Investigations of the Head Check Defects in Rails

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Abstract The article presents the method and results of computed tomography (CT) tests of head-check defects occurring commonly in operation. These are one of the most common defects in rails that can lead to rail rupture. Based on previously performed CT and microscopic observations, rail models with typical defects were created and ultrasound beam propagation simulation was performed to increase the detectability of such defects.

Keywords: Rail, Ultrasound Examination, Head Checking, FEM Analysis

Introduction

Squats and checks, as the most common rail defects in operating conditions, are a serious problem in many rail systems around the world. Despite the work related to the modernization of railway lines, they are the most frequent rail defects in the main Polish railroad tracks managed by PKP PLK. According to UIC 712 card [1] and PKP PLK – Catalog of Defects in Rails [2], these defects are defined as head check defect - type 2223; squat defect -type 227, respectively.

The Railway Research Institute together with PKP PLK conducts a research project implemented as part of the scientific and research project POiR (Intelligent Development Program), which aims to increase the detection of defects in rails, including head checking. In the first part of the tests, as part of the research work, samples of rails with defects were taken, followed by observations, measurements, ultrasound and microscopy. The tests were carried out on 40 rail sections. The next stage was the selection of various head-checks propagation course and their 3D observations using computed tomography [3]. CT tests allowed obtaining images and information about the defect propagation inside the rail, defect size, depth, etc. The article presents the obtained examples of head-checks observed during the tests. Based on the information provided, the 3D models were created and FEM calculations were performed to compare the same mathematical model considering material properties, rail geometry, load, support for a rail with no defects and with head-check defects. The head-check defect was modeled based on previously obtained data from CT tests and observations and measurements performed with light microscopy.

What is a squat? Squats occur in several different forms and their precise definition is still the subject of some debate. All varieties, however, share some common features. They are characterized by cracking which initiates on the rail surface and grows down to a point about 3-6mm below the surface. The cracking then spreads along and across the rail, without growing substantially deeper. The rail surface becomes depressed and a dark patch appears due to a reduced contact from train wheels. Eventually the rail surface may spall out. Figure 1 illustrates some areas of multiple squats commonly termed “squatty” rail.

The head checking defect (H-C) most often appears on the inner edge of the head of the outer rail, arranged in arches. It arises in places where the largest dynamic impact occurs (centrifugal force). It also appears on the lateral edges of railways in a straight track and at crossovers. It looks like small, parallel gaps with varying intervals. The distance between the gaps varies depending on local conditions and the type of steel the rail is made of, ranging from 1 mm to several cm. Defects of this type are difficult to detect, due to the promotion of them, among others, in areas a few millimeters below the rolling surface. The short distance of the ultrasonic wave through the material and the weak reflections make detection of this type of defects difficult [4].

Fig. 1 Headchecking - rail under operating conditions

Microscopic observations of defects in the rail head were made on a KEYENCE VHX - 900F digital microscope. Examples of headchecking defects in the rail head are shown in Fig. 1 and Fig. 2.

