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Rail grade dependent damage behaviour – Characteristics and damage formation hypothesis

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ABSTRACT

This paper investigates the damage behaviour of several pearlitic rail steels with special focus on three specific damage mechanisms – wear, plastic flow and rolling contact fatigue (RCF, head checks in particular). Multiple tests were conducted on a full scale test-rig at voestalpine Schienen GmbH under dry contact conditions. The obtained results were compared with data from selected track tests. The test-rig is capable of producing realistic contact conditions that allow the formation of wear and RCF defects in very short time periods within 100,000 wheel passes. The test-rig results showed the improved wear and RCF resistance of high strength steels clearly. Additionally, a system wear analysis was conducted to outline the interaction of these high strength rail steels with a standard wheel steel. Although the trends are consistent on the rig and in track, the absolute values concerning wear and RCF differ due to some specific differences between track and test-rig conditions. Finally ideas are postulated that explain on one hand the test-rig specific wear behaviour of the rail grades and on the other hand the formation of periodic, rail grade dependent crack spacing of the defect type head checks.

1. Introduction

Since the early days of railway operations rail degradation caused by continuously increasing train frequencies and axle loads is one of the key motivations for rail grade development. The main rail degradation mechanisms can take the form of plastic flow, wear and/or RCF defects which manifest most commonly in the form of head checks and Squats [1,2]. This paper focuses on wear, plastic flow and head checks with emphasis on rail grade dependent formation of these damage types.

The degradation behaviour of five different pearlitic rail grades according to the European specification EN 13674-1:2011 [3] was analysed. The R260 grade represents the standard naturally cooled rail grade which is widely used for all kinds railway applications. This grade is also used as the reference grade for all tests reported in this paper. The grade R350HT is a fine pearlitic heat treated grade with increased wear and RCF resistance. This significantly better track performance led to a European wide recommendation for the use of R350HT rails in curves up to 5000 m [4]. The highest rail degradation rates can be found in the heavy haul environment with axle loads up to 40 t. The hypereutectoid high strength rail grade R400HT represents the current state of the art rail steel with highest wear and RCF resistance, developed to meet the requirements of high damage heavy haul environments. Track tests with this grade in mixed traffic lines with axle loads even below 30 t proved benefits in track performance compared to other heat treated rail steels. Thus, several European infrastructure owners started using this rail grade in high damage mixed traffic conditions [5].

2. Test environment

Experimental work was carried out on a full scale rail wheel test-rig at voestalpine Schienen GmbH (Fig. 1).

As a detailed technical description of the test-rig has been given previously [6–8], only the key characteristics are listed here. The test-rig is capable of simulating real rail-wheel contact conditions to provide an environment that allows the formation of wear and RCF within very short time periods of 3–5 days of testing, which equals to 100,000 wheel passes.

Each test was started with a new rail (60E1) and a new wheel (UIC ORE S1002) profile. The wheel grade was the same for all tests (R7 according to EN 13262:2004 [9]). The mechanical properties of of the tested rail and wheel grades are listed in Tables 1 and 2.

Test parameters used in these tests had been identified in the previous work [6] and were kept constant to provide comparable conditions for all tests:

- Vertical load: 23 t.
- Lateral load: 4 t.

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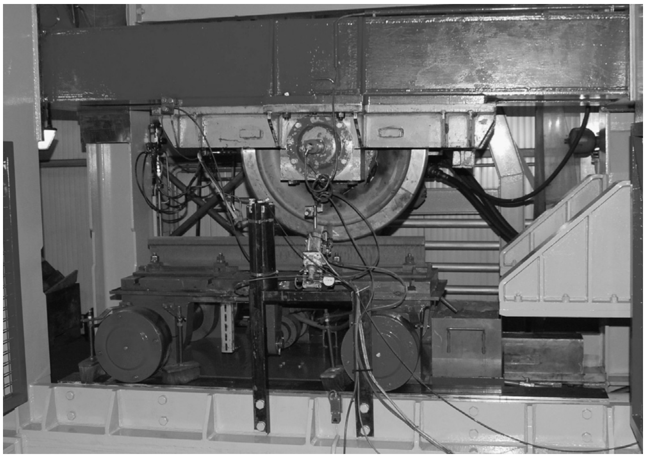

Fig. 1. Full scale rail wheel test-rig at voestalpine Schienen GmbH, Austria capable of producing realistic rail-wheel contact conditions.

Table 1
Rail grades properties.

Grade	$R_{m,\ min}$ [MPa]	$A_{5,\ min}$ [%]	Hardness [BHN]
R260	880	10	260–300
R350HT	1175	9	350–390
R350LHT	1175	9	350–390
R370CrHT	1280	9	370–410
R400HT	1280	8	400–440

Rail grades properties of tested rails according to EN13674-1:2011 [3].

