DAMAGE PREDICTION OF COMPOSITE PIPES

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Introduction

With development of new manufacturing technology to produced composite pipes from different material combinations, multi-layered fiber reinforced composite pipes and others are extensively used in engineering structures [1]. Due to this fact it is necessary to perform corresponding finite element simulations. To be able to estimate critical parts of the pipe and predict pipeline residual lifetime is necessary.

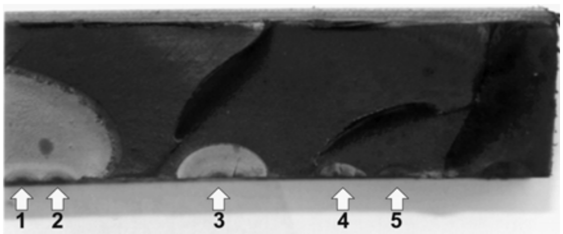

Fig.1. Multiple fracture initiation sites on the inner wall of a failed HDPE tube. The final fracture surface is fully fragile. A length scale is established by the thickness of the tube, which is 40 mm [2].

This article is focused to the estimation of the residual lifetime of the multilayer polymer pipes. The main task is to asses differences in propagation of the creep crack in the multilayer (composite) pipe line in the comparison with conventional homogenous pipe. In the homogenous HDPE tube creep cracks can grow as it visible in Fig.1.

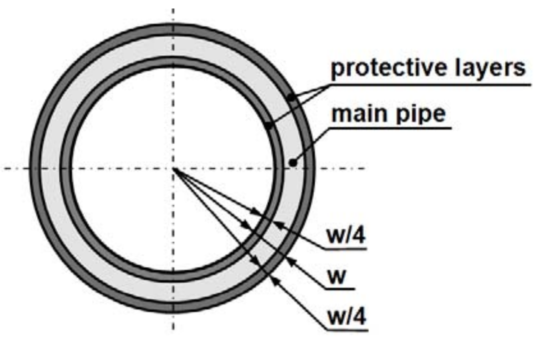

Fig.2. Scheme of three layer pipe studied in the article.

In the case of composite pipe (see e.g. Fig.2) are mainly two additional aspects: crack can be accelerated or decelerated by the existence of the interface and in some special configurations crack can be stopped by the interface.

Because creep damage of such type of the pipe is usually brittle and plastic deformations are localized just around the crack tip small scale yielding conditions are valid. Due to this fact linear elastic fracture mechanics (LEFM) can be used for description of the stress field around the crack tip. In LEFM the stress distribution near the crack tip is described by the stress intensity factor (K_I) which is a function of the external loading and structure geometry. Then, creep crack growth of polymer material can be defined by a K_I versus da/dt curve, which is schematically shown in Fig.3 [3].

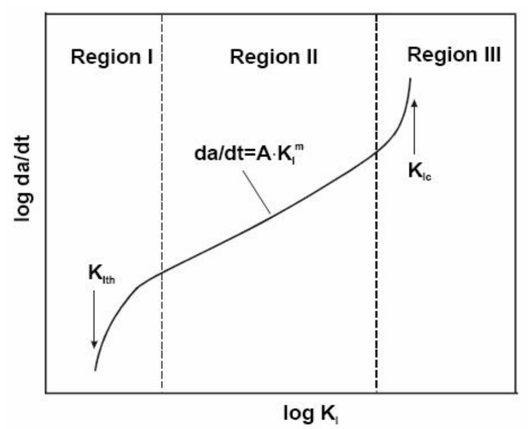

Fig.3. Scheme of creep crack growth rate curve [3].

Region II of this curve can be used for lifetime estimation of pipes. Using equation taking into account the relevant stress intensity factors in a pipe and the considering initial defect of the size a_0 and final crack length a_f the residual lifetime is given as:

$$t = \int_{a_0}^{a_f} \frac{da}{A \cdot \left[K_I\right]^m}, \qquad (1)$$

where K_I is function of the loading conditions and geometry arrangement. In the case of composite pipes K_I is also function of the material properties of the individual layers and they geometrical arrangements. For estimation of the stress intensity factor value in the case of complicated non-homogenous structures numerical modeling has to be used.

