THREE-DIMENSIONAL ELASTOPLASTIC ANALYSIS OF ROLLING CONTACT

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TRB Meeting, January 13, 2003

TALK OUTLINE

- SHAKEDOWN, RESIDUAL STRESS
- DEFORMATION STUDIES RELEVANT TO CONTACT
- BAINITIC AND PEARLITIC RAIL MATERIALS
- CONCLUSIONS

H. F. Moore's Book, p.224

Textbook of the

Materials of Engineering

By HERBERT F. MOORE, *Emeritus*
Research Professor of Engineering Materials
Engineering Experiment Station, University of Illinois
Member, American Society for Testing Materials

WITH A CHAPTER ON CONCRETE
BY HARRISON F. GONNERMAN

A CHAPTER ON CRYSTALLINE
STRUCTURE OF METALS
BY JASPER O. DRAFFIN

AND A CHAPTER ON PLASTICS
BY WILLIAM N. FINDLEY

SEVENTH EDITION

NEW YORK AND LONDON
MCGRAW-HILL BOOK COMPANY, INC.
1947

one side. It will be distorted and there will be set up residual stresses. Now, if the other side is similarly flame-treated, there will be residual stresses that will straighten the plate.

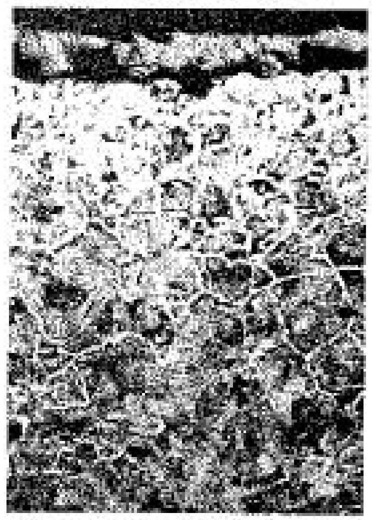


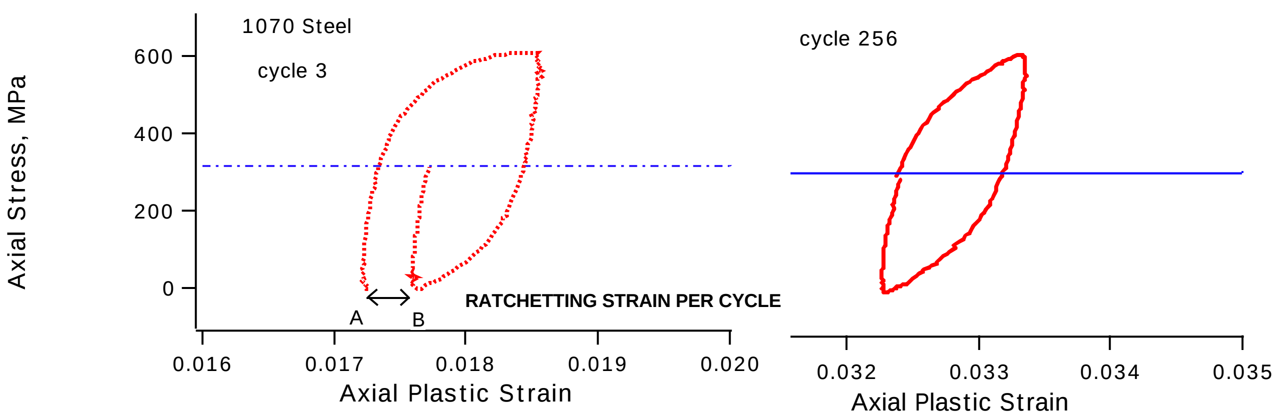
FIG. 73.—Longitudinal section of the head of a railroad rail, showing decarburized surface. The grains of ferrite in the surface zone of the rail head indicate that the steel has been changed from a steel with about 0.70 per cent of carbon to one with about 0.20 per cent carbon. Below the decarburized zone the steel is almost entirely pearlite. At the top of the micrograph can be seen particles of scale which were trapped in polishing. Magnification, 100 times. (Micrograph by N. E. Cramer.)

It will not be distorted, but it will have residual stresses both in the hardened zone on the upper side and in the hardened zone in the lower side, and a stress-relieving treatment is, in general, desirable.

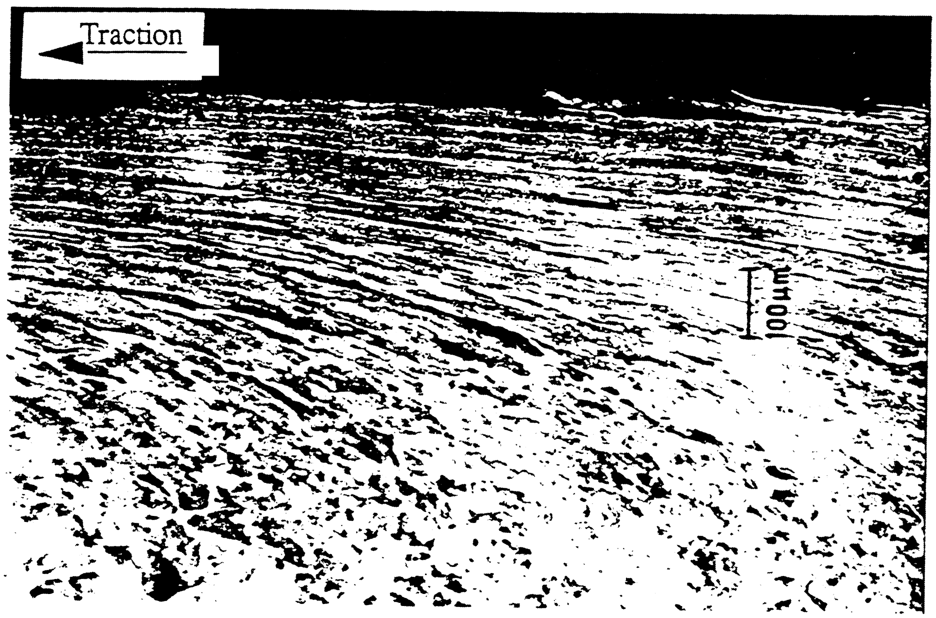
The flame-hardening process may be used to strengthen the metal at points of localized stress concentration. How-

