Volumetric Method to Understand the Effect of T-Stress and Stress Intensity Factor in Arc of Pipe

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1. Introduction and finite element analysis

A second fracture parameter, the T-stress, is used in order to understand the effect of structural and loading configuration at the crack tip, even though the physical significance of the parameter is unknown. T-stress is defined as constant stress acting parallel to the crack and its magnitude is proportional to the nominal stress in the vicinity of the crack. Positive T-stress strengthens the level of crack tip stress triaxiality and leads to high crack tip constraint; while negative T-stress reduces the level of crack tip stress triaxiality and leads to the loss of the crack tip constraint. In this paper, we revise the method proposed by Yang et al. [1] using directly a single finite element (FE) analysis by CASTEM 2000 [2] program. This method, namely the stress difference method (SDM), for computing the elastic T-stress efficiently and accurately by evaluating (σ_{xx} - σ_{yy}) at a point ahead of a crack tip. We then present a volumetric method [3] for computing T-stress and Stress Intensity Factor (K_I) in mode I by modifying the stress difference method, the so-called Modified Stress Difference Method (MSDM). The finite element method was used to determine the crack-tip parameters T and K for the arc of pipe specimens. The structures were modeled by CASTEM 2000 code in two dimensions under plane strain conditions using free-meshed isoparametric quadrilateral elements, with quarter-point singularity elements at the crack-tip. Only one half of the test apparatus was modelled due to symmetry in the geometry and loading conditions.

2. Results and discussions

Because T-stress and mode I stress intensity factor vary relatively little along the crack front, only the results near the crack tip are presented in this section. The stress difference method (SDM) is used to determine T-stress and K_I for distances r behind the crack. These results show the variation of T-stress and SIF with external longitudinal surface crack at a depth for typical crack lengths and (a/t) ratios. An example of the effects of crack length on both T-stress is examined in Fig.2 for a/t = 0.2. These results are influenced by numerical errors which are normally expected from FE results in highly stresses zones. The effects of higher order terms in William's series expansion are significant along the crack length. For small crack growth under predominate mode I loading, T-stress is negative (compressive) and the crack will propagate in the original direction. This is characterized as directional stable crack trajectory.

In Fig. 3, we show the results of SIF obtained from the bending loading. The Variations of SIF, presented in D/t = 36, show that the evolution in SIF with crack length is not monotonic as verified in the 2D analyses. Careful analysis has shown that this distribution may be characterized by three zones.

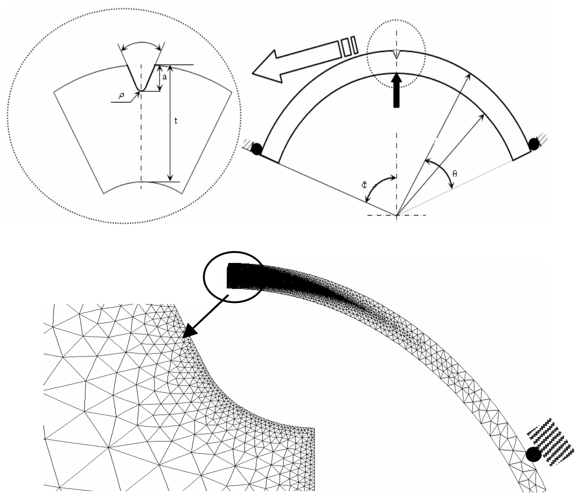

FIG.1: (a) Geometrical boundary conditions and loading configuration using in an arc of pipe. (b) Typical 2D finite-element mesh used to model the cracked arc of pipe for elastic analysis.

