EURAXLES PROJECT WP 3.3

Modelling Methods for helping Design against Fretting Fatigue

WP 3.3a: Initiation of Fretting Fatigue in Press Fits

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WP3.3b: Assessment of Propagation Phase

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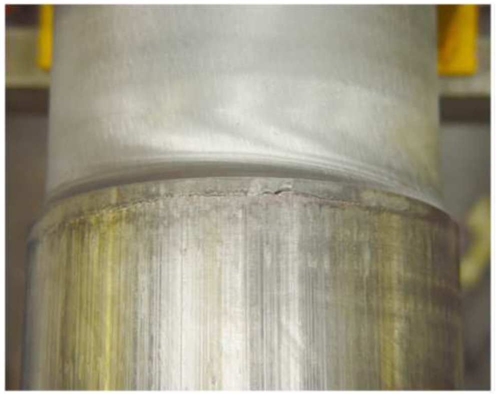
Motivation

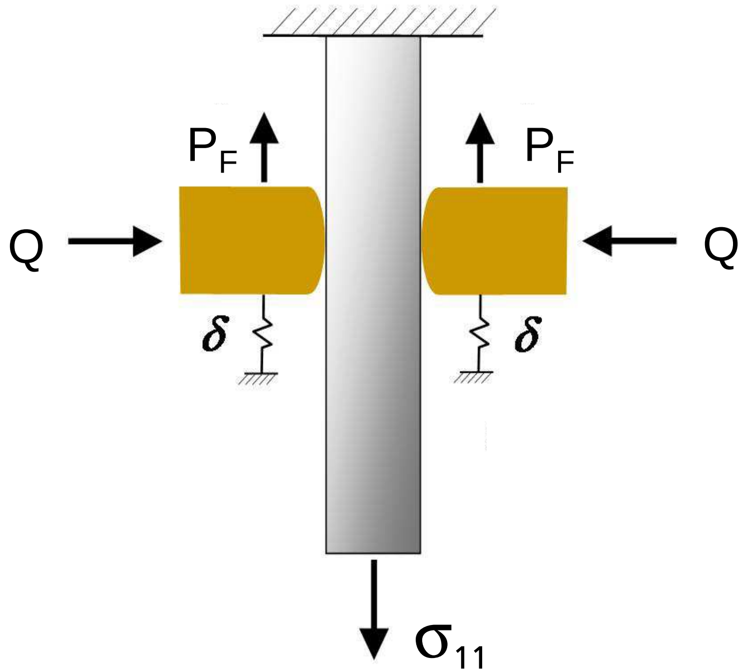
- Up to date full scale tests have to be performed to validate new axle designs and press fit configurations with respect to their fatigue strength
- A representative number of tests is required for statistical data analysis
- Simulation tools may help to pre-evaluate press fit parameters and to save time/costs

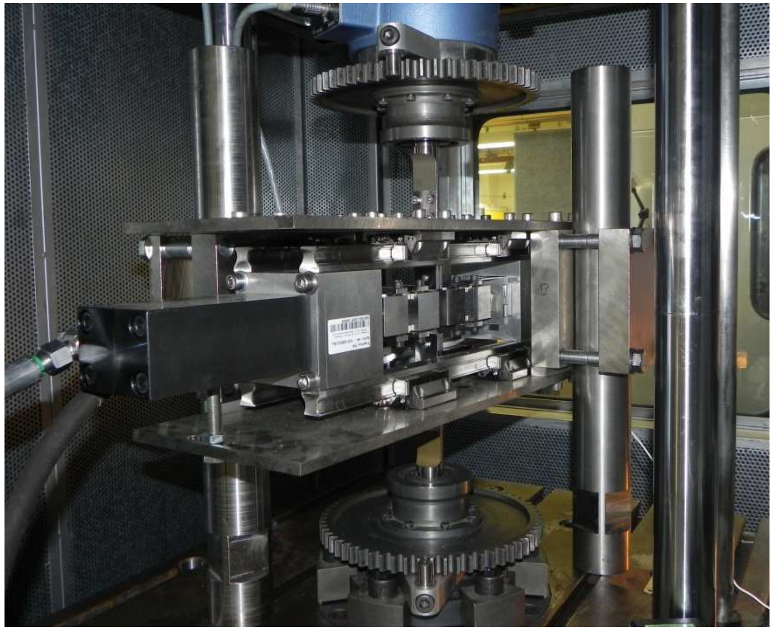


Test rig for fatigue strength assessment of press fits (right) and fatigue cracks in a press fit (left). Traupe et al., Safe and Economic Design of Running Gears, IMAB TU Clausthal, 2004

Fretting Fatigue Tests - Goal and Scope of the Study

- Material characterization under fretting fatigue conditions
- Demonstrate the applicability of numerical analyses to predict the resistance towards initiation of fretting fatigue cracks in railway axles
- Material-pairing EA4T/R8, Net stress ratio R = 0.1

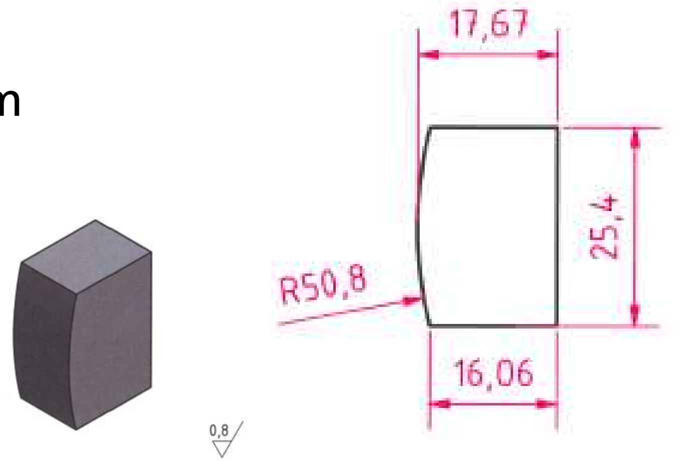


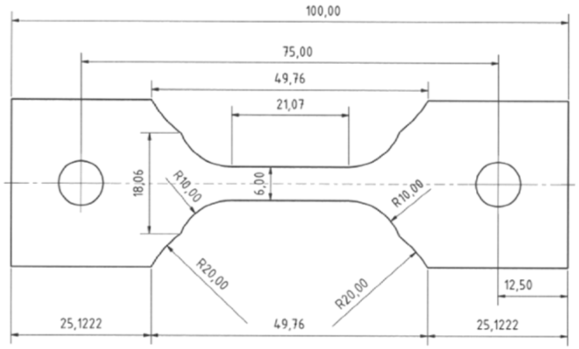


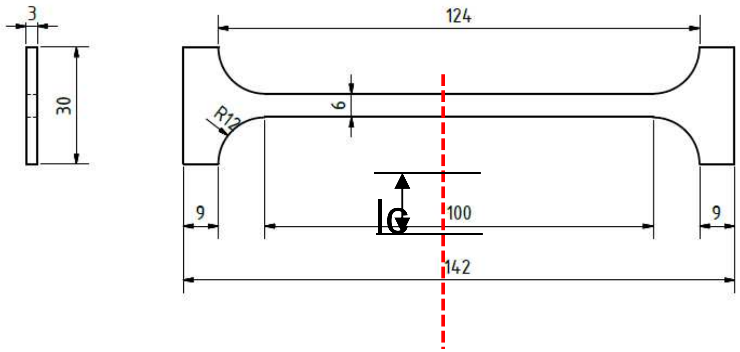
Specimen & Pad Geometries

- 3 types of specimen geometries, EA4T
  b = 10 mm and parallel length lp = 15.96 mm
  b = 6 mm and parallel length lp = 21.07 mm
  b = 6 mm and parallel length lp = 100 mm
  t = 3 mm

