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Freight Railroads- Research from Atoms to Structures

Yük Trenleri-Atomik Boyuttan Gerçek Yapılara Uzanan Bir Araştırma

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Nomenclature- Terimlendirme

Tension- Çekme Gerilimi
Compression- Basma Gerilimi
Thermal Stress- Isıl Gerilme
Strain- Gerinim
Fatigue Limit- Yorulma Sınırı
Yield Stress- Akma Gerilimi
Stress Concentration- Gerilim Yoğunlaşması
Microstructure-İçyapı
Constraint-Kısıt
Texture- Doku
Shear Stress- Makaslama Gerilimi
Slip-Kayma
Stick-Yapışma
Grinding- Taşlama

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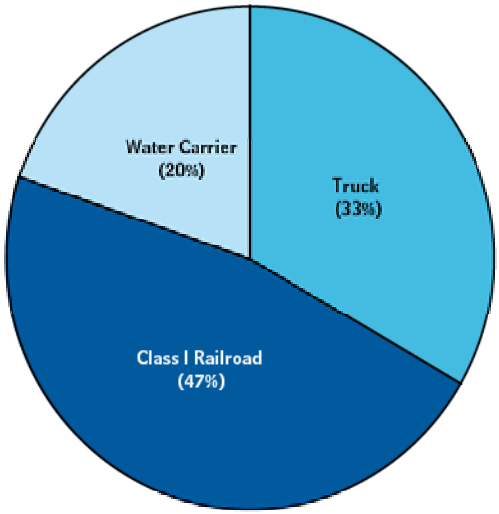
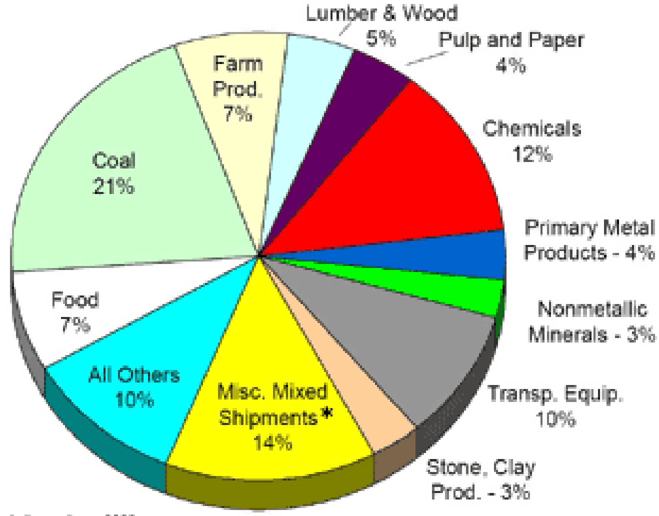
Demiryolu Endüstrisinin Önemi

(Percentage of ton-miles)



Source: Department of Transportation, Bureau of Transportation Statistics, *National Transportation Statistics 2004* (January 2005), Table 1-46, available at www.bts.dot.gov/publications/national_transportation_statistics/2004/index.html.

Class I Gross Freight Revenue by Commodity: 2003



Total $34.8 Billion

*Mostly Intermodal

The U.S. Freight Railroad Industry: 2002

Type of Railroad	Number	Miles Operated*	Employees	Freight Revenue ($ billions)
Class I	7	100,125	157,372	$34.11
Regional	31	15,129	7,807	1.30
Local Linehaul	309	20,015	5,102	0.91
S&T	205	6,429	6,779	0.59
Canadian**	2	570	n/a	n/a
Total	554	142,268	177,060	$36.92

*Excludes trackage rights. **Includes CN and CP operations that are not part of a CN- or CP-owned Class I carrier.

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Talk Outline (Konuşma Taslağı)

•Fatigue/Deformation Preliminaries (Yorulma)

•Wheels- Thermo-mechanical Fatigue

(Tekerlekler,Termo-mekanik Yorulma)

•Rails- Ratcheting and Fatigue/Wear

(Raylar- Gerinme ve Aşınma)

•Materials Design- Diamond Crossing

•(Yeni Mazemelerin Atomik Boyutta Tasarımı-Makas Elması)

•Bearings- Cone Bore Growth

(Rulmanlı Yataklar)

•Conclusions (Sonuçlar)

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Stress Concentrations- Railroad Axles, the Versailles Accident (Gerilim Yoğunlaşması, Ray aksi, Versay Kazası)

William John Macquorn Rankine
Born: 2 July 1820 in Edinburgh, Scotland
Died: 24 Dec 1872 in Glasgow, Scotland

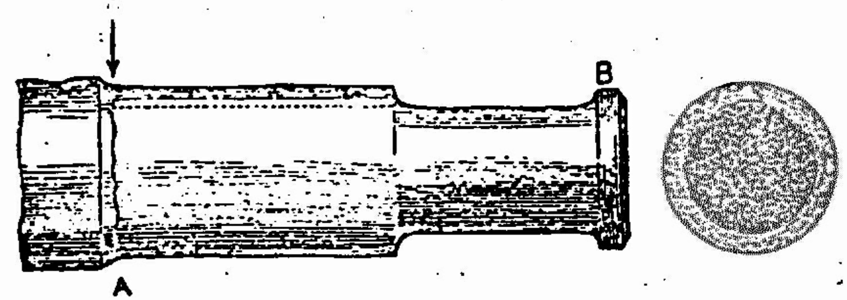

Fig 1. Classic appearance of a fatigue cracked railway axle from Glynn, 1844.

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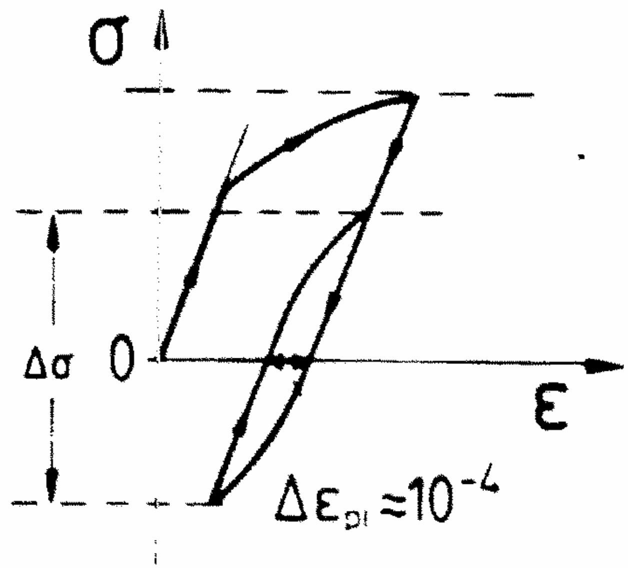
Bauschinger Effect and the Presentation of the Fatigue Limit (Bauschinger etkisi ve Yorulma Sınırı)

Fig. 1: Portrait of Johann Bauschinger, born on June 11, 1834, and died on November 25, 1893.



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Early Observations(A. Ewing, Humphreys, W. Rosenhain, 1899)- Eski İncelemeler

J. A. Ewing and J. C. W. Humfrey.

Phil. Trans., A, vol. 200, *Plate* 9.

Fig. 9. Specimen after 1000 reversals of a stress of 12·4 tons per sq. inch. × 1000.

Fig. 10. Same after 2000 reversals. × 1000.

Fig. 11. Same after 10,000 reversals. × 1000.

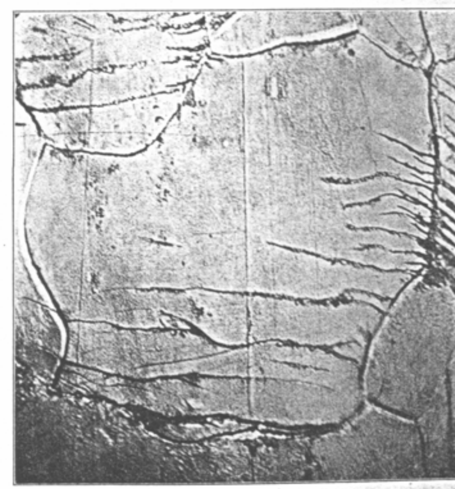

Fig. 12. Same after 40,000 reversals. × 1000.

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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 0.72 per cent of carbon to one with about 0.20 per cent carbon. Below the decarburized zone the steel is almost entirely pearlitic. At the top of the micrograph can be seen particles of scale which were loosened in polishing. Magnification 125 times. (*Micrograph by R. 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-

(Ray üzerinde İçyapı)

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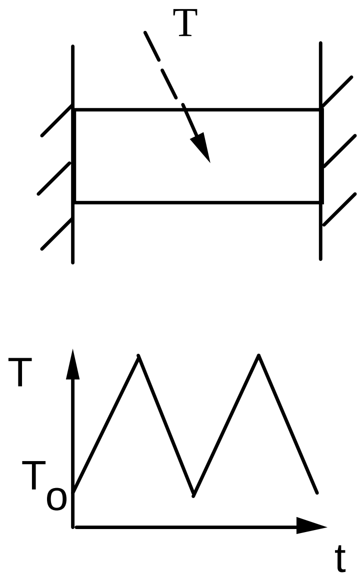
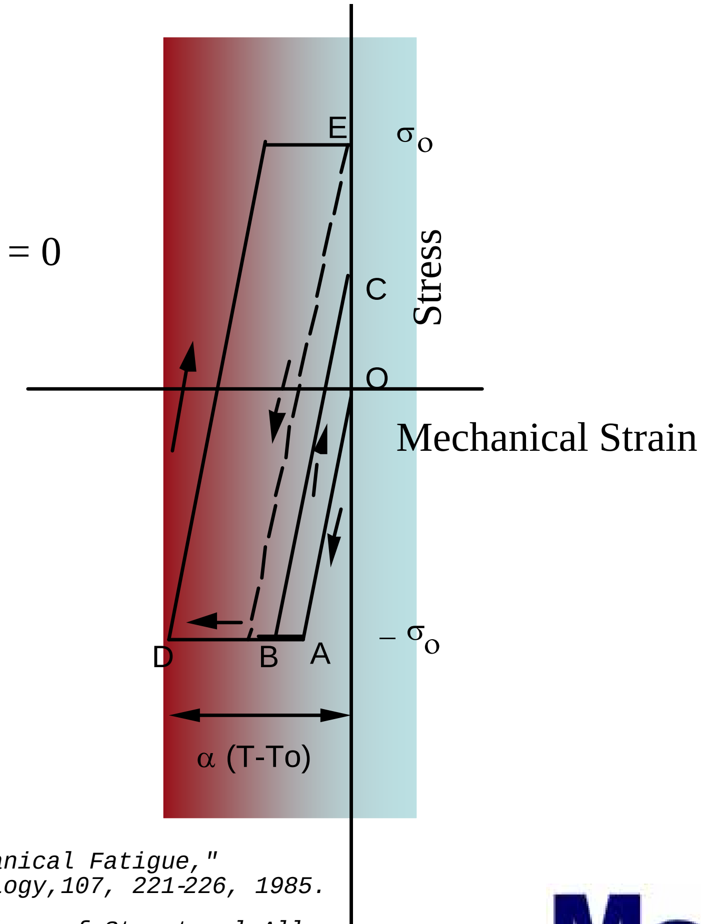
Total Constraint (Tam Kısıtlama)



$\varepsilon_{net} = 0$



Sehitoglu, H., "Constraint Effect in Thermo-mechanical Fatigue," ASME Journal of Engineering Materials and Technology,107, 221-226, 1985.

Sehitoglu, H., Thermal and Thermo-Mechanical Fatigue of Structural Alloys, Handbook on Fatigue and Fracture, ASM, 19, 527-554, 1996.

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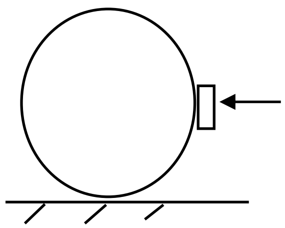
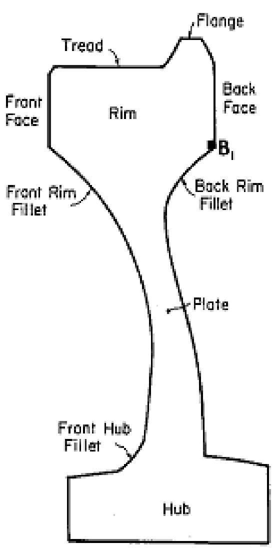
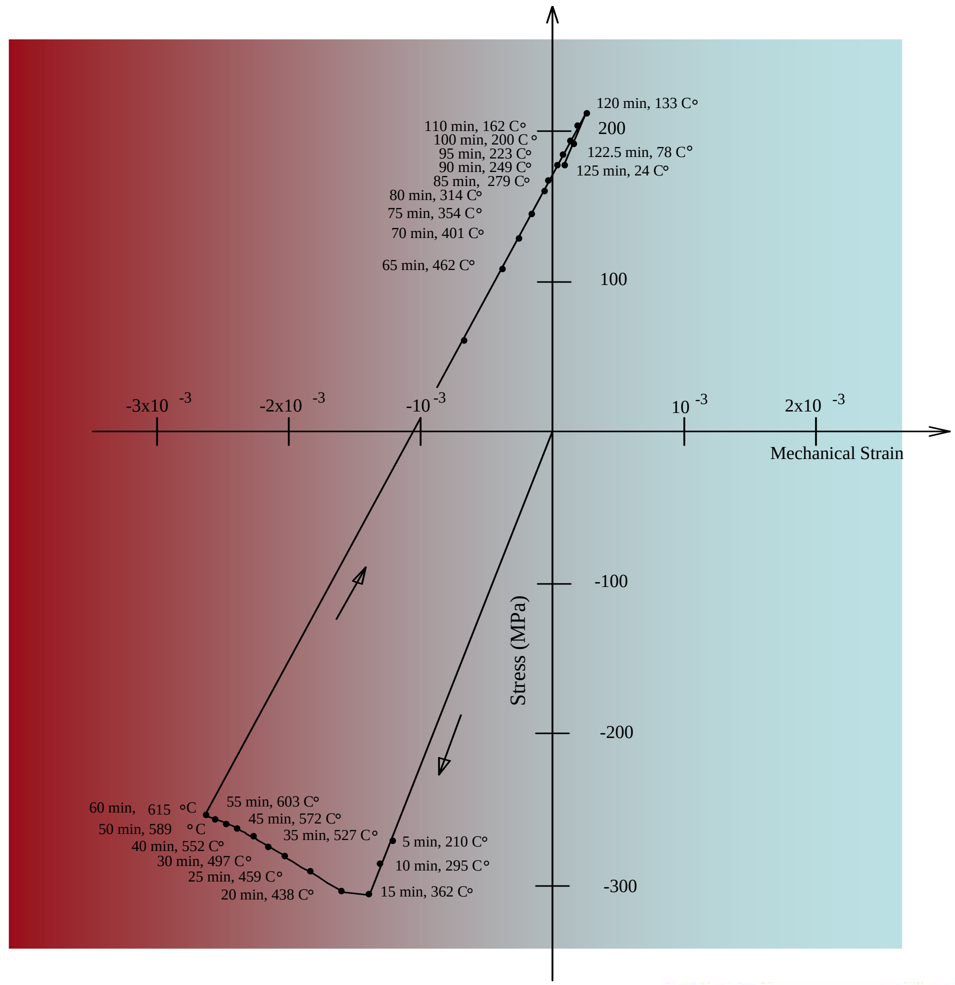
Railroad Wheels under Friction Braking
(Tekerlekler ve fren pabuçları kullanımı)

