BROKEN WHEELS BY CRACKING OF WHEEL WEBS – A NUMERICAL STUDY ON COMBINED THERMAL AND MECHANICAL LOADING

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Introduction

This work presented is part of the UIC initiative "Brake Block Wheel interaction", which is the name of a sector project involving brake block manufacturers, entities in charge of maintenance of wagons, railway undertakings, UIC staff, universities, wagon keepers, wheel and brake blocks manufacturers. It was identified that additional work was required to investigate wheel failures in the form of cracks in webs of wheels that had previously been identified as an area with lack of knowledge in the Joint Network Secretariat "Broken wheels" in 2019. Mechanical loads from wheel–rail contact, see Figure 1, are today generally analyzed separately from tread brake heating, which has proved successful for the usual and established designs. This assumption is investigated in detail in the present paper, assessing fatigue in wheel webs when accounting for the simultaneous impact from elevated temperatures from tread braking and the mechanical loads stemming from the wheel–rail contact. Three wheel designs made from the freight wheel steel grade ER7, which is commonly used for tread braked wheels, are analyzed in detail. The first one is the design ZDB29 "with slope under the rim", which has a known propensity for circumferential cracking of the wheel web that is not present for the two other designs known as Sura Light and ORE.

Numerical modelling

The FE modelling in this study involves thermal and thermomechanical analyses in three steps implemented in the commercial FE code Abaqus. The sequence of steps are as follows: 1) Heat partitioning between brake block, wheel and rail is accounted for in an axisymmetric thermal analysis. 2) Extracted wheel heat flux and cooling fluxes are applied in 3D wheel thermal analysis, see FE mesh in Figure 2. 3) Calculated temperature histories and wheel–rail mechanical loads are employed in a 3D structural analysis. 4) Stresses and strains are extracted and fatigue is assessed. A recently developed viscoplastic material model for the ER7 material is employed, calibrated for temperatures up to 750 °C. The implementation incorporates a thermal damage function to model pearlite spheroidization and a radial hardness correction of the yield stress to mimic the actual hardness distribution that is present after manufacturing.

Results

Calculated maximum tread temperatures are first provided for the three studied wheel designs for brake power levels from 30 kW up to 70 kW, see Figure 3. Fatigue is assessed using high-cycle fatigue criteria by assessing Principal stress range and Crossland stresses and also assessed using low-cycle fatigue according to Coffin-Manson, calculation of fatigue parameter according to Jiang-Sehitoglu and evaluation of plastic ratchetting. For the Coffin-Manson relationship, it was chosen to also employ non-standard temperature dependent fatigue parameters, developed specifically for prediction of the fatigue life of metallic materials at elevated temperature.

Several fatigue criteria are assessed based on the a-priori knowledge from project JNS Broken Wheels that one of the studied wheel designs, the ZDB29 with slope under the rim, has a propensity for circumferential cracking that is not present for the two other wheels (Sura Light and ORE). The cracks have initiated in the web at a position near the wheel rim. Several of the investigated fatigue criteria predict a critical position with respect to the mechanical loading during braking that is consistent with a position near the rim, but only the Crossland criterion separates the known problematic wheel design from the other two wheels, see Figure 4.

Conclusions

The results of the combined calculation of mechanical and thermomechanical loads show that also the wheels with positive operating experience (Sura Light) exceed the current strength specifications for the Crossland criteria, so that a general application of the procedure described requires further investigation.

References

UIC B 169.1 / RP2, Sector Project "BB – Wheel interaction", WP1/Activity 1.2: "Wheel design worst-case scenario assessment" Activity report, UIC 2024

EN 13979-1: Railway applications - Wheelsets and bogies - Monobloc wheels - Technical approval procedure - Part 1: Forged and rolled wheels

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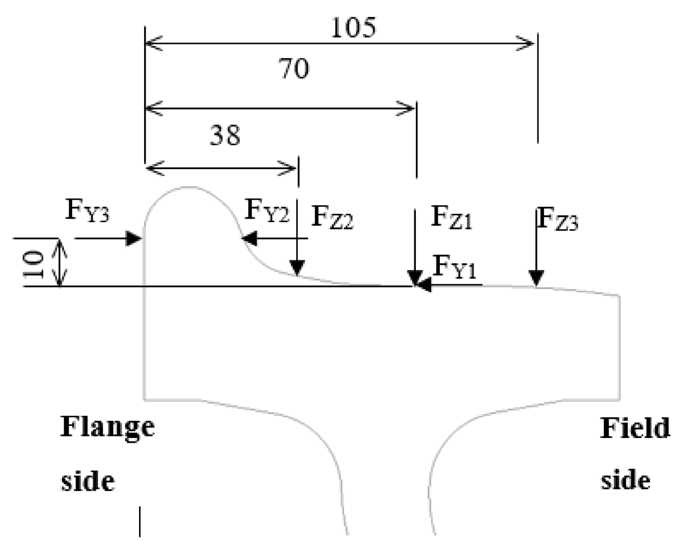

