AE 737: Mechanics of Damage Tolerance

Lecture 14 - Stress based fatigue

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schedule

- 10 Mar - Stress-based fatigue
- 12 Mar - Stress-based fatigue
- 17 Mar - Strain-based fatigue
- 19 Mar - Crack growth, HW6 Due

outline

- fatigue
- nominal and local stress
- fatigue tests
- fatigue life analysis

fatigue

fatigue

- We refer to damage from repeated, or cyclic loads as fatigue damage
- Some of the earliest work on fatigue began in the 1800's
- Chains, railway axles, etc.
- An estimated 80% of failure expenses are due to fatigue

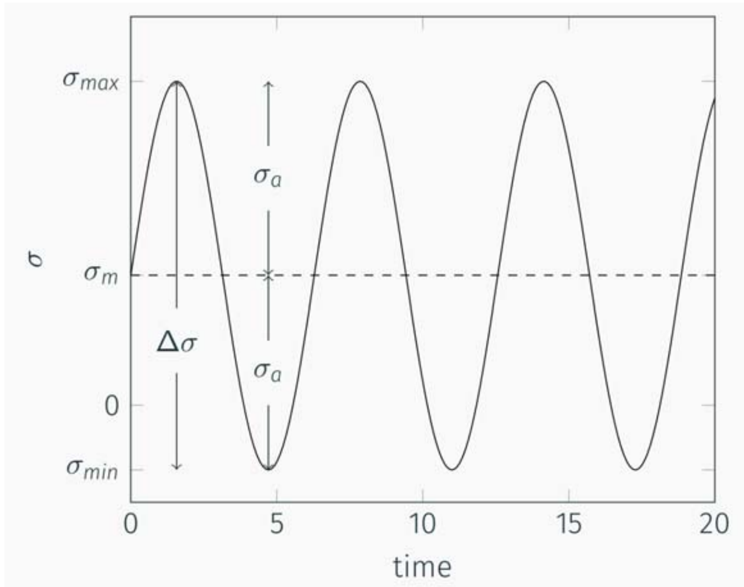
fatigue

- There are three main approaches to fatigue analysis
    - Stress based fatigue analysis
    - Strain based fatigue analysis
    - Fracture mechanics fatigue analysis

stress based fatigue

- One of the simplest assumptions we can make is that a load cycles between a constant maximum and minimum stress value
- This is a good approximation for many cases (axles, for example) and can also be easily replicated experimentally
- This is referred to as constant amplitude stressing

constant amplitude stressing



constant amplitude stressing

- $\Delta\sigma$ is known as the stress range, and is the difference between max and min stress
- σ_m is the mean stress, and can sometimes be zero, but this is not always the case
- σ_a is the stress amplitude, and is the variation about the mean

constant amplitude stressing

- We can express all of these in terms of the maximum and minimum stress

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

constant amplitude stressing

- It is also common to describe some ratios
- The stress ratio, R is defined as

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

- And the amplitude ratio, A is defined as

$$A = \frac{\sigma_a}{\sigma_m}$$

useful relations

- There are some useful relationships between the above equations

$$
\begin{aligned}
\Delta\sigma &= 2\sigma_a = \sigma_{max}(1-R) \\
\sigma_m &= \frac{\sigma_{max}}{2}(1+R) \\
R &= \frac{1-A}{1+A} \\
A &= \frac{1-R}{1+R}
\end{aligned}
$$

nominal and local stress

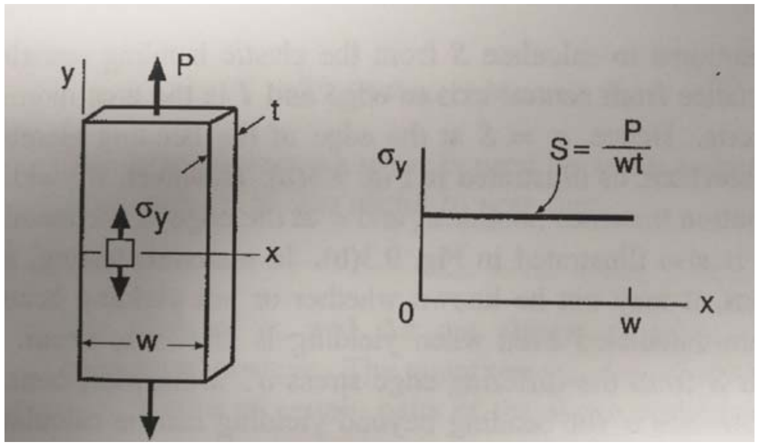
definition and notation

- It is important to distinguish between the nominal (global) stress and the local stress at some point of interest
- We use σ for the stress at a point (local stress)
- We use S as the nominal (global) stress
- In simple tension, $\sigma = S$

