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:

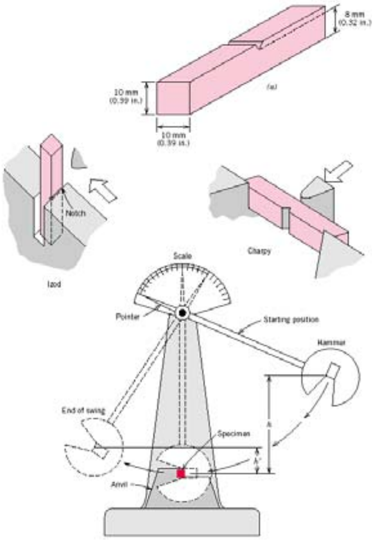
- Triaxial stress state (at notches, cracks etc)
- Low temperatures
- High strain or loading rates

Impact testing is used for:

- ✓ checking quality
- ✓ tendency for brittle failure
- ✓ temperature dependence.

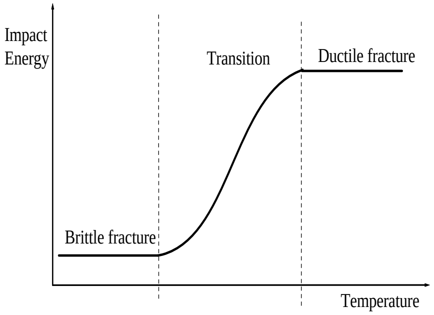
Charpy Test

- 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 ………………

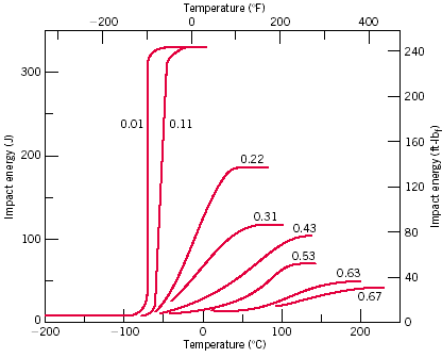


Al and Cu have FCC structure

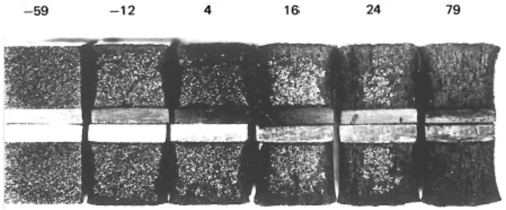
Ductile to Brittle Transition Behavior

- Actual DBT is ………. 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.

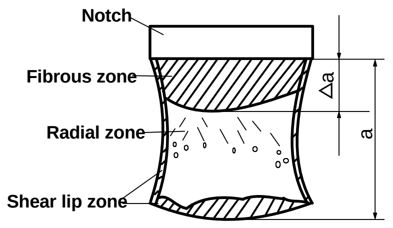
Figure 6-11 *(Hertzberg)*

Ductile to Brittle Transition Behavior

✓ Like tensile specimen, the fractured surface of an impact specimen also contains fibrous, radial (*granular and shiny zone*) and shear lip zones.

✓ Fibrous zones occur during the process of crack propagation in ……… materials.

✓ The proportions of fibrous zone, radial zone and shear lip zone vary with temp. resulting in different test results.



A sketch of the appearance of fractured surface of impact specimen after Charpy test

➢ When temp. drops to a certain value, the area of the fibrous zone ……….. and the area of granular zone ………… sharply. ➔ The fracture behavior of the material transforms from ductile to brittle.

➢ DBT temp is usually determined as the area of crystallization zone accounts for 50% of the whole fractured surface (*i.e. as the temp. at which the failure surface is 50% shiny*), and it is denoted by $FATT_{50}$ (Fracture Appearance Transition Temp.)

