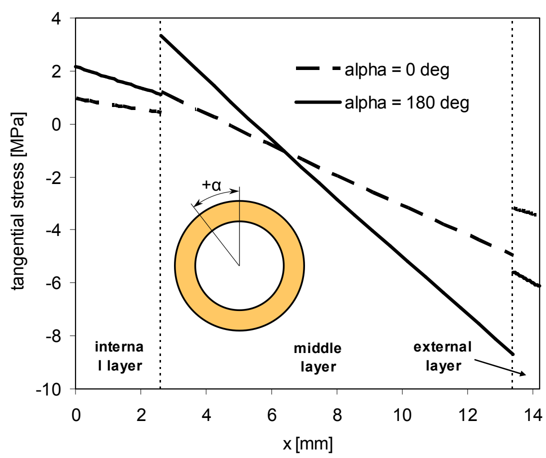

Fig. 5. Distribution of the through-wall tangential stress in the pipe wall

Conclusions

In this paper it is shown that the soil loading has significant influence on the fracture behaviour of buried pipes. The fracture behaviour of the three layer pipe containing inner semi-elliptical or straight crack was numerically studied. It was shown that the layered nature of the pipe leads to significant decrease of the stress intensity factor compared to a homogenous pipe. Furthermore, the material interface between internal and middle layer of the pipe will also contribute to the

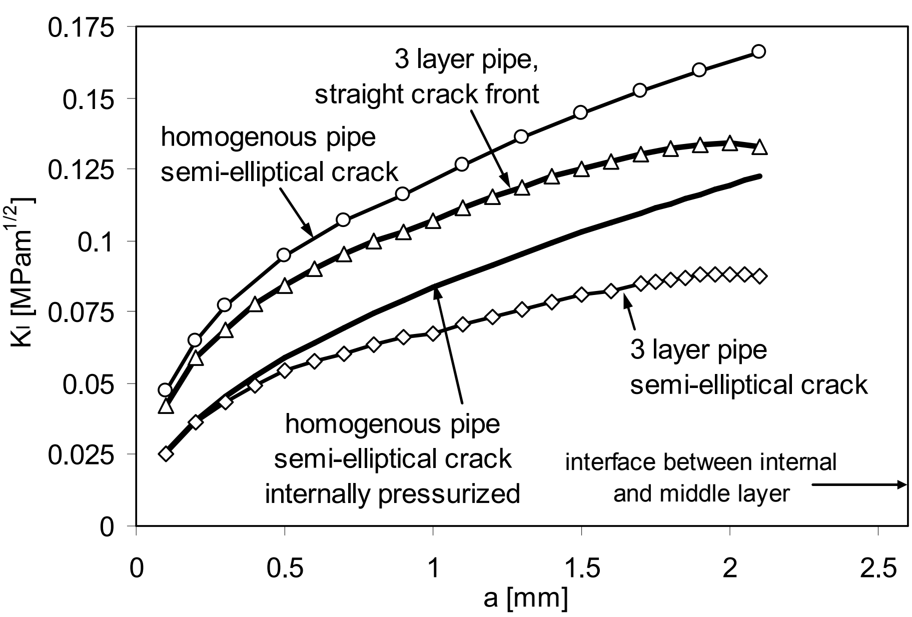

Fig. 6. Stress intensity factor for internal cracks growing in the pipe

decreasing of the stress intensity factor, thereby prolonging the residual lifetime of the three-layer pipe. The results presented in this work can be useful for better prediction of the residual lifetime of the multi-layer polymer pipes subjected to complex loading.

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References

[1] R.K. Watkins, L.R. Anderson: Structural Mechanics of Buried Pipes, CRC Press, Boca Raton, FL, 1999.

[2] P. Hutař, M. Zouhar, L. Náhlík, M. Ševčík, B. Máša: Eng. Fail. Anal. Vol. 33 (2013), p. 151.

[3] L. Andena, M. Rink, R. Frassine, R. Corrieri: Eng. Fract. Mech. Vol. 76 (2009), p. 2666.

[4] A. Frank, W. Freimann, G. Pinter, R.W. Lang: Eng. Fract. Mech. Vol. 76 (2009), p. 2780.

[5] P. Hutař, M. Ševčík, L. Náhlík, G. Pinter, A. Frank, I. Mitev: Eng. Fract. Mech. Vol. 78 (2011), p. 3049.

[6] P. Hutař, M. Ševčík, A. Frank, L. Náhlík, J. Kučera, G. Pinter: Eng. Fract. Mech. Vol. 108 (2013), p. 98.

[7] T.L. Anderson, Fracture Mechanics: Fundamentals and Applications, Second Edition, 2nd ed., CRC Press, 1994.

[8] M. Ševčík, P. Hutař, L. Náhlík, Mech. Compos. Mater. Vol. 47 (2011), p. 263.