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Fatigue

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Fatigue

Part-2: Mechanism of fatigue

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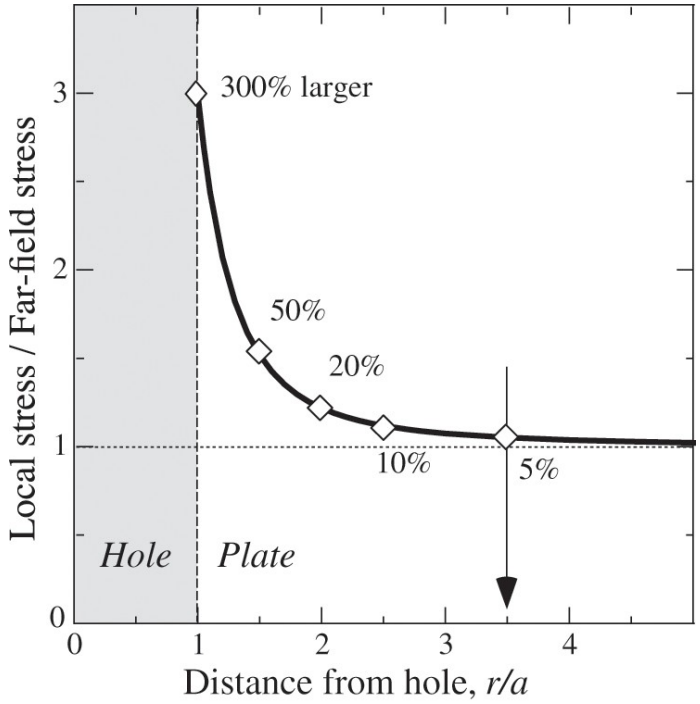
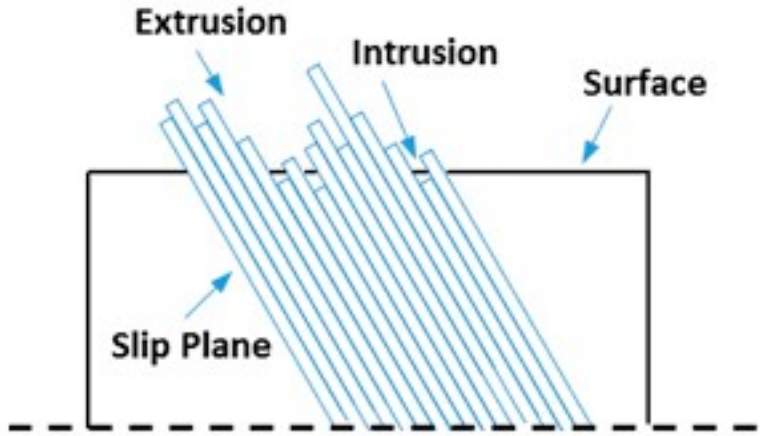
Stages of fatigue

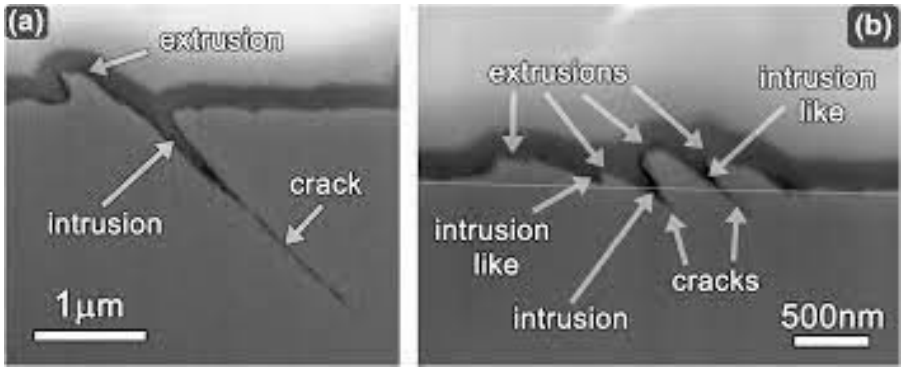
- Fatigue failure stress << static strength
  - Fracture initiating at surface
  - Stress concentrations due to stress raisers
  - $K_t = S_{max} / S_{avg}$ (K_t is fn. of crack length & root radius)
  - $S_{local} > Y.S$
  - Local plastic deformation (through slip)
- Damage accumulation stages
  - Stage-1: Crack initiation (Fatigue analysis: >75% of life)
    - Safe Life design of safety critical (e.g. undercarriage) or less inspectable (wing spar) structures – crack free life assuming no initial macro crack
  - Stage-2: Slow propagation of crack (Fracture analysis)
    - Fail Safe design of easily inspectable structures (e.g. fuselage skin, empennage) – assuming initial macro crack
  - Stage-3: Fast propagation of crack



