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ASSESSMENT OF EXISTING OFFSHORE GAS TRANSIMISSION PIPELINES IN TERMS OF DUCTILE FRACTURE CONTROL USING A MODELING FRAMEWORK

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Abstract
A modeling framework is established to describe running ductile fracture in vintage API grade X52 offshore pipelines. For the structural model, the plasticity and ductile fracture properties were characterized by various laboratory scale tests. Tensile tests up to strain rates of 1000 1/s were performed to calibrate the strain rate dependent plasticity model. Using notched tensile specimens with a wide range of stress states, a hybrid experimental-numerical procedure was performed to determine the parameters of a ductile fracture (FL) model. The material model was successfully verified against the results of instrumented Battelle Drop-Weight Tear (BDWT) tests. The decompression of the CO2-rich gas mixture was described by the GERG-2008 equation of state and implemented as an idealized pressure decay model to reduce the computational cost. Finally, the established modeling framework provides a valuable tool for investigating and evaluating ductile fracture propagation and arrest behavior in vintage offshore pipelines.

1. Introduction
Carbon capture and storage (CCS) has recently gained attention as a way to mitigate climate change by reducing anthropogenic CO_2 emissions. Regarding CO_2 transport, the focus was primarily on examining the possibilities of reusing existing pipeline infrastructure for natural gas. However, for this repurposing, a reassessment of the structural integrity in terms of fracture control is necessary due to the different decompression characteristics of natural gas and CO_2-rich gas mixtures. In this context, combined experimental-numerical investigations offer a feasible way towards evaluating the suitability of pipelines under varying operating conditions. The basis for a reliable numerical assessment is a material model that can describe both plastic deformation and ductile fracture behavior. The present work aims at establishing the modeling framework for the structural integrity assessment of existing pipelines. Through an extensive experimental program, we characterize the plasticity and ductile fracture behavior of a vintage line pipe steel API X52 and use the results to calibrate the material model parameters. The subsequent simulation of dynamic ductile fracture propagation requires, in particular, the quantification of the strain rate effect and the representation of ductile fracture as a function of relevant stress state conditions. Based on the results of BDWT tests, we were able to verify the modelling framework within the strain rate and stress state conditions covered by the investigated lab specimens. It should be noted that the validation of the modeling framework is possible only through results from fracture propagation tests on pipeline sections. However as shown in previous research [1], a verified framework is already a solid basis for investigating and evaluating the structural integrity of gas pipelines. Thus, we demonstrate the capability and potential of this framework in describing the fracture propagation and arrest behavior of existing pipelines for the transportation of CO_2-rich gas mixtures, but also suggest ways to overcome the current limitations.

2. Results
The specimens were extracted in transverse direction from a pipe segment with an outer diameter (*OD*) of 508 mm and a wall thickness (*WT*) of 12.7 mm. Due to the extraction in the transverse direction, the BDWT specimens need to be gull-winged, what causes undesirable effects such as lateral deformations during testing due to their pronounced slenderness. To minimize these effects, a pre-fatigued (PF) crack was introduced into the BDWT specimen with an initial crack ratio of $a/W = 0.3$. Fig. 1 shows the experimental force-displacement curves of the quasi-static BDWT test (left) and the dynamic BDWT test (middle). In general, a good agreement between the experimental and numerical results can be achieved.

For the static BDWT tests, the numerical model yields a slight overestimation of the experimental strain hardening behavior. In the dynamic BDWT test, the load drop in the propagation phase is overestimated in the simulation, thus implying a higher toughness in the simulation and resulting in 14% higher energy compared to the experimental value. The model parameters were subsequently used to estimate the ductile fracture propagation in a pipe segment with a total length of $l = 7$ m. The pipe model is partially entrenched in soil to consider backfill effects during ductile crack propagation. A simplified pressure decay model based on experimental data from full scale burst tests [2,3] was applied on the inner surface of the pipe to describe the loading scenario. The characteristic decompression behavior of CO_2-rich gas mixtures under initial dense phase conditions was considered assuming a constant decompression wave velocity. Starting from an operating pressure of $p = 12.1$ MPa, a saturation pressure of $p_s = 8$ MPa was assumed at the transition into the two-phase region. Fig. 1 (right diagram) shows the predicted crack velocity as a function of the crack length. In the initial phase, the crack propagates with an average velocity of approx. $v_c = 175\ \mathrm{m/s}$, which subsequently drops to $v_c = 115\ \mathrm{m/s}$ due to the interaction of the pipe flaps behind the crack tip with the soil backfill. Afterwards, a transition to a steady state with a fracture velocity of $v_c = 145\ \mathrm{m/s}$ sets in. Thus, no crack arrest is obtained within the investigated simulation time under the assumed operating conditions. By using the established modeling framework, the operating conditions of the existing pipelines can either be evaluated with respect to fracture control or identified to ensure it.

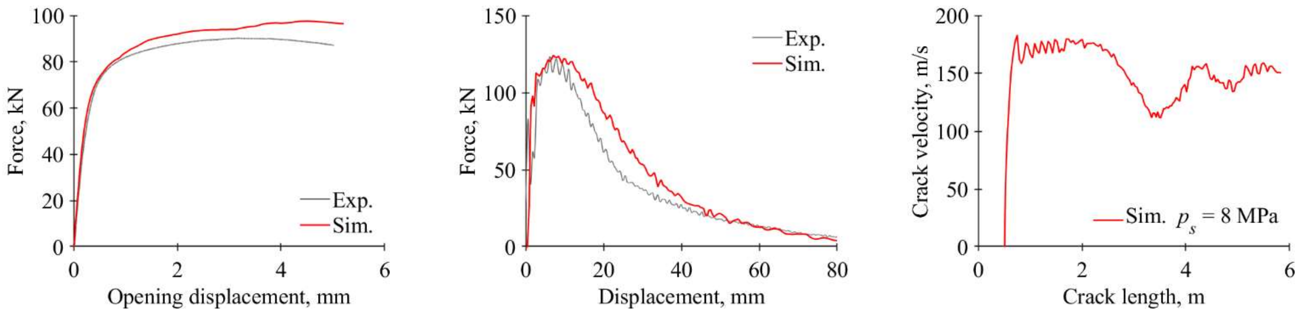

Fig. 1 - Experimental and numerical force-displacement traces from PF BDWT tests under quasi-static (left diagram) and dynamic loading conditions (middle diagram). The right diagram shows the prediction of the ductile fracture propagation velocity in a pipe segment.

3. Conclusions

The presented work aims at establishing a modeling framework for the fracture control of existing offshore pipelines for CO_2 transport. Thus, the mechanical characterization of a vintage API X52 line pipe steel was carried out by using a hybrid experimental-numerical procedure. The calibrated material model allows for an accurate description of the plastic deformation and ductile fracture behavior. Given the assumed operating conditions, the model predicted no crack arrest in the investigated pipe segment. The established framework represents a useful tool to identify possible operating conditions when repurposing a natural gas pipeline for the transport of CO_2-rich gas mixtures.

4. References

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