AE 737 - MECHANICS OF DAMAGE TOLERANCE

Lecture 23

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SCHEDULE

- 19 Apr - Damage Tolerance, Homework 8 Due
- 21 Apr - Exam 2
- 26 Apr - Exam Solutions, Damage Tolerance
- 28 Apr - SPTE, AFGROW, Finite Elements
- 3 May - Finite Elements
- 5 May - Non-Destructive Testing, Composites, Final Project Due May 10

OUTLINE

1. special topics

2. review

3. damage tolerance

4. inpsection cycle

SPECIAL TOPICS

- Damage tolerance is a very broad field, here are some potential things we can discuss for the last few weeks of class
- Non-destructive testing (NDT) (some people use ”Evaluation” instead of testing, NDE)
- Finite element techniques and methods for damage and fracture
- Repairing damaged structures
- Damage in composite materials
- AFGROW
- Composite certification
- Other questions?

REVIEW

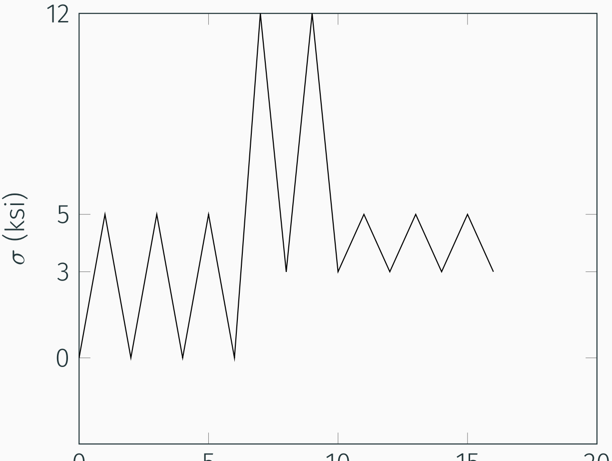
Find the fatigue life of 2024-T4 aluminum ($\sigma_f' = 131$ ksi, $b = -0.102$) under the following load scenario

Stress Term	Min	Max
σ_x	0	15
σ_y	-5	10
τ_{xy}	5	15

GROUP 2

Show how to find the cycles to failure for 7075-T6 ($\sigma_f' = 213$ ksi, $b = -0.143$, $\epsilon_f' = 0.262$ and $c = -0.619$) with $\epsilon_a = 0.40$ and $\sigma_m = 15$ksi

Use the Boeing method to find an equivalent load cycle for the following load spectrum. Repeat this calculation using two different ”cycle counting” methods. Use material properties for 4340 steel ($p = 2.7$, $q = 0.84$, $M_T = 70.0$).



For a wide, center-cracked panel with $C = 10^{-9}$, $n = 4$ and $a_0 = 0.15$ in. Assume $\sigma_{YS} = 70$ ksi.

1. Integrate to find the crack length after 10,000 cycles of $R = 0$, $\sigma_{max} = 10$ ksi loading
2. Calculate the plane stress plastic zone after an overload of $\sigma = 30$ ksi
3. Find the Wheeler parameter (ϕ) for the next cycle of $\sigma_{max} = 10$ ksi loading with $m = 1.5$

DAMAGE TOLERANCE

- Safe Life
    - Assume cracks are present
    - Cracks are not inspectable
    - Use crack growth or fatigue analysis to establish safe life, in which part will not fail
- Damage tolerant
    - Assume cracks are present
    - When cracks grow to a sufficient size, they are inpsectable
    - Inspection cycles are set such that we can be sure crack will not become critical during regular operation

- **Fail safe** multiple load paths, redundancy
- **Limit load** maximum anticipated load
- **Design load** limit load multiplied by some factor of safety (static design)
- **Operating load** stress spectrum (used for crack propagation/fatigue)

STRUCTURAL CATEGORIES

- Single load path - safe life
- Single load path - damage tolerant
- Multiple load path - externally inspectable
- Multiple load path - inspectable prior to failure

- In many structures, multiple load paths are not practical
- It is also possible for the critical crack length to be much smaller than is easily detectable
- In these cases, safe life design is used to identify a certain number of cycles a part can sustain before it needs to be replaced
- This often requires replacing parts pre-maturely

SINGLE LOAD PATH - DAMAGE TOLERANT

- Redundant load paths are not necessary when a part is easily inspectable
- When the detectable crack size is much less than the critical crack length, we can safely inspect a part so that it is only replaced when damage is detected
- Many times this damage can be repaired to avoid replacing the part entirely
- Ideal for large, expensive parts that are easy to access (inspection and repair)

MULTIPLE LOAD PATH - EXTERNALLY INSPECTABLE

- This is a very common scenario in aircraft (skin/stringer)
- In this case, the primary structure is not inspectable
- A secondary structure is inspectable
- The secondary structure can support a certain number of cycles after failure of the primary structure
- Secondary structure can be inspected to observe damage in primary structure

MULTIPLE LOAD PATH - INSPECTABLE PRIOR TO FAILURE

- In this case the primary structure is inspectable
- Otherwise same as externally inspectable structure

INPSECTION CYCLE

- In many industries, an inspection cycle is pre-determined by some governing agency
- We have developed all the equations necessary to determine our own
    1. Determine loading cycle (or equivalent load cycle using Boeing method)
    2. Determine maximum crack length
    3. Determine initial assumed crack length (minimum detectable crack)
    4. Calculate number of cycles/flights until crack grows to maximum allowable size

- Be sure to use a consistent cycle-counting method (rainflow or range-pair)
- Recall the Boeing method for variable amplitude loads

$$\sum_i (z\sigma_{max})_i^p N_i = (S)^p \tag{23.1}$$

CRACK LENGTH

- We can use the residual strength curve to set a maximum crack length
- We also want to ensure that the crack propagation is still in Region II at this point
- Crack growth becomes unstable in Region III

INITIAL CRACK LENGTH

- What is the smallest crack we can detect?
- Liquid penetrant (any material)
- Magnetic particle (ferromagnetic materials)
- Ultrasonic (any material)
- Eddy Current (only for conductive materials)
- Radiographic (X-Ray, nearly any material)

CALCULATE CYCLES

- We can integrate (analytically or numerically) to find the number of cycles it will take for a crack to grow to critical length
- Note that numerical integration is non-conservative, in general
- ΔN should be small enough to give converged solution

EXAMPLE