matrix-dominated failure in thermoplastic composites

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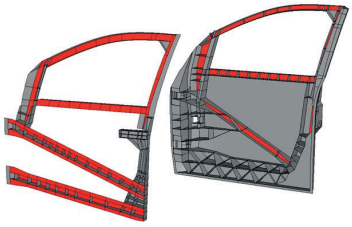
TU/e

thermoplastic composites

BMW i3 composite frame

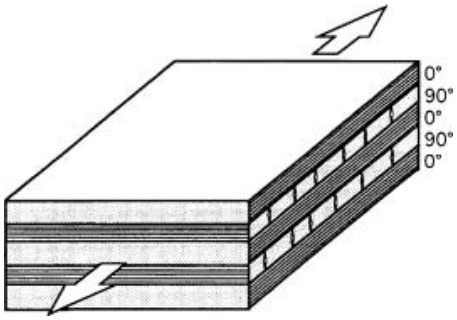
overmoulding [TPRC]

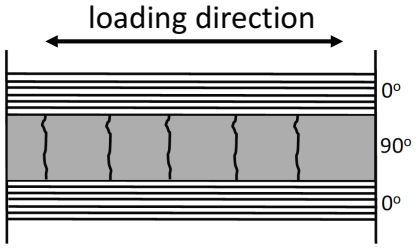


car side door [*Sabic*]

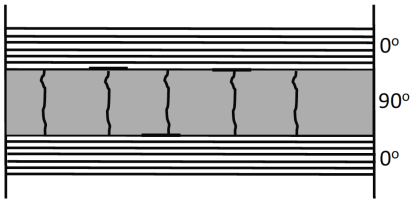
- high strength-to-weight ratio
- mass production methods feasible
- Issues with predictability of long-term performance

damage evolution: cross-ply laminates

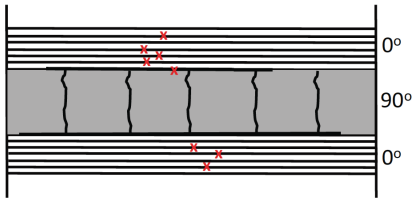




1. transverse matrix cracks

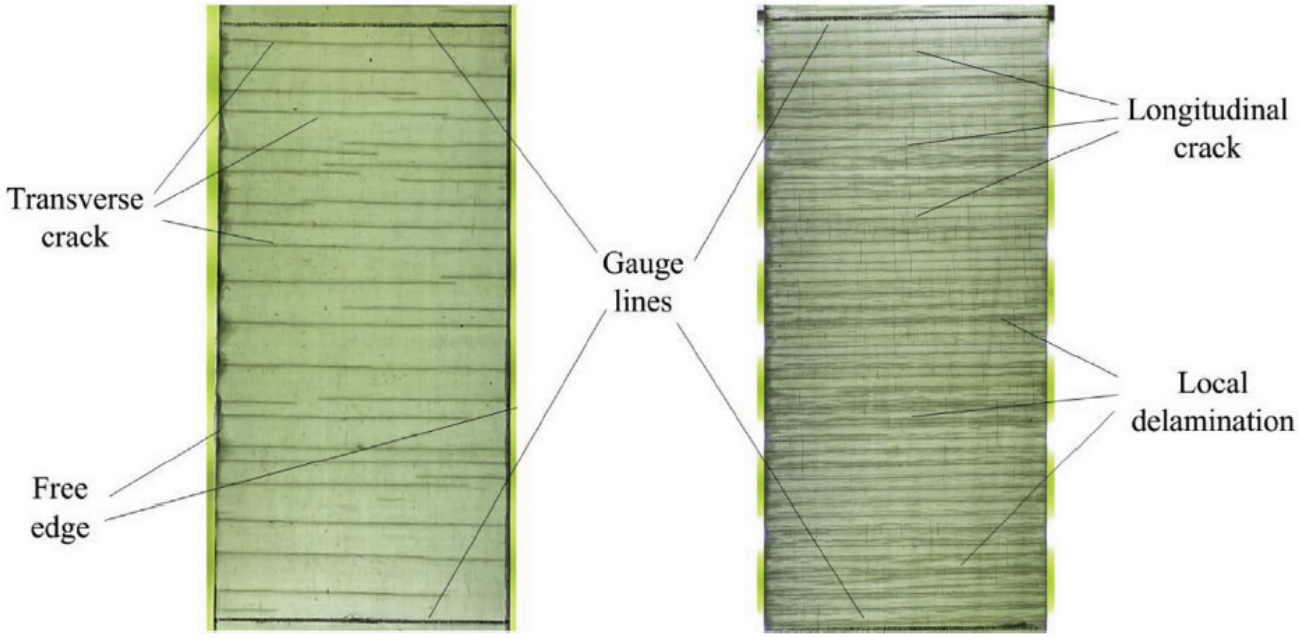


2. delamination 0-90 interface



3. fibre breakage, longitudinal cracks

damage evolution: cross-ply laminates

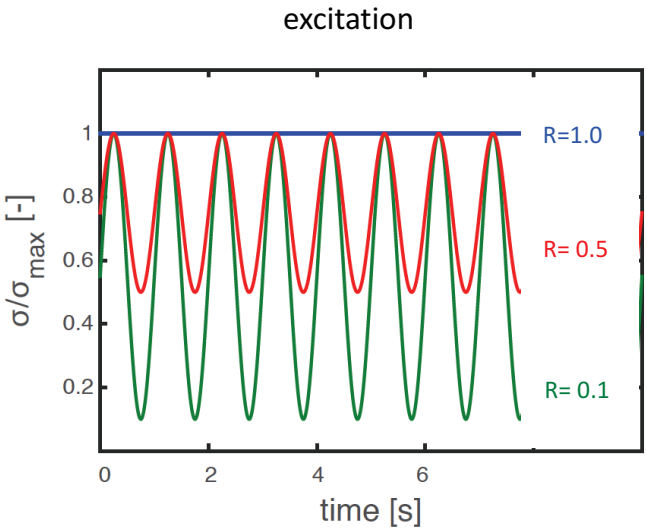


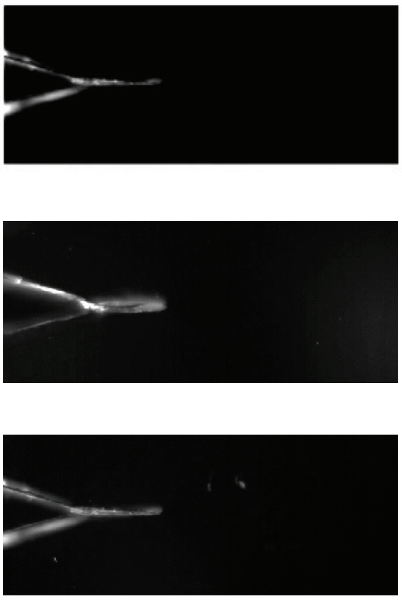
Shen *et al.*, Composites B, 120, 10-26 (2017)

off-axis failure of UD composites

failure mode: crack growth ?

