FE MODELING OF CARBIDE ASSISTED CYCLIC HARDENING IN BEARING STEELS DURING ROLLING CONTACT FATIGUE

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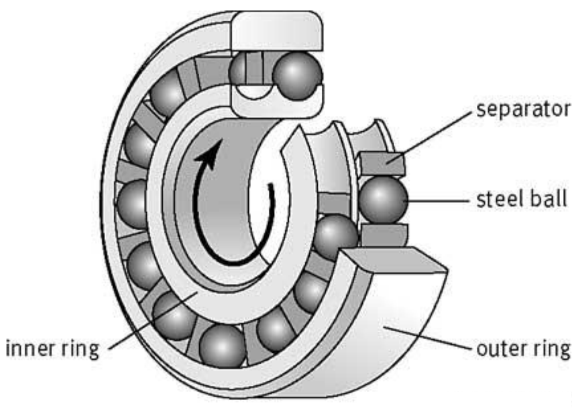
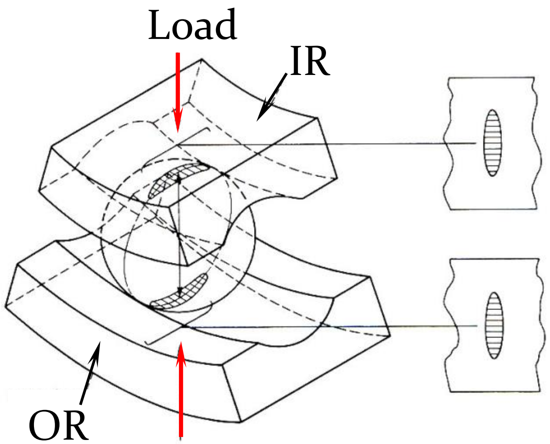
Outline

- Introduction to Rolling Contact Fatigue
- Experimental findings and interpretations (3 ball-on-rod tests)
- Research objective
- FEA modeling technique
- Comparison of results (experimental vs. simulation)
- Conclusions

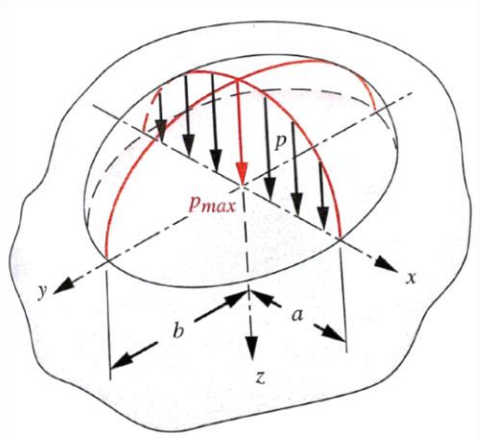
Rolling Contact Fatigue (RCF)



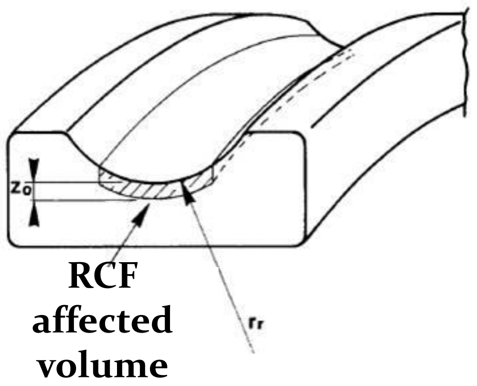
Ref: images.yourdictionary.com



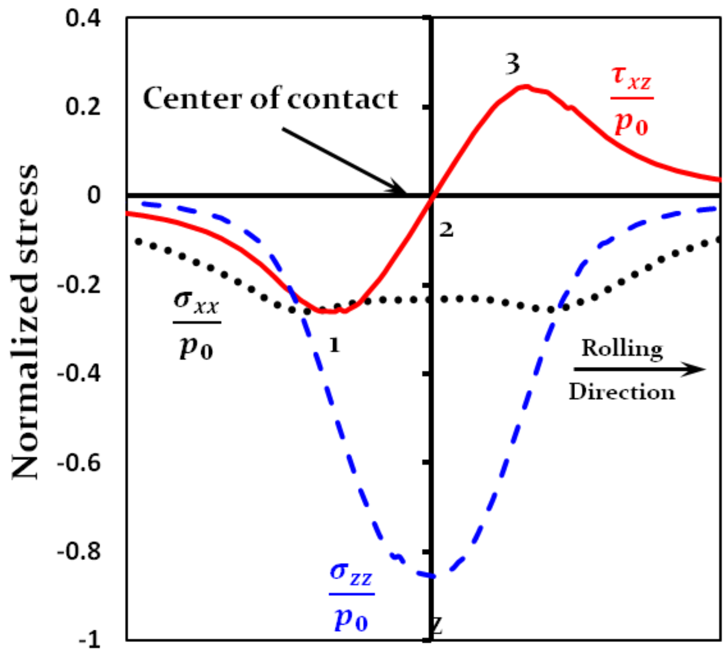
Ref: Hamrock B. & Dowson D. (1981)

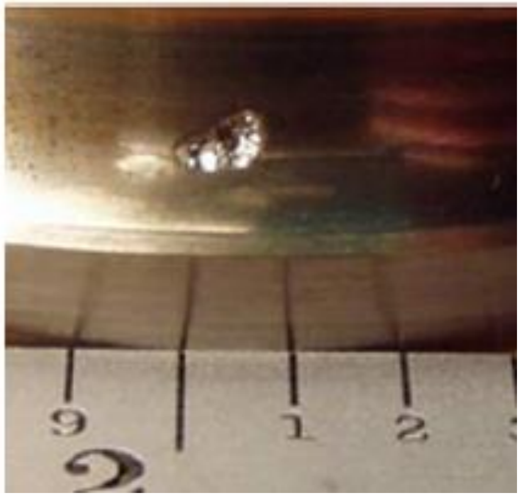


Ref: Norton R. (2000)



Ref: Lundberg & Palmgren (1947)