- 2 types of pads, R8
  a) round
  b) flattened





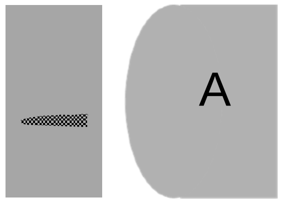


Fretting Fatigue – Overview of Tests performed

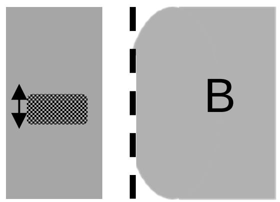
- Test frequency f=120-140Hz
- Fretting fatigue has been initiated for different loading scenarios depending on tensile stress σ_{11}, tranversal loading Q, parallel length l_P and contact length l_c

Specimen	Contact zone	Geometry wxtxL in mm	Tensile stress in MPa	Transvers load in kN	Cycles N	Cracks?	Pad geometry	Remarks
YO1-FF-1	1	10x3x100	350	4,00	1,00E+06	-	A	preliminary test, specimen polished
	2	10x3x100	350	2,00	1,00E+06	-	A	preliminary test, specimen polished
YO1-FF-2	1	6x3x100	350	3,00	1,00E+06	-	A	preliminary test, specimen polished
	2	6x3x100	350	1,40	1,00E+06	-	A	preliminary test, specimen polished
YO1-FF-3	1	6x3x100	350	3,00	1,05E+06	+	A	preliminary test, specimen polished, specimen failure,criterion Δf=2x0,1Hz
YO1-FF-4	1	6x3x100	350	3,00	2,98E+06	+	A	pads and specimen polished, specimen failure,criterion Δf=2x0,1Hz
YO1-FF-5	1	6x3x100	350	3,00	5,00E+06		A	pads and specimen not polished => cracks not detectable
	2	6x3x100	350	3,00	5,00E+06		A	pads and specimen not polished => cracks not detectable
YO1-FF-6	1	6x3x100	350	4,50	5,00E+06		A	pads and specimen not polished => cracks not detectable
YO1-FF-7	1	6x3x100	350	2,00	3,00E+06			pads and specimen not polished => cracks not detectable
	2	6x3x100	350	3,00	3,00E+06			pads and specimen not polished => cracks not detectable
YO1-FF-8	1	6x3x100	350	3,00	5,00E+06			pads and specimen not polished => cracks not detectable
	2	6x3x100	350	2,00	5,00E+06			pads and specimen not polished => cracks not detectable
YO1-FF-9	1	6x3x100	350	3,00	5,00E+06	+	B	pads and specimen polished, test stopped
YO1-FF-10	1	6x3x100	370	1,50	1,00E+06		A	pads and specimen not polished => cracks not detectable
YO1-FF-11	1	6x3x100	350	3,00	1,00E+06	+	B	pads and specimen polished, test stopped
	2	6x3x100	330	1,50	1,00E+06	+	B	pads and specimen polished, test stopped
YO1-FF-12	1	6x3x100	370	1,50	1,00E+06	+	B	pads and specimen polished, test stopped
	2	6x3x100	350	1,50	1,00E+06	+	B	pads and specimen polished, test stopped
YO1-FF-13	1	6x3x100	200	1,50	1,00E+06	-	B	pads and specimen polished, test stopped
	2	6x3x100	250	1,50	1,00E+06	-	B	pads and specimen polished, test stopped
YO1-FF-14	1	6x3x100	300	1,50	1,00E+06	+	B	pads and specimen polished, test stopped
	2	6x3x100	270	1,50	1,00E+06	+	B	pads and specimen polished, test stopped
YO1-FF-15	1	6x3x100	350	1,50	2,00E+05	+	B	pads and specimen polished, test stopped
	2	6x3x100	250	1,50	1,00E+06	-	B	pads and specimen polished, test stopped
YO1-FF-16	1	6x3x100	200	1,50	1,00E+06	-	B	pads and specimen polished, test stopped
	2	6x3x100	200	3,00	1,00E+06	-	B	pads and specimen polished, test stopped
YO1-FF-17	1	6x3x100	250	3,00	1,00E+06	-	B	pads and specimen polished, test stopped
	2	6x3x100	330	3,00	1,00E+06	+	B	pads and specimen polished, test stopped
YO1-FF-41	1	6x3x142	250	1,50	1,00E+06	+	B	pads and specimen polished, test stopped
	2	6x3x142	200	1,50	1,00E+06	-	B	pads and specimen polished, test stopped
YO1-FF-42	1	6x3x142	350	1,50	1,00E+06	+	B	pads and specimen polished, test stopped
	2	6x3x142	300	1,50	1,00E+06	+	B	pads and specimen polished, test stopped
YO1-FF-43	1	6x3x142	350	1,50	1,00E+06	+	B	pads and specimen polished, test stopped
	2	6x3x142	200	1,50	1,00E+06	-	B	pads and specimen polished, test stopped

Pad geometry A, round



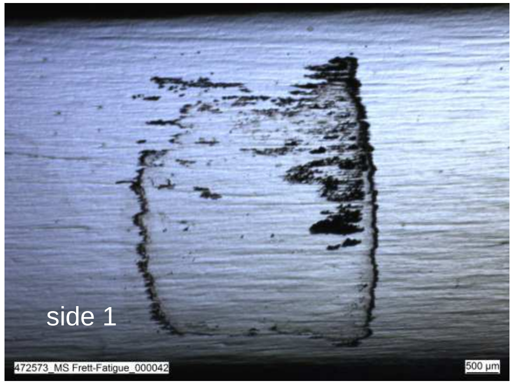
Pad geometry B, flat

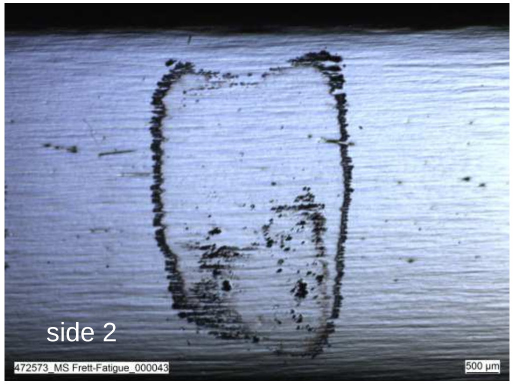


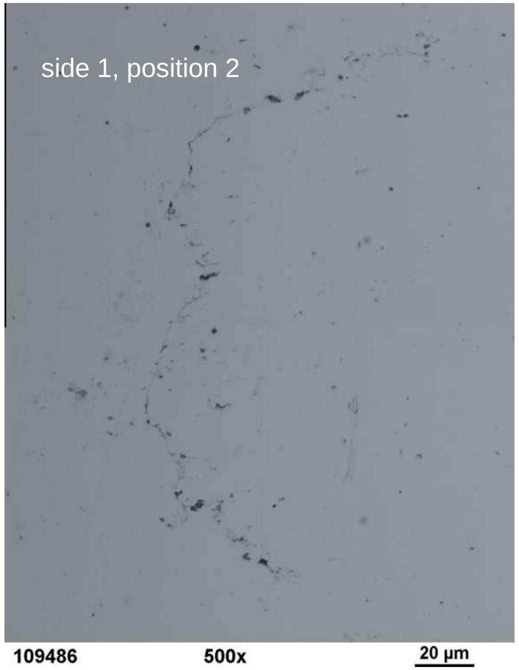
contact length lc = 1.7mm

Fretting Fatigue – Test Results

YO1-FF-17
tensile stress σ_{11}=330MPa, transversal load Q=3kN, cycles N=1E6
contact zone 2, flat pads

