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Fatigue cracking in high-cycle- and very-high-cycle-fatigue areas of peened and unpeened Al-based alloys because of fretting damages

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Abstract

In-service fretting damage influenced the fatigue crack origination in materials under the damaged surface for the very-high-cycle fatigue. Specimens of BS L65 Al–Cu alloy with peened and unpeened surfaces tested under cyclic tension and static compression had the crack initiation on the surface because of fretting damage. The static compression was used to reproduce the fretting damage on the specimen surface. The special methodology was applied to the crack growth analysis in the case of the biaxial stress-state with $R = -1.0$ for the investigated material. The fretting influence on the fatigue crack propagation was estimated on the basis of the functional correction, $F(\mathrm{fr})$, for the stress intensity factor, K_I. The fretting damage influence on the fatigue crack growth was briefly discussed regarding the kinetic curves reproduced from the fractographic analysis. The bimodal S–N curve was introduced to describe the influence of fretting damages on the behaviour of materials in high- and very-high-cycle-fatigue areas.

Keywords: Fretting damage; Fatigue fracture; Synergetic approach; High- and very-high-cycle fatigue; Striation spacing; Fractal dimension; Stress state; Unified kinetic curve; Functional correction

1. Introduction

In-service cyclic loading of a structural element may induce evolution of its structure on the micro-, meso- and macro-scale levels ([1], [2], [3]). Damage is accumulated in the material when stress-state, cyclic loads frequency or R magnitudes vary in a complicated way, to differ from a laboratory experiment. Storage and dissipation of energy are the two concurrent processes experienced by the material under loading.

In the case of the fretting damage influence on the fatigue crack initiation in a solid medium the mechanisms, which usually takes place in a material volume, have dramatic reduction. Fatigue failure originated

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Nomenclature

a	depth of fatigue crack
$(D_{xy})_{\min}^{\max}$	fractal dimension
$d_{\min}$, $d_{\max}$	minimum and maximum value of resolution of digitized pictures
E	Young's modulus
$F(\text{fr})$	the stress intensity factor K_{I} function for fretting damages
K_{e}	equivalent mode I stress intensity factor
K_{I}	mode I stress intensity factor
K_{Is}	the value of K_{e} at $\delta = 2.1 \times 10^{-7}$ m
N_{f}	lifetime to failure (durability)
N_{p}	crack growth period
P	fretting contact normal force per unit length
Q	fretting contact friction force per unit length
R	stress ratio ($\sigma_{\min}/\sigma_{\max}$)
δ	fatigue striation spacing
δ_{sl}	slip value
υ	Poisson's ratio
$\sigma_{0.2}$	0.2% offset yield strength
σ_{n}	normal stress for fretting damage
σ	cyclic stress
σ_{w1}	theoretical fatigue limit for materials
σ_{w2}	tensile cyclic stress for transition from under-surface fatigue crack initiation to the surface
$(\sigma_{\text{w1}} - \sigma_{\text{w2}})$	area of very-high-cycle-fatigue (VHCF) of metals
σ_{w3}	tensile cyclic stress for transition of fatigue crack initiation at the surface from single- to multi-origins
$(\sigma_{\text{w2}} - \sigma_{\text{w3}})$	area of high-cycle-fatigue (HCF) of metals
σ_{w4}	tensile cyclic stress for transition from at-surface to under-surface fatigue crack origination
$(\sigma_{\text{w3}} - \sigma_{\text{w4}})$	area of low-cycle-fatigue (LCF) of metals
$\sigma > \sigma_{\text{w4}}$	area of quasi-static fracture of metals
σ_{T}	theoretical tensile strength
τ_{T}	theoretical shear strength

by fretting is commonly observed in assemblies where surfaces of two components are in contact and small relative movement can exist between them ([3], [4], [5]), Fig. 1. In fact, the crack initiation for in-service long life of components can be seen under the surface ([6]). The area of origin is of conical shape in the case of fretting damages, whose centre is placed under the surface as shown in Fig. 1. The crack origination under the surface in the case of fretting damages of the surface is the result of the very-high-cycle fatigue that takes place in the range of stress levels (σ_{w1}–σ_{w2}) ([7], [8]). In the fretting situation, the stress singularity caused by the contact pressure and the friction force at the edge of the contact patch will speed up the crack initiation process under the surface in the area of VHCF in the range of cyclic loads (σ_{w1}–σ_{w2}) and accelerate the early phase of crack growth ([4], [5], [7], [8]).

The density of fracture energy controls the crack initiation and growth behaviour for the multiparameter applied conditions, however, different from the reference ones ([2], [9]). The stress level σ_0 may be increased or diminished, influenced by the loading conditions. It is assumed here that, as concerns the macroscopic scale level, mode I opening of the crack is always dominating. Based on the 20-year experience of the inspection of the failed elements of aviation constructions, the author is convinced that such an approach is quite realistic ([1], [3]).

As cyclic loading of a construction element continues, mechanisms of damage accumulation replace one another sequentially, each starting and keeping on for a certain time. Then, the contribution of a new mech-