Excessive Wear in Crossings

DEFINITION OF RATCHETTING : INCREMENT OF STRAIN PER CYCLE DUE NONCLOSURE OF THE HYSTERESIS LOOP



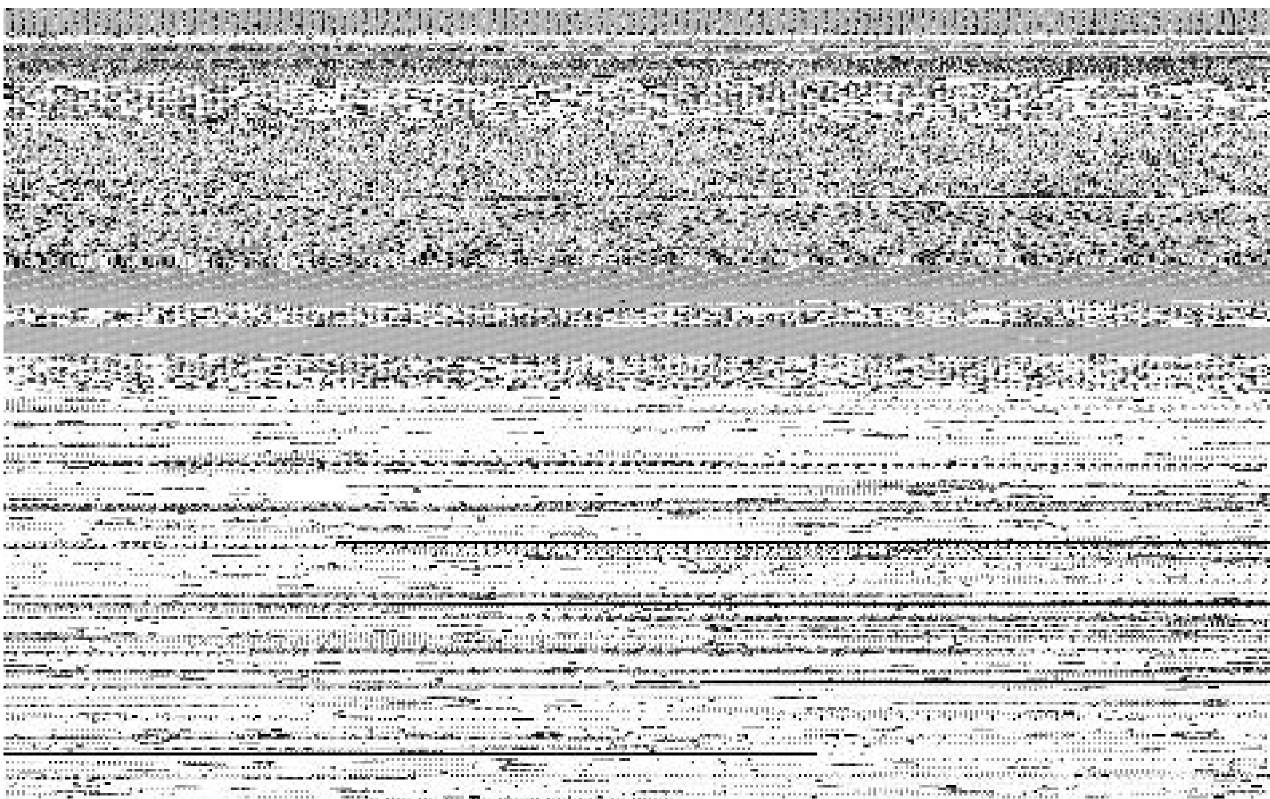
Significant Texture (Orientation) Develops in the Material Under Contact (Tyfour &Benyon)



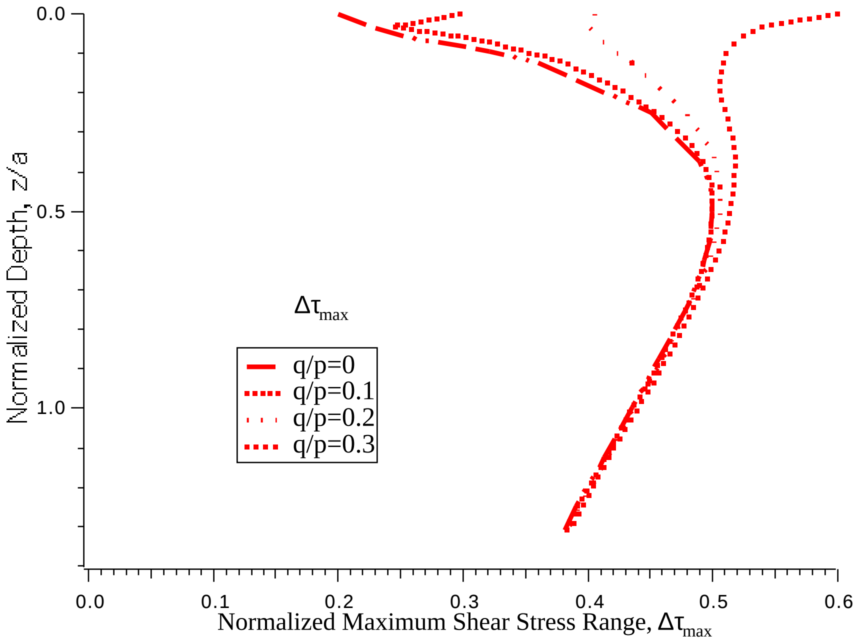
MOTIVATION

- To Model the Ratchetting Plastic Deformation Involved in Rolling Contact and Other Complex Multiaxial Nonproportional Loading
- Specific Emphasis on Long Term Ratchetting and Multiple Step Loading

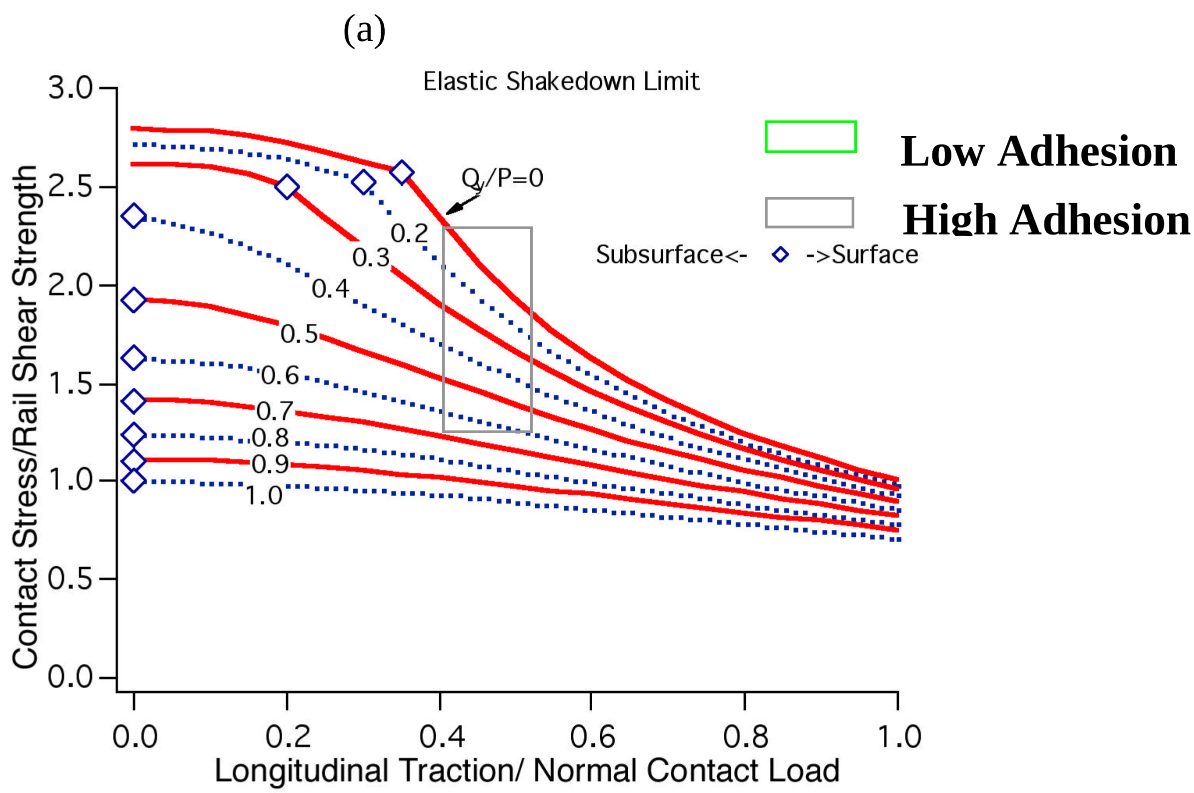
Contact Stress History in wheel -rail contact (Johnson, 1985)