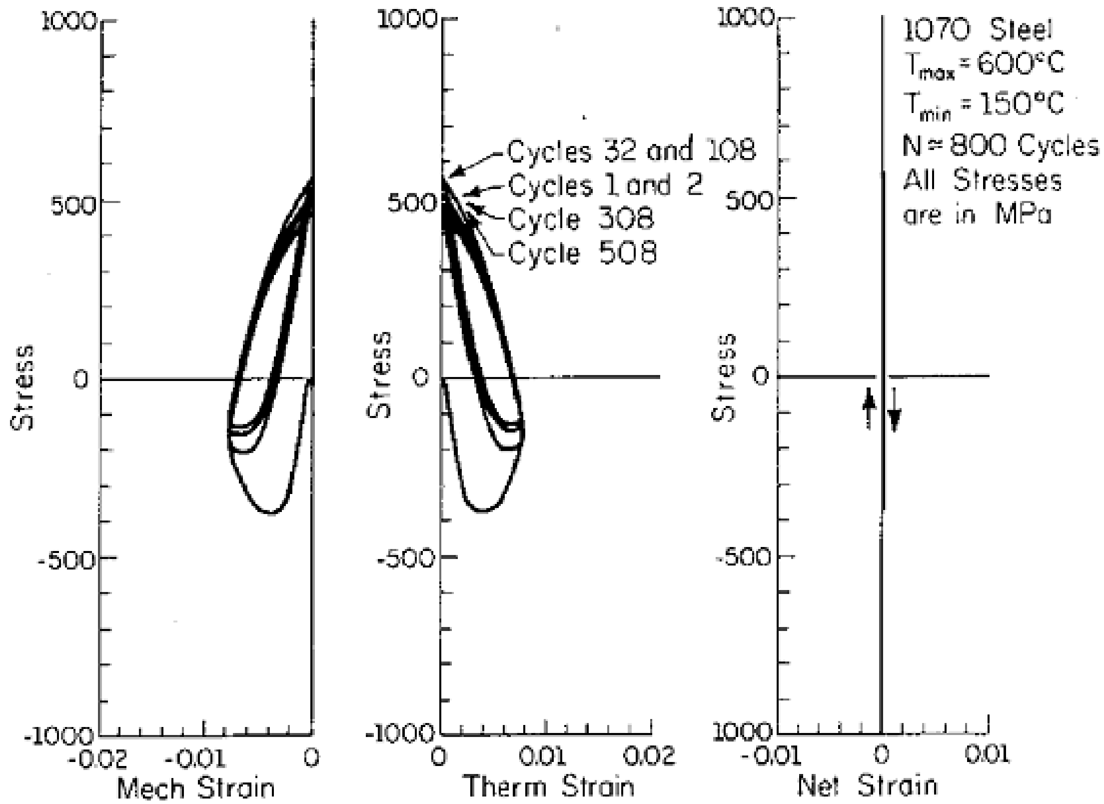






The Stress-strain Response under Total Constraint (Tam kısıtlama)

Hysteresis and Stress-strain Response in Total Constraint



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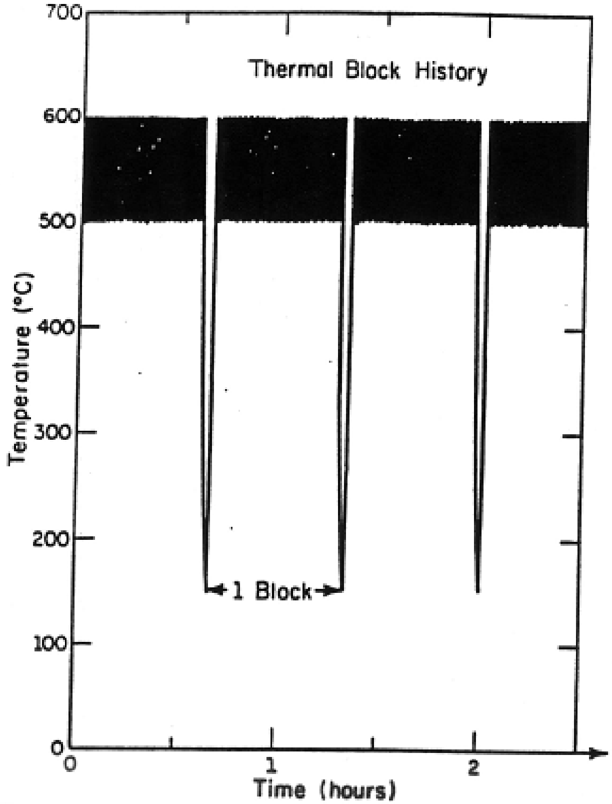
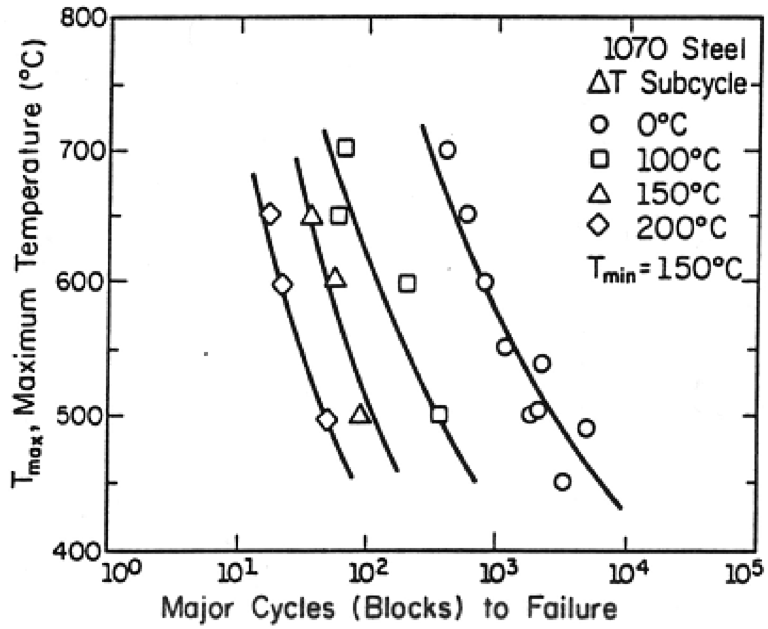
Thermal Block Histories on Steels under Total Constraint
(Blok ısı değişmeleri - tam kısıtlama)





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Significant Texture (Orientation) Develops in the Material Under Contact

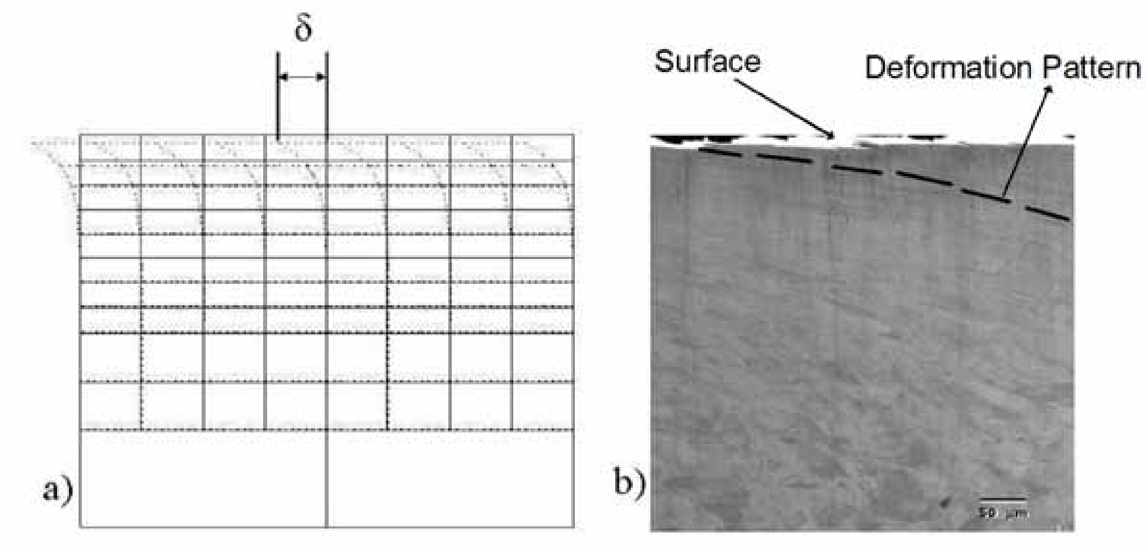
•Ratcheting strain is accumulated residual shear strain in the direction of motion of rolling instance.

For definitions see:

•Jiang, Y. and Sehitoglu, H., 1999, A Model for Rolling Contact Failure,*Wear*, Vol.224, No1., pp.38-49

•Sehitoglu, H. and Jiang, Y., 1993, "Residual Stress Analysis in Rolling Contact," *Rail Quality and Maintenance for Modern Railway Operation*, Kalker *et al.*, Eds., Kluwer Academic Publishers, pp.349-358

•Jiang, Y. and Sehitoglu, H., 1996, Rolling Contact Stress Analysis with the Application of a New Plasticity Model, *Wear*, Vol.191, pp.35-44



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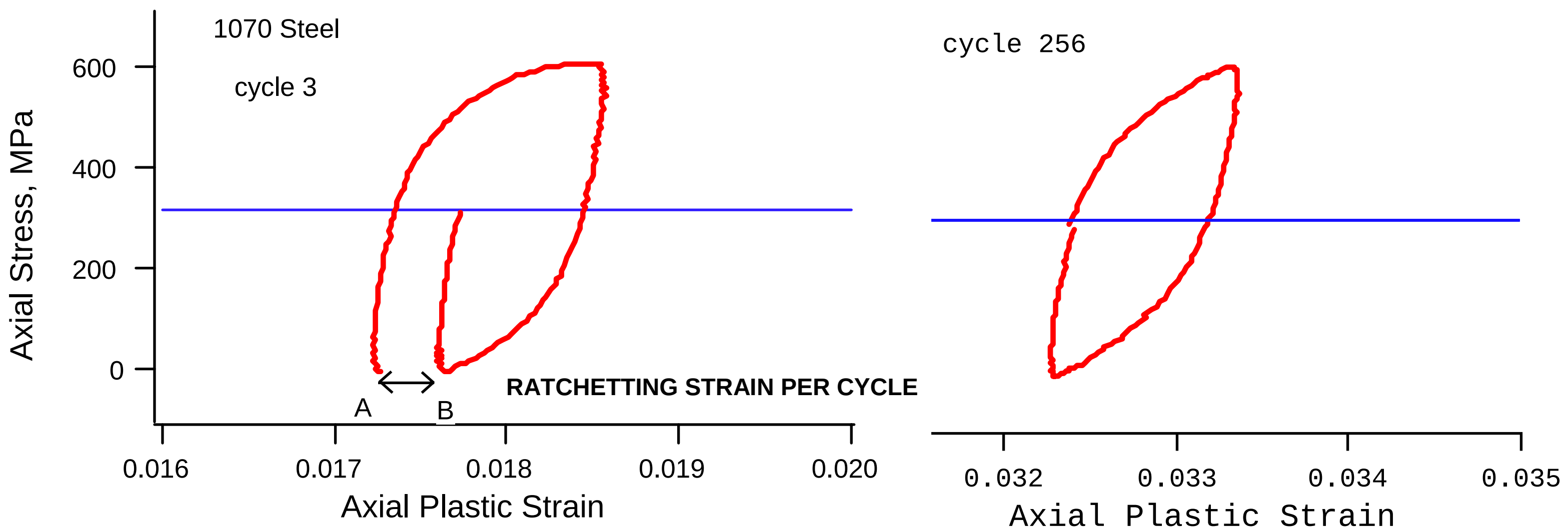
DEFINITION OF RATCHETTING : INCREMENT OF STRAIN PER CYCLE DUE NONCLOSURE OF THE HYSTERESIS LOOP



Jiang, R. and H. Sehitoglu, "Cyclic Ratchetting of 1070 Steel Under Multiaxial Stress States, " *International Journal of Plasticity*, 10:5, 579-608, 1994.

Jiang, R. and H. Sehitoglu, "Multiaxial Cyclic Ratchetting Under Multiple Step

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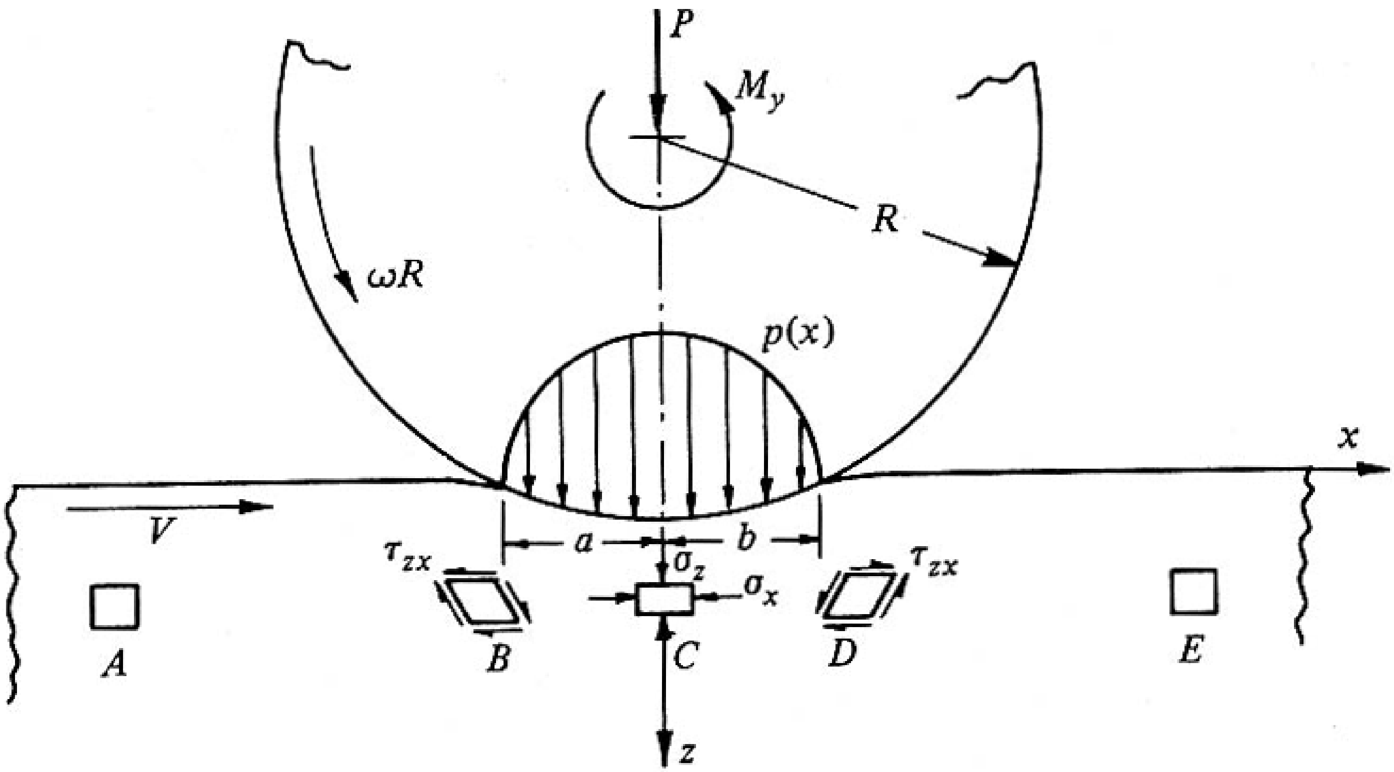
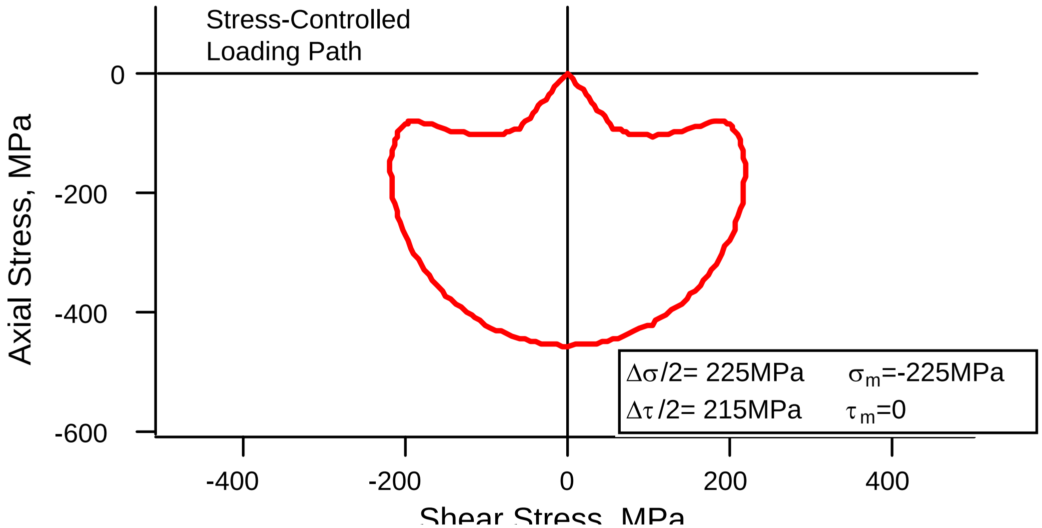
Contact Stress History in wheel -rail contact (Johnson, 1985)

