

Procedure Proposition using a Compact SENT Geometry for Fracture Toughness Assessment in Sour Environment

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ABSTRACT

The DCB method is a crack arrest test, i.e., the specimen is self-loaded with a wedge and the constant displacement configuration makes the SIF decrease as the crack grows. Thus, K_{ISSC} provided from the DCB test could be different from the toughness of a cracked structure under a constant load scenario. The objective of this paper is to present a new experimental method using a compact Single Edge Notched Tension (SENT) specimen for assessing the SIF threshold for crack growth initiation. The test method provides the same framework as Method A of the NACE TM0177 standard. A numerical solution of SIF as a function of load and geometric parameters is derived from Finite Element Analysis. Tests are performed using the DCB and SENT geometries on C110 grade. The obtained results from the two methods are compared and a test protocol for conducting the crack initiation test is proposed.

Keywords: DCB, constant load SENT, hydrogen embrittlement

INTRODUCTION

For many decades several standardized and not standardized methods based on different pre-cracked specimen geometries have been used for quantifying the stress intensity threshold K_{Ith} under environmentally assisted cracking conditions ^(1; 2). Since its implementation in 1990 ⁽²⁾ as method D of NACE TM0177 standard ⁽³⁾ the Double Cantilever Beam (DCB) test method remains in continuous improvements and updates beyond the fact that it is widely used as a tool for quality control, new alloy evaluation, or even material performance mapping regarding environment parameters as temperature, pH, H₂S content and chemical species concentration. Thus, DCB geometry is considered as the most known and used test method to evaluate material fracture toughness under Stress Corrosion Cracking and Sulfide Stress Cracking conditions.

Over the years, numerous studies were done to highlight some difficulties faced when carrying out tests with NACE TM0177 method D and to understand the effect of some test parameters on the stress intensity factor threshold as arm displacement and pre-cracking parameters ^(4; 5), notch type and initial crack length ^(4; 6; 7; 8) and side groove ^(9; 10; 11). Nevertheless, nowadays the DCB test is still a debated issue regarding both the intrinsic variables that are inherent to the specimen geometry and the data validation requirements as specified in the NACE TM0177 standard. Besides, the DCB test is a crack arrest test, i.e. the specimen is self-loaded with a wedge that is considered as constant displacement configuration and where the stress intensity factor (SIF) decreases as the crack grows. Thus, obtain K_{ISCC} from the DCB test could be different from a critical scenario where a cracked structure is under constant load and the applied stress intensity factor is an initiation crack propagation threshold $K_{threshold}$.

For OCTG applications, DCB has been historically used to determine K_{ISCC} of metallic materials, whereas little information is available in the literature on the use of Single Edge Notched Tension (SENT) geometry in sour environments for the determination of fracture toughness. However, the main interest of measuring K_{ISCC} for OCTG applications is to determine the burst strength of flawed pipes, which is a loading condition yielding an increasing stress intensity factor as the crack grows. It is established that the SENT geometry provides the closest behavior in terms of the mechanical loading response of a cracked tubular structure due to the similarity of the stress and strain fields ^(12; 13; 14; 15; 16; 17; 18).

Hence, the current work will add a brick towards the understanding of the impact of the driving force (i.e., decreasing vs increasing SIF) and to the definition of an acceptable testing method for the SENT samples in the corrosive environment, still unknown nowadays. A closed-form expression linking the stress intensity factor to the crack length is derived from 3D Finite Element Analysis. The test method allows an easy setup as it uses the same framework of method A of the NACE TM0177 standard. Tests will be performed using the DCB and the new compact SENT geometries on C110 grade exposed to the sour environment. The obtained results from the two test geometries will be compared and a test protocol for conducting the crack initiation test will be proposed.

Finite Element Analysis for Stress Intensity Factor determination of a compact SENT geometry

Compact SENT specimen geometry

A SENT geometry identified as compact SENT with square transverse section 7x7 mm², 25,4 mm gauge length, and 1 mm notch length was used for fracture toughness evaluation. The SENT specimen with the geometry shape and dimensions as presented in Figure 1 was adopted to be mounted in a common proof ring setup and the threaded end was designed to fit the available device grip.