Figure 1. Mechanical Loads

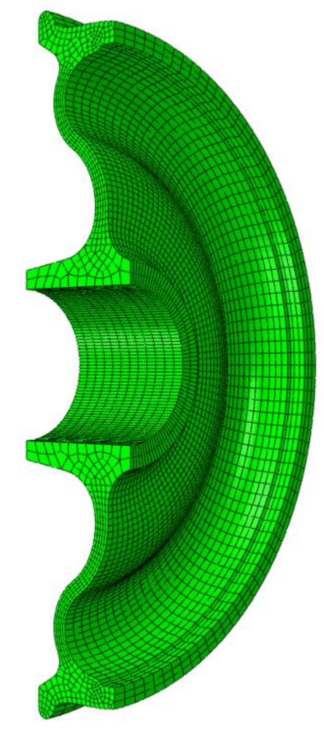

Figure 2. FE mesh

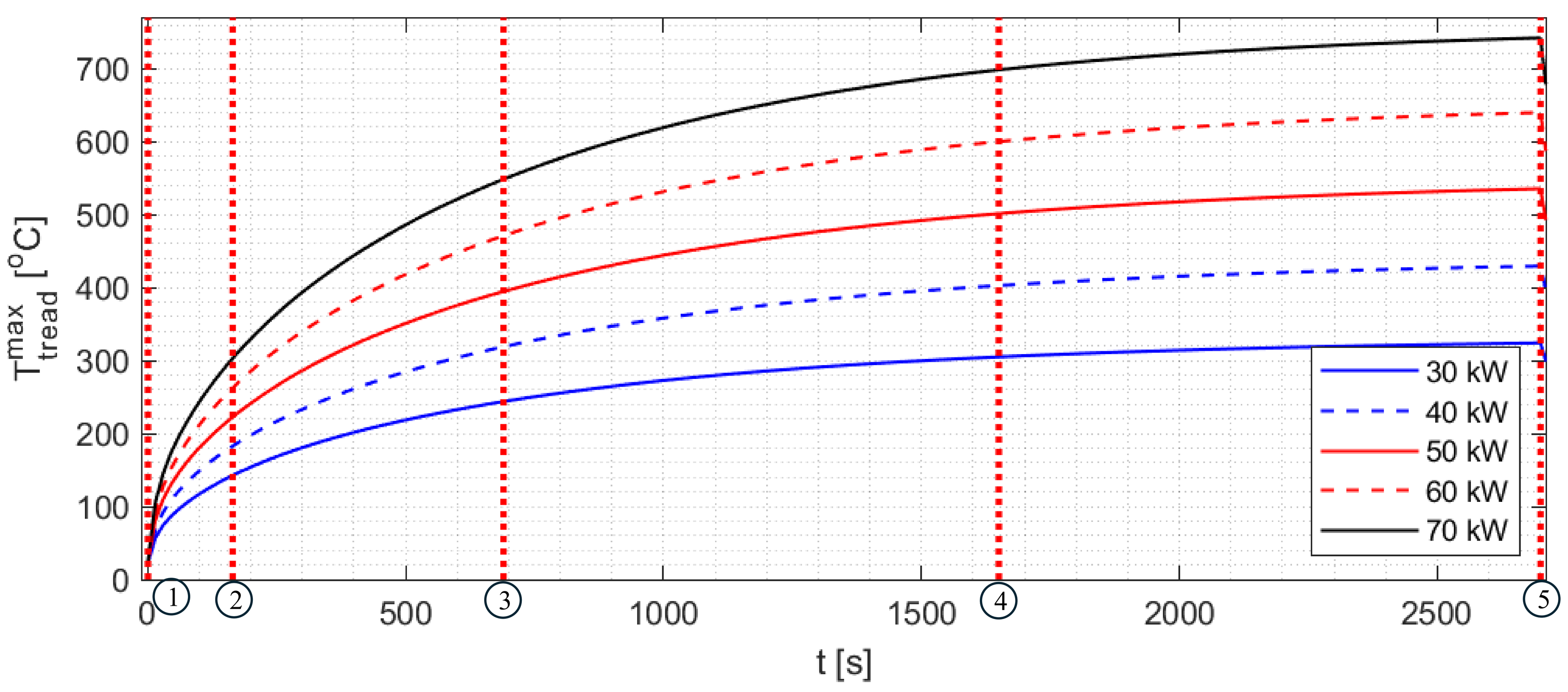

Figure 3: Maximum tread temperatures. Vertical red lines indicate instances when mechanical loads of Figure 1 are applied, see fatigue results below.

