Predictions for fatigue crack growth life of cracked pipes and pipe welds using RMS SIF approach and experimental validation


A B S T R A C T

The objective of the present study is to understand the fatigue crack growth behavior in austenitic stainless steel pipes and pipe welds by carrying out analysis/predictions and experiments. The Paris law has been used for the prediction of fatigue crack growth life. To carry out the analysis, Paris constants have been determined for pipe (base) and pipe weld materials by using Compact Tension (CT) specimens machined from the actual pipe/pipe weld. Analyses have been carried out to predict the fatigue crack growth life of the austenitic stainless steel pipes/pipes welds having part through cracks on the outer surface. In the analyses, Stress Intensity Factors (K) have been evaluated through two different schemes. The first scheme considers the K evaluations at two points of the crack front i.e. maximum crack depth and crack tip at the outer surface. The second scheme accounts for the area averaged root mean square stress intensity factor (K_RMS) at deepest and surface points. Crack growth and the crack shape with loading cycles have been evaluated. In order to validate the analytical procedure/results, experiments have been carried out on full scale pipe and pipe welds with part through circumferential crack. Fatigue crack growth life evaluation using both schemes have been compared with experimental results. Use of stress intensity factor (K_RMS) evaluated using second scheme gives better fatigue crack growth life prediction compared to that of first scheme. Fatigue crack growth in pipe weld (Gas Tungsten Arc Welding) can be predicted well using Paris constants of base material but prediction is non-conservative for pipe weld (Shielded Metal Arc Welding). Further, predictions using fatigue crack growth rate curve of ASME produces conservative results for pipe and GTAW pipe welds and comparable results for SMAW pipe welds.

© 2011 Elsevier Ltd. All rights reserved.

1. Introduction

Most of the failures in the piping components and its welds are due to the fatigue loading. This failure may occur well below the allowable stress limits even under normal operating conditions, which is attributed to the presence of flaws which have either gone undetected during pre-service inspection or appeared in due course of its service. Such failures need a detailed stress/strain analysis to guarantee the integrity of piping component under fatigue loading. Now-a-days, an alternate fail-safe design philosophy such as Leak-Before-Break (LBB) based on fracture mechanics concepts is adopted to demonstrate that piping component will not fail in catastrophic manner. Although, utmost care is taken to prevent catastrophic failure during the design, material selection and fabrication stage but some flaw may go undetected due to the inadequate sensitivity of Non Destructive Examination (NDE) instrument or poor workmanship. LBB philosophy calls for demonstration of insignificant crack growth from the postulated part through crack under cyclic loading in piping component during its design life. This requires investigation on Fatigue Crack Growth (FCG) of piping components with postulated part through flaws for the qualification of LBB design criterion. Higher growth in thickness direction compared to the circumferential direction is desirable from LBB point of view. If the load combinations and the notch geometry are such that the crack grows more along the circumferential direction, then it might become critical and pipe may break without giving prior warning. To address this issue studies are required to be conducted on piping components and their welds with various crack aspect ratios (2c/a) and loading.

Fatigue crack growth rate behavior in various materials has been widely studied [1–7,19,20] for understanding of the fatigue