Variation of Maximum Shear Stress with Increasing Tractions

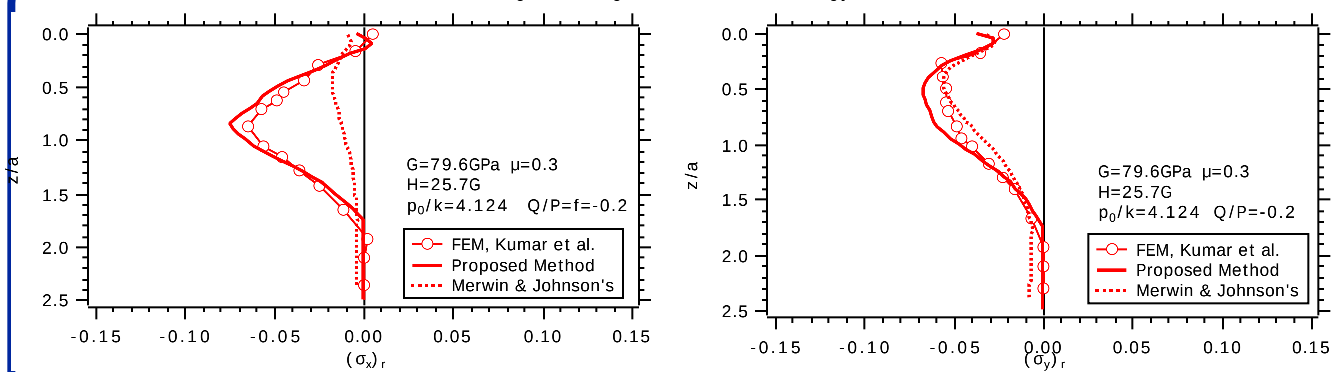


Operation Regimes in Railroad Locomotives

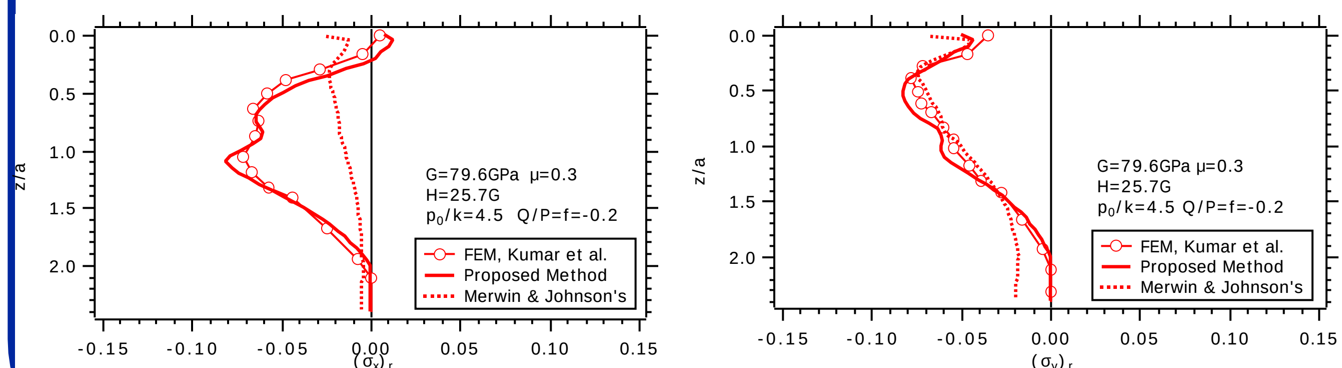


Residual Stress Profiles in Rolling Contact

Jiang, Sehitoglu, ASME J.Tribology, 116:3, 1994



(a) Case I: $p_0/k=4.124$ Q/P=-0.2



(b) Case II: $p_0/k=4.5$ Q/P=-0.2

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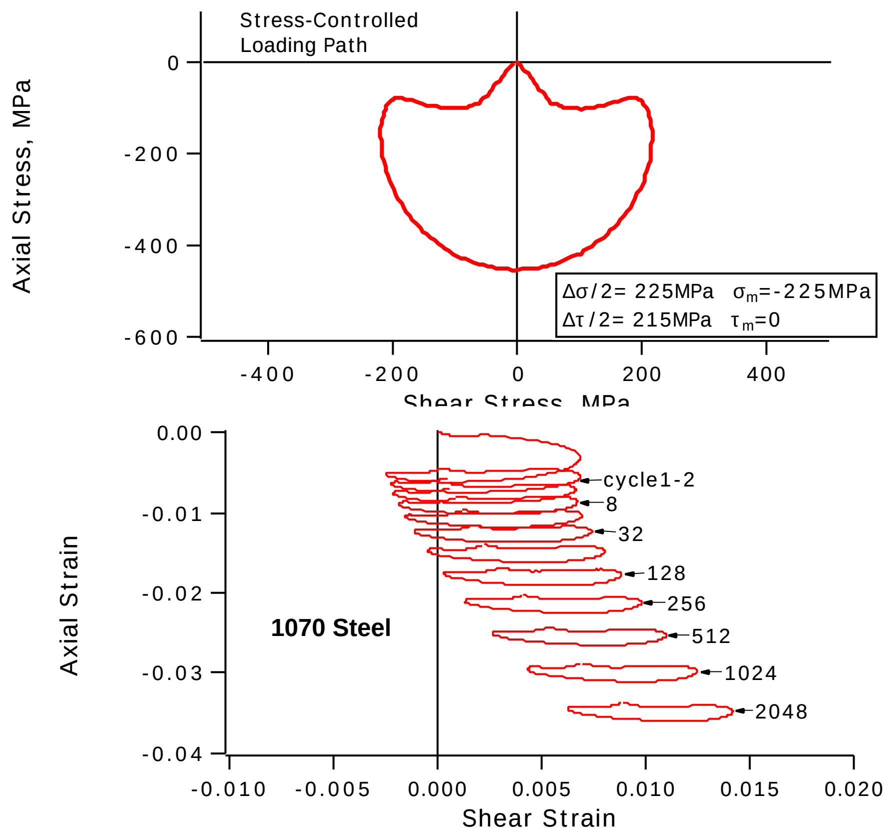
EXPERIMENTAL RATCHETTING FOR A NOPROPORTIONAL AXIAL-TORSIONAL LOADING PATH

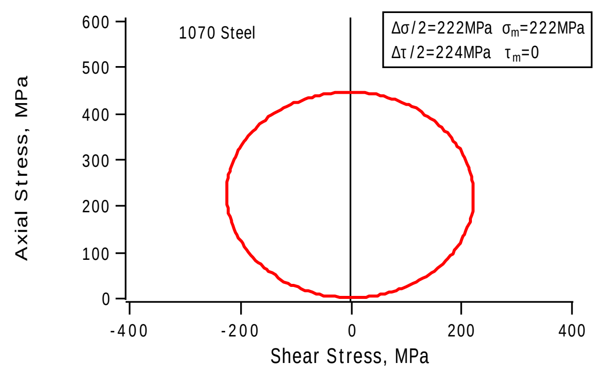
Jiang, Y. and H. Sehitoglu, *ASME JAM*, 63, 726_733, 1996.
Jiang, Y. and H. Sehitoglu, *ASME JAM*, 63, 720_725, 1996.

