On-line detection of fretting fatigue crack initiation by lock-in thermography

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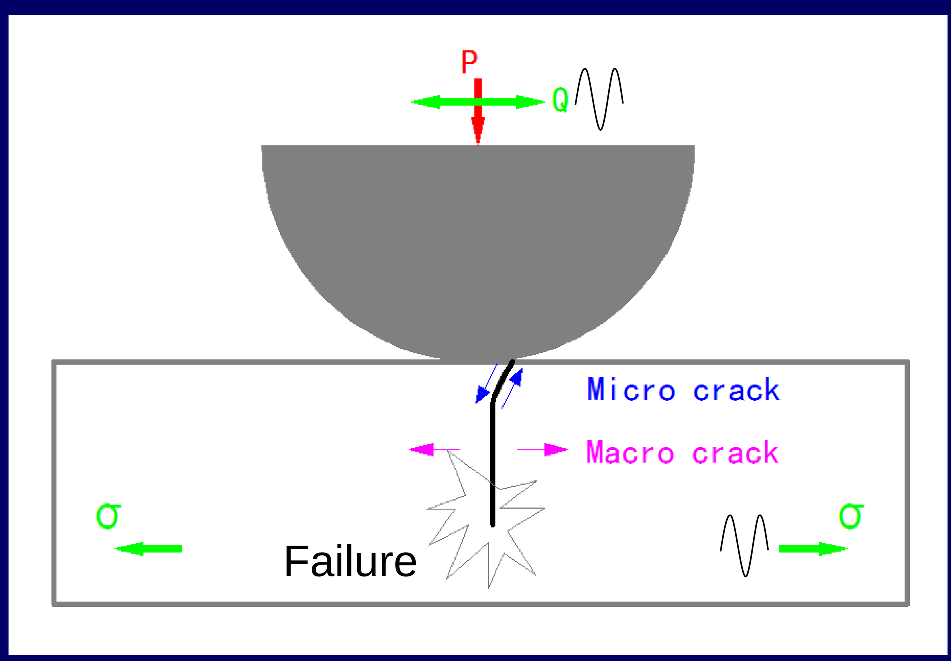
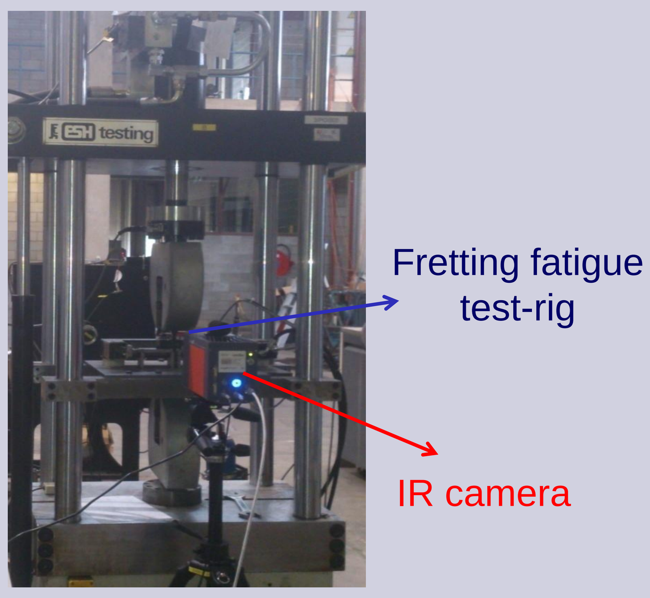


Like plain fatigue, lifetime of fretting fatigue is divided into two proportions: crack initiation and crack propagation. Usually, crack initiation and crack propagation are independently affected by surface phenomena and microstructures, respectively. **Therefore, accurately separating the two parts enables to find right solutions to improve total lifetime**.

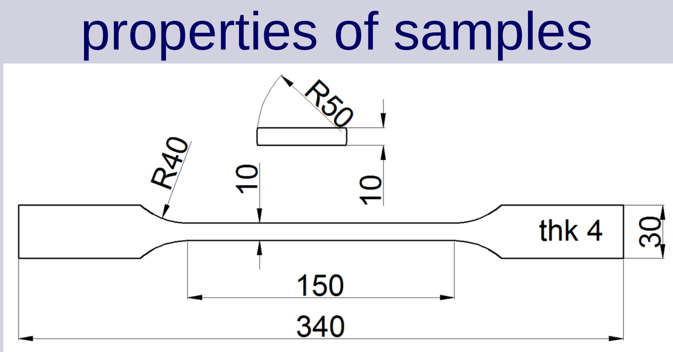
On the other hand, **lack of experimental data to detect micro-cracks in fretting fatigue is a barrier to understand crack-initiation phenomena**. In this study, detection of micro-cracks in fretting fatigue is attempted by thermography. Temperature amplitudes of 4 zones of interests are processed on-line based on lock-in methodology. After running-in and stabilization stages, presence of cracks leads to a rise of the stabilized temperature amplitude of specific zone of interest where cracks are located. After that, tests are stopped and samples are inspected for cracks by microscopy.