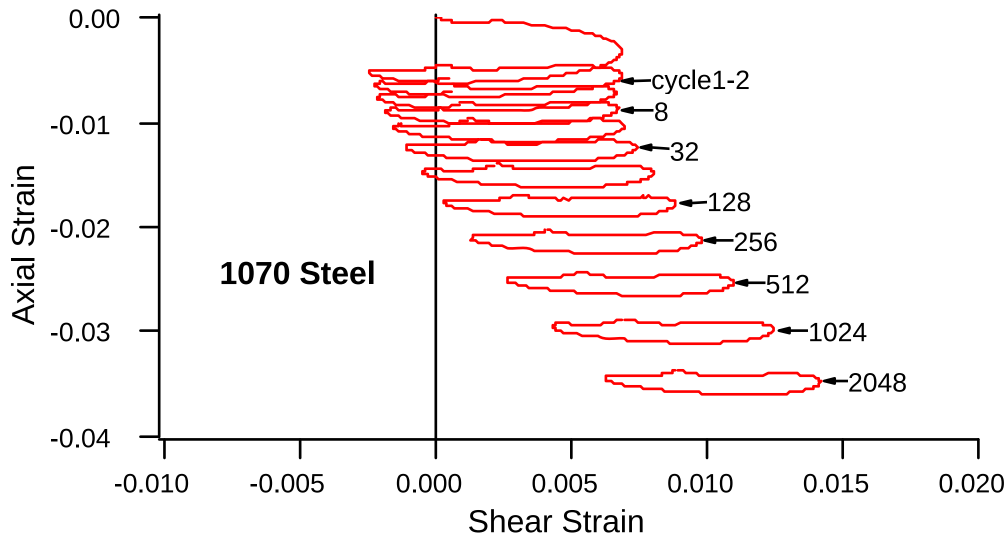


EXPERIMENTAL RATCHETTING FOR A NOPROPORTIONAL AXIAL-TORSIONAL LOADING PATH

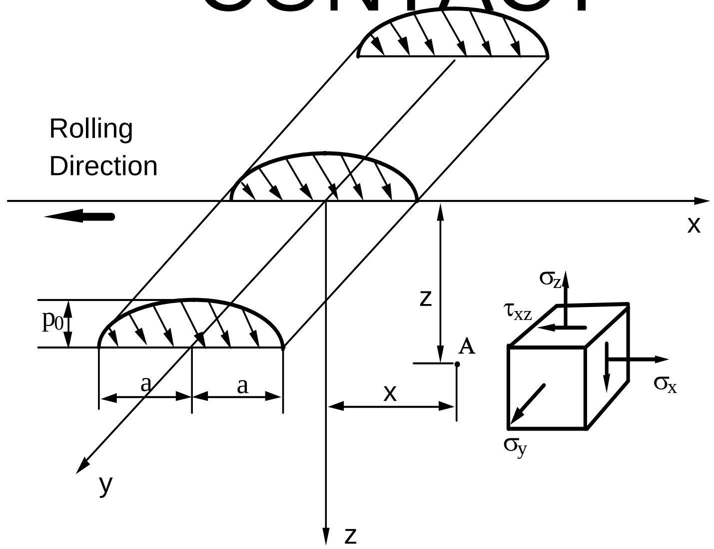
Jiang, Y. and H. Sehitoglu, *ASME JAM*, 63, 726-733, 1996.

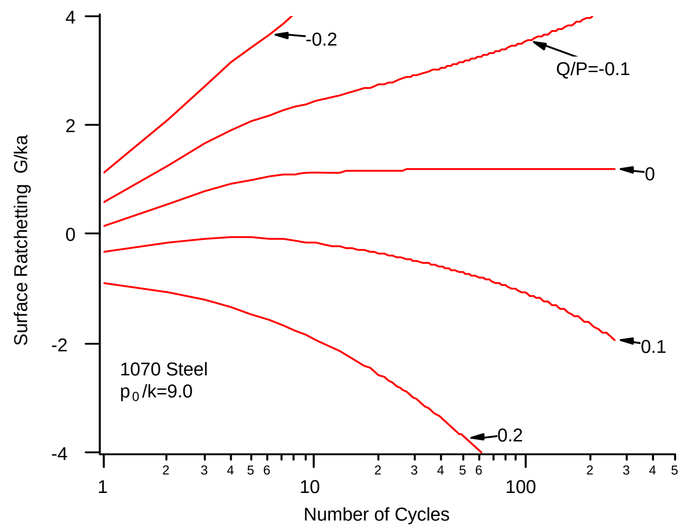
Jiang, Y. and H. Sehitoglu, *ASME JAM*, 63, 720-725, 1996.





SURFACE RATCHETTING IN CONTACT





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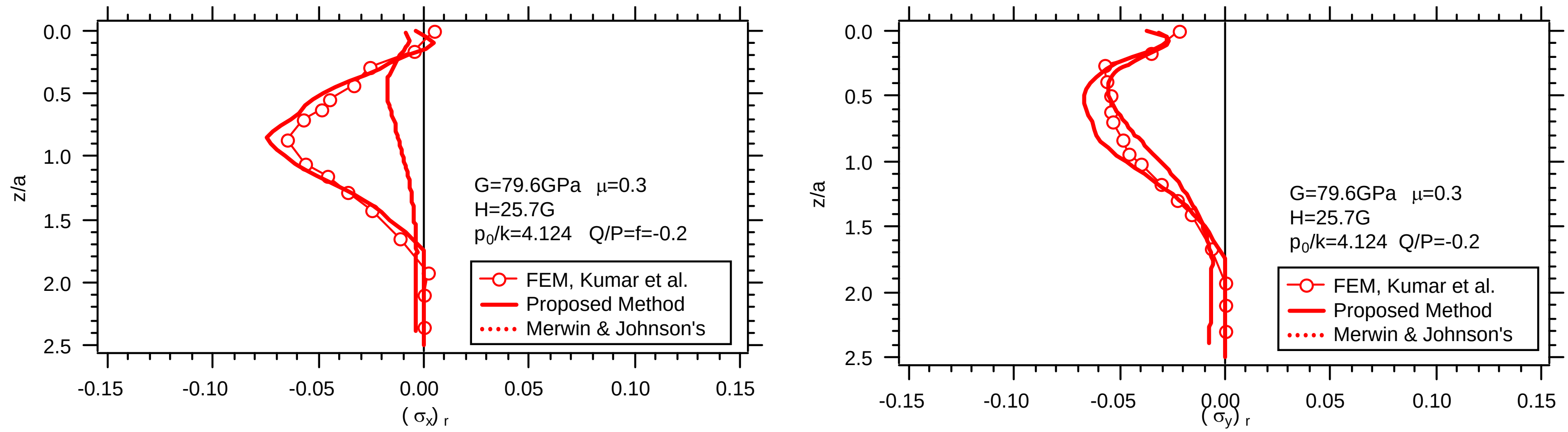
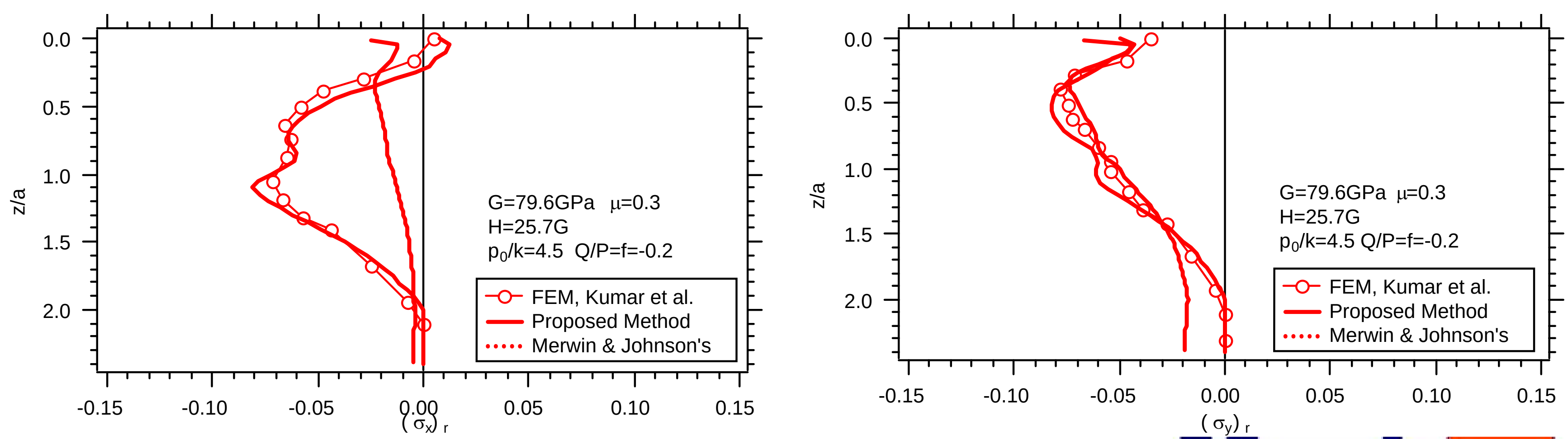
Residual Stress Profiles in Rolling Contact

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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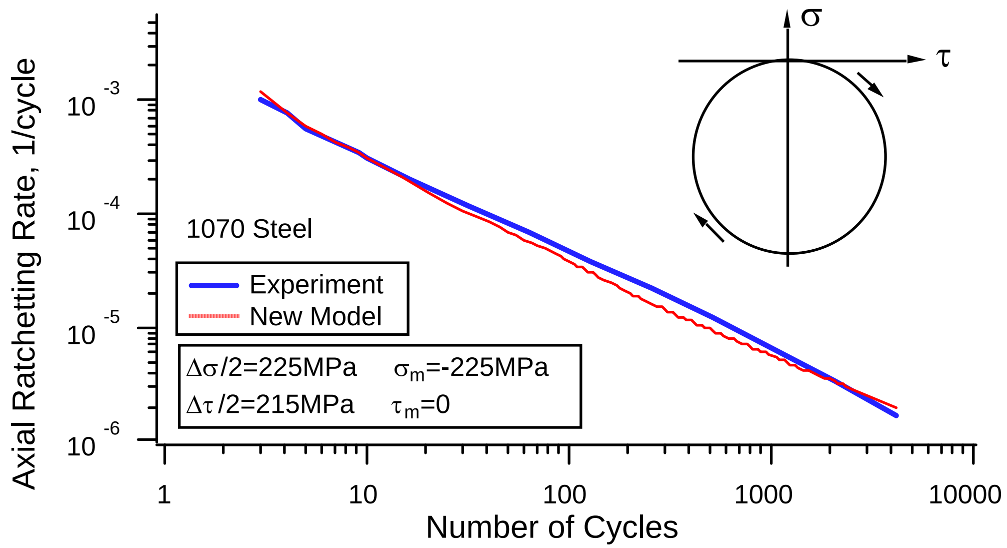
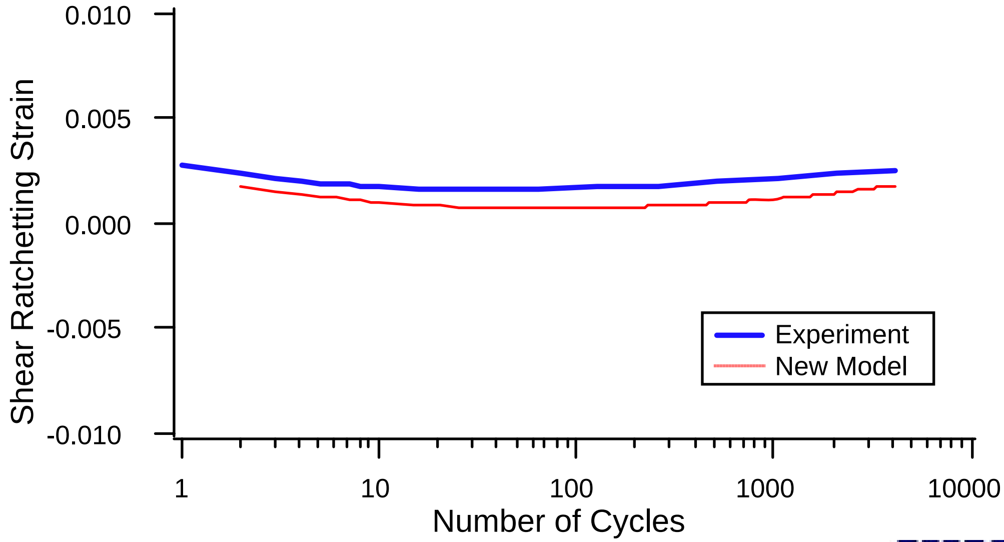
CAPABILITY OF PROPOSED MODEL IN NONPROPORTIONAL LOADING





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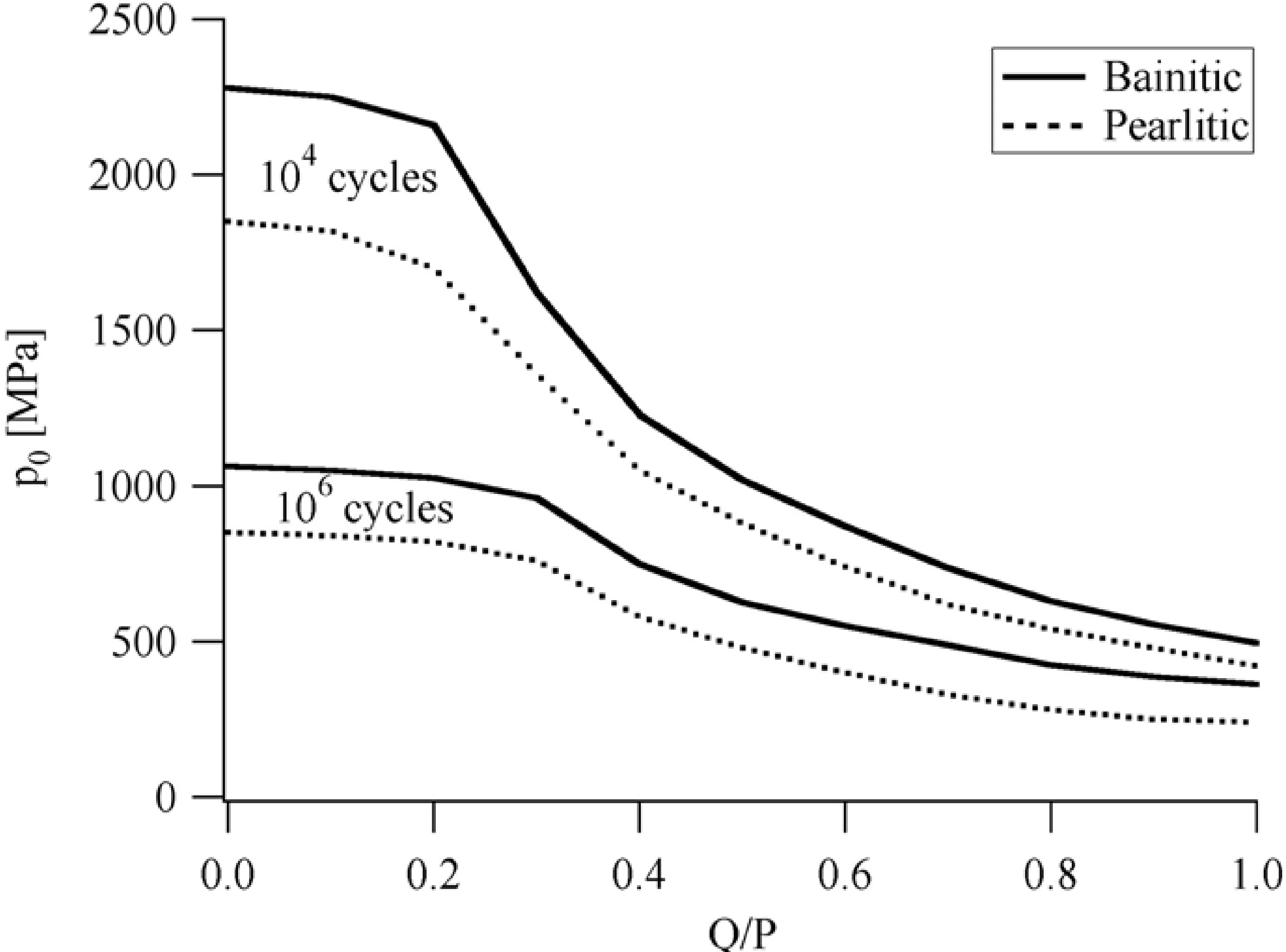
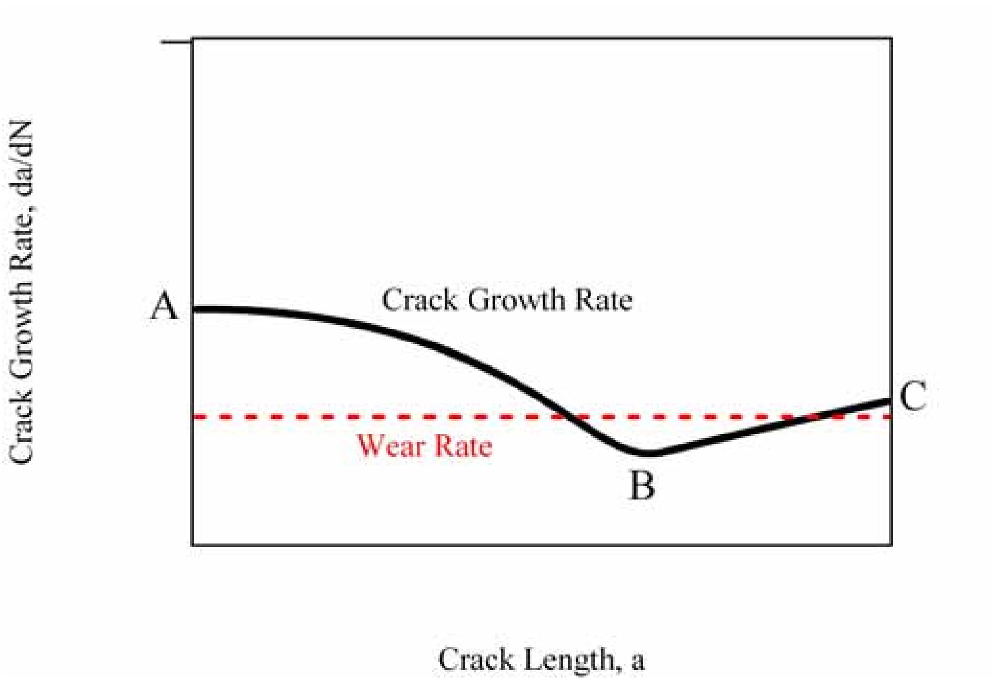
Failure Mechanism Map

