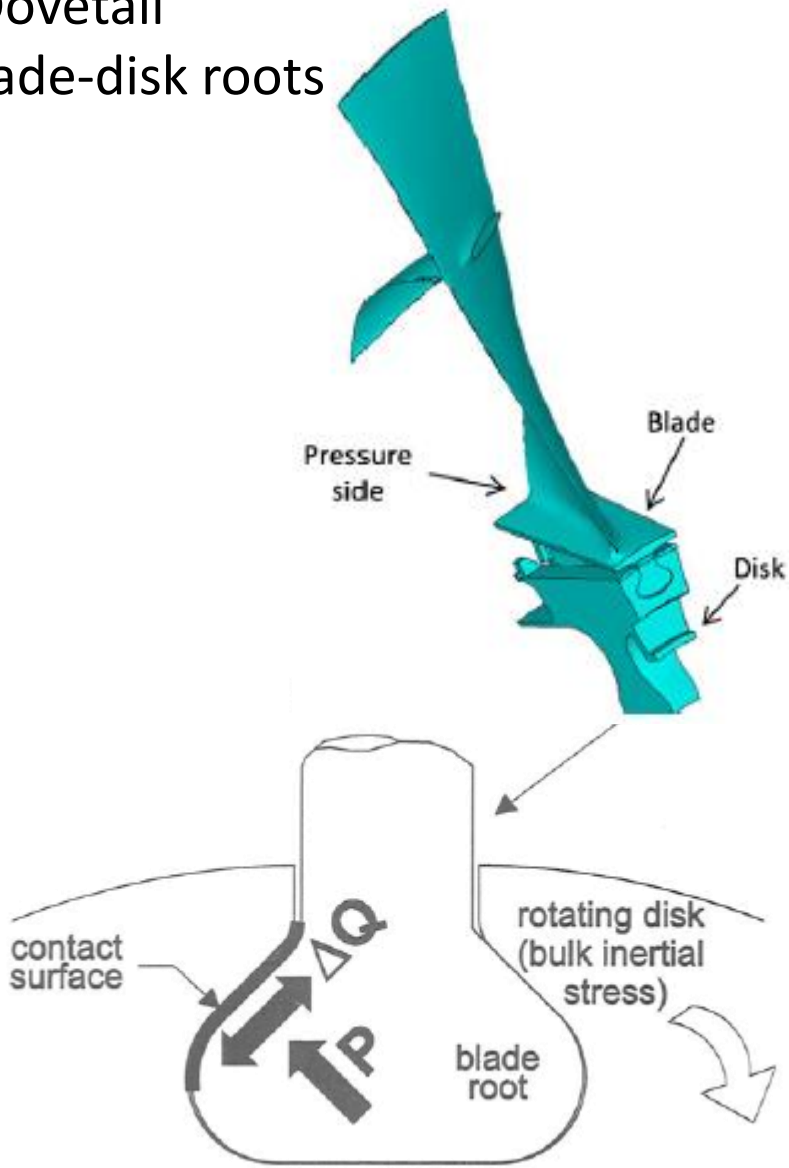
Initial orientation of the fretting fatigue cracks in shrink-fit connection specimens

C. Santus

University of Pisa
DICI – Mechanical Department

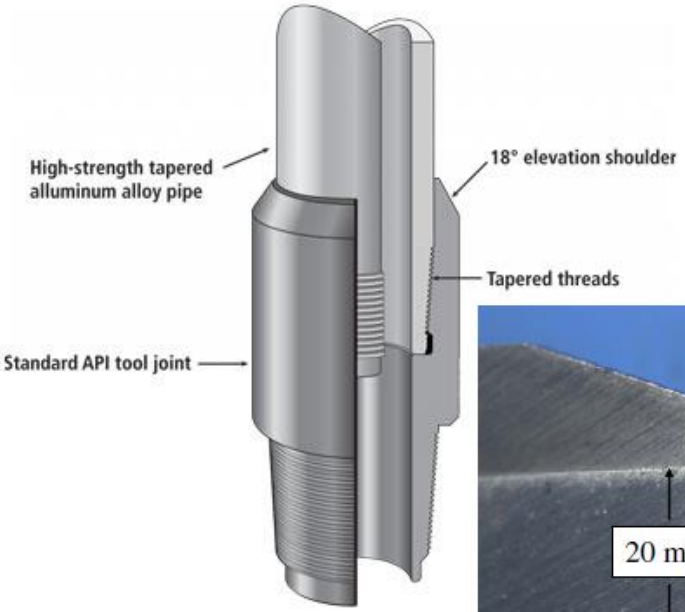
Mechanical connections experiencing Fretting Fatigue

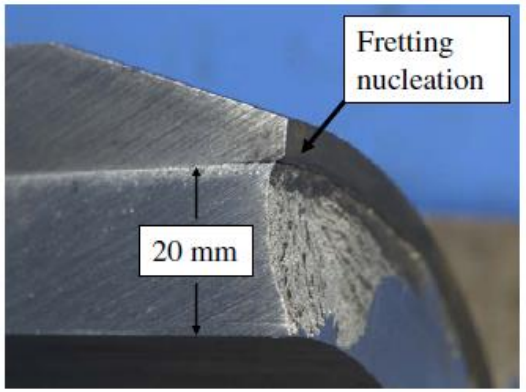
"Dovetail" blade-disk roots

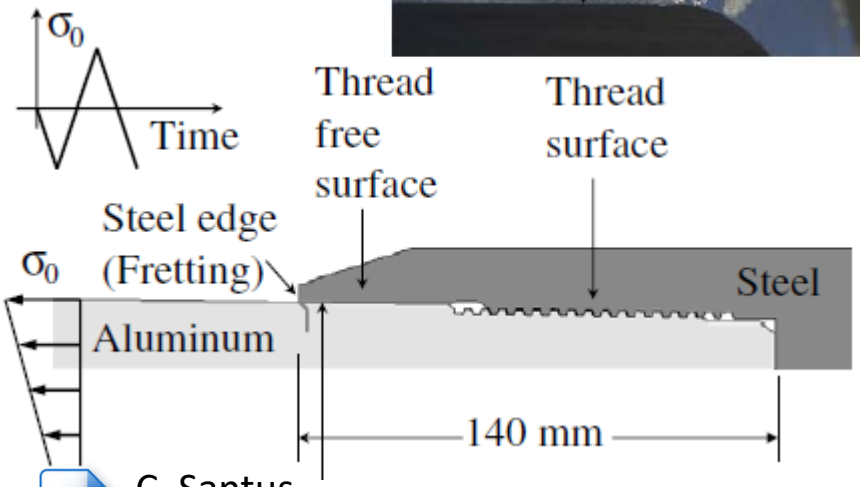


D. Nowell, D. Dini, D.A. Hills
Engineering Fracture Mechanics, 2006

Shrink-fitted tubular connection

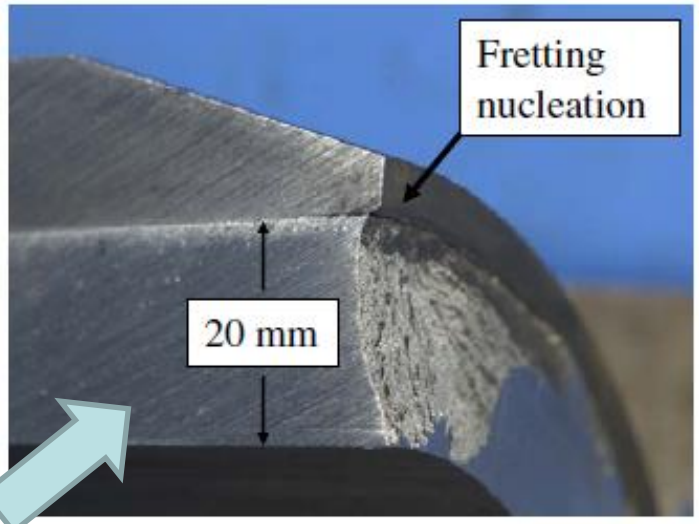




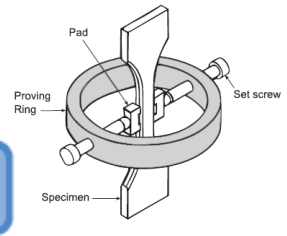


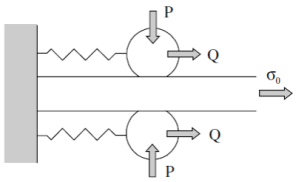
C. Santus
International Journal of Fatigue, 2008

Different types of FF tests



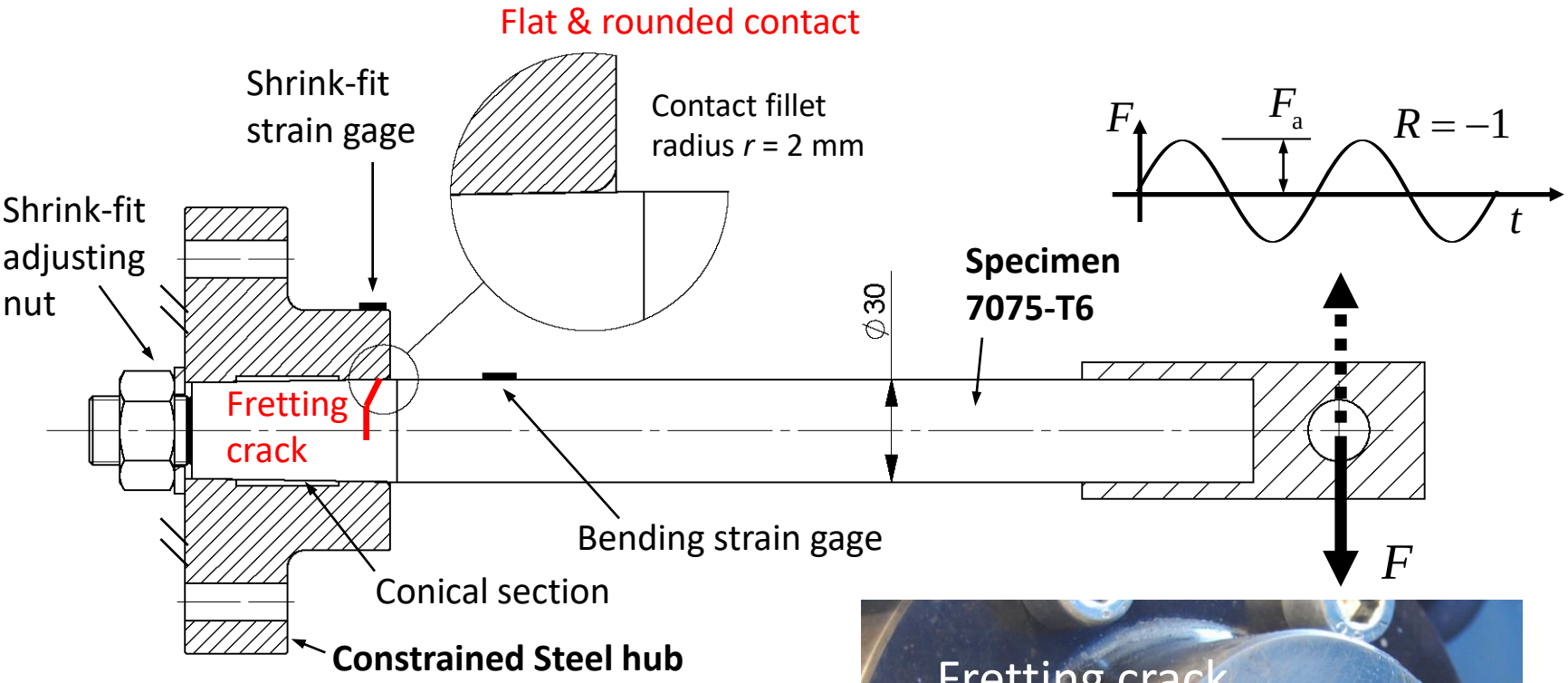
- Fretting fatigue test rigs
  - Coupon scale
    - One actuator test rig
      - Floating fretting bridge
      - Fixed fretting bridge
    - One actuator test rig with adjustable compliance
    - Two actuators test rig
  - Full scale



