Engineering Fracture Mechanics 103 (2013) 26–38

Contents lists available at SciVerse ScienceDirect

Engineering Fracture Mechanics

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

Failure assessment of subsurface rolling contact fatigue in surface hardened components

G. Donzella, A. Mazzù *, C. Petrogalli

University of Brescia, Department of Mechanical and Industrial Engineering, via Branze, 38, 25123 Brescia, Italy

ARTICLE INFO

Keywords:
Rolling contact fatigue
Surface hardening
Failure assessment
Multiaxial fatigue
Subsurface cracks

ABSTRACT

A failure assessment diagram for components subjected to rolling contact with hardness varying along the depth is presented.

The approach takes into account the influence of inherent defects on subsurface fatigue: considering a 2D plane strain model, crack propagation from inherent defects was assessed in terms of applied stress intensity factor; defect-free fatigue was assessed in terms of the Dang Van stress.

By analysing different combinations of loading condition, defect dimension and hardness profile, it was possible to obtain a general relationship for subsurface rolling contact fatigue prediction.

A good agreement was found between predicted contact pressure limit and some published experimental results.

1. Introduction

Components having varying hardness along the depth, subjected to rolling contact loading, are common in industrial applications: gears, cams, bearing are some examples of them. The hardened layer is usually obtained on purpose by heat or mechanical treatments like induction quenching, carburising, nitriding, shot peening, addressing the requirement of high surface resistance, especially to wear, that is one of the most severe damage processes for these components. While surface hardness is usually quite easy to be specified in the design phase, the definition of the optimum hardness profile remains a matter of discussion, as it depends on both working conditions and material mechanical/micro-structural properties [1–3].

Several technical suggestions and recommendations can be found in literature about this topic, mainly coming from practical experiences carried out in specific industrial sectors.

A significant hardness gradient can be also sometimes "naturally" generated in the running-in phase of cyclic contact loading on initially homogeneous components, due to plastic deformation of surface layer and consequent material hardening.

In any case, prediction of rolling contact loading resistance is a complex problem and a comprehensive approach for this aim is not available yet, due to the difficulty in taking in to account the numerous parameters which determine it.

Sadeghi et al. [4] recently published a comprehensive review on damage and life predicting models for RCF: starting from the oldest engineering criterion of Lundberg and Palmgren, he highlighted the importance of a statistical approach in RCF prediction, showing in particular how progressively more detailed models needed a deeper understanding and simulation of the material micro-structure.

* Corresponding author. Tel.: +39 0303715525; fax: +39 0303702449.
E-mail address: angelo.mazzu@ing.unibs.it (A. Mazzù).

0013-7944/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.engfracmech.2012.05.009

Nomenclature

C	constant for limit pressure evaluation
$D_v, \widetilde{D}_v$	coefficients for the weight function
HV_c	Vickers hardness at the core
HV_s	Vickers hardness at the surface
I	failure index
$K_{I\max}$	maximum mode I stress intensity factor
$K_{I\min}$	minimum mode I stress intensity factor
K_{II}	mode II stress intensity factor
K_{IC}	fracture toughness
K_p	crack propagation parameter
R	load ratio
S_p	plain fatigue parameter
S_{ij}	generic component of the stress deviator
$S_{ij,m}$	constant tensor
$\widehat{S}_{ij}$	generic component of the symmetric stress deviator
$\widehat{S}_I$	maximum principal stress evaluated over the symmetric stress deviator
$\widehat{S}_{III}$	minimum principal stress evaluated over the symmetric stress deviator
a	crack size
a_D	intrinsic crack size
a_{Ds}	intrinsic crack size at the contact surface
b	Hertz contact half-width
f	friction coefficient on the contact surface
f_c	friction coefficient between crack faces
h_{II}	weight function for mode II SIF calculation
p	maximum Hertz pressure
t	time
x	coordinate parallel to the contact surface
z	coordinate orthogonal to the contact surface
z_c	critical depth
z_h	hardened depth
ΔK_{th}	threshold stress intensity factor
$\Delta K_{th\ l.c.}$	threshold stress intensity factor for long cracks
ΔK_{IIth}	mode II threshold stress intensity factor
ΔK_{IIIth}	mode III threshold stress intensity factor
$\Delta K_{Ith\,l.c.R=-1}$	mode I threshold stress intensity factor for long cracks with reversed load
$\Delta K_{Ith\,l.c.R=0}$	mode I threshold stress intensity factor for long cracks with pulsating load
$\Delta K_{IIth\,l.c.}$	mode II threshold stress intensity factor for long cracks
$\Delta\sigma_0$	double amplitude reversed uni-axial fatigue limit for crack-free material
$\Delta\tau$	range of the shear stress along the crack direction
$\Delta\tau_0$	single amplitude reversed torsion fatigue limit for crack-free material
$\Delta\tau_{0s}$	single amplitude reversed torsion fatigue limit for crack-free material at the contact surface
$\Delta\tau_{cr}$	limit shear stress range
$\Delta\tau_{xz}$	orthogonal shear stress range
$\Delta\tau_{sh}$	normalised shakedown limit
$\alpha_{D.V.}$	Dang Van equivalent stress parameter
β	shape factor for crack SIF calculation near the contact surface
γ	constant for limit pressure evaluation
δ_{ij}	operator of Kronecker
ρ	ratio of the x coordinate to the crack size
$\sigma_{D.V.}$	Dang Van equivalent stress
σ_H	hydrostatic stress
σ_{UTS}	ultimate tensile strength
σ_{ij}	generic stress component
σ_y	tensile yield stress
τ	shear stress along the crack direction
$\tau_{\max}$	Tresca shear stress
τ_{xz}	orthogonal shear stress