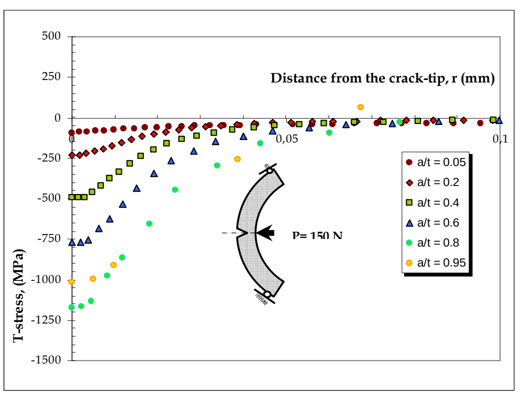

FIG.2: T-stress near the crack tip.

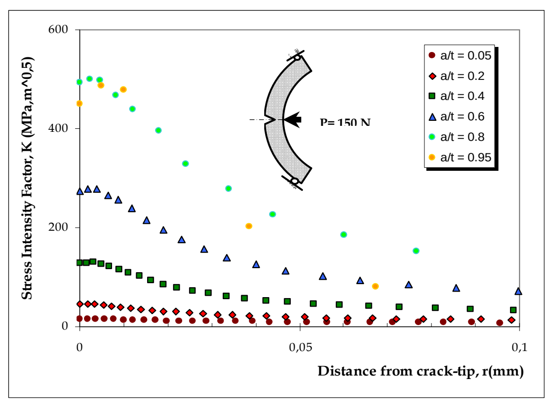

FIG.3: Mode I Stress intensity factor.

3. Evaluation of T-stress and SIF by volumetric method

A careful analysis has shown that this distribution may be characterized by three zones. It is assumed that the fracture process needs certain physical volume. This assumption is supported by the fact that fracture resistance is affected by loading mode, structure geometry and scale effect. Effective Stress Intensity Factor and the effective T-stress can be estimated by averaging the value of SIF distribution along this effective distance. According to recent investigations, other methods are applied to predict the T-stress and stress intensity factors. One of these methods, known as the volumetric approach, is concerned with the modification of the Stress Difference Method (SDM). Volumetric approach is a macro-mechanical method and it uses an elastic-plastic distribution and stress intensity factor gradient evolution to predict stress intensity factor. The main idea of this method is the application of the effective stress intensity factor in a region near notch roots and the study of intrinsic characteristics of this small and essential zone by taking into account the numerical SIF results, including the non linear behavior of materials. By knowing the effective stress intensity factor and the effective distance, one can have the effective T-stress.

From the discussion above, we can conclude that both the nonsingular T-stress and singular K_I terms are needed to describe the fracture under this mode I loading configuration. It is worth noticing that the T-stresses values, calculated for every crack extension in all the samples, are positive but then become negative. This is compatible with the idea that this is responsible for preventing crack kinking in pipe's arc. Using the maximum tangential stress (MTS) approach, the direction of fracture initiation and the onset of crack growth should be investigated at the effective distance a_{eff} from the crack tip and not at the crack tip where r = 0. Since the T-stress and SIF estimate from FE is based on the local membrane and bending components, it provides the computation of an "effective" T-stress (T_{eff}) and an "effective" stress intensity factor (K_{eff}) taking into consideration the current near-tip loading modes.

4. Concluding remarks

Under small scale yielding conditions, which involve high degree of triaxiality at the crack-tip, a single parameter (K_I or J) characterizes crack-tip conditions that can be used as a material property. The single parameter fracture mechanics requires that the plastic zone size, be small compared with other dimensions of the cracked structure, e.g., crack length, size of uncracked ligament, and thickness. However, under excessive plasticity, a single parameter is not sufficient to represent crack-tip fields, and the fracture toughness depends on the size and geometry of the specimen. Such behavior is associated with the elastic T-stress, which affects the size and shape of the plastic zone, crack-tip constraint and fracture toughness.

References

[1] B. Yang, and K. Ravi-Chandar, Engng. Fract. Mech. **64**, 589 (1999).

[2] CASTEM 2000. http://www-cast3m.cea.fr/cast3m/index.jsp.

[3] G. Pluvinage, *Fract. and Fatigue Emanating from Stress Concentrators* (Kluwer, Publisher, 2003).