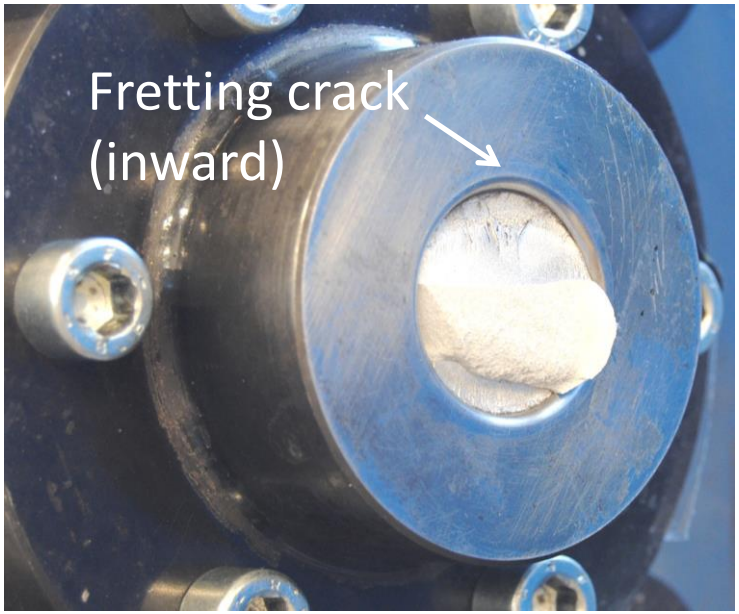


New FF setup

Proposed bending FF test setup



L. Bertini, C. Santus
Int. J. of Fatigue, 2015



Bending Fixed bridge with round geometry:

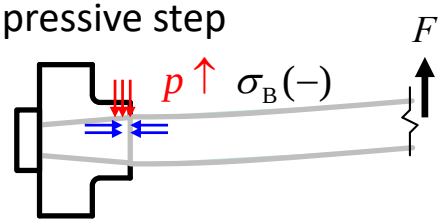
- No lateral edge contact
- No uncontrolled tilt
- Variable contact pressure

Proposed bending FF test setup

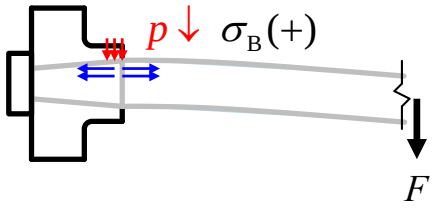
Bending Fixed bridge with round geometry:

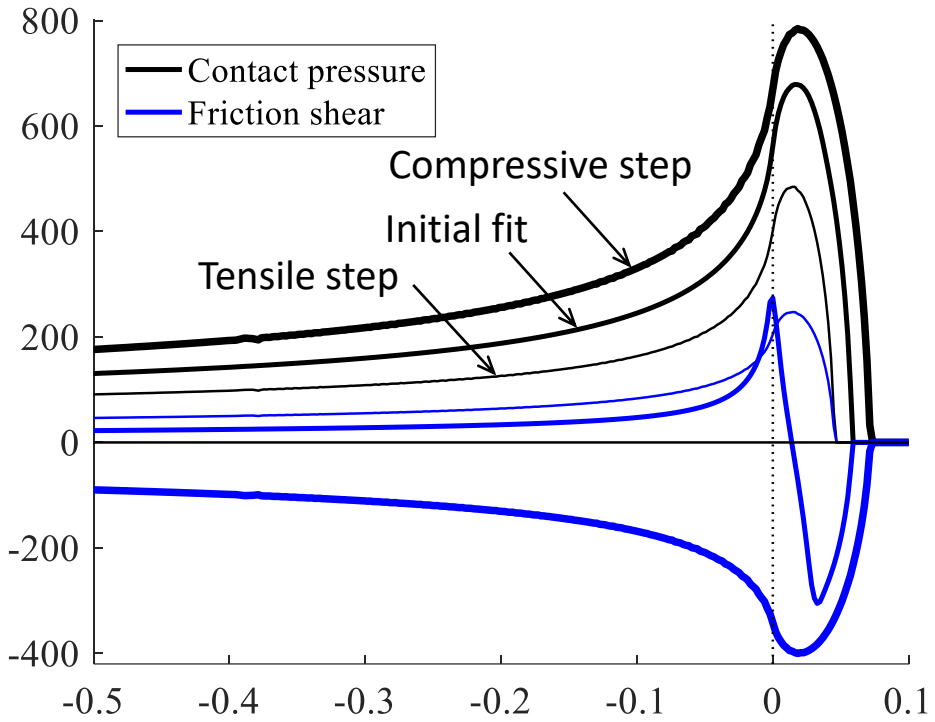
- Variable contact pressure

Compressive step

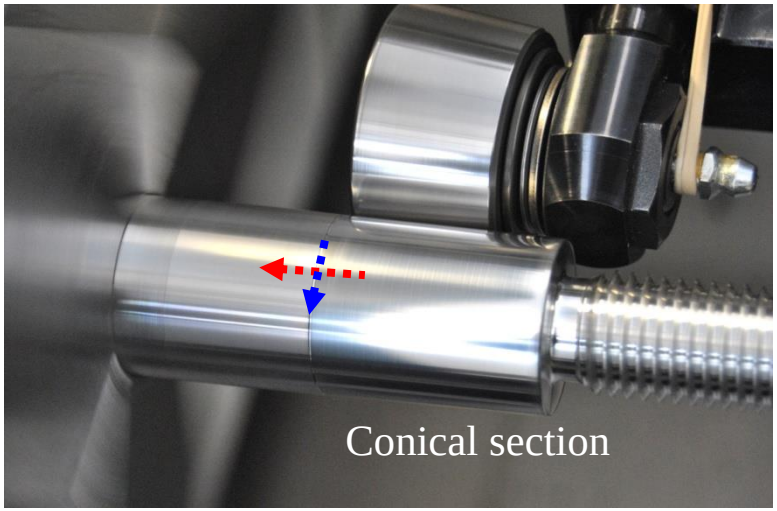


Tensile step



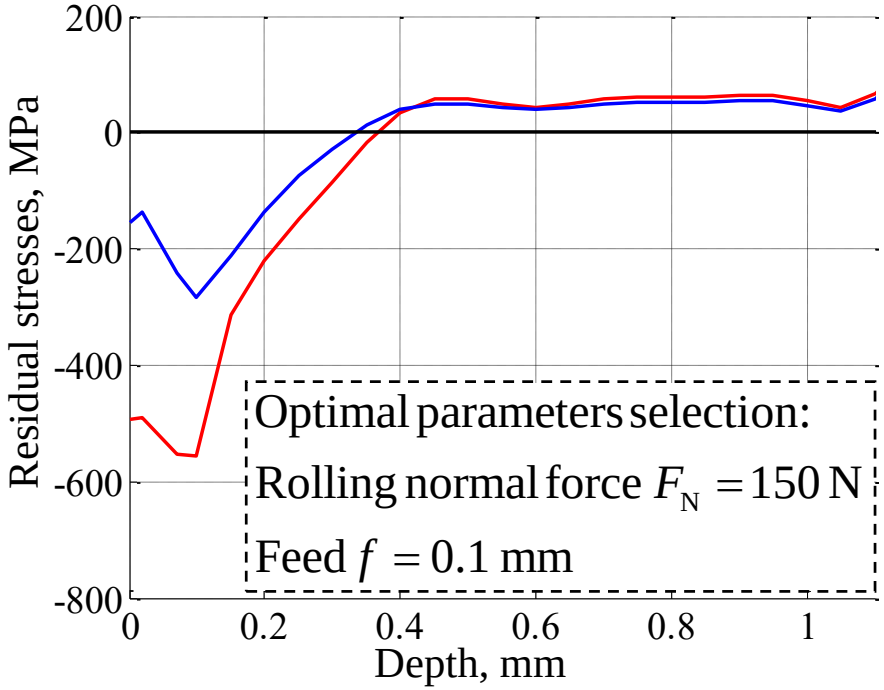


Deep Rolling on bending FF specimens

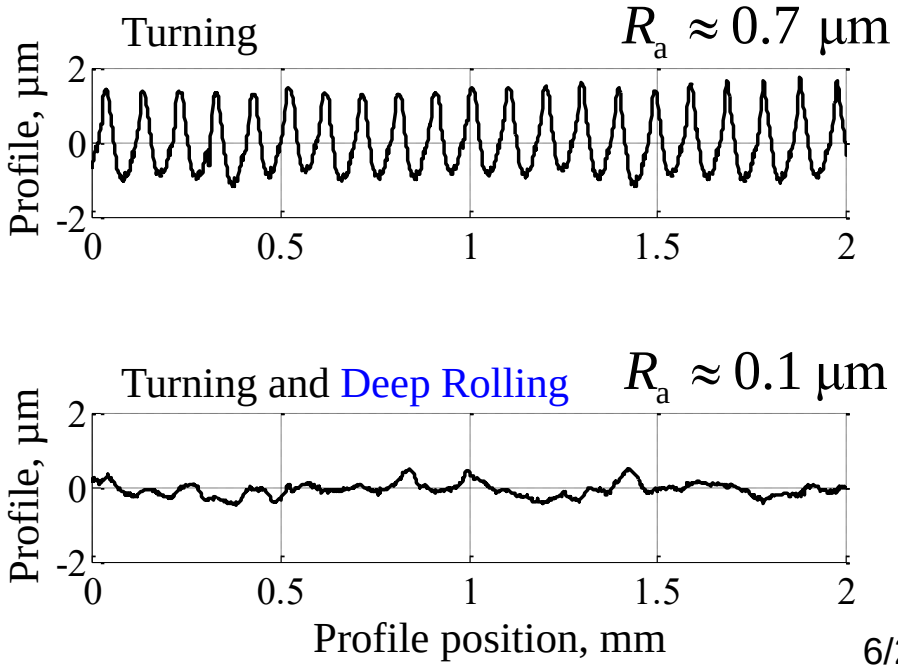


Fatigue strength enhancement:
- compressive Residual Stresses
- higher Surface Finish
- higher Hardness

