CONSTANT CTOA DETERMINATION FOR STABLE DUCTILE CRACK GROWTH AND ITS APPLICATION TO RUNNING FRACTURE CONTROL FOR GAS TRANSMISSION PIPELINE

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Abstract

The crack tip opening angle (CTOA) has been used as a reliable fracture toughness to characterize stable crack growth for thin-wall structures in low-constraint conditions. Recently, it has been found that CTOA can be also utilized as a robust fracture parameter to describe arrest fracture toughness for gas transmission pipelines in modern ductile steels. This is a great improvement of the traditional fracture control technology for gas pipelines, where a Charpy-vee notch (CVN) impact energy based two curve model developed at Battelle (BTCM) was used to determine the arrest toughness. While the CVN-based BCTM is not applicable to modern pipeline steels with grades X70 and above, the CTOA-based BTCM works well for these high grades, but requires constant CTOA. This work develops four methods to determine constant CTOA using the single edge notched bend (SENB) specimens, including a load-displacement linear fit method, a logarithmic load-displacement linear fit method, a stable tearing energy method, and a J-differentiation method. The test results for A285 carbon steel show that these CTOA methods can determine nearly identical critical CTOA values over stable ductile crack growth using the SENB specimens.

1. Introduction

Fracture mechanics methods have been extensively applied to structural design, crack assessment, and asset integrity management of large scale metallic infrastructures in the energy sector, including various pressure vessels, storage tanks and oil/gas transmission pipelines. Many pressure vessels are made of stainless steels, whereas pipelines are made of carbon steels. For these ductile steels, the elastic-plastic fracture mechanics methods are often used for engineering critical analysis (ECA), with fracture toughness being characterized by three fracture parameters: the J-integral, crack tip opening displacement (CTOD), and CTOA. The fracture toughness test methods was reviewed by Zhu and Joyce [1]. The early CTOA testing mainly used thin-wall specimens with surface measurement technologies, and the CTOA criterion was primarily used for thin-wall structures in the aerospace industry. Even so, the CTOA criterion has been tried to use as arrest toughness to improve BCTM (see Fig. 1) for running fracture control for gas pipelines [2]. Different modified methods were then developed for determining critical CTOA for thick-wall specimens, including the simple single specimen method proposed by Xu et al. [3] for drop weight tear test (DWTT) specimens. On this basis, ASTM E3039 [4] was developed in 2016 for experimental determination of CTOA for ferritic steels at the mid-plane of DWTT specimens. Recently, CTOA has been used to improve BTCM [5] as shown in Fig. 2 This paper develops constant CTOA test methods using regular SENB speciomens.

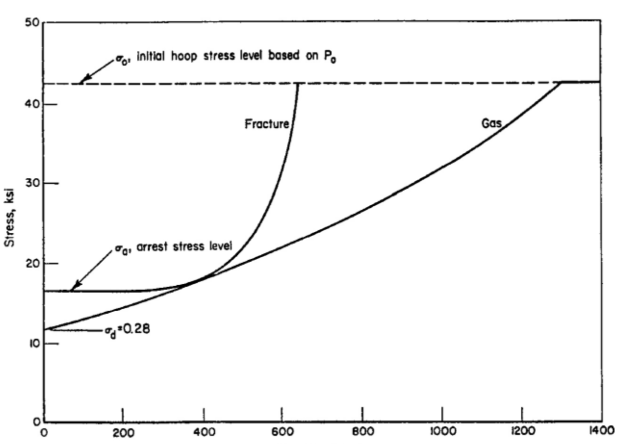

Fig. 1 – Illustration of CVN-based BTCM [1]

