Available online at www.sciencedirect.com
ScienceDirect
Engineering Failure Analysis 16 (2009) 631–638
ENGINEERING FAILURE ANALYSIS
www.elsevier.com/locate/engfailanal

Determination of Paris law constants with a reverse engineering technique

R. Branco [a,*], F.V. Antunes [b], J.A. Martins Ferreira [b], J.M. Silva [c]

[a] *Department of Mechanical Engineering, Polytechnic Institute of Coimbra, 3030-129 Coimbra, Portugal*
[b] *Department of Mechanical Engineering, University of Coimbra, Pinhal de Marrocos, 3030-201 Coimbra, Portugal*
[c] *Department of Aerospace Sciences, University of Beira Interior, 6200-001 Covilhã, Portugal*

Available online 29 February 2008

Abstract

Paris law constants are commonly obtained with a well established procedure based on standard specimens, notched and pre-cracked. Pre-cracking produces through cracks with stable shapes, nearly straight, similar during all propagation. However, in several situations specimens with corner and surface cracks are recommended. In these cases cracks having significant propagation will continuously modify their shape, beginning with corner or surface geometries and subsequently transforming into through cracks, resulting into a transition region with significant crack shape modification. The aim of this paper is to determine Paris law constants from the analysis of crack shapes on the surface of fracture, in regions of intense shape modification. A double-U specimen of a new generation nickel base superalloy was used to obtain experimental crack shapes within transitory region as well as the number of load cycles between them. An automatic crack growth technique based on the finite element method (FEM) was employed to obtain fatigue constants from crack propagation data.

Keywords: Paris law constants; Double-U specimen; Crack shape evolution; Reverse engineering

1. Introduction

Designers must be able to predict fatigue life in structures submitted to cyclic loads. Modern defect-tolerant design approaches to fatigue are based on the premise that engineering structures are inherently flawed, i.e., manufacturing defects are potentially present. The prediction of propagation life is usually based on Paris law:

$$\frac{da}{dN} = C\Delta K^m \tag{1}$$

being ΔK the range of stress intensity factor, and C, m constants that depend on material, stress ratio, temperature, etc. A well established procedure is used in order to determine the Paris law constants, considering

* Corresponding author. Tel.: +351 239 790 700; fax: +351 239 790 701.
E-mail address: rbranco@isec.pt (R. Branco).

1350-6307/$ - see front matter
doi:10.1016/j.engfailanal.2008.02.004

standard specimens, notched and pre-cracked. BS 6835:1988 and ASTM 647-95a standards define all the details necessary to obtain feasible and comparable Paris law constants. However, the application of results from through-crack specimens referred in these standards to corner and surface cracks is not straightforward. Tong et al. [1] and Brown and Hicks [2] found that the use of results from CT specimens to corner cracks gave pessimistic life predictions, i.e., the fatigue life was underestimated. Therefore, taking into consideration that corner and surface cracks are quite frequent, alternative specimen geometries have been developed. A specimen with central hole and corner crack was used to study fatigue initiation and propagation in kitchen sinks [3]. The fatigue propagation in new generation nickel base superalloys, such as Udimet 720 or RR1000, has been studied using specimens representative of gas turbine discs in terms of notch geometry and bulk stress, such as the corner crack [4], the double-U or the washer specimens [5].

Numerical techniques have been successfully used to predict crack shape evolution and fatigue life. One of the most powerful and widely employed techniques described in literature consists of an iterative procedure based on a three-dimensional finite element analysis [6]. Firstly, a numerical model is developed to calculate the displacement field which is used to obtain the stress intensity factors along crack front. A new crack front position and the number of cycles are defined applying an adequate crack growth model, based on experimental $da/dN–\Delta K$ curves. This procedure is then repeated up to the final fracture when the fracture toughness is reached.

The aim of this paper is to propose an experimental–numerical technique oriented to the determination of Paris law constants from propagation regions with significant crack shape modification. Experimental work is required to obtain at least two crack shapes with significant shape modification and the number of load cycles between them. In this work, a double-U specimen of a new generation nickel base superalloy was tested experimentally. Original corner cracks transform into subsequent through cracks and a significant transition region was observed. Intentional marking of fracture surfaces was obtained either by changing stress ratio or loading frequency. An automatic crack growth technique based on the finite element method (FEM) was developed and employed to obtain Paris law constants from transient crack shapes. The Paris law constants C and m are obtained from crack shape change and from the number of load cycles, respectively.

2. Experimental determination of transient crack shapes

The geometry of the double-U specimen employed in this study is presented in Fig. 1. This specimen was developed to reproduce the geometry of a turbine disc at the region of its connection with the blades, since this is a high stress concentration zone prone to fatigue failures. The material considered in this investigation was the nickel base superalloy RR1000 developed by Rolls-Royce for specific usage in turbine discs and high pressure compressors of aeroengines. All tests were performed at 650 °C in a servo hydraulic testing machine with a 100 kN load capacity. Testing temperature was obtained via an electrical furnace. The mechanical properties and the chemical composition of RR1000 at room temperature and at 650 °C are presented in Tables 1 and 2, respectively. Fatigue tests were performed with a load ratio of 0.1 considering two waveforms: sinusoidal with a 5 Hz frequency and trapezoidal with a 30 s dwell time (1–30–1–1 s). A potential drop technique was used for crack propagation monitoring purposes using a DCPD pulsed system coupled with the controller of the servo hydraulic machine. During the tests the loading conditions (either stress ratio or loading frequency) were changed to produce visible marks on the fracture surface which enable the identification of crack shapes. Fig. 2a shows the fracture surface of a specimen submitted to a fatigue test using a sinusoidal load, while

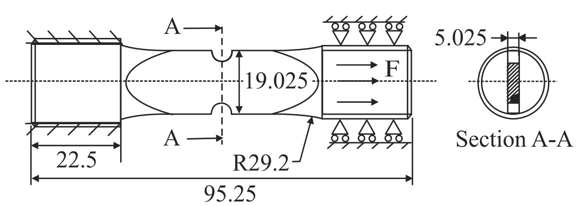

Fig. 1. Double-U specimen (dimensions in mm).