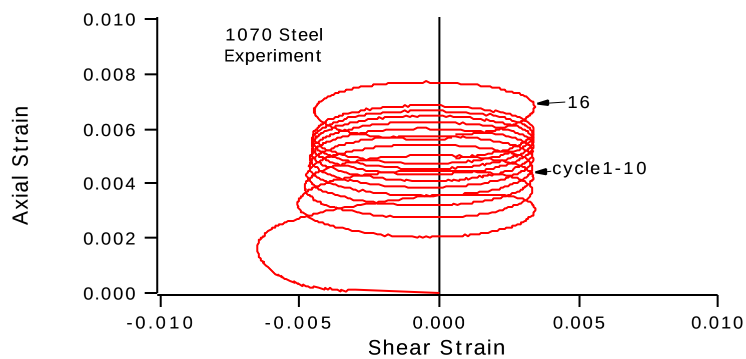


EXPERIMENTAL OBSERVATIONS

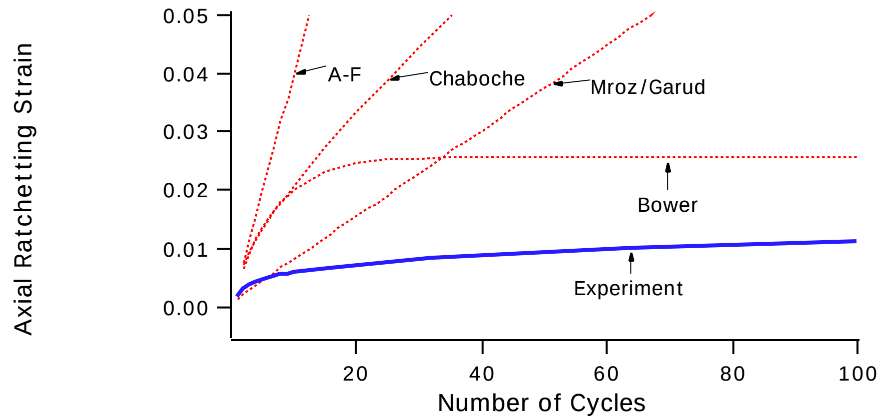
- **The ratchetting direction is coincident with the mean stress direction under single-step proportional loading.**
- **For 1070 Steel, the ratchetting rate decreases with increasing number of loading cycles for both proportional and nonproportional loadings.**
- **Under multiple-step loadings, the material exhibits a memory of the previous loading history.**

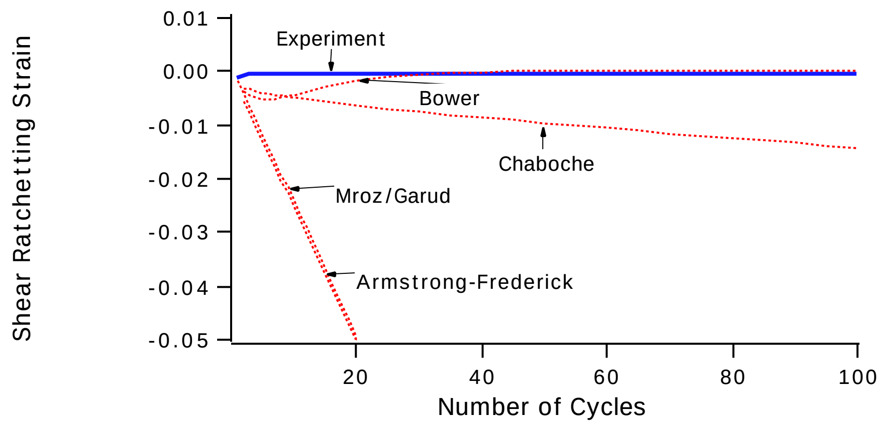
EXPERIMENTAL "ELLIPSE PATH"



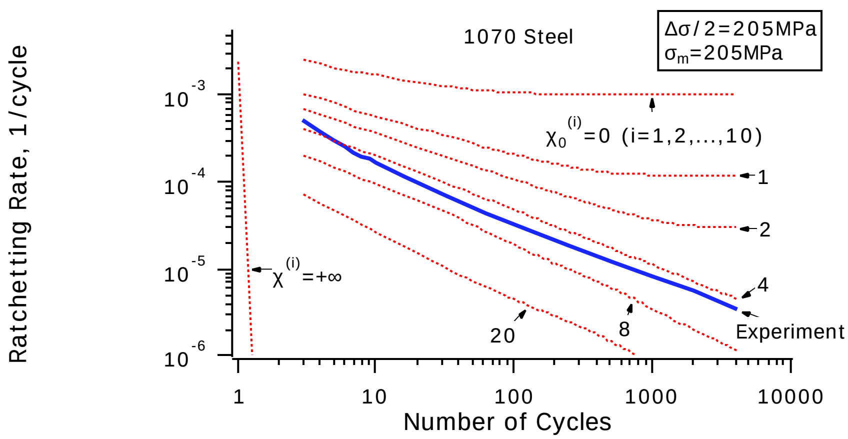


PREDICTION OF THE “ELLIPSE” PATH

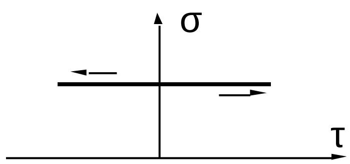


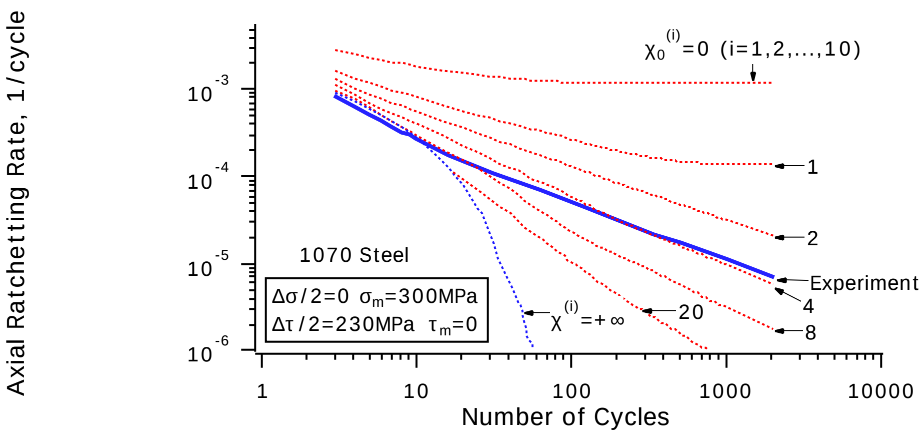


CAPABILITY OF PROPOSED MODEL IN UNIAXIAL LOADING



CAPABILITY OF PROPOSED MODEL IN NONPROPORTIONAL LOADING





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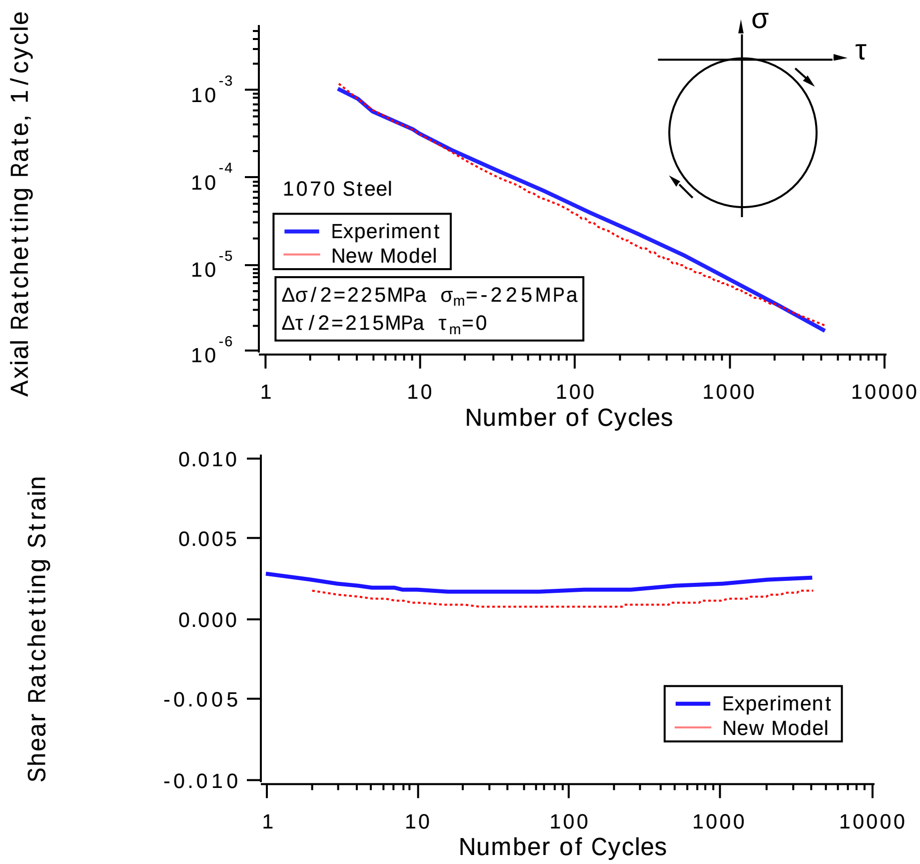
CAPABILITY OF PROPOSED MODEL IN NONPROPORTIONAL LOADING