crack growth: static versus cyclic loading





R=1.0

R= 0.3

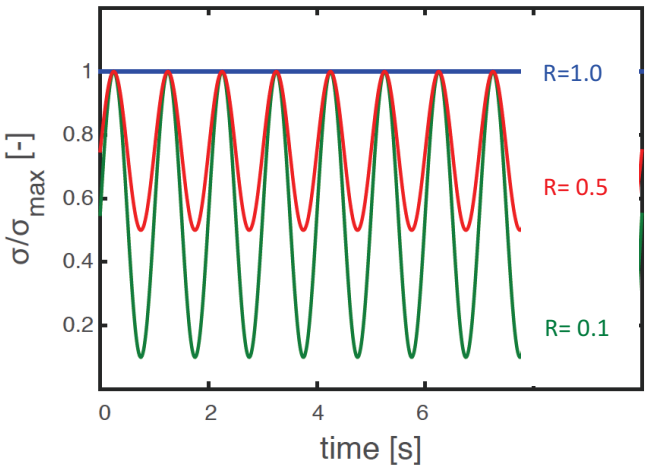
R= 0.1

$$R = \sigma_{min} / \sigma_{max}$$

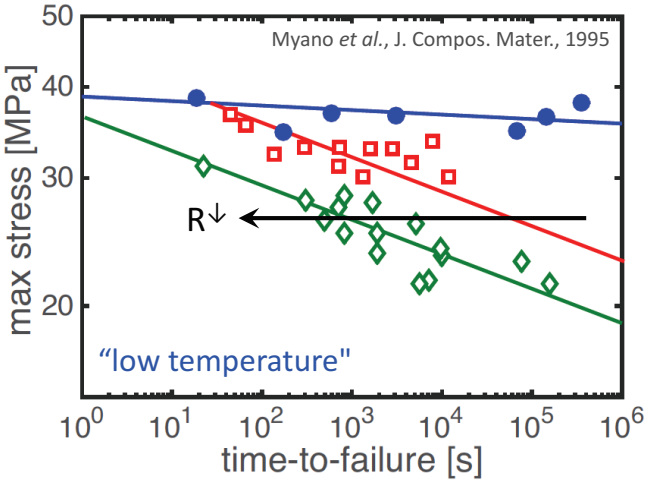
strong acceleration of crack growth in cyclic loading!

crack growth: static versus cyclic loading

excitation



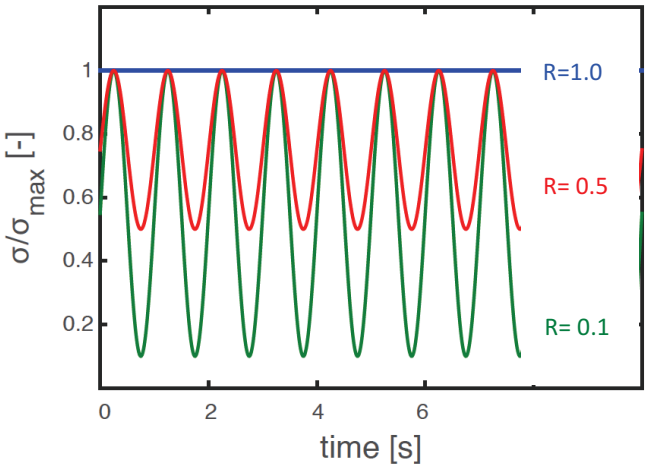
90° off-axis, UD carbon-epoxy



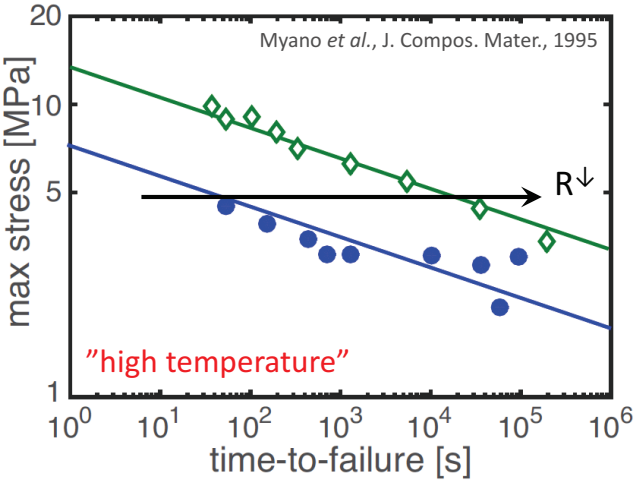
accelleration of fatigue crack propagation by amplitude: crack growth !

crack growth: static versus cyclic loading

excitation

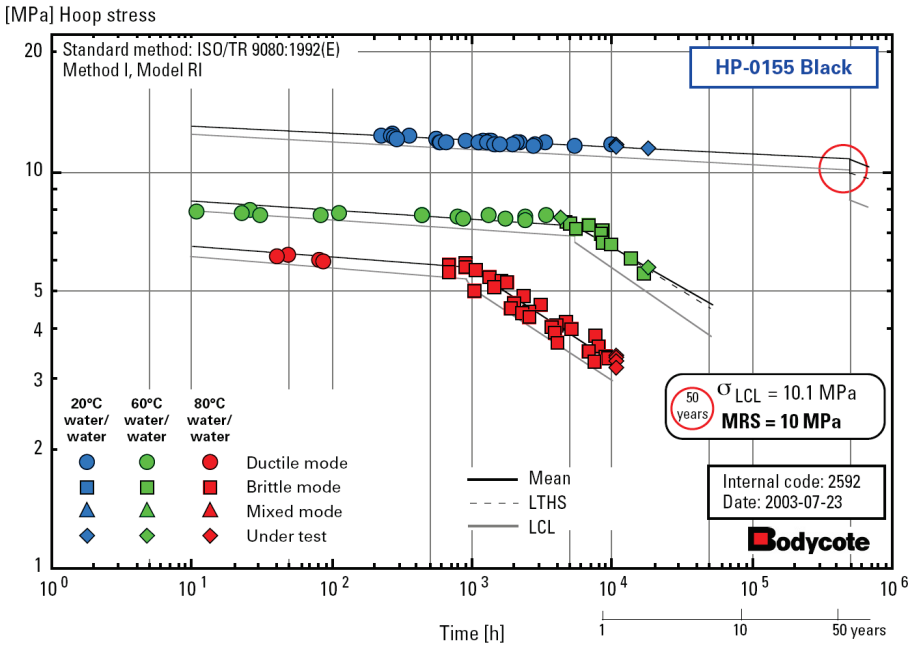


90° off-axis, UD carbon-epoxy

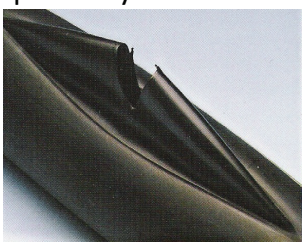


failure delayed in cyclic loading!!

long-term failure modes in thermoplastics



plasticity-controlled

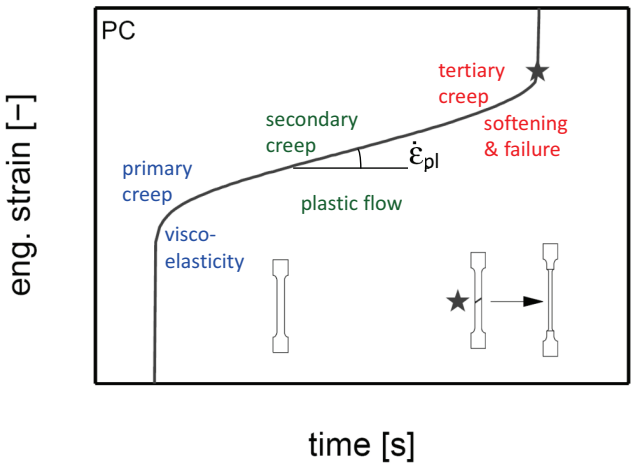


slow crack growth

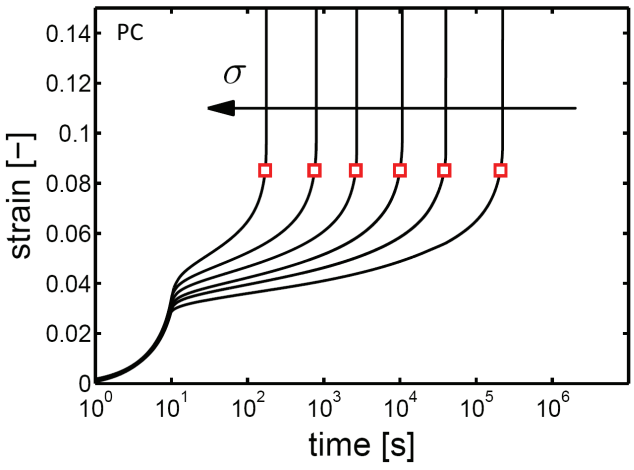
example: PE100 (HP-0155) (www.bodycotepolymer.com)
extrapolation using ISO 9080