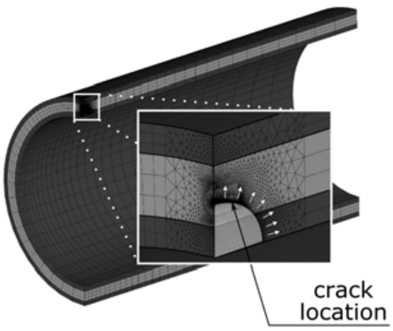

Fig.4. Finite element model of the internally pressured pipe with crack in the main layer from HDPE material

The aim of the article is to estimate crack behaviour in the case of three-layer polymer pipe with inner and outer protective layer, see Fig.2. Outer diameter of the pipe *d*= 110 mm and thickness of the pipe wall w=10 mm is considered.

Discussion of the results and conclusions

To predict residual lifetime of a multilayer pressured pipe, the stress intensity factors during the creep crack propagation has to be estimated. To this aim 3D finite element model of the structure was suggested. A typical configuration used for calculations was symmetrical including around 200 000 finite elements strongly non-homogenously distributed in the structure because of mesh refinements around the crack tip and close to the bi-material interface, see Fig.4.

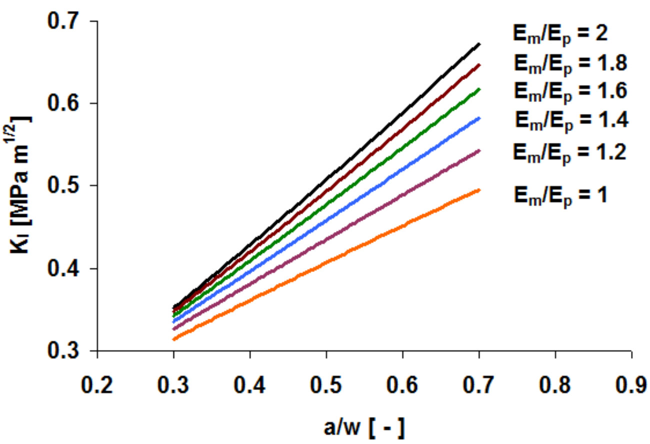

Fig.5. Stress intensity factors obtained for different ratio between Young modulus of the main pipe (E_m) and protective layer (E_p).

Loading conditions correspond to the hoop stress 4MPa. Material properties used for calculation correspond to the high-density polyethylene (HDPE) (Young modulus: 1200 MPa, Poisson ratio: 0.35). The exponential relationship describing stable creep crack growth in this material can be expressed by following relationship:

$$\frac{da}{dt}\left[mm\ s^{-1}\right] = 10^{-6}\left(K_I\left[MPa\ m^{1/2}\right]\right)^6 \qquad (2)$$

The values of the stress intensity factor for the crack located in the main pipe for different ratio between Young moduli of the main pipe and protective layer (E_m/E_p) was estimated, see Fig.5.

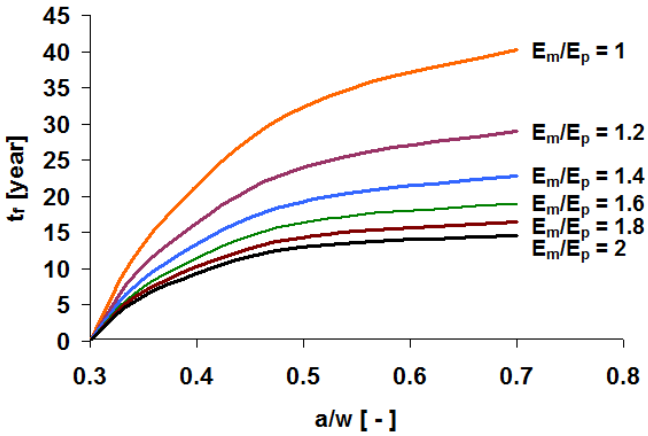

Fig.6. Residual lifetime of the pipe structure in the case of cracked inner protective layer for different ratio between Young modulus of the main pipe (E_m) and protective layer (E_p).

In the pipe systems, usually softer protective layer is used, due to better resistance against crack penetration to the main pipe. Protective material (e.g. XSC-50) has usually better resistance against slow crack growth than traditional HDPE material. It is visible that dangerous situation is, when crack penetrated interface between inner protective layer and main pipe, because softer outer protective layer changes stress state in front of the crack tip and significantly decrease residual lifetime of the structure, see Fig.6. This is the cost we should pay for better resistance of the protective layer against crack propagation from external scratches and better resistance against crack nucleation in the inner surface.

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References

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