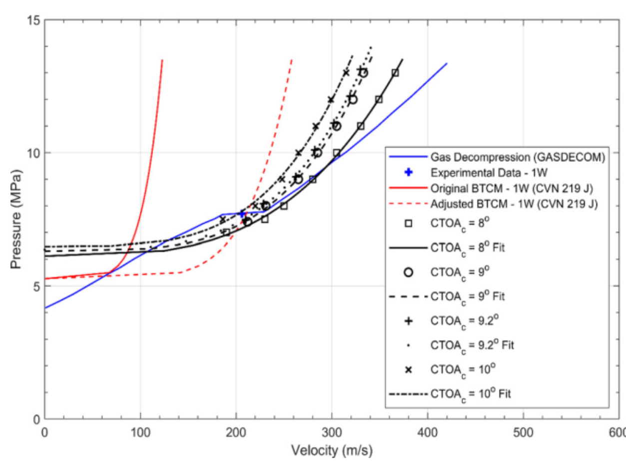

Fig. 2 – Illustraction of CTOA-based BTCM [2]

2. Results

ASTM E3039 CTOA test method was developed for DWTT specimens that are similar to the standard SENB specimens, except for large sizes. Based on the plastic hinge model for SENB, as shown in Fig. 3(a), and from the load (P) - load-line displacement (LLD) data measured during a fracture test, the following four methods are developed for deteriming critical, constant CTOA using regular SENB specimens:

1) P-LLD linear fit model: determines a linearly decreasing CTOA over stable crack growth
2) Ln(P)-LLD linear fit method: determines a constant CTOA over stable crack growth
3) Stable tearing energy method: determines a constant CTOA over stable crack growth
4) J-differentiation method: a comparable critical CTOA over stable crack growth

Using fracture test data from SENB testing on A285 carbon steel, the proposed four methods determine nearly constant CTOA (~11.6°) over a stable crack growth, as shown in Fig. 3(b) for SENB with a deep crack of a/W = 0.715. Futher investigation in Ref. [6] showed that the critical CTOA is nearly constant for a shallow crack of a/W=0.32 and a deep crack of 0.59. Thus, CTOA is independent of constraint level.

(a) (b)

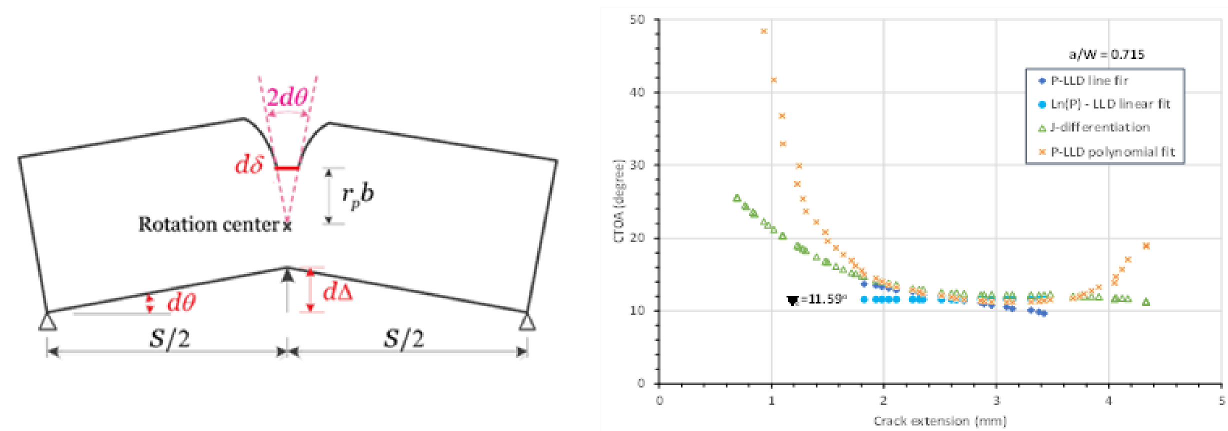

Fig. 3 – (a) SENB specimen and plastic hinge model, (b) CTOA vs crack extension for a deep crack

3. Conclusions

This paper developed four methods to determine a critical CTOA using SENB specimens. Test results for A285 steel showed that the critical CTOA is nearly a constant for all cracks thus independent of constraint.

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