Residual Stresses

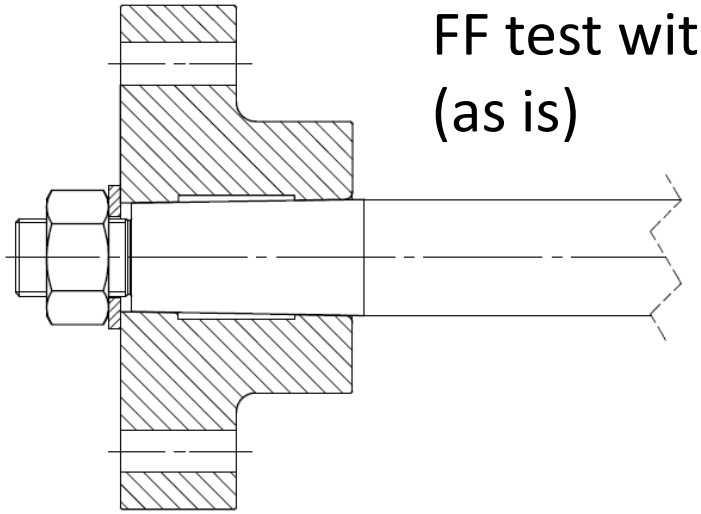


Surface Finish

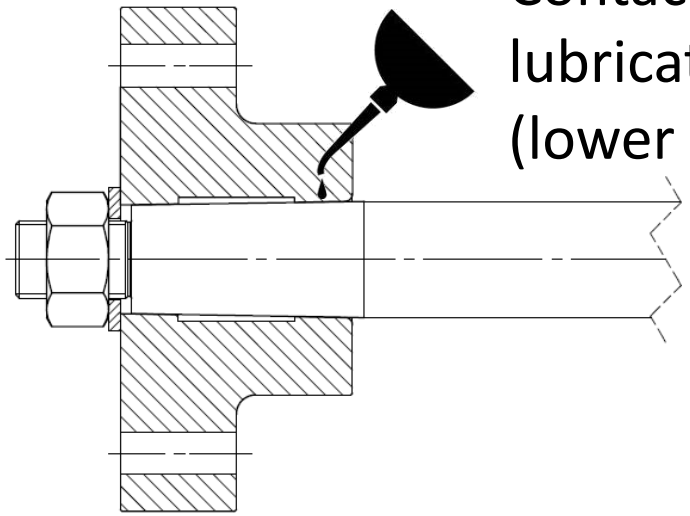


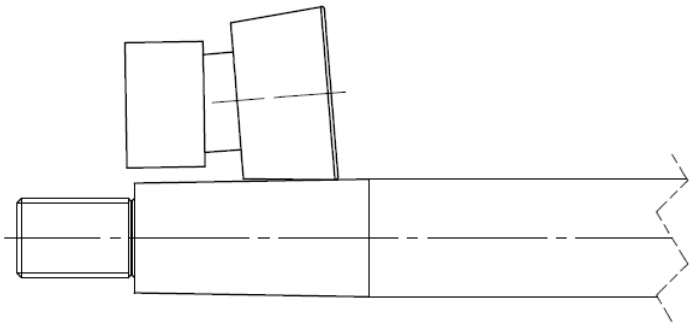
Bending FF test series

FF test with no modification (as is)



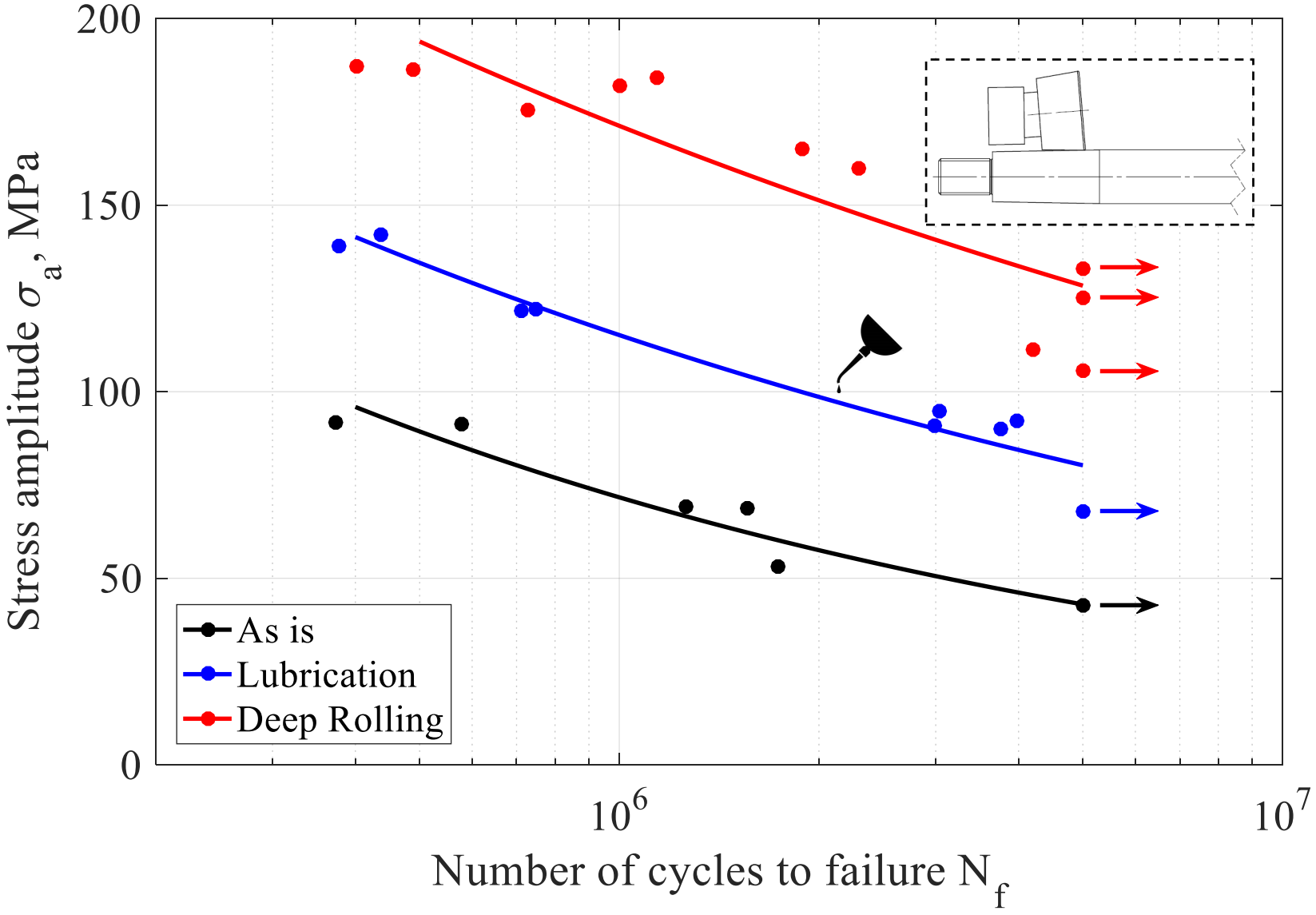
Contact lubrication (lower CoF)



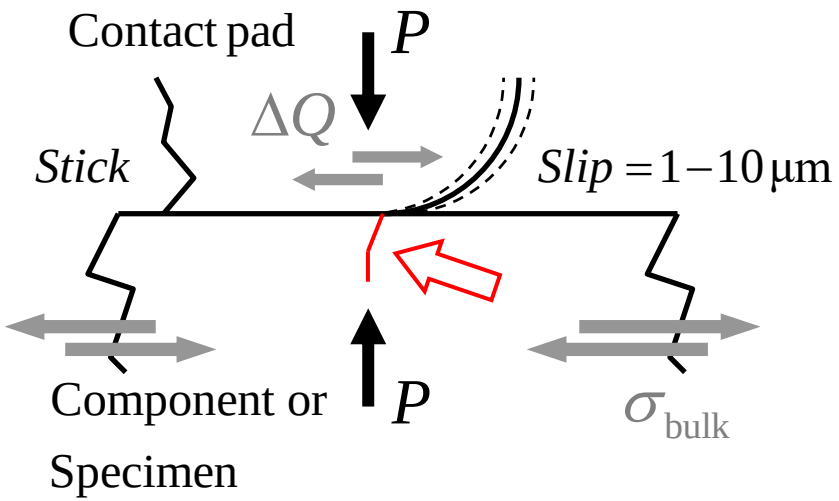


Residual stresses (Deep Rolling)

Bending FF test results



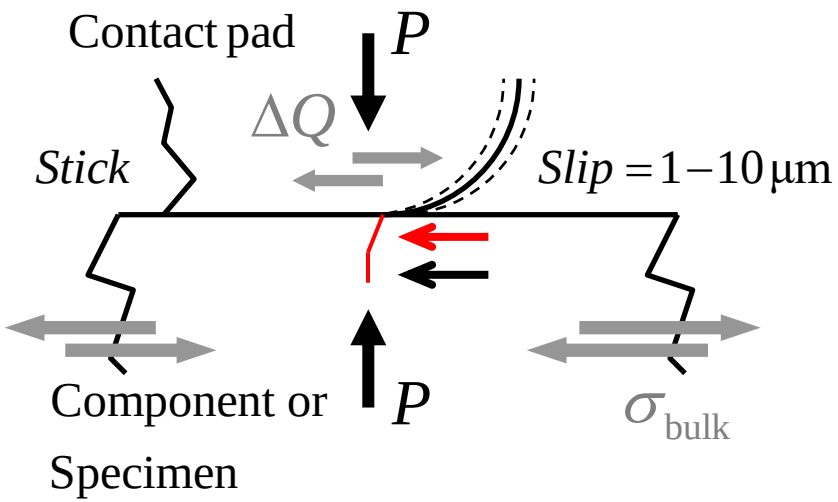
FF loads and local stress conditions



FF crack onset, initiation at the edge of the contact:

- High stress and severe stress gradients
- Non-proportional multiaxiality
- Interaction with the microwear
- Initial orientation ???