Deformed Meshes x-z Plane

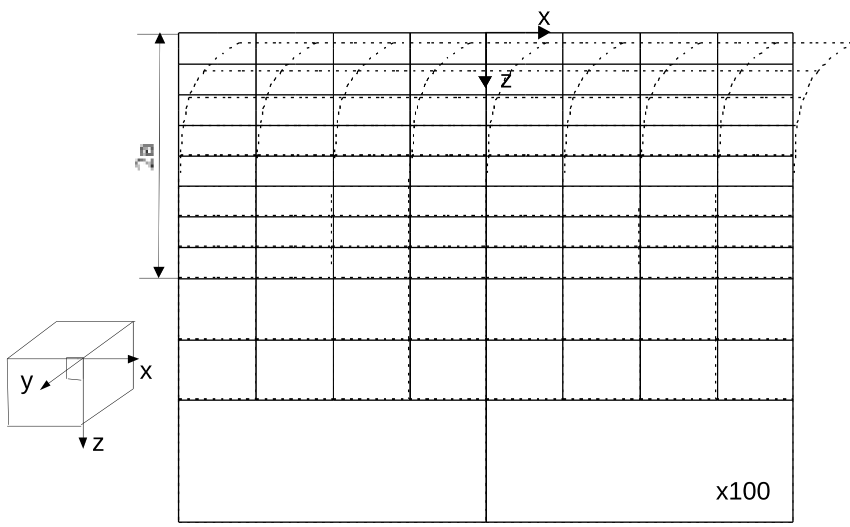
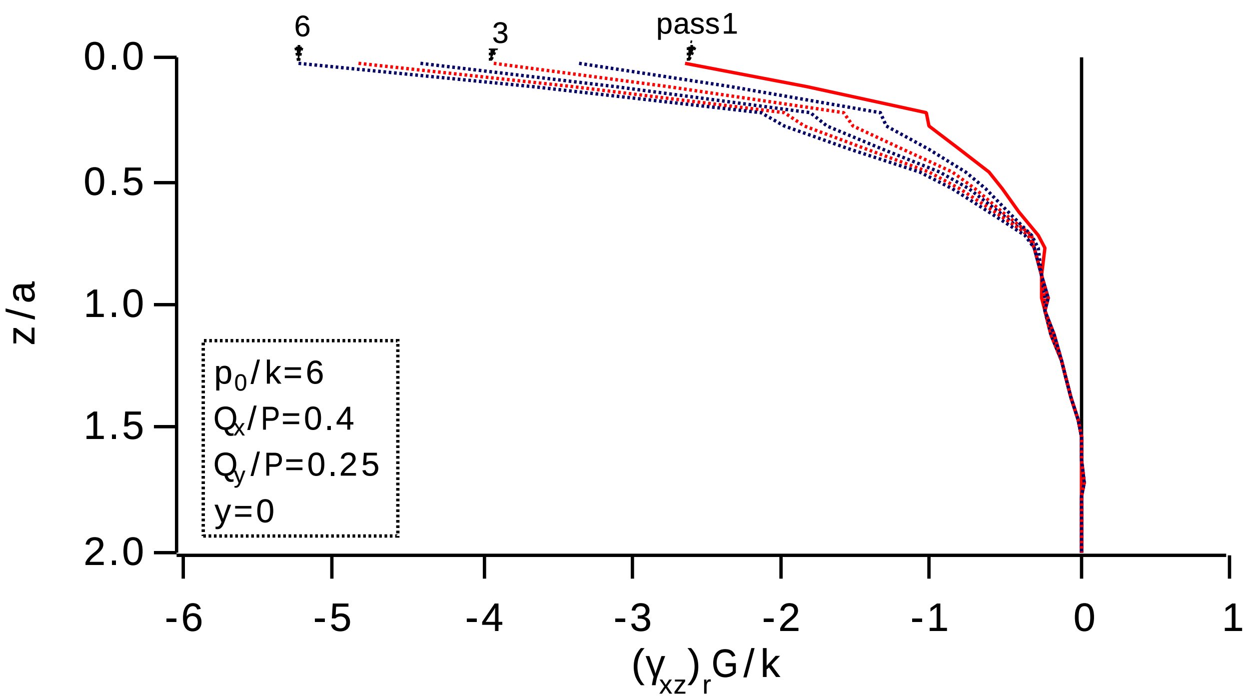
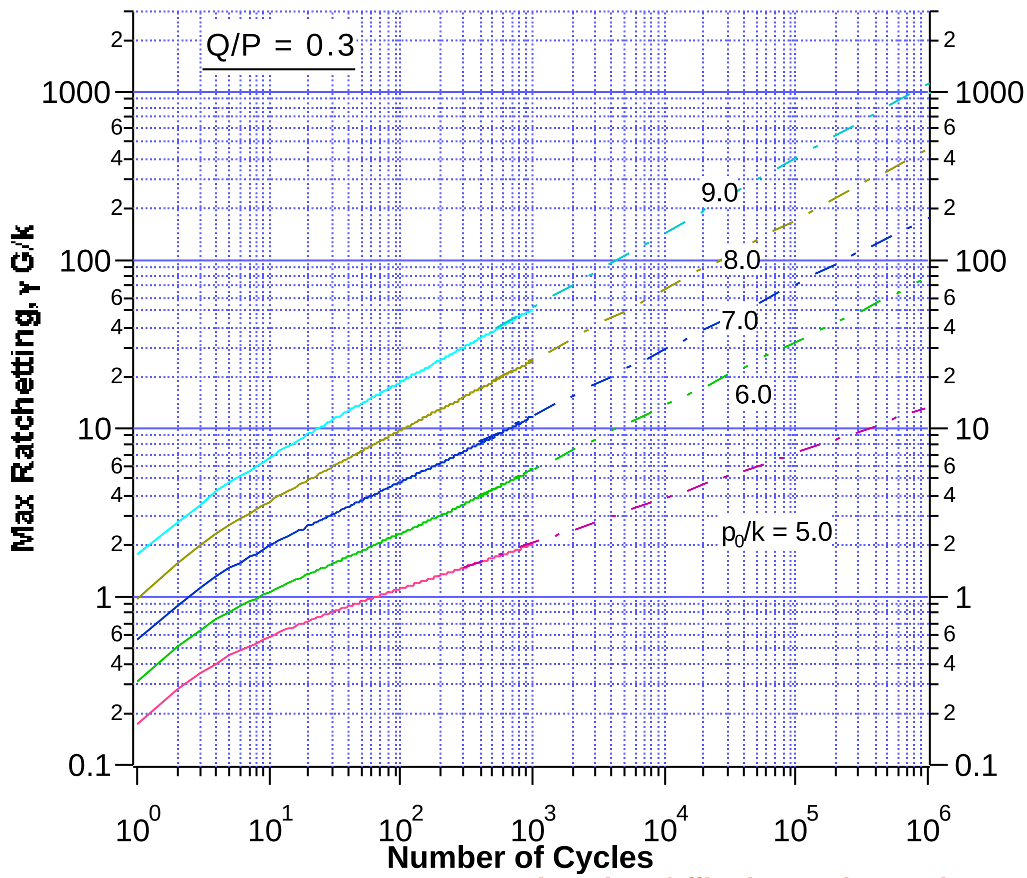