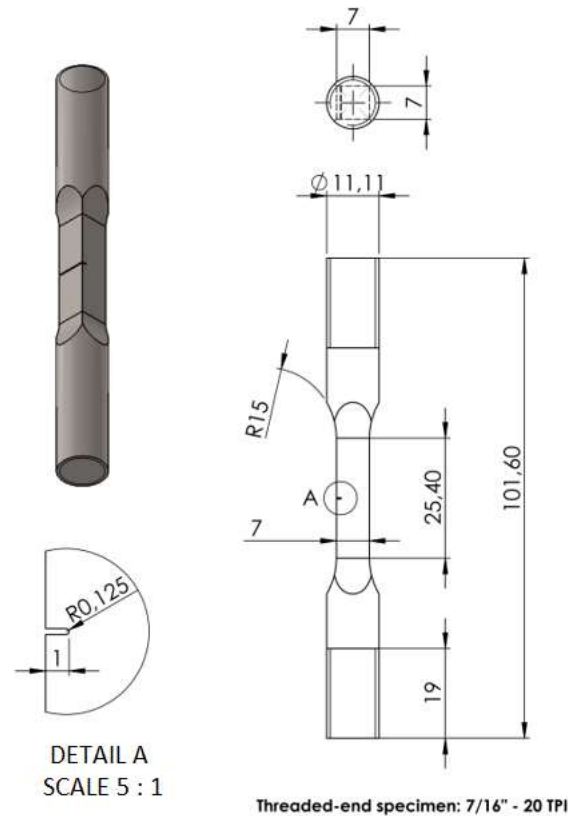


**Figure 1: Schematic drawing of Compact SENT specimen for proof ring setup
(dimensions in mm).**

3D FEA modeling

3D finite element analyses using software CAE ABAQUS v6.13.1 were performed to derive a simple and accurate expression of the stress intensity factor K_I of the compact SENT geometry. Two symmetric plans were explored to reduce the simulation time cost. Figure 2 presents the model of a quarter of the 3D geometry.

All simulations were performed under the fracture mechanics framework considering a linear elastic behavior of the material. A global regular mesh with hexahedral elements of type C3D20 was applied with a refined region around the crack tip as presented in Figure 3. Several analyses were carried out simulating different crack lengths configuration varying α , a/W ratio. In all simulations, a constant load of $P = 5\text{ kN}$ was applied and a numeric value of the maximum K_I was extracted at middle of specimen thickness in the crack front for each a/W evaluated.

A convenient form of K_I factor (equation 1) presented in ASTM E1820⁽¹⁹⁾ was adopted to determine the geometric shape function $f(\alpha)$.

$$K_I = \frac{P}{BW^2} F(\alpha), \alpha = a/W \quad (1)$$

Plotting the numerical result $K_I \frac{BW^{\frac{1}{2}}}{P} = F(\alpha)$ versus α as presented in Figure 4 and approaching the data with a polynomial regression, a mathematical expression for $F(\alpha)$ as a polynomial function of fifth degree is obtained (equation 2). Hence the equation system given by (1) and (2) can be considered for estimating the stress intensity factor of the compact SENT specimen covering a crack length range α for 0.2 to 0.9.

$$F(\alpha) = 43,367 \alpha^5 - 99,185 \alpha^4 + 87,038 \alpha^3 - 31,762 \alpha^2 + 8,8764 \alpha \quad (2)$$

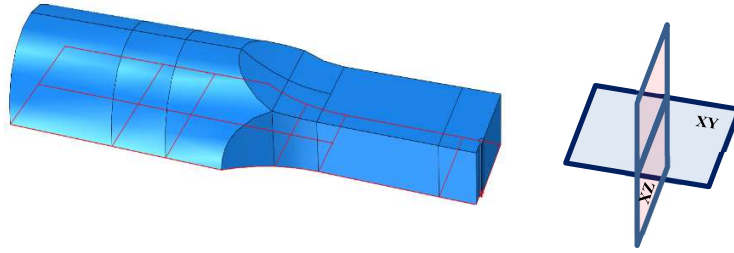


Figure 2: A quarter Compact SENT specimen geometry model. Two symmetry plans.

