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Avalanches in fatigue and crossover from creep to fatigue

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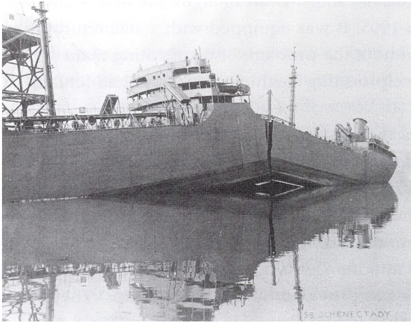
What is fatigue?

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



SS Schenectady

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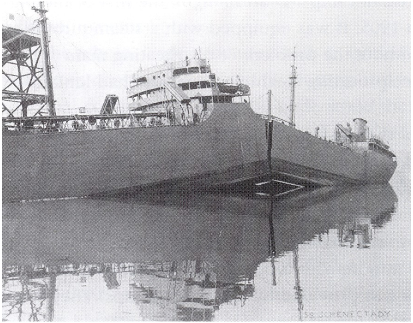
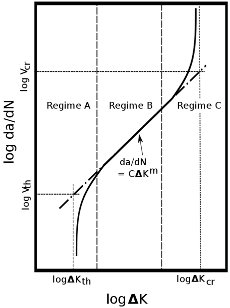


SS Schenectady

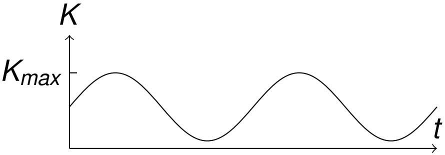
- Apparent self-similarity (Paris–Erdogan law)

$$\frac{da}{dN} \propto \Delta K^m$$

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



Fatigue protocol



$R = 0.1$

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

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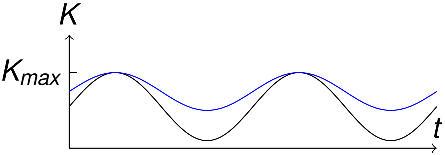

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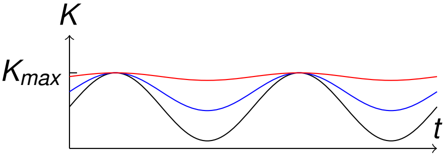

$R = 0.1$ $R = 0.5$ $R = 0.9$

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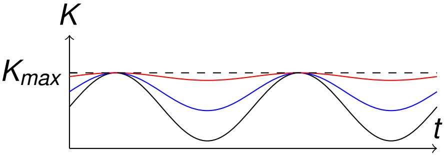

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  $R = 1$

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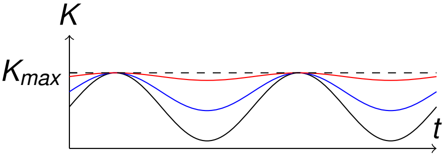

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- Asymmetry coefficient $R = \frac{K_{min}}{K_{max}}$
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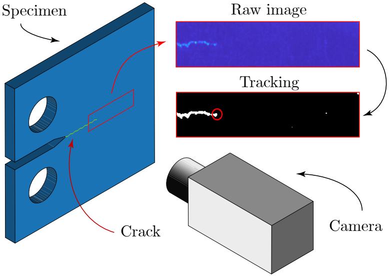
- the goal here is to explore the intermittent crack growth in fatigue [Kokkoniemi et al, JSTAT 2017] and the crossover to creep
- sort of similar to the Oslo Plexiglas experiments [Måløy et al, PRL 2006] but for a geometry more commonly used in the field of material science

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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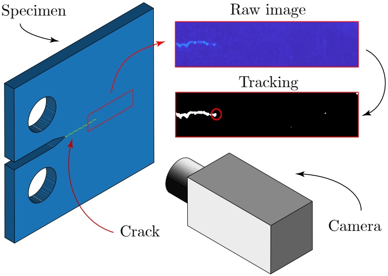

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- transparent PMMA
- placing the camera at an angle allows the tracking of a fracture line
- 1 Hz loading frequency, 1 Hz imaging frequency

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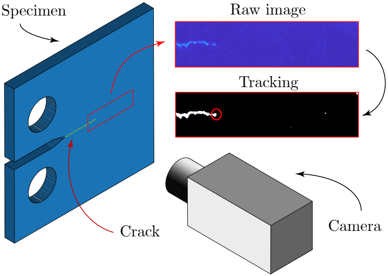

