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RAAI Project: Life-prediction and prognostics for railway axles under corrosion-fatigue damage

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Abstract

Corrosion damage induced by atmospheric agents has been shown to be able to trigger fatigue failures of railway axles. In this paper we firstly discuss consolidated results in modelling the growth of damage under corrosion-fatigue and its detection.

This is the background for describing the development of a new prognostic tool within the RAAI EU-funded project. In details, the new tool relies on a new automated scanner able to efficiently analyse optical measurements of the corroded axle surface and a crack growth simulation tool tuned through full-scale measurements of axle corrosion-fatigue damage.

Keywords: railway axles; corrosion-fatigue ; detection; prognostics

1. Introduction

Localised corrosive attack due to the electrochemical action of atmospheric agents, onto the surface of uncoated axles or corresponding to damaged zones of the coating for coated axles, are often found at the maintenance inspections. Moreover, it has been reported that fatigue cracks initiated at corrosion pits, have been the cause of recent railway axle failures both as reported by Hoddinott (2004); Transportation Safety Board of Canada (2001). The degradation due to corrosion shown by railway axles has increasingly become an area of concern. However, in spite of the many recent research activities on experiments (small-scale and full-scale tests) and degradation models, the problem that remains still open is the unavailability of a tool for quickly assessing the remaining service life of a corroded axle.

This is one of the aims of the RAAI (2015) EU-funded Project, whose concept for a new NDT method for measuring and assessing the corrosion-fatigue damage of an axle is here discussed after a brief overview of the previous results by the authors in this area.

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Nomenclature

d_{p-t-c}	- dimension of pit at the pit-to-crack transition
$\mathcal{B}$, β, n	- parameters of the crack growth model for corrosion fatigue
l	- crack length
l_t	- transition crack length for prevailing coalescence under corrosion-fatigue
l_f	- final crack length at failure
ΔK	- stress intensity factor range
ΔK_{th}	- threshold stress intensity factor range for fatigue crack propagation

2. Background: previous activities

2.1. Development of corrosion-fatigue damage under artificial rainwater

The development of corrosion-fatigue damage for EA1N (a normalized 0.45 % carbon steel with UTS=600 MPa) and EA4T (a Q & T low alloy steel with UTS =700 MPa) exposed to artificial rainwater has been investigated by a series of recent papers by Beretta et al. (2008, 2010); Moretti et al. (2014).

The behaviour of both steels was investigated by small scale specimens subjected to rotating bending under a continuous flow of artificial rainwater. In both the steels the initial phase of the corrosion-fatigue damage is constituted by the formation of pits with tiny secondary pits at the bottom and then the subsequent nucleation of cracks due to the high stress concentration (see Fig. 1).

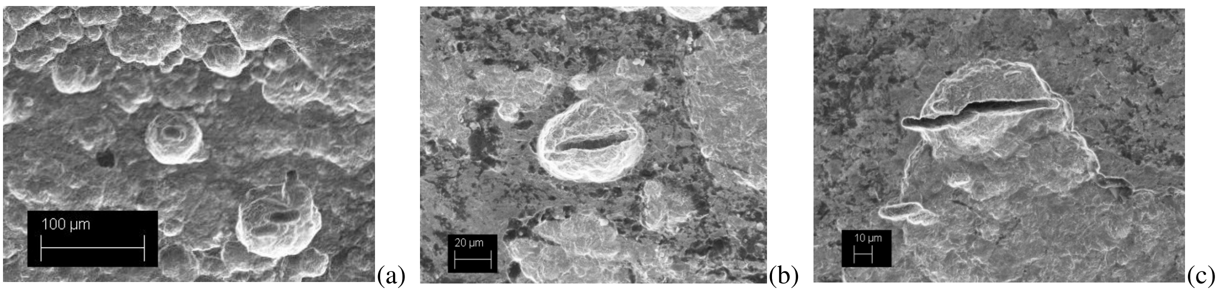

Fig. 1. Three phases of the pit-to-crack transition: a) a secondary pit at the bottom of the primary one; b) the formation of a microcrack; c) the micro-crack grows out of the primary pit (Moretti et al. (2014)).

2.2. Propagation of small cracks

The crack growth rate was obtained from measurements of crack length on the plastic replicas (Fig. 2.a) by the *secant method*. The data showed, at the different stress levels, a significant flattening of the growth curve from a length l_t due to crack coalescence. To describe this peculiar behaviour, we have adopted a crack growth model (an adaptation of the model by Murtaza and Akid (2000)) of the type:

$$\begin{aligned} \frac{dl}{dN} &= \mathcal{B} \cdot \Delta\sigma^{\beta} \cdot l^{n} \quad \text{for} \quad l \leq l_t \\ \frac{dl}{dN} &= \mathcal{B} \cdot \Delta\sigma^{\beta} \cdot l_t^{\,n} \quad \text{for} \quad l > l_t \end{aligned} \tag{1}$$

where l_t is a characteristic length after which there is a prevailing crack coalescence with almost a constant growth rate in small scale specimens, $\mathcal{B}$ - β - n are material parameters obtained by fitting small crack growth data obtained on small scale specimens. This equation is only able to describe the crack growth sustained by the environmental effect. After the crack length has reached a significant size so that $\Delta K > \Delta K_{th}$, the crack then propagates according to the growth rate determined by usual propagation tests in air, as discussed by Moretti et al. (2014).