International Journal of Fatigue 86 (2016) 34–43

Contents lists available at ScienceDirect

International Journal of Fatigue

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

Defect acceptability under full-scale fretting fatigue tests for railway axles

S. Foletti [a,*], S. Beretta [a], G. Gurer [b]

[a] Politecnico di Milano, Dipartimento di Meccanica, Via La Masa 1, 20156 Milan, Italy
[b] Middle East Technical University, Department of Metallurgical and Materials Engineering, 06800 Ankara, Turkey

ARTICLE INFO

Article history:
Received 22 April 2015
Received in revised form 12 August 2015
Accepted 19 August 2015
Available online 2 September 2015

Keywords:
Fretting fatigue
Multiaxial fatigue criteria
Defect acceptability
Railway axles

ABSTRACT

This paper presents a new approach based on the application of a multiaxial high cycle fatigue criterion together with the use of El-Haddad correction for investigation of fretting fatigue in railway axles. Stress path along the axle–wheel contact, determined by the FE analysis, was implemented into different multiaxial fatigue criteria in order to predict critical sites of nucleation. The equivalent fatigue limit expressed by the applied criterion is compared with the crack size dependent fatigue limit described by El-Haddad correction in order to define a defect size acceptability criterion. Verification of the proposed approach was done by post-test failure investigation of the full-scale axle tests conducted as a part of Euraxles project. Scanning electron microscope (SEM) examination of the failed press-fit sections revealed a critical defect size in the order of 200 μm in depth for non-propagating cracks. The obtained results were found to be consistent with the estimations made by the proposed approach.

1. Introduction

Investigation of fretting damage and its prolonged consequences in fatigue life assessment is an important issue in railway axle design. Fretting fatigue in the axle–wheel contact can be described as the repetitive micro sliding of the wheel assembly on press-fit seat due to applied bending and vibration. Multiple-site surface damage caused by fretting is considered to be the source of crack nucleation which can become a propagating crack with further application of cyclic loading. A decreased fatigue life up to 60–75% due to fretting damage has been reported in the literature [1,2].

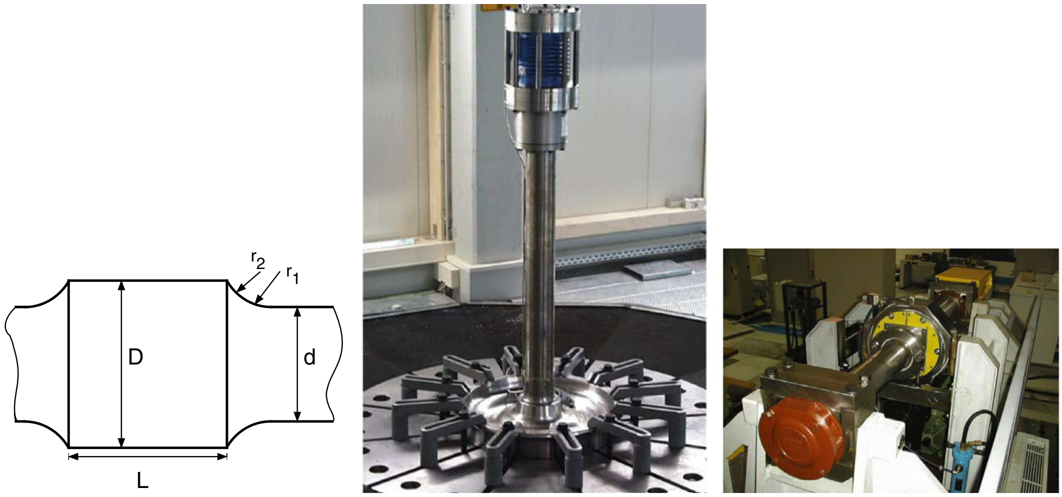
The present study is a part of research activity devoted to validate the fatigue limits described by the European Standards. Main objective of the present study is to develop an acceptability criteria that can be applied in assessment of surface defects inspected at axle press-fits by magnetic particle inspections (MPI). Further contribution to the European Standard EN-13260, which necessitates verification of no crack formation after 10^7 cycles at fatigue limit currently, by evaluating the applicability of presents fatigue limits in the presence of non-propagating surface cracks was also aimed [3]. In the study, press fit surfaces of different EA4T axles have been investigated. A nominal bending stress, not exceeding 240 MPa, was selected in accordance with the EN standards [4–6]. The allowable stress limit at the press fit was reduced to 132 MPa for an axle with a diameter ratio of $D/d = 1.12$ (Fig. 1a) [4,5]. Formation and developments of non-propagating cracks at the press-fit under the influence of fretting was investigated.

A previous study on fretting fatigue of railway axles identified four typical regions for initiation sites located at the root of transition fillet (T-transition), contact edge, stick–slip interface of the contact and sub-surface under contact [4,5]. Hirakawa et al. reported formation of an annular band of fretting corrosion with a width of 7–9 mm starting from the edge of press-fit to the inner press fitted surface for railway axles. Within this band several minute cracks can be observed. However, the cracks which propagated to final failure always observed to initiate from the sites 2–5 mm away from the edge of the press-fit [7].

