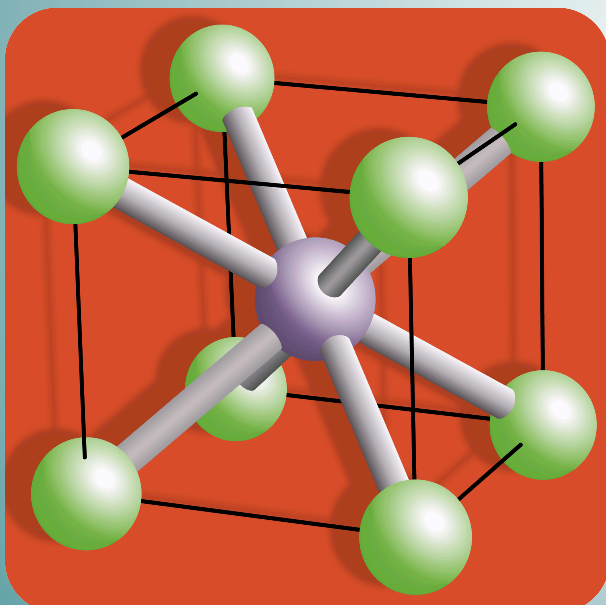
Materials

Topic 7. Fatigue failure



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7.1. THE FATIGUE PHENOMENON

- **Fatigue:**
  - Elements subjected to dynamic and fluctuating loads.
  - Fracture takes place at a lower level than the resistance under static load, usually occurs suddenly and is catastrophic.



7.2. TYPES OF FATIGUE

- According to the existence or not of **cracks**:
  - Uncracked components (initiation, propagation and breakage).
  - Cracked components (propagation and breakage).

No cracks pre-exist; initiation-controlled fracture. Examples: almost any small components like gudgeon pins, ball races, gear teeth, axles, crank shafts, drive shafts.

Cracks pre-exist; propagation controlled fracture. Examples: almost any large structure, particularly those containing welds: bridges, ships, pressure vessels.

- According to the type of **applied stress**:
  - Axial fatigue (tensión and/or compresion).
  - Flexion fatigue.
  - Torsión fatigue.

- According to the **applied stress value**:
  - High-cycle fatigue ($s_{max} < s_Y$).
  - Low- cycle fatigue ($s_{max} > s_Y$).

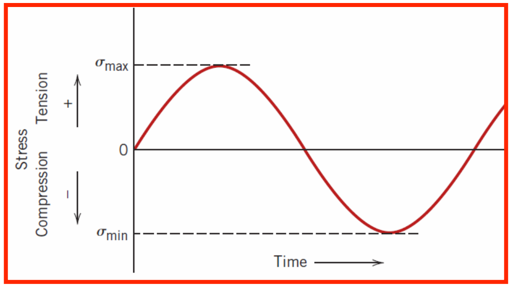
Fatigue at stresses below general yield; $\lesssim 10^4$ cycles to fracture. Examples: all rotating or vibrating systems like wheels, axles, engine components.

Fatigue at stresses above general yield; $\gtrsim 10^4$ cycles to fracture. Examples: core components of nuclear reactors, air-frames, turbine components, any component subject to occasional overloads.

7.3. CYCLIC STRESSES

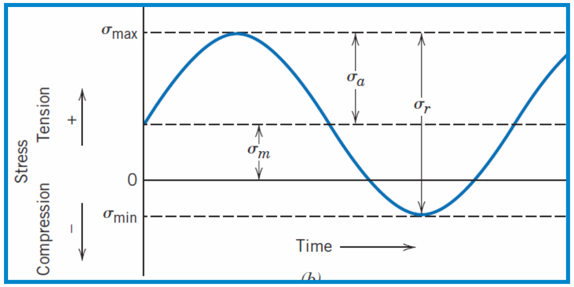
- **The applied stress may be axial (tension-compression), flexural (bending), or torsional (twisting) in nature.Three fluctuating Stress – time modes:**

