Wear 271 (2011) 148–157

Contents lists available at ScienceDirect

Wear

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

Squat growth—Some observations and the validation of numerical predictions

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ARTICLE INFO

Article history:
Received 27 September 2010
Accepted 3 October 2010
Available online 14 October 2010

Keywords:
Rolling contact fatigue
Squat
Numerical prediction
Validation
Friction
Plasticity

ABSTRACT

This paper presents evidences obtained by field monitoring, measurement and survey to show the validity of some numerical predictions about squat growth. The predictions concerns a postulated squat growth process, the relationship between the dynamic contact force and the corrugation-like wave pattern that often follows squats, the high frequency wheel–rail interaction related to squats, and the influence of tangential force on squat growth. The observations reveal signature tunes of squats which may be used for early detection of squats, show the necessity to include high frequency dynamic wheel–rail interaction in squat-related analyses, and provide evidence of relationship between rolling stock performance and squat initiation and growth. In validating the numerical results the model is also verified for its applicability to analyses of squat-related problem and other problems similar in nature. The model can be employed for the solution of three-dimensional frictional rolling contact problems. It can also be used for analyses of loading conditions of wheel–rail contact at short wave defects, and the associated damages such as wear, plastic deformation, fatigue and corrugation.

1. Introduction

1.1. Literature review

Squats were first reported in the 1950s in Japan where they were described as the 'black spot' [1–3]. In the 1970s they became known in the UK [4]. In other European countries they were reported later [5,6]. A definition of squats can be found in [7]. In recent years squats have become an important rolling contact fatigue (RCF) problem for railways such as ProRail—the Dutch Railways [6,8].

Research on squats has been carried out over the past decades. In [9] Clayton presented a research programme of the British Rail Research, the goal of which was to develop a failure model based on small scale laboratory test; some results were reported in [9,10].

In 1987 the European Rail Research Institute (ERRI) started the D173 Rolling Contact Fatigue Programme, an overview of which can be found in [11]. Squats were investigated in this programme; some of the results were summarized by Cannon and Pradier [11]. The major work on squats in the frame of this project was on crack growth, which was presented by Bogdanski et al. [12]. Since then Bogdanski et al. have published a series of work related to cracks of squats, especially in relation to fluid entrapment, with the latest being [13].

In [14] Kondo et al. presented the history of Shinkansen rail surface shelling which was also squats, and discussed the causes, growth and detection; grinding was the countermeasure. Some recent work on the squats in Japan was reported by Ishida et al. [15], in which the initiation mechanism and the effect of grinding were discussed. Other works on squats can be found in [16–19].

1.2. Three characteristics of squats

One of the most striking visual characteristics of mature squats may be the shape of two lungs, or the shape which looks like a permanent deformation indented by somebody sitting, or squatting on the rail, see Figs. 1(b) and 2(b). This seems to be the origin of the name of squat.

Another characteristic that is often associated with squats is the V, U, Y or circular shaped cracks [7,21,22] which can be seen in Figs. 2(b), 3(a) and 4(a). An illustration of the shape of the surface cracks is given in the right lower corner of Fig. 3(a). It is believed that the cracks initiate in the surface [9,11,14,19], and grow till about 3–6 mm deep in the subsurface, before they branch downward transversely [7,9,14,19], see Figs. 3(b) and 4(b). In [4,21] explanations are given about how cracks of squats may initiate from indentations of periodicity of the wheel circumference and how squats grow from surface cracks.

The third characteristic is the widening of the running band at squats [7,21,22], see Figs. 1, 2(b), 3, 4, etc. This local widening of the contact surface is obviously a result of plastic deformation caused by impact of the wheels on the rail. A proper analysis of the con-

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doi:10.1016/j.wear.2010.10.051

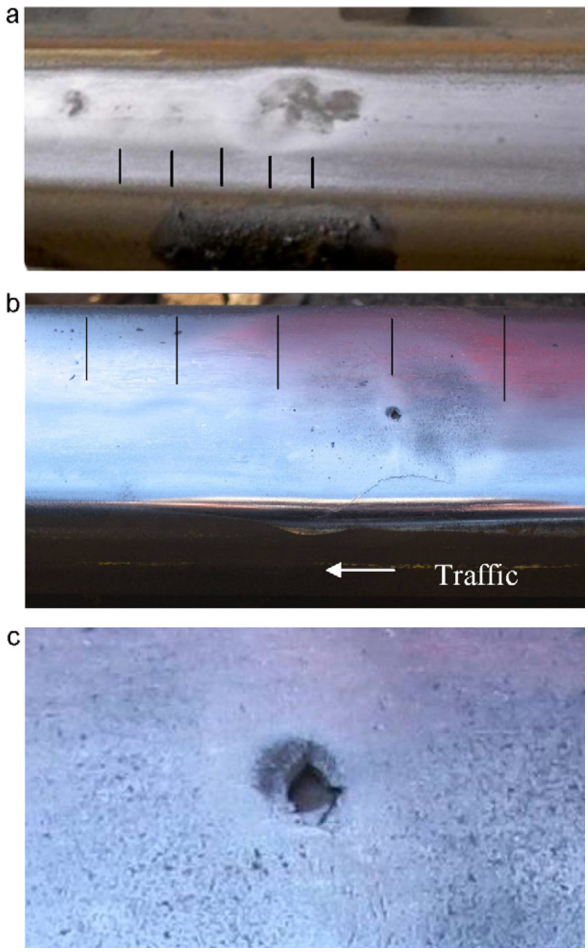

Fig. 1. Squats initiated from indentations. The vertical bars indicate the wave patterns related to the squats. Traffic is from right to left. (a) A squat initiated from an indentation by a roller bearing ball [20] in Sweden. (b) A squat initiated from an indentation which is at the centre. The wavelength is estimated to be between 25 and 35 mm (Courtesy of René Heyder, Deutsche Bahn AG). (c) Zoom-in of the indentation in (b). Its diameter is about 6 mm in the photo. But its initial size may be significantly different due to the large plastic deformation.