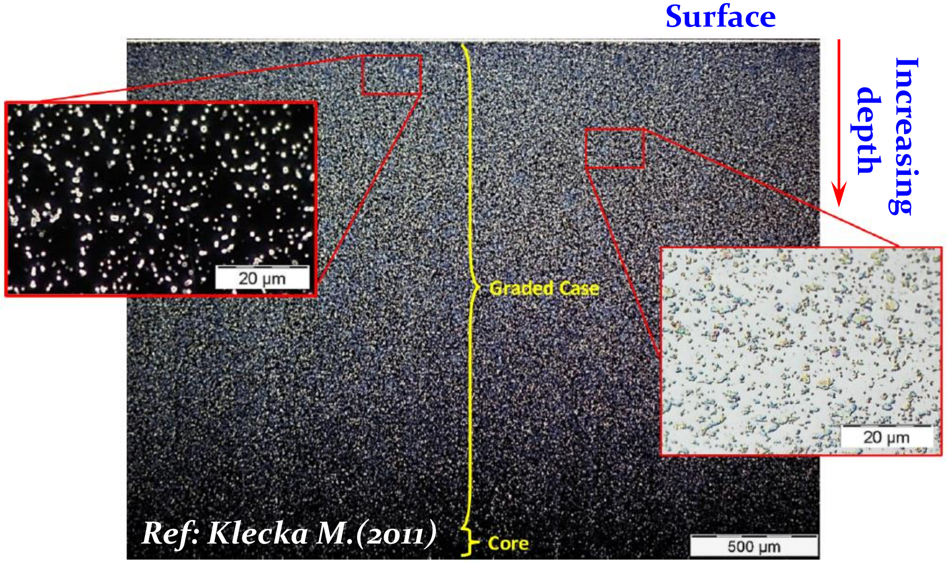


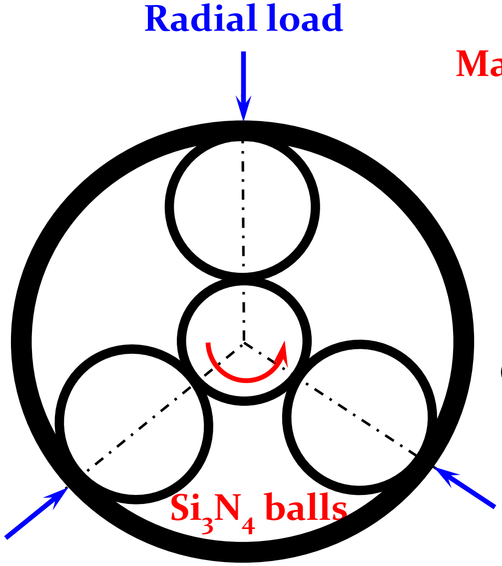
Ref: Branch N. (2010)

Accelerated Ball-on-Rod RCF Test

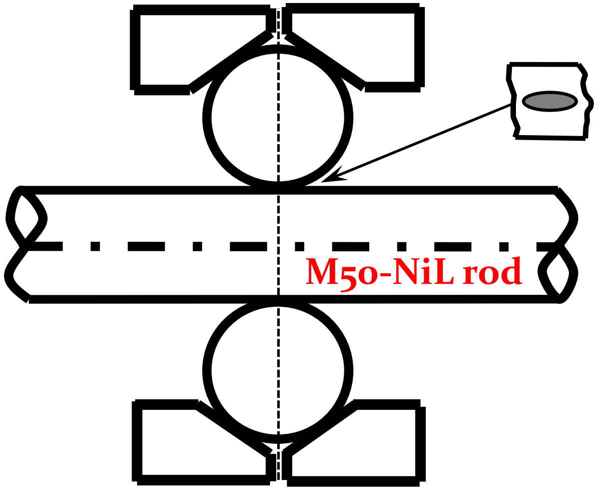
M50-NiL bearing steel

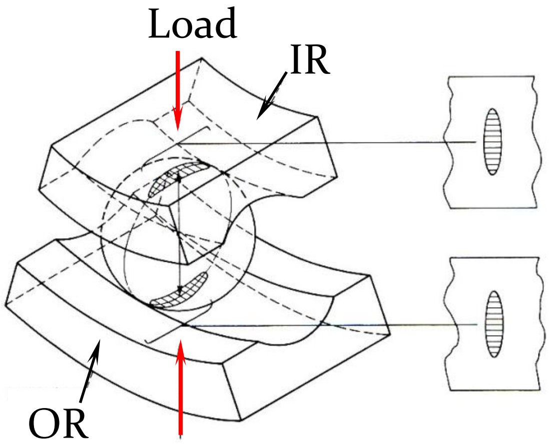
- Case hardened steel
- Graded material properties
- Vanadium carbides
- Spherical, uniformly distributed and ~1 µm





8600 RCF cycles/min
Max. Hertz stress can be controlled





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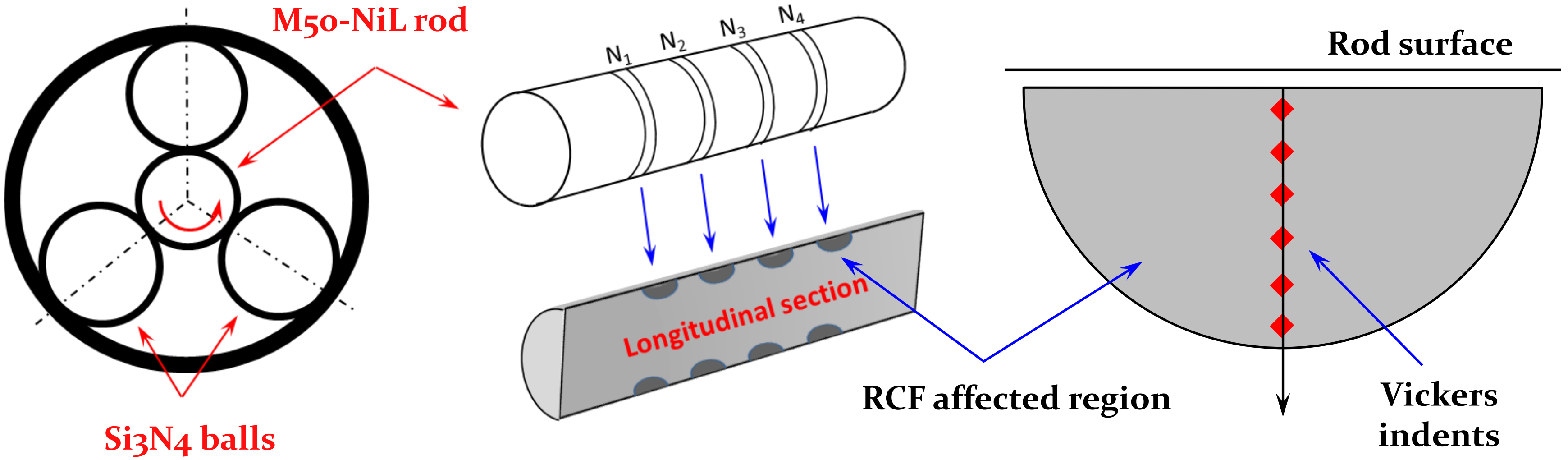
Experimental Results