Reversed stress cycle



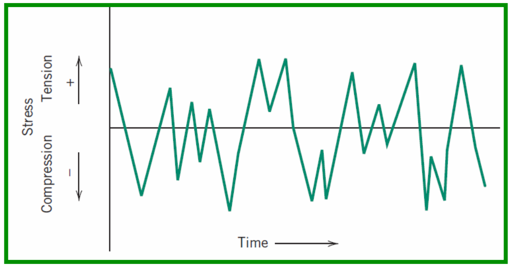
The stress alternates from a máximum tensile stress (+) to a máximum compressive stress of equal magnitude.

Repeated stress cycle



Maximum and minimum stresses are asymmetrical relative to the zero-stress level.

Random stress cycle



- **Parameters to characterize the fluctuating stress cycle:**
  - **Mean stress:**
  - **Stress amplitude.**
  - **Range of stress.**
  - **Stress ratio.**

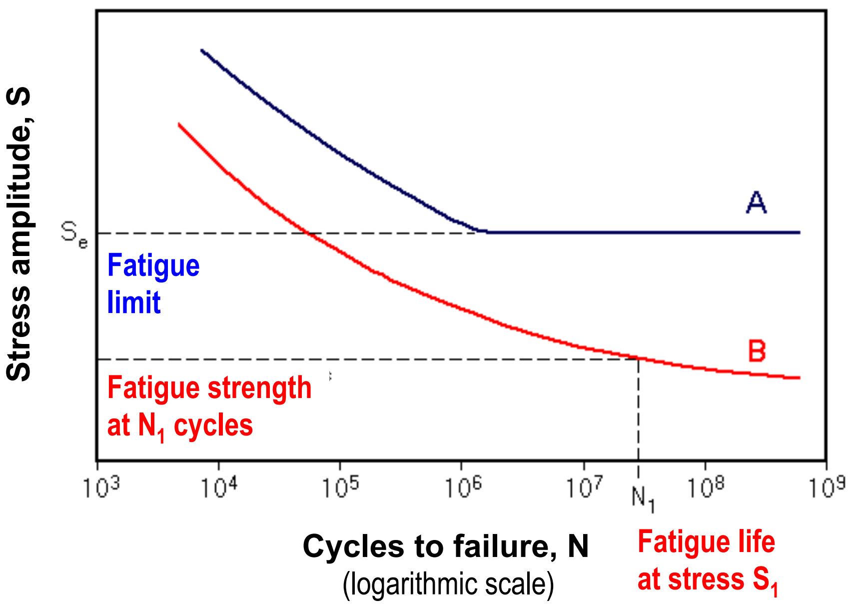
$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2} \qquad \sigma_a = \frac{\sigma_{max} - \sigma_{min}}{2} \qquad \Delta\sigma = \sigma_{max} - \sigma_{min} \qquad R = \frac{\sigma_{min}}{\sigma_{max}}$$

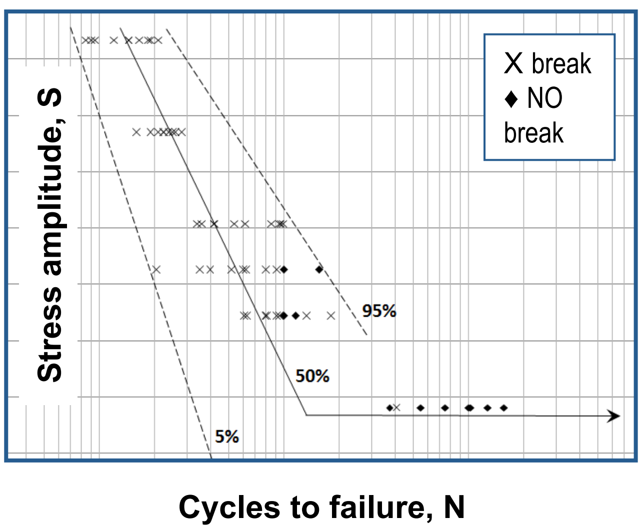
7.4. FATIGUE BEHAVIOR OF UNCRACKED COMPONENTS

