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MODELING OF LARGE BIAXIAL STRAINS IN PEARLITIC RAIL STEELS

KNUT ANDREAS MEYER, MAGNUS EKH, JOHAN AHLSTRÖM AND JIM BROUZOULIS

Chalmers University of Technology
412 96 Gothenburg, Sweden
Web page: http://www.chalmers.se

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Summary. R260 pearlitic rail steel has been deformed to a shear strain of 2 in an axial torsion testing machine. This corresponds to a deformation 0.1 mm below the surface of rails in service. It is shown that the standard Chaboche model is unable to accurately predict the biaxial behavior. A model proposed by Bari and Hassan (2002) to improve multiaxial ratcheting is therefore implemented and compared with the experimental data.

1 INTRODUCTION

Large shear strains accumulate close to the running surface of rails during service. Used rails can have shear strains above 12 at the running surface. These shear strains decrease rapidly to less than 2 at 0.1 mm below the running surface [1]. Rolling contact fatigue (RCF) is closely related to the accumulation of plastic strains, and predicting this requires constitutive models that are accurate for both large strains and cyclic multiaxial loading.

Standard cyclic plasticity models, such as the Chaboche model and the Ohno Wang model have shown a deficiency in modeling the ratcheting response for biaxial loading [2]. A remedy for this was proposed by Bari and Hassan (2002), giving accurate prediction of tension/internal pressure ratcheting experiments.

It is difficult to achieve the large shear strains found in rails experimentally. High Pressure Torsion (HPT) is one method that can produce such large strains [3]. The high hydrostatic compressive stress in HPT allows for the large shear strains, but the complicated contact conditions make it difficult to model the process. Biaxial axial torsion testing of cylindrical specimens is an alternative to HPT experiments. The lack of radial confinement yields a lower hydrostatic compressive stress, and thereby also lowering the achievable shear strain. The advantage is a torque response that can be correlated to the material response without significant influence from the gripping contact conditions.

2 Experimental setup

Cylindrical specimens with a gauge diameter of 10 mm and gauge length of 20 mm, have been extracted from new R260 rail heads. The experiments were then conducted on a MTS Servo-hydraulic Axial Torsion test rig with load cells of 100 kN and 1100 Nm. Cross-talk between the load cells have been identified and compensated for. Local strain measurements could only be performed during the initial phase of the rotation, due to limitations in the torsional range of the extensometer. Actuator position sensors have therefore been used to measure the specimens' rotation and axial displacement. The machine stiffness has been taken into account to obtain actual specimen motions. The full load sequence used is given below:

1. Ramp axial load
2. Rotate from $-45°$ to $+45°$
3. Unload axial and torsional load
4. Release specimen and reset machine.
5. Go to 1 and continue until specimen failure

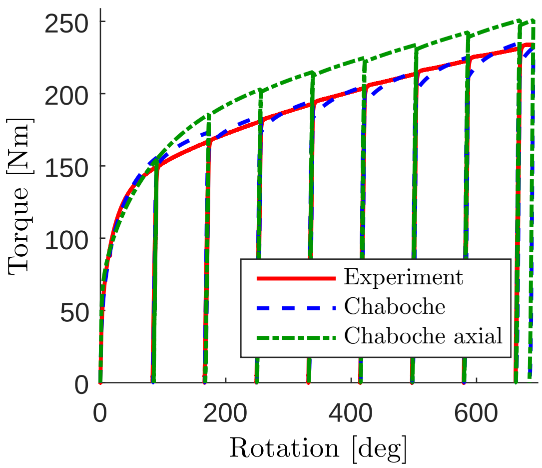
A weak material rate dependence has been identified, but for this study we have chosen to neglect this. The chosen rotation speed in the experiments was 90 °/min.

3 Simulation methodology

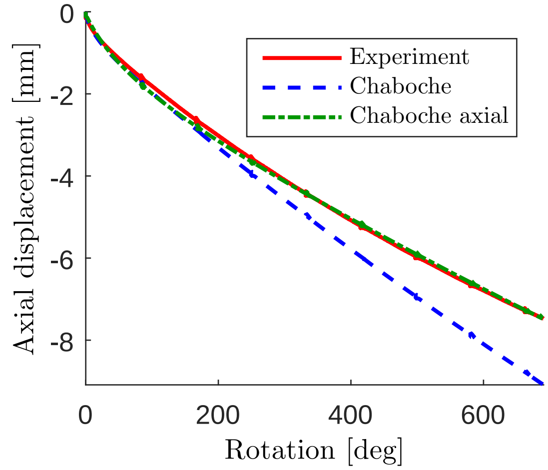
The performance of different material models are evaluated using the experimental data. To obtain the torque and axial displacements measured in the experiment, a finite element model of the specimen is analyzed. Utilizing symmetry, a model of half the specimen has been created using Abaqus' axisymmetric elements with twist (CGRAX8R). An Abaqus analysis is set up with the same load sequence as in the experiment. Using the Nelder-Mead Simplex optimization algorithm, the optimal set of material parameter values is searched for using 10 different starting guesses. The objective function is the weighted distance between the experiments and simulations of the torque and axial displacement during the rotation step (no. 2 in the load sequence).

A natural first choice of material model is the standard Chaboche model that is available in Abaqus. For simplicity a single backstress has been chosen, as the main purpose of this study is to evaluate the multiaxial behavior. Working from a thermodynamic framework, the next choice of model is a hyperelasto-plastic formulation of the Chaboche model [4]. It is implemented in a user material routine (UMAT) for Abaqus.

The third choice of model is based on the suggestion by Bari and Hassan [2], which consists of a combination of Armstrong-Frederick and Burlet-Cailletaud [5] kinematic hardening saturation. The Burlet-Cailletaud saturation gives an evolution of backstress



(a) Fit for torque response



(b) Fit for axial displacement

Figure 1: Chaboche model fits for nominal axial stress −500 MPa with objective function weight on torque response (blue dashed) or axial response (green dash-dot)

in the normal direction of the yield surface. The Armstrong-Frederick rule gives saturating evolution along the direction of the current backstress. These models coincide for uniaxial loading. The extension to the hyperelasto-plastic version of Bari and Hassan's model [6] has been implemented as an UMAT.

4 RESULTS

As expected, no clear advantage was found using a hyperelasto-plastic formulated Chaboche model, compared to the small-strain formulation, in terms of the multiaxial behavior. Therefore, only the results for the small strain formulated Chaboche model are presented in Figure 1. One result, which is shown in Figure 1, is that we can only find values for the material parameters enabling an accurate fit for either torque or axial displacement. It seems, however, much more difficult to predict both responses accurately with the same set of material parameter values. Motivated by this, the corresponding material parameter identification for the Bari and Hassan model will be conducted and results presented at the conference.

5 CONCLUSIONS

The two main conclusions from the work so far are:

1. The Chaboche model cannot accurately predict the biaxial axial torsion loading situation from the experiments

2. Large shear strains corresponding to 0.1 mm below the running band of rails can be achieved in the axial torsion test rig.

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