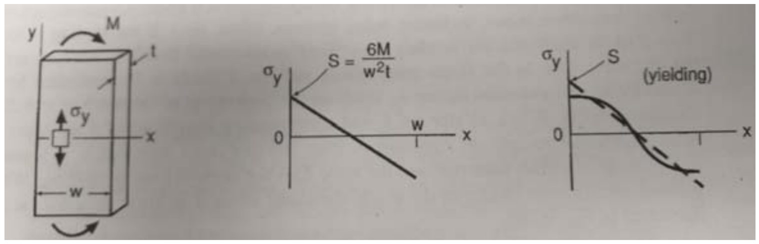
notation

- For many cases (bending, notches), $\sigma \neq S$ in general
- We must also be careful to note σ_y, in some cases $S < \sigma_y$ but at some locations $\sigma > \sigma_y$

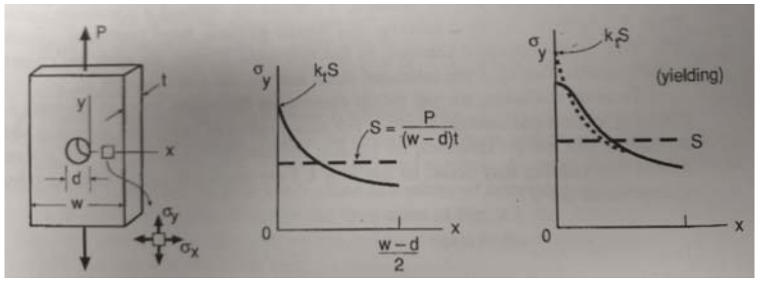
simple tension



bending



notches



P
t
y
x
d
w
σ_y
σ_x
σ_y
k_tS
$S = \frac{P}{(w-d)t}$
0
x
$\frac{w-d}{2}$
σ_y
k_tS
(yielding)
S
0
x

fatigue life analysis

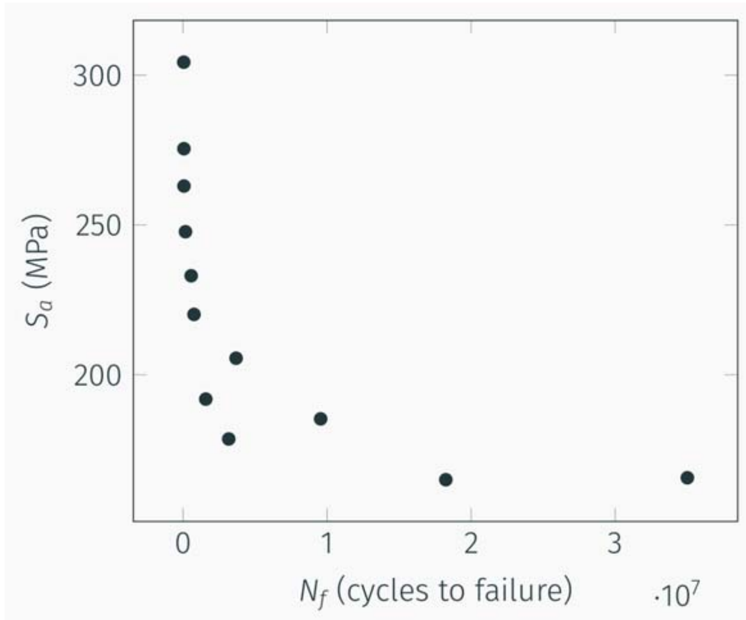
stress life curves

- Stress-life curves, or S-N curves, are generated from test data to predict the number of cycles to failure
- In general, one set (or family) of S-N curves is generated using the same σ_m
- Usually S_a (the nominal stress equivalent of σ_a) is plotted versus N (the number of cycles)

stress life curves

- Each individual point on an S-N curve represents one fatigue experiment
- To find enough data to form statistical significance, as well as to fit a curve across all levels of fatigue is very time-consuming
- In the following plot, if only one test was performed for each point, the total number of cycles tested would be about $7.3x10^7$
- For a 100 Hz machine, this represents over 200 hours of consecutive testing

