Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 160 (2016) 199 – 206

Procedia Engineering

www.elsevier.com/locate/procedia

XVIII International Colloquium on Mechanical Fatigue of Metals (ICMFM XVIII)

FATIGUE SURFACE CRACK GROWTH IN ALUMINUM ALLOYS UNDER DIFFERENT TEMPERATURES

R. Yarullin, I. Ishtyryakov *

Kazan Scientific Center of Russian Academy of Sciences, Kazan, Russia

Abstract

The variation of crack growth behavior is studied under cyclic axial tension fatigue loading for the different temperatures conditions. The subject for studies is cylindrical hollow specimens of B95 and D16 aluminum alloys with semi-elliptical surface cracks. By experimental studies for considered temperature conditions the relations between the crack sizes on the free surface of specimen, crack opening displacements (COD), crack growth rate and aspect ratio were obtained. These relationships are useful for automation of experimental studies of surface crack growth. For the same specimen configuration and the different crack front position as a function of cyclic tension loading and temperatures conditions, the following constraint parameters were analyzed, namely, the non-singular *T*-stress, *Tz* -factor and the stress triaxiality parameter *h* in the 3D series of elastic-plastic computations. The governing parameter of the elastic-plastic stress fields *In*-factor distributions along various crack fronts was also determined from numerical calculations. The plastic stress intensity factor (SIF) approach was applied to the fatigue crack growth on the free surface of the hollow specimens as well as the deepest point of the semi-elliptical surface crack front. As result principal particularities of the fatigue surface crack growth rate as a function of temperature conditions are established.

Peer-review under responsibility of the University of Oviedo

Keywords: surface crack; aluminum alloys; tension fatigue loading; crack growth; different temperatures

1. Introduction

The circular cylindrical metallic components of aircraft structure, power engineering elements, pressure vessel and piping are subjected to temperature variations from -60°C (213K) to more than 250°C (523K). In most cases,

* Corresponding author. Tel.: +7-843-236-31-02; fax: +7-843-236-31-02.
E-mail address: yarullin_r@mail.ru

1877-7058
Peer-review under responsibility of the University of Oviedo
doi:10.1016/j.proeng.2016.08.881

part-through flaws appear on the free surface of the cylinder and defects are approximately considered as semi-elliptical cracks. The fatigue growth analysis of surface cracks under different environmental conditions is very important for many engineering applications in order to quantify the structural safety according to the so-called damage tolerant design. Therefore fracture mechanics properties and material data at such temperature extremes are needed for material selection and design.

Some researches provides detailed plastic limit load solutions for cylinders containing part-through external and internal surface cracks under combined axial tension, internal pressure and global bending [1]. The numerical analysis has been carried out to calculate the aspect ratio changes for different values of the geometrical parameters for both cylinder and surface flow [2]. The fatigue failure of cylindrical specimens often develops from surface flaws, and thus several analyses have been carried out to determine the stress intensity factors along the front of an edge defects and crack growth rate study on this base [3-8].

The sensitivity of aluminium alloys to environment changes have begun to explore else in the mid-1970s. During that time some researchers reported a significant reduction in the toughness and crack growth of several 7000 series aluminium sheet materials at low temperature [9-11]. Other researchers [12] have reported that the temperature dependence of fatigue crack formation and microstructure-scale growth from constituent particles in 7075-T651 and 7050-T651 is quantified via load induced fracture surface marker bands.

The Paris law constants and threshold stress intensity range (ΔKth) have been measured for S460 and S980 structural grade base plate material at room temperature and -70°C. These results support the conclusions found in the literature that the fatigue crack growth rate decreases with lower temperatures until the Fatigue Ductile-Brittle Transition (FDBT), and then it increases again [13].

The growth of fatigue cracks at elevated temperatures (25–800°C) was studied [14]. The fatigue crack growth behaviour of a ferrite stainless steel has been investigated as a function of test temperature, thermal exposure and frequency at intermediate growth rates. In general, fatigue crack growth rates increased with increasing temperature and in the temperature range 500-700 °C growth rates were described by a kinetic process with an activation energy of 48 kJ/mole.

Furthermore, other environmental effects should be taken into account to assess the structural component safety: for example, the humidity and salt air content play an important role especially under fatigue loading. In this paper, only the temperature effects are considered and the fatigue crack propagation is examined.

Firstly, experimental results of fatigue crack growth for a crack starting from a semi-elliptical edge notch in cylindrical hollow specimens under low/high and room temperature are given. The influence of different temperature conditions on fatigue life of cylindrical specimens is discussed. The relations of crack opening displacement and crack length on the free surface of specimens are obtained. Using the aforementioned relations, the crack front shape and crack growth rate in the depth direction can be predicted. Secondly, constrain parameters behaviour and governing parameter of elastic-plastic stress field distribution along the crack front was obtained using FEM analysis. Third, crack growth interpretation is performed using the traditional elastic and new plastic stress intensity factors [15-17]. Different crack growth rate is observed in the direction of the deepest point of the crack front with respect to the free surface of the hollow cylindrical specimen as a function of temperature conditions.

2. Experimental study

The test materials are most popular in aircraft industry aluminum alloys D16T and B95AT (analogue of 2024 and 7075 aluminum). All tests were carried out at room (23°C or 296K), low (-60°C or 213K) and high (250°C or 523K) temperature. Low/high temperature tests were performed by using following equipment: *Bi-00-101 UTM Test System* with fatigue rated axial dynamic load cell (capacity +/- 50kN) and *Bi-06-303* series axial extensometer; Climatic Chamber *CM Envirosystems* with temperature range: -60°C to 250°C (Fig.1).

The first step of experimental study was determination the main mechanical properties of considered alloys. The tension testing was performed in accordance with ASTM E8. Obtained main mechanical properties are listed in Table 1, where E is the Young's modulus, σ_s is the nominal ultimate tensile strength, σ_0 is the monotonic tensile yield strength, σ_u is the true ultimate tensile strength, δ is the elongation, ψ is the reduction of area, n is the strain hardening exponent and α is the strain hardening coefficient. The distributions of this data for both materials are