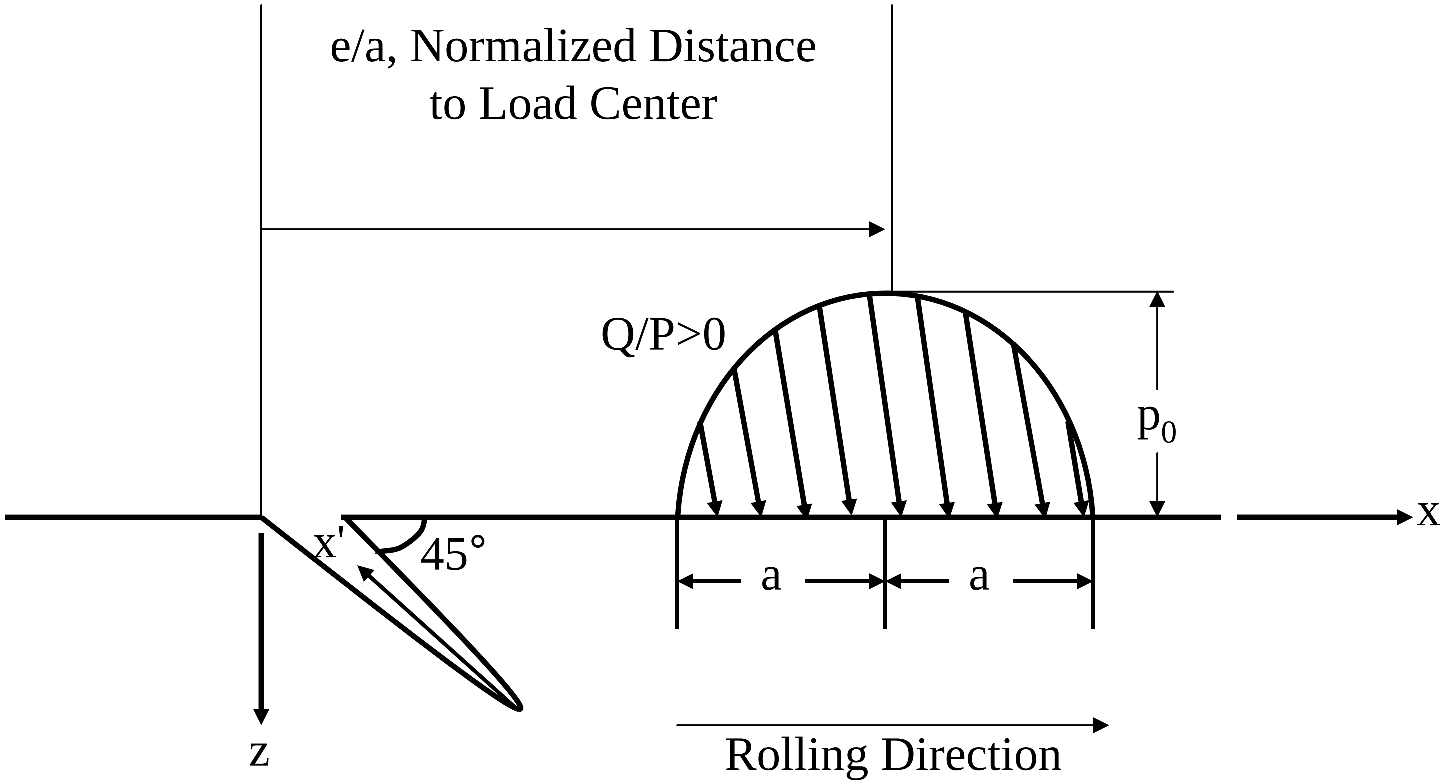


Crack Propagation



A: Crack initiation
A-B:As crack length increases, the crack propagation rate decreases
B-C: At longer crack lengths the crack growth rates increase again

High wear (and crack mouth truncation) rate: Crack will be worn away.
Low wear (and crack mouth truncation) rate: ZERO NET crack growth rate possible.



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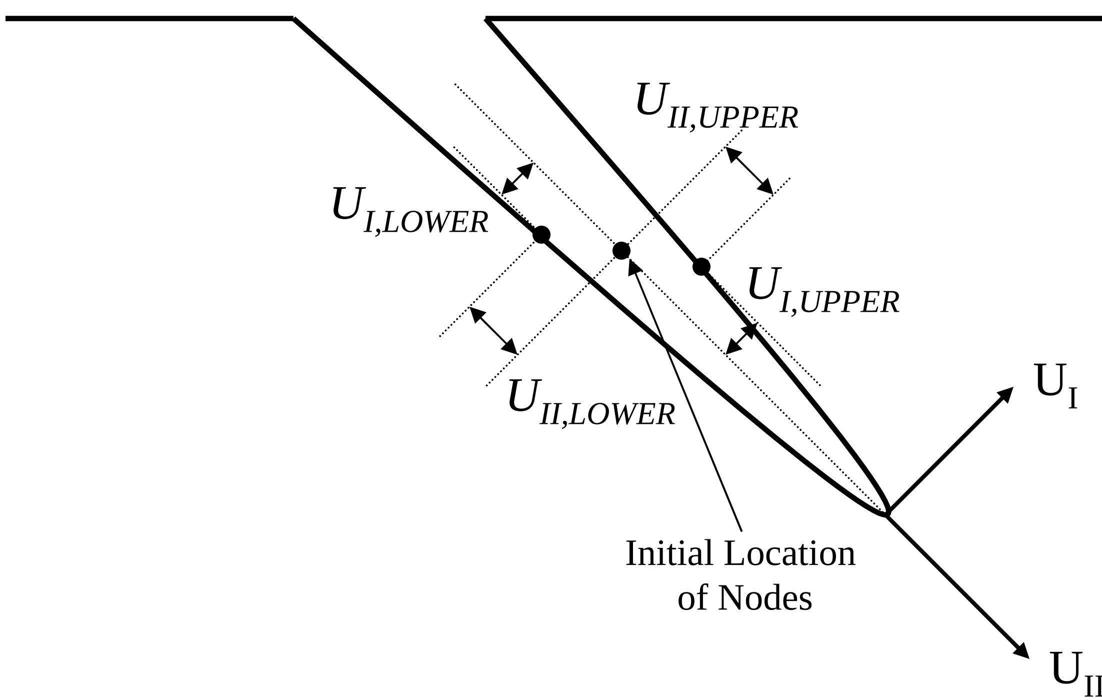

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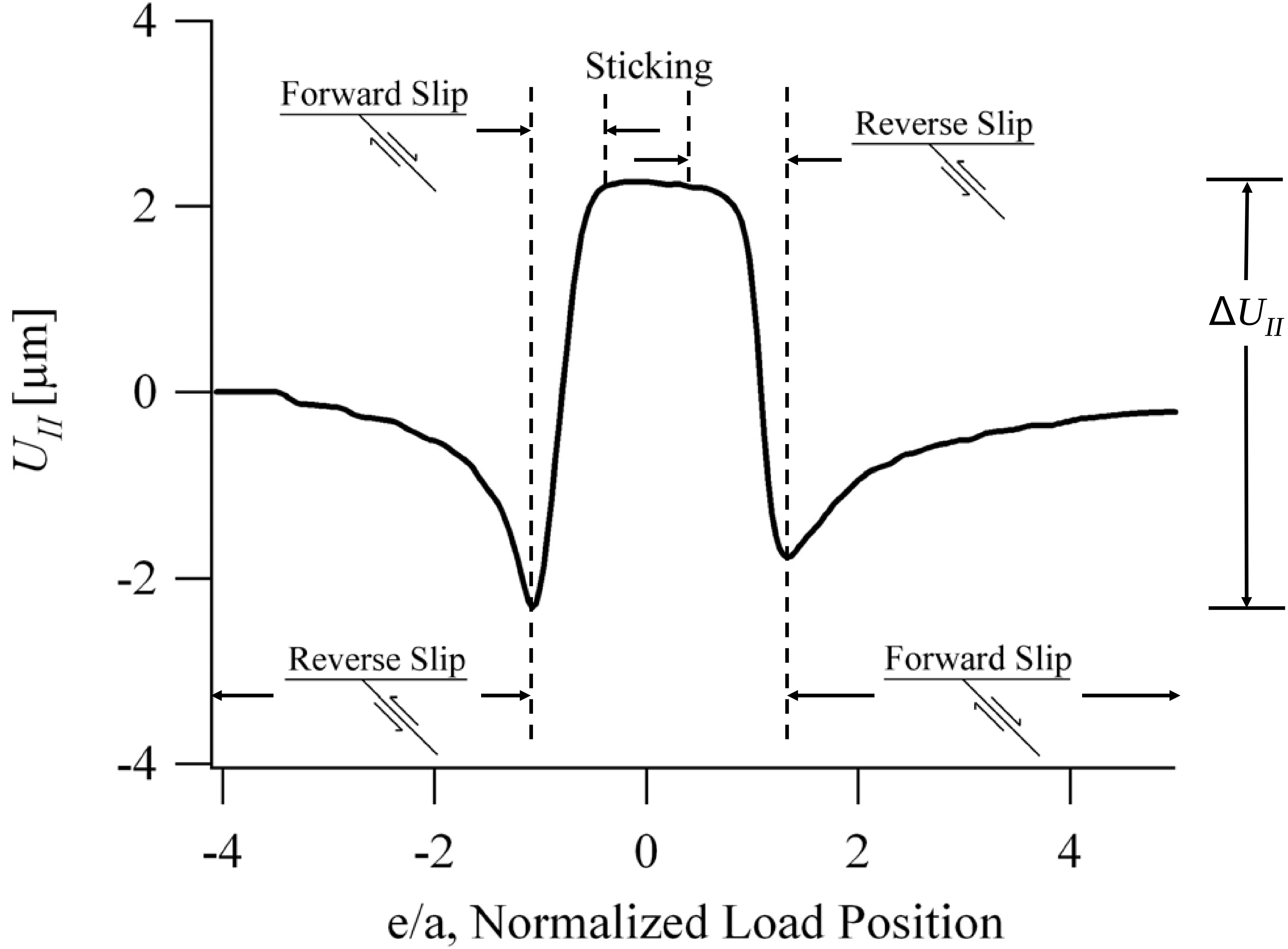
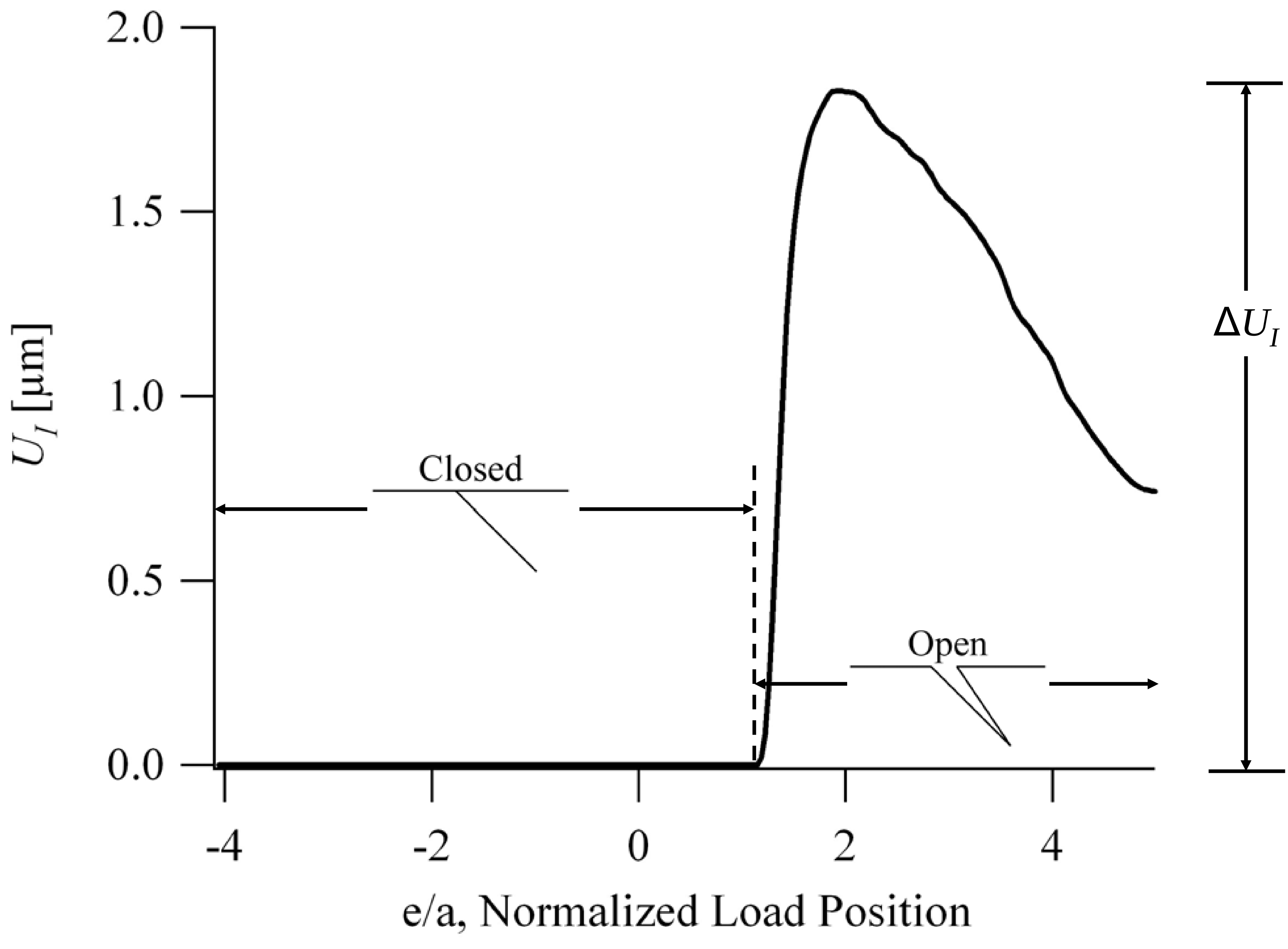
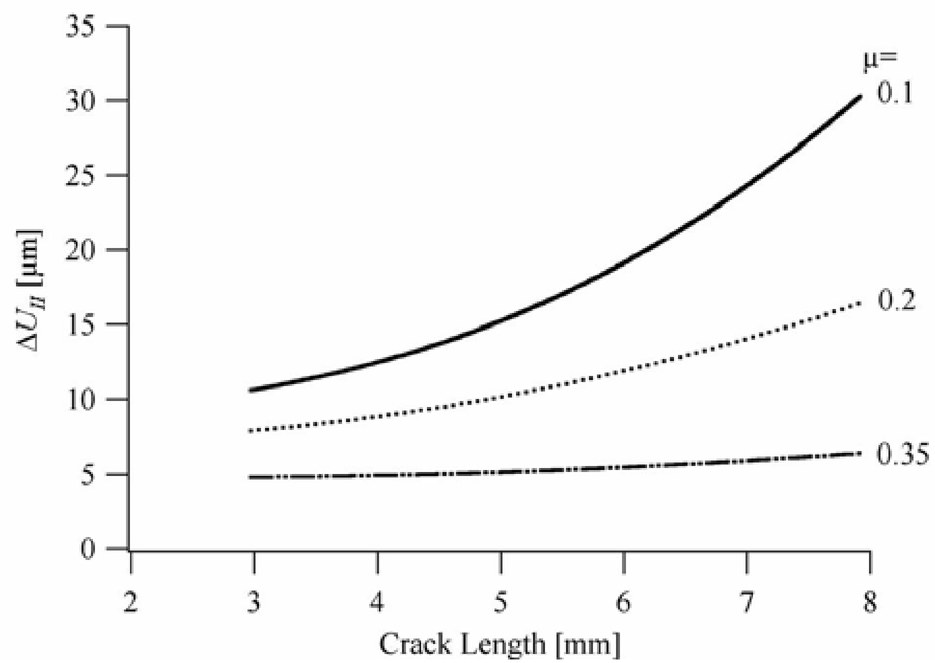