Stage-1: Crack initiation

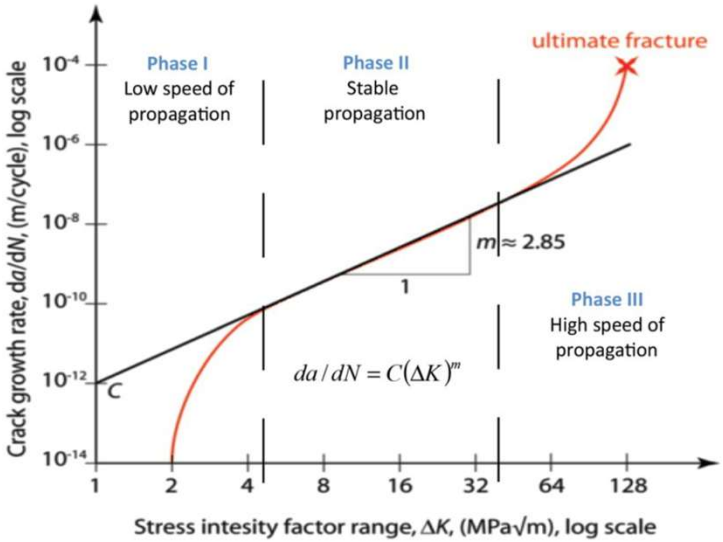
- Stress raisers
- S_{max} or S_{local} > YS
- Local plastic deformation
- Shear based slip (in slip planes along slip directions)
- Reversal of cycle
- Change in direction of slip planes
- Formation of extrusions & intrusions
- Intrusions act as small cracks
- Intrusion crack grows, cuts through grain boundaries to slip planes of adjacent grains
- Macroscopic surface crack





