Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Engineering Fracture Mechanics 71 (2004) 2015–2032
Engineering Fracture Mechanics
www.elsevier.com/locate/engfracmech

The effects of warm pre-stressing on cleavage fracture. Part 1: evaluation of experiments

D.J. Smith [a,*], S. Hadidimoud [a], H. Fowler [b]

[a] Department of Mechanical Engineering, Queen's Building, University of Bristol, Bristol BS8 1TR, UK
[b] Frazer-Nash Consultancy Limited, Bristol BS51 5TE, UK

Received 12 November 2002; received in revised form 22 August 2003; accepted 30 September 2003

Abstract

An experimental programme has been performed to characterise the mechanical parameters and the fracture response of two steels, BS1501 and A533B. These are widely used in pressure vessel technology. The role of load history on improvements in cleavage fracture toughness has been investigated. Scatter within experimental cleavage toughness data has been described by using the model proposed by Wallin [Defect Assessment in Components, Fundamentals and Applications, ESIS/EGF 9, Mechanical Engineering Publications, London, 1991, p. 415] and combined with Chell [Int. J. Fract. 17 (1981) 61] model for warm pre-stressing (WPS) effect. The influence of parameters such as repeated cyclic pre-loading, sub-critical crack growth and specimen size on the WPS effect has also been noted. Finally the importance of the role of crack tip blunting and near tip residual stress field in describing the effect is discussed.

Keywords: Pressure vessel steel; WPS effect; Cleavage fracture; Scatter; Residual stress

1. Introduction

The effect of warm pre-stressing (WPS, or proof loading) at an upper shelf temperature on cleavage fracture at a subsequent lower shelf temperature has been studied extensively. A brief review of these studies is given later. As shown schematically in Fig. 1, if the load–unload–cool–fracture (LUCF) cycle is applied to a pre-cracked specimen the lower shelf cleavage toughness is increased following WPS on the upper shelf. However the interaction between the WPS and the subsequent toughness distribution has received less attention. This paper presents and summarises the results of detailed investigations into the brittle fracture response of two pressure vessel steels following WPS. A series of tests were carried out to determine the scatter in cleavage fracture toughness of A533B class 1 and BS1501 pressure vessel steels. The scatter in cleavage toughness following WPS was also obtained. The experimental programme used single edge notched bend, SEN(B) and compact tension, C(T) specimens.

* Correspondence author. Tel.: +44-117-928-8212; fax: +44-117-929-4423.
E-mail address: david.smith@bristol.ac.uk (D.J. Smith).

0013-7944/$ - see front matter
doi:10.1016/j.engfracmech.2003.09.003

Nomenclature

B	thickness (mm)
B_0	reference thickness (mm)
K_f	toughness at fracture, experimental (MPa $\sqrt{m}$)
K_{Ic}	mode-I fracture toughness, theoretical (MPa $\sqrt{m}$)
K_0	reference toughness, Wallin parameter (MPa $\sqrt{m}$)
K_{min}	minimum toughness, Wallin parameter (MPa $\sqrt{m}$)
$K_{0,f}$	fitted reference toughness (MPa $\sqrt{m}$)
$K_{min,f}$	fitted minimum toughness (MPa $\sqrt{m}$)
K_1	applied (pre-load) toughness (MPa $\sqrt{m}$)
n	Wallin exponent
P_f	probability of failure
Δa	crack extension (mm)
σ_{Y1}	yield point at proof load temperature (MPa)
σ_{Y2}	yield point at fracture temperature (MPa)

To place the work in context, earlier studies on the effects of WPS and probabilistic studies on cleavage fracture toughness are reviewed briefly.

1.1. Overview of WPS effect on cleavage fracture toughness

The warm pre-stress effect theories proposed by Chell et al. [2,3], based on J-integral, and by Curry [4] based on the Ritchie, Knott, Rice (RKR) model are the main theories used in WPS experimental studies. These theories are also explained in the accompanying paper, part 2. Using the Chell model, Chell and Haigh [5] proposed a simple lower bound WPS failure criterion. Chell [6] also studied the effect of sub-critical crack growth on fracture toughness of ferritic steels following WPS. Smith and Garwood [7,8] provided a more detailed review of the effects of WPS on cleavage fracture in pressure vessel steels and also presented results from a comprehensive experimental programme using A533B steel SEN(B) specimens. Results were compared to the theories of Chell [2] and Curry [4], and good overall agreement was found. Reed and Knott [9–11] examined different pre-loading regimes for A533B weld steel using four-point bend specimens. Their findings suggest that the main effect of WPS is associated with a residual stress field at the crack tip.

The contribution of parameters such as material's strain hardening, crack tip blunting and residual stress to the WPS effect was also investigated by Pokrovsky et al. [12]. Further investigations include those by Okamura et al. [13,14] and Timofeev and Smirnov [15]. Cheng and Noble [16] studied the WPS effect for different fracture mechanisms including inter-granular, cleavage, and a mixture of the two. They found that a consistent WPS effect could be obtained irrespective of the fracture mechanism. They also argued that crack blunting influenced the WPS effect. Stöckl et al. [17] similarly suggest that crack tip blunting is the major factor in the effect of WPS.

1.2. Overview of probabilistic studies of cleavage fracture toughness

Quantification of the scatter in fracture toughness is generally associated with the use of statistical approaches. These are mostly based on the weakest link theory proposed by Weibull [18,19]. For cleavage fracture the statistical local approach proposed by Beremin [20,21] forms the basis for the majority of the