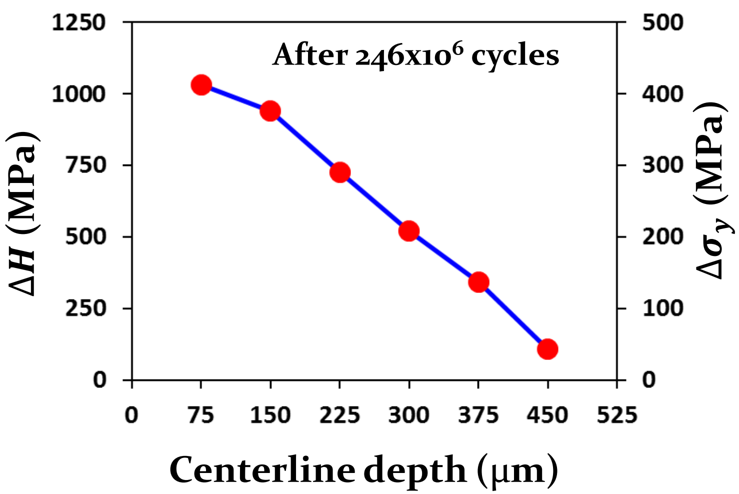


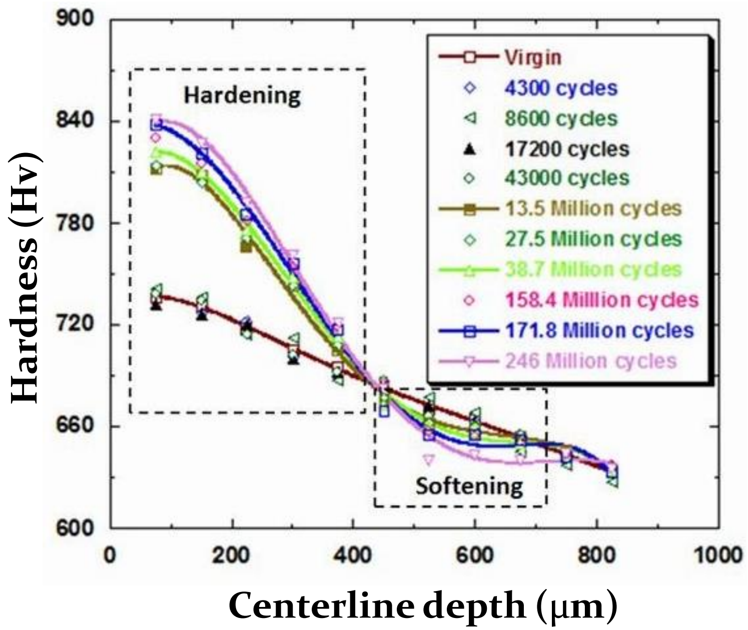
Tabor's rule

$$\sigma_y = \frac{H}{CF}$$

For M50-NiL

$$CF = 2.5$$





Ref: Bhattacharyya et al.(2014)

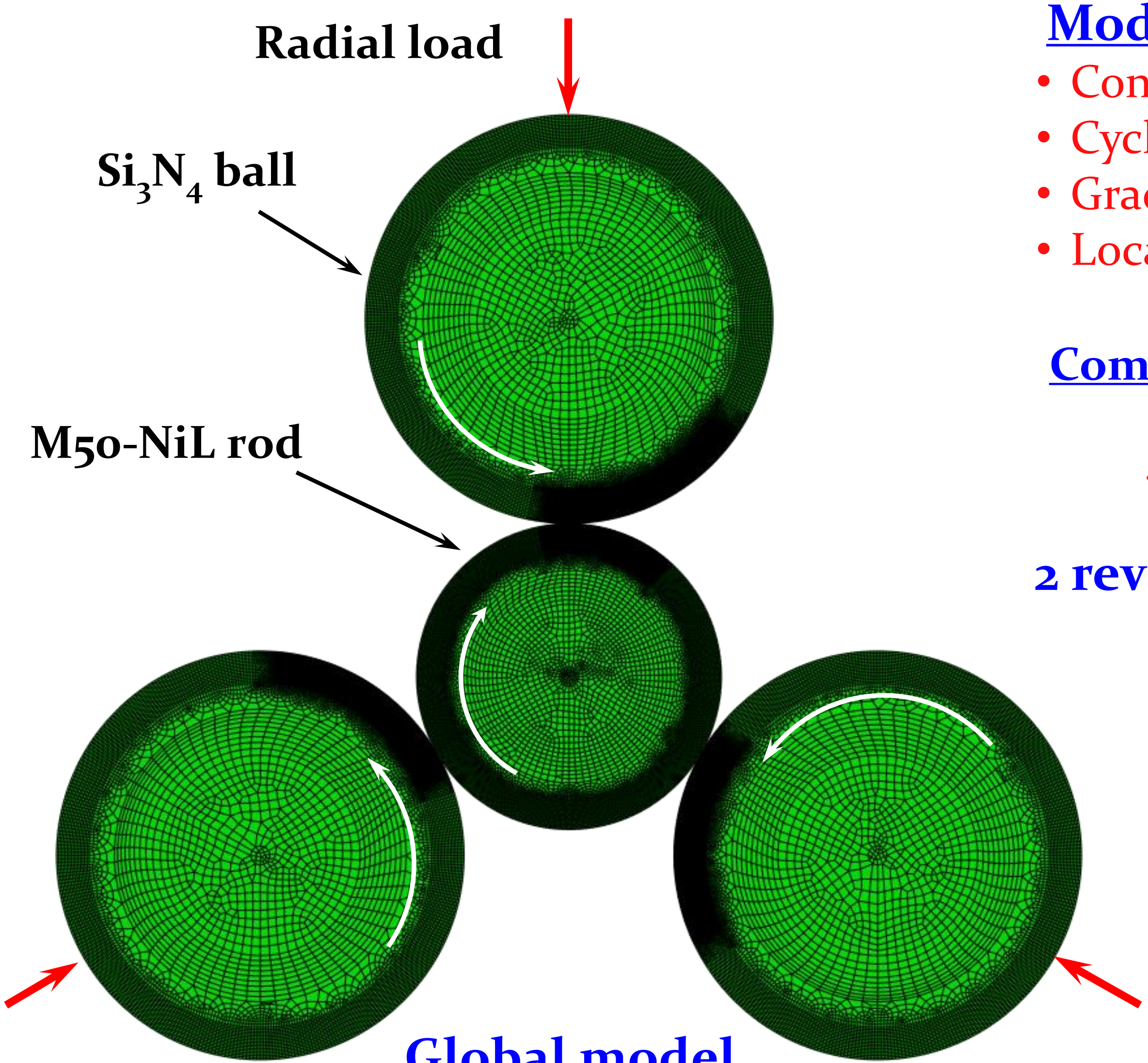
Research Goals

The primary objective of this research is to understand the cause of such increase in hardness over millions of RCF cycles i.e. *cyclic hardening*.