- No rail cant or angle of attack between wheel and rail – forced lateral contact by lateral load.
- Friction conditions: dry ($\mu \approx 0.5$–0.6).
- Uni-directional loading: the rail was loaded only in one direction and he wheel was lifted from the wheel during the return movement.

3. Examination procedures

3.1. Wear

Wear was measured with a MiniProf Rail instrument at predefined intervals on three positions on the rail and on two positions on the wheel. The standard W1, W2 and W3 wear parameters of rails were determined with respect to the actual profiles measured before starting of each test (Fig. 2).

As this method only provides a selective wear impression, the area loss of wheel and rail profile in the contact area was calculated as well. A special MS Excel macro was programmed that used exported profile data from the MiniProf software to determine the parameters "contact width" [mm] and area loss [mm^2].

3.2. Plastic deformation

The freely available image analysis software ImageJ 1.44p [10] was used to determine the depth of plastic deformation on etched transversal micrograph images. As already presented in [7], special filters were applied to the images to visualise the degree of deformation and to measure the depth of deformation (see Fig. 3).

3.3. Crack analysis

The extensive crack analysis included two examination parts. Magnetic particle inspection photos were used to analyse crack spacing on the rail surface by using the image analysis software. Additionally, a detailed crack analysis of the crack pattern in a 20 mm window was conducted for all rail grades. The second part of the examination focused on the analysis of crack depths on a longitudinal micrograph according to the ERRI procedure [11], as shown in Fig. 4.

Table 2
Wheel grade properties.

R_{eh} [MPa]	R_m [MPa]	A_5 [%]	Hardness [BHN]
≥ 520	820/940	14	235

Mechanical data of test-rig wheel grade ER7 according to EN13262:2004 [9].

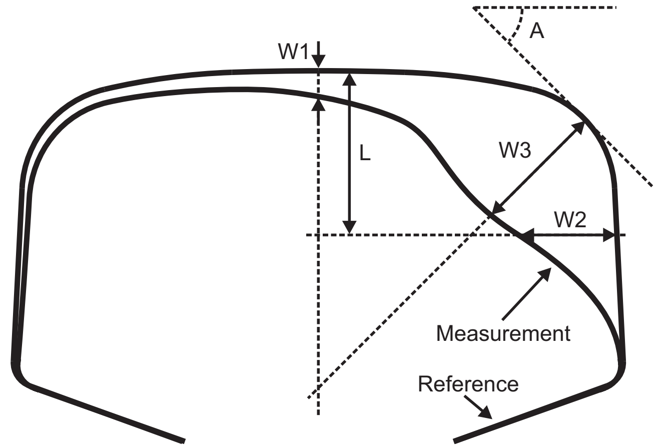

Fig. 2. Definition of standard W1, W2 and W3 calculations. Tangent angle "*A*" typically set to 45°.

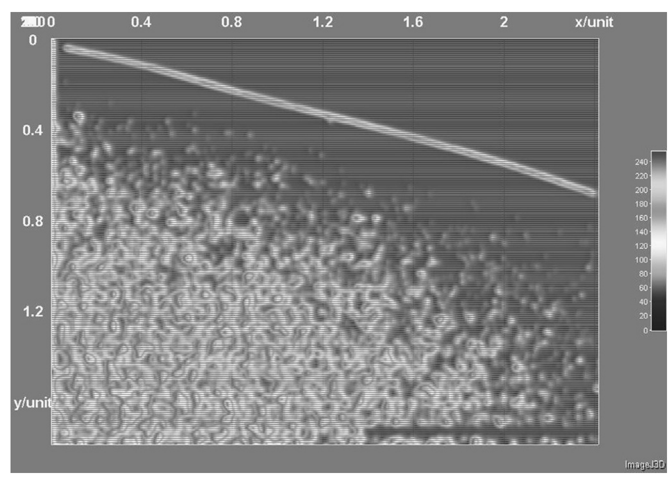

Fig. 3. Image analysis example, determination of deformation depth with the help of the Software Image J 1.44p. X-axis and y-axis units in [mm].

4. Test-rig results

4.1. Wear analysis

Fig. 5 shows the results of a W3 examination with varying tangent angles A (9.9°, 35°, 45° and 70°) for the rail grade R260 (see Fig. 2 for explanation of tangent angle *A*).

Dependent on the location on the rail surface, the wear pattern can be quite diverging. As this does not give a clear indication of the wear resistance of a specific rail grade, an area loss calculation