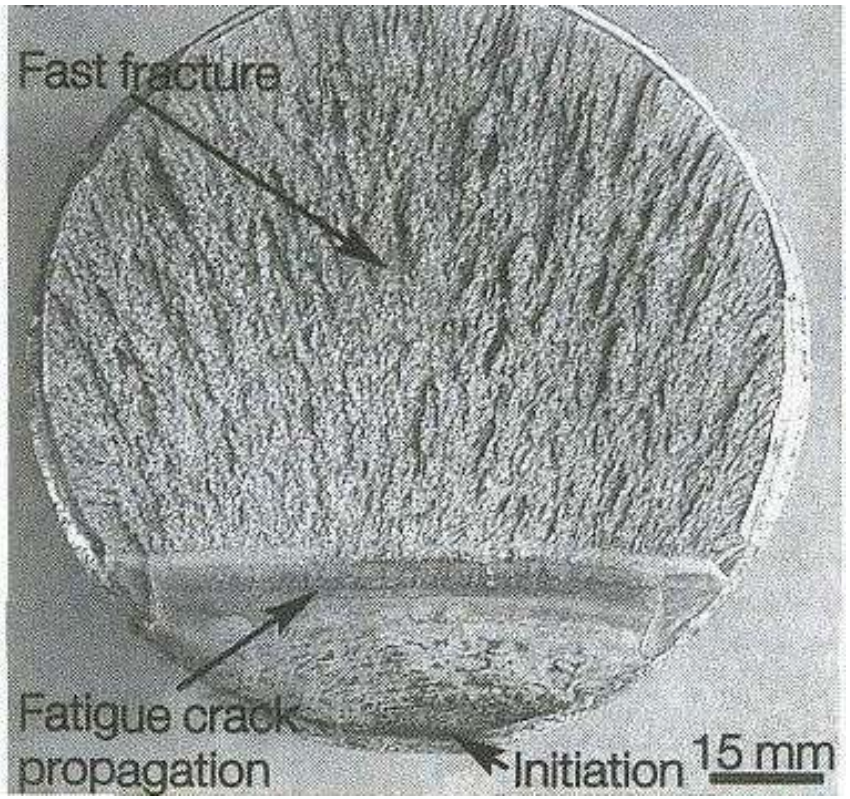
Stage-2: Slow propagation of crack

- Tensile cycle
  - Opening of the crack
  - Advancement of the crack
- Cycle reversal
  - Closure of the crack
  - Sharpening of the crack
- Net advancement in each cycle = crack advancement in tensile cycle – crack closure in compression cycle
  - If net advancement = 0: Infinite fatigue life
  - Else, crack growth rate (da/dN) as per Paris Law / Paris Erdogan equation
    - ΔK = Range of stress intensity factor = $K_{max} - K_{min}$ in a load cycle
    - $K = \sigma \times (\pi.a)^{1/2} \times f$ (geometry)
    - C & m are material constants, m is typically 2-4, but can be as high as 10 for low fracture toughness materials