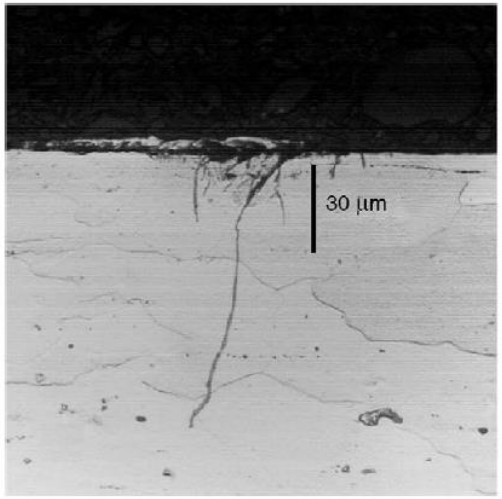
FF initial crack



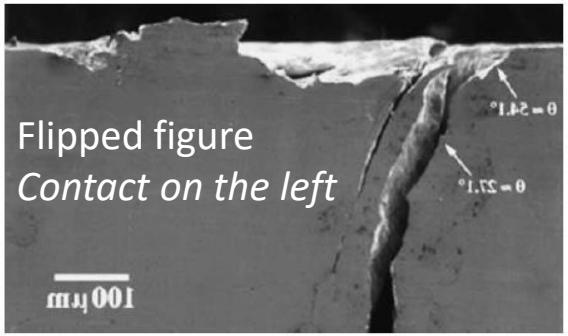
FF crack:

- Initial orientation inwards, beneath the contact (different angles)
- Subsequent propagation perpendicular (Mode I)

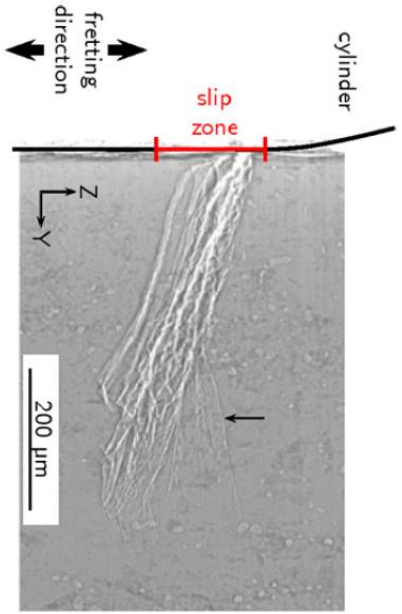
Examples:



D.L. McDiarmid
Fatigue Fract Eng Mater Struct, 1994



D.R. Swalla, R.W. Neu
Tribology International, 2001



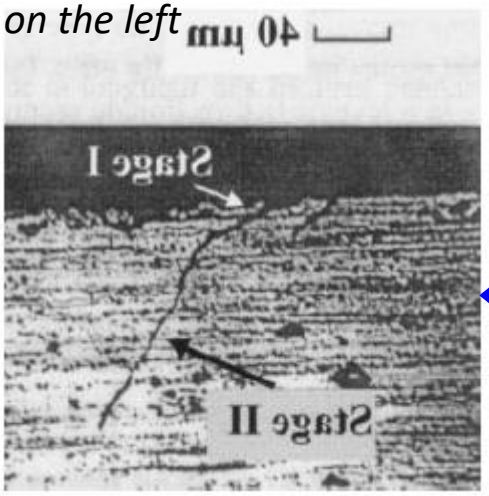
H. Proudhon, J-Y. Buffière, S. Fouvry
Engineering Fracture Mechanics, 2007

FF initial crack – Type I and Type II

Flipped figures

Contact on the left

(a)



(b)

Fig. 3 Crack propagation direction during Stage I and Stage II. (a) Type I crack. (b) Type II crack.

V. Lamacq, M.C. Dubourg
Fatigue Fract Engng Mater Struct, **1999**

Classification of the FF crack:

- Type I (shear crack)

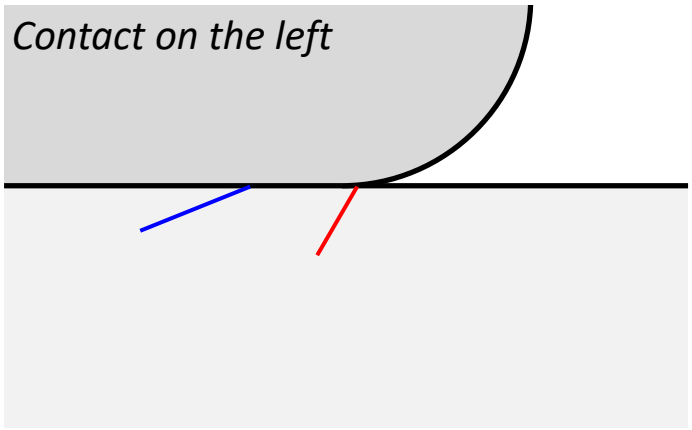
Inside of contact

Stage I with a shallow angle

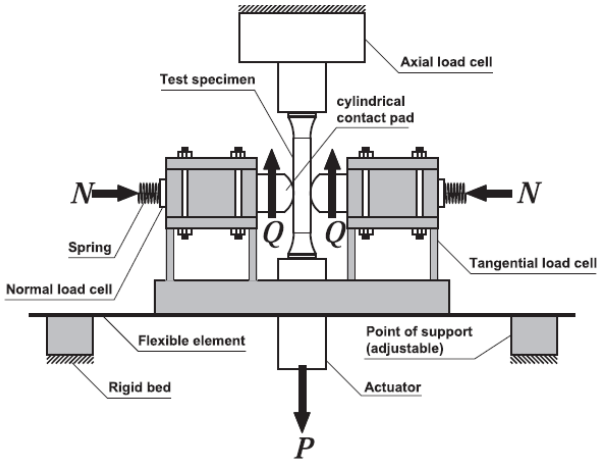
- Type II (tensile crack)

Edge of contact

Stage I almost perpendicular



FF initial crack – Predictive stress parameters



C. Navarro, J. Vázquez, J. Domínguez
International Journal of Fatigue, 2017

J. Vázquez, C. Navarro, J. Domínguez
Tribology International, 2017

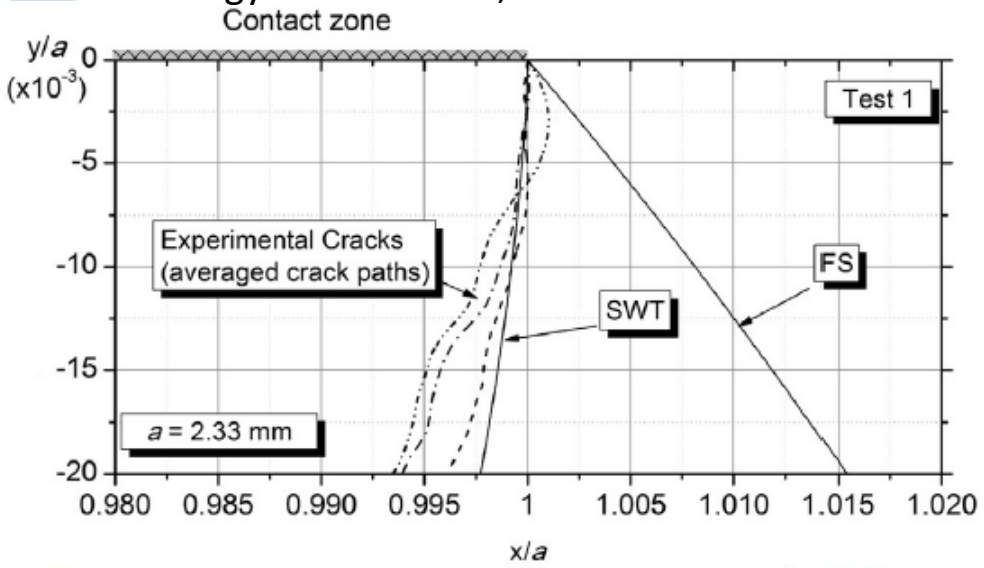
Fatemi-Socie (Shear based parameter)

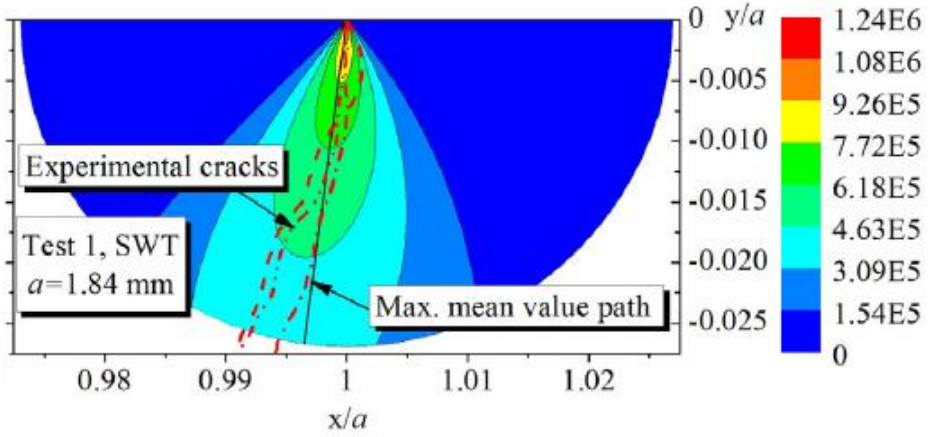
$$FS = \frac{\Delta\gamma}{2}\left(1 + k\frac{\sigma_{max}^{n}}{\sigma_{y}}\right)$$

Smith-Watson-Topper (Tensile based par.)

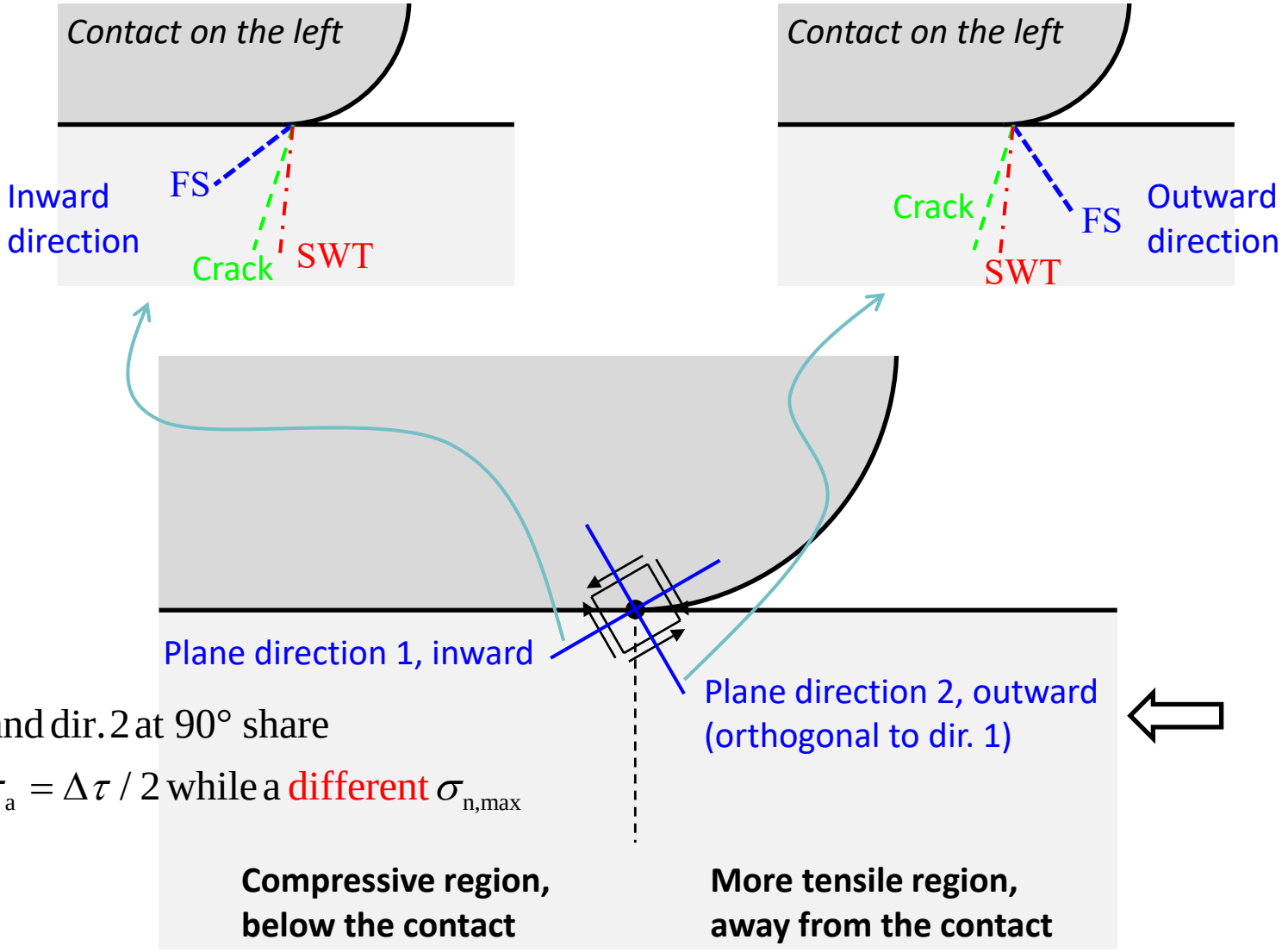
$$SWT = \sigma_{max}^{n}\frac{\Delta\varepsilon}{2}$$