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)

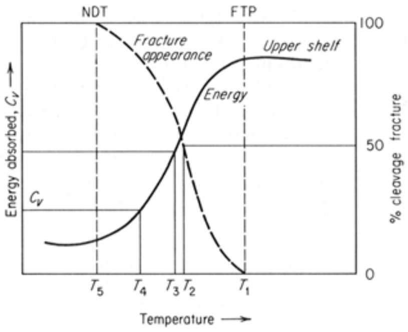


Figure 14-6. Various criteria of transition-temperature obtained from Charpy tests

The **lower** this temperature, the **greater** the fracture toughness

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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.

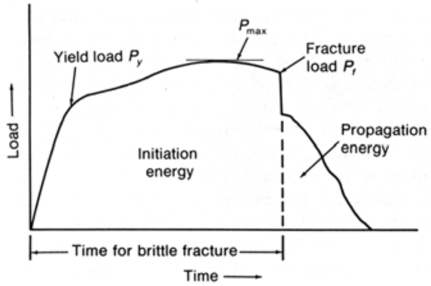
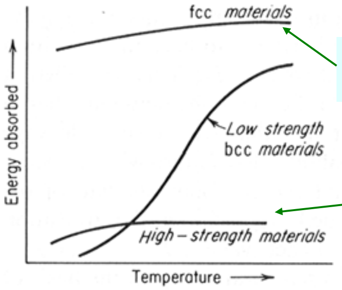


Figure 14-4 *(Dieter)* Load-time history for an instrumented Charpy test.



Austenitic stainless steels, copper, most HCP metals

e.g. low - medium carbon steels

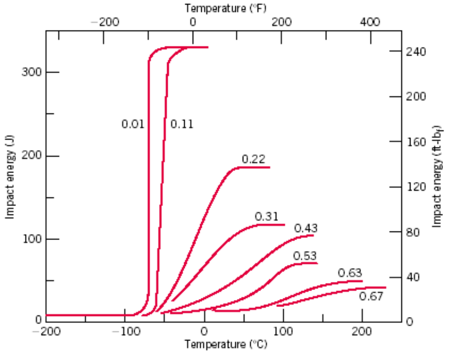
High strength steels, aluminum, titanium

Metallurgical Factors Affecting T_T

- For steels: As %C↑ ⇒ σ_y↑, σ_{TS}↑, H↑, % El↓, CVN↓ and **T_T↑**

- *This can be countered by adding Manganese - Mn : C should be 3:1*

- Phosphorous increases T_T, Oxygen in steel ………. T_T:
  - *semi-killed (add Si) and*
  - *fully-killed (add Si +Al) to remove oxygen*



Remember also: as grain size ↓ toughness ………. and T_T↓. *Niobium* and *vanadium* added to keep grain size small.

Metallurgical Factors Affecting T_T

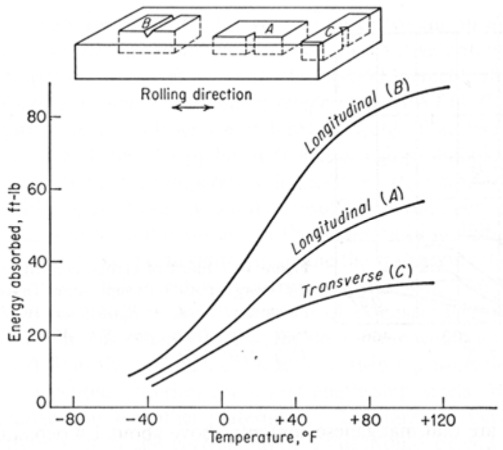
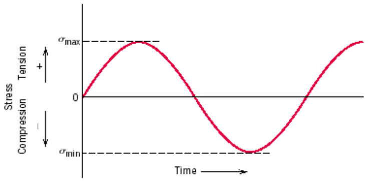


***Figure 14-8 (Deiter)** Effect of specimen orientation on Charpy transition-temperature curves.*

- Rolled and forged products may have varying impact behaviour due to grain orientation.
- Note that the difference is not as large at lower temperatures.