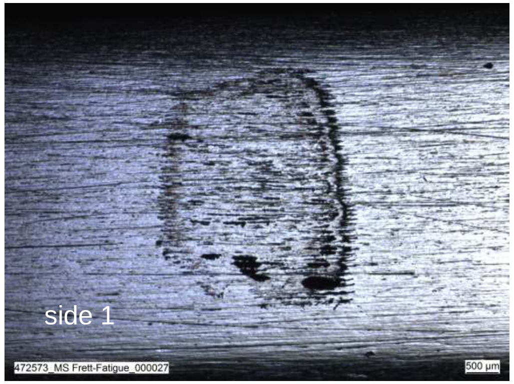


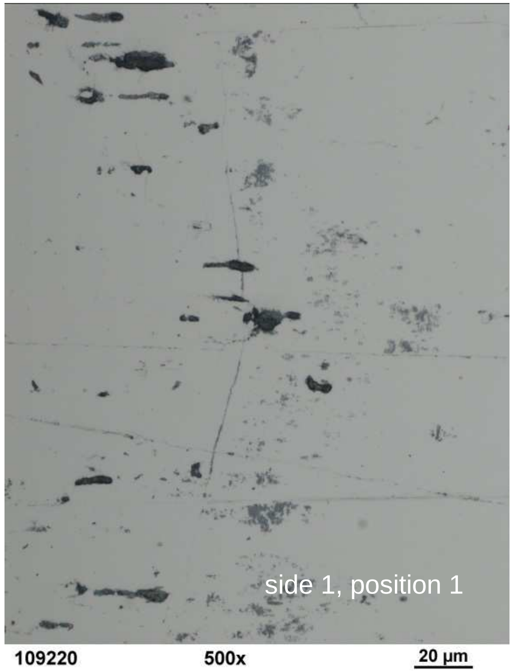




Fretting Fatigue – Test Results

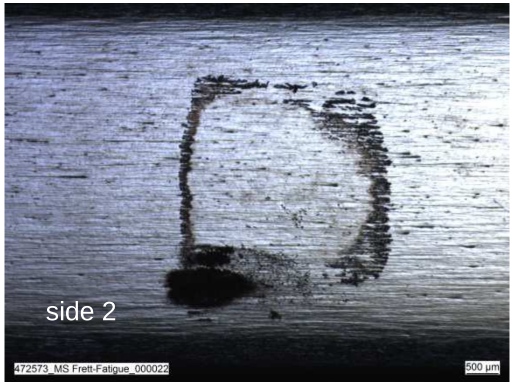
YO1-FF-42
tensile stress σ_{11}=300MPa, transversal load Q=1,5kN, cycles N=1E6
contact zone 2, flat pads





Fretting Fatigue – Test Results

YO1-FF-41
tensile stress σ_{11}=200MPa, transversal load Q=1,5kN, cycles N=1E6
contact zone 1, flat pads



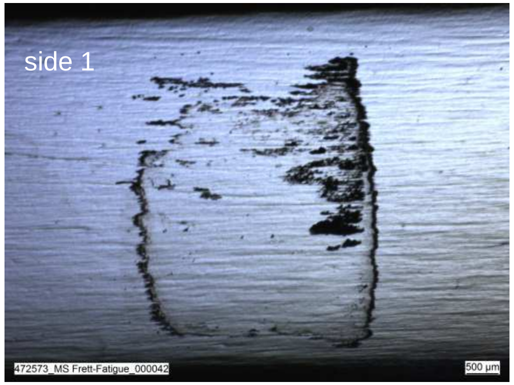
no fretting fatigue cracks detected

Fretting Fatigue – Summary of Test Results

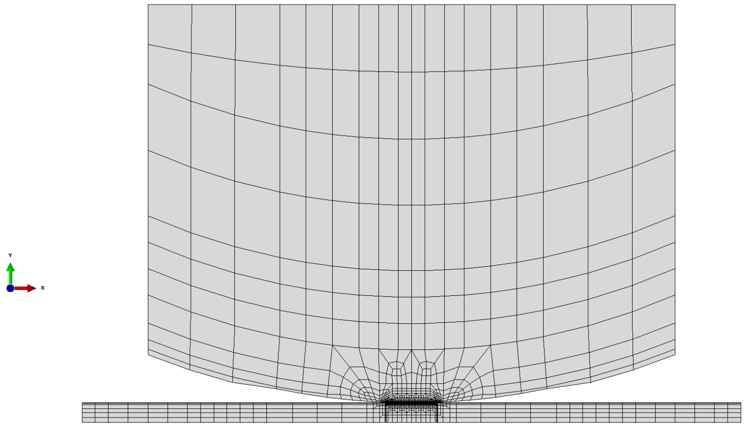
Fretting fatigue cracks were initiated and were found following the loading scenarios

N = 1E6 cycles with Q = 1.5 kN and σ_{11} = 270-350 MPa
N = 2E5 cycles with Q = 1.5 kN and σ_{11} = 350 MPa
N = 5E6 cycles with Q = 3 kN and σ_{11} = 350 MPa
N = 1E6 cycles with Q = 3 kN and σ_{11} = 350 MPa
N = 1E6 cycles with Q = 1.5 kN and σ_{11} = 250-350 MPa (with increased parallel specimen length)

