ARTICLE IN PRESS
CRAS2B:3538

C. R. Mecanique ••• (••••) •••–•••

Contents lists available at ScienceDirect

Comptes Rendus Mecanique

www.sciencedirect.com

An engineering predictive approach of fatigue crack growth behavior: The case of the lug-type joint

Ahmed Bahloul, Amal Ben Ahmed *, Chokri Bouraoui

Laboratoire de mécanique de Sousse, École nationale d'ingénieurs de Sousse, Université de Sousse, BP 264, Erriadh, 4023, Sousse, Tunisia

ARTICLE INFO

Article history:
Received 3 September 2017
Accepted 21 October 2017
Available online xxxx

Keywords:
XFEM
FCG reliability
Iso-probabilistic FCG life curves
MCS
Fatigue life prediction

ABSTRACT

The present attempt proposes a predictive approach of the fatigue crack growth (FCG) behavior of a lug-type joint used in an aeronautic context. The crack tip residual stress distribution and material dispersions are considered. The developed approach was implemented by coupling the Extended Finite Element Method (XFEM), the Residual Corrected Stress Intensity Factor (RC-SIF), developed by the authors, and the Monte Carlo simulation (MCS) method. The Lemaitre–Chaboche model, developed upon the ABAQUS commercial code, was considered for characterizing material behavior. The developed approach treats FCG life by considering the stochastic behavior of material parameters and the crack tip residual stress field during propagation. Comparing with experimental data, the proposed approach exhibits a good ability in evaluating the FCG reliability of a cracked lug-type joint subjected to different loading conditions. The iso-probabilistic P–a–N curves can be used as an efficient tool for ensuring the safety behavior of cracked components.

1. Introduction

Fatigue failure is among the most detrimental failure modes in several industrial fields such as the automotive, marine, and aeronautical ones. During cyclic loading, micro-cracks can be initiated and propagate in mechanical structures, causing catastrophic consequences, even when the ultimate strength of the material is much higher than the applied stress level. Because of several aircraft crashes, whether in military or in civilian aircraft, all aerospace components were designed in agreement with the damage tolerance design philosophy. This design principle is detailed in the Damage Tolerant Design Handbook and in the Joint Services Structural Guidelines JSSG 2006.

When cracks occur, the remaining fatigue life of these components is considered as the main important factor that should be predicted to ensure correctly the safety behavior of such components. In the literature, several models have been proposed to investigate the FCG life evaluation of cracked structures [1–9]. Looking for a model engineering approach that could evaluate the FCG life of mechanical structures in a reliable way, still remains a challenging topic in various industrial sectors. The Lug-type joint (also called attachment lug) is considered as the primary structural component in the aeronautical industry owing to its widespread use in different airframe structures. It is used generally to connect components with other mechanical structures such as wings to fuselage, engines to pylons, and spoilers to wings. During its service life,

* Corresponding author.
E-mail address: bahloulahmad1@outlook.fr (A.B. Ahmed).

https://doi.org/10.1016/j.crme.2017.10.003
1631-0721/

Nomenclature

a	Crack size	mm
E	Modulus of elasticity	MPa
$I(\{x\})$	Indicator failure function	
EPFM	Elastic Plastic Fracture Mechanics	
FCG	Fatigue Crack Growth	
L	Load function	
MCS	Monte Carlo simulation	
MTS	Maximum Tangential Stress criterion	
N_{MC}	Total number of MCS methods	
PDF	Probability density function	
P_f	Failure probability	
R	Stress ratio	
RC-SIF	Residual corrected stress intensity factor	$MPa\cdot m^{1/2}$
S	Strength function	
SIF	Stress intensity factor	
t	Thickness of the specimen	mm
σ_{max}	Maximum applied stress	MPa
σ_{res}	Residual stress	MPa
σ_y	Yield strength	MPa
XFEM	Extended finite element method	

a growing crack may occur near the hole edge of the attachment lug, leading to disastrous consequences. Due to the risks incurred in the aeronautical field, several researchers [60–67] have been interested in the FCG modelling of these structures.

Based on experimental data, James and Anderson [10] studied the SIF for lugs containing through-the-thickness cracks. Later, an empirical expression for the SIF evaluation was proposed by Liu and Kan [11], based on their experimental works. Aberson and Anderson [12] studied the calculation of the stress intensity factor for nonsymmetrical cracked lugs. They used a special crack-tip singularity element for this purpose. Using the boundary element method, Rigby and Aliabadi [13] evaluated the stress intensity factor for straight lugs subjected to both cosine and uniform pressure distribution.

Based on vast experimental and analytical investigations undertaken to predict the FCG life of the lug-type joint, Kim et al. [14] proved that the residual FCG life of the lug-type joint is affected by the increase in the clipping load level. Mikheevskiy et al. [15] used the Unigrow model to estimate the FCG life of a cracked lug under cyclic loading. They implemented the weight function technique for computing SIFs. Baljanovic and Maksimovic [16] developed a computational procedure to evaluate the FCG lives of cracked lugs. They used the quarter-point (Q–P) singular finite elements for extracting the SIFs near the crack tip. Residual fatigue lives were estimated, under constant amplitude loading, using the two-parameter driving force model [3,4]. Recently, Naderi and Iyyer [17] used the XFEM [18] to evaluate SIFs. The Walker equation was introduced to estimate the FCG life of the aircraft lug under cyclic loading. More recently, the authors [19] proposed the Residual-Corrected SIF parameter to consider the effect of crack-tip compressive residual stress filed for predicting FCG lives of cracked lugs. Even though appreciable studies have been proposed for modelling the FCG of cracked lug-type joints, all of them have been conducted with deterministic models. However, fatigue life is random in nature [20].

The present paper aims at developing a predictive procedure able to evaluate the residual FCG life of a 7075-T6 aluminum alloy cracked lug component, considering the stochastic behavior of the material parameters and the impact of the crack-tip residual stress distribution on the FCG rate. The proposed approach was implemented by coupling the XFEM, the RC-SIF, and the Monte Carlo simulation (MCS) methods. The XFEM embedded in the commercial code ABAQUS was implemented to simulate the crack growth path. Different attachment lug configurations subjected to different load ratios are considered. A comparison between the suggested approach and the available experimental data is performed.

2. Computational engineering approach

2.1. Procedure for FCG life estimation

It is generally admitted that the crack tip stress/strain fields are of paramount importance for controlling the FCG mechanism. When elastic–plastic behavior is assumed, the evaluation of this crack tip stress/strain field is absolutely dependent on the power of analytical and numerical tools. In the case of metal materials, a plastic zone is taking place close to the crack region during crack propagation. This crack tip plastic zone has a significant effect on the FCG process. It was showed [8,21,22] that the relationship between the SIFs and the crack tip stress/strain fields is often affected by residual stresses generated by reversed plastic deformations. Since fracture mechanics is principally based on the SIF determination for predicting crack growth path, FCG rate and FCG life, there is an imperative need to quantify the impact of these residual stresses in terms of SIF. Therefore, the weight function technique [23] can be used to convert the obtained residual stresses in terms of SIF known as residual stress intensity factor K_{res}:

$$K_{res} = \int_{x=0}^{x=a} \sigma_{res} m(x,a) \mathrm{d}x \tag{1}$$

where $m(x,a)$ and σ_{res} represent, respectively, the weight function expression [24–26] and the residual stress field surrounding the crack tip:

Please cite this article in press as: A. Bahloul et al., An engineering predictive approach of fatigue crack growth behavior: The case of the lug-type joint, C. R. Mecanique (2017), https://doi.org/10.1016/j.crme.2017.10.003