plasticity-controlled failure of thermoplastics

constant stress

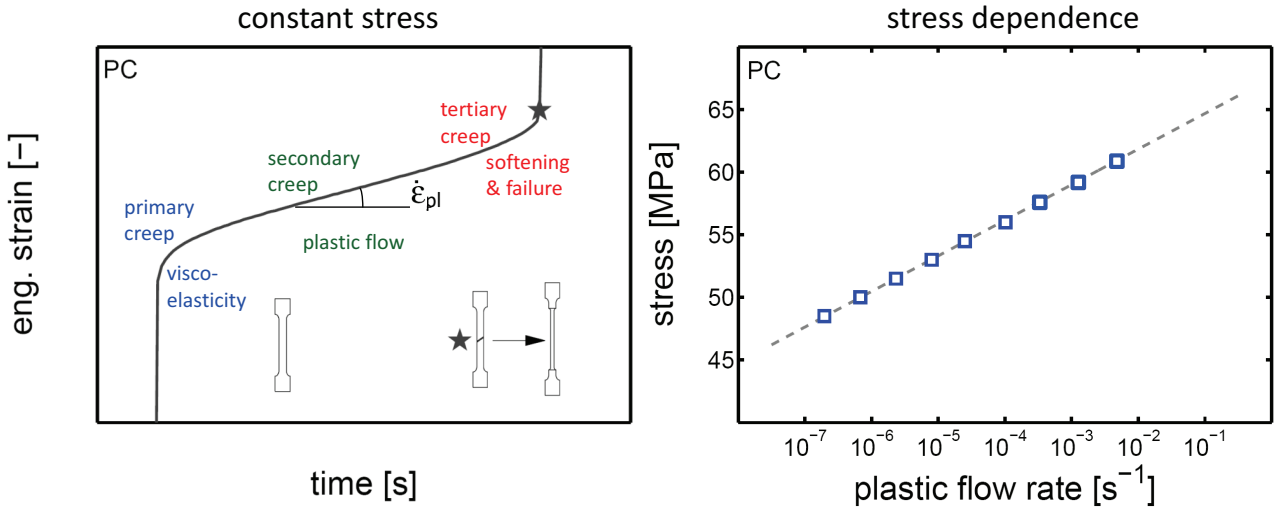


stress dependence



failure originates from accumulation of plastic strain

plasticity-controlled failure of thermoplastics



failure originates from accumulation of plastic strain

deformation kinetics: uniaxial extension

$$\dot{\varepsilon}_{pl}(T,\sigma) = \dot{\varepsilon}_0(S) \cdot \exp\left(-\frac{\Delta U}{RT}\right) \cdot \sinh\left(\frac{\sigma V^*}{kT}\right)$$

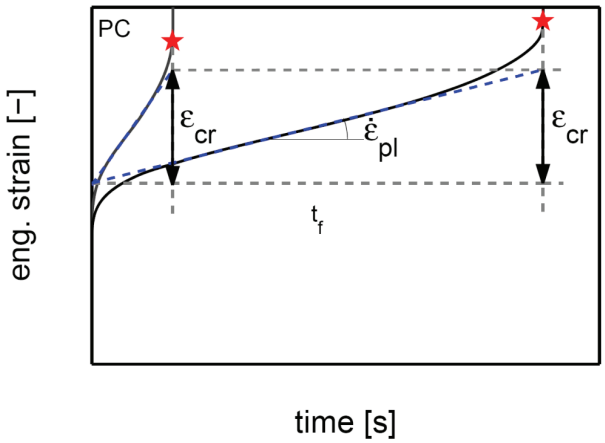
changes in state
- prior thermal history
- progressive aging

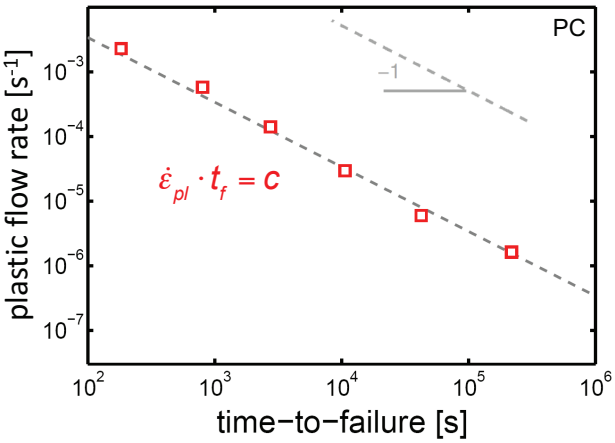
deformation kinetics
- stress-dependence
- temperature dependence

$\Delta U, V^*$ independent of thermodynamic state

Henry Eyring

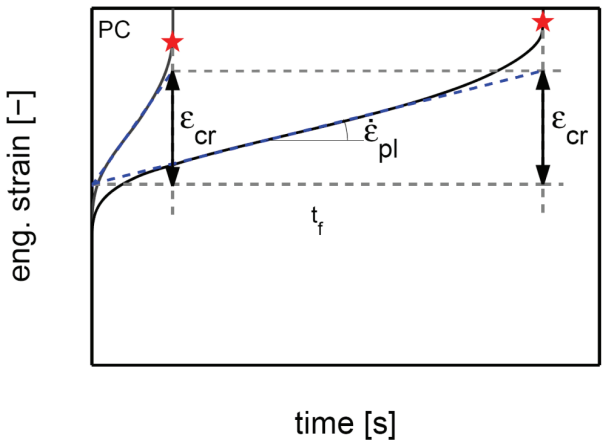
life time prediction: concept of critical strain

