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Experiments on crack propagation and threshold at defects in press-fits of railway axles

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Abstract

Fatigue strength under fretting fatigue is one of the open problems in the area of fatigue. In the case of railway wheel-axle press-fits, there are no records of recent failures because design rules are today based on making the shape of geometrical transitions the most stressed point. However, it is important to analyze correctly the acceptability of defects and micro-cracks at press-fits.

In this paper, after a preliminary presentation of the results obtained by a new criterion for predicting the non-propagation of cracks under rolling contact fatigue conditions, a new series of experiments on full-scale axle press-fits containing artificial defects is presented and discussed. Results show the modified Dang Van criterion is adequate for describing the development of natural cracks and cracks from artificial defects. The latter, characterized by a depth of $250 - 350\,\mu m$, are competitors of fretting cracks naturally developed from surface scars and surface damage.

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Keywords: fretting; defects; threshold; propagation; railway axles

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1. Introduction

The investigation of fretting damage and its prolonged consequences in fatigue life assessment is an important issue in railway axle design. Fretting fatigue in axle-wheel press-fits can be described as the repetitive micro sliding of the wheel assembly on press-fit seat due to applied bending and vibrations. Multiple-site surface damage caused by fretting is considered to be the source of crack nucleation, which can become a propagating crack by further application of cyclic loading.

The first aim of the present study is to verify whether the fatigue strength values reported in the relevant European Standard are compatible with the presence of indications usually detected by magnetic particle inspection (MPI) at the end of a fatigue test. This looks to be a significant improvement with respect to the current European Standard EN

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13260 (2009), which requires that "it shall be verified on three specimens that no cracks has appeared after 10^7 cycles of a load creating a surface stress equal to the fatigue limit" (quote from EN 13260 (2009)).

The second aim is to establish a criterion for the acceptability of defects at press-fits in railway axles. In a previous study, see Foletti et al. (2016), the multiaxial high cycle fatigue criterion proposed by Dang Van et al. (1989) and (1993), modified as proposed by Desimone et al. (2006), was applied to the stress distribution, obtained by finite element (FE) analysis. This analysis was conducted along the press-fit contact area for a stress level corresponding to the fatigue strength at 10^7 cycles for press-fits as determined within the Euraxles European Collaborative Project, see Cervello (2016). In detail, the obtained equivalent stress has been treated as the fatigue strength of the material containing defects (the surface damage and scars induced by stick-slip conditions) expressed as a function of defect size through the El Haddad correction, El Haddad et al. (1979). This approach allowed to estimate a maximum allowable depth of defects (for the stress levels corresponding to full-scale fatigue strength at 10^7 cycles) of the order of $250 - 350\,\mu m$.

In this paper, those predictions have been compared with test results on full-scale axles with artificial micro-notches, performed as a part of a collaboration project between PoliMi and Lucchini RS. Experimental tests have then been analysed in terms of fatigue test results and fractographic evidences, which showed a competition of cracks initiating at micronotches and natural fretting cracks.

2. Criterion for fatigue strength/threshold condition of defects under fretting

The proposed procedure is based on a finite element (FE) analysis so as to obtain the stress path under the press fit seat. The stress tensor is used as input in the Dang Van criterion to determine an equivalent stress. The Dang Van criterion can be expressed as, Dang Van et al. (1989) and (1993):

$$\tau_{DV}(t) + \alpha_{DV}\sigma_h(t) \leq \tau_w \tag{1}$$

where α_{DV} is a material constant, τ_w is the fatigue limit in reversed torsion, $\sigma_h(t)$ is the instantaneous hydrostatic component of the stress tensor and $\tau_{DV}(t)$ is the instantaneous value of the Tresca shear stress at mesoscale level. In order to avoid non-conservative predictions in rolling contact fatigue (RCF) problems, Desimone et al. (2006), argued that the failure locus in the region with $\sigma_h(t) < 0$ should be modified into a constant value:

$$\tau_{DV}(t) \leq \tau_w = \frac{\sigma_w}{2} \quad \text{for} \quad \sigma_h < 0 \tag{2}$$

Adopting this failure locus, which is conservative by 10 % with respect to experiments on microdefects under RCF, Foletti et al. (2014), an equivalent stress can be simply expressed for $\sigma_h < 0$ as:

$$\sigma_{eq}^{DV} = 2 \cdot \max\left(\tau_{DV}(t)\right) \leq \sigma_w \tag{3}$$

If the relationship between fatigue strength σ_w and defect size is described through the model:

$$\sigma_w = \sigma_{wo}\sqrt{\frac{\sqrt{area_o}}{\sqrt{area} + \sqrt{area_o}}} \tag{4}$$

where $\sqrt{area}$ is the defect size expressed by Murakami's parameter (see Murakami (2002)) and $\sqrt{area_o}$ is the El-Haddad's parameter expressed in the same way, the critical defect size for a given multiaxial stress σ_{eq}^{DV} can then be determined:

$$\sqrt{area}_{crit} \;:\; \sigma_{eq}^{DV} = \sigma_w \tag{5}$$

Considering a shallow 2D surface crack with a length c, the parameter can be calculated as $\sqrt{area} = \sqrt{10} \cdot c$ (see Murakami (2002)). It is therefore simple to find a critical defect size (or depth by knowing the orientation angle, see Fig. 1a) for a given multiaxial stress state (provided that $\sigma_h < 0$). The orientation of the critical defect size can be obtained by considering the critical plane version of the Dang Van criterion. Considering a material plane defined by its unit normal vector $\underline{n}$ the Dang Van shear stress can be defined as:

$$\tau_{DV}\left(\phi, \theta, t\right) = \|\underline{\tau}\left(\phi, \theta, t\right) - \underline{\tau}_m\left(\phi, \theta\right)\| \tag{6}$$