Mechanism of fretting fatigue in railway axle is explained by the multiple-site nucleation of non-propagating cracks under the influence of fretting damage described as multiple-site damage (MSD) [8]. Beyond certain limits of loading, framed by application of multiaxial fatigue criteria along the stress path, transformation of non-propagating cracks to a state of propagation might take place. Propagation of long-cracks, driven by the applied bulk stress, results in final fracture of the axle as cyclic loading proceeds [8]. Experimental fretting studies on different materials has shown that majority of fatigue life has been spent in formation of a engineering crack in the cases of cylindrical contacts [1,8–13]. In other

* Corresponding author.
E-mail address: stefano.foletti@polimi.it (S. Foletti).

http://dx.doi.org/10.1016/j.ijfatigue.2015.08.023
0142-1123/



(a) (b) (c)

Fig. 1. Test rigs and testpiece geometry: (a) Detailed shape of the press-fitted part. (b) Test rig for Minden type tests. (c) Test rig for Vitry type tests.

words, a rapid increase in crack propagation rate is observed when the propagating cracks originated from different sources are merged with one another to form a major crack.

For the reasons given determination of the limiting size for non-propagating cracks and selection of a proper multiaxial fatigue criterion well-describing the multiaxiality of the applied load case is essential. In the present study, two different multiaxial criteria, Dang Van [14] and Liu–Mahadevan [15], were applied to the stress distribution along press-fit contact obtained by finite element (FE) analysis.These two criteria, with a suitable modification for Dang Van [16] have presented remarkable results for the investigation of microcrack advance under influence the rolling contact fatigue [17].The obtained equivalent stress for each criterion was checked against the fatigue limit of the material expressed as a function of defect size through the El Haddad correction [18].The prediction capability for the proposed approach has been evaluated by comparing full-scale axle test results, performed as a part of Euraxles project with the data produced by the analytical approach [19]. Axles with two different axle geometries were tested in test benches until a fatigue life of 10^7 cycles was achieved. Tested axles are dismantled and prepared for macro and micro examination.

In macro examination, magnetic particle inspection (MPI) of the failed and run-out axles was done in order to detect indications of macro cracking under press-fit seat region. Inspected orientations of major cracks are measured and expressed in distance with respect to the contact edge. Obtained experimental results are compared with the critical site estimations made by the proposed analytical method.

Micro examination was done on the samples sectioned from the cracked regions identified by macro examination. Sectioned samples were examined under SEM in order to investigate size,orientation and distribution of non-propagating cracks as well as the defect size from which a crack starts to propagate. Crack size measurements taken from the SEM images were used in characterization of critical size for non-propagating cracks. Obtained results are compared with the critical size estimations for the corresponding region made by the proposed analytical method. In conclusion, the applicability of each multiaxial fatigue criterion for explaining the limiting conditions for fretting fatigue of railway axles has been discussed.

Table 1
Axle geometry at press-fit.

	D [mm]	d [mm]	D/d	r_1 [mm]	r_2 [mm]	l [mm]
F1-Vitry	190	160	1.19	75	15	185
F4-Vitry	165	147	1.12	75	15	185
F4-Minden	165	147	1.12	75	15	190

Table 2
Full scale fretting fatigue test results on railway axles.

Test rig type	Test #	σ_{nom} [MPa]	Test results	Failure location – main crack
F1-Vitry	1	153	Failed ($N = 1.69 \times 10^6$ cycles)	Wheel seat at about 20 mm from the T-transition
F1-Vitry	2	141	Run-out ($N = 10^7$ cycles)	
F1-Vitry	3	153	Failed ($N = 1.47 \times 10^6$ cycles)	Wheel seat at about 20 mm from the T-transition
F4-Vitry	1	120	Failed ($N = 7.70x10^6$ cycles)	Wheel seat at about 10 mm from the T-transition
F4-Vitry	2	108	Run-out ($N = 10^7$ cycles)	
F4-Vitry	3	120	Run-out ($N = 10^7$ cycles)	
F4-Vitry	4	132	Failed ($N = 4.98 \times 10^6$ cycles)	Wheel seat at about 10 mm from the T-transition
F4-Vitry	5	120	Failed ($N = 2.10 \times 10^6$ cycles)	Wheel seat at about 10 mm from the T-transition
F4-Minden	1	132	Failed ($N = 10^7$ cycles)	Wheel seat at about 4 mm from the T-transition
F4-Minden	2	126	Failed ($N = 10^7$ cycles)	Wheel seat at about 15 mm from the T-transition
F4-Minden	3	120	Run-Out ($N = 10^7$ cycles)	
F4-Minden	4	132	Failed ($N = 10^7$ cycles)	Wheel seat at about 7 mm from the T-transition