International Journal of Fatigue 33 (2011) 69–74

Contents lists available at ScienceDirect

International Journal of Fatigue

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

# Cyclic deformation behaviour of railway wheel steels in the very high cycle fatigue (VHCF) regime

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ARTICLE INFO

*Article history:*
Received 21 December 2009
Received in revised form 19 July 2010
Accepted 20 July 2010
Available online 24 July 2010

*Keywords:*
Railway wheel steels
Fatigue behaviour
Very high cycle fatigue (VHCF) regime
Frequency, temperature and electrical resistance measurements
Microstructure

ABSTRACT

In the present contribution, the cyclic deformation behaviour of the railway wheel steels SAE 1050 and SAE 1060 was investigated in the very high cycle fatigue (VHCF) regime using a resonance testing device at a frequency of 200 Hz. The specimens were machined from the area of the 'limiting-diameter' of original monobloc-wheels. The wheels were provided by a system supplier of the Deutsche Bahn AG. The cyclic deformation behaviour is analysed by using highly precise methods for measuring the frequency, temperature and electrical resistance, which show deformation-induced changes of the microstructure within the bulk material during the fatigue process. The initial state of the material is investigated thoroughly by using light-, scanning- and transmission electron microscopy. The dislocation structure was investigated in defined fatigue states showing dislocation walls at 5% $N_f$ and dislocation cells at 85% $N_f$. *S–N* (Woehler) curves are presented for both wheel steels. Fatigue failures at $N_f > 10^7$ were observed.


## 1. Introduction

Railway wheels, which are used in high-speed passenger-traffic, are loaded in service by $5 \times 10^8$–$10^9$ revolutions of the wheels at a frequency of up to 25 Hz. With resonance testing devices it is possible to realize a frequency of 200 Hz to reach numbers of cycles in the very high cycle fatigue (VHCF) regime in an appropriate testing time. To ensure a safe and economic application of high-speed passenger-traffic wheels it is necessary to investigate the cyclic deformation and fatigue behaviour in the service-relevant area of the 'limiting-diameter', which must sustain loadings in the VHCF-regime [1,2]. The area of the 'limiting-diameter' is the minimum diameter of a monobloc wheel, which is usually 25–35 mm below the tread [3]. Due to the loading conditions (e.g. wear and brakings), polygonisation of the wheels is observed, which leads to a reduced wheel concentricity. During maintenance reprofiling is carried out to ensure optimal wheel roundness by turning until the actual wheel surface is in the range of the 'limiting-diameter'. Thus the 'limiting-diameter' has to sustain loadings in the VHCF-regime [4].

To examine the cyclic deformation behaviour high-precision measurement techniques using temperature [5–7] and electrical resistance data [6–9] were applied. Moreover it is possible to measure the frequency change of the resonance testing device during the fatigue test. The frequency change can be attributed to changes in the damping of the specimen as a consequence of micro-plastic deformation and therefore it is possible to investigate the cyclic deformation behaviour by frequency measurements. The mentioned measurement techniques can be used equally to examine the cyclic deformation behaviour. To enable a characterization of the microstructural changes during the fatigue experiments transmission electron microscopy (TEM) investigations have been carried out at defined fatigue states. Moreover the fracture surfaces have been investigated using light (LM) and scanning electron microscopy (SEM).

## 2. Materials

The investigated railway wheels are manufactured from the unalloyed medium carbon steels SAE 1050 and SAE 1060. The industrial heat-treatment for both steels consists of austenising, spraying a cooling liquid on the rim, the so-called 'rim chilling', and finally annealing. Specimens were machined in rolling direction from the rim of wheels 35 mm below the tread, corresponding to the 'limiting-diameter' or the so-called 'wear boundary'. The 'limiting-diameter' is the smallest diameter, which is allowed to be reached in service. In this area, the wheel has to sustain load cycles in the VHCF range.

Table 1 shows the chemical composition of the two railway wheel materials, which are in accordance with the limit values according to DIN EN 13262. Compared to the wheel steel SAE 1050 with a carbon- (C-) content of 0.49 wt.% the wheel steel SAE 1060 exhibits a slightly higher C-content of 0.58 wt.%.

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doi:10.1016/j.ijfatigue.2010.07.010

**Table 1**

| Elements wt.% | C | Si | Mn | Cr | Cu | Mo | Ni |
|---|---|---|---|---|---|---|---|
| SAE 1050 | 0.49 | 0.30 | 0.77 | 0.23 | 0.04 | 0.02 | 0.16 |
| SAE 1060 | 0.58 | 0.28 | 0.70 | 0.16 | 0.03 | 0.03 | 0.11 |

The initial state of the material in the area of the 'limiting-diameter' was investigated using LM and SEM. Scanning electron micrographs (Fig. 1) show the ferritic–pearlitic microstructure for the wheel steel SAE 1050 (a) and the wheel steel SAE 1060 (b). As expected the steel with the higher carbon content exhibits a lower ferrite content with an average value of 8.0 area%. Ferrite content for SAE 1050 amounts 10.2 area%. The heat treatment of both wheel steels is identical and the difference in the ferrite content can be ascribed to the higher carbon content of the steel SAE 1060.

