Outline

- Impact Testing
- Charpy Test
- Ductile to Brittle Transition Temperature
- Metallurgical Factors Affecting $T_T$
- Fatigue
- Fatigue Testing
- Types of Fatigue

Impact Testing

- Charpy and Izod tests measure impact energy or notch toughness
- Charpy V-notch (CVN) most common

Before fracture mechanics - impact testing was used to measure impact behaviour and likelihood of brittle fracture. Developed to detect the onset of brittle failure in ductile materials e.g. steel ships, bridges etc.

- Still used in quality control and Standards (ship plate etc).

Three main factors were producing these fractures in service:
- Triaxial stress state (at notches, cracks etc)
- Low temperatures
- High strain or loading rates

Impact testing is used for:
- checking quality
- tendency for brittle failure
- temperature dependence.

Charpy Test

- Use standard sized bar specimens with a central notch
- Weighted pendulum released from a height, $h$
- Impacts the specimen behind the notch (stress concentration)
- Fracture of specimen occurs and energy is absorbed
- The pendulum travels to point, $h'$, where $h' < h$
- Obtain the amount of absorbed energy from scale
  - .......... and .......... test method

Ductile to Brittle Transition in Steel

- Primary function of Charpy test
- At high temperature, CVN for steel is relatively high but drops with decrease in temperature
- At low temperature steel can be brittle
- The sudden drop in impact energy is the ................. transition (DBT)
- Steels should always be used above their DBT
- Polymers also experience DBT
- Aluminum and copper alloys show Al and Cu have FCC structure
Ductile to Brittle Transition Behavior

- Actual DBT is difficult to define, instead minimum requirement of CVN = 20J (15ft.lb) is used.
- DBT changes with carbon content in steel.
- Steels: 0.01-0.67% carbon

Can use fracture surface appearance to estimate the DBT.

Brittle, shiny, faceted, bright, flat overall, no or little deformation.

Fibrous, grey, dull, possibly ridged. Sides may be pulled in. Hinged.

Figure 6-11 (Hertzberg)

Selecting Transition Temperature

- $T_1$: Conservative, above $T_1$ fracture is 100% fibrous. Fracture Transition Plastic (FTP) - very demanding.
- $T_2$: 50% cleavage - 50% ductile Fracture Appearance Trans. Temp. (FATT).
- $T_3$: Average of upper and lower shelf values. (often approx = $T_2$)
- $T_4$: Arbitrary value of energy absorbed, (CVN) e.g. 20 J (15 ft.lb) for low strength ship steel. Ductility Transition Temp.
- $T_5$: 100% cleavage fracture. Nil Ductility Temperature (NDT)

Charpy Test

An instrumented Charpy test allows determination of energy required to crack and also energy to crack rather than just total energy for fracture.

Figure 14-6 (Dieter) Load-time history for an instrumented Charpy test.

Austenitic stainless steels, copper, most HCP metals

e.g. low - medium carbon steels

High strength steels, aluminum, titanium
For steels: As %C $\uparrow$, $\sigma_y$ $\uparrow$, $\sigma_{TS}$ $\uparrow$, H $\uparrow$, % El $\downarrow$, CVN $\downarrow$ and $T_T$ $\uparrow$.

- This can be countered by adding Manganese - Mn : C should be 3:1
- Phosphorous increases $T_T$, Oxygen in steel to remove oxygen
- semi-killed (add Si) and
- fully-killed (add Si + Al)

Remember also: as grain size $\downarrow$ toughness $\downarrow$ and $T_T$ $\downarrow$.

Niobium and vanadium added to keep grain size small.

Rolled and forged products may have varying impact behaviour due to grain orientation.

Note that the difference is not as large at lower temperatures.

**Metallurgical Factors Affecting $T_T$**

**Effects of specimen orientation on Charpy transition-temperature curves.**

**Fatigue**

- Occurs under dynamic or fluctuating stresses
  - Examples: bridges, automobiles, aircraft and machine components
  - Failure can occur at static loading
  - Accumulated damage (cracking) occurs over a long period of time $\rightarrow$ catastrophic failure
  - 90% of metal failures due to mechanical causes occur in fatigue!
  - Also occurs in ceramics, polymers and composites
  - Appears as brittle-like failure even in ductile materials
  - Usually breaks without warning; no or very little, observable plastic deformation (some micro-deformation).

