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THERMO-MECHANICAL FATIGUE OF RAILWAY WHEELS

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1 ABSTRACT

Wheel tread damage is one of the elusive phenomena that still limits the capacity of wheels from reaching desired mileage performance in the order of a million km. The tread material, in the block (tread) braked wheels, is subjected to high contact stresses induced by rolling and sliding of the wheel and also elevated temperatures due to frictional heat generation (between brake block–wheel and wheel–rail). The thermal loading results in the stresses induced by constrained thermal expansion. Moreover, the lowered strength of the material at the elevated temperatures has an impact on the resulting stress strain field in the tread.

Extensive studies have been carried out on rolling contact fatigue of treads but limited analyses have taken the temperature effects into account. However, recent efforts, regarding both simulation efforts [1,2] and experimental works [3,4], have enhanced the understanding of RCF damage during tread braking.

In the presented study, thermal cracking of railway wheel treads is investigated using a combined experimental and numerical approach. Experimental results are presented from controlled brake rig tests of repeated stop braking cycles of a railway wheel that is in rolling contact with a so-called railwheel. The test conditions are numerically analysed using finite element (FE) simulations that account for the thermomechanical loading of the wheel tread.

Three stop braking cases are experimentally studied. In two of the stop braking cases a sinter brake block is used, one more severe case (initial speed of 160 km/h) that is found to yield thermal cracks at the rolling circle after only some few cycles and one less severe case (initial speed of 130 km/h) that yields cracks after a larger number of stop cycles. In addition, stop braking tests are performed using an organic composite brake block (initial

speed of 160 km/h) and it is found that they give a longer time before cracking than for the cases with the sinter brake block.

In addition, for braking with sinter brake blocks, results from thermal imaging reveal a frictionally excited thermoelastic instability phenomenon called "banding" where the contact between the brake block and the wheel occurs only over a fraction of the block width. In such cases, the nominally uniform pressure distribution is unstable, giving localization of load and heat generation which results in local high temperatures. However, the banding is less pronounced when braking with organic composite brake blocks and the local temperatures on the tread are lower.

In the numerical simulations of brake rig tests, thermal banding is taken into account by employing three types of contact banding on the wheel tread, see e.g. Fig (1). A material model of viscoplasticity type, with a combination of nonlinear isotropic and kinematic hardening, is utilized at simulations. Basically, the nonlinear kinematic hardening has been tuned to fit the cyclic hardening of the material whereas the viscous behavior is determined from experiments with stress relaxation for prolonged time periods of constant compression.

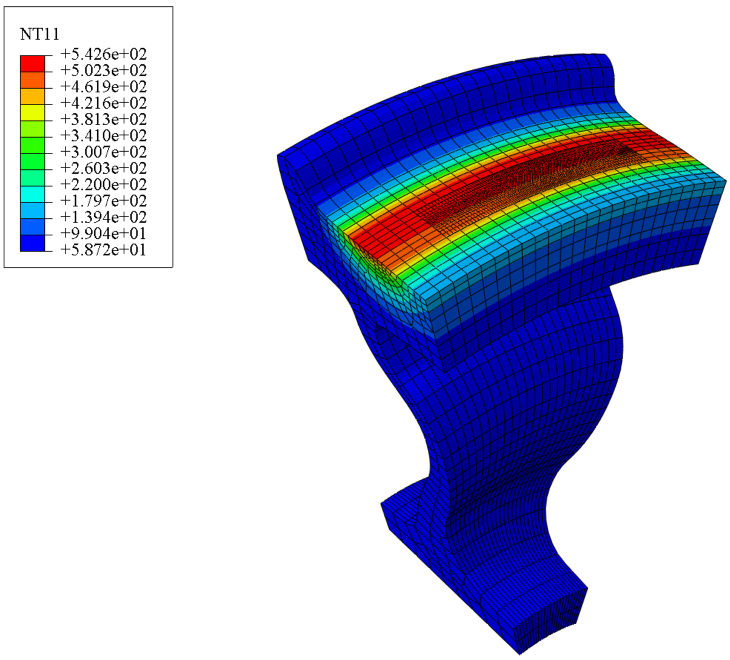

Figure 1: *An example of temperature distribution for the braking case with sinter brake block and initial speed of 160 km/h with 50 mm band width.*

Simulations of a stop braking cycles consisting of thermal and mechanical analyses are carried out in three steps:

1. Axisymmetric thermal analyses where the time dependent brake power is introduced

as a heat source.

2. The wheel-railwheel contact pressure distribution is numerically evaluated from indentation type of FE-analyses. A partial slip distribution for the tangential stresses at the wheel-rail is considered, using a model motivated by Carter's theory[5].

3. Wheel temperature histories, obtained in the first step, and the mechanical rolling contact stresses, obtained in the second step, are finally applied in 3D structural analyses.

Due to computational limits, it is not possible to simulate the entire thermomechanical braking cycle featuring hundreds of wheel revolutions. In order to still being able to study the combined effect of mechanical and thermal loading a simplified loading scheme is used. Mechanical loading is introduced at chosen time instances during the simulated braking cycle. During such instances the temperature is kept constant.

Resulting variations of stresses and strains in the material near-to the wheel tread are studied in detail for the assessed braking load cases. Fatigue life predictions are estimated from the evaluated ratcheting response using a simplified accumulation rule. The life time predictions are found to be in reasonable agreement with experimental results.

The presented work constitutes one step towards experimental validation of simulation models for studying RCF damage at tread braking. It is found that it is instrumental to perform combined experimental and numerical studies in order to reveal the key phenomena that ultimately will be part of controlling the service life of tread braked wheels.

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