ASE324: Aerospace Materials Laboratory

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Lecture 18

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Fatigue failure

- Failure of materials subjected to cyclic loading.

- **High-cycle fatigue**: no pre-existing cracks, low stress level, large number of cycles to failure ($> 10^4$).
- **Low-cycle fatigue**: no pre-existing cracks, high stress level, small number of cycles to failure ($< 10^3$).
- **Fatigue crack growth**: with pre-existing cracks, fail after crack reaches a critical size.
Fatigue mechanisms

- Low-cycle fatigue: plastic deformation
- High-cycle fatigue: stress concentration
High-cycle fatigue

• Most of the lifetime is spent initiating rather than propagating cracks.
• Number of cycles to failure depends on the stress amplitude, S-N curve.
• The frequency and the shape of loading history of each cycle have little effect.

\[
\sigma_a = \frac{\sigma_{\text{max}} - \sigma_{\text{min}}}{2}
\]
\[
\sigma_m = \frac{\sigma_{\text{max}} + \sigma_{\text{min}}}{2}
\]
• Steel has a limit (fatigue strength, $\sim 0.5 \sigma_{\text{UTS}}$), below which the fatigue life is infinite.

• Aluminum does not have a limit. Use the stress amplitude corresponding to a specified fatigue life (e.g., $N = 10^7$) as fatigue strength.
Basquin’s law

\[ \sigma_a N_f^a = C \]
Mean stress effect

- Goodman’s rule

\[ \sigma_a (N_f, \sigma_m) = \sigma_a (N_f, 0) \left[ 1 - \frac{\sigma_m}{\sigma_{UTS}} \right] \]
Cumulative damage

- Miner’s rule

\[ \frac{N_1}{N_{f1}} + \frac{N_2}{N_{f2}} + \frac{N_3}{N_{f3}} + \cdots < 1 \]
Surface treatments

• Most fatigue cracks initiate at the surface (scratches, grooves, etc.).
• Surface treatments can improve the fatigue resistance.
  – Polishing
  – shot-peening: imposes compressive residual stresses within a thin surface layer).
  – Case hardening: modifies the surface layer to increase surface hardness and introduce residual compressive stresses.
Photograph of a steel gear that has been “case hardened.” The outer surface layer was selectively hardened by a high-temperature heat treatment during which carbon from the surrounding atmosphere diffused into the surface. The “case” appears as the dark outer rim of that segment of the gear that has been sectioned. Actual size.
(Photograph courtesy of Surface Division Midland-Ross.)
Fatigue testing

**Figure 8.16** Schematic diagram of fatigue-testing apparatus for making rotating-bending tests. (From *Materials Science in Engineering*, 4/E by Keyser, Carl A., © Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ.)
Tapered beam fatigue test

Fully-stressed within the tapered part.

\[ \sigma = \frac{M_y}{I} \]
Assignments

- Lab Manual, pp. 113: 1, 2, 3, 5(a).

- Due at the final exam (August 16, Saturday, 7pm).

- Question 6: example.