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Failure resistance of drilling rig casing pipes with an axial crack

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Working conditions of casing pipes in drilling rigs can significantly influence the initiation and development of damage in the material, and therefore also the safe service of the entire system. In this work, an integrity assessment of a pipe with initial defect (machined surface crack) is presented. The position of this defect is on the external surface; unlike transport pipes, where internal surface is often endangered due to the contact with the fluid, casing pipes are also often exposed to damages at the external surface. A pipe segment exposed to internal pressure is examined experimentally and numerically, using the finite element method. Experimental setup included tracking of crack mouth opening displacement (CMOD) values, as well as J integral. Criteria for pipe failure are determined on the finite element (FE) models of the pipe; fracture initiation and plastic collapse are considered as failure mechanisms. Several 3D models with different crack sizes are evaluated. 2D plane strain models are also examined, to determine the applicability limits of this simplified approach. Integrity assessment criteria for the analysed geometries are discussed. Assessment of fracture resistance of the pipeline material is also considered in this work. Besides the standard SENB specimens, Ring specimens cut from the pipe are tested, and the results are compared. Both specimen geometries are modelled using local approach to fracture, by application of the micromechanical Complete Gurson model (CGM), developed by Z.L. Zhang. It is shown that the Ring specimens have similar fracture conditions under bending load as SENB specimens. Since they are much simpler to fabricate from the pipe than standard specimens, it is concluded that they can be used for assessment of fracture of the pipes with axial cracks.

1. Introduction

Working loads of pipelines used in oil and gas drilling rigs, mechanical and thermal loads, are typically coupled with the effects of the corrosive environment which can accelerate the initiation and development of defects in the material. Therefore, structural integrity assessment for pipes with defects is very important for ensuring the safe exploitation and prediction/prevention of possible failure scenarios. In this work, a pipe, manufactured by high frequency contact welding (HF) of API J55 steel, is considered;

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influence of a defect (machined surface crack) on the load carrying capacity is analysed. The crack is in axial direction, bearing in mind that this type of defect is the most severe for the cylindrical pressurized components.

Many recent investigations, [1–20], have dealt with the analysis of the deformation behaviour, failure, integrity assessment and remaining service life of pipelines. Fracture parameters for the pipes with cracks are analysed in [1–5]. Most of the studies from the literature deal with conditions for fracture initiation, i.e. determining the loading level which will cause the existing crack to extend. Further development of fracture in pipelines, crack growth, is modelled in [6] using the cohesive zone model, in [7] using the extended finite element method, while micromechanical approach was applied in [8]. The other mechanism of failure of the pipeline components with cracks – plastic collapse, is also considered in literature, e.g. [9–11]. Different geometries are tested, including straight pipes [9] and pipe elbows with different geometries [10,11].

In addition to cracks or crack-like defects, volumetric defects (which represent the corrosion pits), are also often considered in the literature, [12–15]. In most of the literature dealing with volumetric corrosion defects, plastic collapse of the ligament (thin area of the pipe wall) is considered as failure condition. On the other hand, local approach to fracture is used in the papers [14,15] to track the crack growth initiation at the bottom of a pit, while notch fracture mechanics is applied with a similar aim in [16]. As a conservative approach, in the paper [17] corrosion pits are actually modelled as pre-cracks. Stress corrosion cracking, as a mechanism combining the mechanical load and aggressive medium effect, is analysed in [18]. Since some of the initial defects can be prevented in the pipe fabrication procedure, quality testing of the welded (seam) pipes is considered in [19].

The work presented in this paper includes testing of a pipe segment (taken from a drilling rig pipeline) with axial crack, exposed to internal pressure. J integral value for the surface crack on the pipe is determined by so-called direct measurement, which includes the use of combined experimental – computational procedure. Integrity is assessed through determining the loads corresponding to the two distinct failure modes – crack growth initiation and plastic collapse of the ligament ahead of the crack front. Crack growth initiation is predicted by the critical value of the J integral, while elastic – perfectly plastic material behaviour is applied for plastic collapse analyses, [9–11].

Besides the finite element (FE) model resembling the tested crack geometry, several 3D models with different crack sizes are evaluated. Dependence of maximum internal pressure on the defect size is obtained. Simplified 2D plane strain models are also examined, with an aim to determine the applicability of such approach; these models correspond to the pipe with an infinitely long crack.

Additionally, testing of specimens was performed. It included standard single edge notch bend specimens and new, so called Ring specimens, proposed in [21–23]. A comparison of these two is made, based on the behaviour under the same type of loading – bending. Having in mind that the Ring specimens have shown rather similar behaviour as the standard SENB ones (based on F-CTOD curves, CTOD-Δa curves and stress triaxiality values), they can be used for determination of fracture resistance for smaller diameters of pipes. The limitation for the pipe diameter is determined by the available testing machine – maximum load and space.

2. Pipe testing

2.1. Experimental testing

A casing pipe manufactured by high frequency, HF, welding with an axial surface crack is experimentally tested. The pipe was withdrawn from a drilling rig during a reparation procedure after about 70,000 h (8 years); this period is much shorter than the designed service life (up to 30 years). The pressure test is conducted on a pipe segment capped at both ends (by welding). The main dimensions of the pipe and the crack are shown in Fig. 1; the nominal pipe wall thickness t is 6.98 mm, crack length L is 200 mm, while crack depth a is 3.5 mm. The loading (internal pressure) was increased to the maximum value of 220 bar. The strains in the vicinity of the pre-crack were determined by series of the strain gauges. The crack mouth opening displacement (CMOD) was measured using COD gauge.

Chemical composition and main tensile properties of API J55 steel are given in Tables 1 and 2. More details on the testing of pipeline material can be found in [24], where experimental testing was performed on the specimens cut from the exploited pipeline, as well as on those cut from a new pipe of the same grade.

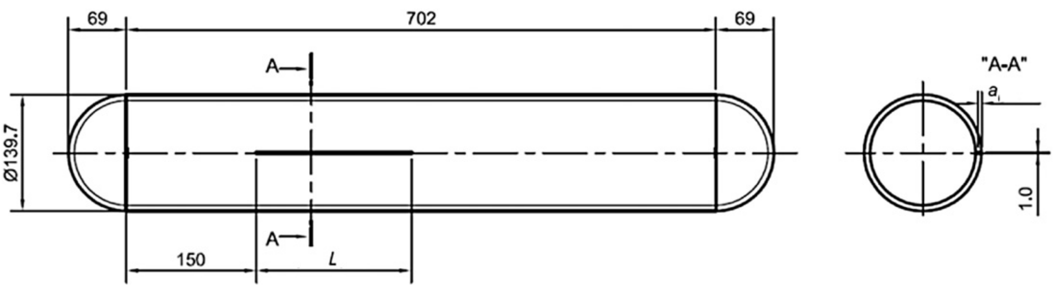

Fig. 1. Dimensions of the pipe and crack (all measures are in mm, crack length L is 200 mm, while crack depth a is 3.5 mm – these two values are varied in numerical analysis, which is shown later).