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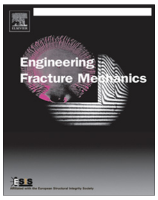

Fatigue crack growth law identification by Digital Image Correlation and electrical potential method for ductile cast iron

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ABSTRACT

In this paper, a comparison between two methods used to identify fatigue crack propagation law is conducted: Digital Image Correlation (DIC) and Direct Current Potential Drop (DCPD). For this purpose, fatigue tests were conducted at R-ratio of 0.1 on a ductile cast iron commonly used for exhaust manifolds manufacturing. Results show a good agreement between the methods illustrating the accuracy of each technique for the analysis of fatigue crack growth. Moreover, an interest of DIC is also to allow studying the plasticity that occurs at the crack tip during the fatigue test.

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1. Introduction

In the automotive industry, significant effort is devoted to satisfying the new legal environmental rules and to reduce weight. These constraints lead to a more demanding use of material, especially in case of engine components submitted to important mechanical loadings (thermo-mechanical fatigue, creep, fatigue induced by vibrations). In the area of fatigue design, mechanical reliability is one of the most important challenges, in spite of over 150 years of research into fatigue life prediction [1]. Designing against fatigue failure conducted to engineering rules such as the S-N curve or simplified equations as Basquin [2] for HCF (High Cycle Fatigue) and Manson-Coffin [3,4] for LCF (Low Cycle Fatigue). Nevertheless, the fatigue lifetime of an engine part is related to the crack initiation, its growth at microscale (short cracks) and then at structure scale (long cracks) until failure.

With the emergence of fracture mechanics, a more ambitious task has been undertaken - the prediction of the propagation behaviour of fatigue cracks. This study is based on fracture mechanics concepts, developed from 1920. Griffith [5] showed that the fracture of an elastic-brittle medium can be characterized by a variable, called later energy release rate. In the forties, Westergaard [6] and Muskhelishvili [7] gave analytical formulas of mechanical fields close to a crack in a linear elastic medium. In 1956, Irwin [8] and Williams [9], from singularities fields studies, defined the Stress Intensity Factor (SIF) notion to quantify singularity at the crack tip for the three cracking modes ($K_I,\ K_{II},\ K_{III}$). Under certain conditions, Williams

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Nomenclature

a	crack length
a_n	amplitudes associated with iDIC
a_0	initial crack length
da/dN	fatigue crack growth rate
dx	gap between equivalent elastic position of the crack tip and the origin of constructed Williams functions
$f(\bar{x})$	reference picture
$g(\bar{x})$	deformed picture
k_i	coefficients for corrective function
m	Paris' law parameter
n	Williams' series order
r_{int}	inner radius for identification zone
r_{ext}	external radius for identification zone
$\bar{u}(\bar{x})$	displacement field
$\bar{x}$	position field
x_{tip}	crack tip position
y	distance from the potential probe to the crack
B	specimen thickness
C	Paris' law parameter
F	applied load
K_I	opening mode stress intensity factor
K_I^{max}	maximum stress intensity factor
K_{II}	shearing mode stress intensity factor
L	specimen length
R	ratio between the minimum and the maximum applied load
R_p	plastic zone radius
V	electrical potential
V_0	initial electrical potential
Y	corrective function for finite size effects
W	specimen width
α	ratio between the crack length and the specimen width
ΔK	stress intensity factor range
∇	gradient operator
$\varepsilon(\bar{x})$	grey level residual
η^2	least square error
(r,θ)	polar coordinates
ϕ	steady state electrical potential
σ_y	yield stress
$\bar{\psi}_n$	shape functions associated with iDIC
ω_i^n	amplitude for the mode i of cracking and nth order for Williams' series

characterized the displacement field near the crack front with expansion series distinguishing the contributions of each cracking mode. In the linear elastic fracture mechanics framework, Paris and Erdogan [10] studied the propagation of long fatigue cracks and showed that the propagation velocity is clearly not constant in time and depends on the SIF range ΔK. During the stable crack propagation, also called the Paris regime, the crack growth rate da/dN is a power function of the SIF range leading to the well known Paris equation:

$$da/dN = C(\Delta K)^m \tag{1}$$

where C and m are experimentally obtained constants. Thus, the law identification requires to assess the crack length and SIFs values.

The first step is to experimentally determine the crack geometry with an accurate measurement of the crack length (or the crack tip position). Several methods can be used such as *post mortem* fatigue striations observation, but some materials such as the ductile cast irons studied here do not allow them to be directly observed [11]. Fatigue crack front marking can be expected with overloads, load ratio modifications or with heat tinting [12], taking the risk to impact the crack velocity. Among all the methods, the electrical [13] and optical monitoring are particularly interesting because a continuous follow-up is possible and a measurements automation can be considered. On the one hand, it eliminates uncertainties

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