International Journal of Fatigue 86 (2016) 24–33

Contents lists available at ScienceDirect

International Journal of Fatigue

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

Experimental and numerical study on crack initiation under fretting fatigue loading

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A R T I C L E I N F O

Article history:
Received 14 April 2015
Received in revised form 18 September 2015
Accepted 22 September 2015
Available online 23 October 2015

Keywords:
Fretting fatigue
Crack initiation
Multiaxial fatigue damage parameter

A B S T R A C T

Press-fitted railway axles and wheels are subjected to fretting fatigue loading with a potential hazard of crack initiation in press fits. Typically, the resistance against crack initiation and propagation in press fits is investigated in full-scale tests, which procedure is both costly and time consuming. In this context, combined experimental and numerical approaches are of increasing practical importance, as these may reduce the experimental effort and, moreover, provide a basis for the transferability of experimental results to different axle geometries and materials. This study aims at evaluating stress–strain conditions under which fretting fatigue crack initiation is likely to occur. Experiments on small-scale specimens under varying fretting fatigue load parameters and their finite-element modelling to characterize the resulting stress–strain fields are performed. Subsequently, different multiaxial fatigue parameters are applied to predict crack initiation under fretting fatigue conditions.

1. Introduction

Fretting fatigue is a complex phenomenon which has been investigated in many respects by different researches, e.g. [1–7]. Material behaviour under fretting fatigue is influenced by various factors, e.g. material pairing, contact area geometry, multiaxial stress state within the contact zone, surface roughness, environmental effects, coefficient of friction, loading velocity. The fatigue life of railway axles can be limited by crack initiation in press fitting locations, in particular within the contact zone between the axle and the wheel. Both the service experience and laboratory tests reveal that, under certain conditions, circumferential cracks can initiate in press fits subjected to rotary bending, caused by small relative movements of friction surfaces being in contact. The risk of axle failure can then arise if such cracks propagate in the radial direction. Currently, the resistance of press-fitted railway axles and wheels against crack initiation and crack propagation as well as technical developments subjected to the improvement of the fretting fatigue crack resistance are investigated mainly in full-scale axle tests, see Fig. 1 [8].

However, such tests are time consuming and expensive. Furthermore, results gained from a particular test series are not directly transferable to other combinations of the axle design and material. Therefore, combined experimental and numerical assessment procedures helping to reduce the experimental effort are essential from the practical point of view. The aim of this study performed within the framework of the research project EURAXLES [9] is to contribute to the development of a methodology by which means the number of expensive full-scale axle tests can be reduced or replaced by small-scale specimen testing accompanied by numerical analyses. For this purpose, a series of small-scale specimen tests is performed under fretting fatigue conditions using a specially designed test set-up. The load parameters, such as the stress amplitude, contact load and relative slip between the contact surfaces, were varied or selected to achieve conditions relevant for axles in service. Additionally, numerical analyses of the test specimens are performed to estimate the respective stress–strain fields and evaluate a potential applicability of multiaxial fatigue parameters for predicting material damage under fretting fatigue conditions. Note that issues of the fatigue crack propagation in press fits are out of scope of this study.

2. Experimental set-up

To experimentally simulate loading scenarios which are relevant for fretting fatigue initiation due to relative movements within the contact zone of an axle-wheel press fit connection, a test concept [1,2] schematically shown in Fig. 2 (left) was adopted in this study. During a test, cyclic axial loading with a constant stress

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http://dx.doi.org/10.1016/j.ijfatigue.2015.09.022
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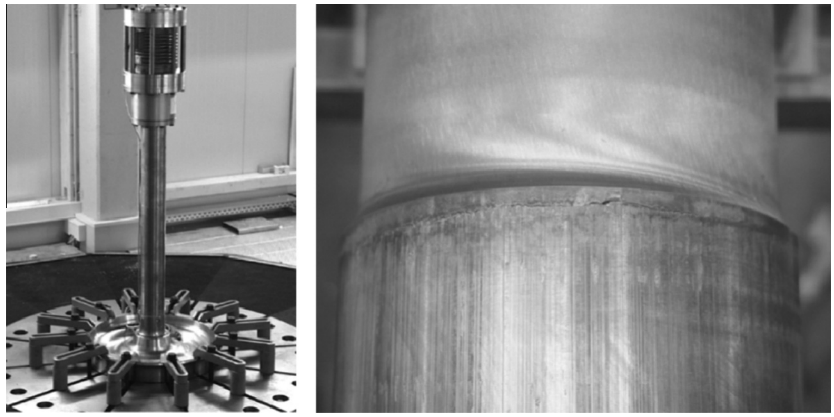

Fig. 1. Example of a test rig for fatigue strength assessment of axles in press fits (left) and fatigue cracks in a press fit (right). Taken from [8].

