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Determination of the elastic-plastic fracture mechanics Z-factor for alloy 182 weld metal flaws

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ABSTRACT

One of the ways that the ASME Section XI code incorporates elastic-plastic fracture mechanics (EPFM) in the Section XI Appendix C flaw evaluation procedures for circumferential cracks is through a parameter called Z-factor. This parameter allows the simpler limit-load (or Net-Section-Collapse) solutions to be used with a multiplier from EPFM analyses. This paper shows how 3-D finite element (FE) analyses were employed to investigate the sensitivity of the crack-driving force as a function of crack location (i.e., crack in the center of weld, or closer to the stainless or low alloy steel sides) in an Alloy 182 dissimilar metal weld (DMW), and how an appropriate (or equivalent) stress-strain curve was determined for use in the *J*-estimation schemes. The *J*-estimation schemes are then used to cover a wider range of variables, i.e., pipe diameters, cracks lengths, and also incorporate crack growth by ductile tearing. The Z-factor equations as a function of pipe diameter were calculated using the LBB.ENG2 *J*-estimation scheme along with the most conservative equivalent stress-strain curve from the FE analyses. The proposed Z-factor approach was then validated against an Alloy 182 DMW full-scale pipe test that had a circumferential through-wall crack in the fusion line. The predicted EPFM maximum load showed excellent agreement with the experimental result. Furthermore, it was shown that the proposed Z-factor equation is not sensitive to the location of the crack.

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1. Introduction

The existing ASME elastic-plastic fracture mechanics (EPFM) analyses include a relatively simple correction factor to the limit-load solution to account for EPFM failure of a circumferential crack in a pipe. The correction factor is called a Z-factor, which is a function of the material toughness as well as the pipe diameter. The Z-factor is the ratio of the nominal stress calculated using the Net-Section-Collapse method divided by the nominal stress calculated using EPFM methods. The early work [1] on the development of a Z-factor used the GE/EPRI circumferential through-wall-cracked pipe solutions [2] where the pipe was loaded in bending. In that work, it was recognized that the maximum load ratio of limit-load to the GE/EPRI EPFM predictions varied with crack length, but reached a maximum ratio for a crack that was 25–30% of the circumference. For simplicity and conservatism, this maximum ratio of the limit-load/EPFM maximum loads was taken as the Z-factor. This Z-factor also increased with pipe diameter, and would be higher for lower toughness materials.

After the early development of the ASME Z-factors, a large number of full-scale pipe tests were conducted and compared to a variety of *J*-estimation analyses [3–5]. These results showed that the GE/EPRI *J*-estimation scheme was the most conservative in predicting maximum loads for circumferentially cracked pipes. The method that was the most accurate (compared to experimental results) was the one developed by Brust and Gilles [6] called the LBB.ENG2 method. It should also be noted that for cracks in welds, some earlier finite element (FE) analyses and experimental results showed that the applied crack-driving force (*J*-applied) was best calculated by using the base metal stress-strain curve (rather than the weld metal stress-strain curve) together with the weld metal *J-R* curve to predict the fracture behavior [7]. There has been work in the past, where elastic and elastic-plastic crack-driving force for cracks in the interface between elastic or power-law plastic bi-materials [8]. In addition, there has been work on *J*-estimation of interfacial cracks in plane and cylindrical geometries of bi-materials [9]. More related to dissimilar metal welds (DMW), there has been work to assess the creep crack growth in DMW using a fracture specimen [10]. Some of these works have demonstrated

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