AE 737 - MECHANICS OF DAMAGE TOLERANCE

Lecture 19

Dr. Nicholas Smith

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SCHEDULE

- 5 Apr - Crack Growth, Homework 7 due, Homework 8 assigned
- 7 Apr - Crack Growth, Stress Spectrum
- 12 Apr - Retardation, Boeing Commercial Method
- 14 Apr - Exam Review, Homework 8 Due
- 19 Apr - Damage Tolerance
- 21 Apr - Exam 2

FINAL PROJECT CLARIFICATION

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- By ”crack growth” I intended ”crack nucleation,” which is a phrase to describe stress and strain based fatigue analysis
- ”Crack propagation” is what I intended by what your text calls ”crack growth”, and refers to fracture mechanics-based fatigue analysis

OFFICE HOURS

- I have a meeting this Friday afternoon (4/8)
- Office hours will be Monday 4/11 from 3:00 - 5:00
- As always you can e-mail me to schedule another time, or ask your questions via e-mail

OUTLINE

1. mean stress effects
2. multiaxial loading
3. crack growth rate
4. crack growth rate equations

MEAN STRESS EFFECTS

- In regions where plastic strain is significant, some applied mean stress is likely to be relaxed through cyclic plastic strain

MEAN STRESS IN STRAIN-BASED FATIGUE

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- When the plastic strain is not significant, mean stress will exist
- Mean strain does not generally affect fatigue life

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MORROW APPROACH

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$$\sigma_a = \sigma_f' \left[\left(1 - \frac{\sigma_m}{\sigma_f'} \right)^{\frac{1}{b}} (2N_f) \right]^b \tag{19.2}$$

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$$\epsilon_a = \frac{\sigma_f'}{E}\left(1 - \frac{\sigma_m}{\sigma_f'}\right)(2N_f)^b + \epsilon_f'\left(1 - \frac{\sigma_m}{\sigma_f'}\right)^{\frac{c}{b}}(2N_f)^c \tag{19.4}$$

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- From the zero-mean stress graph, find the point corresponding to your applied strain
- For a non zero mean stress, this point represents (ϵ_a, N^*), we can now solve for N_f using 19.3

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- There is no convenient solution method for this form, and it generally must be solved numerically, or plotted with many families of σ_m

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- This method can also be solved graphically if a plot of $\sigma_{max}\epsilon_a$ is made using zero-mean data. All we need to do is find the new $\sigma_{max}\epsilon_a$ point to find a new N_f

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COMPARISON

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- The Morrow method is very good for steel
- The modified Morrow method gives improved results in many materials
- The SWT approach is very good for general use, but is non-conservative with a compressive mean stress

EXAMPLE

MULTIAXIAL LOADING

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$$\epsilon_{1a} = \frac{\frac{\sigma_f'}{E}(1-\nu\lambda)(2N_f)^b + \epsilon_f'(1-0.5\lambda)(2N_f)^c}{\sqrt{1-\lambda+\lambda^2}} \tag{19.7}$$

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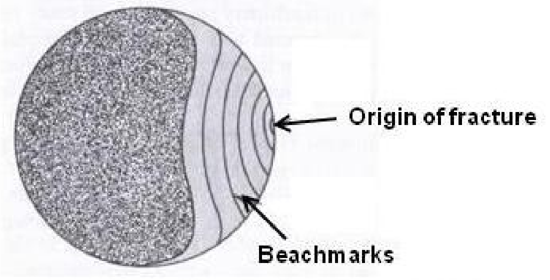
$$\bar{\epsilon_a} = \frac{\sigma_f'}{E}(2N_f)^b + 2^{1-T}\epsilon_f'(2N_f)^c \tag{19.9}$$

CRACK GROWTH RATE

FRACTURE SURFACE



Fatigue Fracture with Beachmarks

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- It would be beneficial to predict at what rate a crack will extend

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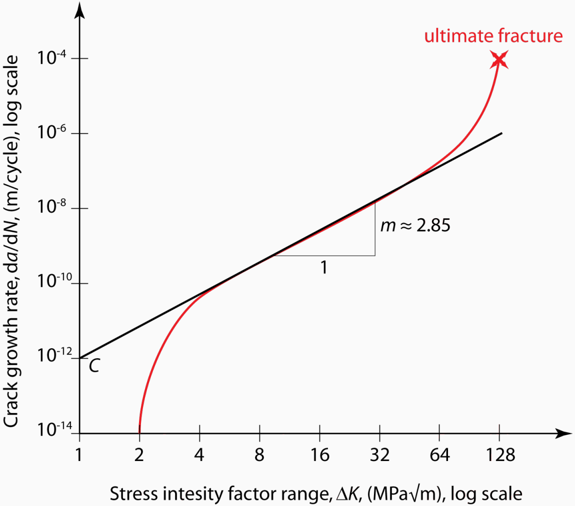
- This chart is then commonly divided into three regions


ultimate fracture
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
Crack growth rate, da/dN, (m/cycle), log scale
$m \approx 2.85$
1
C
1
2
4
8
16
32
64
128
Stress intesity factor range, ΔK, (MPa$\sqrt{}$m), log scale