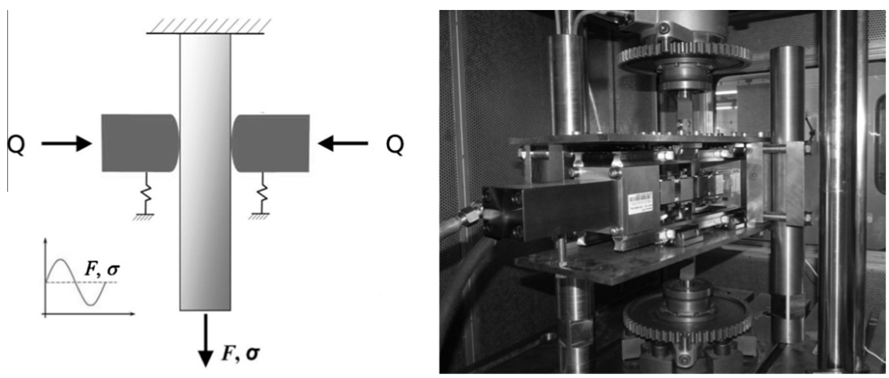

Fig. 2. Schematic representation of the fretting fatigue test concept [1,2] (left) and test fixture adopted in this study (right).

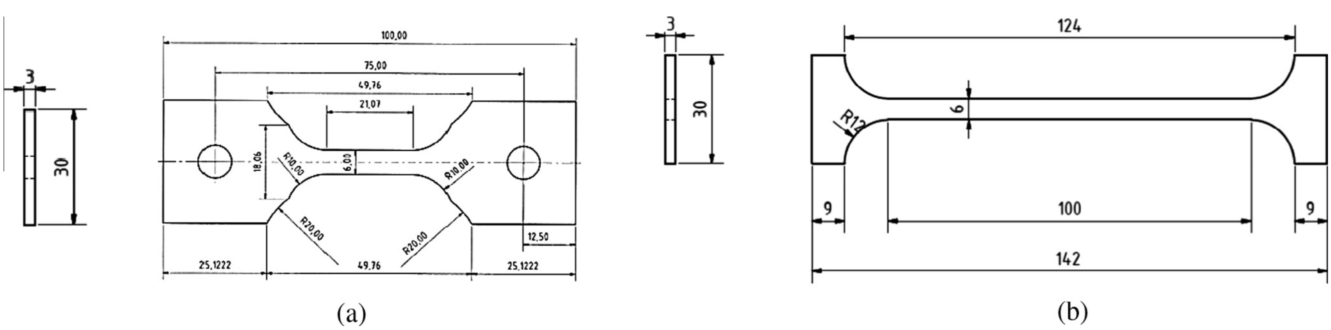

Fig. 3. Specimen geometries used in fretting fatigue tests: (a) specimen #1; (b) specimen #2.

amplitude (or a maximum stress σ_{appl}) is applied to the specimen end by means of a standard testing machine (here resonant testing machine). The transverse contact load Q is applied and controlled by an independent hydraulic system via contact pads which clamp the specimen from two opposite sides. Thus, definite load combinations can be introduced which lead to a relative slip δ between the specimen and the pads within the contact zone. The resulting displacement should be small with respect to the total contact length in order to evoke fretting fatigue conditions [7]. In particular, the range of the contact slip realized in this study varied within some 5 – 20 μm, while the length of the contact zone was about l_c = 1.7 mm. To implement the above test concept, the set-up shown in Fig. 2 (right) was designed and manufactured.

In the tests, two specimen geometries were used as shown in Fig. 3. Both specimens have a width of w = 6 mm, whereas the uniform lengths were chosen to be l_s = 21 mm (specimen #1) and l_s = 100 mm (specimen #2), respectively. When increasing the specimen length, the overall longitudinal displacement and the resulting contact slip were also increased.

Two pad geometries shown in Fig. 4 were used in the tests. The overall pad width was w_p = 12 mm, while the contact side was machined as either a continuously round surface with a radius of r = 50.8 mm or being additionally flattened over a length of l_c = 1.7 mm (type B). In the latter case, the resulting nominal contact area estimated at Q = 0 kN was $w \times l_c = 6 \times 1.7 = 10.2$ mm^2. In contrast, the type A pad produces a narrow contact zone with an indefinite width, thus leading to less reproducible test results. As a consequence, no fretting fatigue cracks were observed when using type A pads and applying the same load parameters as in the tests with the flattened pad geometry. Consequently, the test