Figure 14(b) Deformed Mesh: x-z Plane

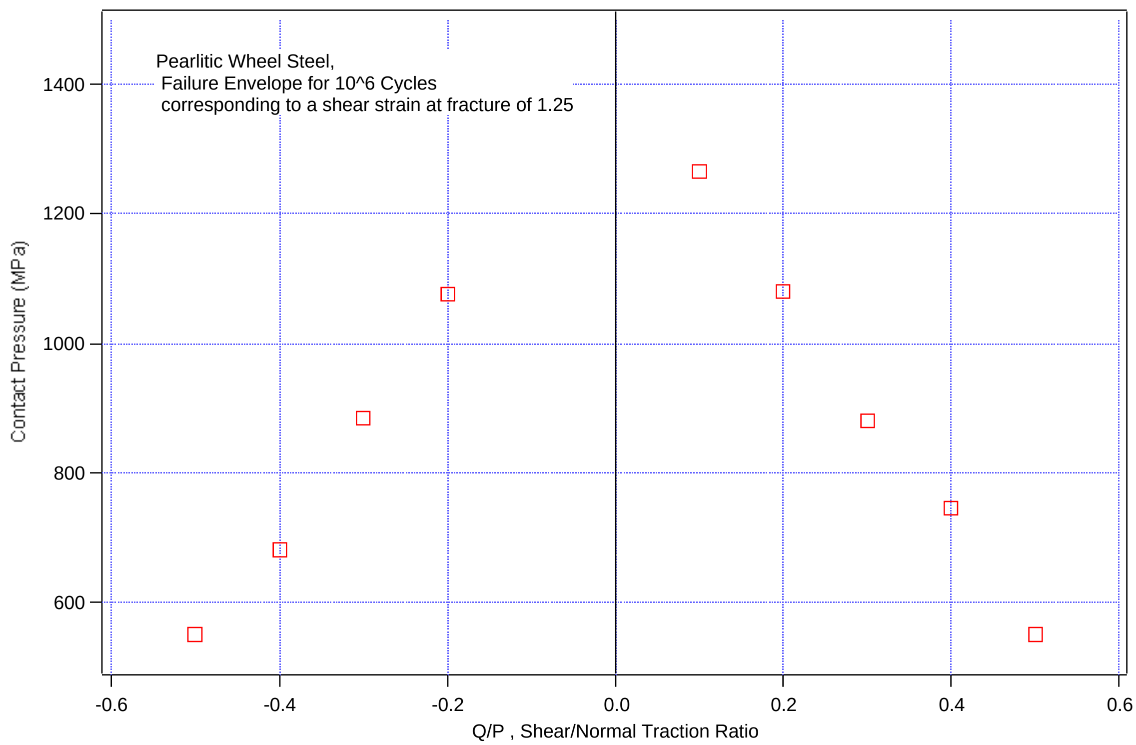
Shear Strain Accumulation with Cycles



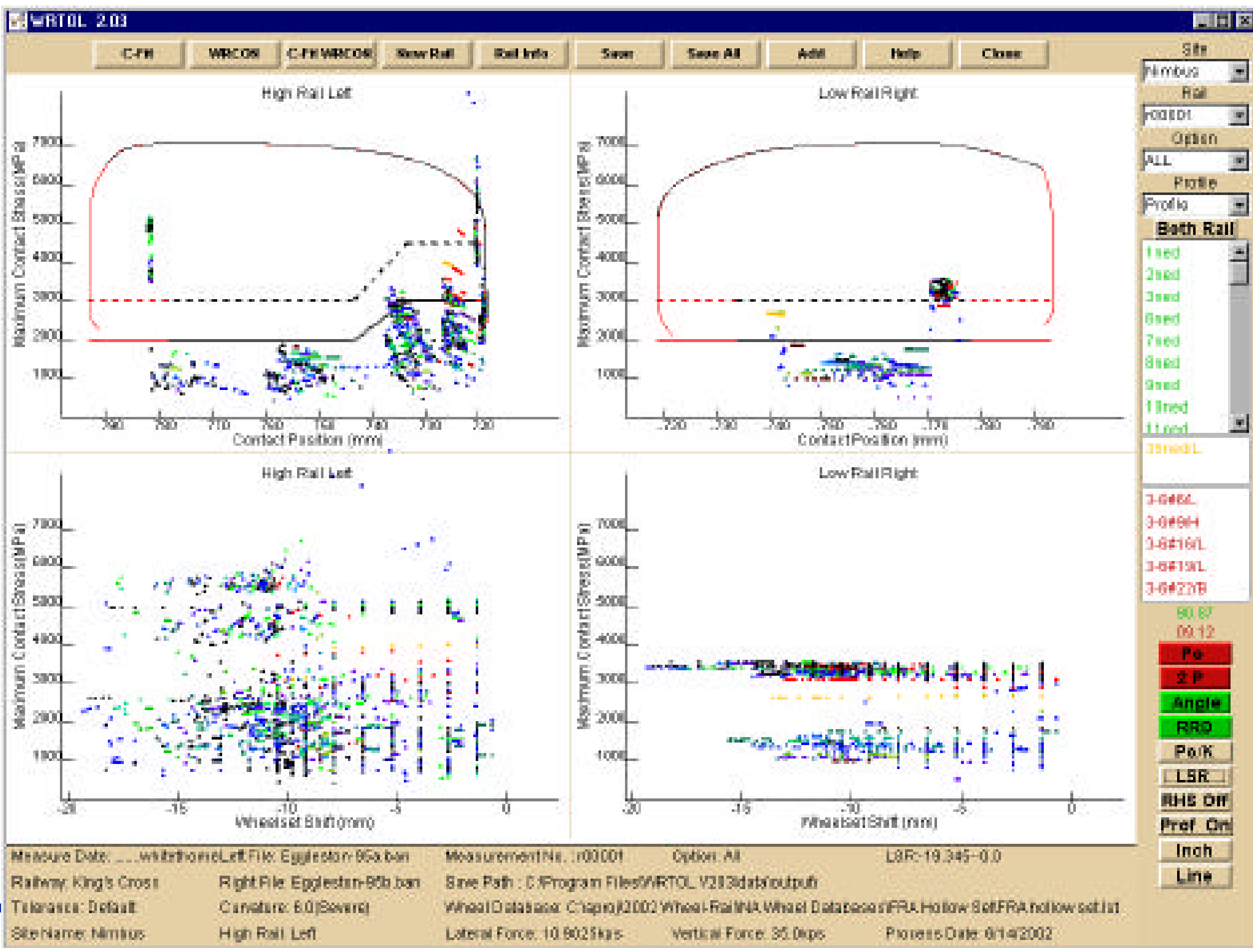
Ratchetting as a Function of Cycles (Passes)



Permissible Contact Pressure Based on a Ratchetting Strain Criteria

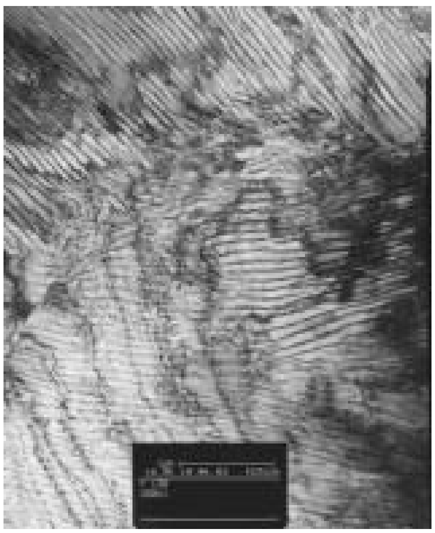


Sawley and Kristan (TTCI), 2001



RAIL MATERIALS

TEM images of Pearlitic steel virgin rail specimens cut from the surface showing different alignments of lamellae in the throughout the microstructure.