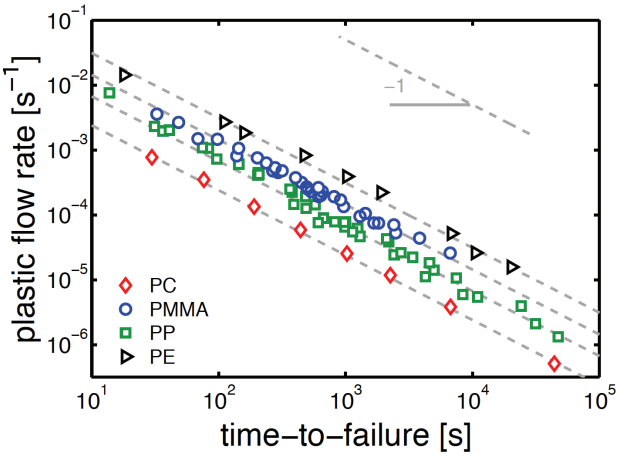




$$t_f(\sigma) = \frac{\varepsilon_{cr}}{\dot{\varepsilon}_{pl}(\sigma)}$$

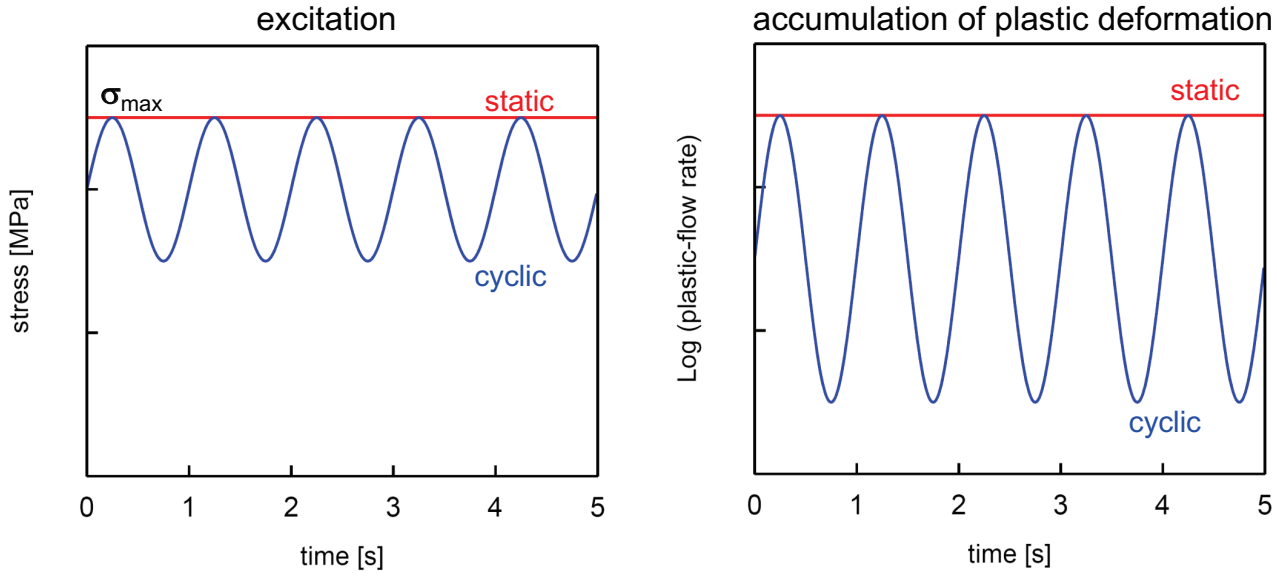
life time prediction: concept of critical strain



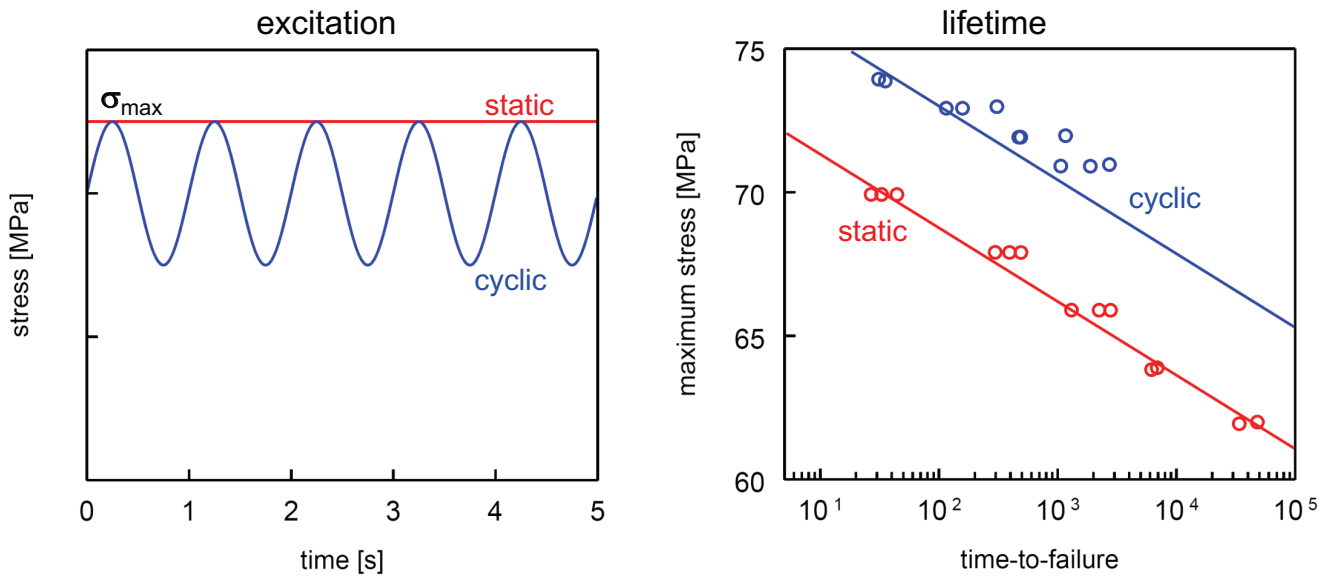


$$t_f(\sigma) = \frac{\varepsilon_{cr}}{\dot{\varepsilon}_{pl}(\sigma)}$$

plasticity-controlled failure: cyclic loading



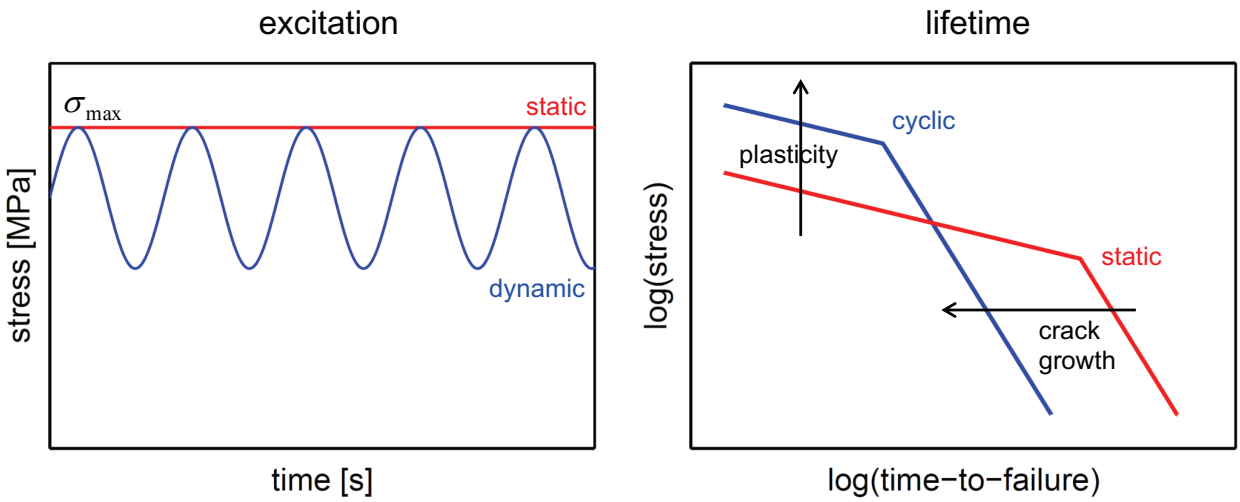
plasticity-controlled failure: cyclic loading