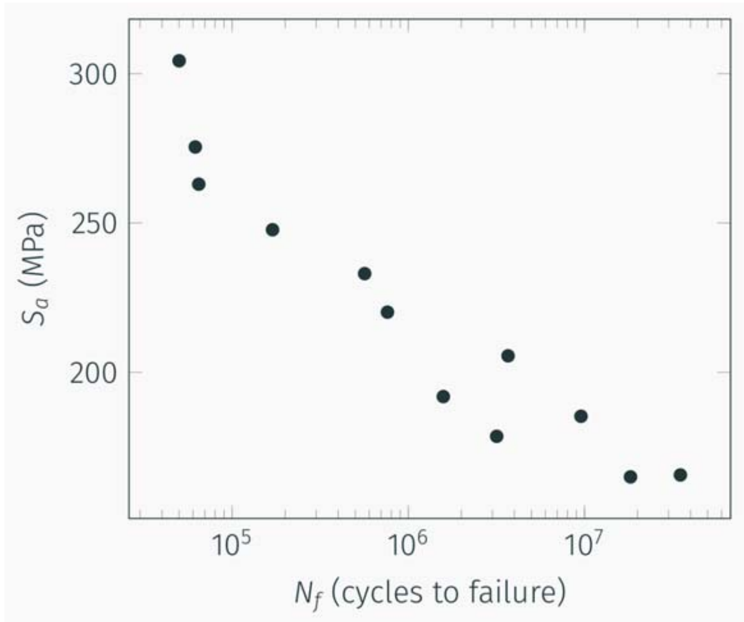
stress life curves



stress life curves

- On a linear scale, the data appear not to agree well with any standard fit
- It is also very difficult to differentiate between low-cycle fatigue failure stresses
- Instead S-N curves are often plotted on a semi-log or log-log scale, so pay attention to the axes

stress life curves



curve fits

- If the curve is nearly linear on a log-linear plot, we use the following form to fit the data

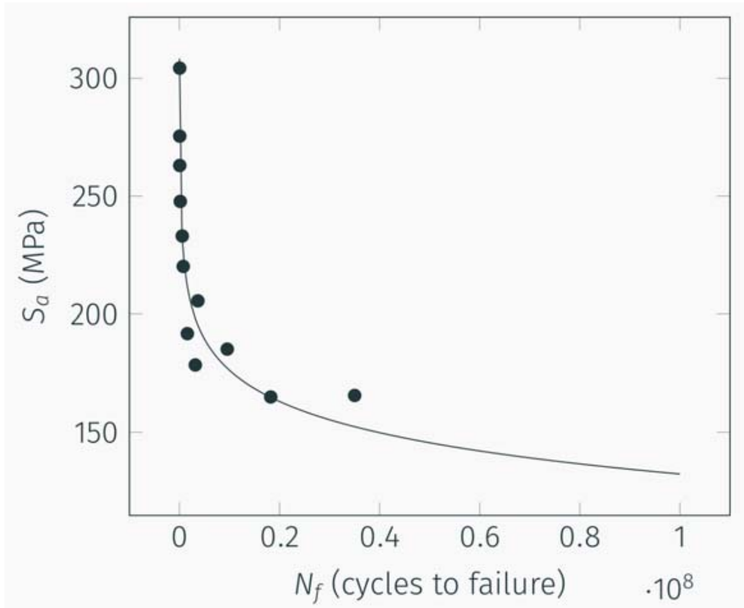
$$\sigma_a = C + D \log N_f$$

- When the data are instead linear on a log-log scale, the following form is generally used