In doing so we would also learn,

- The response of bearing steels to the RCF loads
- Role of microstructure towards RCF failures
- Account for material plasticity
- Determination of cyclically evolving stress-strain fields

Finite Element Model of RCF Test



Global model

Model accounts for:

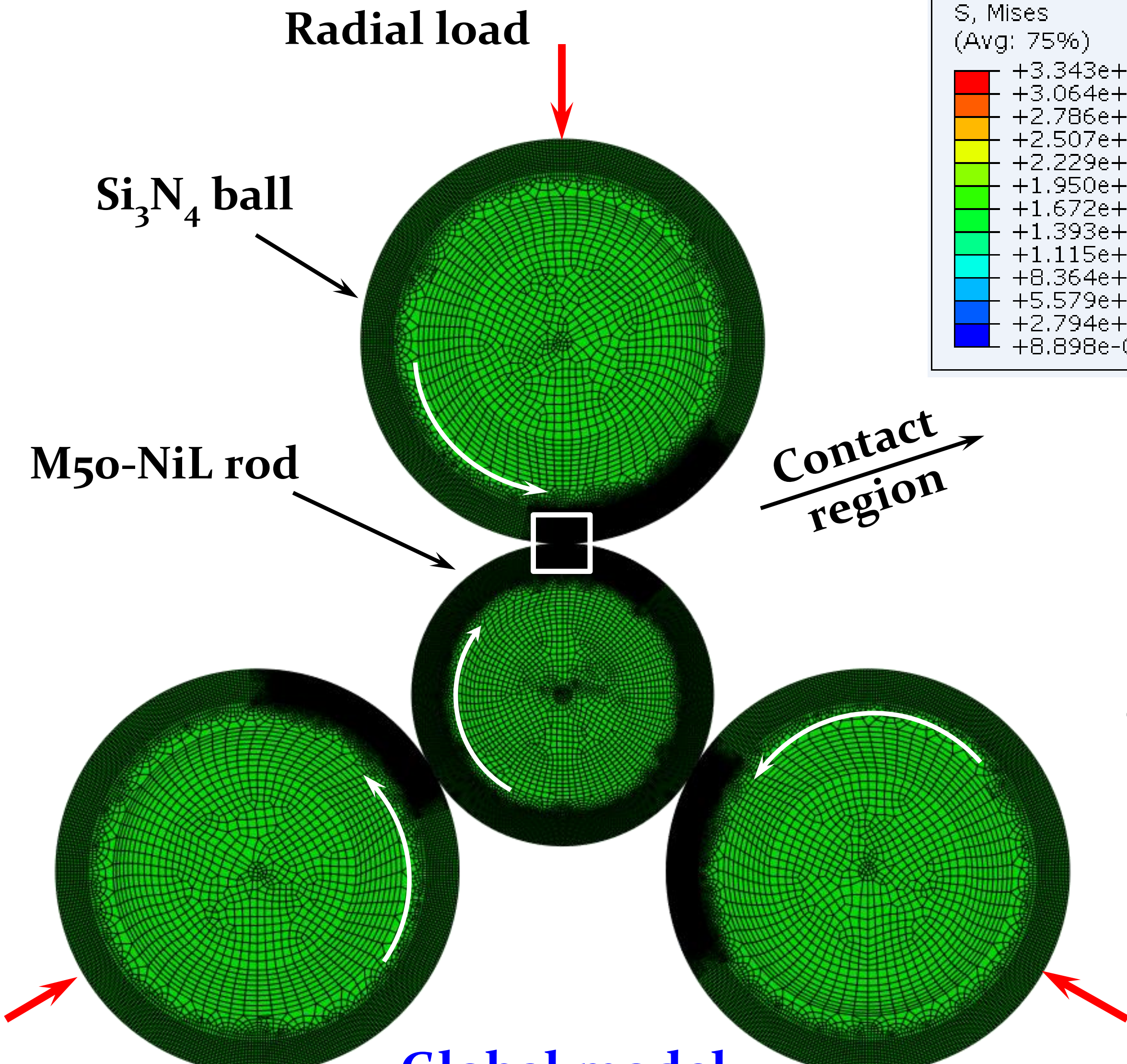
- Continuously changing contact
- Cyclic plasticity
- Graded material properties
- Localized & Multiaxial stresses

Computationally expensive

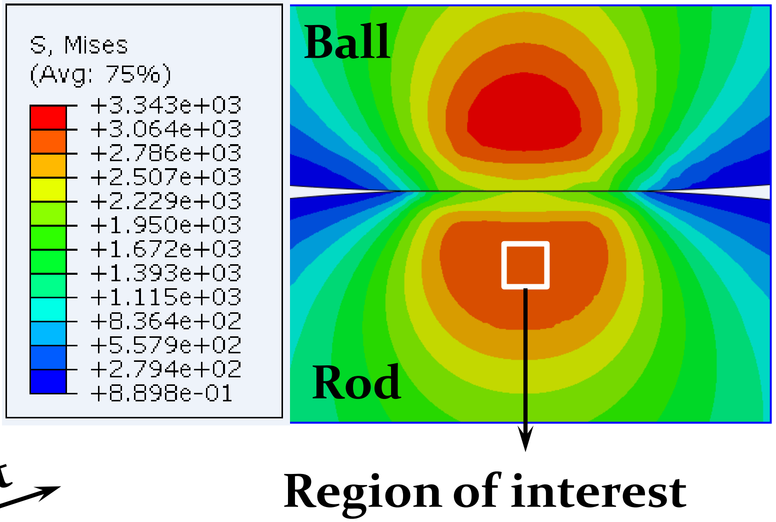
40 hrs./rev of rod

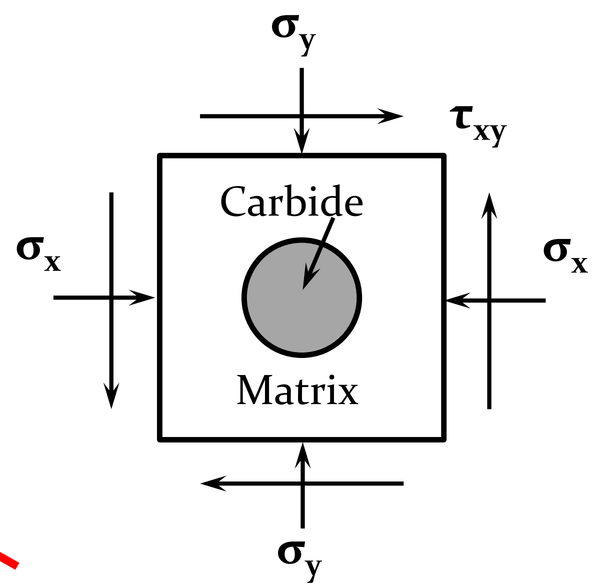
2 revolutions are simulated i.e. 6 RCF cycles