cyclic load has longest time-to-failure

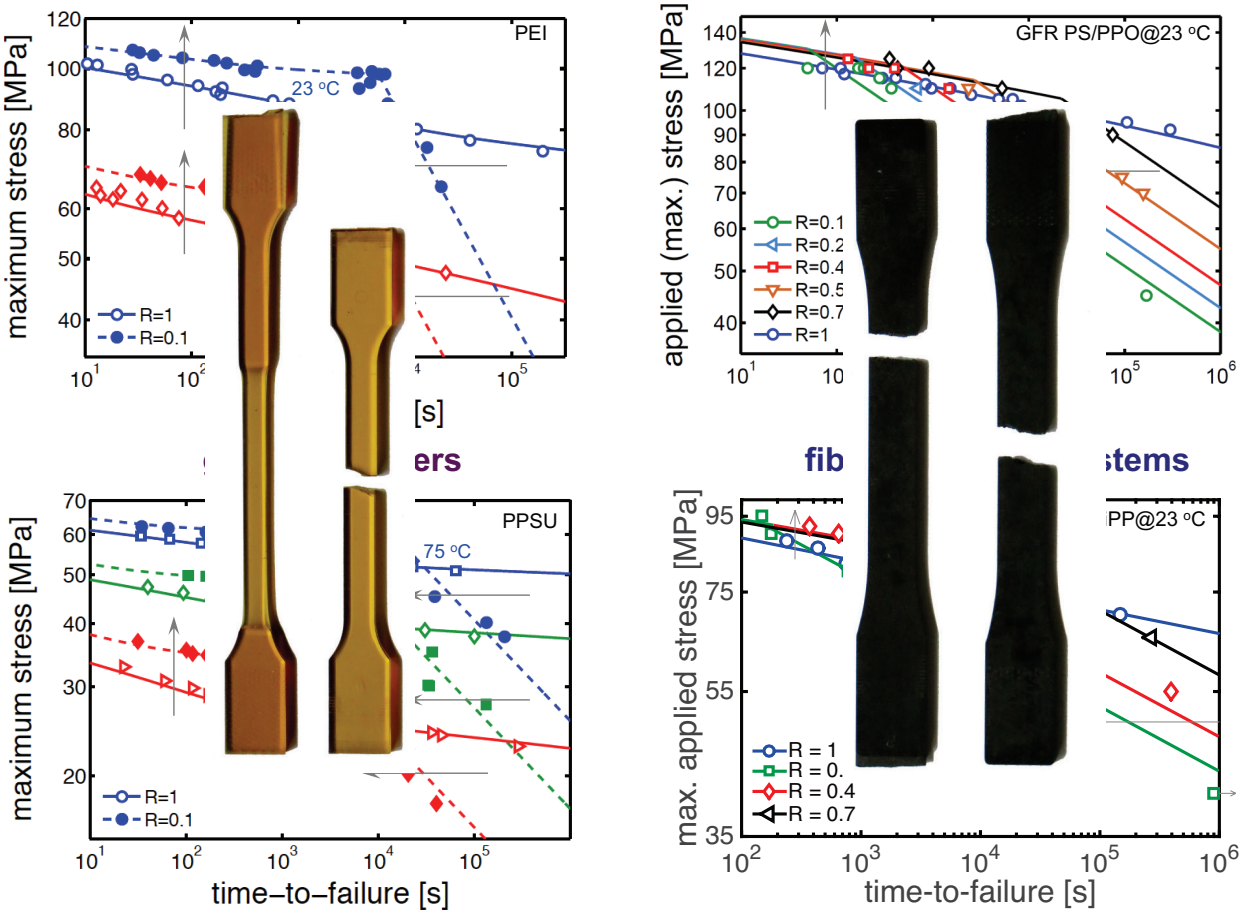
lifetime improves as a result of decreasing rate of plastic strain accumulation

cyclic loading: time-to-failure



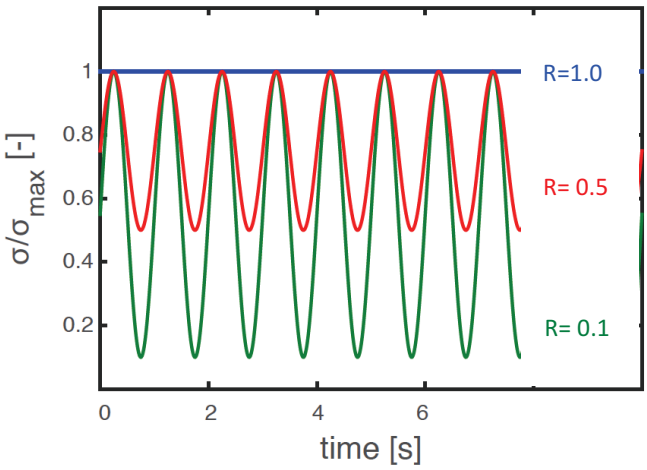
cyclic loading has a different effect on both failure modes!

Kanters *et al.*, Polym. Test., 2016

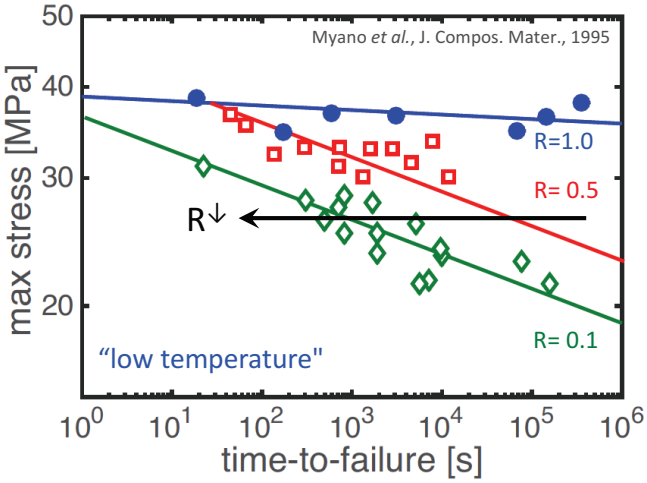


back to composites: matrix-dominated failure

excitation



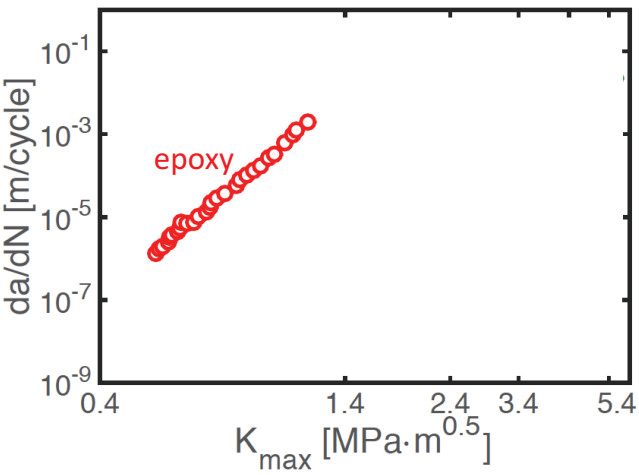
90° off-axis, UD carbon-epoxy



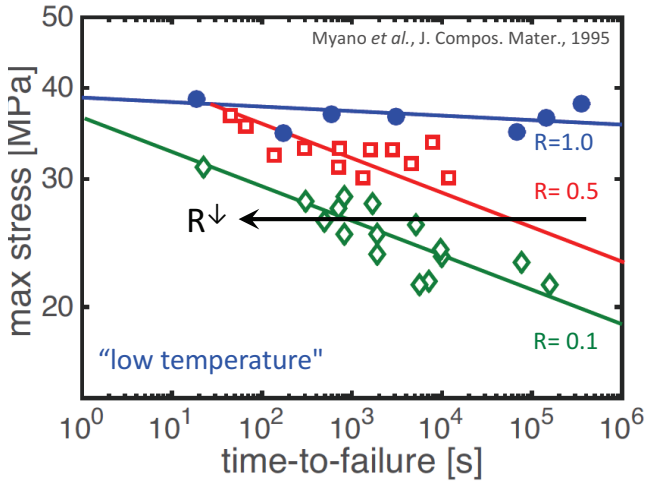
accelleration of fatigue failure by amplitude: **crack growth** !

