Plastic Deformation Behaviour of High Strength Rail Steels in Heavy Haul Railway Systems

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Motivations

- Plastic deformation accumulation under cyclic loading, i.e. ratcheting, plays a key role in causing rolling contact failure of rails;
- Demanding conditions imposed by rail transport with higher axle load and increasing annual haulage rate give rise to rail degradations.

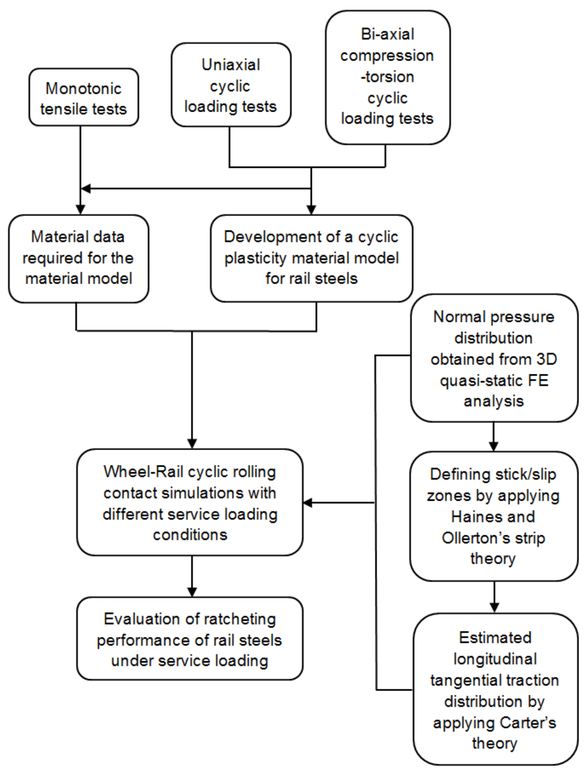
Project Objectives

1. To study the ratcheting behaviour of rail steels in laboratory conditions;
2. To develop a reliable cyclic constitutive plasticity material model for rail steels;
3. To evaluate the ratcheting performance of rail steels under practical cyclic rolling contact.

Methods and Materials

Three high strength pearlitic rail steels with different chemical composition in particular carbon level currently used in heavy haul railway operations in Australia were considered.

- Low alloy heat-treated grade (LAHT) with carbon content of 0.8%;
- Two hypereutectoid rail steel grades with carbon content of 1.0% (HE1) and carbon content of 0.85% (HE2), respectively.

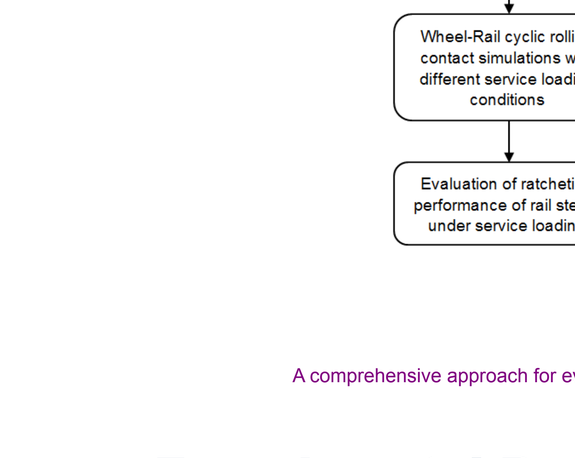


A comprehensive approach for evaluating ratcheting performance of rail steels.

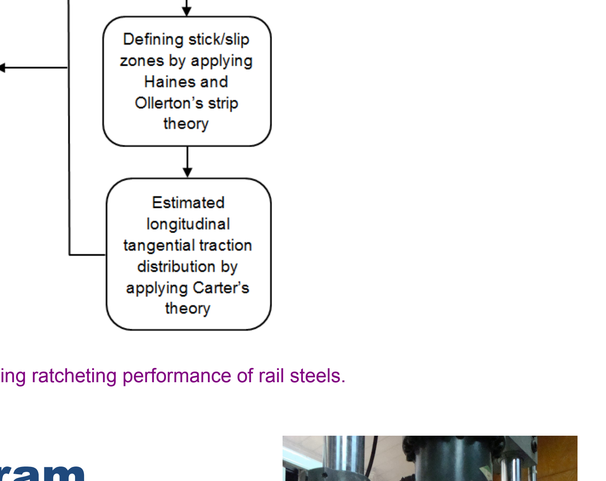
Experimental Program

1. Monotonic tensile test - to measure basic mechanical parameters;
2. Uni-axial cyclic loading tests - to investigate the uni-axial ratcheting behaviour;
3. Bi-axial compression-torsion cyclic loading tests - to investigate the bi-axial ratcheting behaviour.

MTS809-250kN machine.



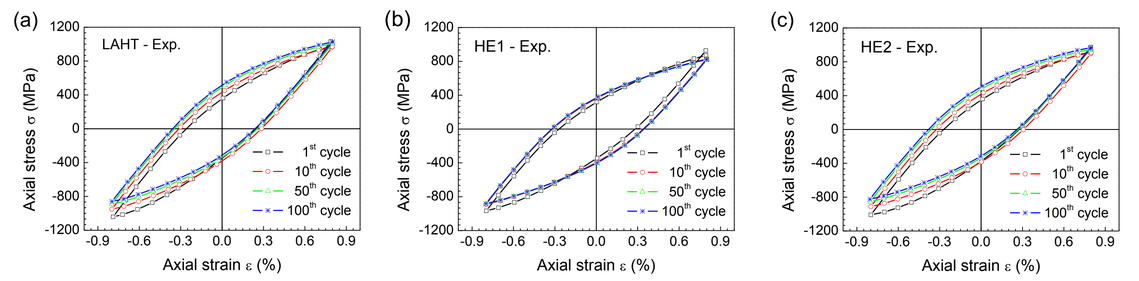
Specimen type 1: Solid specimens (GB/T 228.1-2010)