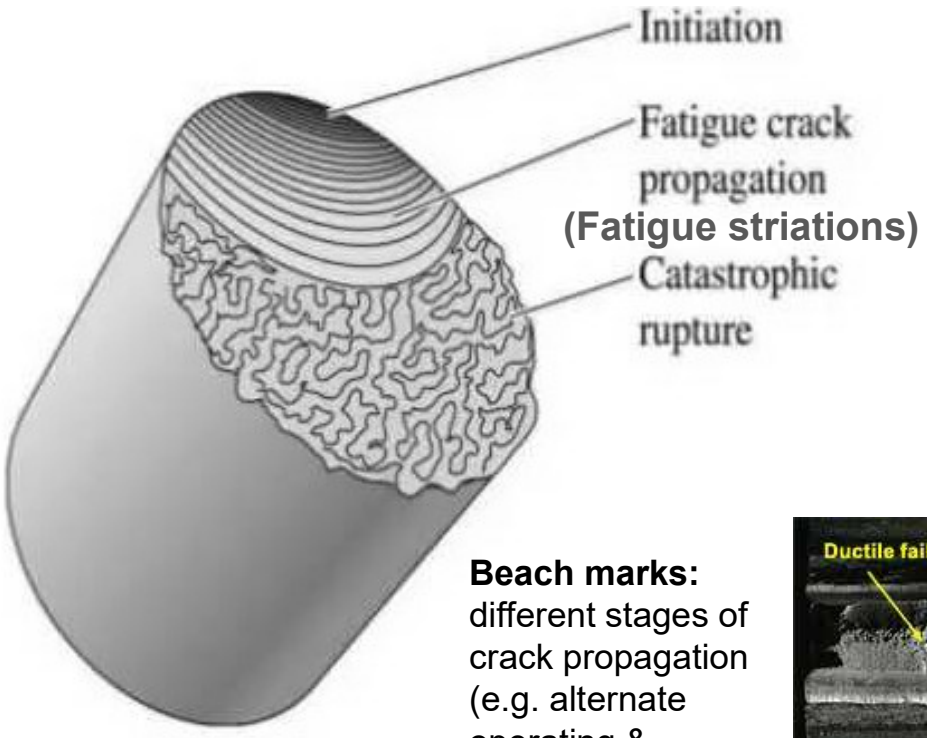


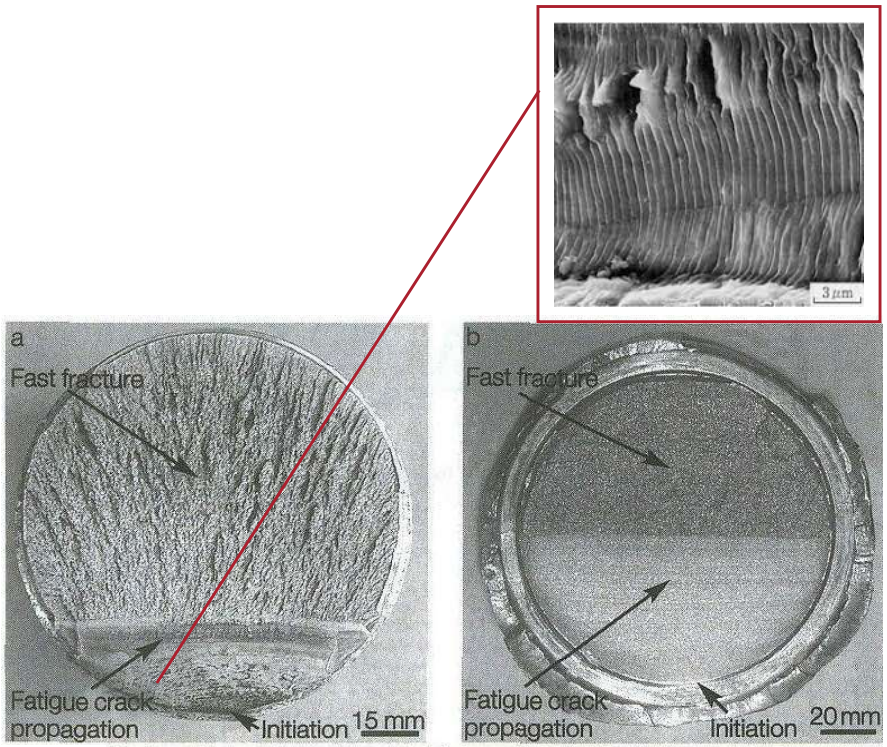
Stage-3: Fast propagation of crack

- Progress of crack
- Lowering of load bearing area
- S_{local} > UTS
- Fracture of material



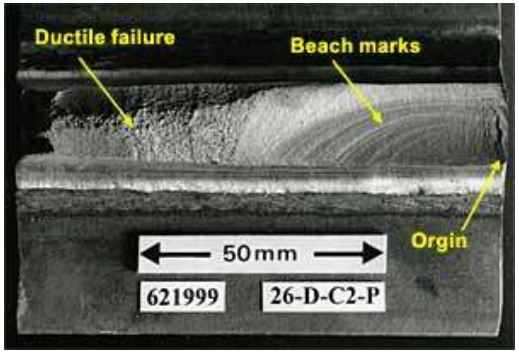
Fatigue fractography



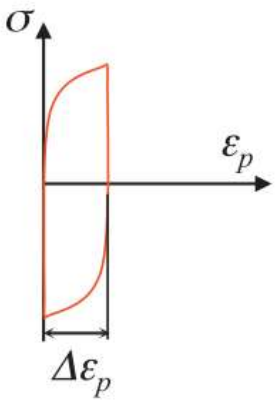


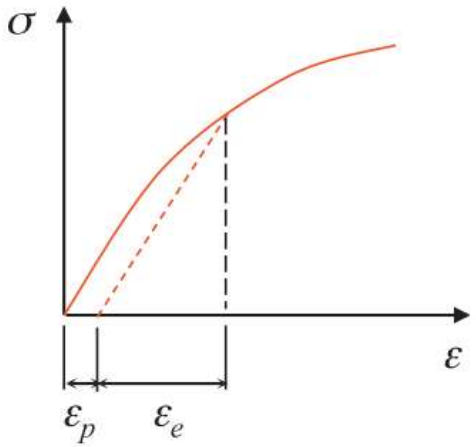
Fatigue fracture surface: (a) high applied load; (b) low applied load.

Beach marks: different stages of crack propagation (e.g. alternate operating & stopping of a machine)



Energy considerations in fatigue





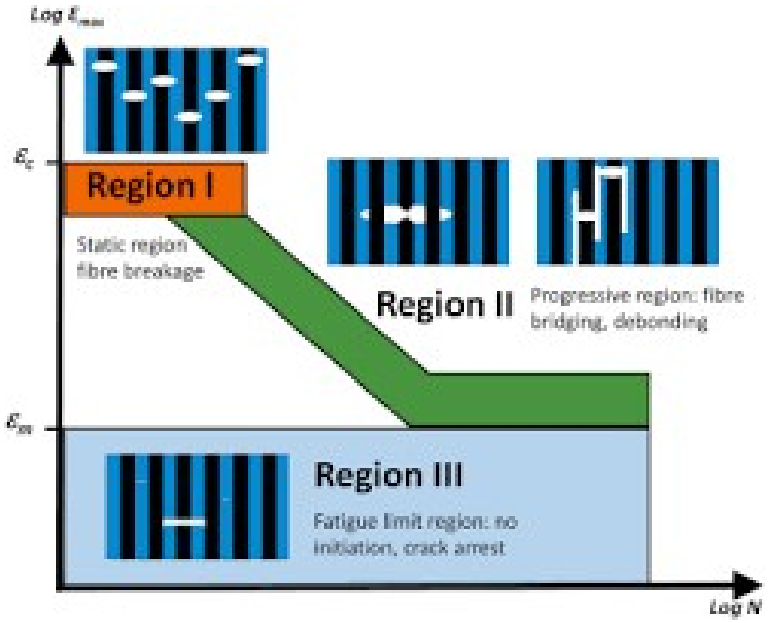
Wp (HCF) ~ 100 x Wp (static)