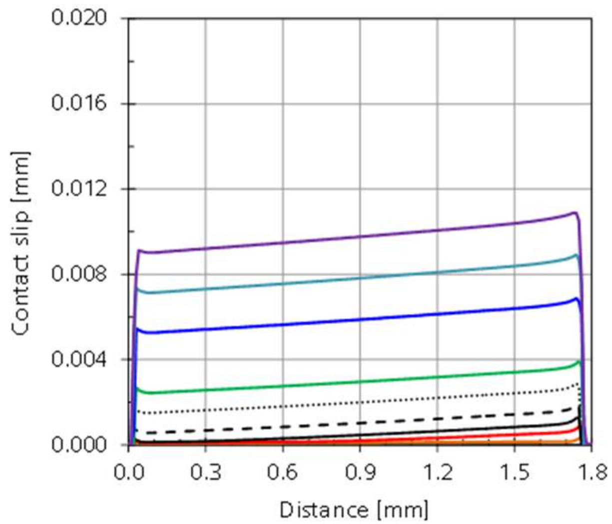
loading direction σ_{11}



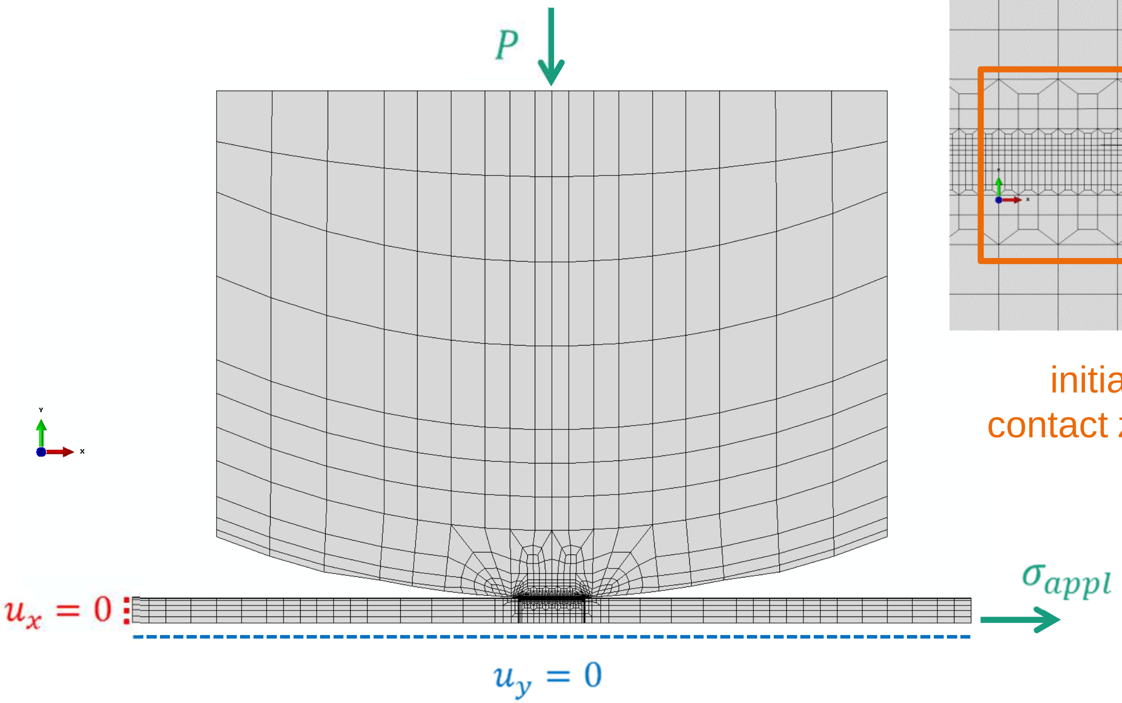
Fretting Fatigue – Numerical Approach: Overview

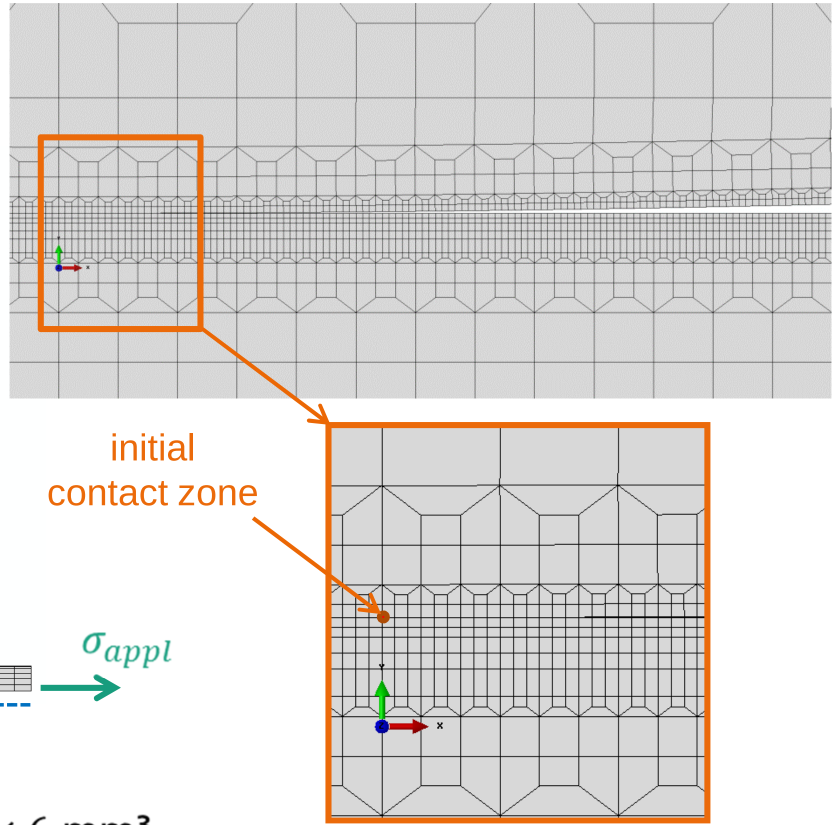


- Calculation/analysis of influential parameters such as stresses/strains, contact slip
- Application of multiaxial fatigue parameters



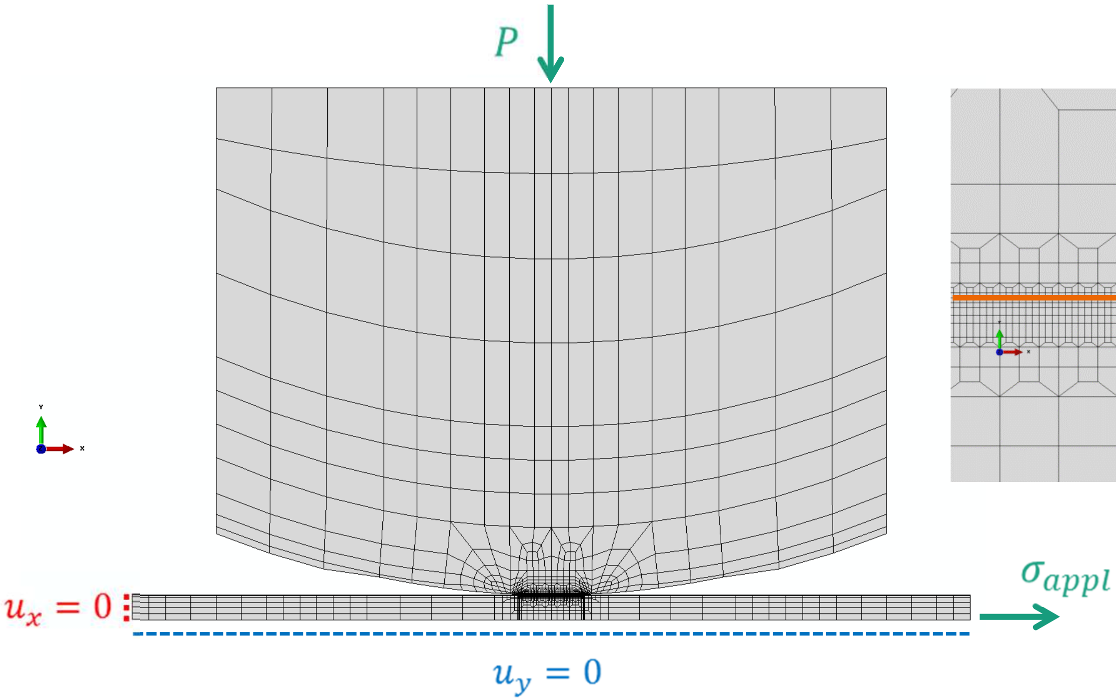
FE modelling: Model #1

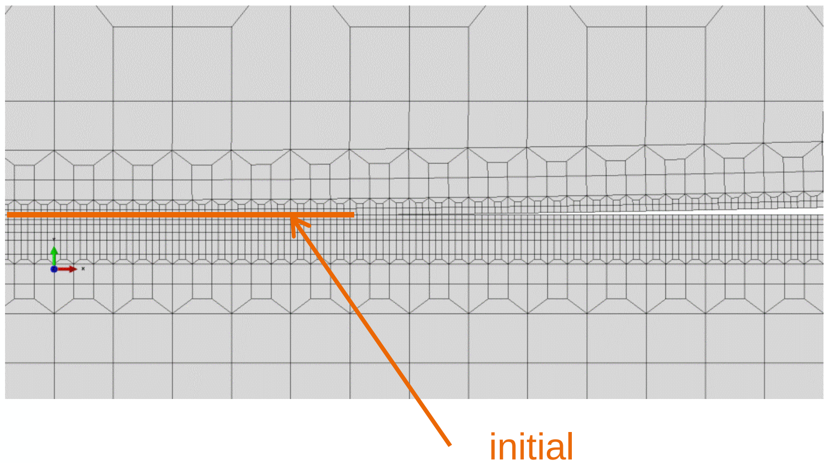




- 2D plane strain model, $L \times t \times W = 50 \times 3 \times 6$ mm³
- **Round pad surface (initially line contact)**
- Coefficient of friction $COF = 0.6$
- Cyclic tension at $R = 0.1$