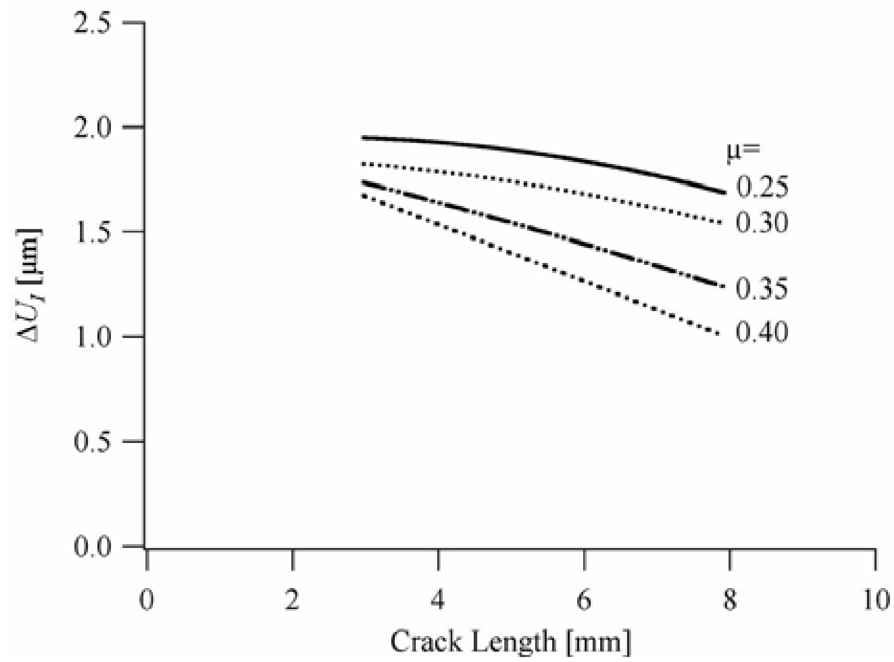
4
2
0
-2
-4
U_{II} [μm]
Sticking
Forward Slip
Reverse Slip
Reverse Slip
Forward Slip
ΔU_{II}
-4
-2
0
2
4
e/a, Normalized Load Position



2.0
1.5
1.0
0.5
0.0
U_I [μm]
Closed
Open
ΔU_I
-4
-2
0
2
4
e/a, Normalized Load Position

Variation of Sliding and Opening Displacements as a Function of Crack Length





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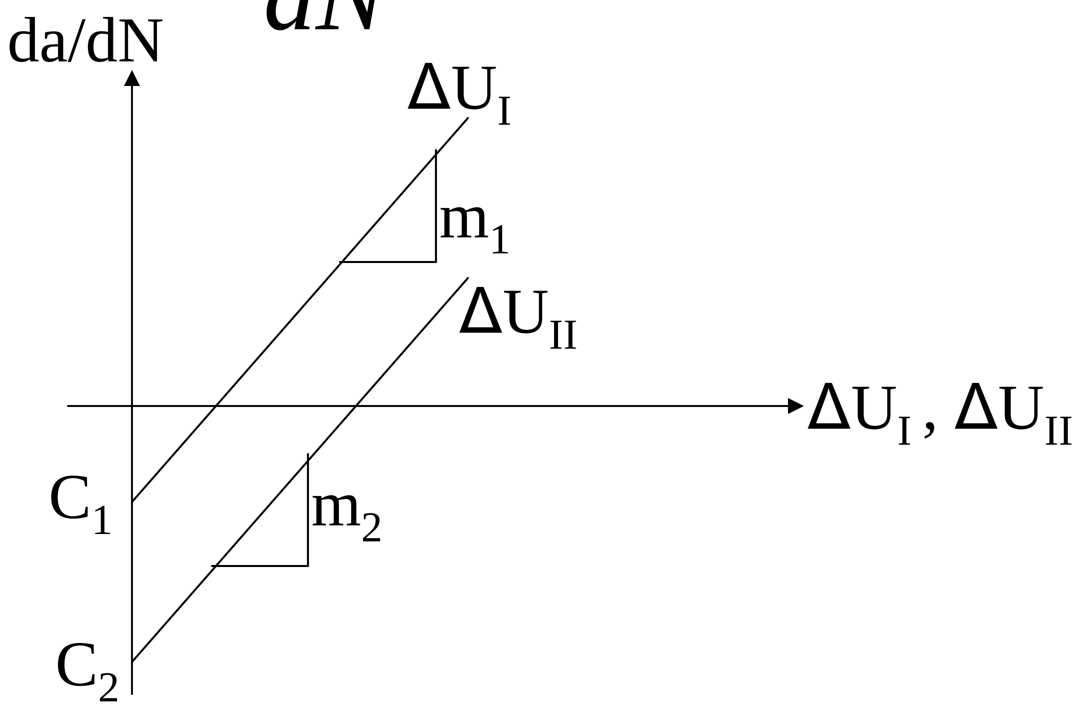
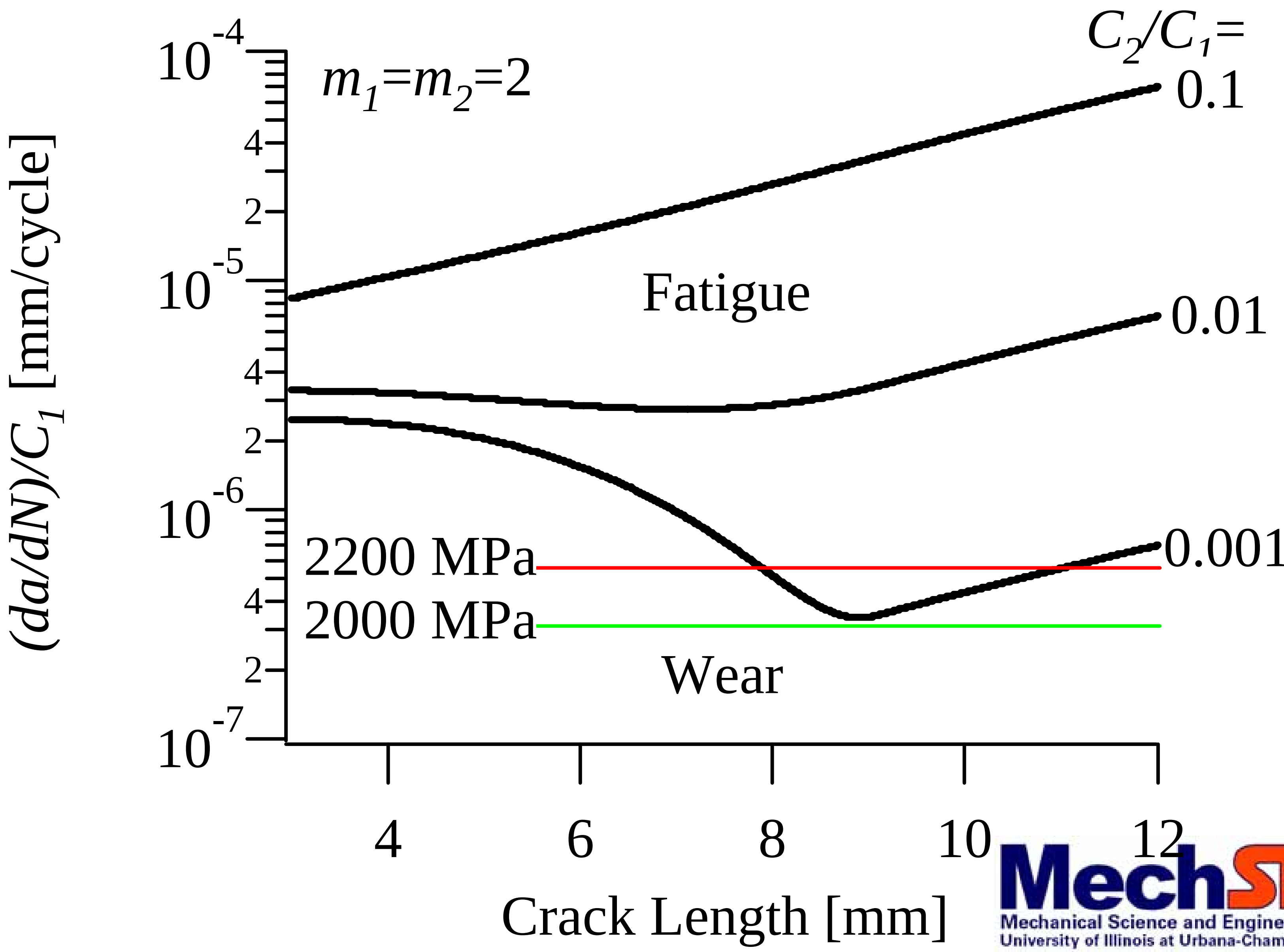
Crack Propagation

$$\frac{da}{dN} = C_1 \left(\Delta U_I\right)^{m_1} + C_2 \left(\Delta U_{II}\right)^{m_2}$$



Data for da/dN in sliding is not available: Normalization by C_1



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Grinding Operations after Weld Metal deposition

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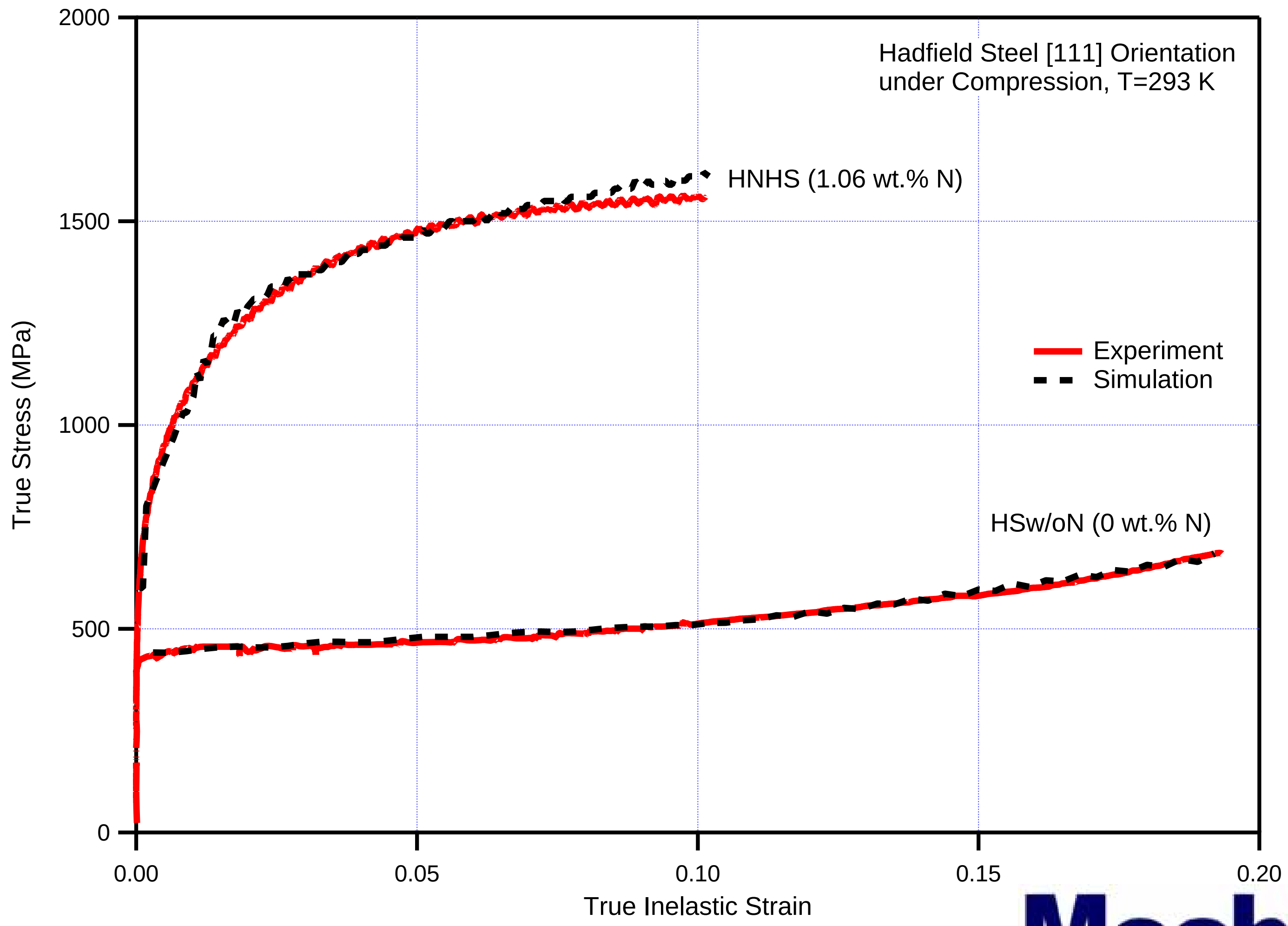
FeMnN-Theory vs. Experiment - [111] Orientation