Fatigue

- Occurs under *dynamic or fluctuating* stresses
- Examples: bridges, automobiles, aircraft and machine components
- Failure can occur at …………… stress than under *static loading*
- Accumulated damage (cracking) occurs over a long period of time → *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*).



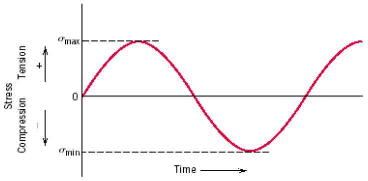
Fatigue consists of two stages:

- Crack Initiation

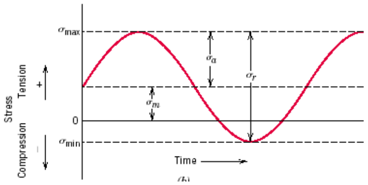
- Crack Propagation

Cyclic Stresses

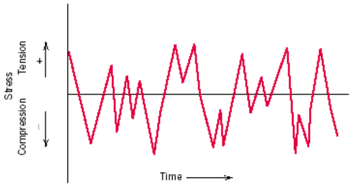
- Applied stress:
  - axial (compression-tension)
  - flexural (bending)
  - torsional (twisting)



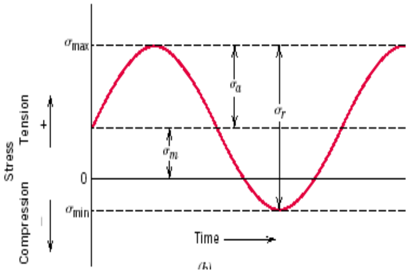
- *Reversed stress cycle* is where the sinusoidal stress is of equal amplitude ➔ about a mean of zero
  - σ_{max} is tensile and σ_{min} is compressive



- *Repeated stress* occurs when σ_{max} and σ_{min} are ……………… about σ = 0
- *Random stress* often occurs in engineering and is less easy to quantify



Cyclic Stresses



- Mean stress, σ_m is defined as:

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

- *Range of stresses* (σ_r) is the difference between σ_{max} and σ_{min}:

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

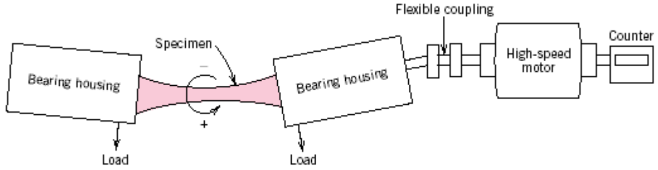
- *Stress amplitude*, σ_a:

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

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

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

Fatigue Testing and S-N Curves



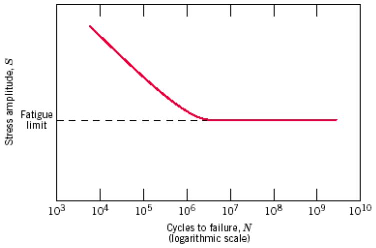
- Laboratory simulation using *rotating beam test*.
- It creates a reverse cycle bending with rotation (compression/tension)
- Apply a stress of $\sigma_{max} \sim 2/3\ \sigma_{TS}$
- Measure number of cycles (N) to failure
- Repeat using progressively *lower* σ_{max} (S)
- Plot S vs. log N → S-N curve

Fatigue Testing and S-N Curves

Two types of S-N curve

1. *Fatigue (endurance) limit* for ferrous and titanium alloys

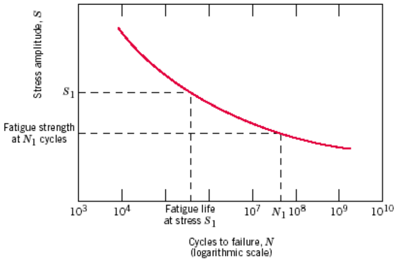
- FL = 0.35 - 0.6 σ_{TS} (*typical*ly)



