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Pressure vessel steels crack driving force assessment using different models

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ABSTRACT

Fracture behavior of two pressure vessel steels, 20MnMoNi55 and 50CrMo4, was numerically investigated in this work. The research was conducted using numerical models of single-edge notched bend (SENB) and disk compact type (DCT) specimens. *J*-integral, an important fracture mechanics parameter, was chosen as a criterion for the fracture behavior comparison of two mentioned steels. *J*-integral values were determined using newly developed numerical algorithm coupled with finite element (FE) analysis. Numerically obtained *J*-integral values are presented as a measure of crack driving force versus crack growth size (Δa) for a range of initial crack sizes ($a/W = 0.25, 0.375, 0.5, 0.625$). Fracture behavior of two steels was investigated using numerical models of pressure vessels containing also inner axial crack of different sizes ($a/t = 0.25, 0.375, 0.5, 0.625$). Although *J*-integral values cannot be transferred from specimens to real structures, results obtained on pressure vessels have proved useful in engineering assessment of fracture behavior of such structures.

1. Introduction

Cracks appearing in structures due to imperfections in design, manufacturing, service or maintaining, can exert an influence on their reliability and safety. Therefore, it is important to determine how existing cracks can threat integrity of structures and their components. Fracture mechanics provides theories and parameters useful for such tasks. One of the fracture mechanics parameters is *J*-integral, suitable for quantifying crack driving force when material ahead of crack tip exhibits elastic-plastic behavior. When dealing with a crack growing from initial length *a*, *J*-integral values should be obtained for a number of crack extensions (Δa). Such results can be presented in *J*-Δa sets of values, i.e. variation of crack driving force during crack extension.

Although most of the researches concentrate on determining *J*-integral values using standardized specimens and procedures [1], sometimes it is useful to conduct investigation on real structures and their components. This is particularly important during the process of the design optimization. Nowadays, developed numerical methods and finite element (FE) software offer a powerful tool for conducting such investigations. Still, numerically obtained results need to be verified by some kind of experiment.

In this paper, fracture behavior of pressure vessel materials was numerically investigated on the FE models of single-edge notched bend (SENB) specimen, disk compact type (DCT) specimen and pressure vessel. For the purpose of determining *J*-integral, a numerical algorithm was developed that uses FE analysis results as input. Resulting *J* values are presented as a measure of crack driving force versus crack growth size (Δa) for a range of initial crack lengths, *a*.

Some of the previous works on similar matter include a problem solution study regarding stress intensity factors (SIF) of semi-elliptical cracks located in the stress concentration areas of a pressure vessel [2]. The problem was numerically solved using a global–local FE analysis. The stress field at the crack area varies along the axial, the circumferential, as well as, through-the-thickness directions. Further, the stress triaxiality is an important parameter in explaining the geometry dependence of crack resistance curves [3]. By comparing the so-called stress triaxiality across the ligament of a specimen and a cracked component, it is possible to assess whether the cracked component exhibits similar fracture behavior to the specimen. The influence of crack depth on fracture behavior was considered in a case of 20MnMoNi55 steel [4]. For this purpose crack resistance curves were obtained from specimens pre-cracked to various *a*/*t*. An optimal pressure vessels design procedure requires knowledge of their failure behavior in case of existing imperfections or cracks [5].

2. Theoretical background

J-integral is a path-independent integral that can be drawn around the tip of a crack and viewed as both an energy release rate parameter and a stress intensity parameter. It was presented by Rice [6] in a two-dimensional form and with reference to Fig. 1 it can be written as:

$$J = \int_{\Gamma} \left(W dy - T_i \frac{\partial u_i}{\partial x} ds \right), \qquad (1)$$

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