High cycle fatigue – initiation

Two primary causes

◇ From stress concentrations, such as pores, inclusions, initial cracks etc.
  • There will be a local increase of the stress levels

◇ Due to a pile-up of dislocations, which will form slip bands, which will grow to form cracks
  • Cracks form due to a local decrease in the fatigue strength

Which of this two mechanisms that will dominate depends on the purity of the material, the nature of the loading, etc.
For some materials, there is a stress amplitude below which no fatigue failures will occur. This is called the **fatigue limit**. The fatigue limit can be considered to be a material parameter.

Designing for infinite life is to assure that **no stress levels exceed the fatigue limit**

But how do we translate the fatigue limit to other types of loading?
The Wöhler (S-N) curve

- The Wöhler curve shows **fatigue life** corresponding to a certain **stress amplitude**
- It is also called a S-N-curve
- The diagram is primarily valid for **uniaxial loading**
- The curve does not take into account any effects of the **mid value** of the stress during a stress cycle
- Consequently, the curve is only valid for loading with a certain R-ratio
- There are also Wöhler curves for entire components (e.g. chains, wheel axles). Then, fatigue life is normally plotted against applied load
Using the Wöhler (S-N) curve

- This slope on the Wöhler curve can be described by the equation:
  \[ \sigma_a^m \cdot N_f = K \]

- The Wöhler diagram can be used to design for finite (and infinite) life.

- This can be done either for a given service loading or a given service life.

Given stress amplitude

Gives allowable stress amplitude

No fatigue damage is induced, the component can sustain an infinite number of load cycles.

Given service life

Given stress amplitude

Gives pertinent fatigue life

"steel"

"aluminum"
How to Construct a Wöhler Diagram

For alternating loading,\[\sigma_{FRA} = \sigma_{UTS}\]

For pulsating loading\[\sigma_{FRA} = \sigma_{UTS}/2\]

Note that the Wöhler curve is only valid for a certain R-value\[R = \sigma_{\text{min}}/\sigma_{\text{max}}\]

For steel, the fatigue limit corresponds to\[10^6 < N < 10^7\]
The fatigue limits for two cases:

- **fully reversed** tension/compression (or bending)
- **pulsating** tension (or bending) and the yield limit, are needed to create the diagram.

The diagram is only valid for uniaxial loading.

The diagram is valid for different R-ratios.
Reduction of the Haigh Diagram

◊ **Reduction is made on the “amplitude axis”**

◊ Reduction is normally made with respect to

  - **Surface roughness** (taking also the effect of *corrosion* into account) – $K$
  
  - **Size of the raw material** – $\lambda$
  
  - **Loaded volume** (no reduction in the case of a notch) – $\delta$
  
  - **Fatigue notch factor** – $K_f$

◊ The reduction factors are taken from diagrams (see *Material Fatigue*, p.9-12)

◊ The fatigue notch factor is determined from

$$K_f = 1 + q(K_t - 1)$$

where $K_t$ is the stress concentration factor and $q$ depends on the notch radius ($q < 1$, which gives $K_f < K_t$)
Using the Haigh Diagram

- Create the Haigh diagram
- Reduce the Haigh diagram
- Insert your service stress, $P$, in the reduced Haigh diagram
- Check if you're in the "safe" area. Calculate safety factors

Uniaxial High Cycle Fatigue

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