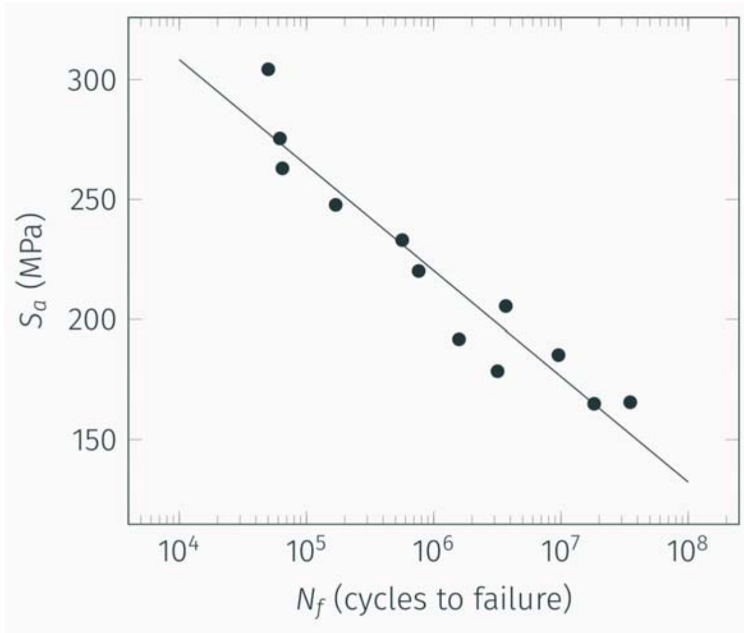
$$\sigma_a = \sigma_f'(2N_f)^b$$

- σ_f' and b are often considered material properties and can often be looked up on a table (p. 235)

curve fit


300
250
200
150
S_a (MPa)
0
0.2
0.4
0.6
0.8
1
N_f (cycles to failure)
$\cdot 10^8$

stress life curves



fatigue limit

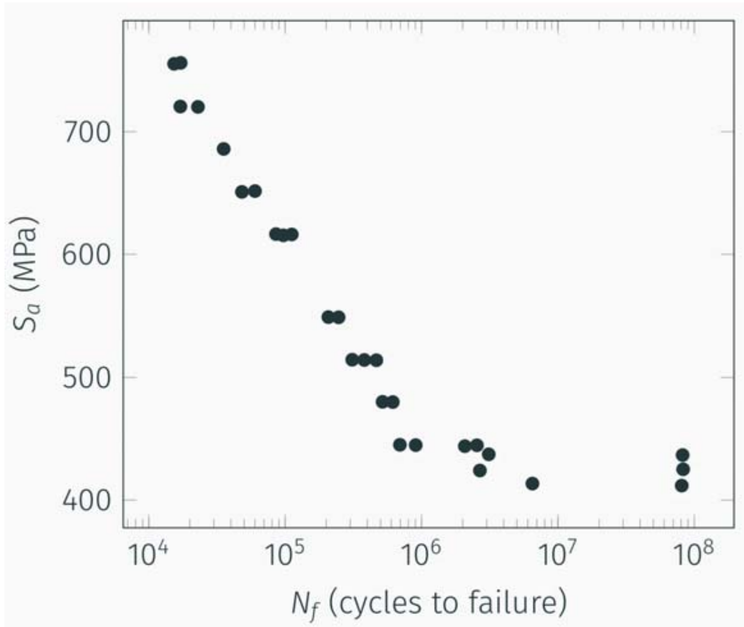
fatigue limit

- The fatigue limit, or endurance limit, is a feature of some materials where below a certain stress, no fatigue failure is observed
- Below the fatigue limit, this material is considered to have infinite life
- This most notably occurs in plain-carbon and low-alloy steels
- In these materials, σ_e is considered to be a material property

fatigue limit

- This phenomenon is not typical of aluminum or copper alloys
- It is sometimes arbitrarily assigned using whatever the failure stress is at some large number of cycles (10^7 or 10^8)

fatigue limit



high and low cycle fatigue

- Some other important terms are high cycle fatigue and low cycle fatigue
- “High cycle fatigue” generally is considered anything above 10^3 cycles, but varies somewhat by material

high and low cycle fatigue

- High cycle fatigue occurs when the stress is sufficiently low that yielding effects do not dominate behavior
- When yielding effects do dominate behavior, the strain-based approach is more appropriate