AE 737: Mechanics of Damage Tolerance

Lecture 13 - Project Discussion

Dr. Nicholas Smith

Wichita State University, Department of Aerospace Engineering

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schedule

- 17 Mar - Project Discussion, Fatigue
- 19 Mar - HW5 Self-grade due
- 22 Mar - Stress-based Fatigue
- 24 Mar - Stress-based Fatigue
- 26 Mar - Project Abstract Due
- 29 Mar - Strain-based Fatigue

outline

- exam
- final project
- fatigue
- nominal and local stress
- fatigue tests

exam

final project

general description

- This is in place of a final exam
- Should demonstrate your understanding of the course as a whole
- Choose any real object
- Needs to undergo some cyclic loading (for fatigue)
- Materials, loads, and any other “given” data can be made up

overview

- Estimate stress intensity factor at some critical location
- Estimate residual strength (use a “typical” crack length)
- Estimate fatigue life
- Estimate crack propagation
- Suggest reasonable inspection cycle for safe use
- Suggest an improvement to make part more damage tolerant

grade breakdown

- Per course syllabus, project will be worth 25% of final grade
- 5% Project abstract submission and approval
- 15% for each major component
  - stress intensity factor
  - residual strength
  - fatigue
  - crack propagation
  - inspection cycle

grade breakdown

- 10% for damage tolerant improvement
- 10% general presentation, organization, and grammar

project abstract

- Main purpose of abstract is for you to make sure your idea fits with project purpose
- I will give you feedback on how to tweak your proposed idea to better meet project purpose
- Abstract submission should be 1-2 pages
- Briefly describe your chosen part, how it undergoes cyclic loading, what location you intend to consider for the stress intensity factor.
- This is like a proposal: convince me that your idea has what it takes to be a great final project

justify assumptions

- You will need to make many assumptions in order to complete this project
- Clearly state your assumptions and justify them (i.e. if you assume plane strain conditions, justify that by showing how thick your part is)
- Although will not have experimental or FE analysis specific to your part, use concepts from other data in the text (stiffeners, multiple site damage) in a qualitative manner

figures

- Figures can greatly enhance your project report, if you use them well
- Many readers will jump to figures in a report, include sufficient information in caption and axis labels so a reader with general damage tolerance understanding can understand your figure
- This will interest them in the rest of your paper

examples

- Last year I did not curve final project grades
- Some examples of a couple of good project reports have been posted to blackboard (and here[1])
- You should not use their projects, but they have very good use of figures, as well as an appropriate balance of both depth and breadth in the their analysis

[1] https://ndaman.github.io/damagetolerance/#/2/2

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

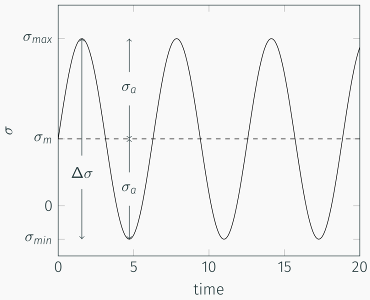
fatigue

- 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

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

nominal and local stress

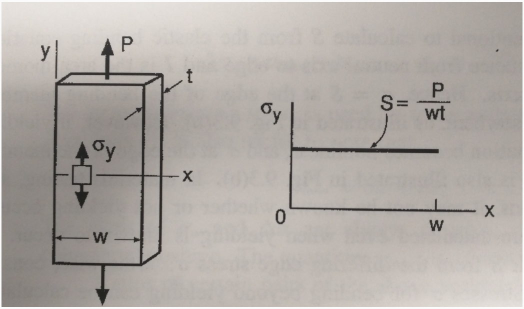
definition and notation

- 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, $\sigma = S$

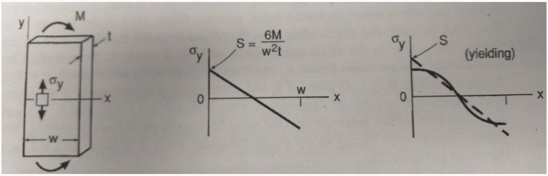
notation

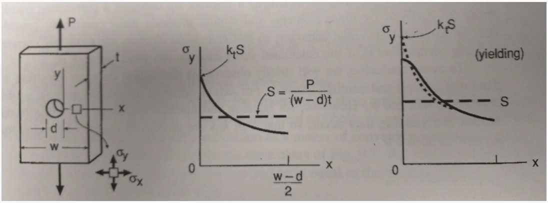
- For many cases (bending, notches), $\sigma \neq S$ in general
- We must also be careful to note σ_y, in some cases $S < \sigma_y$ but at some locations $\sigma > \sigma_y$

simple tension



bending





fatigue tests

rotating cantilever beam

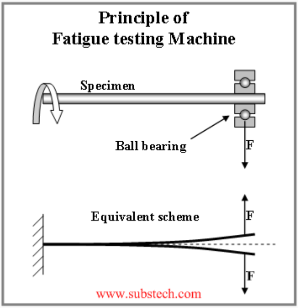


Figure 1: Stress variation through a cantilever beam

rotating four-point bend

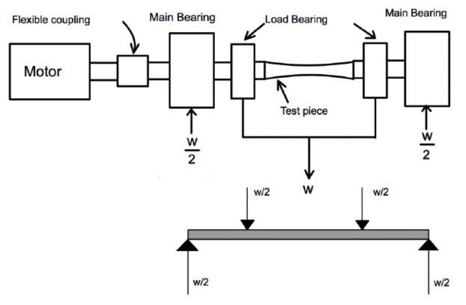
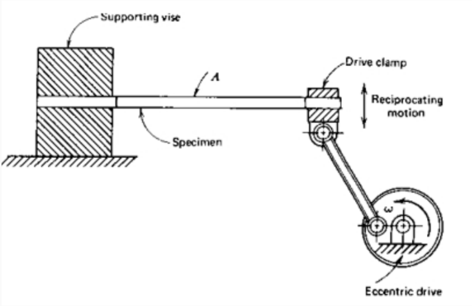


Figure 2: Four-point bend test gives uniform stress along the top and bottom surfaces

fatigue tests

- The above rotating methods are very common, but in their current configurations can only be used for zero mean stress
- a reciprocating bend test can be used for non-zero mean stress

reciprocating bend test



axial fatigue test

fatigue tests

- The length of a fatigue test is determined by two factors
  1. How many cycles it takes for the specified load to cause failure
  2. The speed of the motor controlling the test

fatigue tests

- Servohydraulic machines generally have a speed of 10 - 100 Hz.
- At a speed of 100 Hz, it would take 28 hours for 107 cycles, 12 days for 108 cycles, and nearly 4 months for 109 cycles
- While some machines can test at very high speeds, the inertia of the sample can interfere with results