Fretting fatigue test and thermography

Experimental set-up

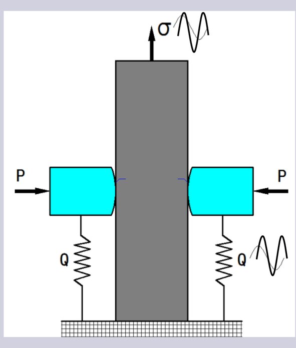


Geometry and mechanical properties of samples

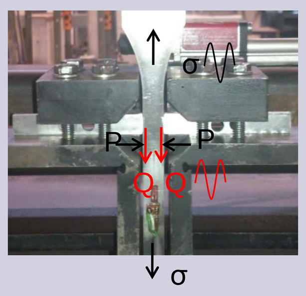


AL2024-T3	σ_y [MPa]	σ_{ult} [MPa]	K_{IC} [MPa √mm]
Specifications	≥325	≥450	-
Literature	383	506	2083

Fretting fatigue test



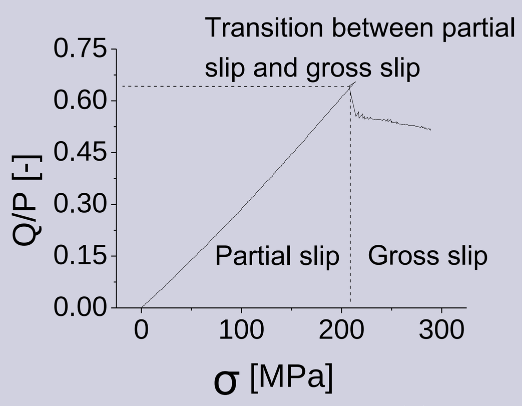
Schematic drawing of fretting fatigue test

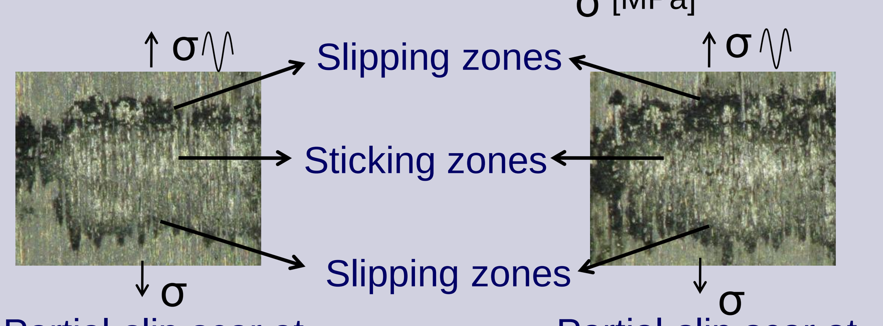


Picture of the fretting fatigue test

Test conditions of fretting fatigue

σ_{max} [MPa]	200
f [Hz]	5
R (σ_{min} /σ_{max}) [-]	0
P [N]	1000
Q_{max}/P [-]	0.6