Good agreement SWT and Type II (tensile) FF crack





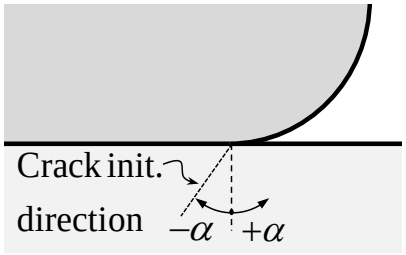
Shear based parameters, 90° periodicity



Dir.1 and dir.2 at 90° share

same $\tau_a = \Delta\tau / 2$ while a different $\sigma_{n,max}$

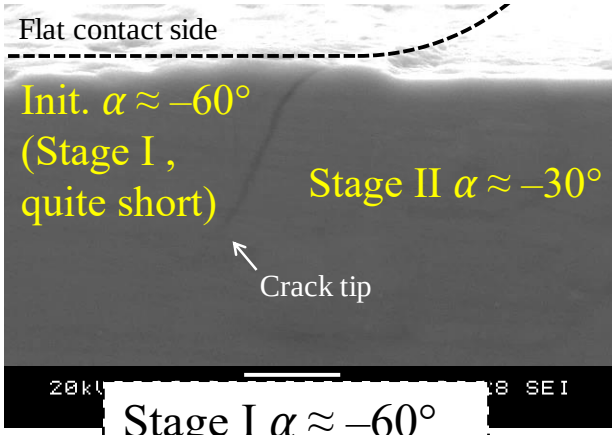
Bending FF cracks, experimental evidence



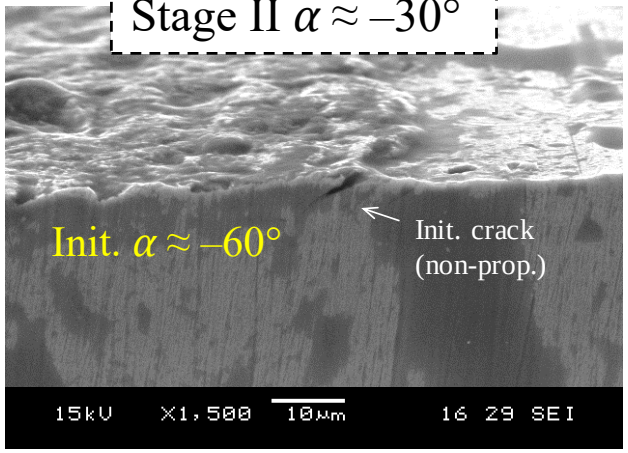
Type II - Tensile based
due to the higher CoF

Shallow cracks observed
(Type I - Shear based)
due to the receding *cont. pressure*
during the tensile half-cycle

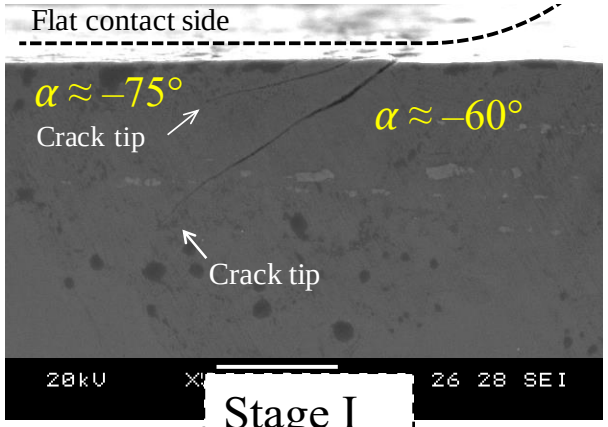
As is



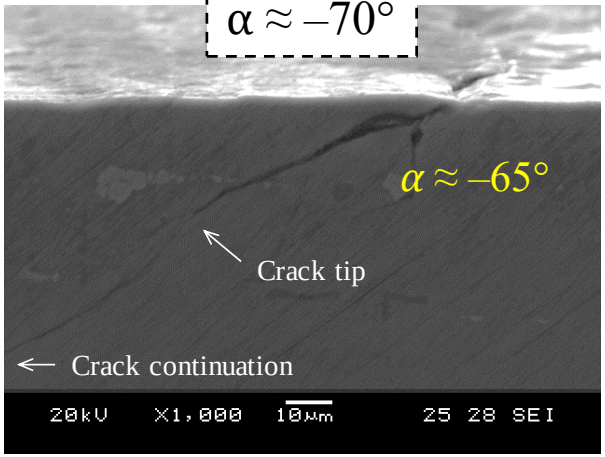
Stage I $\alpha \approx -60°$
Stage II $\alpha \approx -30°$



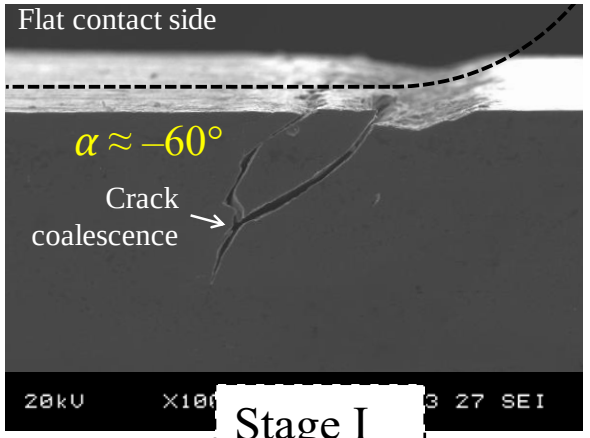
Lubrication – Lower CoF



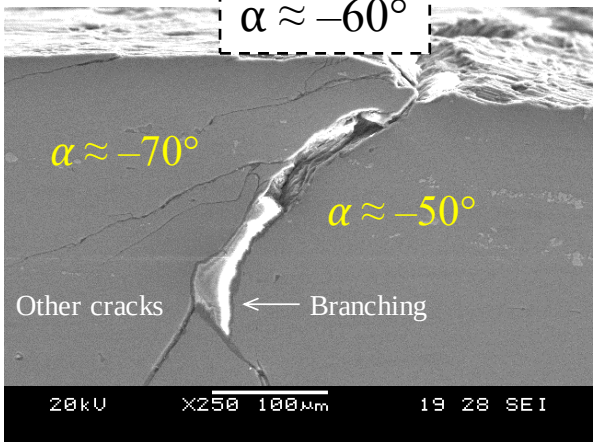
Stage I
$\alpha \approx -70°$



Deep Rolling – Res. Stresses

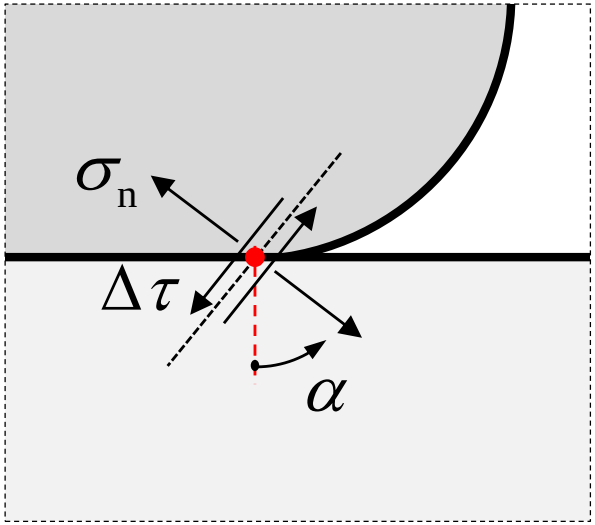


Stage I
$\alpha \approx -60°$

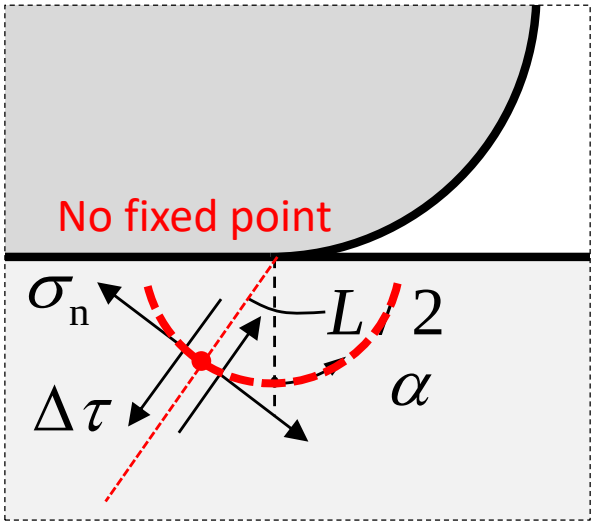


Stress parameter definitions and material properties

Stress calc. I – Hot Spot



Stress calc. II – Point Method
(following the critical plane)



Material properties for 7075-T6
- Critical distance length value
- Multiaxial criteria parameters

$$L = \frac{1}{\pi}\left(\frac{\Delta K_{th}}{\Delta\sigma_{-1}}\right)^2 = 0.056\,\text{mm}$$

$$\text{FS} = \tau_a\left(1 + k_{FS}\frac{\sigma_{n,max}}{\sigma_y}\right),\quad k_{FS} = 0.44$$

$$\text{SWT} = \sqrt{\sigma_{n,a}\,\sigma_{n,max}}$$

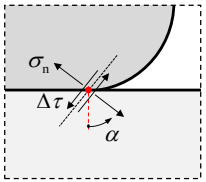
C. Santus, D. Taylor, M. Benedetti
International Journal of Fatigue, 2018

