Fatigue Crack Growth

Ashraf -F. Bastawros
Aerospace and Engineering Mechanics
Iowa State University
bastaw@iastate.edu, X4-3039
Howe Hall Rm. 2347
Spring 2006

Importance of Fatigue

• Bottom line: Fluctuating loads are more detriment than monotonic loading
• Example: Comet Airliner– First jet propelled aircraft.
  - Actual cabin differential pressure during flight 8.5psi (57kPa)
  - The design pressure was 20psi (138kPa), [FOS >2].
  - Pressurized once to double its working pressure of 114kPa
    Thought would not fail under the action of fatigue \(\text{[WRONG]}\)
    Crack growth due to cyclic loading caused catastrophic failure of the aircraft

Types of Fatigue Loading

• Mechanical Fatigue: pure fluctuation in applied load
• Fretting Fatigue: cyclic stress with oscillatory relative motion and frictional sliding.
• Contact Fatigue: rolling and sliding contact
• Corrosion Fatigue: chemical aggressive or embitterment.
• Creep Fatigue: cyclic loading at constant elevated temperature
• Thermal Fatigue: cyclic temperature at constant or zero load
• Thermo-mechanical Fatigue: combined cyclic variation of both loading and temperature
Cyclic Loading Definitions

• Typical stress history during cyclic loading

Parameters defining a cyclic loading history
- Stress Range: \( \Delta \sigma = \sigma_{\text{max}} - \sigma_{\text{min}} \)
- K-Range: \( \Delta K = K_{\text{max}} - K_{\text{min}} \)
- Stress amplitude: \( \sigma_a = \frac{1}{2} (\sigma_{\text{max}} - \sigma_{\text{min}}) \)
- Mean Stress: \( \sigma_m = \frac{1}{2} (\sigma_{\text{max}} + \sigma_{\text{min}}) \)
- Loading ratio: \( R = \frac{\sigma_{\text{min}}}{\sigma_{\text{max}}} \)
- \( N_f \): No. of cycle to failure

Cyclic vs. Static Loading

Key difference between static and cyclic loading
- **Static**: until applied \( K \) reaches \( K_c \) (30MPa\( \sqrt{m} \) for example) the crack will not grow
- **Cyclic**: \( K \) applied can be few percent of \( K_c \) (3MPa\( \sqrt{m} \) for example). Over time, the crack grows.

The design could be safe under static loading, but any cyclic loading must be considered.
Paris, Gomez and Anderson (A rational analytical theory of fatigue, the Trend in Engineering, Vol 13, 9-14, 1961) postulated that the rate of crack growth depends on $\Delta K$ in the following way:

$$\frac{\Delta a}{\Delta N} \rightarrow \frac{da}{dN} = C(\Delta K)^n$$

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- Stage I: Linear growth
- Stage II: Power law growth
- Stage III: Near threshold growth

$\sigma = \Delta \sigma$ is a geometric constant depends on the specimen type.

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- Regime A: Low to moderate stress levels
- Regime B: Intermediate stress levels
- Regime C: High stress levels

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* $r_a$ and $d_p$ refer to the cyclic plastic zone size and the grain size, respectively.

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