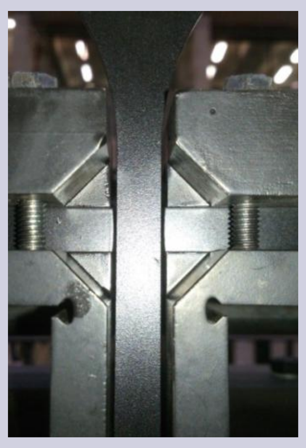




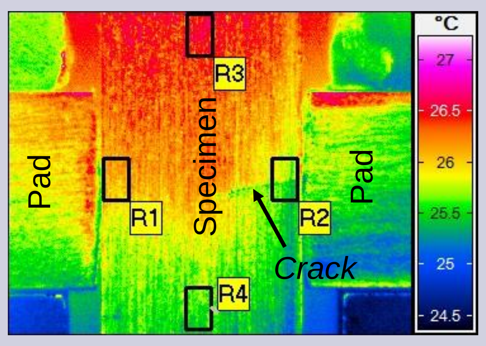
Partial-slip scar at left-side contact

Partial-slip scar at right-side contact

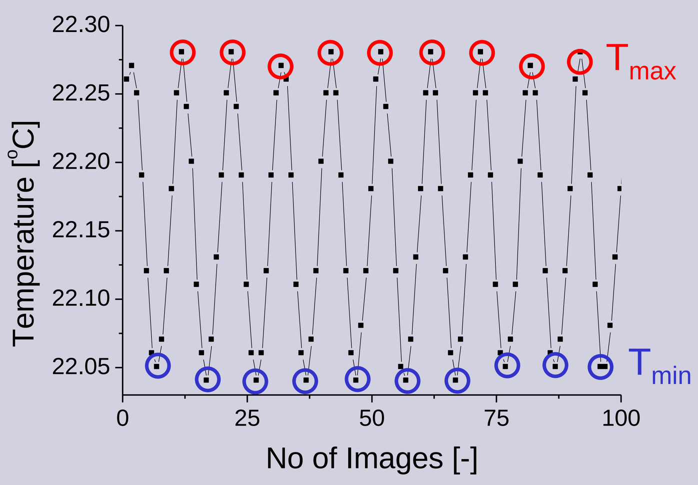
Thermography



Painted specimen in black

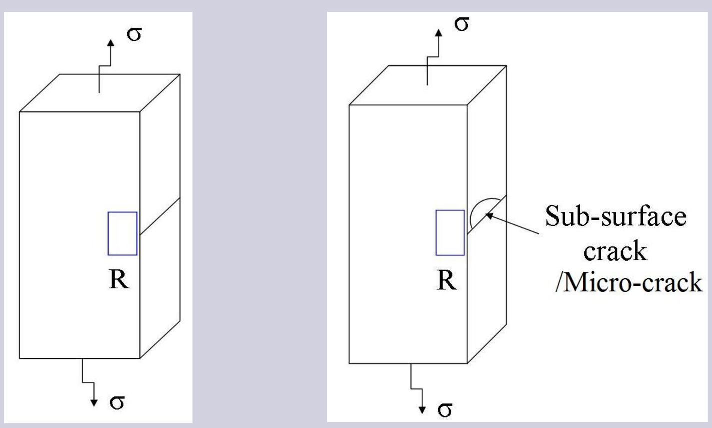


Thermal image with 4 zones of interests



Thermal data is grabbed on-line through **Matlab** with a frame rate of 50 Hz, which allows to have 10 thermal images per fatigue cycle. Temperature amplitude per cycle ($T_a = \Delta T/2 = (T_{max} - T_{min})/2$) is monitored in order to detect crack initiation.

Concept for detection of crack initiation



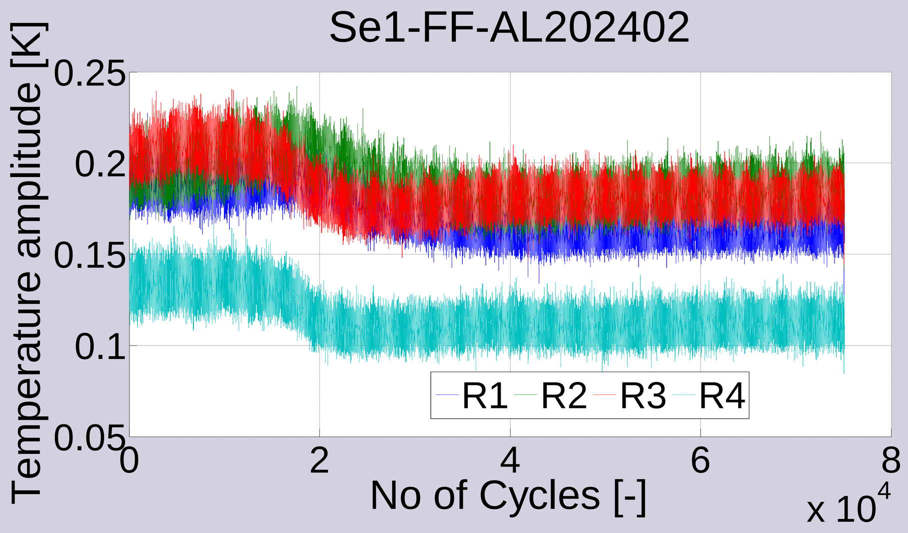
Presence of micro-cracks or sub-surface cracks causes rise to temperature amplitude (T_a) since stress concentration leads to increased Δσ or ΔT.