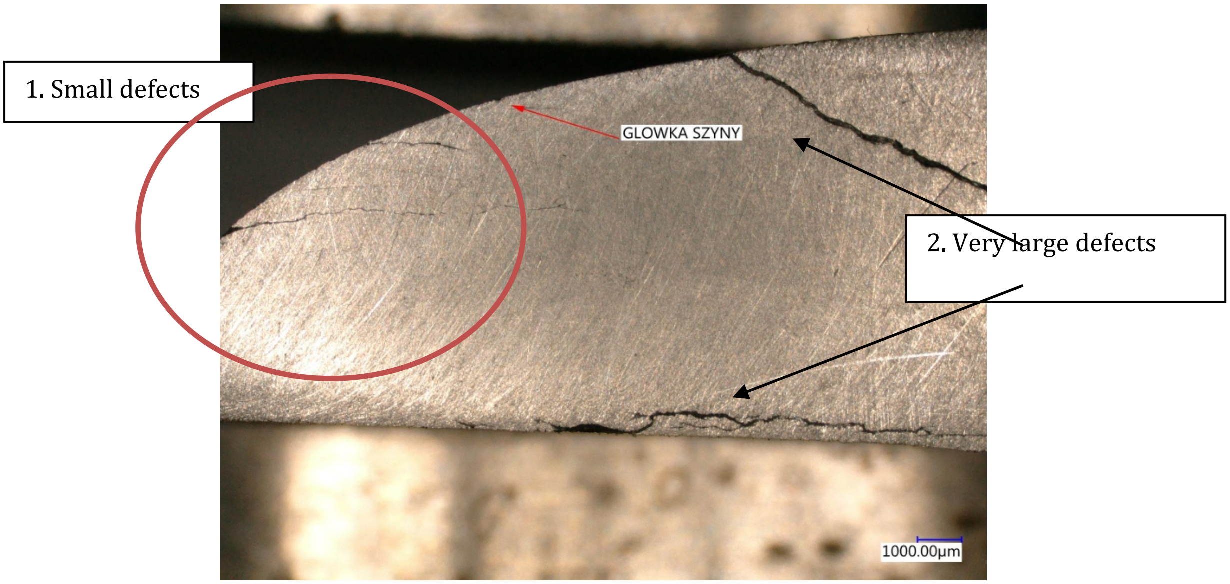

Fig. 2 Head checking occurring in the rail head - cross section (microscopic observations).

Observations and measurements in a plane perpendicular to the rail cross section presented in Fig. 2, shows two cracks reaching up 10 mm, as well as four smaller ones in the surface zone of approx. 3 to 5. These photographs highlight how dangerous this type of defect is, because the complex crack net with significant propagation may lead to material decohesion in a short time.

Fig. 3 Head checking defects occurring in the rail head - cross-section (top) - destruction zone under the surface of the rolling zone approx. 2 mm (microscopic observations) - (bottom).

Computed tomography tests

CT examinations were performed on GEphoenix v/tome/x m tomograph with a panel detector using a 300 kV X-ray tube. The examples of spatial images of propagation of head checking defects are presented below.

Fig. 4. Visualization of the sample in the editor "myVGL"

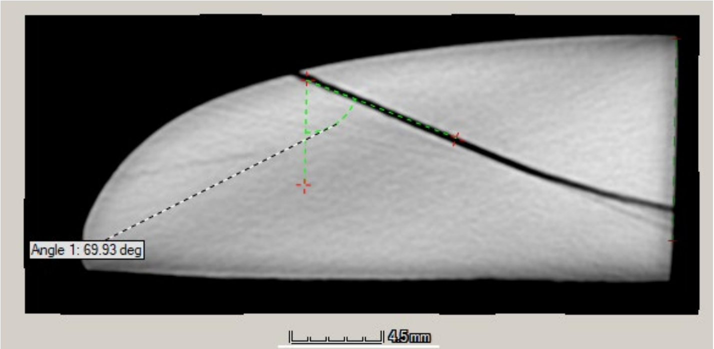

Fig. 5. Visualization of the method of measuring the defect penetration angle.

Based on the CT observation, the dimensions of the head-check defect on the surface and the depth of their retention were assessed. These quantities were characterized on the graph – Fig. 6.

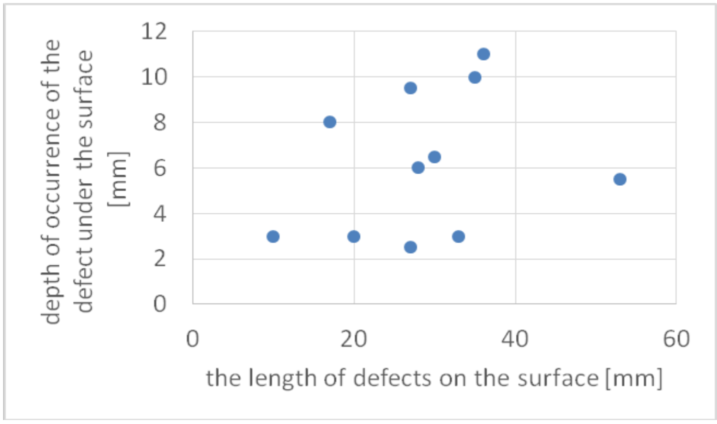

Fig. 6. Relationship between the depth of the crack and its length on the surface [own source]