back to composites: matrix-dominated failure

fatigue crack propagation

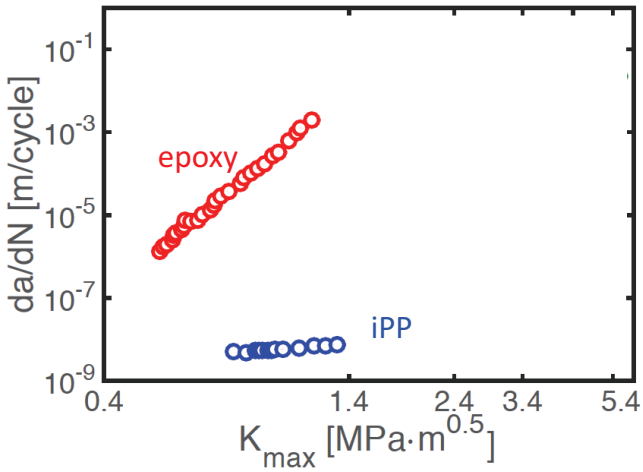


90° off-axis, UD carbon-epoxy

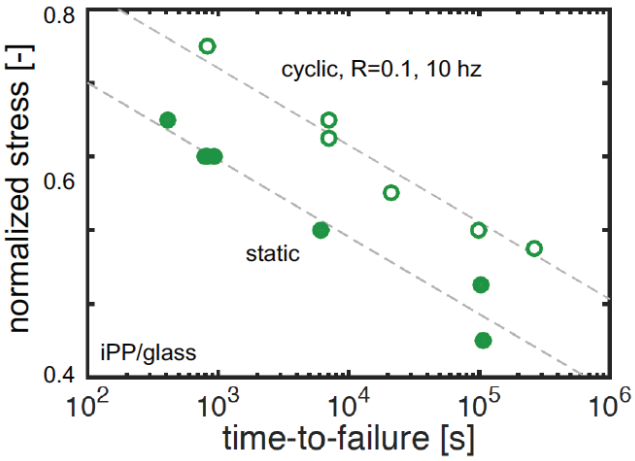


back to composites: matrix-dominated failure

fatigue crack propagation



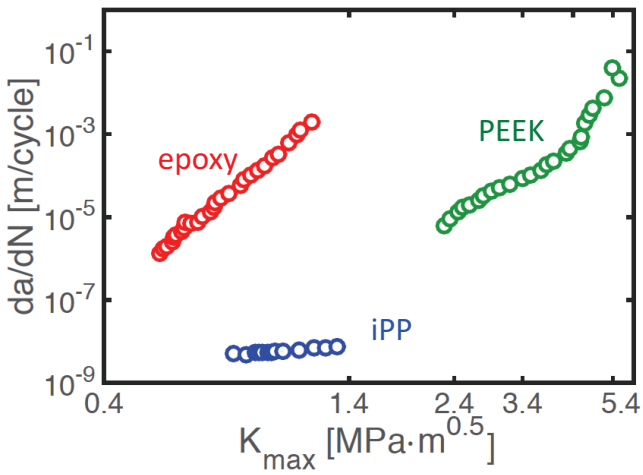
90° off-axis, UD glass-iPP



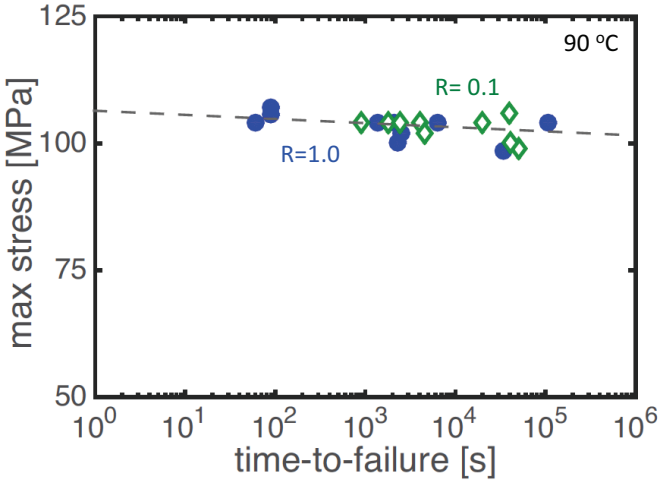
failure delayed in cyclic loading: **plasticity-controlled** failure!!

back to composites: matrix-dominated failure

fatigue crack propagation

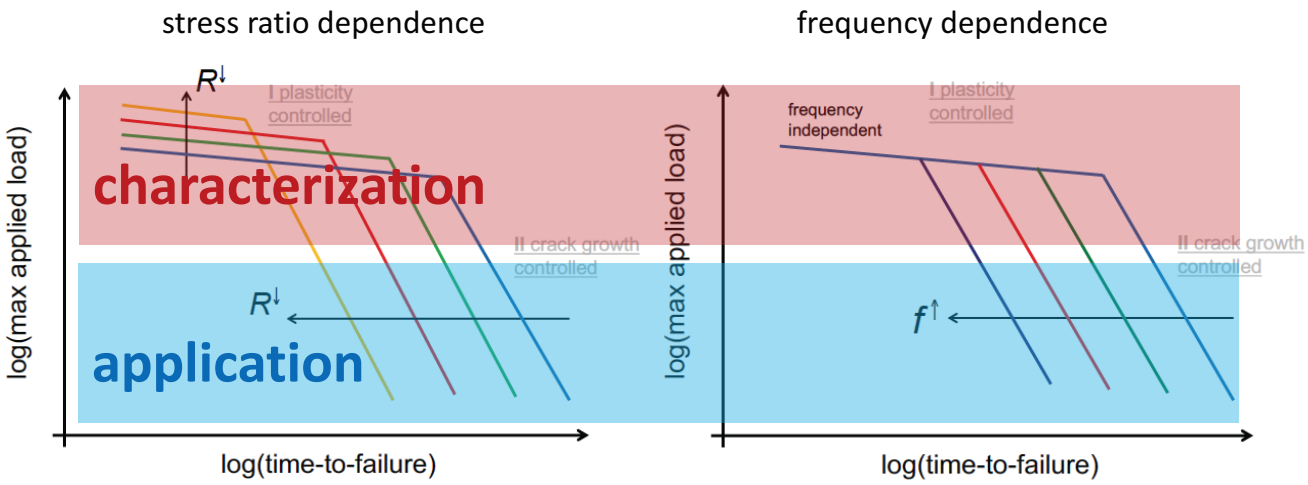


90° off-axis, UD carbon-PEEK



no acceleration or change of kinetics in cyclic loading!!

