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ScienceDirect
Engineering Fracture Mechanics 75 (2008) 3599–3610
Engineering Fracture Mechanics
www.elsevier.com/locate/engfracmech

On the use of the crack tip opening angle parameter to explain the ductile crack growth behavior of miniature compact specimens

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Received 11 August 2006; received in revised form 9 May 2007
Available online 18 May 2007

Abstract

Experimental crack resistance curves obtained from miniature compact tension, MC(T), specimens were found to be significantly less tough than those obtained on standard one inch 1T-C(T) specimens. In order to investigate the fundamental reasons behind this unexpected result, local approaches to fracture based on the Rice and Tracey void growth model and the crack tip opening angle (CTOA) concept are used. Local crack growth criteria are identified on test results obtained from 1T-C(T) and are used to predict the MC(T) behavior. Results demonstrate that the CTOA parameter is very effective as it allows transferring results from MC(T) to larger specimens, it is easy to implement in a finite element code, it is mesh size insensitive and can be actually measured although its experimental determination is not straightforward. The β parameter derived from the Rice and Tracey void growth model is unable to explain the experimental results. The possible reasons for the poor performance of the β parameter are discussed.

Keywords: Ductile crack growth; MC(T); RPV steel; CTOA

1. Introduction

The vessel of a pressurized water reactor (PWR) is an essential component for which integrity should be guaranteed throughout the lifetime of the reactor. In the core region, the reactor pressure vessel (RPV) base material and welds are subject to high neutron fluence and thermal ageing, which can both induce embrittlement. In order to ensure safe operating conditions, the RPV-material properties are monitored within a mandatory surveillance program containing Charpy specimens made of representative RPV materials. The main purpose of this program is the evaluation of the fracture toughness within the ductile to brittle transition region and in the upper shelf.

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0013-7944/$ - see front matter
doi:10.1016/j.engfracmech.2007.05.008

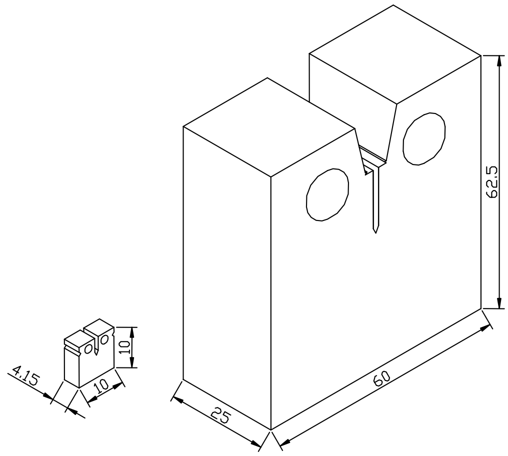

Fig. 1. Isometric view of the MC(T) and 1T-C(T) geometries.

In order to better evaluate the actual material toughness in the upper shelf, direct fracture toughness measurements are desirable. As the amount of available representative irradiated material is very limited and consists mainly of half broken Charpy specimens tested within the conventional surveillance program, those measurements should be performed on small or miniaturized specimens [1]. In this respect, miniature compact tension, MC(T), is an appealing geometry as it can be easily machined from broken Charpy specimens and has already been successfully used within the ductile to brittle transition region [2]. The specimen is scalable to a 1T-C(T) specimen and its actual dimensions are: thickness $B = 4.15$ mm, width $W = 8.3$ mm and hole diameter 2 mm. Fig. 1 shows a comparison between MC(T) and 1T-C(T). The clip gauge used to monitor displacement is located on the load-line for both geometries. Due to space constraints, the clip gauge is externally placed for the MC(T).

Although ductile crack growth is less sensitive to loss of constraint than brittle failure, experimental crack resistance curves of MC(T) were found to be significantly less tough than results obtained on standard 1T-C(T) specimens [3–6]. Fig. 2 shows a typical comparison between crack resistance curves obtained from MC(T) and 1T-C(T). The deviation is observed at a J level of about 300 kJ/m^2. Experiments confirming the result shown in Fig. 2 are now available on five reactor pressure vessel steels and one A106 piping material [3–6]. Different test techniques were used, namely the multiple specimen test technique, unloading compliance, potential drop and the normalization data reduction technique. All techniques corroborate the experimental circumstances illustrated in Fig. 2. It should be noted that a lot of experimental data [7] obtained outside the

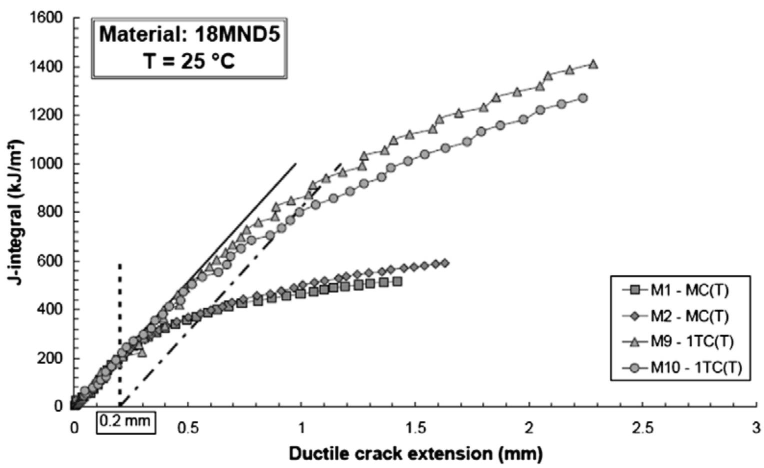

Fig. 2. Typical experimental J–R curve from [3].