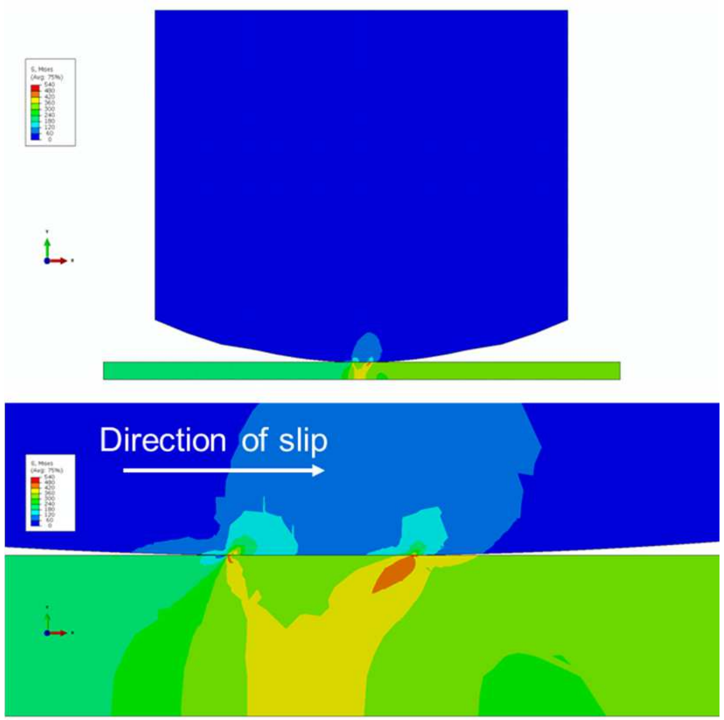
FE modelling: Model #2



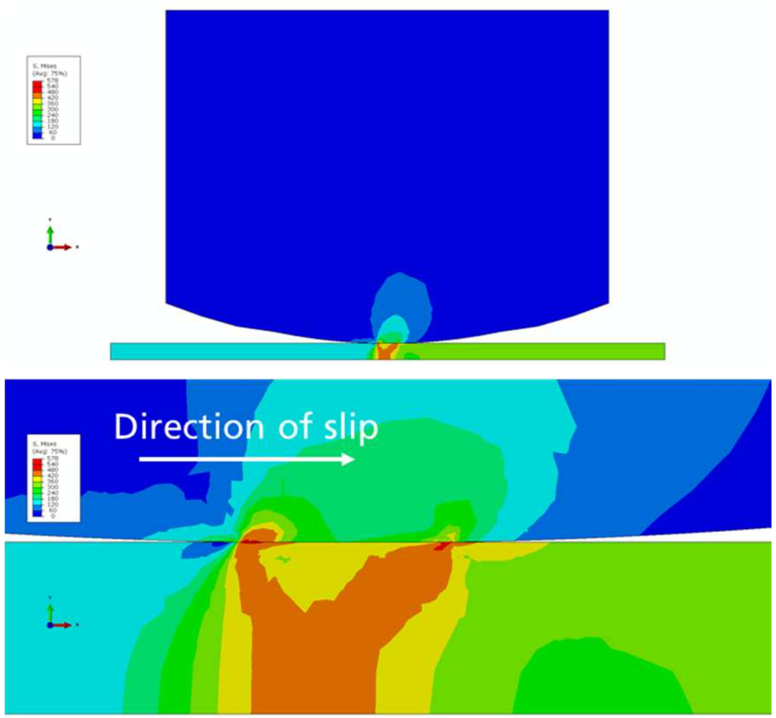


- 2D plane strain model, $L \times t \times W = 50 \times 3 \times 6$ mm³
- **Flattened pad surface (surface contact)**
- Coefficient of friction $COF = 0.6$
- Cyclic tension at $R = 0.1$

Stress/Strain Analysis: Model #2

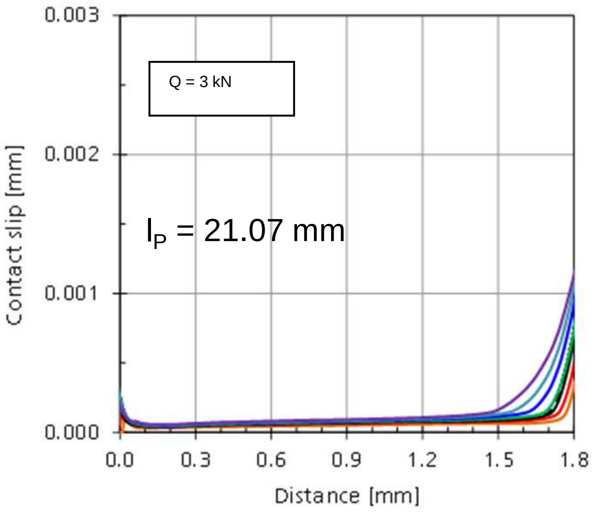


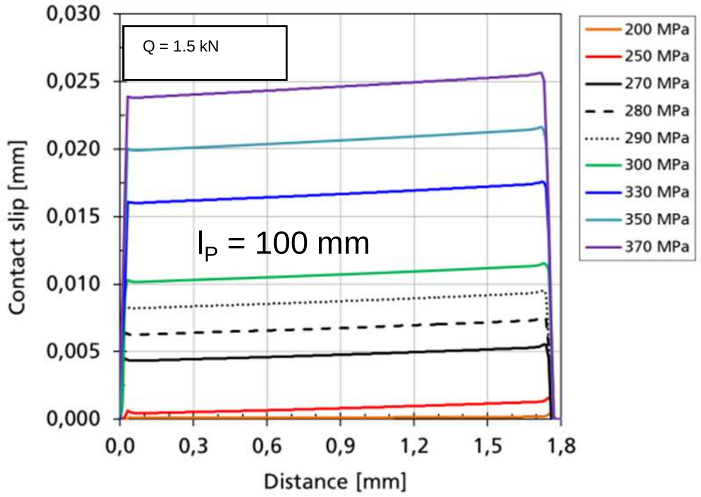
Von Mises stress at maximum applied stress
$Q = 1.5$ kN and $\sigma = 350\ MPa$

