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CTOA levels of welded joint in API X70 pipe steel

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ABSTRACT

The CTOA toughness and fracture morphology of growing crack in spirally welded steel pipe of grade API X70 were investigated. An optical test procedure based on modified double cantilever beam was used which produced a measure of the steady-state ductile fracture toughness for test material. From this, CTOA value of 8.2° and 7.5° were obtained for base and weld metal, respectively. The specimens fracture surfaces were examined next, which demonstrated dimple-typed shear mode fracture. Discussion on the difficulties in establishing measures of fracture resistance in pipeline steels and potential advantages and limitations of the applied test technique conclude the paper.

1. Introduction

The safety and structural integrity of high-pressure pipeline systems is important for continuous transportation of energy resources from the production sites to the market. Different fracture criteria have been used over the past decades for safety assessment of pipelines. The CTOA fracture toughness proved to be promising.

1.1. CTOA background

Failure information from full-scale burst experiments on modern thermo-mechanical controlled rolling (TMCP) gas pipeline steels, having yield strength level of 690 MPa and higher has shown that the CTOA fracture criterion can be effectively used to predict the arrest/propagation behaviour of the pipe against possible axial ductile fractures [1,2]. The use of CTOA as an alternative or an addition to the Charpy V-notch and drop weight tear test (DWTT) fracture energy in pipelines is currently under review [3,4]. The main advantages of CTOA are that it could be directly measured from the crack opening profile, and also can be related to the geometry of the fracturing pipe. Furthermore, it can be implemented easily in finite element models of the propagating fracture process [5].

Extensive combinations of experimental and computational works on aerospace aluminium alloys (e.g. by Newman and Dawicke [6,7]) and on gas pipeline steels (e.g. by Mannucci [8], Demofonti [9], Wilkowski et al. [10] and others [11–16]) showed that the CTOA data approached a plateau during the steady state phase of shear crack propagation. This suggested that a steady CTOA could be considered as a material property and used as either an addition or an alternative to the absorbed fracture energy for the assessment of the toughness of pipeline steels. Once the stable CTOA data is obtained, the failure arrest/propagation model in terms of CTOA fracture toughness can be expressed as:

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Nomenclature

C	constant
$CTOA_{material}$	fracture toughness (resistance force) of the material (°)
$CTOA_{applied}$	the crack driving force acting at the crack tip (°)
$CTOD$	crack tip opening displacement (mm)
D	pipe outside diameter (mm)
E	pipe elastic modulus (GPa)
H	pipe wall thickness (mm)
K	strength coefficient (MPa)
m	constant
n	strain hardening exponent
n	constant
q	constant
YS	yield strength (MPa)
TS	tensile strength (MPa)
σ_h	hoop stress (MPa)

$$CTOA_{material} > CTOA_{applied} \tag{1}$$

where $CTOA_{material}$ is the fracture toughness (resistance force) of the material (see Fig. 1), and $CTOA_{applied}$ is the crack driving force acting at the crack tip. Whenever this inequality is satisfied, any potential fracture should be arrested in the pipeline.

In Fig. 1, ductile slant fracture propagating in the pipe axial direction is demonstrated together with a close-up of crack tip region. Using this configuration, a simple geometric relationship can be derived for $CTOA_{material}$ measurement in ductile crack growth:

$$CTOA_{material} = 2\tan^{-1}\left(\frac{CTOD}{2x}\right) \tag{2}$$

where $CTOD$ is crack tip opening displacement and x the distance behind the crack tip where $CTOA_{material}$ is measured. The x parameter is usually in the range of 0.5–1.5 mm [17]. Eq. (2) has been extensively used in accompany with optical techniques for CTOA estimation of tough aluminium alloy panels used in spacecraft fuselages [6,17].

1.2. Application of CTOA toughness in gas pipelines

In the field of pipeline industry, full-thickness burst tests on high-grade pipeline steels have shown that the CTOA fracture criterion is promising. This is demonstrated in Fig. 2 [18].

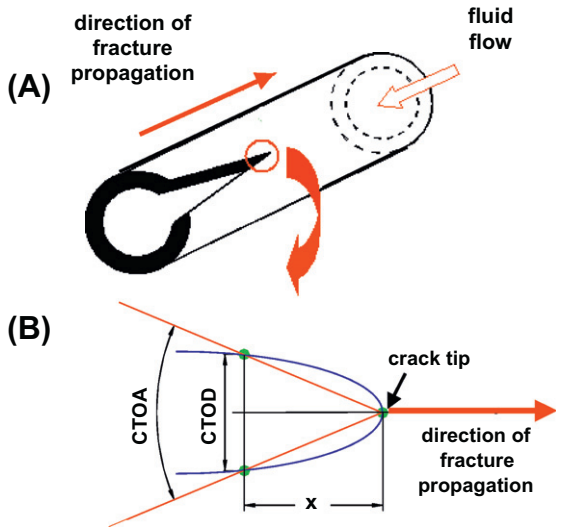

Fig. 1. Definition of CTOA from the fracture flaps measured at a fixed distance (x) behind the moving crack tip.