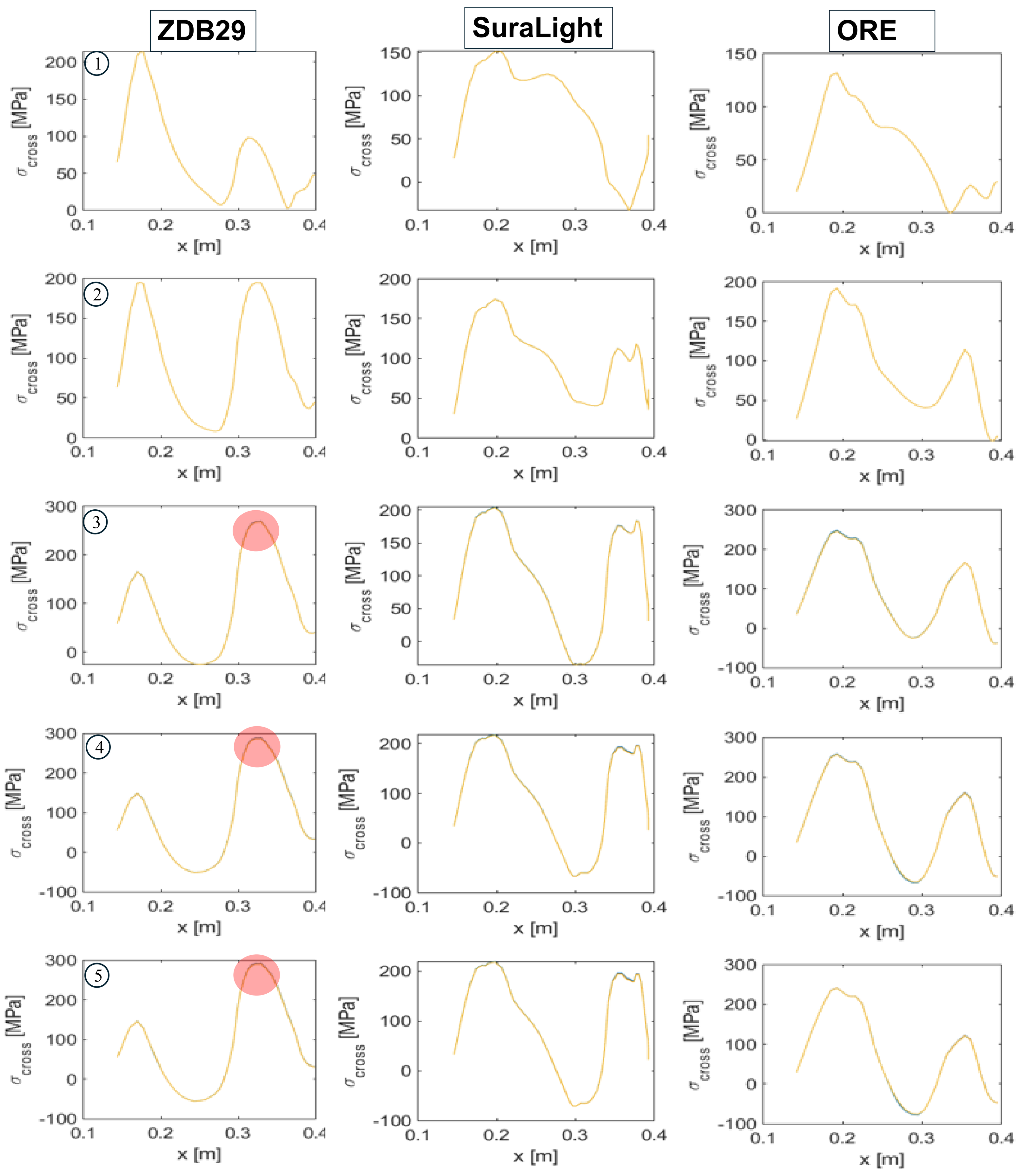

Figure 4: Crossland fatigue stress for field side of web as function of radial coordinate at brake power 50 kW during instances 1-5 of first brake cycle. Fatigue limit 220 MPa.

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