2. *No fatigue limit* with ……………. alloys (Al, Mg and Cu)

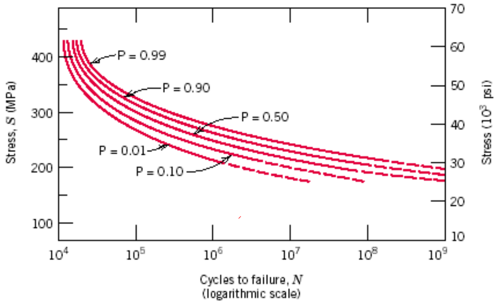
→ Need to define a fatigue strength at a specified number of cycles (10^7)

→ *Fatigue life* (N_f) is the number of cycles at a specified stress level (S_1)



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 ……………… **of fatigue** failure at certain stress level, it is more accurate than "average" value as is normally shown.

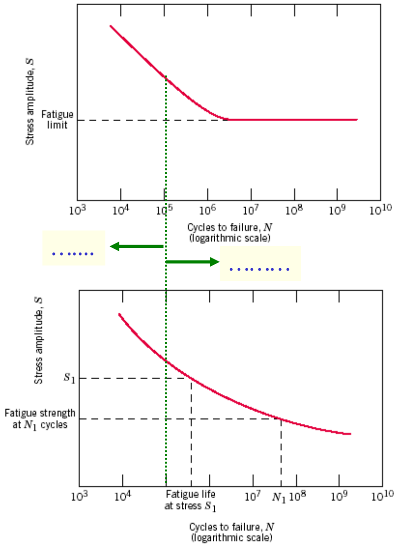
Types of Fatigue

Low cycle fatigue

- high loads → ……. N_f (10^4-10^5 cycles)
- high stress environment with high design stress and small safety factor, DS ≈ σ_{ys}
- scheduled inspection and maintenance of parts (aircraft)
- most common cause of fatigue cracking and failure

High cycle fatigue

- low loads → ……. N_f (>10^5)
- typically involves low design stresses, DS << σ_{ys}
- less common cause of failure, results from poor design or environmental effects



Low-Cycle Fatigue

- This type of cycling is more likely in nuclear pressure-vessels, steam turbines, and similar components where repeated stresses are created by thermal fluctuations.

- e.g if material is constrained and then heated, thermal stresses are generated; if it is not constrained we have cyclic thermal strains (i.e. heating and cooling of vessels).

  - *Fatigue results from cyclic ……..:* this is induced by the restraint of the dimensional expansion and/or contraction occurring due to varying the temperature.

Low-Cycle Fatigue

Coffin-Manson (1950's) relation: $$\frac{\Delta\varepsilon_p}{2} = \varepsilon_f'(2N)^C$$

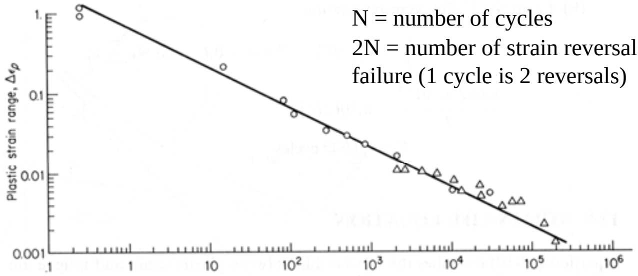
where $\Delta\varepsilon_p/2$ = plastic strain amplitude

ε_f'= fatigue ductility coefficient ≈ true strain at fracture, ε_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



N = number of cycles
2N = number of strain reversals to failure (1 cycle is 2 reversals)

Also see Hertzberg Figure 9-40

Figure 12-13 Low-cycle fatigue curve ($\Delta\varepsilon_p$ vs. N) for Type 347 stainless steel. *(From L. F. Coffin,*

Next time:

Continue Fatigue