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HIP Equipment

Tensile Testing Equipment

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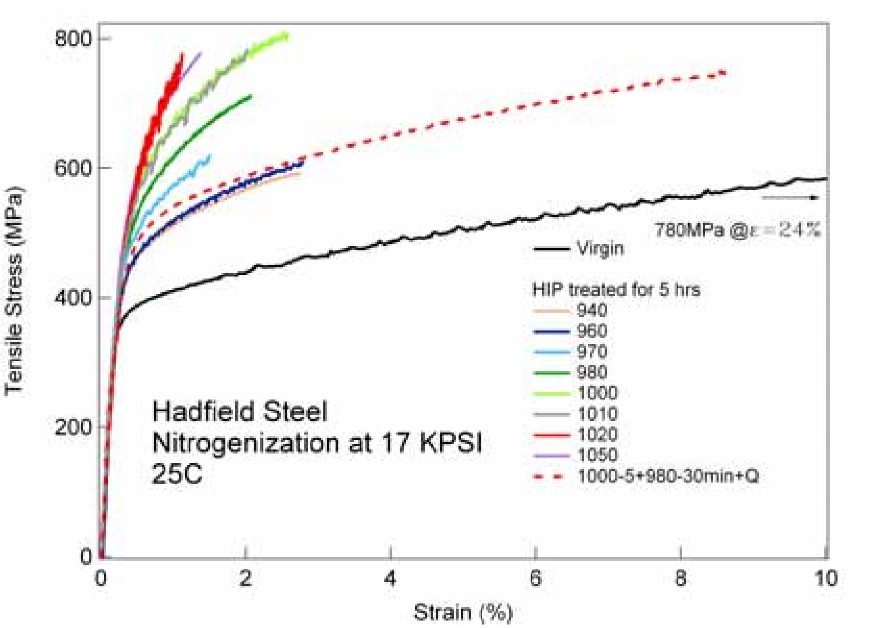
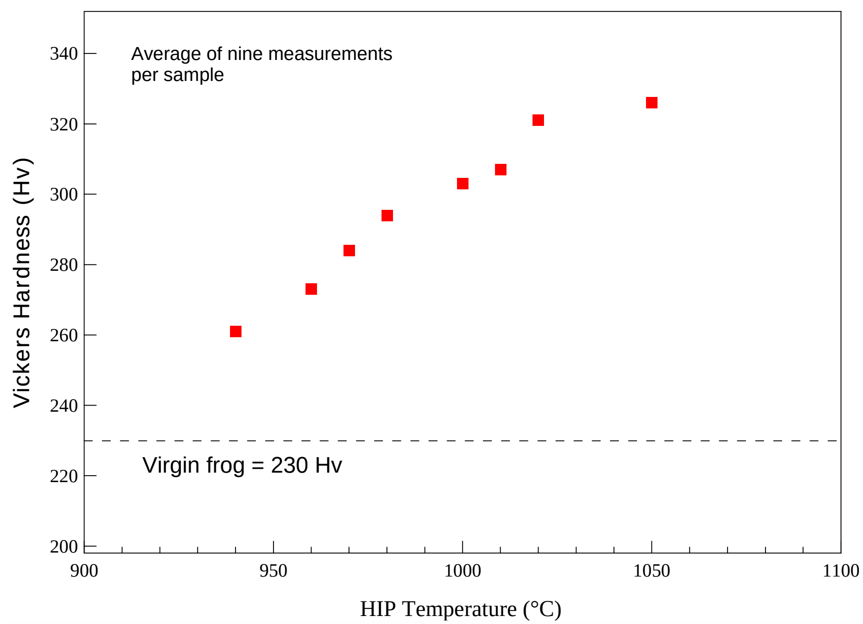
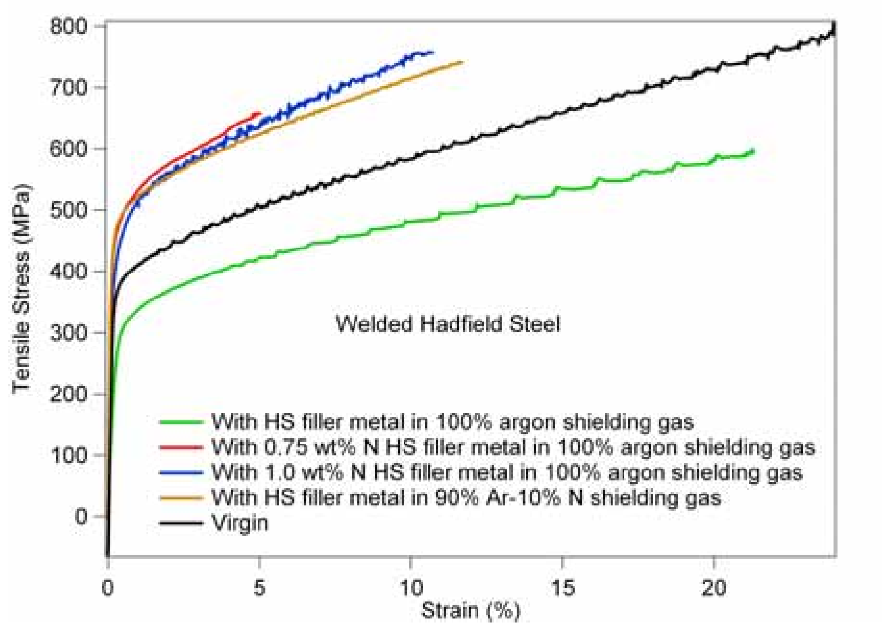
Mechanical Testing

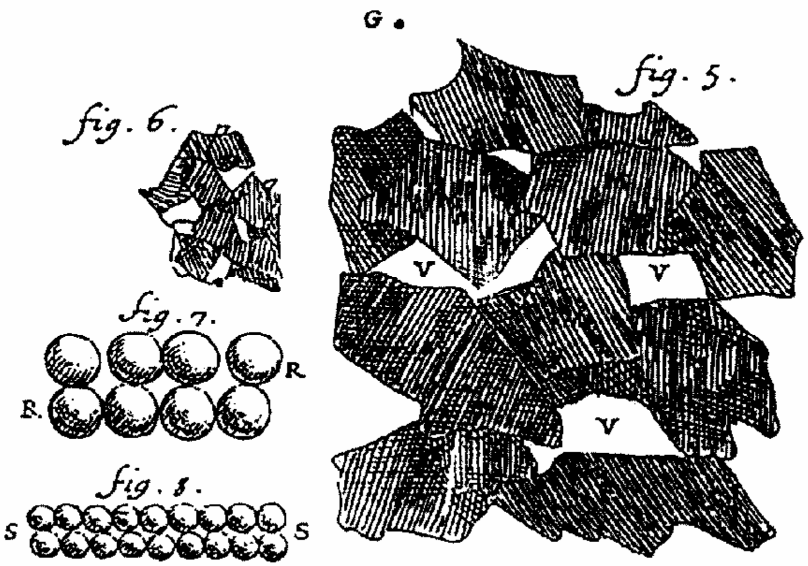




1. Strength increases with increased HIP treatment temperature
2. Some ductility can be regained by a subsequent 980C-30min treatment
3. Vickers hardness reflects strength trends
4. Introducing nitrogen by welding can increase strength



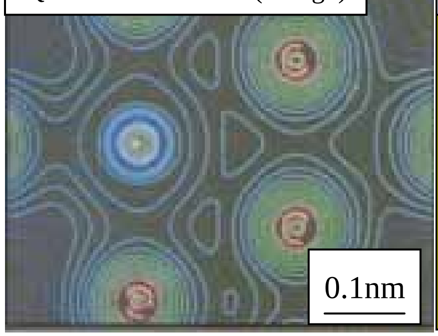
Hierarchical Materials-Mechanics Design



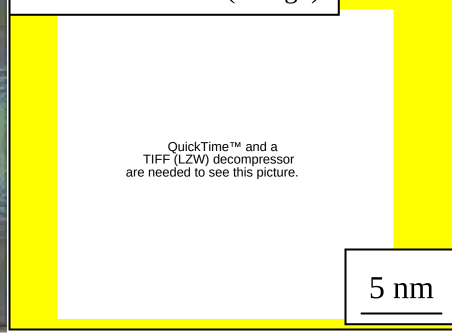
Multilevel Microstructure as envisioned by Reamur in 1722

Physics - Materials Science - Mechanical Sciences and Eng. (Mech./Aero/Civil)

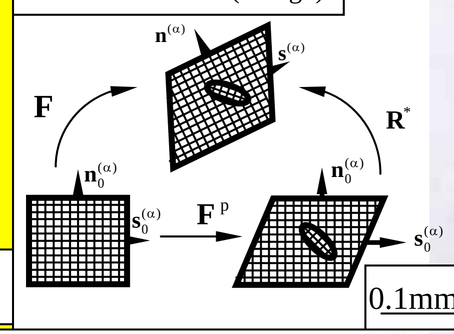
Quantum Mechanics (Design)



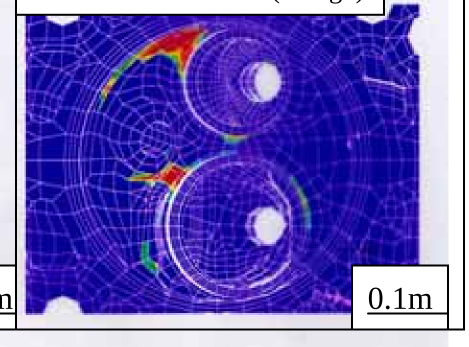
Nano- Mechanics (Design)



Micro-Mechanics (Design)



Structural Mechanics (Design)



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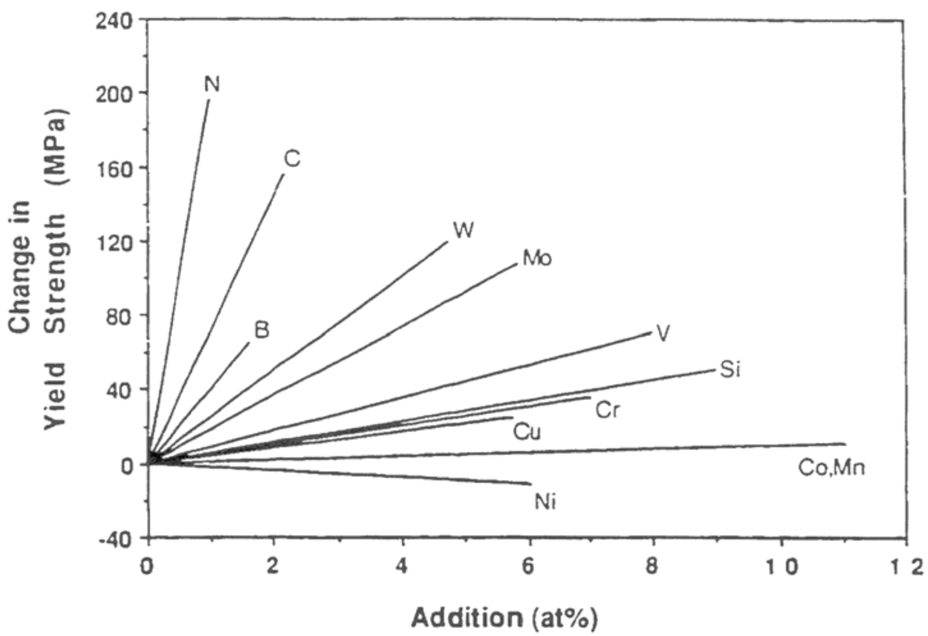
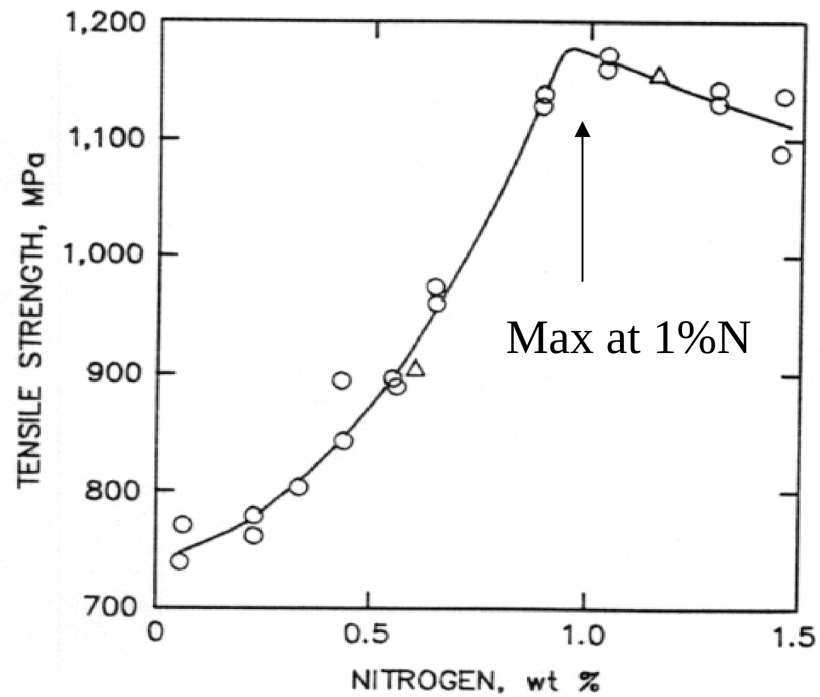
Addition of nitrogen to Fe-based materials



J. Reed, J.Metals, 1989.



Rawers and Slavens (1995)

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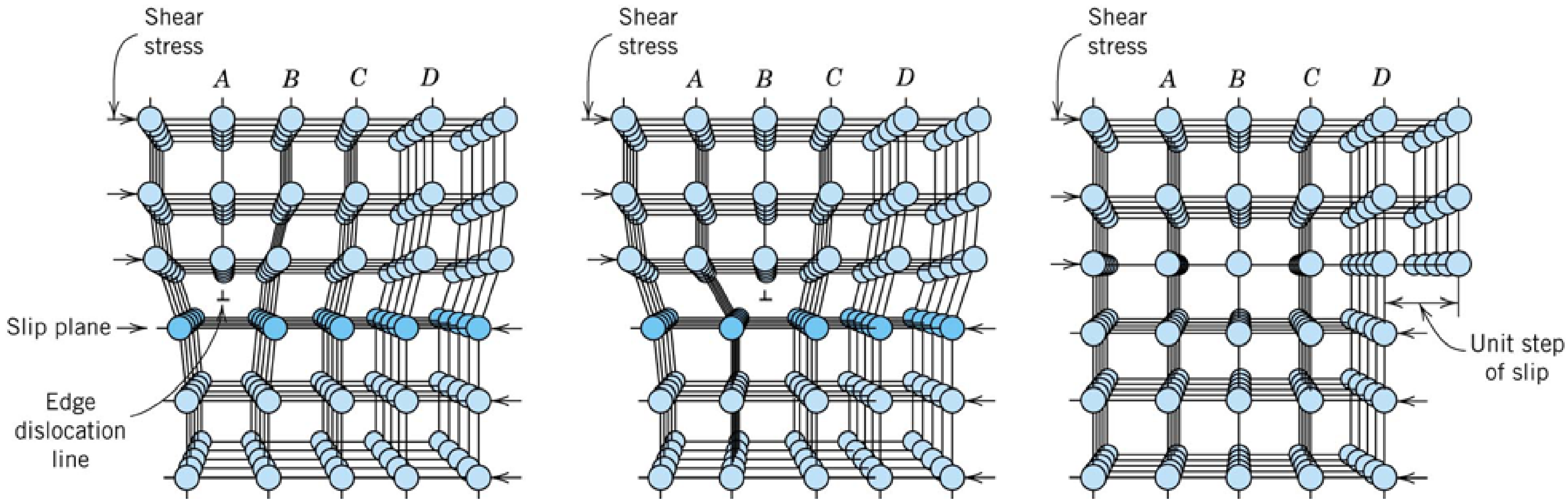
Background- Dislocations are line defects in materials



Callister, Material Science and Engineering: An Introduction

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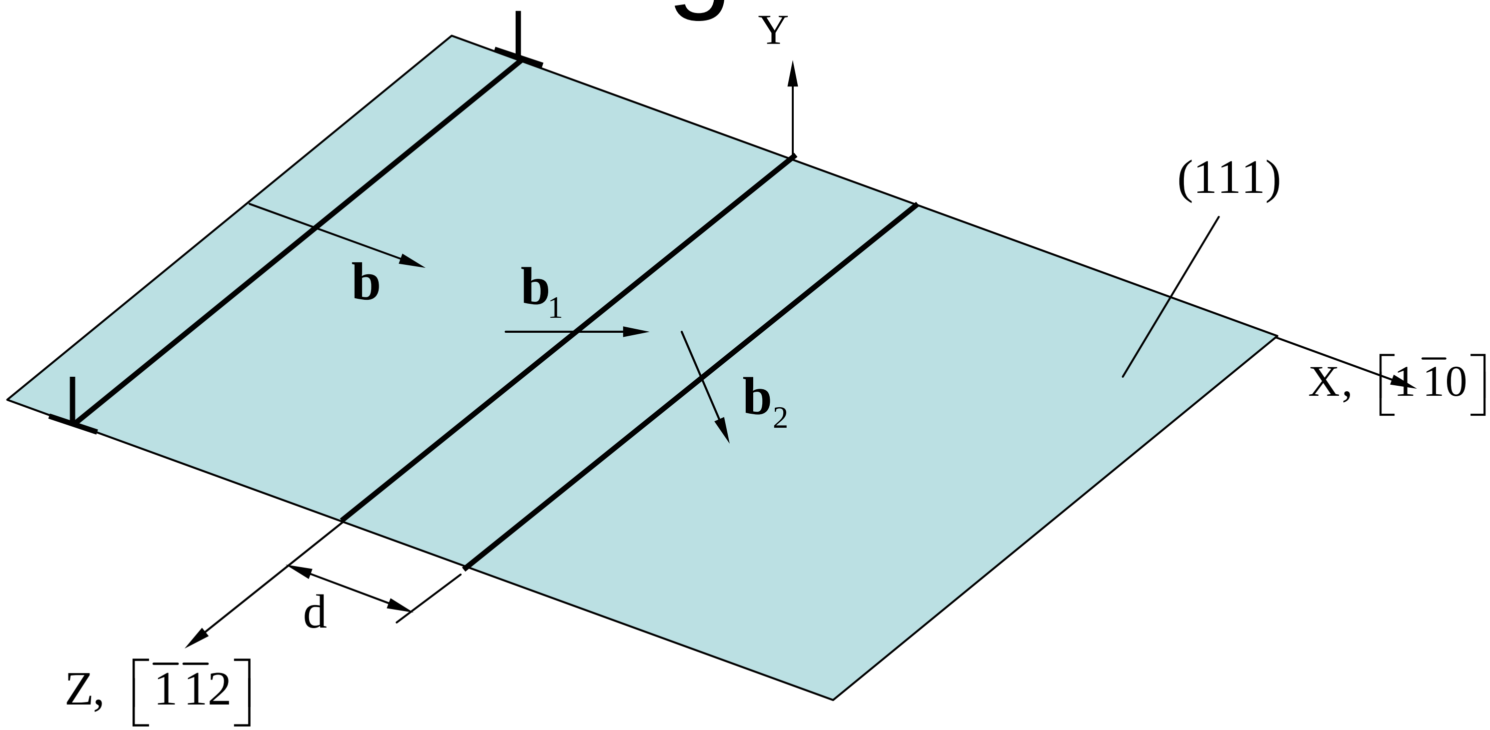
Extended edge dislocation



$$\mathbf{b} = \mathbf{b}_1 + \mathbf{b}_2$$

$$\frac{1}{2}\left[1\bar{1}0\right] = \frac{1}{6}\left[2\bar{1}\bar{1}\right] + \frac{1}{6}\left[1\bar{2}1\right]$$