tact at squats deserves therefore the solution of rolling contact in continuum dynamics because it concerns the elastic-plastic fields in the wheel and rail caused by the impact.

Among other ones, these three characteristics are typical of squats in the intermediate and late stages of their development. They are, however, not necessarily always followed exactly by all squats. Fig. 1(a) shows that the lung-like shape is somewhat disturbed. At the last stage before fracture more cracks may be visible in the surface; the lung-like shape might become less obvious, see Fig. 4(a) for an example. But the nearly circular boundary of a lung due to the widening of the running band can still be seen in Fig. 4(b).

This paper concerns squats and rail top defects which will eventually grow into squats. The definition of squats given in [7] is followed, as can be seen from the discussion.

1.3. Squat initiation—light squat

Indentation by hard objects in the wheel–rail contact has been reported [6,8,9,14] as a source of squat initiation. Although it is often difficult to identify from a squat of a late stage what has been the initiating cause, balls from rolling bearing (Fig. 1(a)) or from aerosol paint can have been found to be among such hard materials. Ballast stones have also been reported as a source in Japan [14].

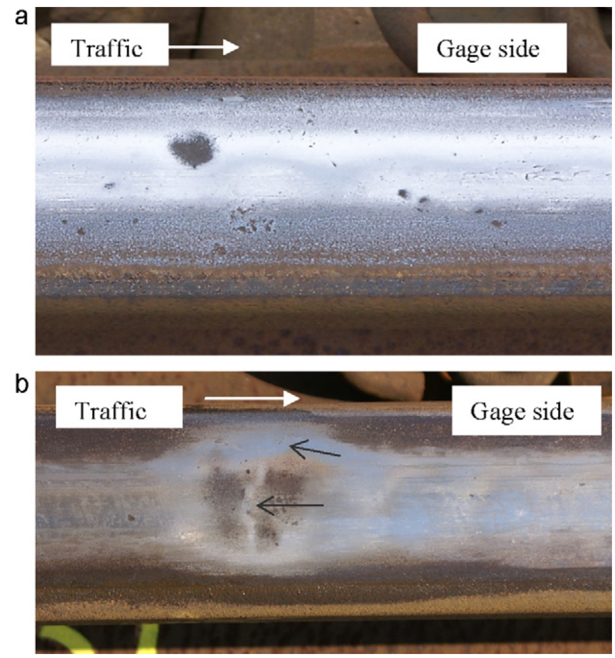

Fig. 2. (a) A light squat, and (b) a mature squat with visible U crack near the gage corner and cracks in the middle, pointed by the black arrows.

Squats grown from indentations do not have the above mentioned three characteristics in the beginning. The lung-like locally depressed surface and the cracks are results of the severe plastic deformation caused by the repeated dynamic wheel–rail interaction at the indentations and the consequential exhaustion of ductility of the rail material.

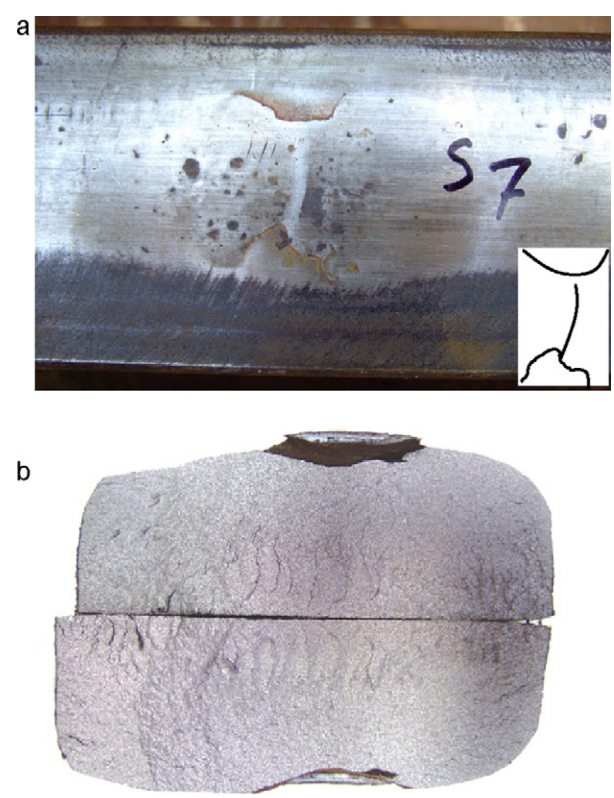

Fig. 3. A squat with a crack depth of 3.5 mm at the deepest point. (a) The squat. (b) The cross-section of the squat of (a) broken by four-point bending.