Finite Element Model of RCF Test



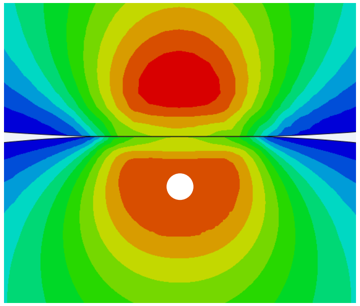
Global model





Submodel

Orthogonal Shear Stress Cycle



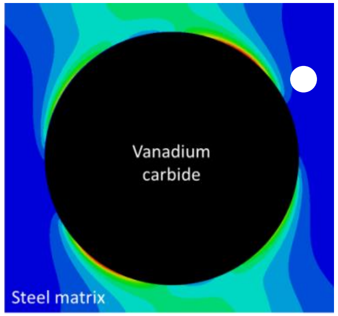
Carbides (or any other form of heterogeneity)

↓

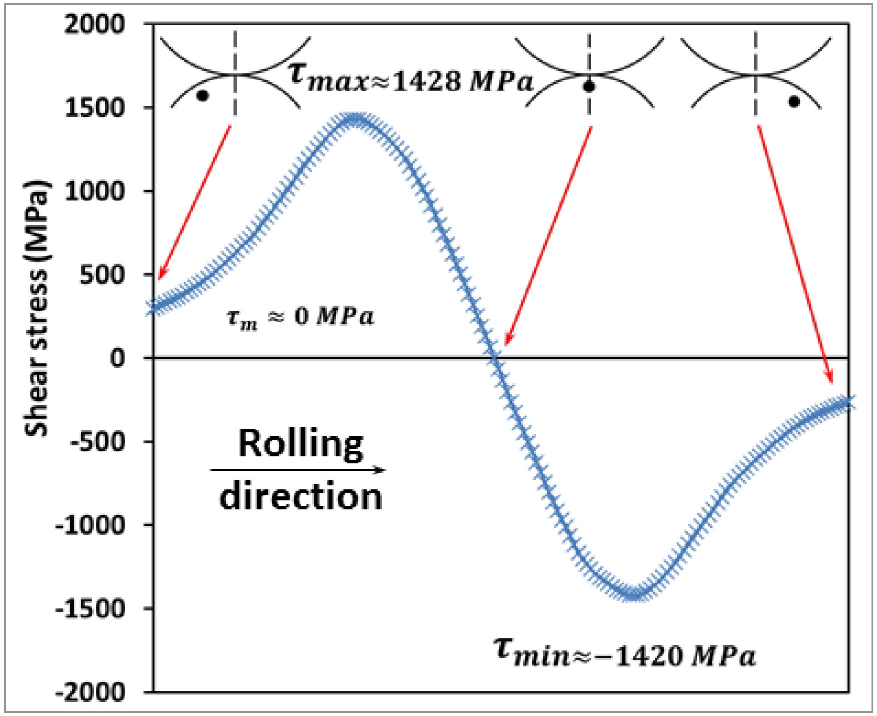
Alter shear stress cycle

↓

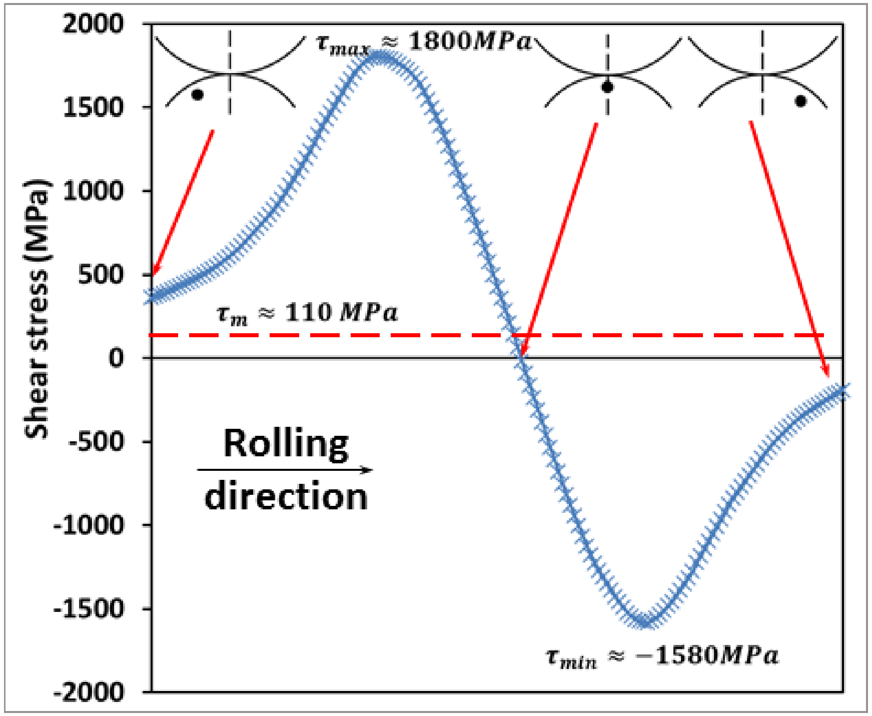
Non-zero mean shear stress



Global model (without carbides)