Fatigue consists of two stages:
- Crack Initiation
- Crack Propagation

**Cyclic Stresses**

- Applied stress:
  - axial (compression-tension)
  - flexural (bending)
  - torsional (twisting)

- Reversed stress cycle is where the sinusoidal stress is of equal amplitude about a mean of zero
  - $\sigma_{max}$ is tensile and $\sigma_{min}$ is compressive

- Repeated stress occurs when $\sigma_{max}$ and $\sigma_{min}$ are about $\sigma = 0$

- Random stress often occurs in engineering and is less easy to quantify
Cyclic Stresses

- Mean stress, $\sigma_m$ is defined as:

$$\sigma_m = \frac{\sigma_{\text{max}} + \sigma_{\text{min}}}{2}$$

- Range of stresses ($\sigma_r$) is the difference between $\sigma_{\text{max}}$ and $\sigma_{\text{min}}$:

$$\sigma_r = \sigma_{\text{max}} - \sigma_{\text{min}}$$

- Stress amplitude, $\sigma_a$:

$$\sigma_a = \frac{\sigma_r}{2} = \frac{\sigma_{\text{max}} - \sigma_{\text{min}}}{2}$$

- Ratio of max. and min. stress is the stress ratio, $R$:

$$R = \frac{\sigma_{\text{min}}}{\sigma_{\text{max}}}$$

Fatigue Testing and S-N Curves

- Laboratory simulation using rotating beam test.
- It creates a reverse cycle bending with rotation (compression/tension).
- Apply a stress of $\sigma_{\text{max}} \approx 2/3 \sigma_{\text{TS}}$.
- Measure number of cycles (N) to failure.
- Repeat using progressively lower $\sigma_{\text{max}}$ (S).
- Plot S vs. log N → S-N curve.

Fatigue Testing and S-N Curves

- Two types of S-N curve
  1. Fatigue (endurance) limit for ferrous and titanium alloys
     - FL = 0.35 - 0.6 $\sigma_{\text{TS}}$ (typically)
  2. No fatigue limit with alloys (Al, Mg and Cu)
     - Need to define a fatigue strength at a specified number of cycles ($10^7$)
     - Fatigue life ($N_f$) is the number of cycles at a specified stress level ($S_f$)

Statistical Nature of Fatigue

- The data on S-N curves are scattered due to material variability and test parameters are difficult to control.
- Fatigue strengths are usually average values.
- Probability of failure (P) defined, e.g. at 215MPa 1% of samples fail at $10^6$ cycles.
- Since, this type of curves shows the statistical nature of fatigue failure at certain stress level, it is more accurate than “average” value as is normally shown.
Types of Fatigue

Low cycle fatigue
- high loads \( \rightarrow \) \( N_f \) (10^4-10^5 cycles)
- high stress environment with high design stress and small safety factor, \( \Delta S \approx \sigma_{ys} \)
- scheduled inspection and maintenance of parts (aircraft)
- most common cause of fatigue cracking and failure

High cycle fatigue
- low loads \( \rightarrow \) \( N_f \) (>10^5)
- typically involves low design stresses, \( \Delta S \ll \sigma_{ys} \)
- less common cause of failure, results from poor design or environmental effects

Low-Cycle Fatigue

Coffin-Manson (1950's) relation: 
\[
\frac{\Delta \varepsilon_p}{2} = \varepsilon_f' \left(2N\right)^C
\]
where \( \Delta \varepsilon_p/2 \) = plastic strain amplitude
\( \varepsilon_f' \) = fatigue ductility coefficient \( \approx \) true strain at fracture, \( \varepsilon_f \)
\( C \) = fatigue ductility exponent
(-0.5 to -0.7 for most metals; lower \( C \) value = longer life)

- Stress is high enough for plastic deformation to take place
- Strain is more representative than stress in this case

Next time:
Continue Fatigue