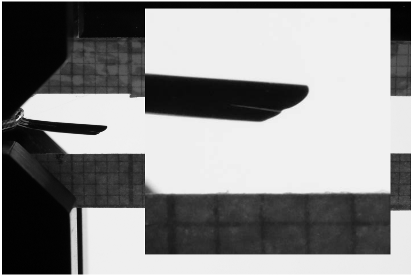

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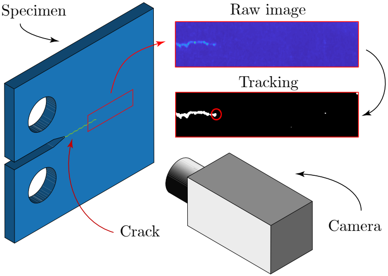

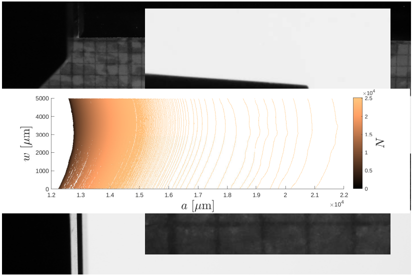

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Naive attempt from creep to fatigue

Thermally activated process $v = v_c \exp\left(-\beta \Delta E\right)$

Below depinning threshold $\Delta E = \frac{1}{\beta_d}\left[\left(\frac{G}{G_c}\right)^{-\mu} - 1\right]$, $G \propto K^2$

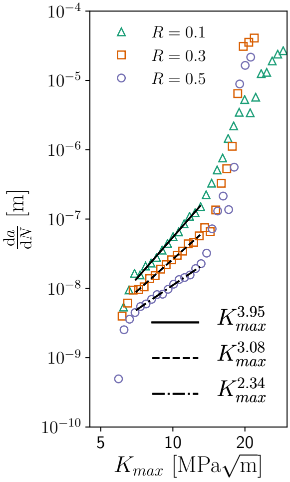
Integrate the velocity over the loading cycle

$$v_{fat} = \frac{\Delta a}{\Delta N} = \int_0^{1/f} v\,\mathrm{d}t = v_c e^{\frac{\beta}{\beta_d}} \int_0^{1/f} \exp\left[-\frac{\beta}{\beta_d}\left(\frac{K(t)}{K_c}\right)^{-2\mu}\right]\mathrm{d}t$$

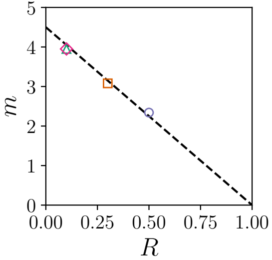
where $K(t) = \frac{K_{max}+K_{min}}{2} + \frac{\Delta K}{2}\sin\left(2\pi f t\right)$

Saddle-point integration gives $v_{fat} \propto K_{max}^{\mu} \exp\left[-\frac{\beta}{\beta_d}\left(\frac{K_{max}}{K_c}\right)^{-2\mu}\right]$

Aluminum samples



- flattening of the Paris regime in the Paris plots
  - m linearly decreases with R



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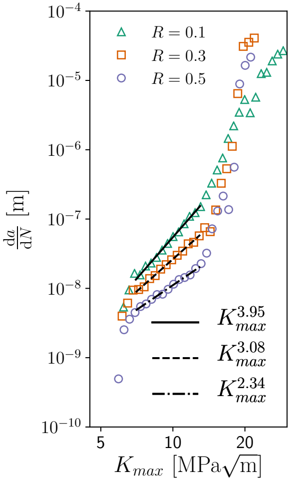

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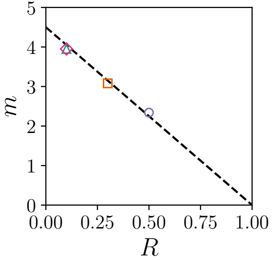
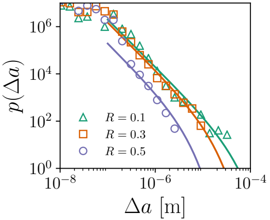
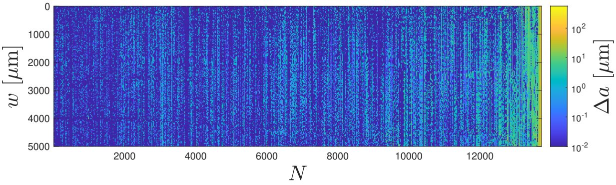