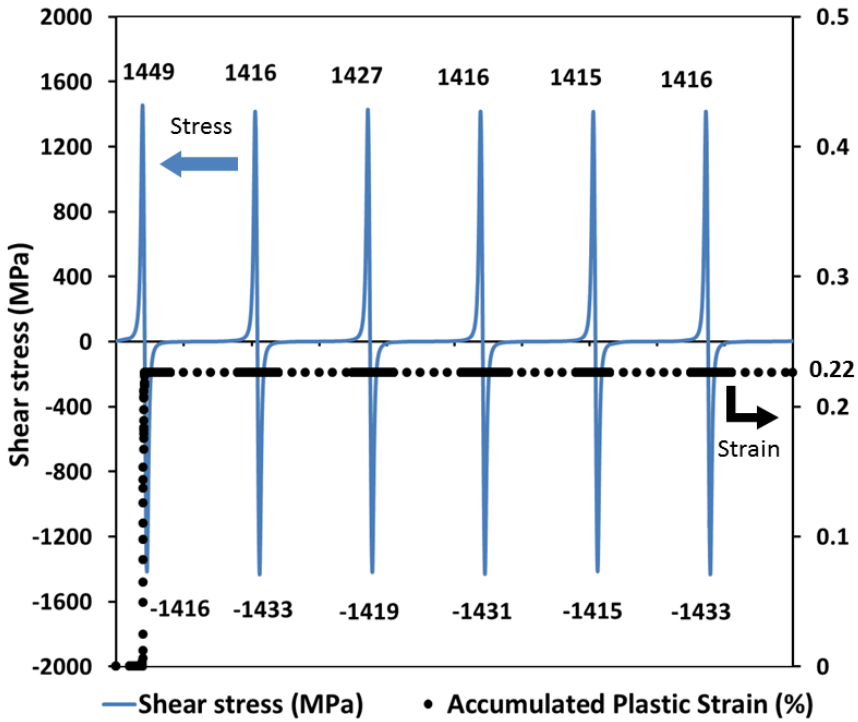


Submodel (with Carbides)



Ratcheting Near Carbide Particle

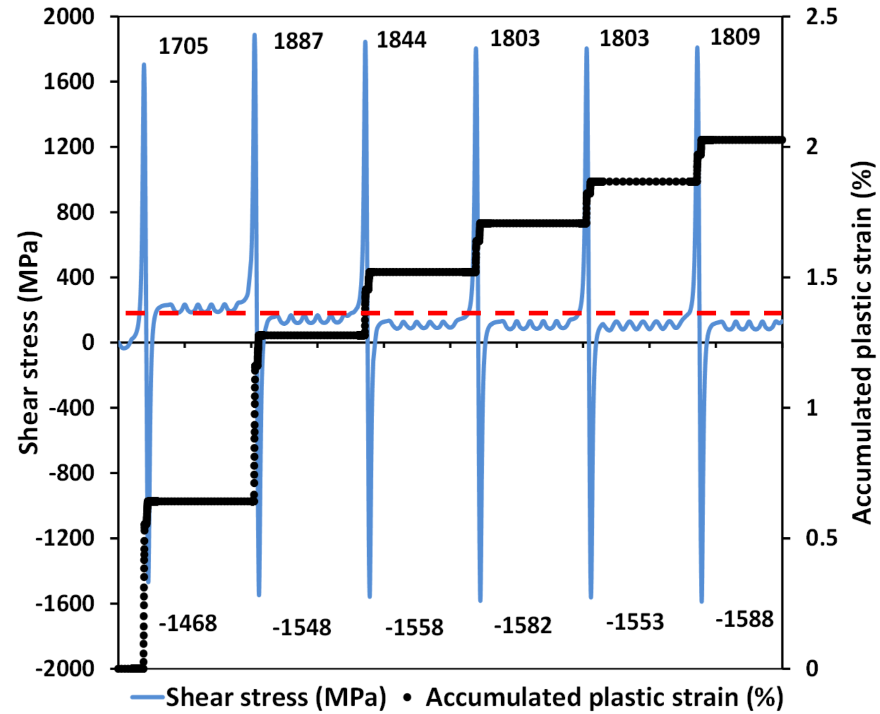
Global model (without carbide)



Global model does not cyclically accumulate plastic strain

Elastic shakedown

Submodel (with carbide)

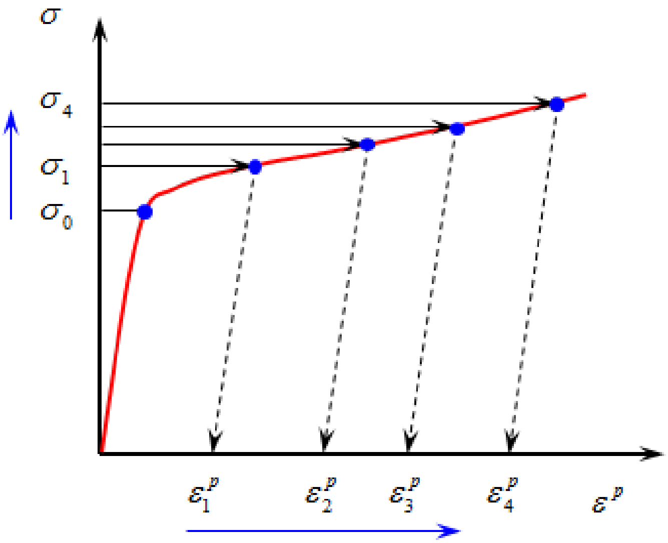


The stress concentration and non-zero mean stress promote continuous plastic strain accumulation

Ratcheting mechanism

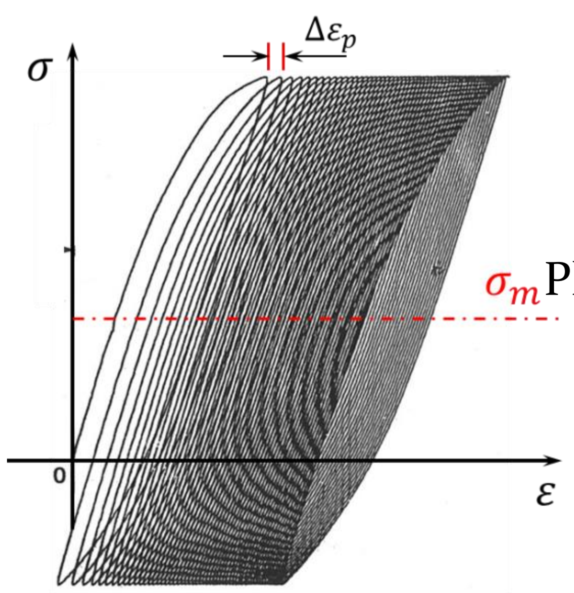
A.S. Pandkar, N. Arakere, G. Subhash, "Microstructure-sensitive accumulation of plastic strain due to ratcheting in bearing steels subject to Rolling Contact Fatigue", **International Journal of Fatigue**, 63 (2014) 191-202.v

Ratcheting ⇔ Cyclic hardening



Monotonic loading

Plastic strain accumulation ⇔ Material hardening (Increase in yield stress)