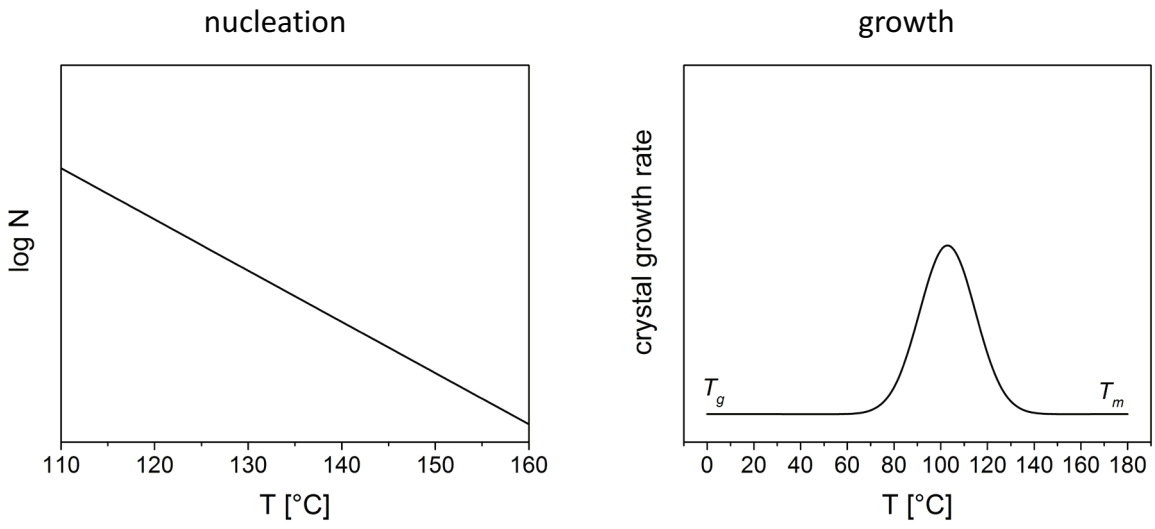
slow crack-growth vs plasticity-controlled



in practical applications, lifetime is likely controlled by slow crack growth

in fatigue characterization, other mechanisms may contribute !!!

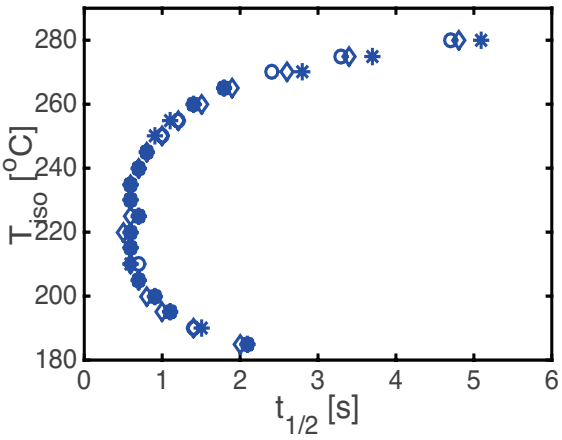
influence of processing: crystallization



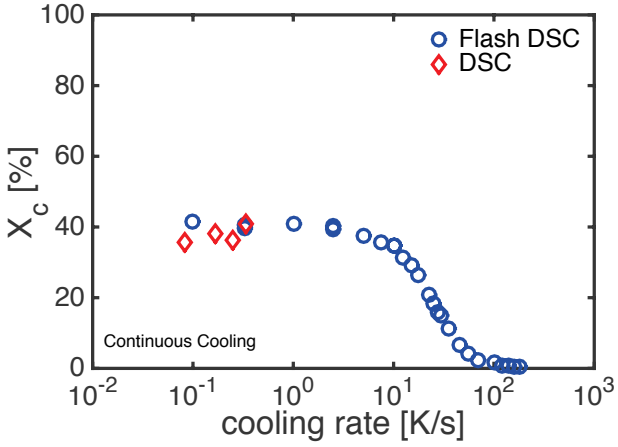
crystallization is controlled by nucleation and growth
which both depend on temperature and pressure

influence of processing: PEEK

TTT diagram



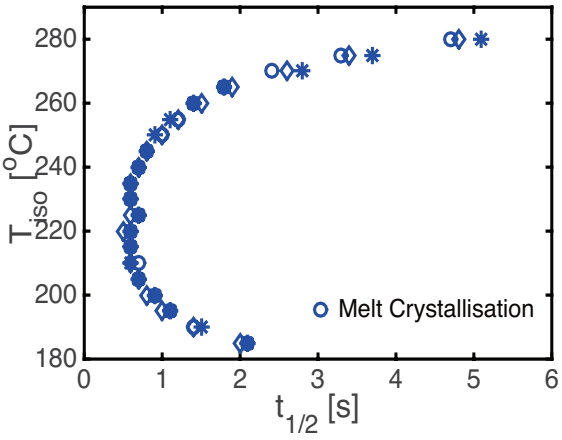
degree of crystallinity



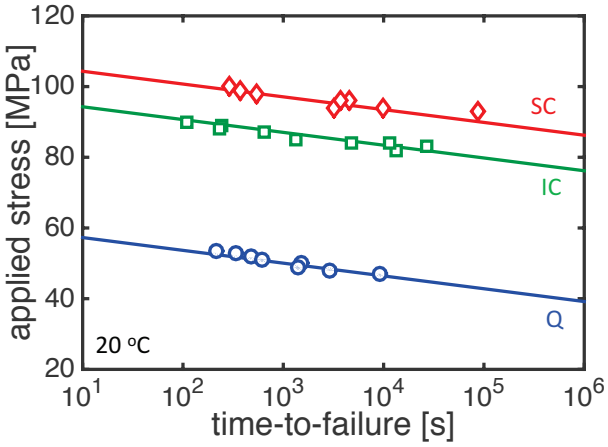
PEEK amorphous at 100 K/s (quenching)

influence of processing: PEEK

TTT diagram



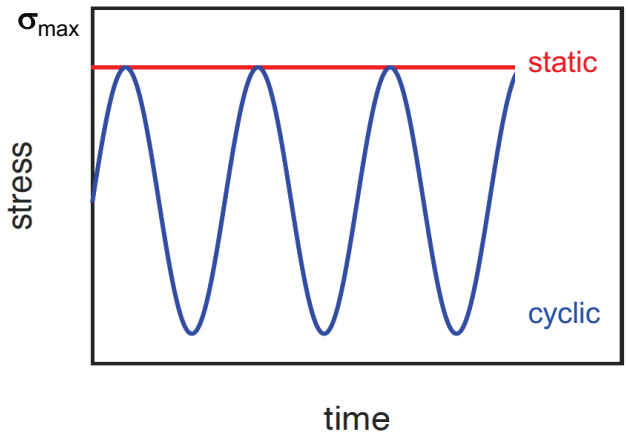
mechanical performance
~~creep rupture~~



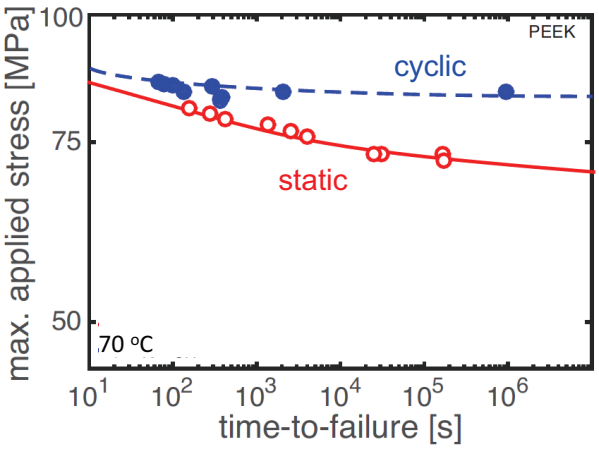
PEEK amorphous at 100 K/s (quenching)