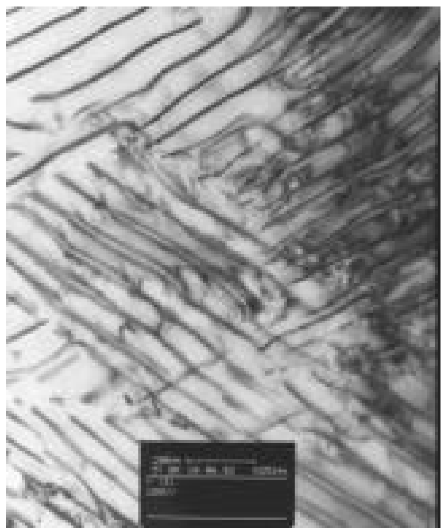
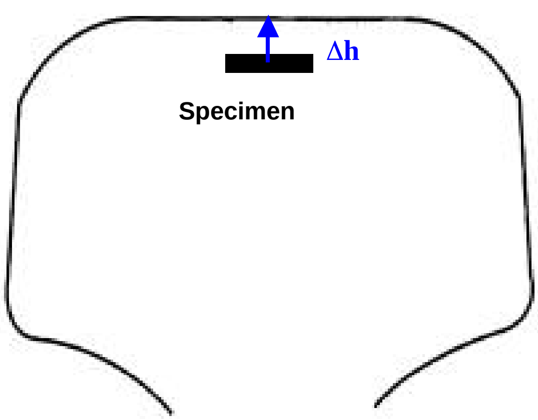
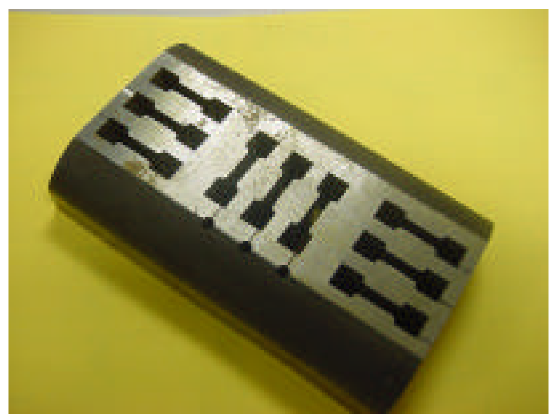


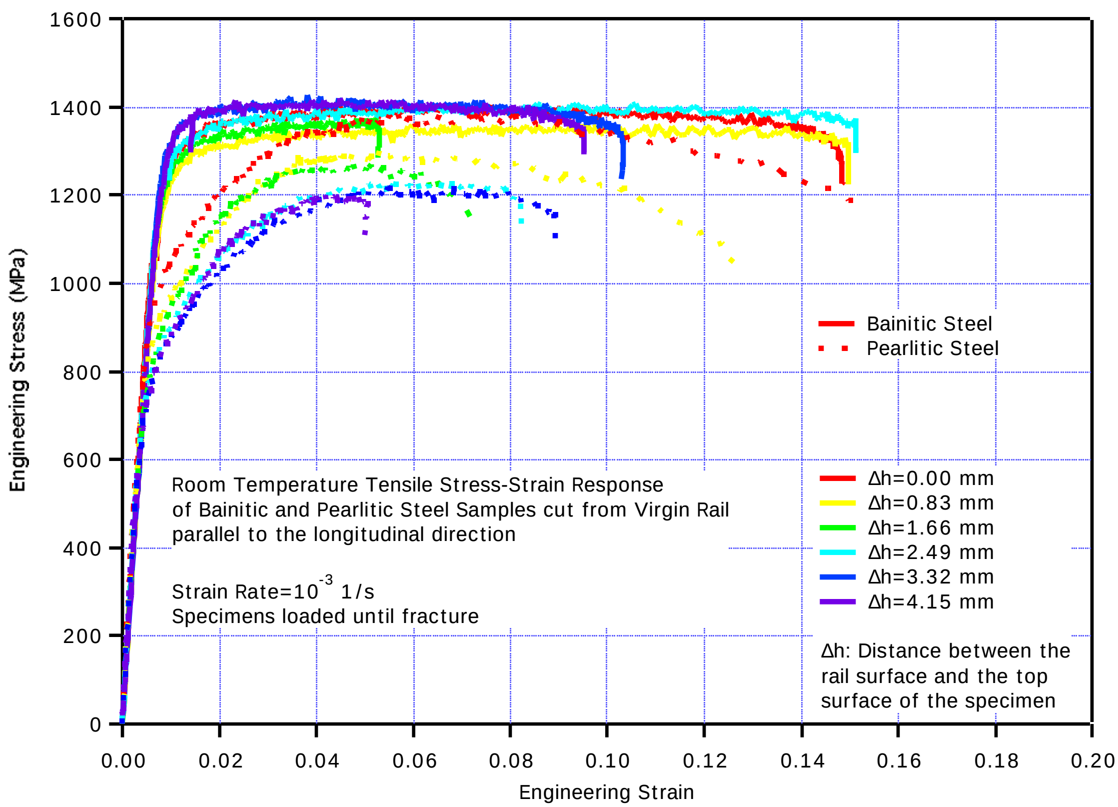
Figure showing the extraction convention for the virgin rail tensile specimens.



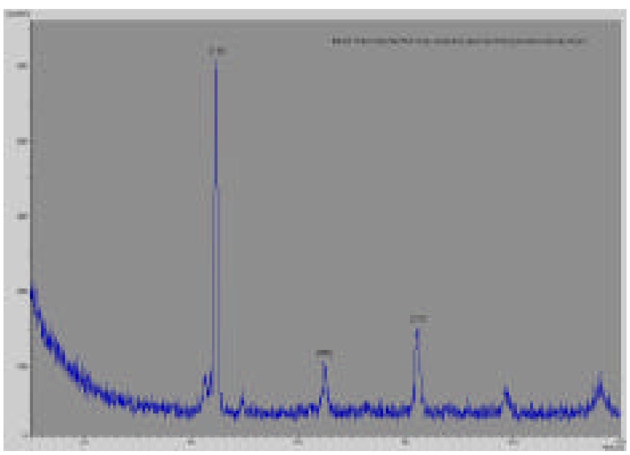
Picture showing the orientation of specimens cut from the virgin rails.



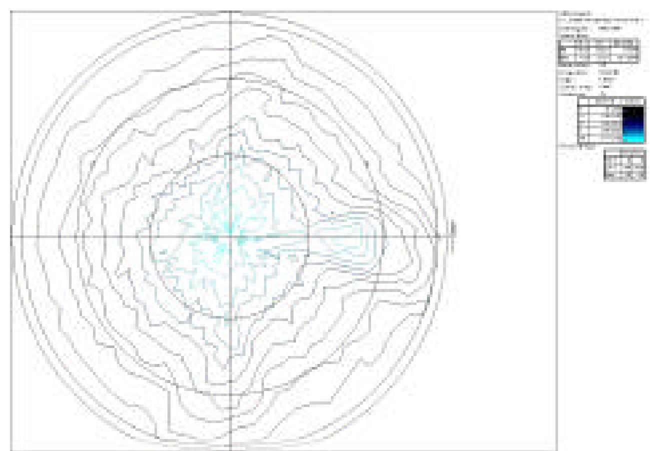
Monotonic room temperature tensile test results for the Bainitic and Pearlitic steel virgin rail specimens cut parallel to longitudinal direction.