- **Fatigue of small components with good surface finish.**
- **Their life has three phases:**
  - **Crack initiation, t_N.**
  - **Propagation up to a critical size, t_C.**
  - **Sudden breakage.**

Life time, $t_L = t_N + t_C$

- **Wöhler curve (The S - N curve).**





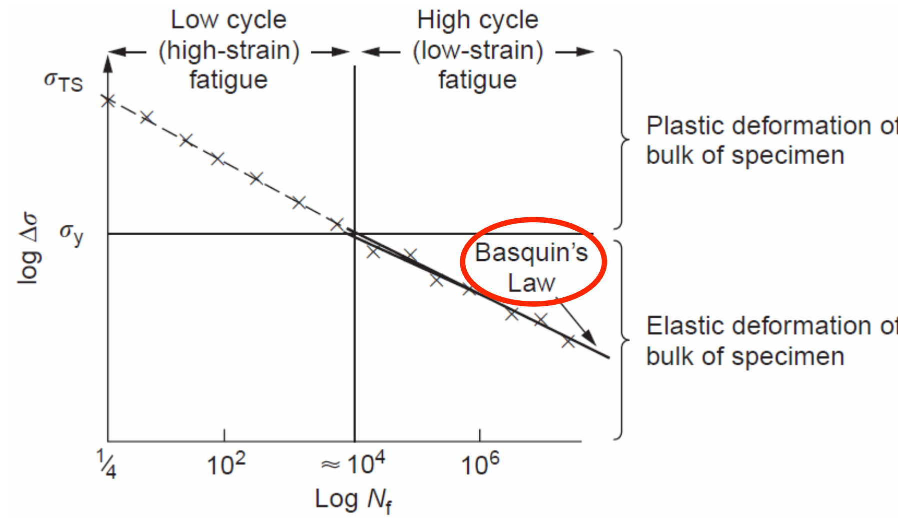
EXPERIMENTAL FITS

Mathematical fit ($\sigma_m = 0$):

Low-cycle fatigue where $\sigma_{max} < \sigma_Y$: Basquin's Law

$$\Delta\sigma \cdot N^a = C_1$$

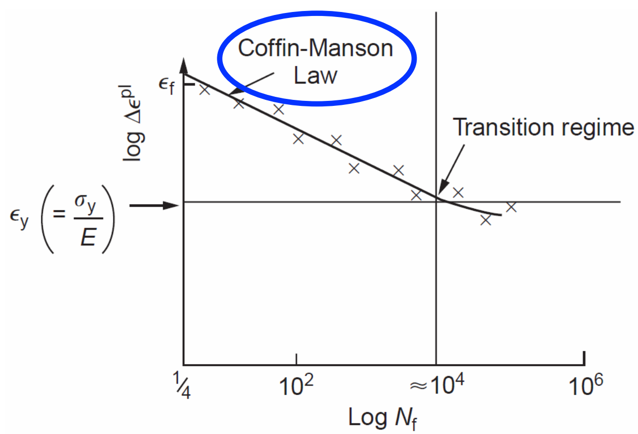
(a, C_1 constans)



Low-cycle fatigue where $\sigma_{max} > \sigma_Y$: The Coffin-Manson Law

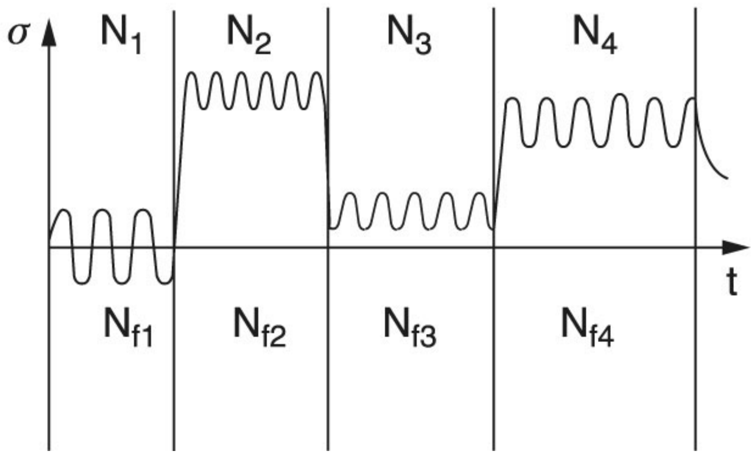
$$\Delta\varepsilon^{pl} \cdot N^b = C_2$$