$$\Delta\sigma_{kk} = -\frac{\rho C_p}{\alpha T_0}\Delta T \qquad \Delta\sigma_{kk}^{\uparrow} = -\frac{\rho C_p}{\alpha T_0}\Delta T^{\uparrow}$$

ρ : density; C_p : specific heat at constant pressure; T_0 : initial temperature

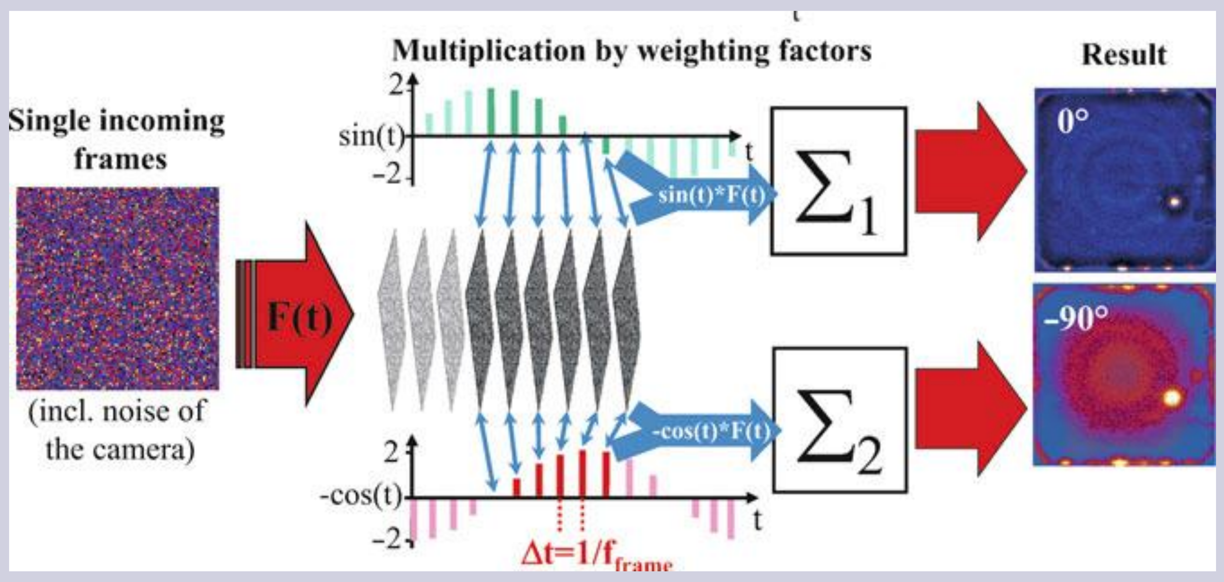
Results and discussion

Raw temperature amplitude vs no. of cycles (**AL2024-T3**)



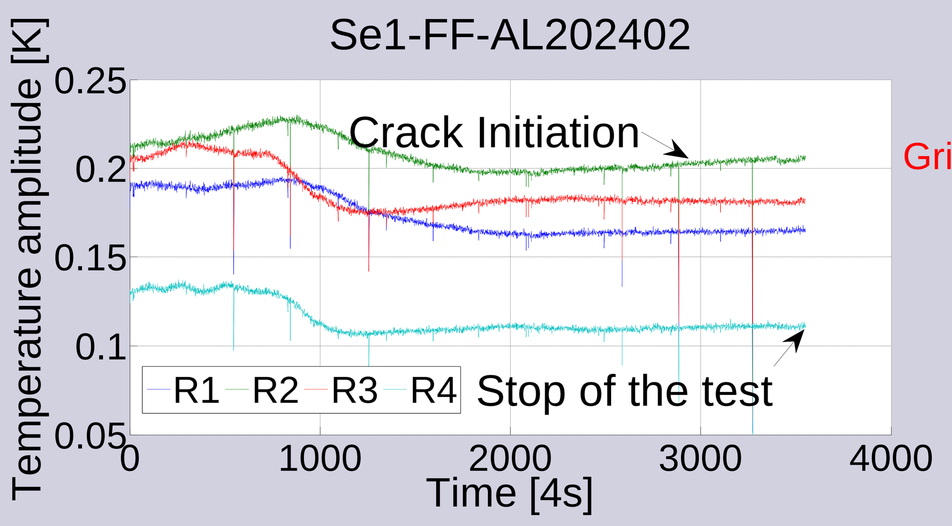
When cracks appear in the fretting fatigue zone, stress concentration is generated which causes an increase of stabilized stress amplitude and consequently an increase of temperature change. (too large signal-to-noise ratio)