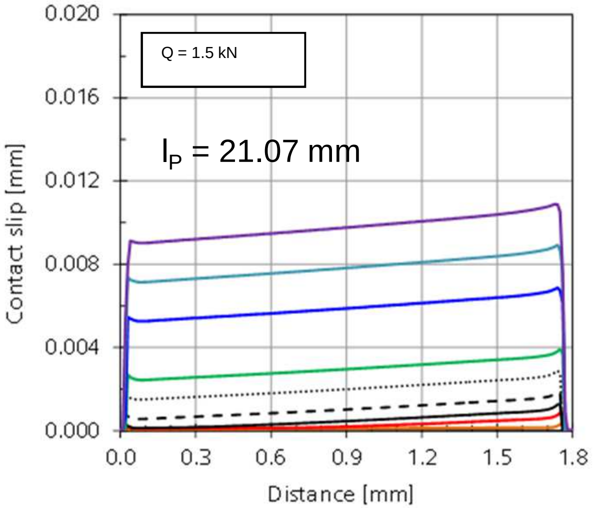


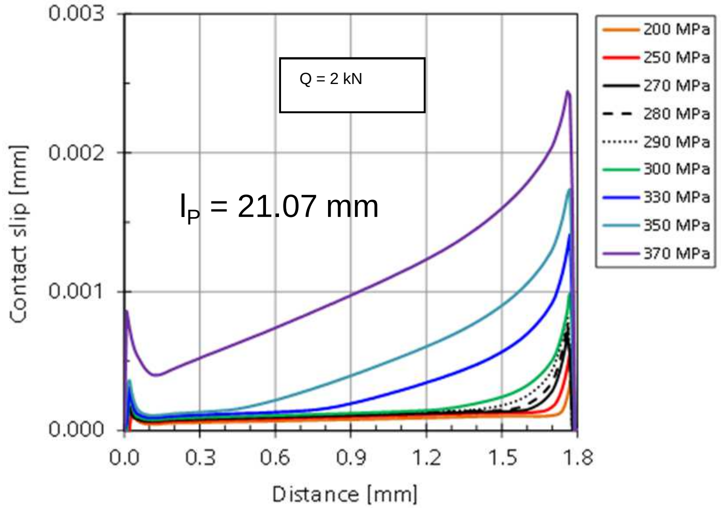
Von Mises stress at maximum applied stress
$Q = 3$ kN and $\sigma = 350\ MPa$

Analysis of Contact slip: Model #2; l_c = 1.7 mm









Fatigue (Damage) Parameters

- Take account of the mean stress and multiaxial stress state
- Allow for comparing test results for different specimen types and loading conditions
  → potential for component's assessment based on uniaxial S-N curves
- Stress / strain / energy based parameter formulation, e.g.

Smith, Watson, Topper

$$\sigma_{n,\max}\frac{\Delta\varepsilon_1}{2}=\frac{\sigma_f'^2}{E}\left(2N_f\right)^{2b}+\sigma_f'\varepsilon_f'\left(2N_f\right)^{b+c}$$

$$P_{SWT}=\sqrt{\sigma_{n,\max}\frac{\Delta\varepsilon_1}{2}E}$$

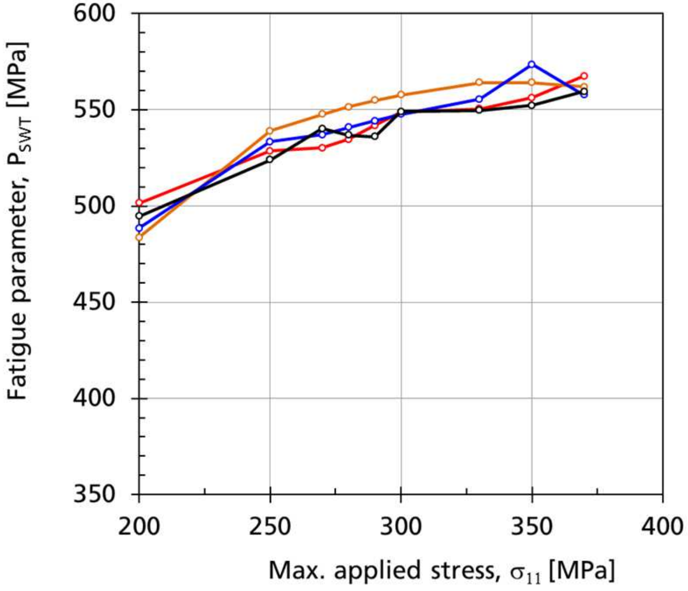
Wang, Brown

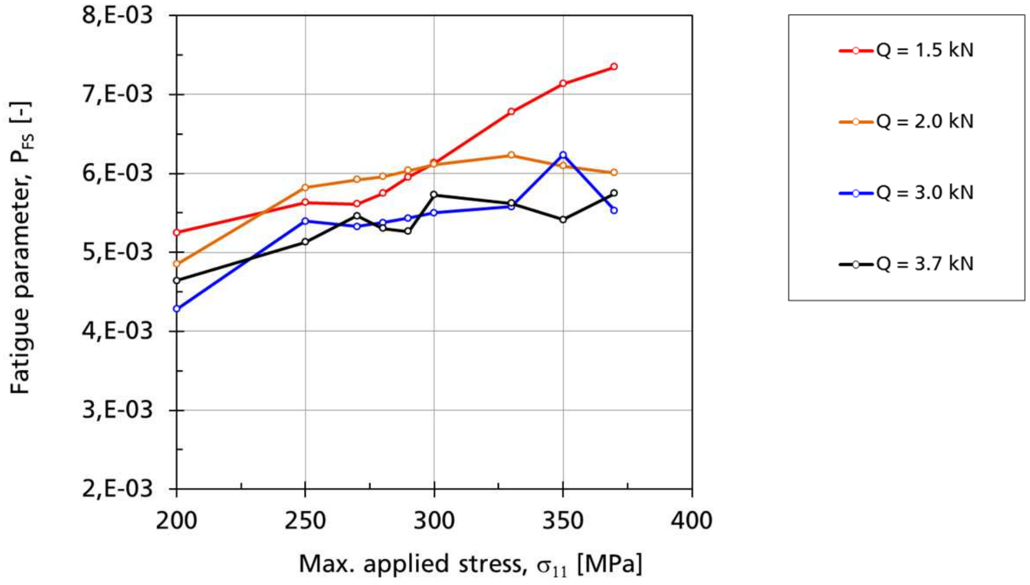
$$P_{WB}=\frac{\Delta\gamma_{\max}}{2}+\frac{\Delta\varepsilon_n}{2}=1{,}65\frac{\sigma_f'}{E}\left(2N_f\right)^{b}+1{,}75\varepsilon_f'\left(2N_f\right)^{c}$$

Fatemi, Socie

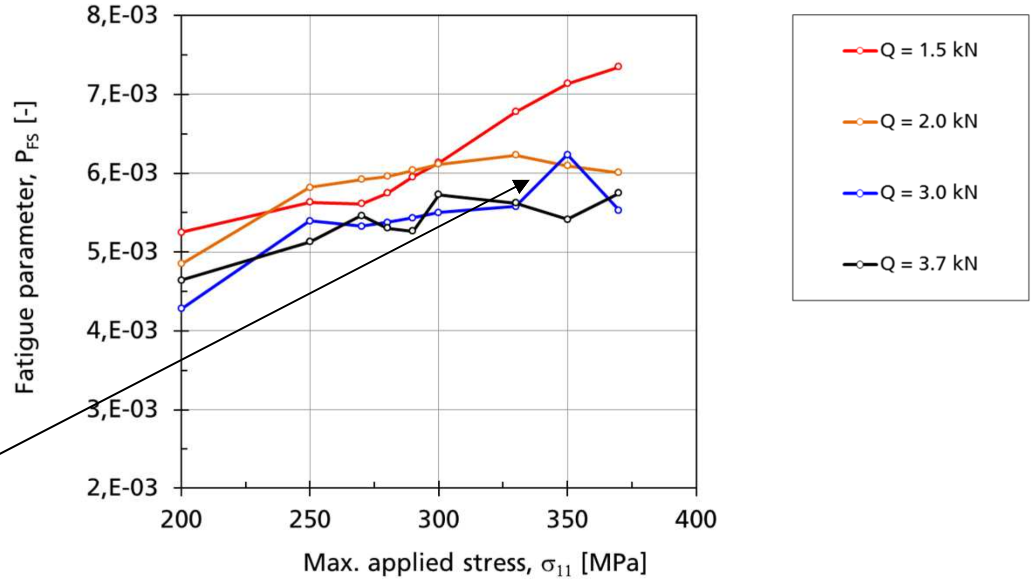
$$P_{FS}=\frac{\Delta\gamma}{2}\left(1+k\frac{\sigma_{n,\max}}{\sigma_0}\right)=\frac{\tau_f'}{G}\left(2N_f\right)^{b\gamma}+\gamma_f'\left(2N_f\right)^{c\gamma}$$