(b, C_2 constans)



- **Complex fit when $\sigma_m \neq 0$ or $\Delta\sigma \neq$ constants.**

- **When Δσ varies during the lifetime of a component, the approach adopted is to sum the damage according to Miner's Rule of cumulative damage.**



$$\boxed{\sum_i \frac{N_i}{N_{f_i}} = 1}$$

N_i	Number of cycles applied ($D\sigma_i$).
N_{fi}	Number of cycles to fracture under the stress cycle in region i ($D\sigma_i$).
N_i / N_{fi}	Fraction of the lifetime used up after Ni cycles in that region.

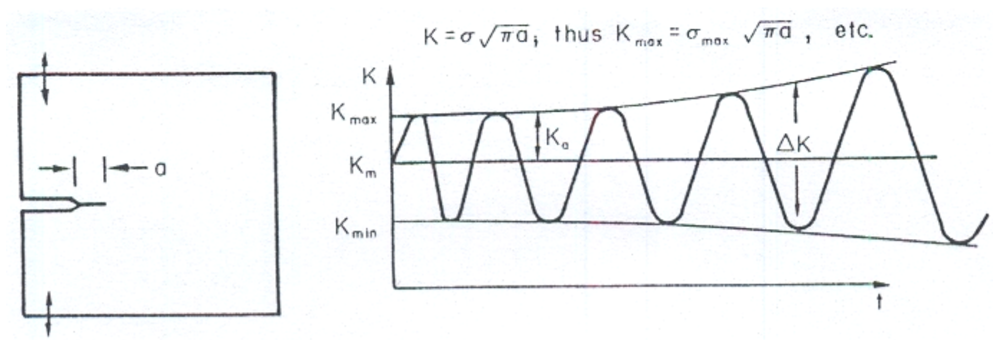
- **MINER'S Rule of cumulative damage.**

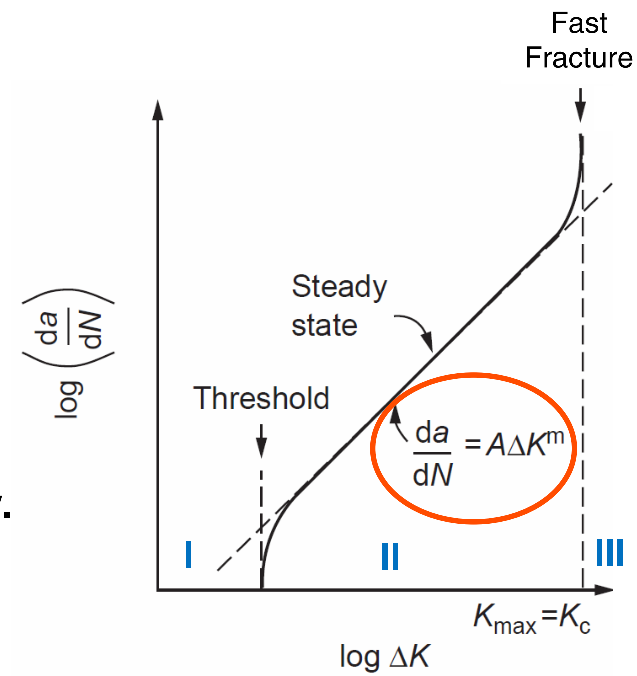
7.5. FATIGUE BEHAVIOR OF CRACKED COMPONENTS

