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Creep fracture mechanics parameters for internal axial surface cracks in pressurized cylinders and creep crack growth analysis

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ABSTRACT

In the present study, a low alloy Cr–Mo steel cylinder subjected to internal pressure at high temperature with a semi-elliptical crack located at the inner surface is considered. The creep crack driving force parameter C^*-integrals calculated by finite element (FE) method, are compared with results from previous studies, which indicates that empirical equations may be inaccurate under some conditions. A total of 96 cases for wide practical ranges of geometry and material parameters are performed to obtain systematic FE results of C^*-integral, which are tabulated and formulated in this paper. It is observed that the maximum C^*-integral may occur neither at the deepest point nor at the surface point when the aspect ratio is large enough and the value of C^*-integral is significantly sensitive to the crack depth ratio. Furthermore, based on the proposed equations for estimating C^*-integrals and a step-by-step analysis procedure, crack profile development, crack depth, crack length and remaining life prediction are obtained for surface cracks with various initial aspect ratios. It is found that when the crack depth ratio is increased, there is no obvious convergence of crack aspect ratio observed. The magnitude of half crack length increment is always minor compared with the crack depth increment. In addition, the remaining life is much more dependent on the surface crack depth than on the surface crack length.

1. Introduction

Crack-like defects are inevitably generated in most metal materials and components during the manufacturing process or in service. To assess the safety of the structures containing surface flaws, the knowledge of surface crack growth is very essential which includes the fracture parameters along the crack front and the shape variation, to which considerable efforts have been devoted. Assuming a maintaining semi-elliptical profile, Raju and Newman [1] proposed a two-degree-of-freedom method, for the first time, to perform surface crack growth in plates. Furthermore, Lin and Smith [2,3] performed a multiple-degree-of-freedom method using numerical calculation to obtain the stress intensity factor along the crack front and predict the next defect geometry. In much the same way, Kayser et al. [4] employed a similar FE method in discussing the Leak Before Break (LBB) procedure. It is noteworthy that K, stress intensity factor (SIF), was employed as the parameter to characterize the crack growth in all the above-mentioned literature.

With the advent of post-industrial civilization, higher operating temperatures and pressures have been adopted to improve the efficiency of energy conversion systems, which increase the risk of structure failure in creep regime [5,6]. Thus far, ample experimental evidences have suggested that K or J-integral is not appropriate for interpretation of crack growth rate under creep conditions, and yet for steady state creep, the rate-dependent parameter C^*-integral is much more applicable [7,8]. In addition, the C^*-integral can be obtained from creep displacement rate by experiment [9]. On the basis of previous work, Kim et al. [10,11] proposed an optimized reference stress method to estimate the C^*-integral for surface cracks in cylinders. Yoon et al. [12] suggested an estimation equation to calculate the C^*-integral value and then to assess the creep crack growth life, as well as to predict the evolution of creep crack shape. However, comparisons of different published C^*-integral results for a surface crack show large discrepancies and thus the reliability is still questionable. Such a lack of confidence is believed to result from the low availability of systematic FE results of C^*-integral in the past.

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