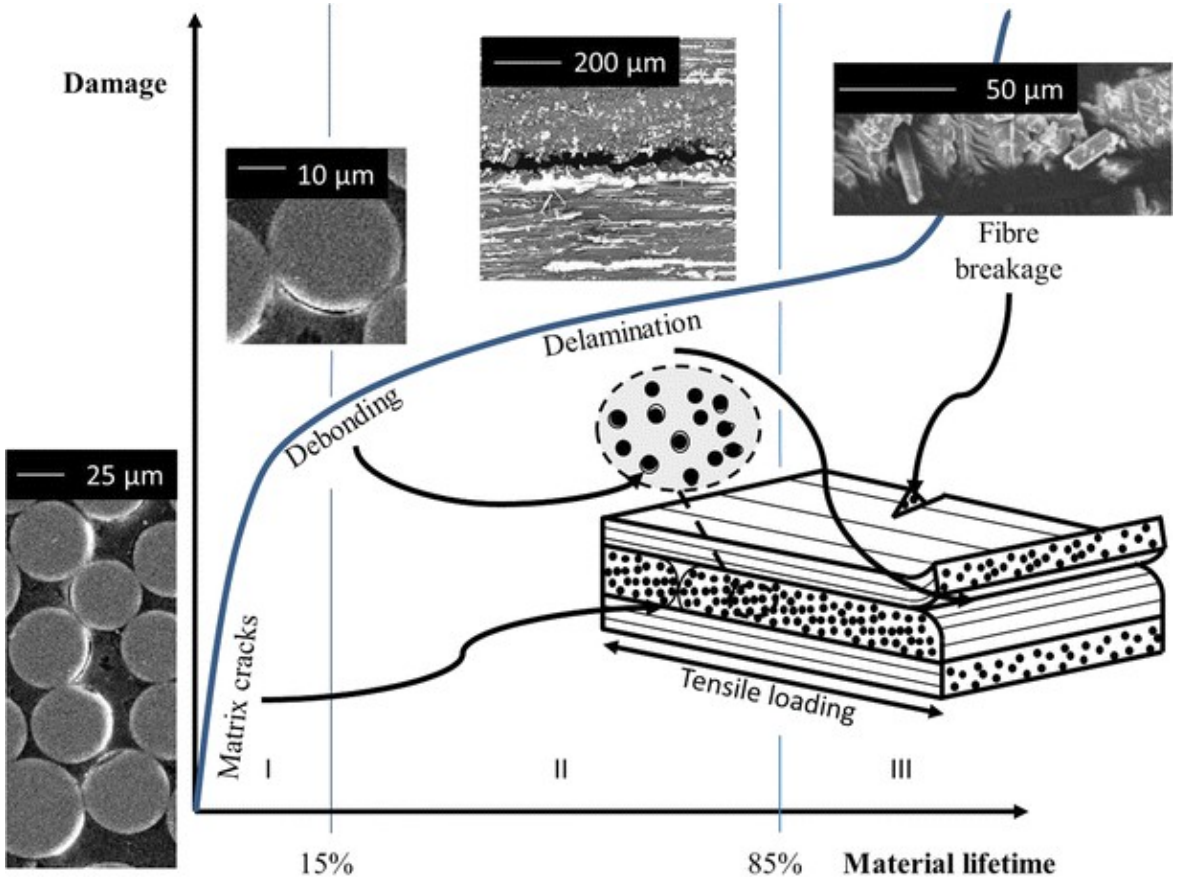
Total plastic strain energy: $W_p = \Delta W.N_f$ *"Fatigue toughness"*

Note:

- Plastic strain energy : is responsible for crack initiation (fatigue)
- Elastic strain energy : is responsible for crack propagation (fracture)

Fatigue in composites





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End of Part-2

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Thank you

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