ae 737 - mechanics of damage tolerance

Lecture 20

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SCHEDULE

- 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
- 26 Apr - Exam Solutions, Damage Tolerance

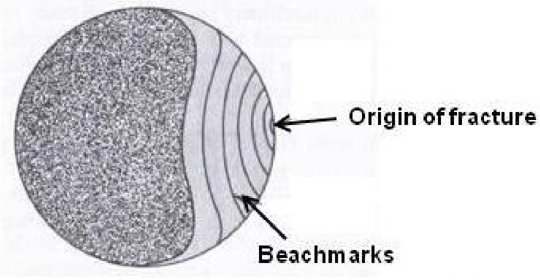
OFFICE HOURS

- 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

1. crack growth rate
2. factors affecting crack propagation
3. numerical algorithm

CRACK GROWTH RATE

FRACTURE SURFACE

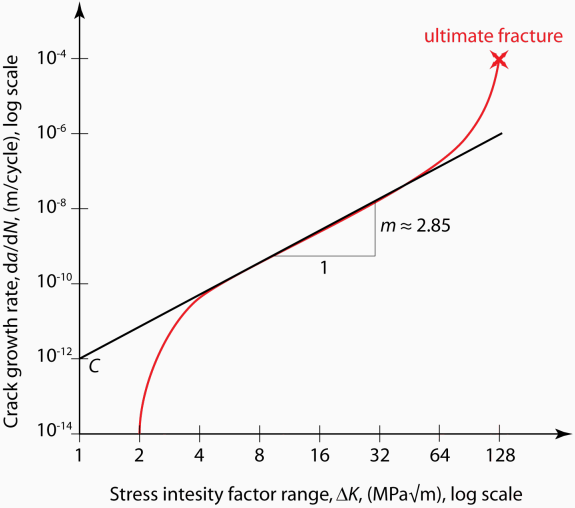


Fatigue Fracture with Beachmarks

CRACK GROWTH RATE

- Crack growth rate can be measured experimentally
- Using a center-crack specimen, a fatigue load is applied
- The crack length is measured and plotted vs. the number of cycles
- The slope of this curve ($\frac{da}{dN}$) is then plotted vs. either $K_{I,max}$ or ΔK_I on a log-log scale
- This chart is then commonly divided into three regions

DA-DN VS K



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

- In Region I crack growth is very slow and/or difficult to measure
- In many cases, da/dN corresponds to the spacing between atoms!
- The point at which the da/dN curve intersects the x-axis is known as the fatigue threshold, K^{th}
- Typically 3-15 $\text{ksi}\sqrt{\text{in}}$ for steel
- 3-6 $\text{ksi}\sqrt{\text{in}}$ for aluminum

- Most important region for general engineering analysis
- Once a crack is present, most of the growth and life occurs in Region II
- Generally linear in the log-log scale

REGION III

- Unstable crack growth
- Usually neglected (we expect failure before Region III fully develops in actual parts)
- Can be significant for parts where we expect high stress and relatively short life

- The crack growth rate curve is considered a material property
- The same considerations for thickness apply as with fracture toughness (K_c vs. K_{Ic})
- Is also a function of the load ratio, $R = \sigma_{min}/\sigma_{max}$

R EFFECTS

- While the x-axis can be either ΔK or K_{max}, the shape of the data is the same
- When we look at the effects of load ratio, R, the axis causes some differences on the plot
- With ΔK on the x-axis, increasing R will shift the curve up and to the left, shifting the fatigue threshold and fracture toughness on the graph as well
- With K_{max} on the x-axis, increasing R shifts the curve down and to the right, but fatigue threshold and fracture toughness keep same values
- In general, R dependence vanishes for $R > 0.8$ or $R < -0.3$. This effect is known as the band width

PARIS EXAMPLE

FACTORS AFFECTING CRACK PROPAGATION

FACTORS AFFECTING CRACK PROPAGATION

- thickness
- stress ratio
- temperature
- environment
- frequency
- crack orientation
- manufacturer
- heat treatment

THICKNESS

- We already discussed the effects of thickness on fracture toughness
- The same effects are important in crack propagation
- In thin (plane stress) plates, cracks can be treated as through cracks
- In thick plates (plain strain), we generally need to consider the crack shape

- Cyclic life is primarily a function of K_i/K_c where K_i is the stress intensity factor in the first cycle
- Other experiments indicate a relationship between $\frac{d(a/Q)}{dN}$ and K_{max}
- Q is a shape parameter for elliptical flaws

