International Journal of Pressure Vessels and Piping 88 (2011) 256–261

Contents lists available at ScienceDirect

International Journal of Pressure Vessels and Piping

journal homepage: www.elsevier.com/locate/ijpvp

Development of an analytical reference stress equation for inner-diameter defected curved plates in tension

Stijn Hertelé [a,*], Wim De Waele [b], Rudi Denys [b]

[a] FWO Flanders aspirant, Ghent University, Laboratory Soete, Sint-Pietersnieuwstraat 41, 9000 Gent, Belgium
[b] Ghent University, Laboratory Soete, Sint-Pietersnieuwstraat 41, 9000 Gent, Belgium

ARTICLE INFO

Article history:
Received 7 April 2010
Received in revised form
13 April 2011
Accepted 13 April 2011

Keywords:
Defect assessment
Limit load
Reference stress
Curved wide plate

ABSTRACT

The tensile failure behaviour of defected structures is determined by plastic collapse and fracture. Reference stress equations can be used to predict these failure modes. Up to now, some solutions have been developed for flat plates and pipes. For curved plates, which are applied for pipe girth weld testing, however, no solutions can be found in the literature. Therefore, the authors have developed a reference stress equation that applies for curved plates with a part-through defect, located centrally along the inner diameter. The solution is global, and similar to the Goodall and Webster equation for flat plates. This article elaborates the analytical development and studies the influence of all geometrical parameters, plate curvature in particular. It is found that the solution converges to the Goodall and Webster equation for increasingly flat plates, and allows larger tensile stresses for increasingly curved plates. Hence, the proposed equation is less conservative for inner-diameter defected curved plates than Goodall and Webster's equivalent for flat plates. Nevertheless, the difference between Goodall and Webster's solution and the proposed solution is fairly restricted (less than 5% for all considered geometries). An extensive validation of the proposed equation is part of current and future work.

1. Introduction

Generally, the failure of a defected structure is governed by two different failure modes: plastic collapse and fracture. Both modes can be simultaneously investigated using a failure assessment diagram (FAD) as described in some standards and recommended practices, e.g. R6 [1], BS7910 [2], FITNET [3], API RP579 [4].

On the one hand, the calculation of proximity to plastic collapse in a FAD analysis (plotted on the horizontal axis) requires knowledge of a limit load, defined as the collapse load of the structure, assuming a perfectly plastic material. A situation of 'local collapse' can be investigated, in which case the limit load corresponds to a collapse of the ligament ahead of the defect. In contrast, 'global collapse' refers to the yielding of the entire cross section containing the defect. Completely equivalent to the concept of a limit load is the so-called reference stress. This stress is defined in such a way that, when the limit load is achieved, it reaches the metal's yield strength. The concept of reference stress assumes a perfectly plastic yielding behaviour. By definition, limit load and reference stress are connected through the following relation [5]:

$$\frac{\sigma_{ref}}{\sigma_y} = \frac{P}{P_L} \tag{1}$$

where σ_{ref} is the reference stress, σ_y the yield stress, P the applied load, and P_L the limit load. In a FAD diagram, σ_{ref}/σ_y is denoted as L_r and plotted on the horizontal axis.

On the other hand, the calculation of proximity to fracture in a FAD analysis (plotted on the vertical axis) requires knowledge of the crack driving force, expressed in terms of stress intensity factor K, crack tip opening displacement (CTOD) or J integral. K applies to linear-elastic fracture mechanics, whereas CTOD and J integral are related quantities in elastic-plastic fracture mechanics. To estimate the crack driving force, Ainsworth [5,6] started from Kumar and Shih's [7] results to obtain an expression for J integral that requires a reference stress:

$$J = \frac{K^2}{E'}\left(\frac{E\epsilon_{ref}}{\sigma_{ref}} + \frac{\sigma_{ref}^3}{2E\epsilon_{ref}\sigma_y^2}\right) \tag{2}$$

In this expression, K is the linear-elastic mode-I stress intensity factor, E' is equal to Young's modulus E for plane stress, and to $E/(1-\nu^2)$ for plane strain, where ν is Poisson's ratio. ϵ_{ref} is the reference strain, which corresponds to σ_{ref} on the stress–strain diagram of the material. A reference stress that corresponds to the

* Corresponding author. Tel.: +32 9 264 32 76; fax: +32 9 264 32 95.
E-mail address: stijn.hertele@ugent.be (S. Hertelé).

0308-0161/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijpvp.2011.04.001