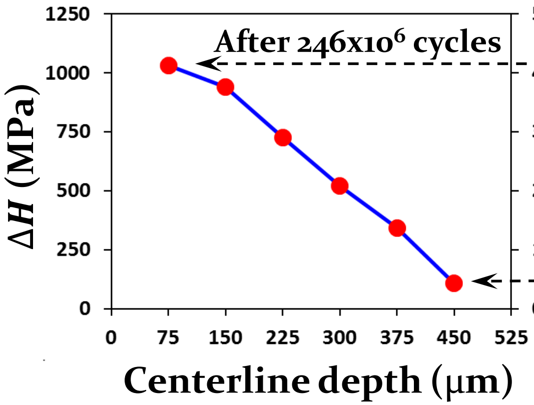
Cyclic loading

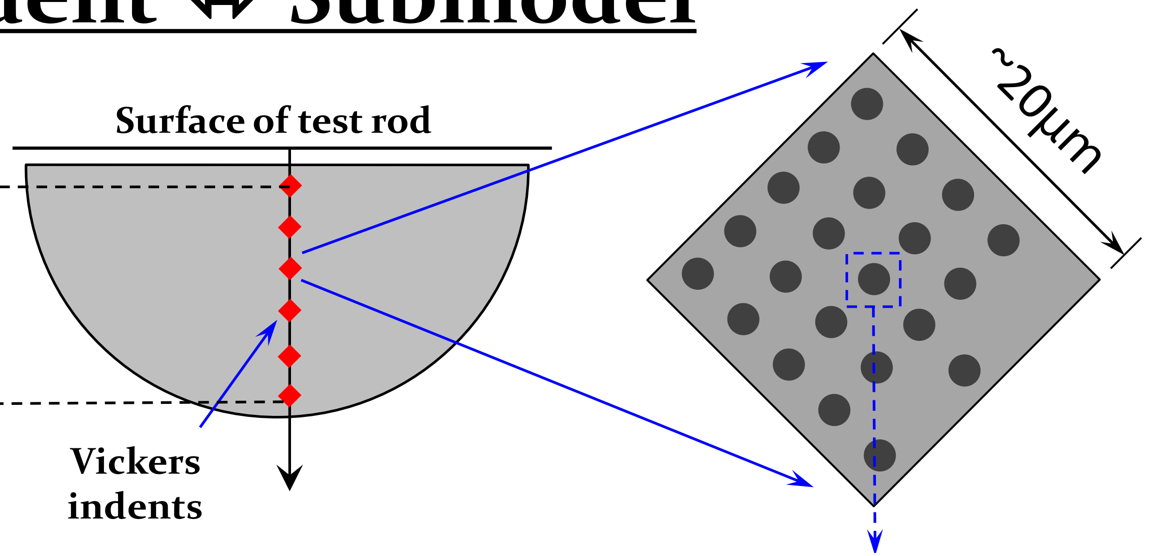
Continuous Plastic strain accumulation (**Ratcheting**) ⇔ Continuous Yield stress increase (**Cyclic hardening**)

localized ratcheting ⇔ cyclic hardening

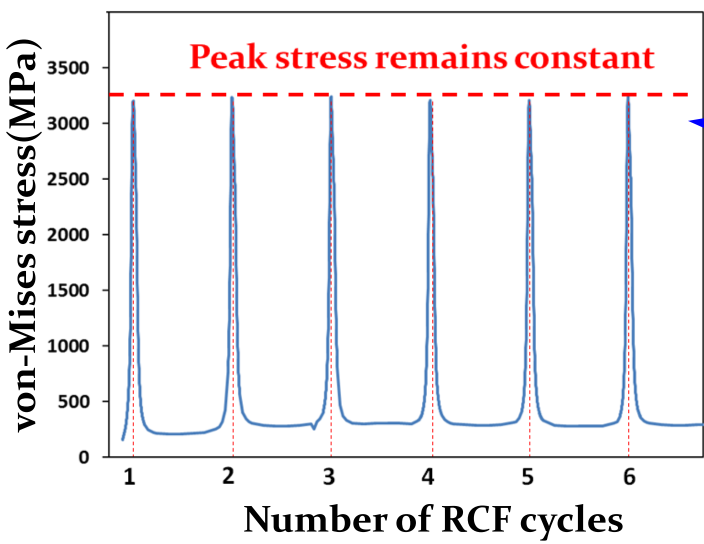
Ref: Stephens et al.(2000)