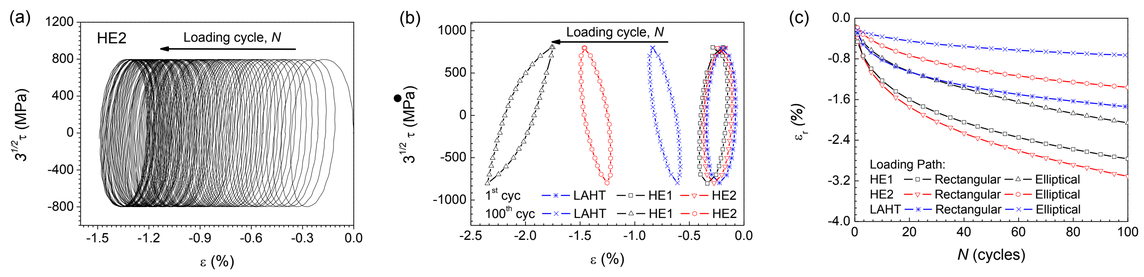
Specimen type 2: Thin-walled tubular specimens ((ASTM E2207-02)

Experimental Results

- Obvious cyclic softening occurred in all three rail steels under uni-axial strain cycling;
- All three rail steels behaved slightly different under tension and compression;
- Both ratcheting strain and ratcheting strain rate were strongly influenced by the non-proportional loading path.



Experimental results obtained from uni-axial strain cycling.



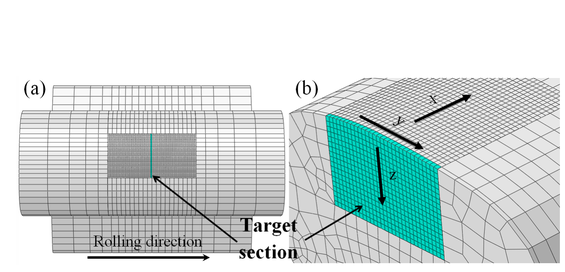
Experimental results obtained from bi-axial cyclic loading tests.

Cyclic Plasticity Material Model

- A cyclic constitutive plasticity material model, which can satisfactorily describe both uniaxial and biaxial ratcheting behaviour of rail steels, steels was developed;
- A non-proportional multi-axial parameter Φ was coupled into isotropic softening and kinematic hardening.

Evaluation of Ratcheting Performance

- The current study combined FEA , strip theory and Carter's theory to simulate wheel-rail cyclic rolling contact;
- Ratcheting performance of the rail steels was numerically evaluated by the crack initiation life;
- Crack initiation life of rail steels can be reasonably predicted from the comprehensive approach;
- HE2 steel provides the best ratcheting performance under higher axle loads such as those used in heavy haul railway operations.



Numerical model for wheel-rail cyclic rolling contact simulation.

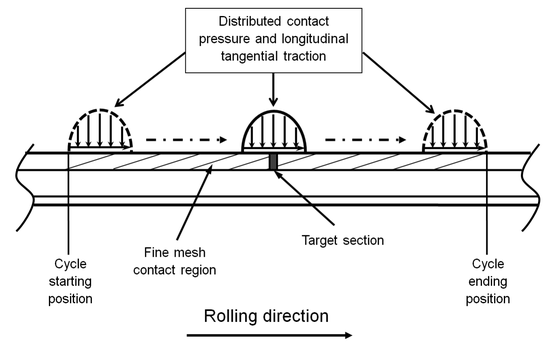
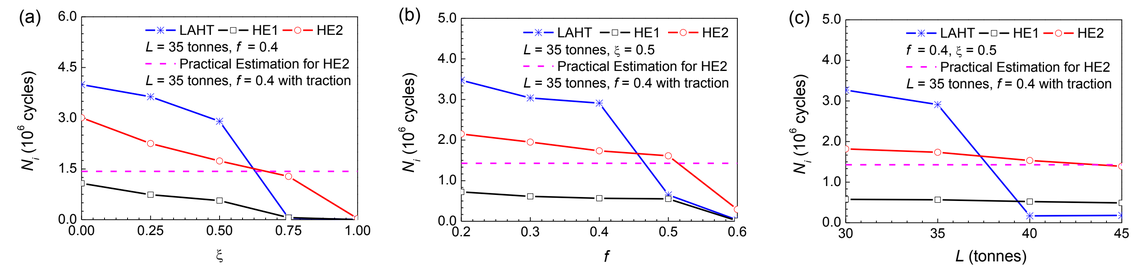


Illustration of moving contact load distributions on the rail surface



Performance of the rail steels under (a) different traction coefficient; (b) different friction coefficient; and (c) different axle load.

Achievements and Contributions

- Both uni-axial and bi-axial ratcheting behaviour of rail steels was investigated in a systematic experimental program;
- A cyclic constitutive plasticity material model for rail steels was developed;
- Plastic ratcheting in the rail head of rail steels under in-service rolling contact conditions was reasonably predicted by FEA;
- A comprehensive approach was developed to evaluate the ratcheting performance of rail steels under cyclic rolling contact in service;
- The outcomes can provide useful information to railway operator(s) for the selection and development of rail steels and the development of effective maintenance strategy for a specific track in practice.