## 3. Experimental procedure

Fig. 2 shows the experimental setup for fatigue tests with the electromechanical resonance device. Analysis of the cyclic deformation behaviour was realised by measurements of the change in temperature $\Delta T$, electrical resistance $\Delta R$ and frequency $\Delta f$. The measurement of the change in temperature $\Delta T$ was carried out by using three thermocouples which were fixed at the specimen surface; $T_1$ in the middle of the gauge length, and $T_2$ as well as $T_3$ at the transitions from the gauge length to the specimen shafts. The change in temperature $\Delta T$ is exclusively caused by cyclic plastic deformation of the material in the gauge length. The cross sectional area of the specimen shafts is significantly larger as in the gauge length and therefore they show only elastic deformations. The change in temperature $\Delta T$ was calculated according to Eq. (1) [10].

$$\Delta T = T_1 - 0.5 \cdot (T_2 + T_3) \quad (1)$$

The change in the electrical resistance $\Delta R$ was measured by wires which were attached to the transitions from the gauge length to the specimen shafts, and a highly constant direct current flow through the specimen was realised. The electrical resistance changes in a characteristic manner during cyclic loading due to microstructural changes in the bulk material. Besides changes in the specimen geometry the electrical resistance $\Delta R$ directly depends on changes in the specific electrical resistance $\rho^*$ of the wheel material. The $\Delta R$ measurement is very sensitive for deformation-induced changes in the microstructure, e.g. dislocation density and arrangement, as well as vacancies, pores and microcracks [11].

The change in the frequency $\Delta f$ of the electromechanical resonance device is another helpful component for the characterization of the fatigue behaviour. The specimen is part of the spring-mass-system of the testing machine. Therefore, changes in the damping behaviour of the specimens which are caused by cyclic softening

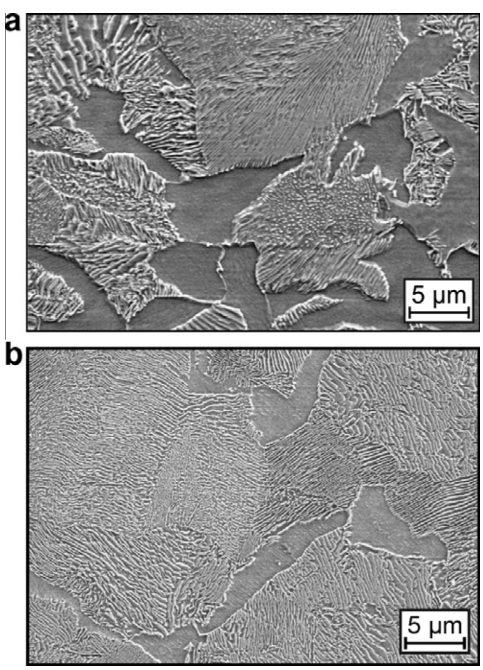


Fig. 1.

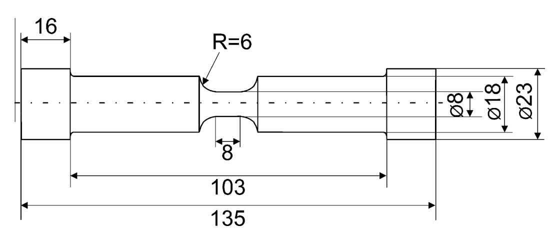


Fig. 3.

**Table 2**

| | $R_{eS}$ (MPa) | $R_m$ (MPa) | A (%) | Z (%) |
|---|---|---|---|---|
| SAE 1050 | 493 | 815 | 11.5 | 45.8 |
| SAE 1060 | 557 | 908 | 10.2 | 42.4 |

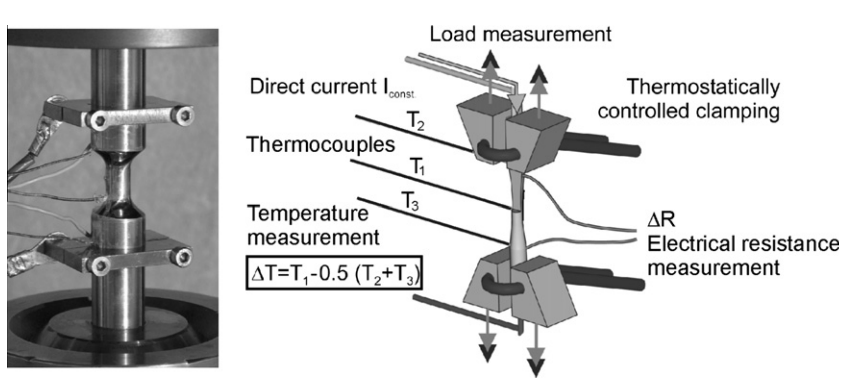


Fig. 2.