PEEK: influence of loading history

excitation



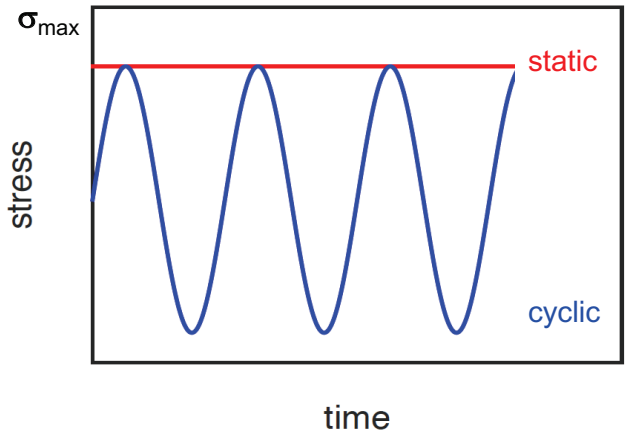
lifetime



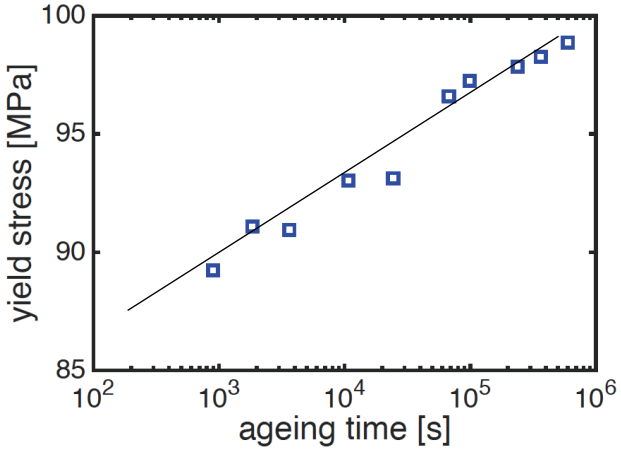
onset of an endurance limit is observed

PEEK: influence of loading history

excitation

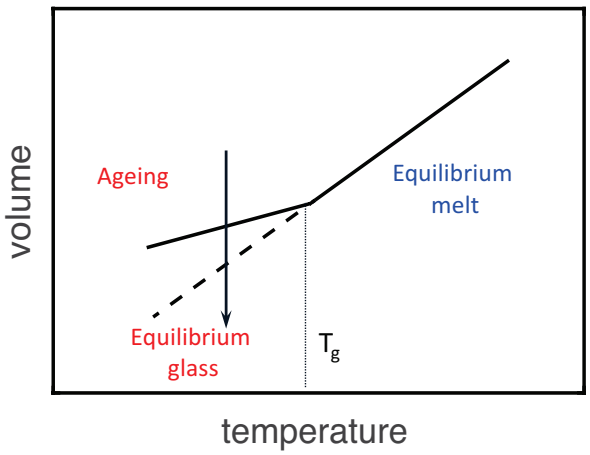


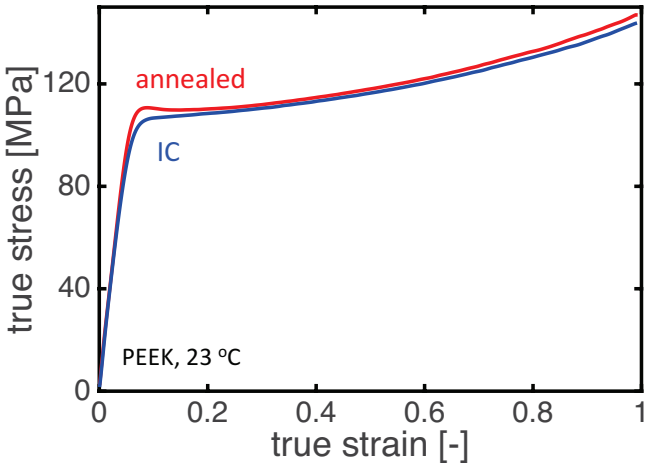
yield stress evolution



endurance limit related to structural changes: physical ageing process *accelerated by temperature and applied stress*

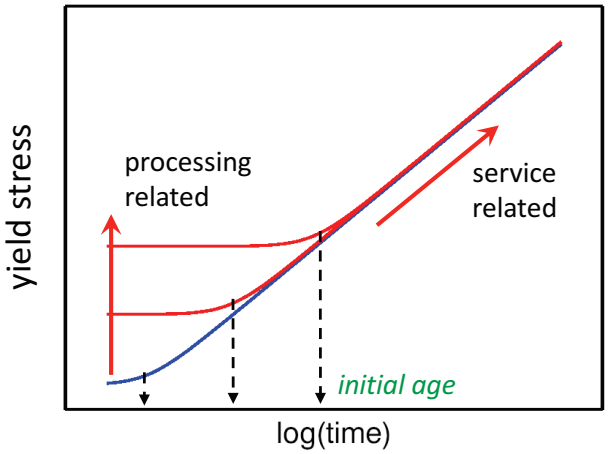
yield stress evolution in PEEK





below T_g thermodynamic state moves toward equilibrium: physical ageing

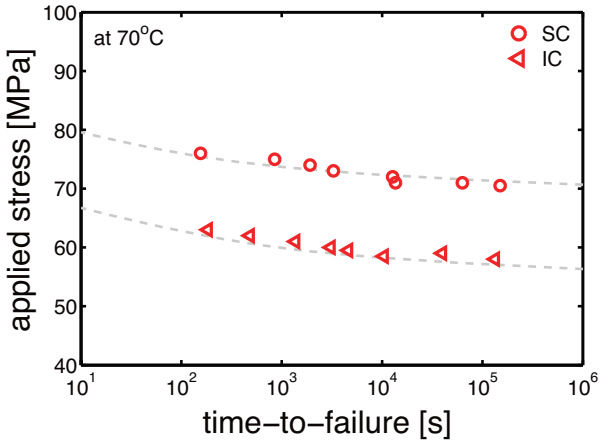
yield stress evolution



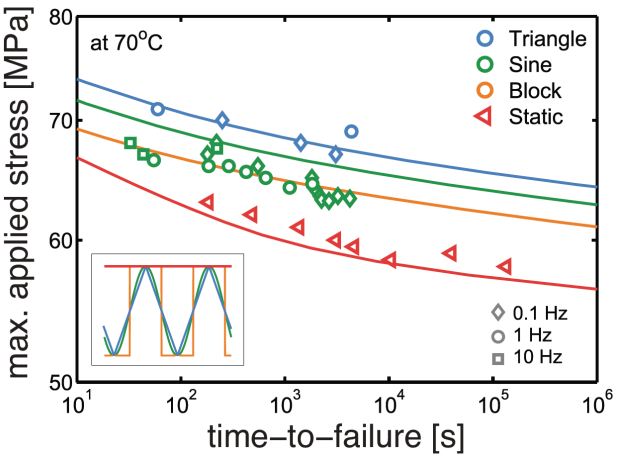
ageing accelerated by temperature and applied stress

plasticity-controlled failure: endurance limit

processing conditions



loading history



endurance limit originates from stress-enhanced ageing; consequently it will depend on temperature, processing and loading history

conclusion

- off-axis strength of UD composites may be plasticity-controlled
- this gives rise to a pronounced dependence to:
  - processing conditions
  - storage & loading history
- the presence of plasticity requires:
  - different short term to long-term translation
  - In general: more testing