Engineering Failure Analysis 35 (2013) 645–651

Contents lists available at SciVerse ScienceDirect

Engineering Failure Analysis

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

Stress state factor evaluation based on a fractographic analysis for use in the crack growth FASTRAN retardation model of the AFGROW computing code

Jiří Běhal *, Lucie Nováková

Strength of Structures Department, Aerospace Research and Test Establishment (VZLU), Beranových 130, 199 05 Prague, Czech Republic

ARTICLE INFO

Article history:
Available online 1 July 2013

Keywords:
Crack growth
Fractography
Plane strain
Plane stress
Fatigue crack retardation

ABSTRACT

The FASTRAN crack growth retardation model uses stress state descriptors to consider the local stress state ahead of the crack tip. Using the FASTRAN model implemented in the AFGROW computing code, the descriptor is input into the retardation model as a constant tensile (compressive) constraint factor along with the corresponding crack growth rate.

The paper presents an evaluation based on a fractographic analysis of fracture surfaces of middle tension M(T) specimens from Al-alloy, which were used for the standard crack growth rate measurement under constant amplitude loading. There are typically three zones on the fracture surface: the flat zone that is perpendicular to the loading force and represents the tension mode of specimen cracking, the slant zone that is approximately 45° deviated from the loading force direction and a transient zone between them. It is shown that a significant correlation between crack length, local crack growth rate and the sizes of the zones exist.

Crack lengths relevant to the zones and corresponding crack growth rates were processed by statistical procedures. A continuous uniform distribution is a very good statistical model of the logarithm of the crack growth rates on both sides of the transient zone. In the retardation model, this distribution can be accounted for by using the means of the probability functions.

A sub-scale structural model was tested for fatigue crack growth under a random loading process representing real operational conditions. Using the typical values of constraint factors for a "pure" plain stress and plain strain states and the crack growth rates evaluated by the fractographic analysis as input parameters, the crack growth curves calculated by the AFGROW code using the FASTRAN retardation model were compared with the crack growth data measured in the experiment.

The AFGROW output crack growth curves fit to the experimental measured ones without any additional tuning of the retardation model parameters.

1. Introduction

In the past few years, but mainly since the Damage Tolerance approach became preferred for aircraft structure design, many analytical tools have been developed for fatigue crack growth analyses. The simplest model is the model without retardation.

* Corresponding author. Tel.: +420 225 115 193; fax: +420 283 920 018.
E-mail address: behal@vzlu.cz (J. Běhal).

1350-6307/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.engfailanal.2013.06.014

The advanced models respect the fact that each overloading has a retardation effect that cannot be neglected. Due to the complex effects of material structures and loading sequences, practically all crack growth retardation models involve an input parameter, which should be tuned by special tests. The data should be obtained under the typical operational load sequence on a specimen that is made from the same material as the structure.

There were problems with the VZLU in-house software (PREDIKCE). The software was not suitable, even if a few modifications were made.

Looking for a more suitable analytical tool, the FASTRAN retardation model, which is implemented in a commercial software package, was identified. The FASTRAN retardation model has a significant advantage: it accounts for the stress state.

Generally, FASTRAN is a crack growth prediction approach based on a crack closure concept [2]. Physically is based on Dugdale yield zone model, which formation depends on a stress state in the part and can be expressed by coefficient α. To bring back to memory the stress state effect on the crack closure behaviour, there is listing of a few equations by [2]:

$$K_{open}/K_{max} = A_0 + A_1 \times R + A_2 \times R^2 + A_3 \times R^3;\ \text{for } R \geqslant 0 \tag{1}$$

$$R = K_{min}/K_{max} \tag{2}$$

The coefficients A_0, A_1, A_2, A_3 are [2]:

$$A_0 = (0.825 - 0.34 \times \alpha + 0.05 \times \alpha^2) \times [\cos((\pi \times S_{max} \times F_w)/(2 \times \sigma_0))]^{1/2} \tag{3}$$

$$A_1 = (0.415 - 0.71 \times \alpha) \times [(S_{max} \times F_w)/\sigma_0] \tag{4}$$

$$A_2 = 1 - A_0 - A_1 - A_3 \tag{5}$$

$$A_3 = 2 \times A_0 + A_1 - 1 \tag{6}$$

where K_{open} is the crack open stress intensity factor, K_{min} and K_{max} are the minimum and maximum stress intensity factors, A_0, A_1, A_2, A_3 are the coefficients according to Eq. (3) up to (6), R is the stress ratio, S_{max} is the highest algebraic value of the stress in the loading cycle, F_w is the finite width correction, σ_0 is the flow stress and α is the plane stress/strain constraint factor.

The positive contribution of that model is a fact, that all parameters can be interpreted physically. Damage tolerance analysis of airplane structure, for example, is very complex task and any subjective approach should be eliminated.

2. Fractographic examination

Crack growth rates are generally measured on material specimens according to a standard. The standard ASTM E647-11 [1] is commonly used in aeronautical practice. Even if it is possible to use a compact C(T) specimen, the M(T) specimen is recommended for this purpose because the test can be run continuously over a wider range of crack growth rates. Nevertheless, two samples are generally used to obtain data for all required range values of the stress intensity factor by changing the load level and keeping the same stress ratio.

Using the M(T) specimen, four surface crack traces can be measured on both sides.

The crack growth rates are evaluated by the standard methodology and are published as material characteristics. At this point, we can say that standard requirements are satisfied.

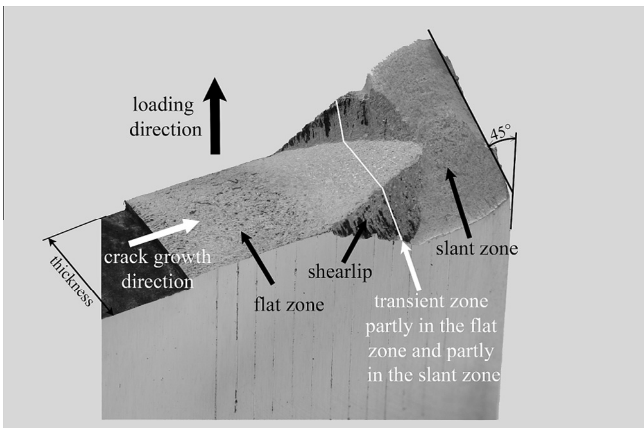

Fig. 1. Flat, slant and transient zones on the fracture surface.