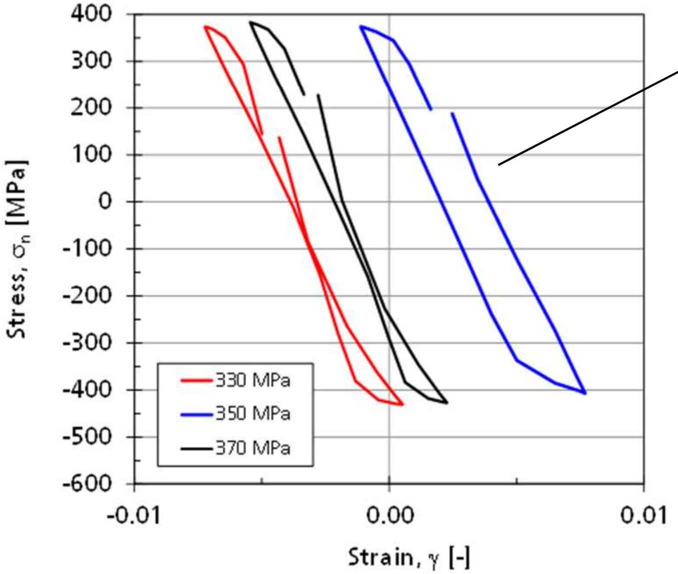
Fatigue (Damage) Parameters: Model #2





Fatigue (Damage) Parameters: Model #2

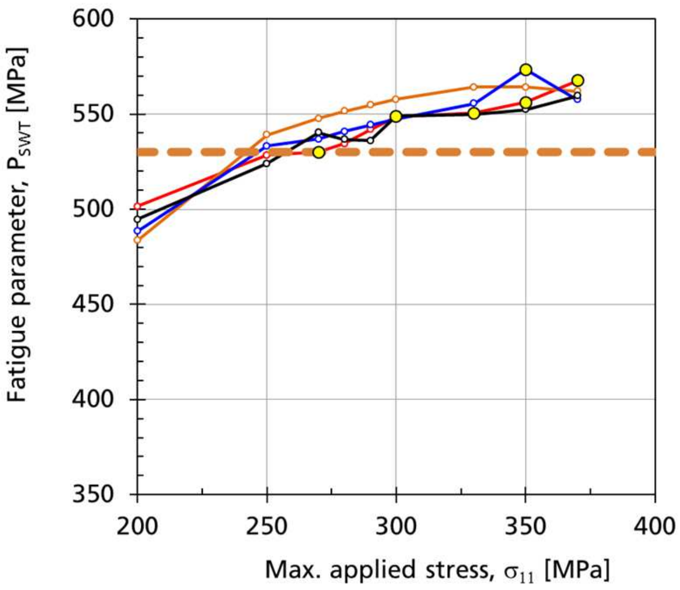


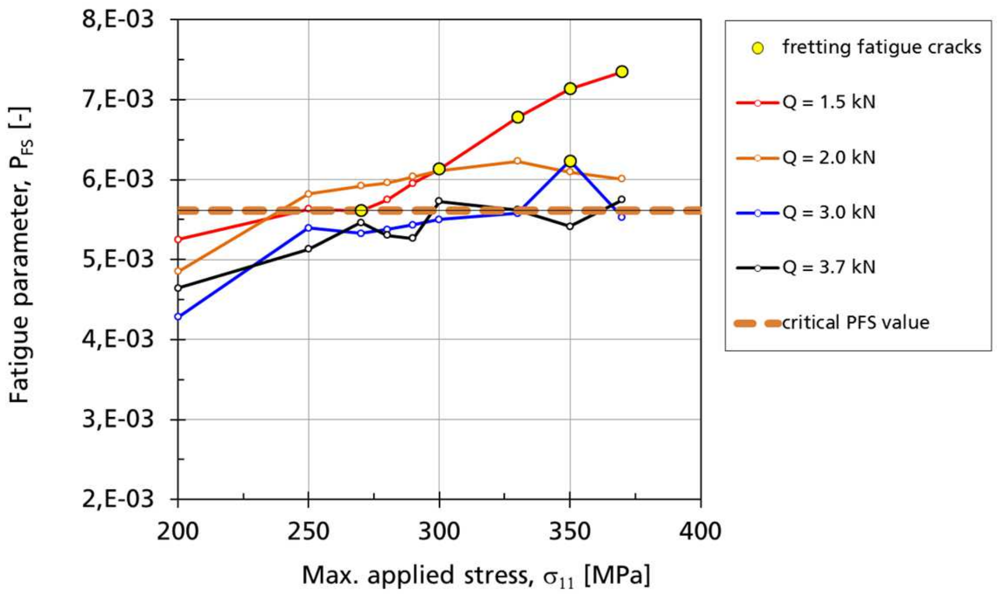


Q = 3 kN

SWT vs FS: Model #2

Fatigue damage parameter P_{SWT} and P_{FS} as a function of σ_{11}, l_P = 21.07 mm