J. Vázquez, C. Navarro, J. Domínguez
Tribology International, 2017

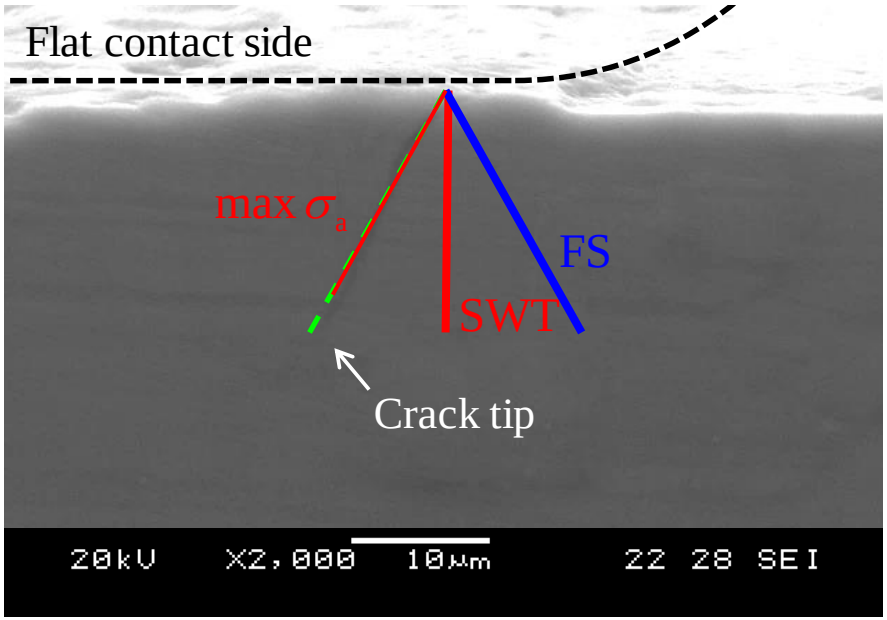
FF crack initial direction prediction

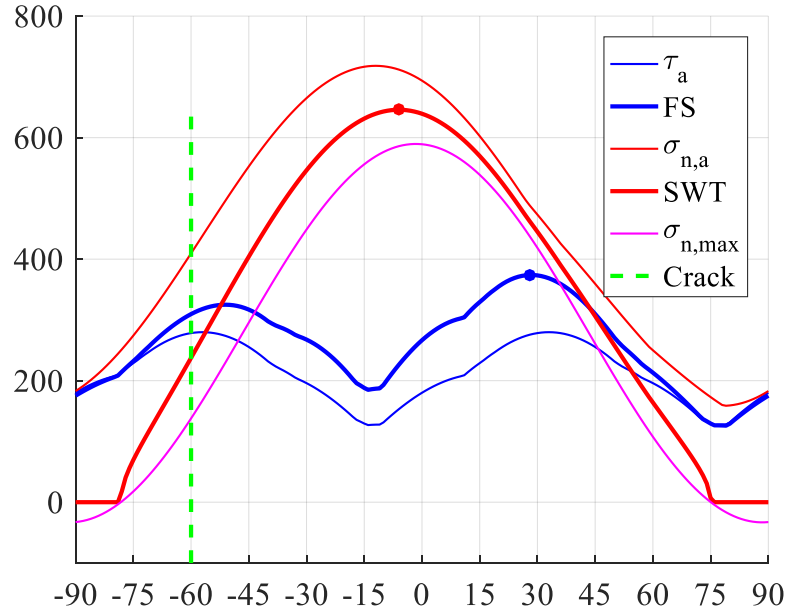
As is

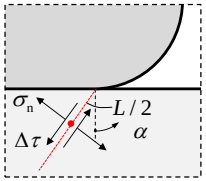
Stage I $\alpha \approx -60°$
Stage II $\alpha \approx -30°$



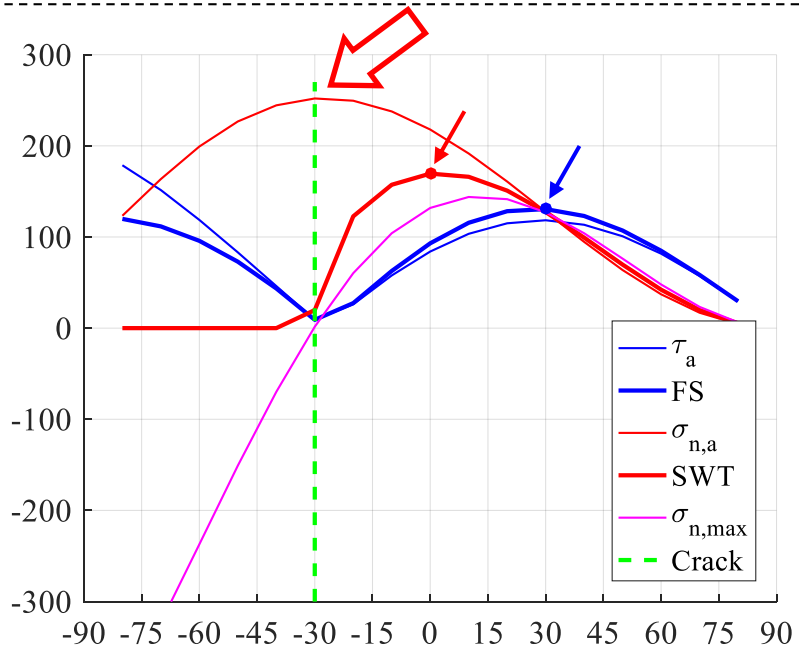
Hot Spot





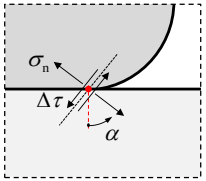


Point Met.