Bainitic Steel Virgin Rail Rolling Direction Texture

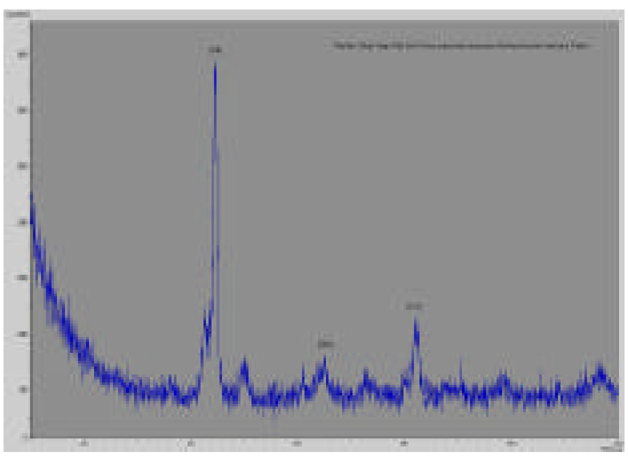


Intensity Peaks

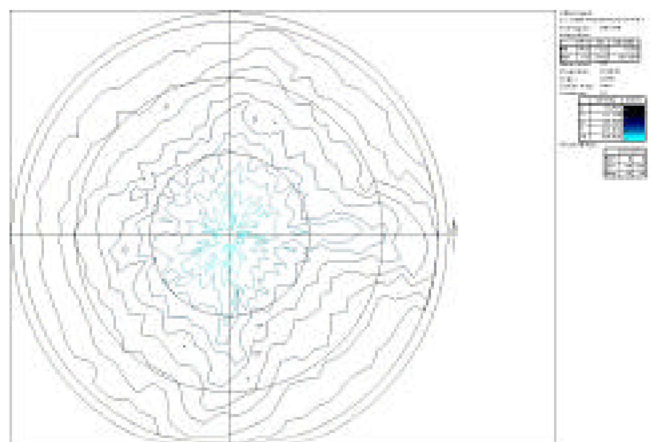


(110) Pole Figure

Pearlitic Steel Virgin Rail Rolling Direction Texture

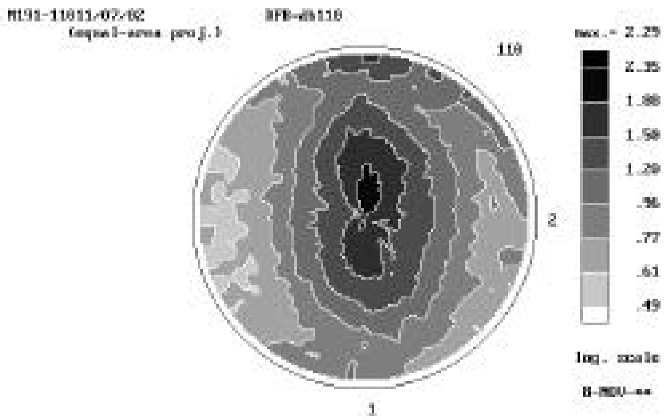


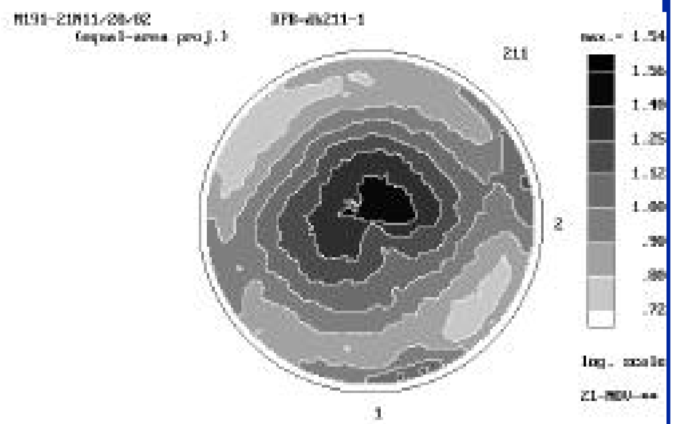
Intensity Peaks



(110) Pole Figure

Bainitic Steel Virgin Rail Surface Texture

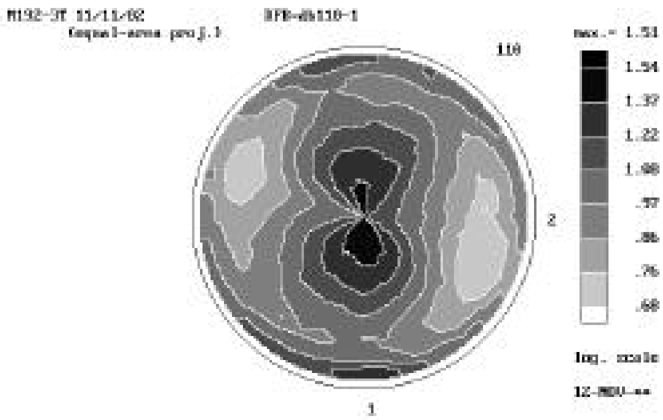




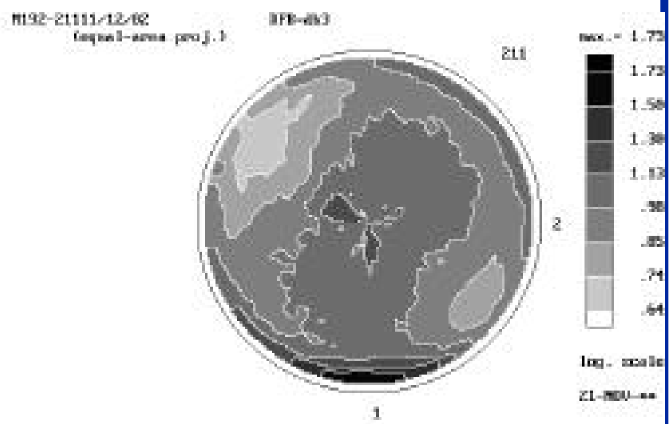
(110) Pole Figure

(211) Pole Figure

Pearlitic Steel Virgin Rail Surface Texture

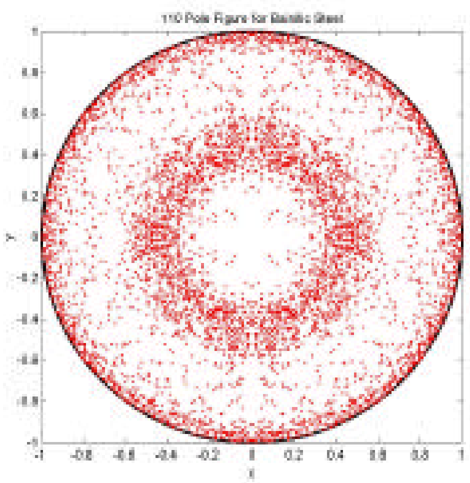


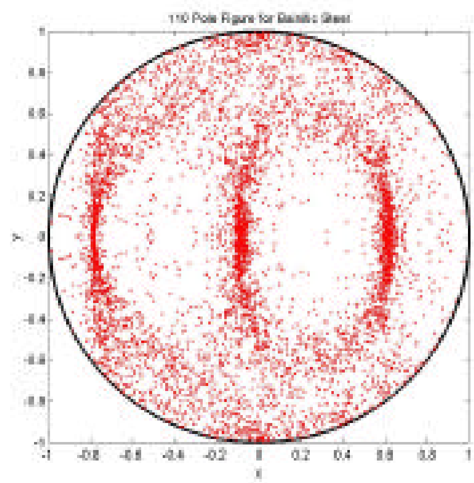
(110) Pole Figure



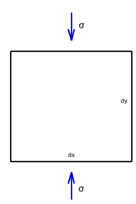
(211) Pole Figure

Change of Texture with Plastic Deformation



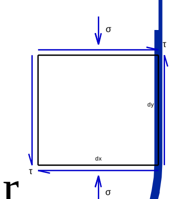


(110) Pole Figure



After 50% Compressive Strain

(110) Pole Figure



After Superimposed Shear and Compression

Conclusions

(1)As the shear tractions (adhesion levels above 35%) increase, for the same wheel loads, the plastic strains increase.

(2) The severity of rail surface displacements becomes pronounced as both the longitudinal and lateral shear tractions are increased.

(3) Factors other than yield strength could play a significant role in rolling contact behavior and wear.