Avalanches in fatigue and crossover from creep to fatigue

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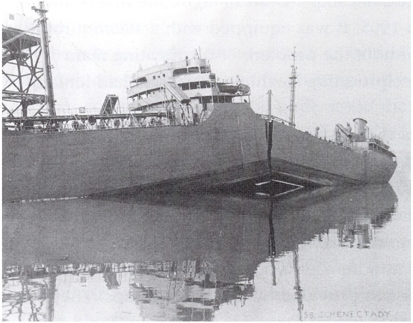
What is fatigue?

- Material response to repetitive loading
- Important for many practical applications



SS Schenectady

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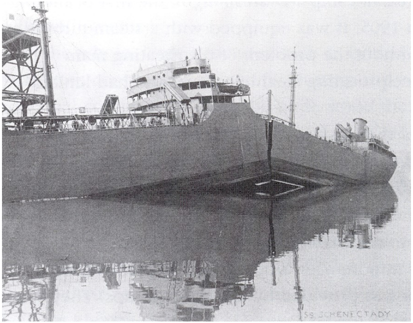

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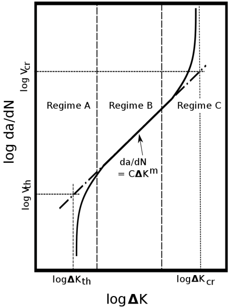
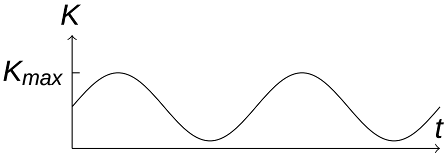
- Apparent self-similarity (Paris–Erdogan law)

$$\frac{da}{dN} \; / \; K^m$$

  - a crack length
  - N loading cycles
  - K stress intensity factor
  - $K = K_{max} \quad K_{min}$



Fatigue protocol



$R = 0.1$

- Asymmetry coefficient
  $R = \frac{K_{min}}{K_{max}}$

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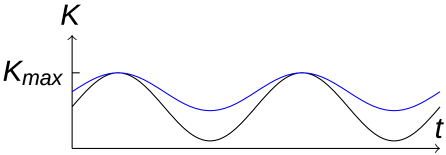

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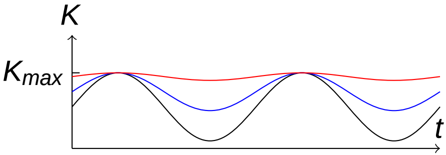

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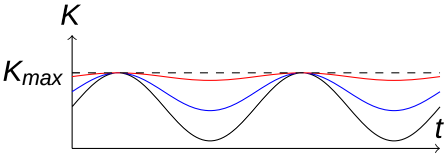

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- Creep as the limiting case
  $R = 1$

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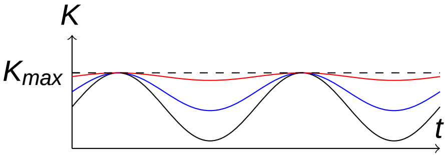

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- Asymmetry coefficient $R = \frac{K_{min}}{K_{max}}$
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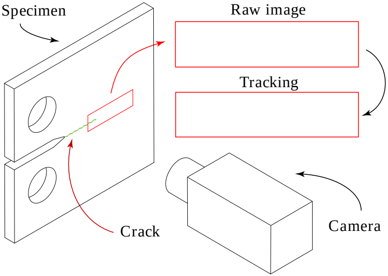
- the goal here is to explore the intermittent crack growth in fatigue [Kokkoniemi et al, JSTAT 2017] and the crossover to creep
- sort of similar to the Oslo Plexiglas experiments [Måløy et al, PRL 2006] but for a geometry more commonly used in the field of material science

Experimental setup



Lomakin et al, PRResearch 2021

- CT-specimens of 1050 Al alloy
- 10 Hz loading frequency, 0.25 Hz imaging frequency
- crack tip position tracked from the images

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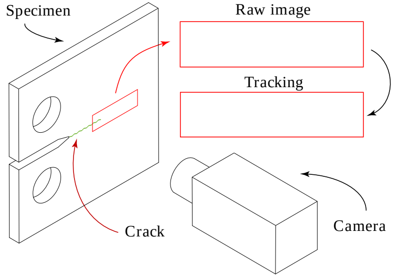

