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Fatigue strength assessment of railway axles considering small-scale tests and damage calculations

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Abstract

Small scale fatigue tests aimed at determining the S-N diagram and the Miner Index to be adopted for fatigue damage assessment of railway axles were carried out within the frame of the frame of the research activities of EU funded EURAXLES project. Fatigue tests performed on steel grades EA4T and EA1N adopted by the European EN13103/13104 standards with both constant and variable amplitude loading are reported. The variable amplitude loading fatigue tests were carried out by using loading spectra derived from actual load measurements of fatigue bending moment in railway axles under significant service conditions. The consistent version of Miner's rule (according to the FKM-Guideline) with an allowable damage sum D_{crit} = 0.3 adopted in combination with 2.5% percentile (p2.5%) of the S-N curve derived experimentally with small specimens proved to be adequate as design criterion, thus enabling the transferability of small scale fatigue tests to full scale railway axles that would lead to improved fatigue resistance of railway axles with new designs.

Keywords: S-N diagram, Fatigue damage, variable amplitude, Miner Index, railway axles

1. Introduction

To maintain and to further increase its competitive advantage in the globalised market, the European railway industry requires new and improved methods for the design of railway axes, allowing higher and improved levels of safety and reliability. Currently, the fatigue assessment of railway axles according to EN 13103 and/or EN 13104 standards is usually based on a constant amplitude fatigue assessment under extreme load conditions. However, in order to increase the level of reliability of new and improved designs, the European railway industry is more and more frequently required to perform fatigue assessments with increased level of details based on measured stress spectra. In addition to that, designers require new and improve methods, allowing the transferability of fatigue test results obtained with laboratory specimens to actual components, as it's been shown, among others, by Gänser et al. (2016) and by Zerbst et al. (2013).

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The EU funded project EURAXLES has been successful at introducing revised axles design concepts by taking into account of actual service loading conditions and of the experimentally determined fatigue limits, including new materials and methods in order to predict the 'failure probability'. Within the frame of Euraxles project, see Unife (2010), a fatigue test campaign on the steel grades EA1N and EA4T according to EN 13261 has been carried out with both constant and variable amplitude loading. The variable amplitude loading spectra were derived by loading spectra measured during service by one of the partners of the Euraxles project and made available for the scope of generating fatigue tests results that could allow transferability of the test results to actual railway axle fatigue strength assessment. In the present paper, the results of the fatigue tests under constant and variable amplitude loading of the steel grades EA4T and EA1N are given, complemented by an in-depth analysis of the fatigue test results aiming at identifying the allowable (or critical) damage sum leading to conservative fatigue assessment.

Nomenclature

k slope of the S-N diagram
k' slope of the S-N diagram for $S \leq S_D$ according to Haibach ($k' = 2k - 1$)
N number of cycles to failure
N_D position of the knee of the S-N diagram under constant amplitude stresses
S applied stress
S_D fatigue endurance strength

2. Constant amplitude fatigue tests

2.1. Axles cut-up plan and specimen preparation

In the Euraxles project, the fatigue behavior of two railway axle steels, EA1N and EA4T according to the definition of the EN standards, was investigated. The nominal monotonic (tensile) properties of the materials according to EN 13261 are reported in Tab. 1.

Grade	R_e (N/mm^2)	R_m (N/mm^2)	A_5 %
EA4T	≥ 420	650–800	≥ 18
EA1N	≥ 320	550–650	≥ 22

Table 1. Nominal tensile properties of EA4T and EA1N axle steels according to EN 13261.

Fatigue specimens were designed so that tension-compression axial fatigue tests could be carried out by employing the resonance fatigue test equipment Rumul Testronic 100 (Russenberger Prüfmachinen AG) available in the laboratories of both Politecnico di Milano and Fraunhofer IWM. Specimens were extracted from segments of railway axles that were cut in large pieces for the purpose of obtaining specimens for the research activities of the Euraxles project, see Unife (2010). In Fig. 1 the geometry of the specimens and the cut-up of a segment of an axles with the positions of the specimens is also shown. As it may be observed in Fig. 1, specimens for conducting the fatigue tests in the finite life regime with higher loading amplitudes were also taken out of the axles and manufactured with cylindrical ends and with an identical shape of the central gauge section, so that they could be tested with a MTS 810 servohydraulic test systems. In Fig. 1(c), specimens with a shape suitable for strain controlled low-cycle fatigue (LCF) tests are also shown, even if those LCF tests will not be discussed in this paper.

Segments of railway axles manufactured by 3 different European producers, partners of the Euraxles project, were used for the production of the fatigue specimens. Politecnico di Milano carried out fatigue tests with EA4T specimens of all three producers (in the following, due to confidentiality issues, they are referred to as Producer A, B, C), while Fraunhofer IWM performed fatigue tests with specimens extracted from the axles manufactured by producer A on both EA4T and EA1N steels.