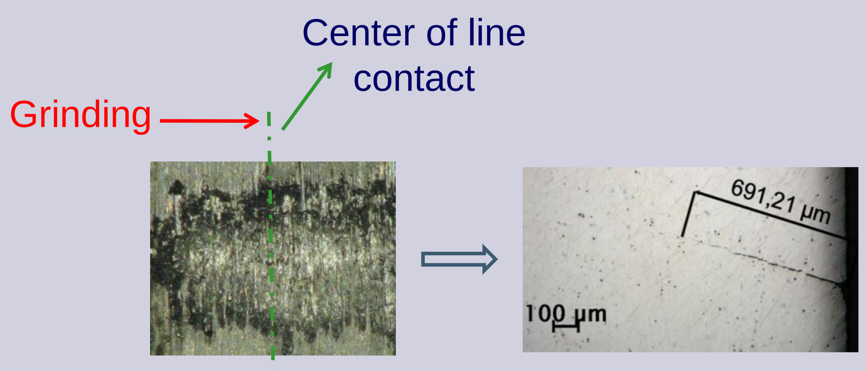
Lock-in method to reduce noises



To extract a signal amplitude at a specific frequency (fatigue frequency) out of a noisy environment !!!

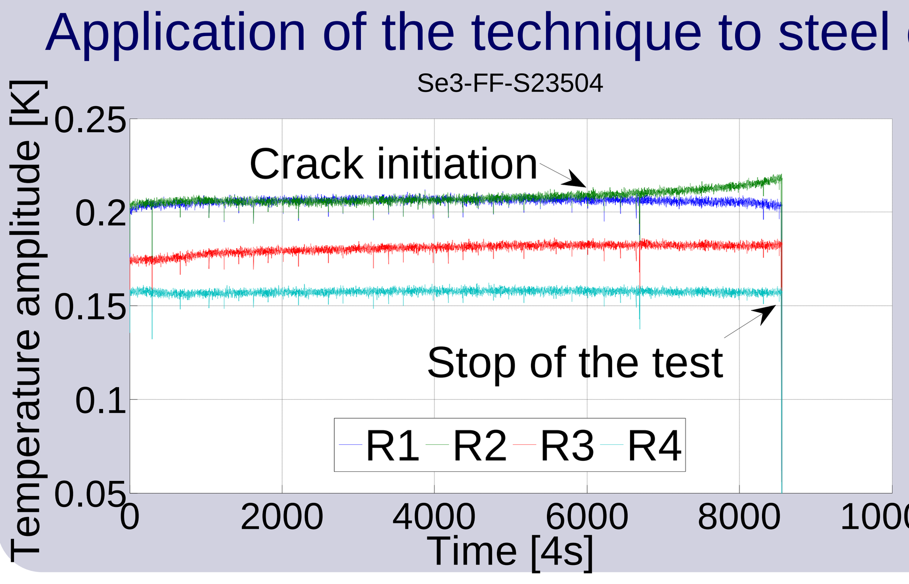
Lock-in temperature amplitude vs time (**AL2024-T3**)

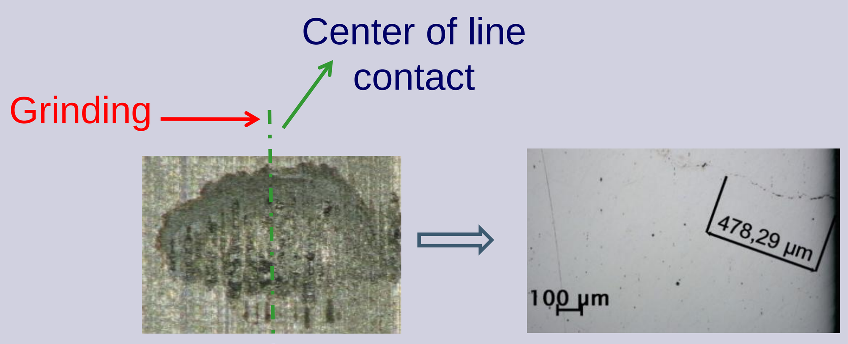




Off-line inspection for cracks

Application of the technique to steel of grade **S235JRC**





Off-line inspection for cracks

Conclusions

- ❖ Thermography is shown to be a powerful technique to detect micro-crack initiation of fretting fatigue tests
- ❖ Lock-in signal processing enables to improve signal-to-noise ratio and extract a small signal amplitude out of noisy environment
- ❖ The technique is expected to be a tool for crack initiation detection of any other materials under fretting fatigue conditions

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