- **The nucleation phase does not exist. It must be avoided that the defect reaches a critical size.**
- **Analysis of crack propagation rate.**

Paris' Law

$$\boxed{\frac{da}{dN} = A \cdot (\Delta K)^m}$$





- **Region I: the existing cracks do not grow.**
- **Region II: lineal behavior according to Paris Law.**
- **Region III: fast grow that leads to the breakage.**

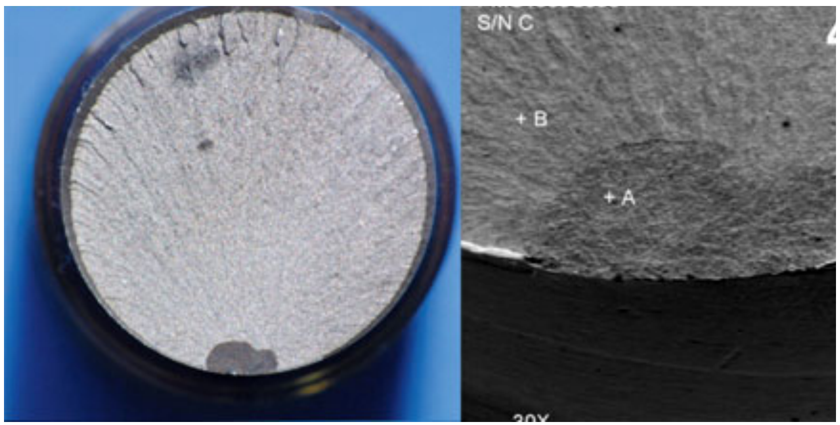
- **N_R is calculated integrating the Paris' Law.**
- **Limits of integration: a_0 and a_C.**

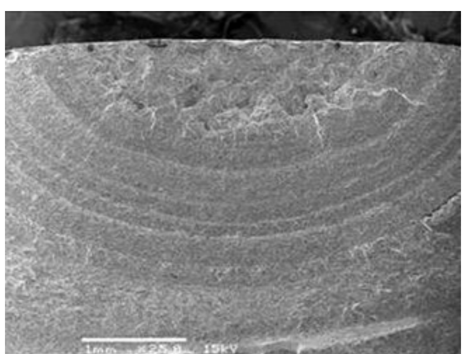
7.6. PHYSICAL ASPECTS OF FATIGUE BREAKAGE

- **The propagation direction is oriented ⊥ to the stress applied. The surface is characterized by two aspects (beachmarks and striations).**

Beachmark

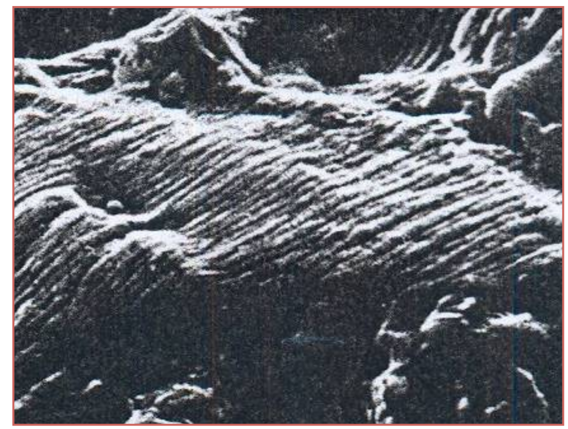
Macroscopics (rest periods).