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- The same considerations for thickness apply as with fracture toughness (K_c vs. K_{Ic})
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- In general, R dependence vanishes for $R > 0.8$ or $R < -0.3$. This effect is known as the band width

CRACK GROWTH RATE EQUATIONS

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    4. Stress ratio effects
    5. Band width of R-curves

PARIS LAW

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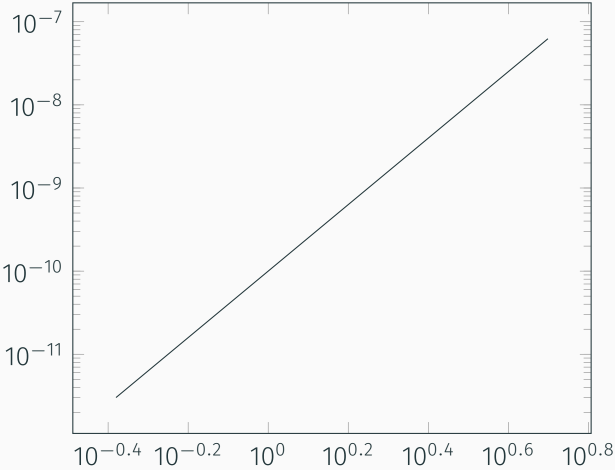
- Note: this assumes the x-axis is ΔK, but $\Delta K = (1 - R)K_{max}$, so we can easily convert


10^{-7}
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10^{-9}
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10^{0}
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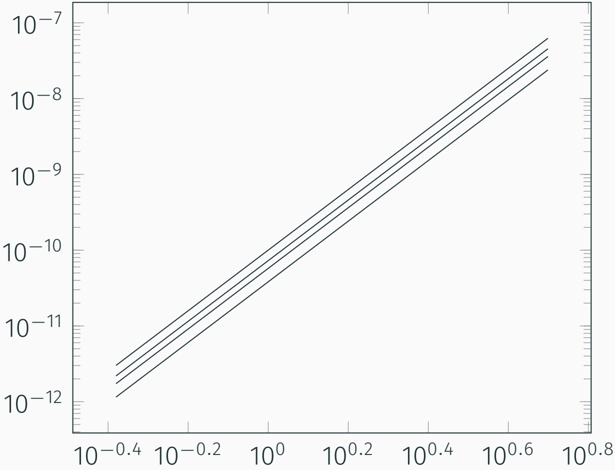
- Gives a good fit for Region II with R-dependence and band width

WALKER



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$$\frac{da}{dN} = \frac{C\left[(1-R)K_{max}\right]^n}{(1-R)K_c - (1-R)K_{max}} \tag{19.12}$$

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$$\frac{da}{dN} = \frac{C\left[(1-R)^m K_{max}\right]^n}{\left[(1-R)^m K_c - (1-R)^m K_{max}\right]^L} \tag{19.13}$$

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$$\frac{da}{dN} = C_1 + C_2 \tanh^{-1}\left[\frac{\log\left(\frac{K_{max}^2}{K_o K_c}\right)}{\log(K_c/K_o)}\right] \tag{19.14}$$

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$$K_{eff} = (1-R)^m K_{max} \tag{19.16}$$

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$$\frac{da}{dN} = C\left[\frac{1-f}{1-R}\Delta K\right]^n \frac{\left[1-\frac{\Delta K_{th}}{\Delta K}\right]}{\left[1-\frac{K_{max}}{K_{crit}}\right]} \tag{19.17}$$

NASGROW GROWTH RATE EQUATION

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- The curve fit parameters can be found in p. 307 of your text (or the NASGROLW/AFGROW documentation)

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CONVERSION OF CONSTANTS

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- Forman:

$$\frac{da}{dN} = \frac{C_F}{(1-R)K_c - \Delta K}(\Delta K)^{n_f} \tag{19.21}$$

Walker-Boeing	Walker-AFGROW	Forman
$10^{-4}\left(\frac{1}{mT}\right)^{p}$	$C_w = 10^{-4}\left(\frac{1}{mT}\right)^{p}$	$C_F = (K_c - 1)10^{-4}\left(\frac{1}{mT}\right)^{p}$
q	$m = q$	
p	$n_w = p$	$n_f = p$