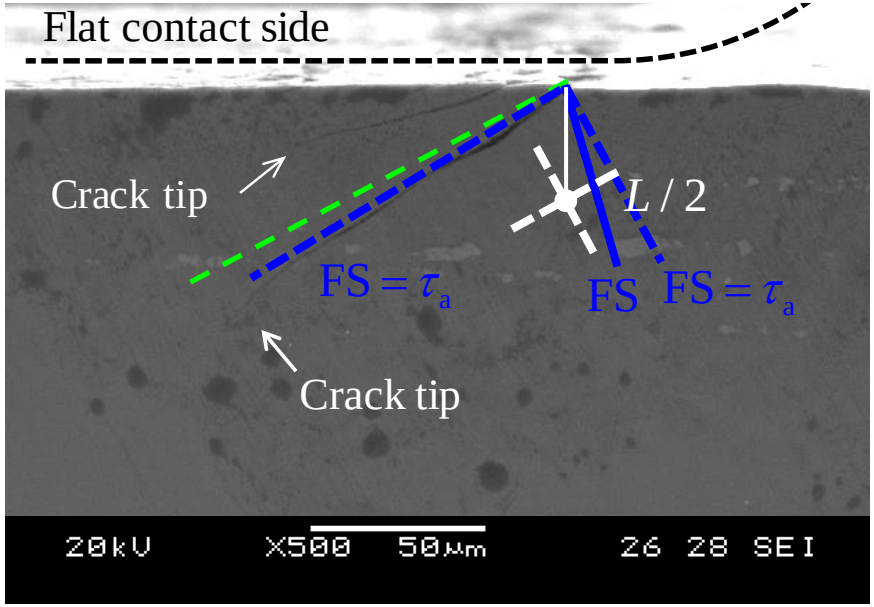
FF crack initial direction prediction

Lubrication – Lower CoF

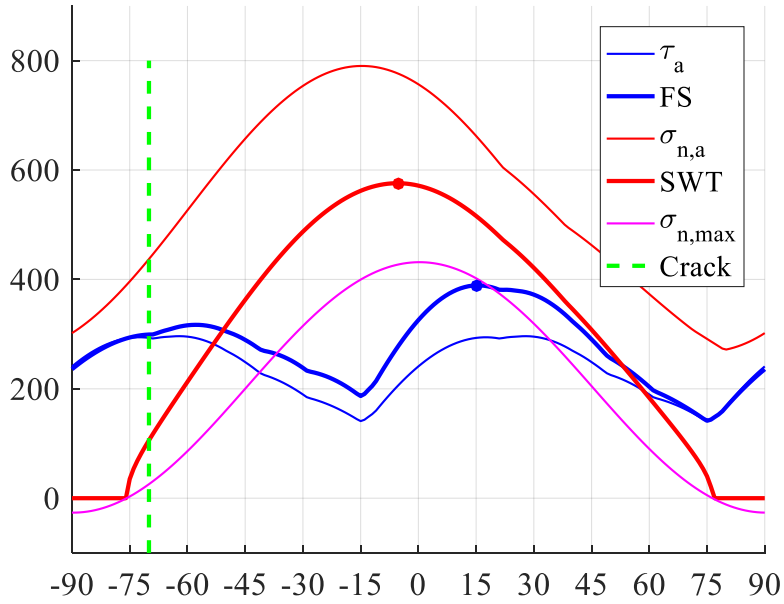


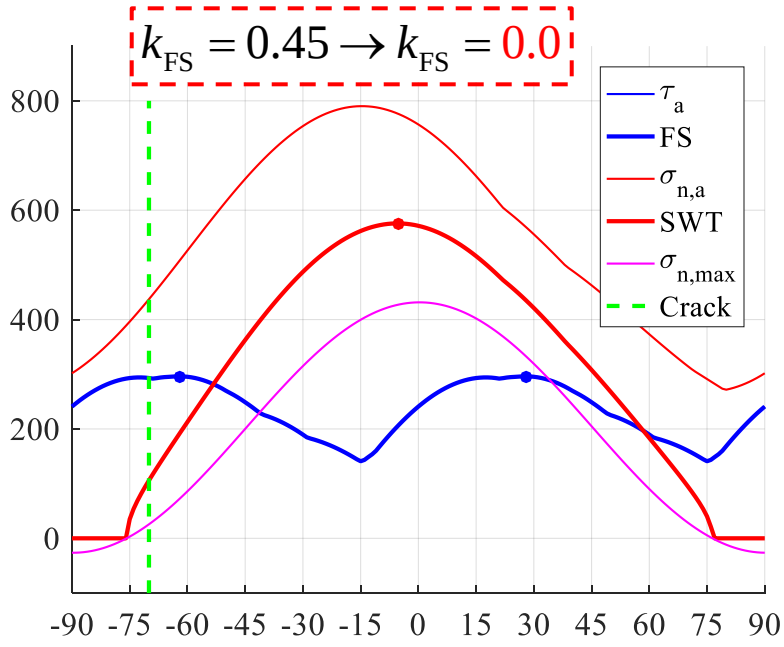
Hot Spot

Hot-spot,
or PM with a fixed point



90° ambiguity

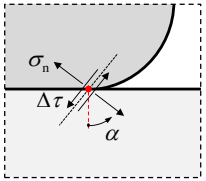




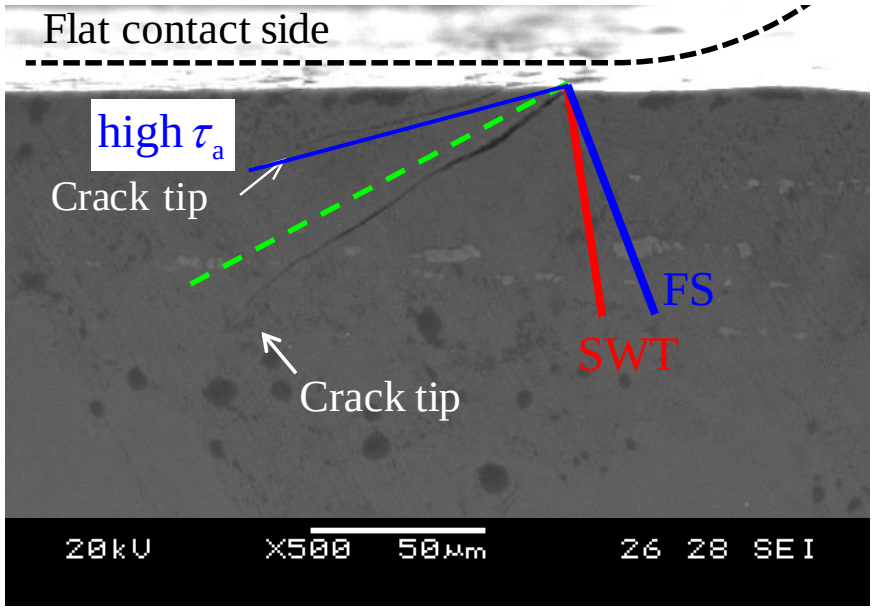
FF crack initial direction prediction

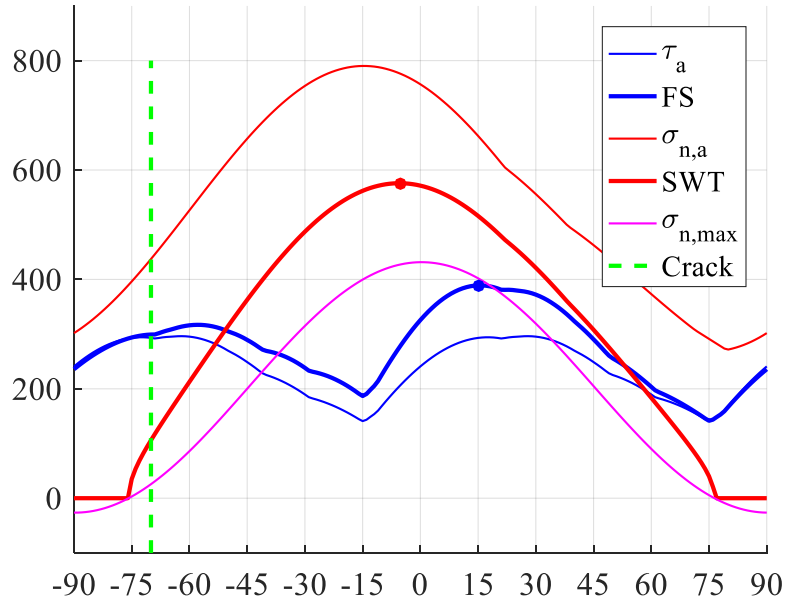
Lubrication – Lower CoF

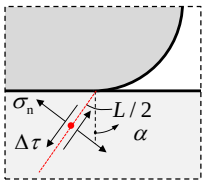
Crack angle
$\alpha \approx -70°$



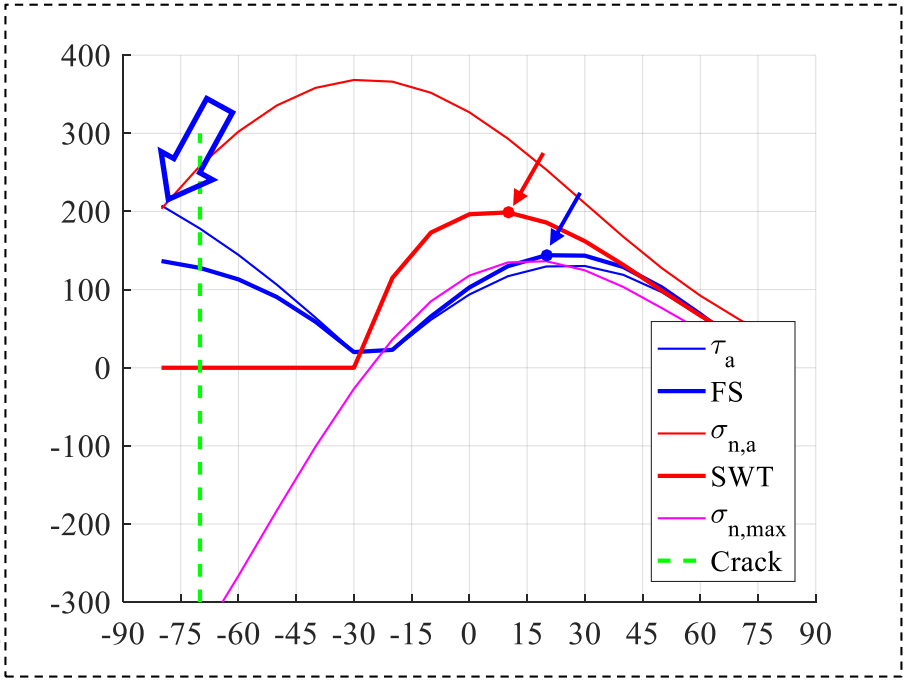
Hot Spot







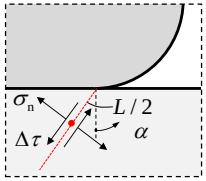
Point Met.



FF crack initial direction prediction

Lubrication – Lower CoF

α parameter effect



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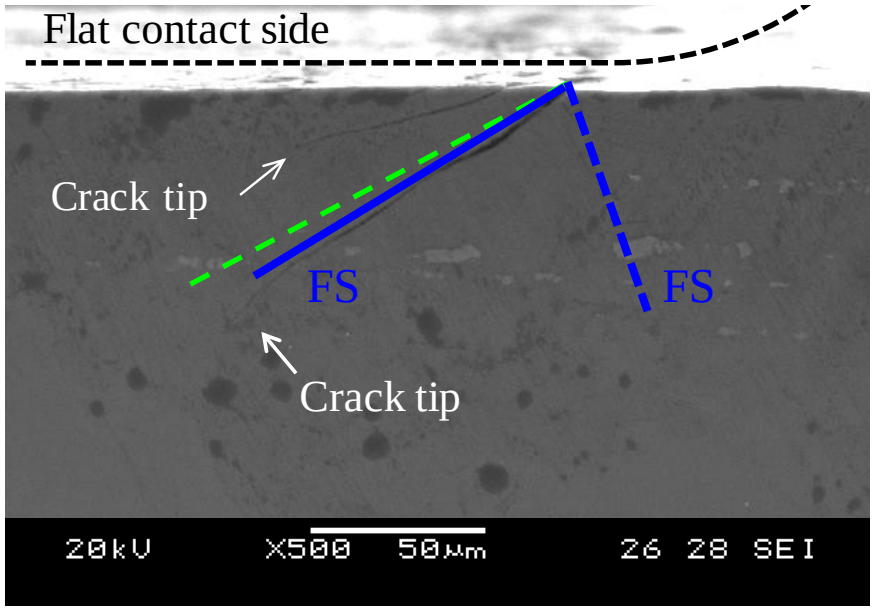
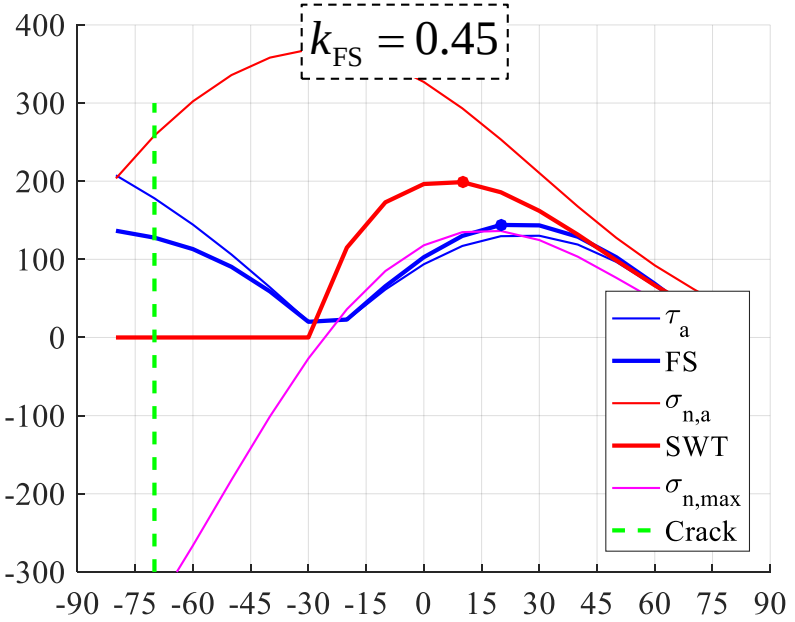
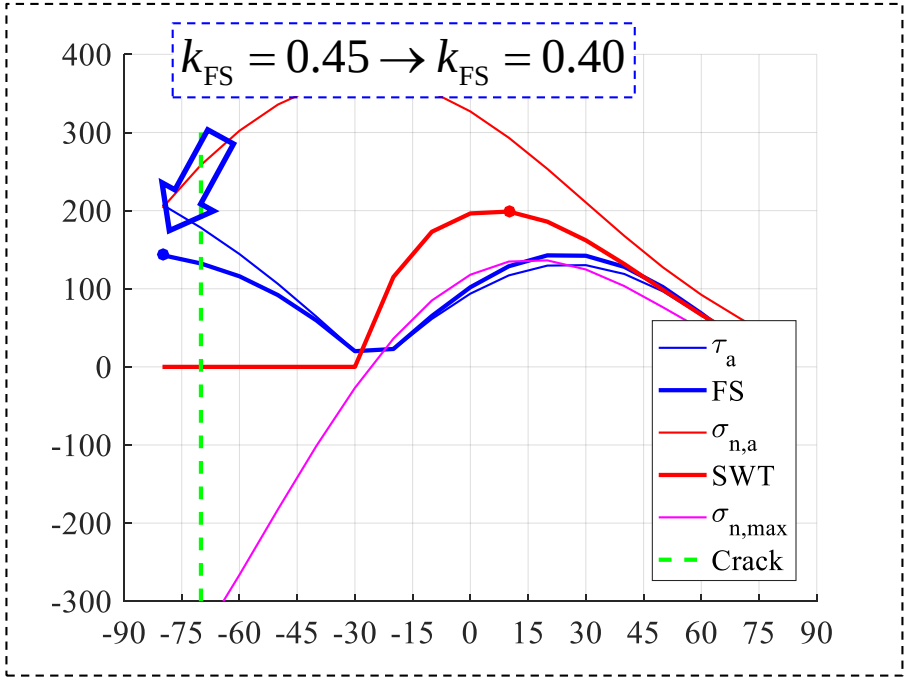