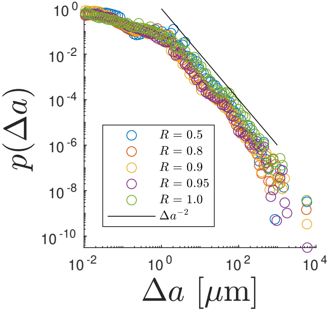
- power-law distributed jump sizes

$$p(\Delta a) \propto \Delta a^{-2} e^{-\frac{\Delta a}{\Delta a_0}}$$

PMMA samples – local velocities



- velocity of a 1D crack line



- a power-law distributed tail with an exponent of roughly 2
- not much variation in the distribution

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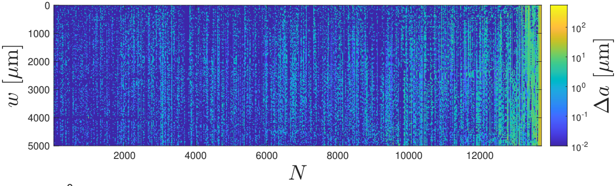

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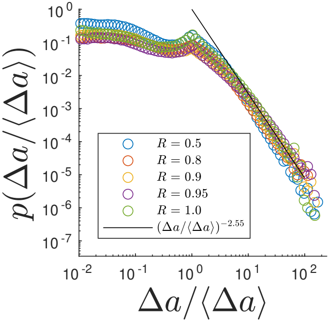
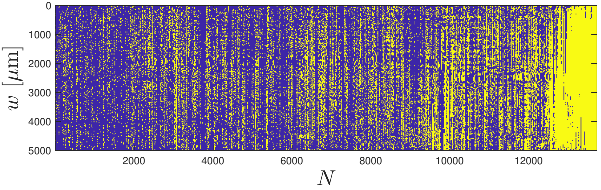
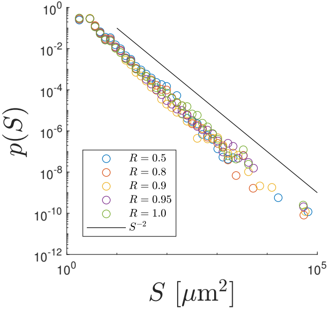


- a power-law distributed tail with an exponent of roughly 2
- not much variation in the distribution
- Oslo experiments [Måløy et al, PRL 2006] had an exponent 2.55 (for the normalized velocity)

PMMA samples – avalanche sizes

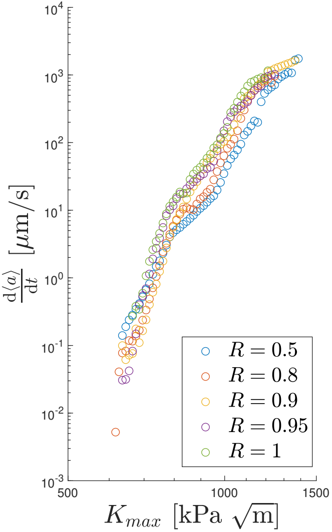


- the local velocity is thresholded to yield avalanche clusters



- 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 $\langle a \rangle$
- 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?

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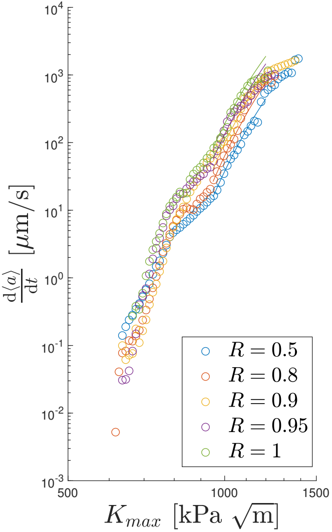

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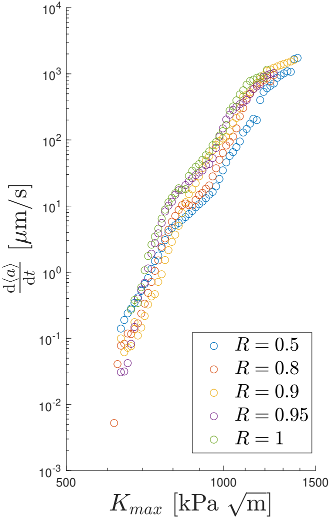
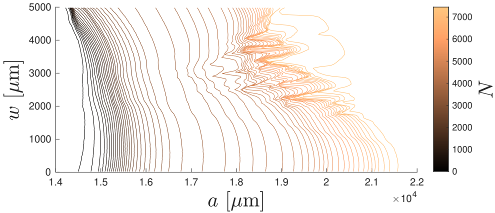
- two regimes
  - related to the strain rate sensitivity of PMMA?
  - the naive brittle approach works for the end part of the experiments

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