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- transparent PMMA
- placing the camera at an angle allows the tracking of a fracture line
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Naive attempt from creep to fatigue

Thermally activated process $v = v_c \exp(\quad E)$

Below depinning threshold $E = \frac{1}{\ d} \quad \frac{G}{G_c} \quad 1 \ , G / \ K^2$

Integrate the velocity over the loading cycle

$$v_{fat} = \frac{a}{N} = \int_0^{1=f} v\,dt = v_c e^{\overline{\ d}} \int_0^{1=f} \exp \,"\, \frac{}{d} \quad \frac{K(t)}{K_c} \quad {}^{2} \# \, dt$$

where $K(t) = \frac{K_{max} + K_{min}}{2} + \frac{K}{2} \sin(2 \ ft)$

Saddle-point integration gives $v_{fat} / \ K_{max} \exp \quad \frac{}{d} \quad \frac{K_{max}}{K_c} \quad {}^{2}$

Aluminum samples

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  - m linearly decreases with R

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  - *m* linearly decreases with *R*

- power-law distributed jump sizes

$$p(\ a)\ /\ \ a^{\ 2} e^{\ \frac{a}{a_0}}$$

PMMA samples – local velocities

- velocity of a 1D crack line

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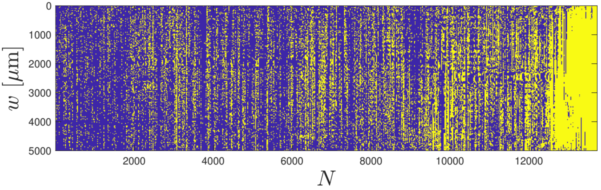
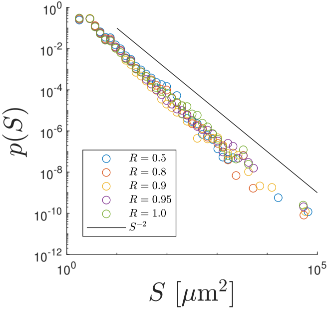
- Oslo experiments [Måløy et al, PRL 2006] had an exponent 2.55 (for the normalized velocity)

PMMA samples – avalanche sizes



- the local velocity is thresholded to yield avalanche clusters



- still a power-law with an exponent of roughly 2
- again not much variation in the distribution
- Oslo experiments [Måløy et al, PRL 2006] had an exponent around 1.5-1.7 (some variation depending on the methodology)

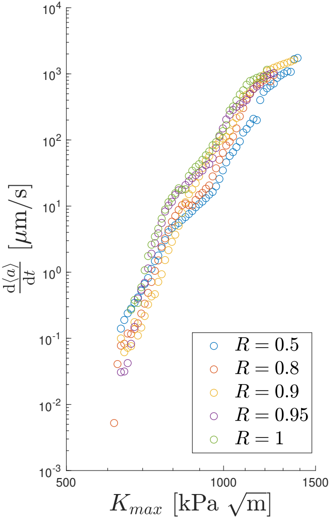
PMMA samples – Paris curves

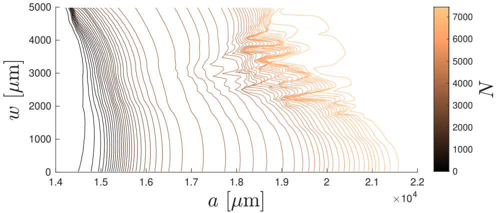
- the crack velocity considered as the time derivative of the mean crack position *hai*
- there is a lot of sample-to-sample variation in this mean velocity
  - the variation seems to increase with increasing *R*
- two regimes
  - related to the strain rate sensitivity of PMMA?

PMMA samples – Paris curves

- the crack velocity considered as the time derivative of the mean crack position $\langle a \rangle$
- there is a lot of sample-to-sample variation in this mean velocity
  - the variation seems to increase with increasing R
- two regimes
  - related to the strain rate sensitivity of PMMA?
  - the naive brittle approach works for the end part of the experiments

PMMA samples – front shape





- the large velocity fluctuations might be related to variations in the front shape
  - pinning at some defect

Conclusions

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- the local dynamics seem fairly constant with varying loading conditions
- the "universal" exponent of 2 is high
  - this might partially be explained by the nonstationarity of the velocity