Reasonable α_{FS} value
or plasticity effect on the normal stress (compressive quite high)

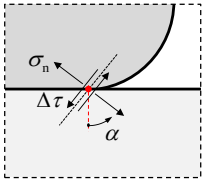




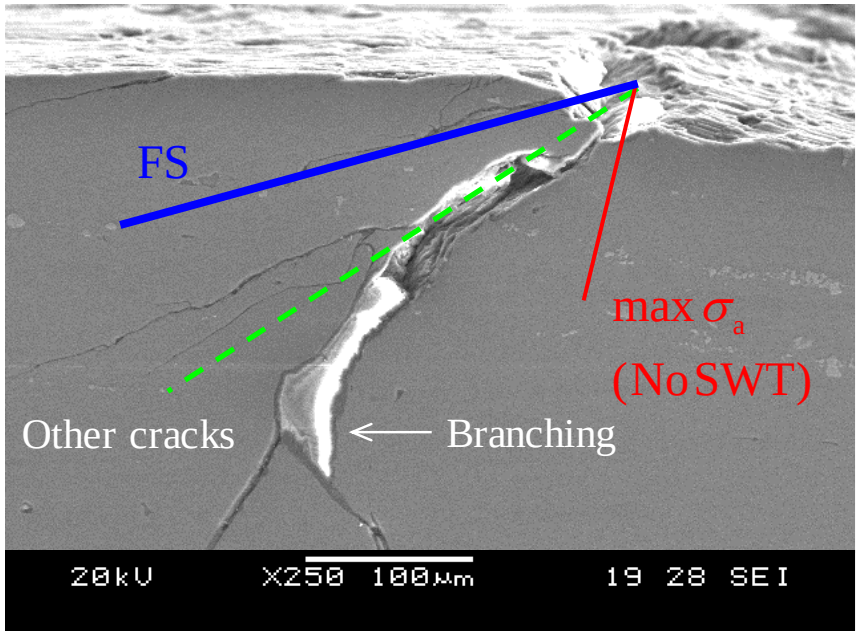
FF crack initial direction prediction

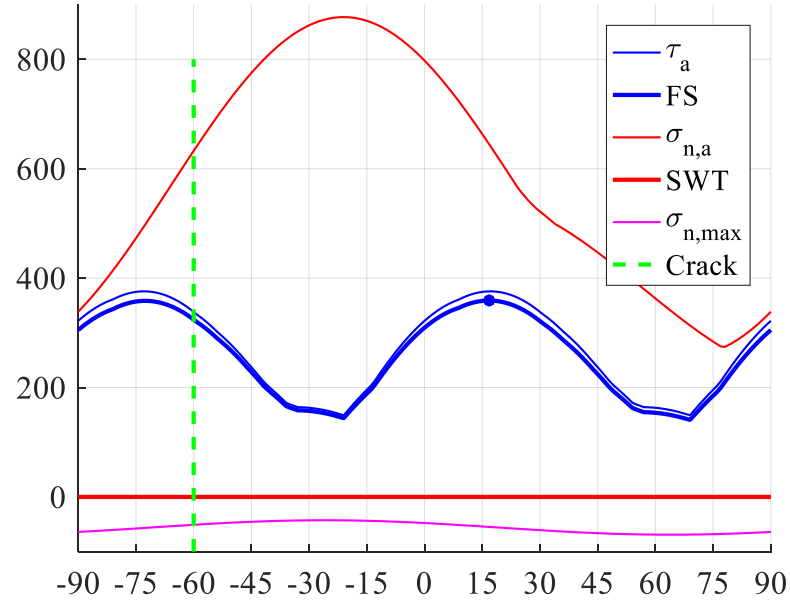
Deep Rolling – Res. Stresses

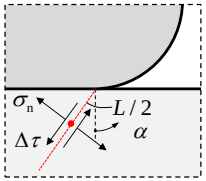
Crack angle
$\alpha \approx -60°$



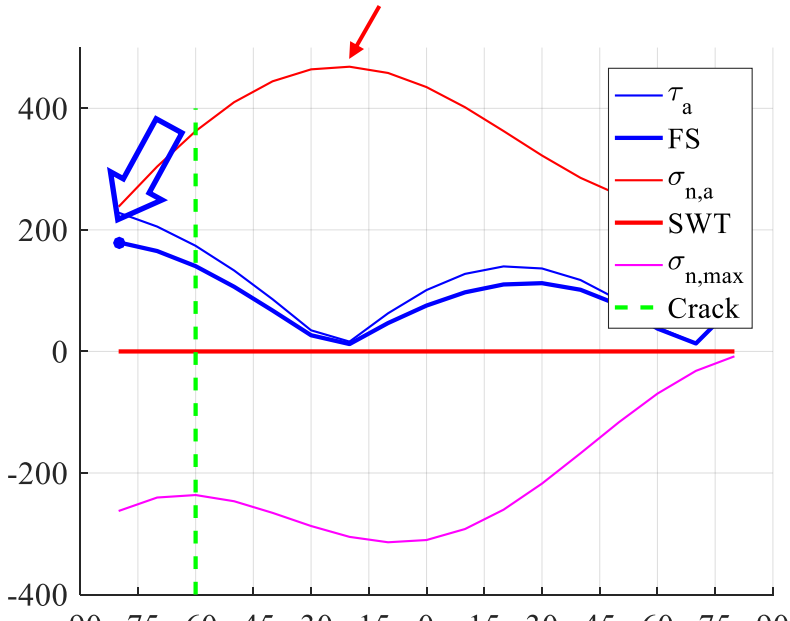
Hot Spot







Point Met.

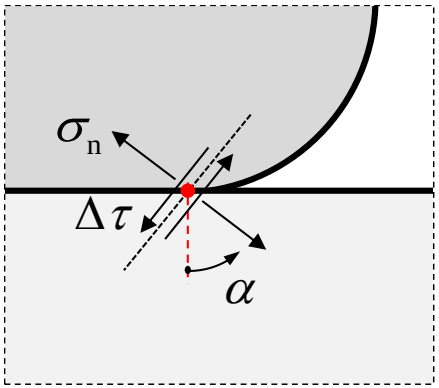


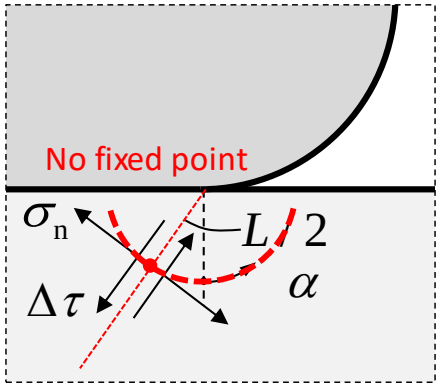
Conclusions

- *Fretting Fatigue* tests for the Shrink-fitted application
  - As is (no modification)
  - Lubrication, lower CoF
  - Deep Rolled, compressive residual stresses

- Type I (Shear) cracks, Predicted initial FF crack outward, instead of inward (below the contact), high compressive normal stress

- Correct direction prediction with a Critical Distance method along the analyzed plane and a lesser effect of the normal stress

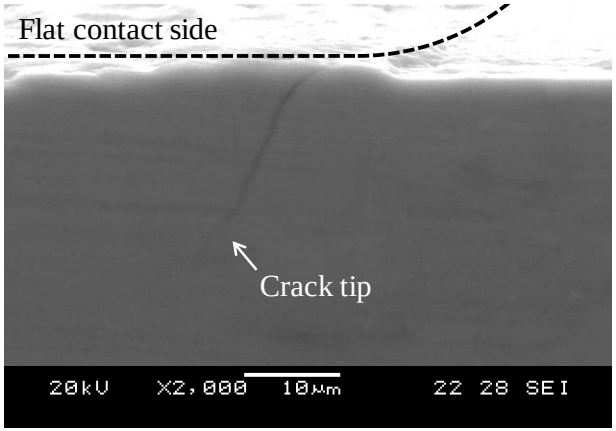


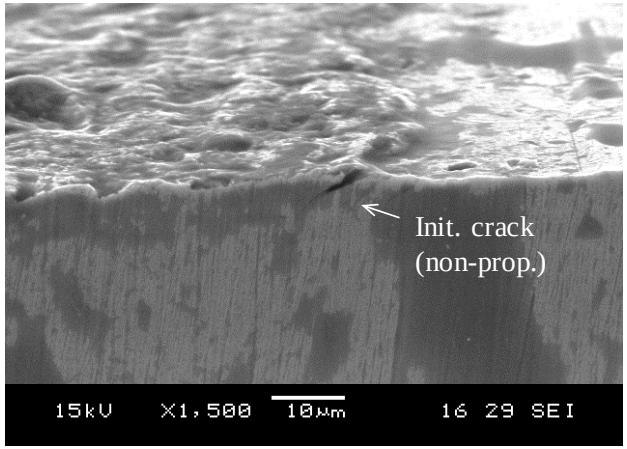


Thanks for your attention

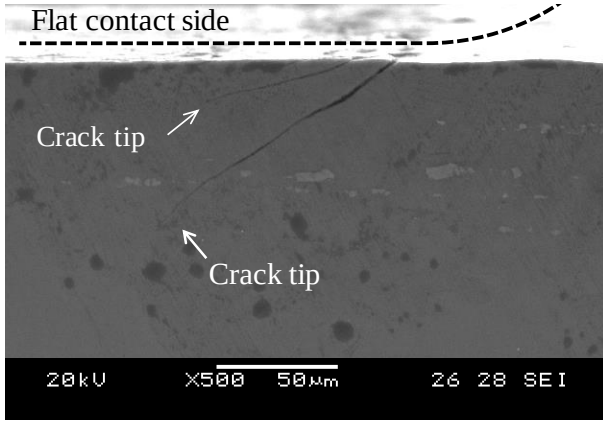
… any questions?

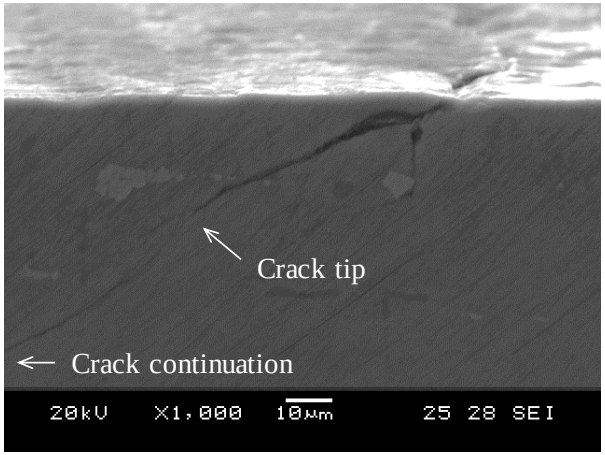
As is





Lubrication – Lower CoF





Deep Rolling – Res. Stresses