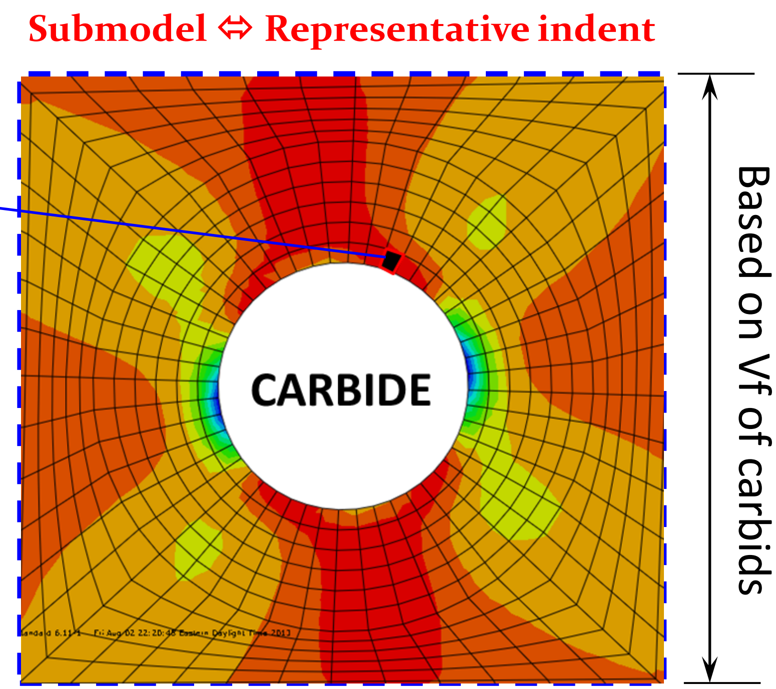
Indent ⇔ Submodel



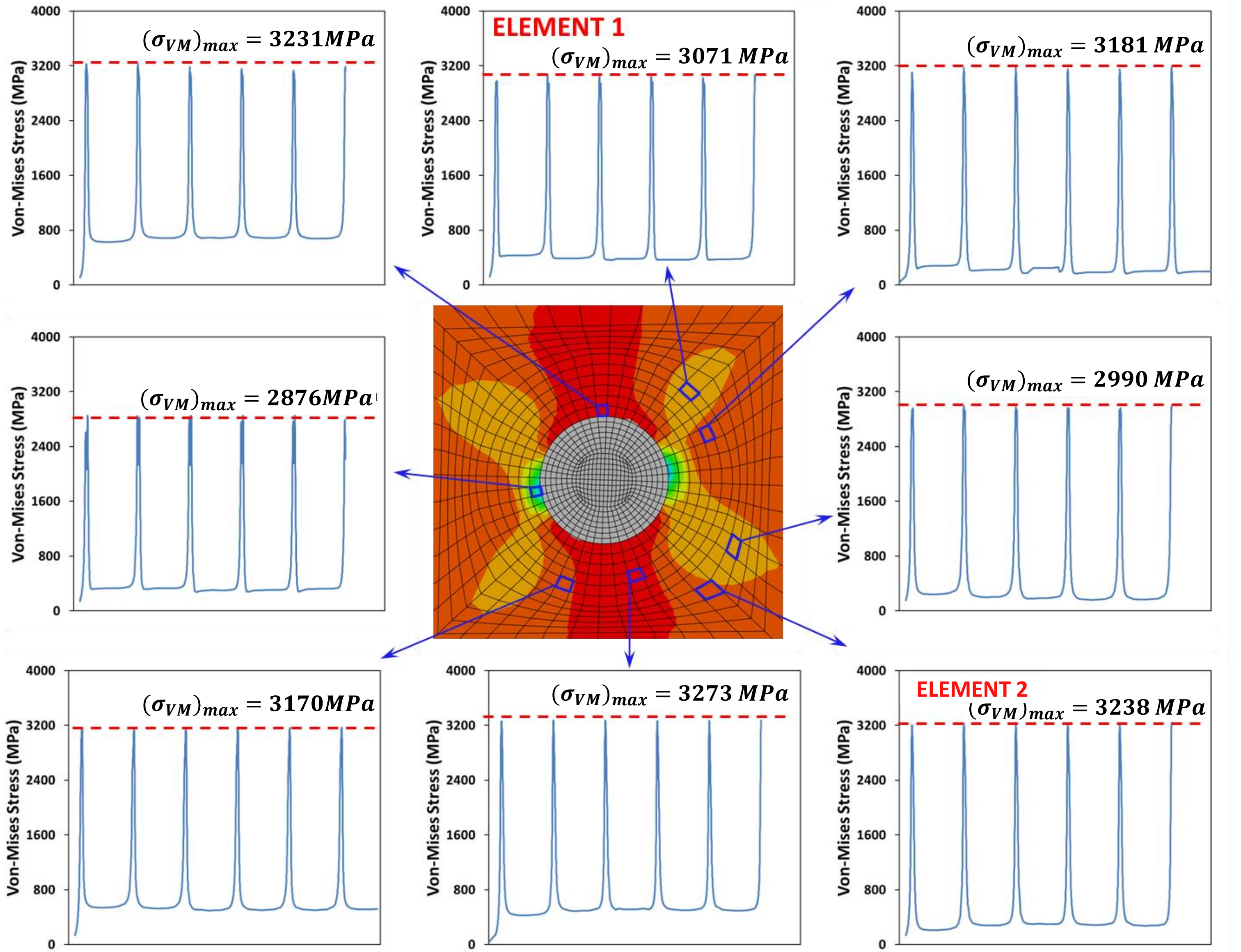


Upper stress limit controls the extent of cyclic hardening





Variation of Cyclic Hardening Near Carbide



Average Cyclic Hardening over an indent

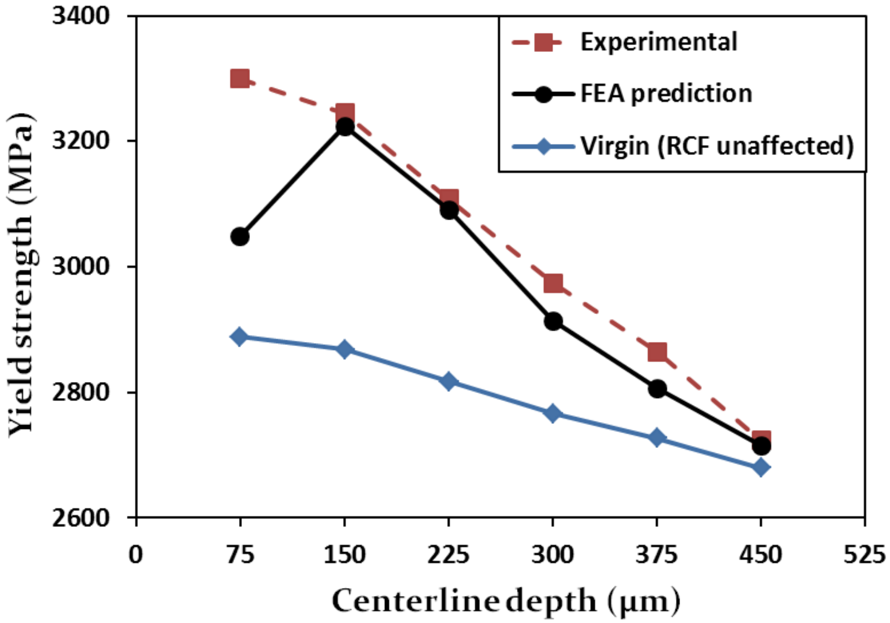
$$(\sigma_y)_{FEA} = \frac{\sum_{n=1}^{N}\left[V_n \times ((\sigma_{VM})_{\max})_n\right]}{\sum_{n=1}^{N} V_n}$$

$(\sigma_y)_{FEA}$ – volume averaged yield strength

V_n – volume of a FE 'n'

$((\sigma_{VM})_{\max})_n$ – peak von-Mises stress in FE 'n'

N – number of FE in the submodel



Discrepancy at 75 μm depth can be attributed to:

- Edge effects (indent is closest to the surface)
- Cyclic hardening is governed by max. VM stress that occurs at 150 μm
- 2D plain strain model instead of 3D model

Conclusions

1. Carbide particles → Shear stress cycle with non-zero mean stress
2. Stress-controlled loading + Non-zero mean stress → Ratchetting
3. Ratcheting → Cyclic hardening during RCF

Publications

1. **A.S. Pandkar, N. Arakere, G. Subhash**, "Microstructure-sensitive accumulation of plastic strain due to ratcheting in bearing steels subject to Rolling Contact Fatigue", **International Journal of Fatigue**, 63 (2014) 191-202.v

2. **A.S. Pandkar, N. Arakere, G. Subhash**, "Ratcheting-based microstructure-sensitive modeling of the cyclic hardening response of case-hardened bearing steels subject to Rolling Contact Fatigue", **International Journal of Fatigue**, 73 (2014) 119-131.

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