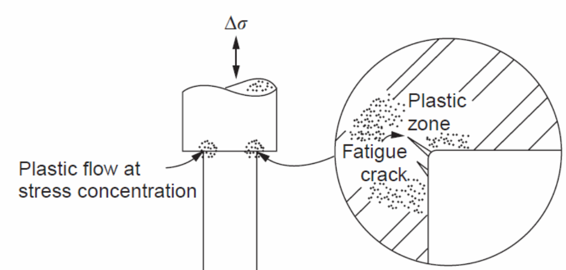




Striations

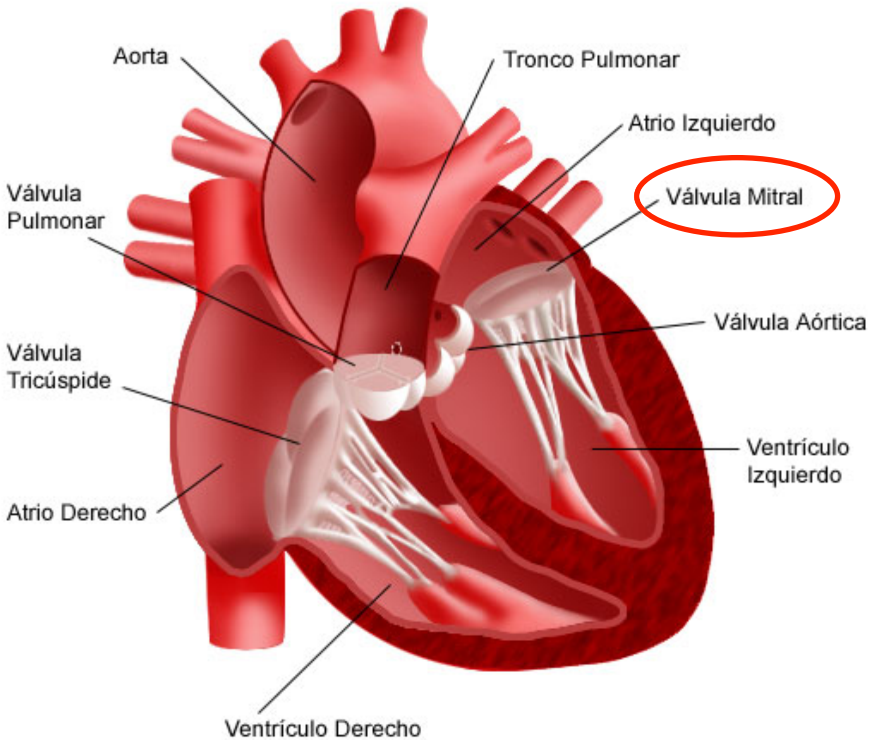
Microscopics (the advance of a crack front during a single cycle).

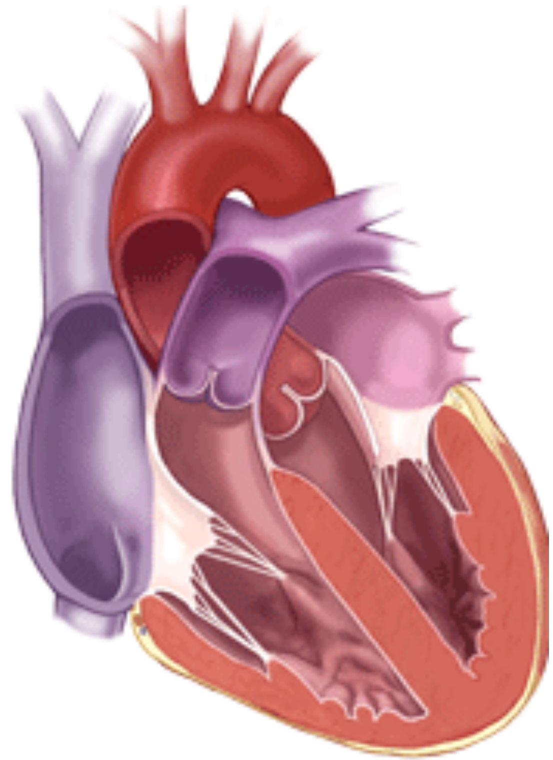




How cracks form in high-cycle fatigue.

7.7. PRACTICAL CASE 1: FATIGUE TEST OF A MITRAL CORDAE TENDINEAE





7.7. PRACTICAL CASE 2: FATIGUE TESTS ON SUPERESTRUCTURE RAILWAY COMPONENTS