Z direction is equivalent to <112> direction for GSFE

X direction equivalent to <110> direction for GSFE

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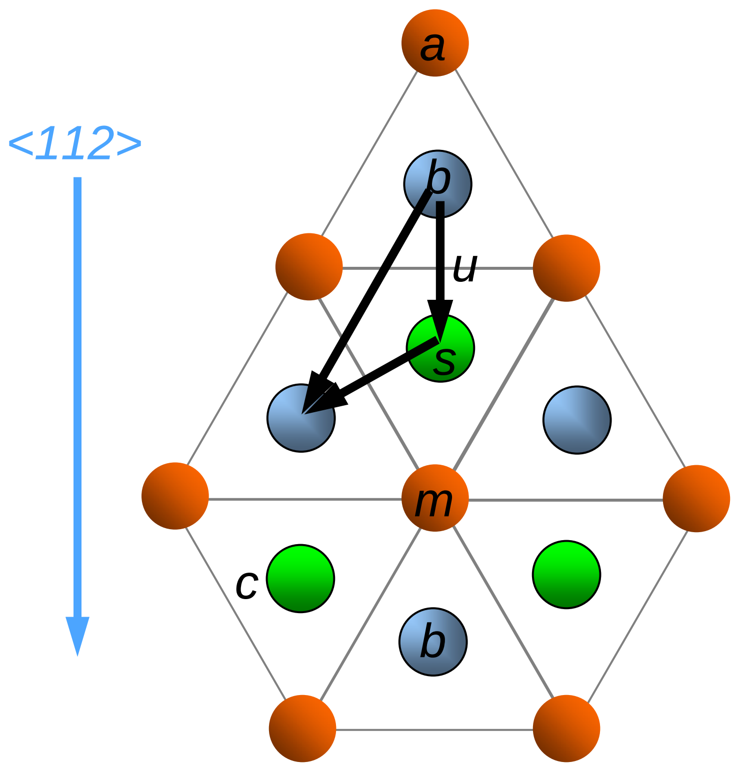
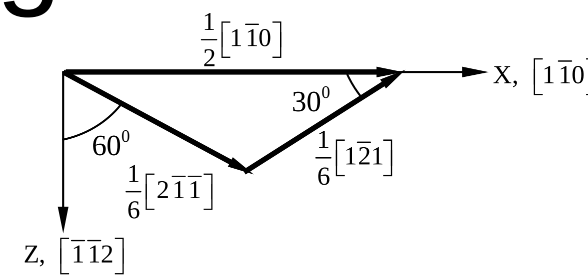
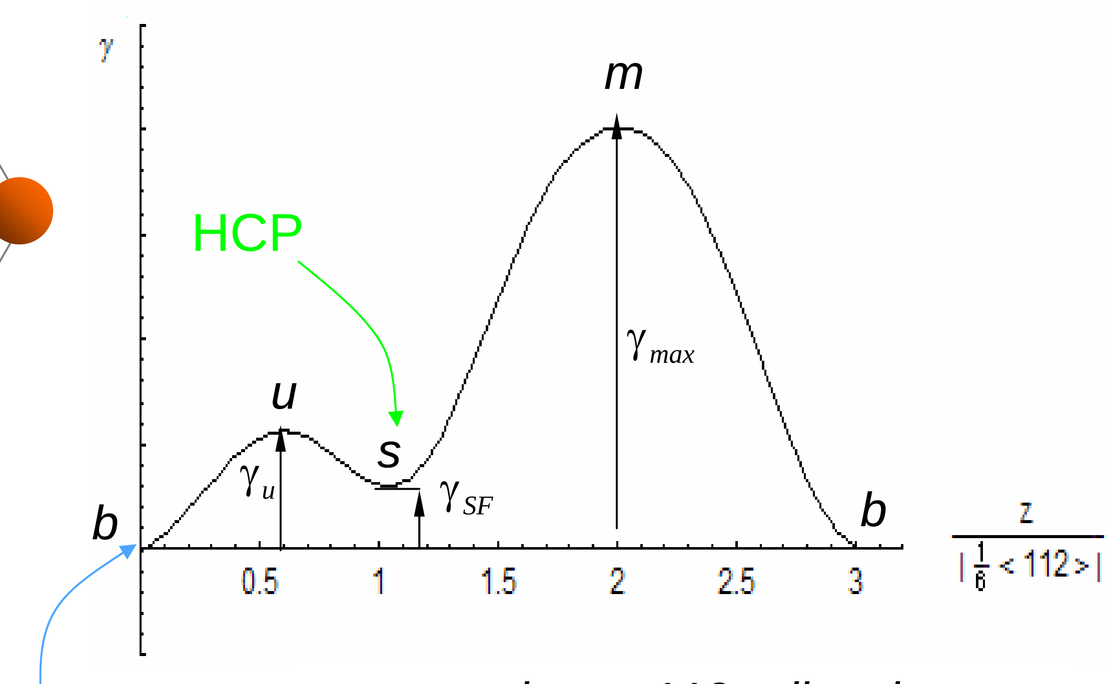
GSFE curve along <112>



FCC lattice



60^0 symmetry of γ surface



γ-curve along <112> direction

S. Kibey, J.B. Liu, M.J. Curtis, D.D. Johnson, H. Sehitoglu, "Stacking Fault Energy and Stacking Fault Widths in High Nitrogen Steels," Acta Mater. 54, 2991-3001 (2006).

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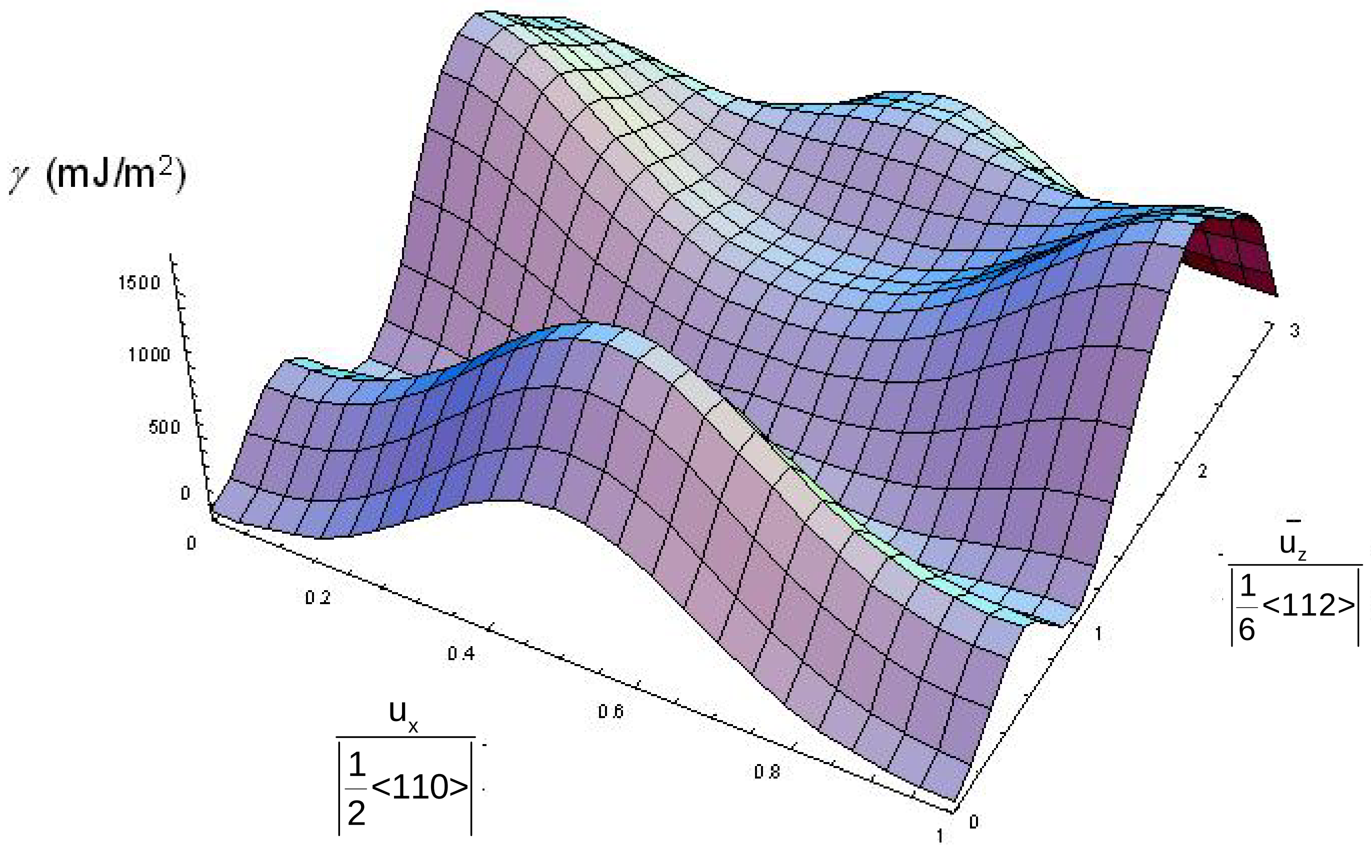
Fourier fit for GSFE Fe-4 at.%N



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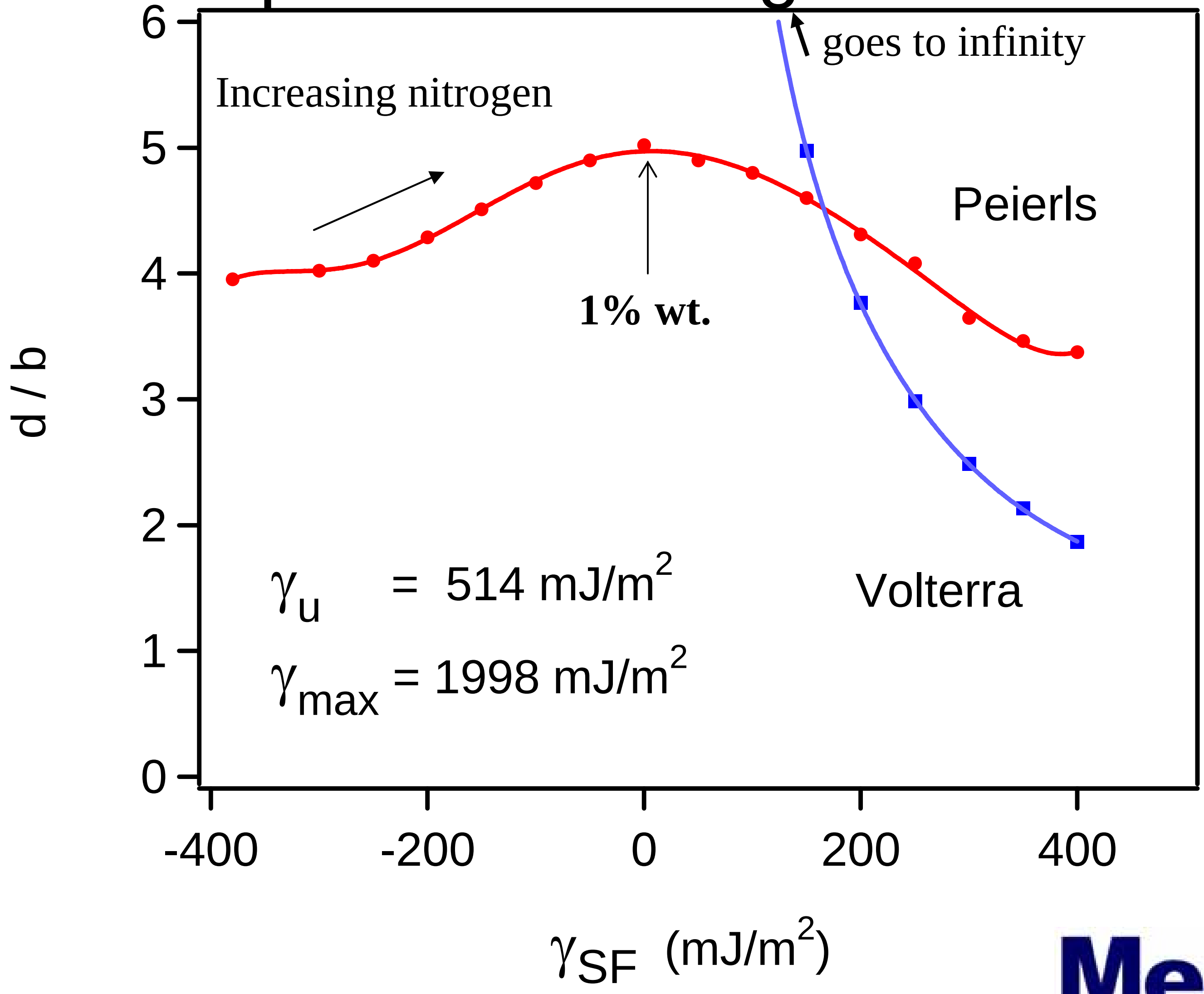
Effect of stable SFE (note finite separation for negative values)



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Talk Outline (Konuşma Taslağı)

•Fatigue/Deformation Preliminaries (Yorulma)

•Wheels- Thermo-mechanical Fatigue

(Tekerlekler,Termo-mekanik Yorulma)

•Rails- Ratcheting and Fatigue/Wear

(Raylar- Gerinme ve Aşınma)

•Materials Design- Diamond Crossing

•(Yeni Mazemelerin Atomik Boyutta Tasarımı-Makas Elması)

•Bearings- Cone Bore Growth

(Rulmanlı Yataklar)

•Conclusions (Sonuçlar)