FEM Analysis

On the basis of previously performed CT examinations and microscopic observations, examples of defect models in the 60E1 profile rail were created. Simulations of the propagation of ultrasonic waves in the rail material were made in the Altair Hyperworks program with Solver Optistruct [5]. Examplary simulations are shown below in Fig. 7 and Fig. 8.

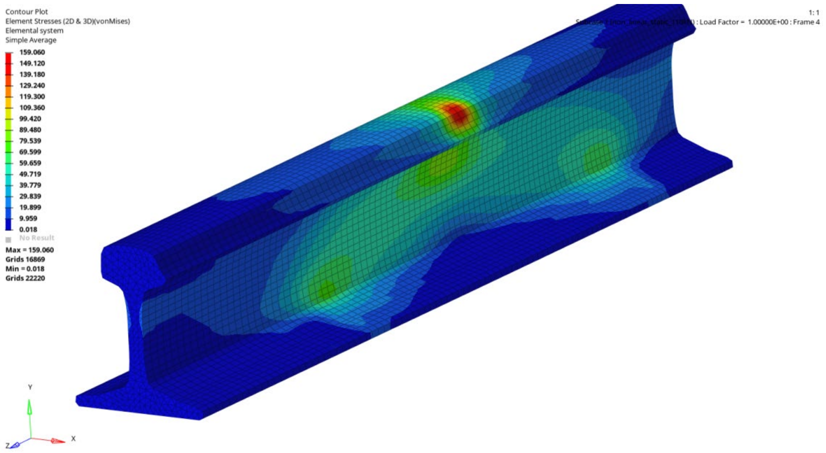

Fig. 7 Distribution von Mises stresses in rail 60E1 rail without defects.

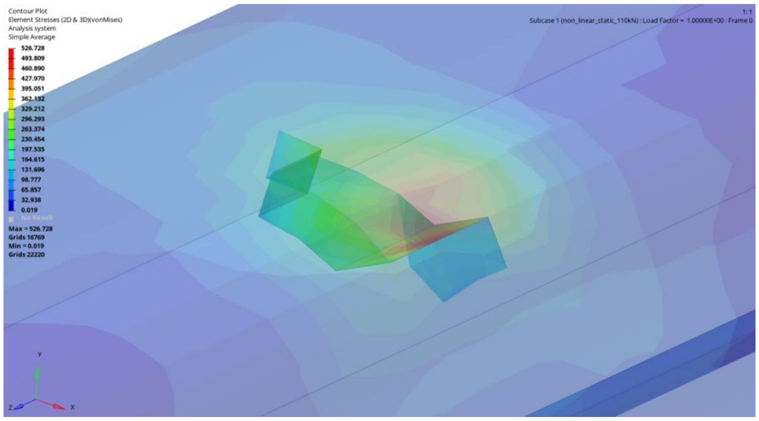

Fig. 8 View of the 60E1 rail with modeled head-check defects (see transparency view).

Conclusion

FEM analysis showed that for the same simulation assumptions, both without and after the introduction of a specific head-check defect, there is a significant increase in plastic deformation in the defect area, and thus a significant increase in stress. These calculations indicate that any contact of a freight wagon wheel (with a load close to the permissible load) causes crack propagation.

The presented photographic documentation and analysis of the results of headcheck defects show that these defects are difficult to detect due to their nature - occurrence below the surface and in the area of the rolling part of the rail, and numerous millimeter cracks. In addition, the numerous cracks net can quickly lead to material decohesion under further operating conditions.

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