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Unloading compliance correlations for throughwall circumferentially cracked elbow to measure crack growth during fracture tests

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ABSTRACT

The unloading compliance technique is very commonly used to measure crack growth during fracture experiment. The pre-requisite of this technique is an equation correlating crack length with unloading compliance. Such correlations are easily available for small specimens. But no such correlation exists for elbows. Unlike conventional geometries, elbow cross section ovalises during deformation which makes the problem non-linear. Considering these complexities, new compliance correlations are proposed based on non-linear FEA for throughwall circumferentially cracked elbow under in-plane bending moment. The proposed correlations are expressed in terms of normalized parameters to make them independent of specific values of geometric dimensions.

1. Introduction

The unloading compliance technique is one of the most commonly used and also the simplest methods to measure crack growth during fracture test of small specimens, e.g. Compact Tension (CT) and Three Point Bend (TPB), etc. [1]. This technique allows crack growth to be inferred from the unloading compliance values at periodic intervals during the fracture tests. The pre-requisite of this technique is the availability of an equation that correlates crack length with unloading compliance. Such correlations are easily available [1] for small specimens, (e.g. CT and TPB). However, the same is not true for piping components, which are commonly tested all over the world to resolve various fracture mechanics issues. Recently, Chattopadhyay et al. [2] proposed a new unloading compliance correlation for through wall circumferentially cracked (TCC) pipe under bending. Similar equation for elbow or pipe bend is still not available in the open literature. The development of unloading compliance correlation for through wall cracked elbow thus forms the motivation for the present work. As mentioned in [2], development of compliance correlation for pipe/elbow has additional challenges due to ovalisation of cross section during deformation. In case of pipe, the degree of ovalisation is very small. However, in case of elbow, the degree of ovalisation is quite significant and nature of ovalisation is even different for in-plane closing and opening bending moment [3]. Considering all these complexities, an elaborate numerical study has been undertaken to develop unloading compliance correlations for through wall cracked elbow. Nonlinear finite element analysis considering both geometric and material nonlinearity has been carried out for 90° elbows of different R/t ratios with various sizes of through wall circumferential cracks at extrados under in-plane closing bending moment and at intrados under in-plane opening bending moment. The basic

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Nomenclature

C	compliance value at elastic–plastic load level
C_0	initial elastic compliance
E	Young's modulus
M	bending moment
M_L	plastic limit moment
m M/M_L	normalized bending moment applied
R	mean radius of elbow cross section
R_b	mean bend radius of elbow
t	wall thickness of elbow cross section
δ	crack mouth opening displacement calculated at mid-length, mid-thickness
$\lambda_0 = \pi R^2 C_0 E$	non-dimensional initial elastic compliance
θ	semi circumferential crack angle in an elbow
σ_f	flow stress in elastic-perfectly plastic material tensile property idealization
CMOD	crack mouth opening displacement
CT	Compact Tension
PHT	primary heat transport
TCC	throughwall circumferentially cracked
TPB	Three Point Bend
UTS	ultimate tensile stress
YP	yield point

approach has been the same as adopted for pipe [2]. First, an equation correlating initial elastic compliance and crack angle of TCC elbow has been developed. Subsequently, the ratios of compliance at different value of load/deformation and the initial elastic compliance have been evaluated to include the effect of load/deformation on compliance.

2. Finite element analysis

The finite element method is used to develop the compliance correlations. Elbow with through wall circumferential crack at extrados/intrados subjected to in-plane closing/opening bending moment (Figs. 1a and 1b) is considered for analysis. Each elbow is loaded till around the theoretical plastic collapse bending moment with periodic unloading. Theoretical plastic collapse bending moment is calculated using the equations proposed by Chattopadhyay et al. [4].

The load vs. crack mouth opening displacement (CMOD) has been generated for the entire load range with periodic unloading. The CMOD is calculated at the middle of crack length (where it is maximum) and at mid-thickness. The amount of unloading is around 15% of collapse moment. Stiffness is evaluated from the slope of the load–CMOD curve by linear curve fitting of the middle portion of the unloading path leaving aside the top and bottom 1% of collapse moment. Compliance is evaluated by taking reciprocal of this stiffness evaluated at different stages of loading including the initial elastic portion. Compliance is defined as follows:

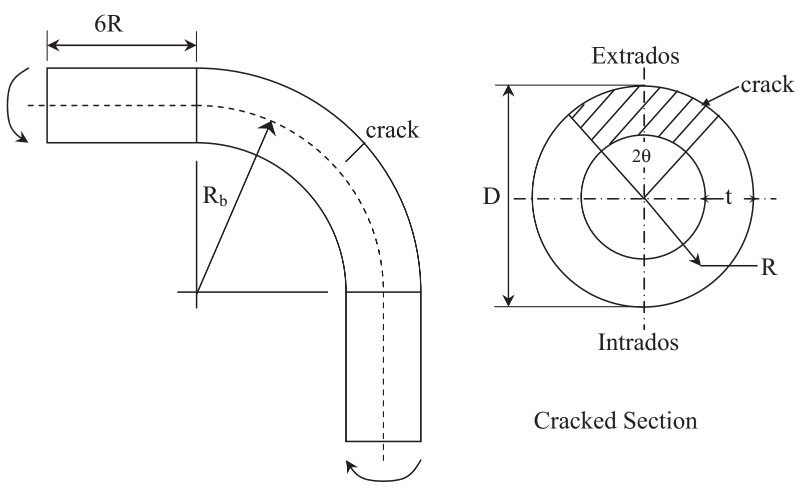

Fig. 1a. Geometry of elbow with a through wall circumferential crack at extrados under closing bending moment.