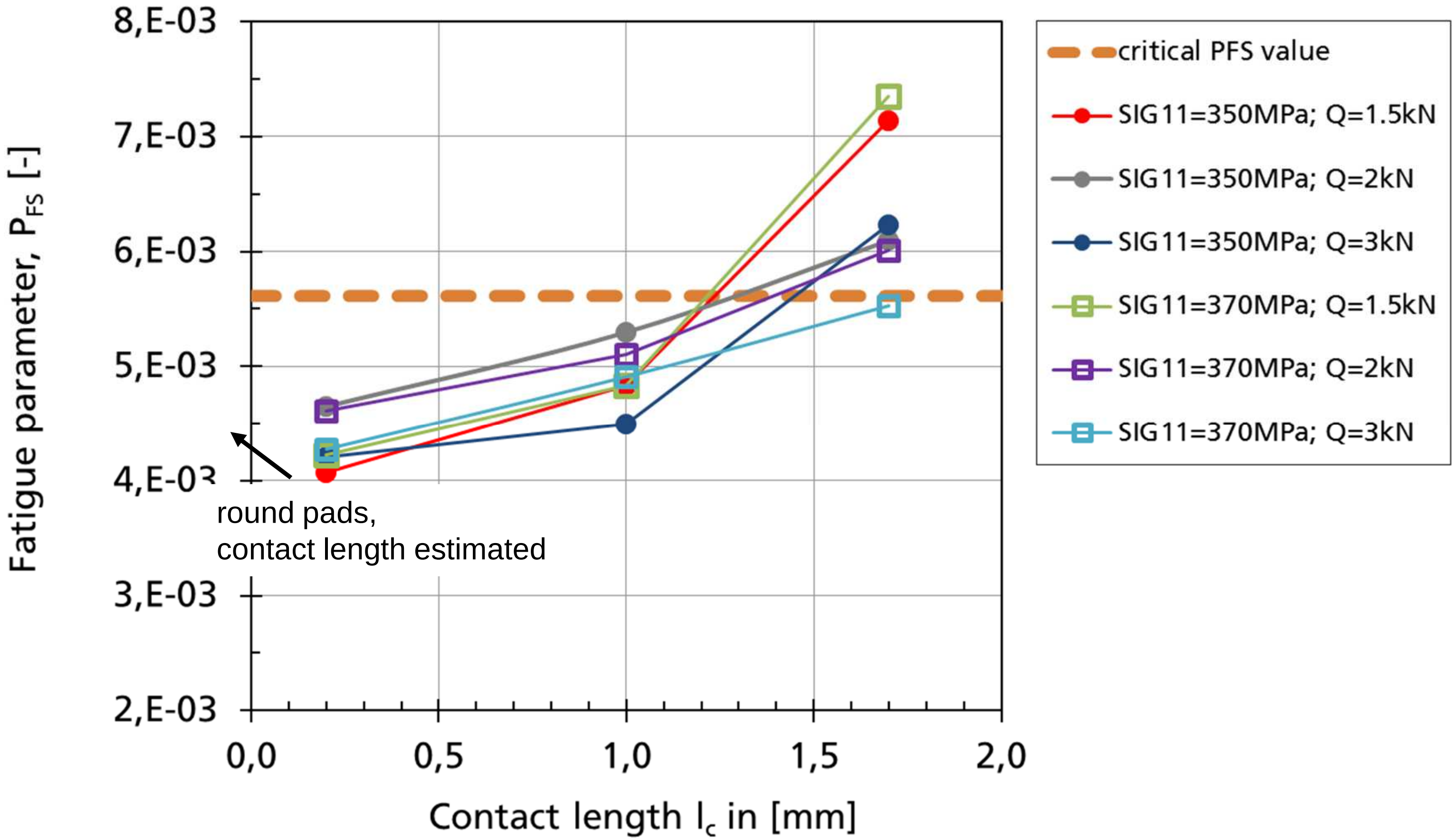




For $P_{FS} > P_{FS,crit.}$ = 0,0056
the initiation of fretting fatigue cracks is expected

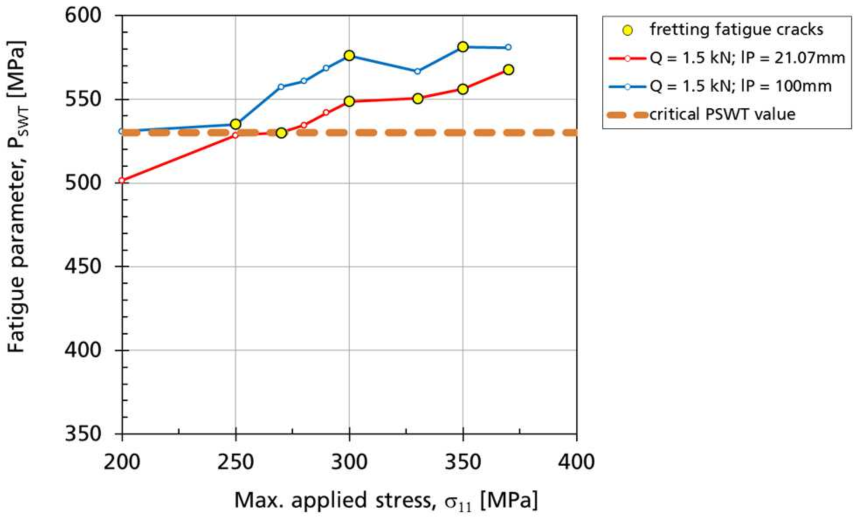
Round vs Flat Pads: Model #1 / Model #2

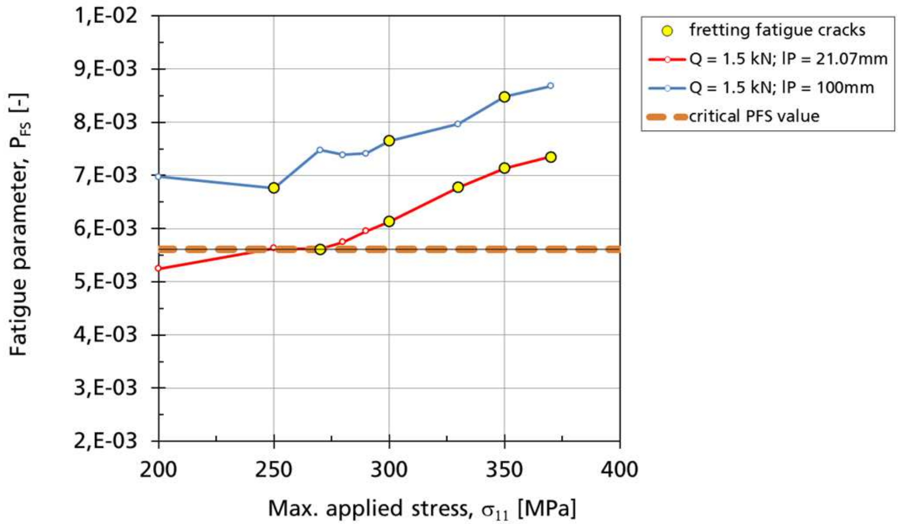
Fatigue parameter P_{FS} as a function of contact length (round pads, flat pads)



SWT vs FS: Model #2

Comparison of fatigue parameter P_{SWT} and P_{FS} for l_P = 21.07 mm and 100 mm





Conclusions: Experimental Part

- A test configuration which enables the loading of a given material pairing has been developed. By means of this test configuration fretting fatigue cracks initiated and were found following the loading scenarios

  N = 1E6 cycles with Q = 1.5 kN and σ_{11} = 270-350 MPa

  N = 2E5 cycles with Q = 1.5 kN and σ_{11} = 350 MPa

  N = 5E6 cycles with Q = 3 kN and σ_{11} = 350 MPa

  N = 1E6 cycles with Q = 3 kN and σ_{11} = 350 MPa

  N = 1E6 cycles with Q = 1.5 kN and σ_{11} = 250-350 MPa
  (with increased parallel specimen length)

Conclusions: Numerical Part

- The P_{FS} fatigue parameter was estimated to be the most suitable one as it takes into account the shear deformation $\Delta\gamma$ in the contact zone
- FE analyses support the experimental finding that increasing the contact area (change from initial line to initial surface contact) facilitates crack initiation
- Test results determined with specimens with an increased parallel length showed that fretting fatigue cracks tend to initiate at lower longitudinal stresses (σ_{11} =250 MPa instead of 270 MPa) applying the same transversal load of Q =1.5 kN
- Evaluating the experimental findings and the FE calculations an estimate for the critical fretting fatigue parameter $P_{FS,crit.}$ = 0,0056 was derived
- Due to scale effects up to now the results and the derived $P_{FS,crit.}$ = 0,0056 are only valid for the small scale specimens investigated
- To be able to evaluate the potential of the approach for an industrial application further investigations and numerical analyses on small and full scale press fits are necessary

Thank you for your attention