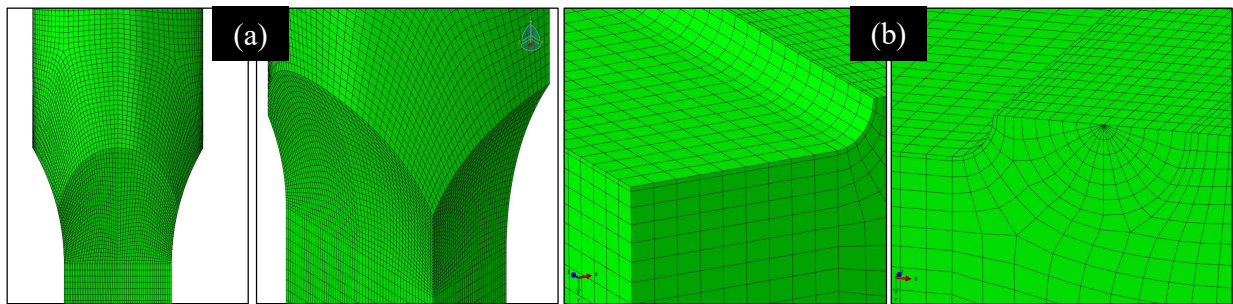


Figure 3: 3D Mesh of the compact SENT geometry. (a) Near the threaded end. (b) In the vicinity of the notch and the crack.

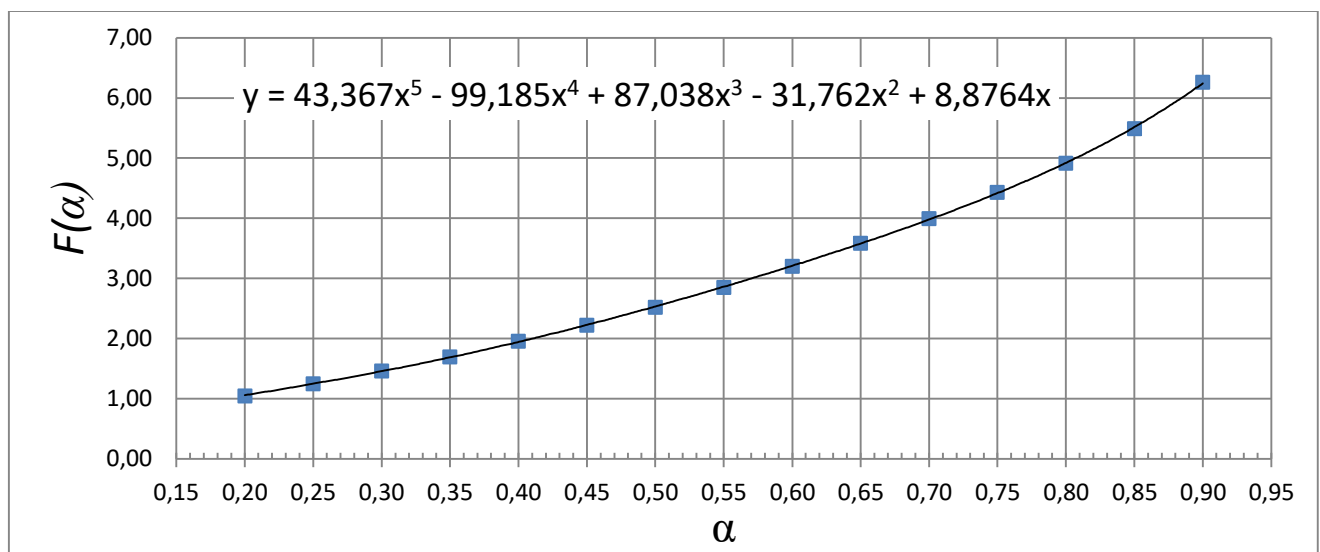


Figure 4: Determination of the geometric shape function $F(\alpha)$.