- In general (for most aluminum alloys) cracks propagate more slowly with a decrease in temperature
- This trend is exactly opposite the trend for K_c
- The effect varies in different materials
- Most materials benefit from slightly lower temperatures, but as temperatures are further decreased the crack growth rate increases again

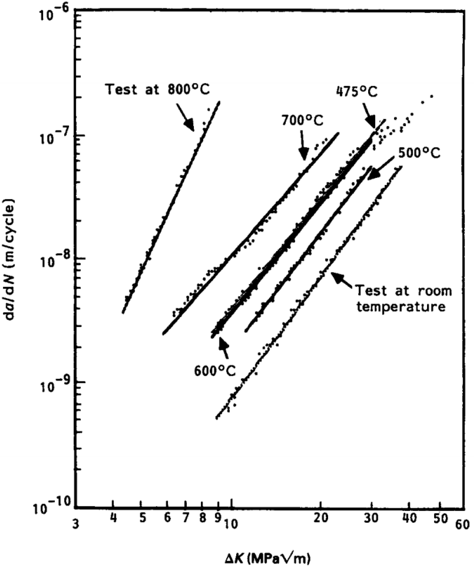


Fig. 2 Mid-range fatigue crack-growth rates with alternating stress intensity factor for 18%Cr–Nb ferritic stainless steel at

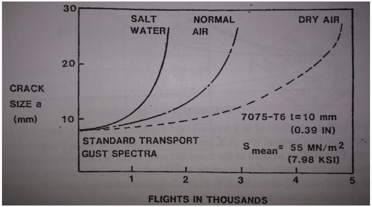
TEMPERATURE

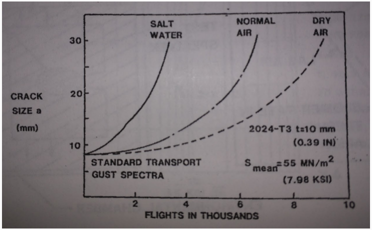
- In general, temperature effects can not be predicted well
- Instead, materials should be tested at a range of temperatures to establish a range of operating temperatures with corresponding crack growth data

ENVIRONMENT

- There are many conditions in the environment that can affect crack growth
- Moisture greatly increases the crack growth rate
- Salt water increases crack growth rate even further
- These effects have varying strength depending on the material used

ENVIRONMENT





- Further, the shape of the applied load curve has a significant effect when combined with adverse environments
- Crack growth is faster when the load increases slowly and decreases rapidly
- Crack growth is slower when the load increases rapidly and decreases slowly

- When the environment is corrosive, the test frequency is of particular importance
- At low frequencies, a corrosive environment increases the threshold, K^{th}
- However in Region II, crack growth is faster
- This effect can be explained by the corrosive environment blunting the crack tip

FREQUENCY

- There is conflicting information about the effect of frequency in the absence of a corrosive environment
- Some experiments have found a frequency dependence, while others have not
- Many claim that the frequency dependence is due to small amounts of water in air during frequency dependence experiment

CRACK ORIENTATION

- For rolled plates, a crack will generally propagate faster parallel to the rolling direction
- In many materials, however, the difference between orientations is not significant when compared to scatter, and it is often neglected
- Some materials behave very differently with different crack orientations (i.e. the slope of the paris law curve is different), so care should be taken based on the material used

- Different manufacturers of the same material can produce different crack growth rates
- Some reasons for this may be
- Slight variation in composition
- Site cleanliness (inclusions)
- Heat treatment/cold rolling variations

- Different heat and surface treatments are often applied
- They provide various benefits (corrosion resistance, residual stress, residual stress relief)
- But they will also affect the crack growth rate

NUMERICAL ALGORITHM

- While the Paris Law can be integrated directly (for simple load cases), many of the other formulas cannot
- A simple numerical algorithm for determining incremental crack growth is

$$a_{i+1} = a_i + \left(\frac{da}{dN}\right)_i (\Delta N)_i \tag{20.1}$$

- This method is quite tedious by hand (need many a_i values for this to be accurate)
- But is simple to do in Excel, MATLAB, Python, or many other codes
- For most accurate results, use $\Delta N = 1$, but this is often unnecessary
- When trying to use large ΔN, check convergence by using larger and smaller ΔN values

BOEING-WALKER EXAMPLE

- In practice variable loads are often seen
- The most basic way to handle these is to simply calculate the crack length after each block of loading
- We will discuss an alternate method, which is more convenient for flight ”blocks” next class
- We will also discuss ”retardation” models next class

VARIABLE LOAD EXAMPLE