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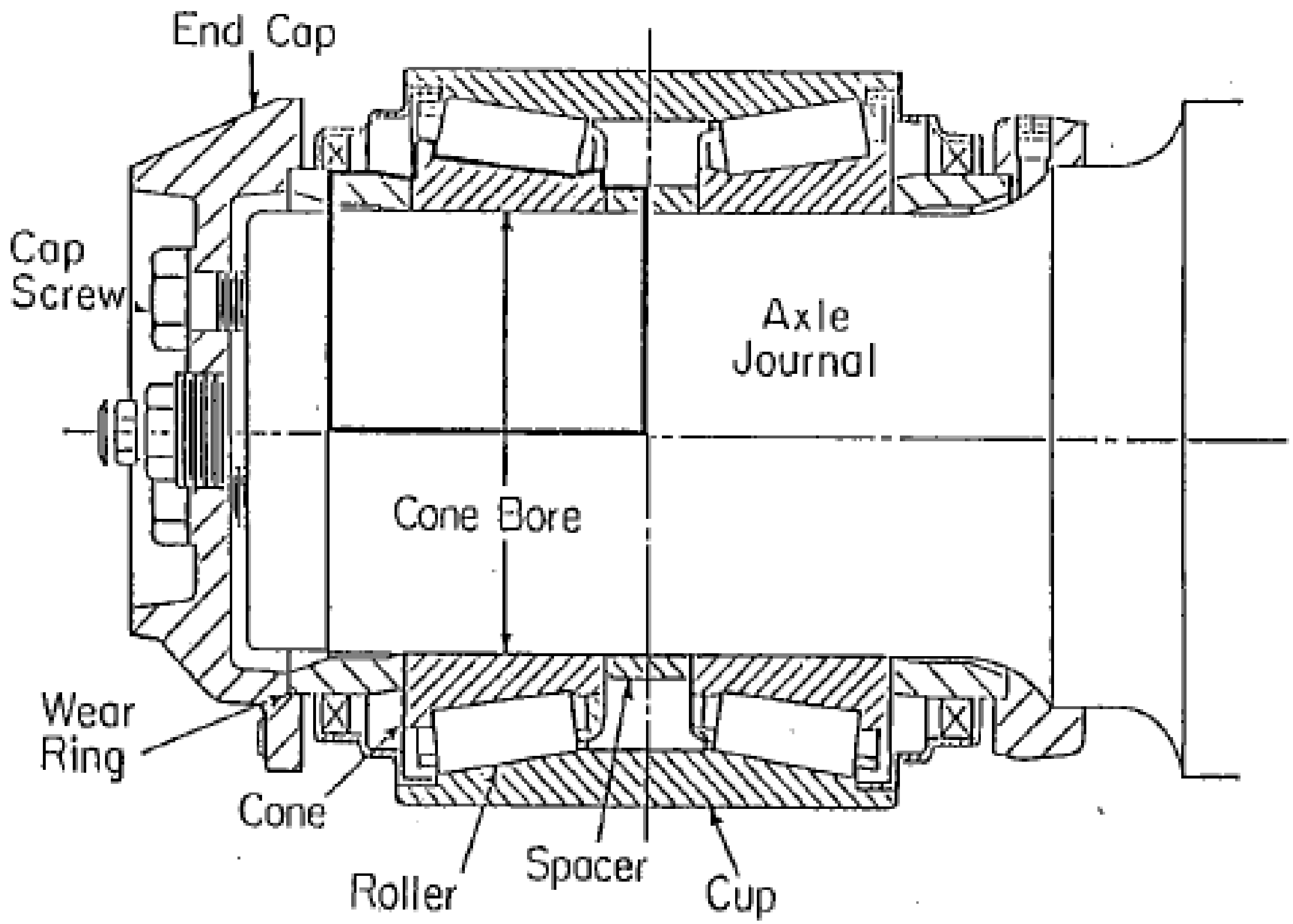
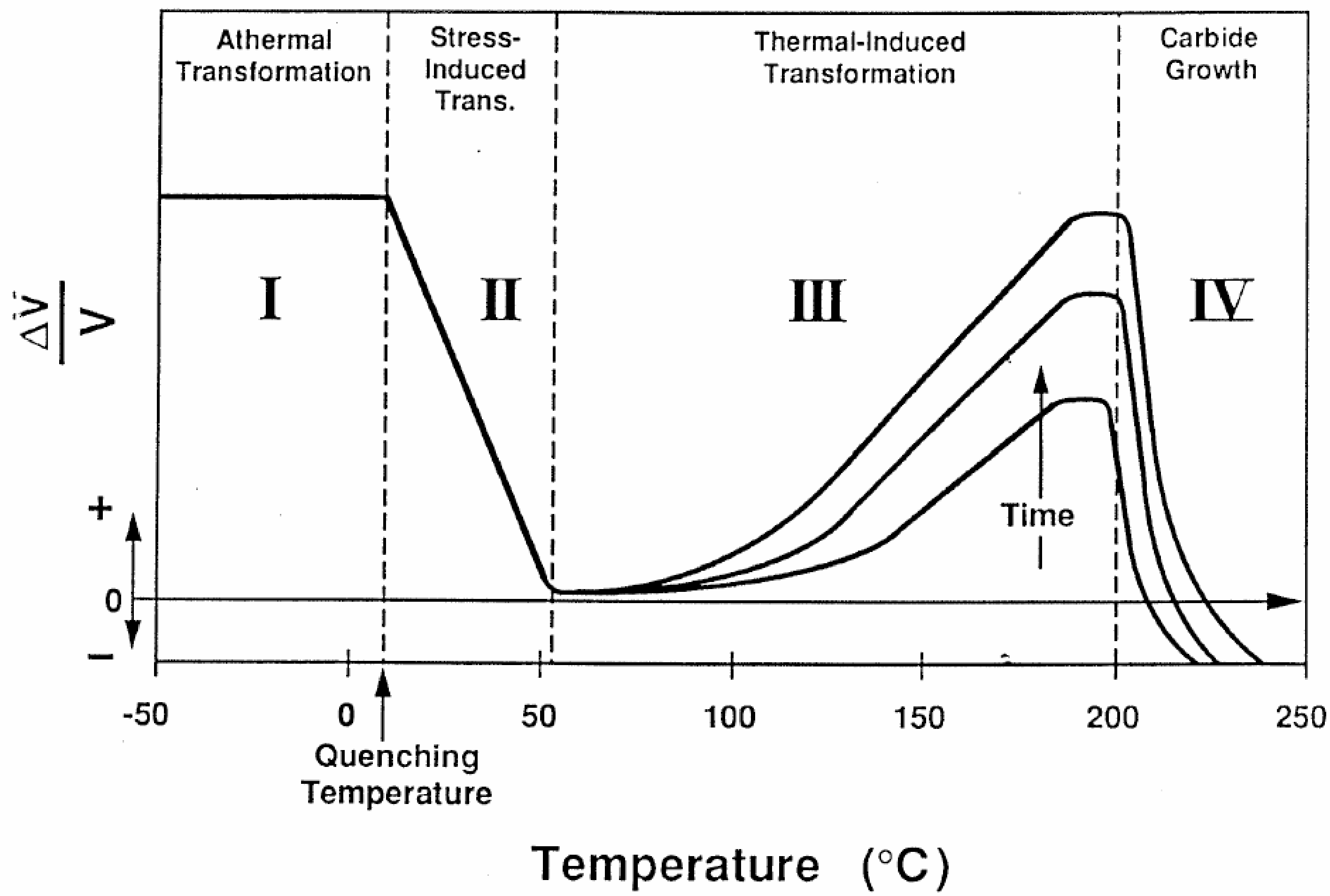


Neu, R. and H. Sehitoglu, "Determination of Cone Bore Growth Due to Microstructural Changes," *ASME Journal of Tribology*, 112, 433-441, 1990.

Neu, R. and H. Sehitoglu, "Transformation of Retained Austenite in Carburized 4320 Steel," *Metallurgical Transactions*, 22A, 1491-1500, 1990.

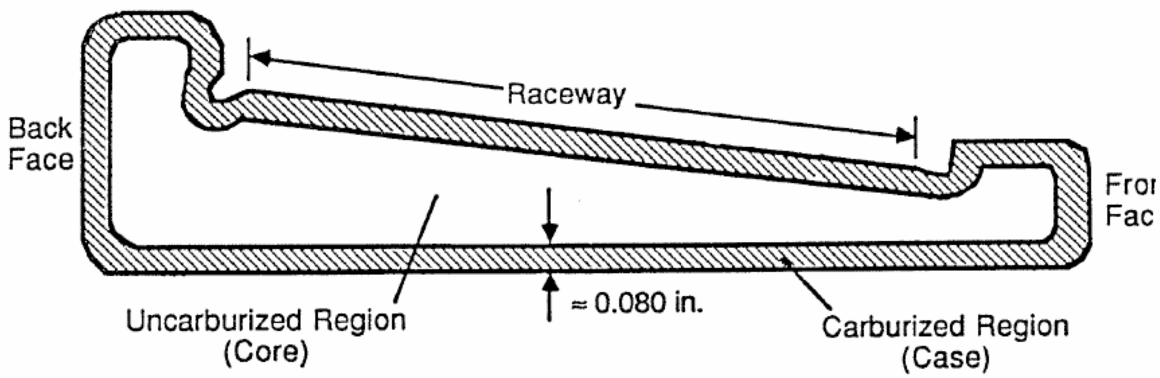
SUMMARY OF MECHANISMS



Neu, R. and H. Sehitoglu, "Low-Temperature Creep of a Carburized Steel," *Metallurgical Transactions*, 23A, 2619-2624, 1992.

Neu, R. and H. Sehitoglu, "Thermal-Induced Transformations of Retained Austenite in the Simulated Case of a Carburized Steel," *ASME Journal of Engineering Materials and*

Cross Section of Cone



CROSS SECTION OF CARBURIZED CONE SHOWING THE EXTENT OF CARBURIZED REGION

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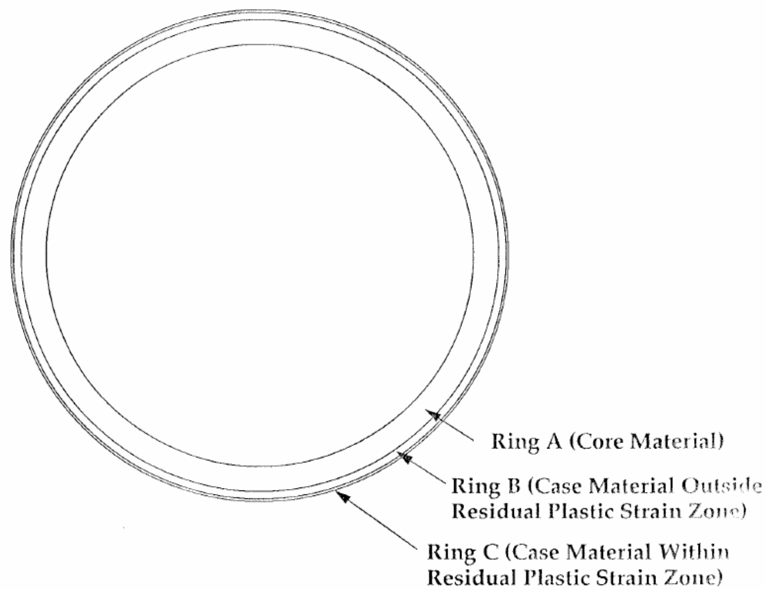
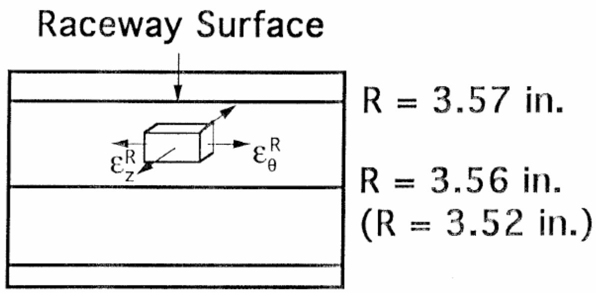
MODIFIED THREE RING MODEL





Neu, R. and H. Sehitoglu, "Simulation of Cone Bore Growth in Bearings with a Three-Ring Model," *ASME Journal of Applied Mechanics*, 61:3,589-595, 1994.

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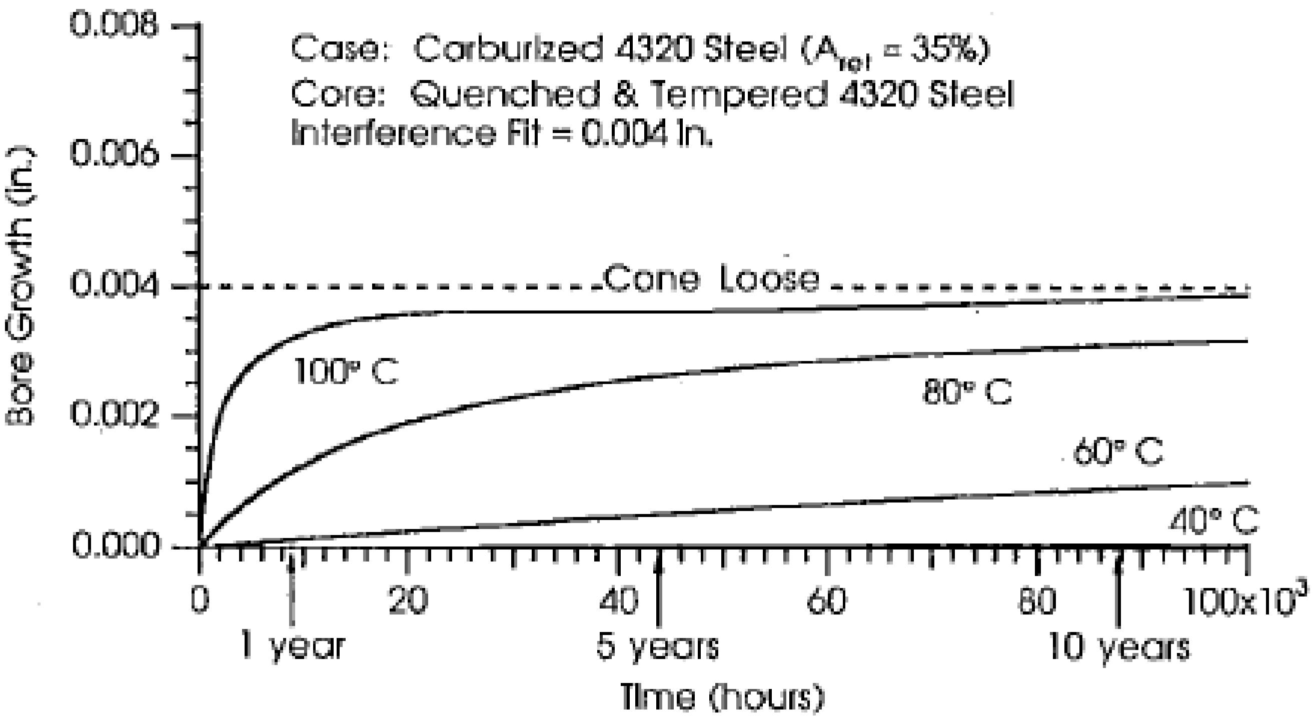
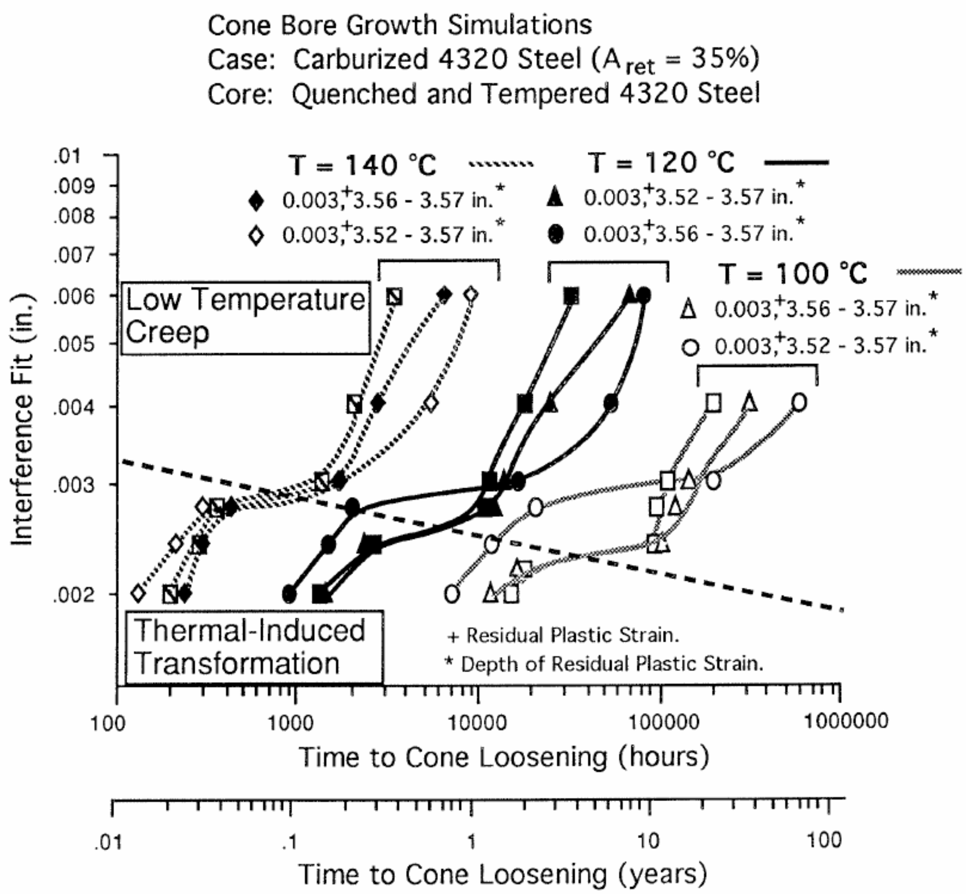


Case: Carburized 4320 Steel (A_{ret} = 35%)
Core: Quenched & Tempered 4320 Steel
Interference Fit = 0.004 in.
Cone Loose
100° C
80° C
60° C
40° C
Bore Growth (in.)
0.008
0.006
0.004
0.002
0.000
0
20
40
60
80
100x10³
1 year
5 years
10 years
Time (hours)



CONE BORE GROWTH SIMULATIONS USING THE THREE RING MODEL (A_{RET}=35%)

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Conclusions (Sonuçlar)

(1) ‘Mechanics of Materials’ plays a crucial role in understanding the integrity of the rails, wheels,crossings, bearings and other components. (Maddeler mekaniği ray, tekerlek,makas, ve yatay rulmanların güvenirliğini anlamak açısından önemli bir rol oynamaktadır.)

(2) New tools are available for experiments and modeling in the ‘mechanics and materials’ fields.(Deneyler ve model yapmak için mühendislikte yeni gelişmeler ortaya çıkmaktadır.)

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