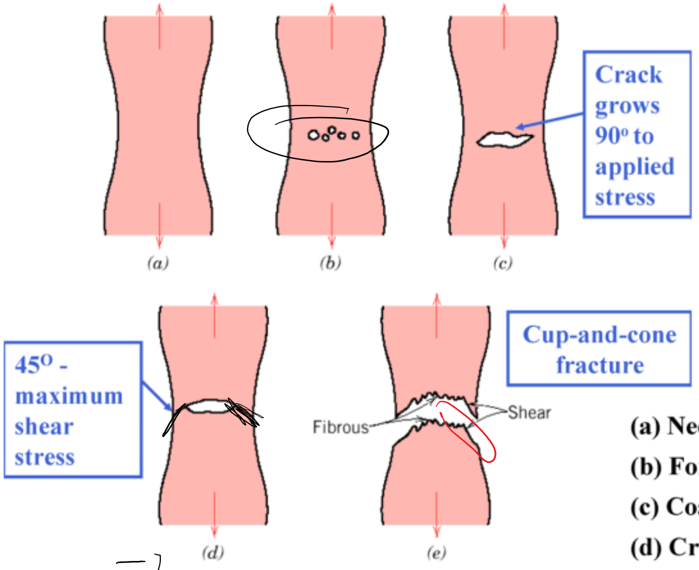
2020/08/24

Monday, August 24, 2020 1:48 PM



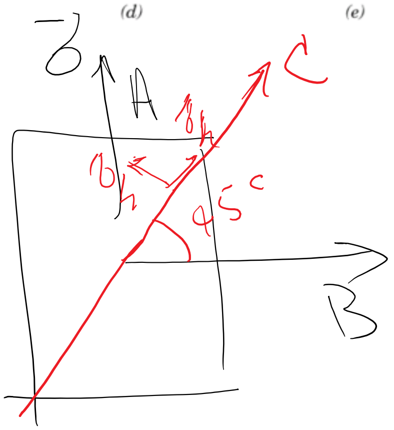
(a) Necking

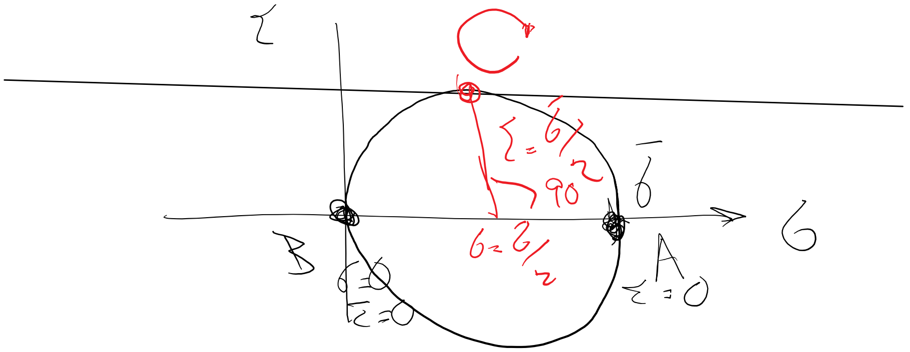
(b) Formation of microvoids

(c) Coalescence of microvoids to form a crack

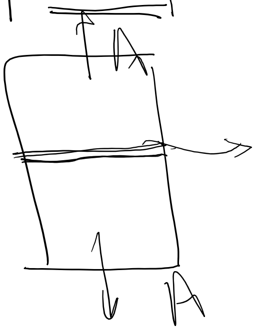
(d) Crack propagation by shear deformation

(e) Fracture



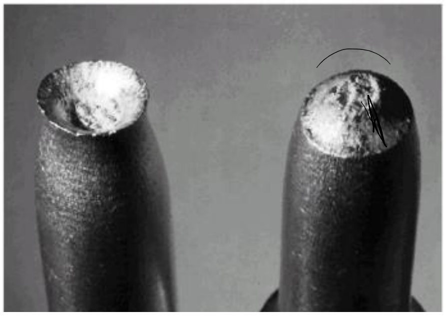


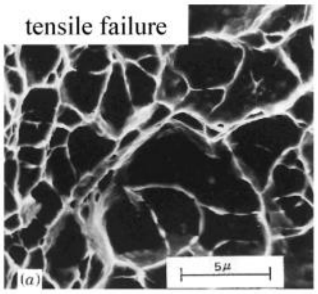
Brittle tensile fracture

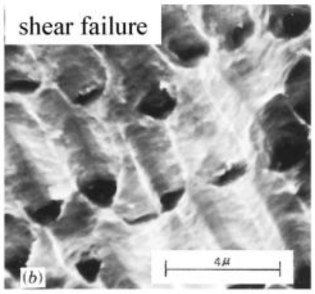


relatively smooth (maximum tensile stress

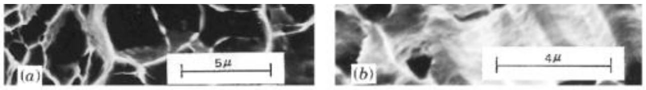
Ductile Fracture





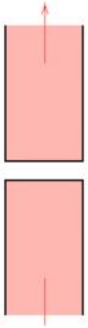


(Cup-and-cone fracture in Al)

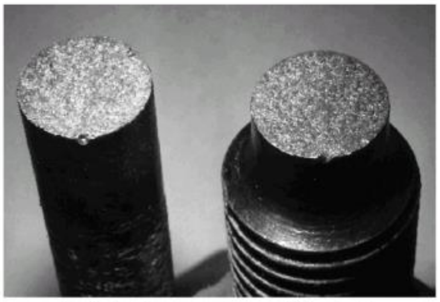


Scanning Electron Microscopy: *Fractographic* studies at high resolution. Spherical "dimples" correspond to microvoids that initiate crack formation.

Brittle Fracture (Limited Dislocation Mobility)



- No appreciable plastic deformation
- Crack propagation is very fast
- Crack propagates nearly perpendicular to the direction of the applied stress
- Crack often propagates by cleavage - breaking of atomic bonds along specific crystallographic planes (cleavage planes).



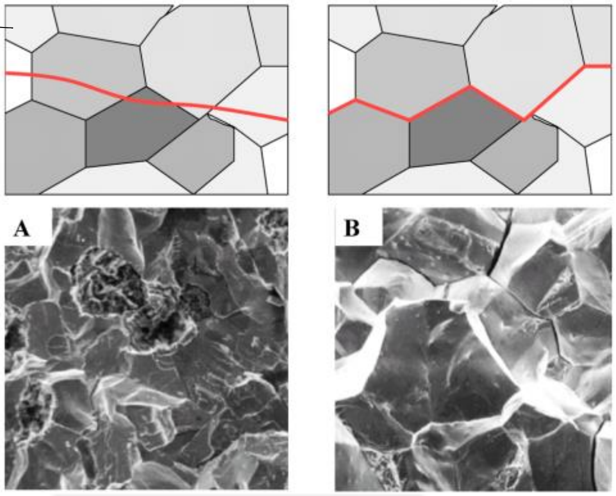
Brittle fracture in a mild steel

Brittle Fracture

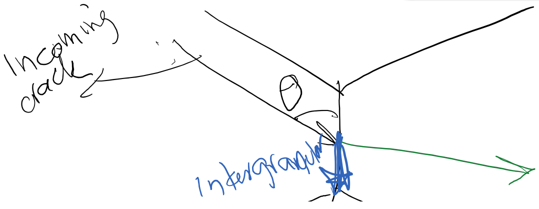
A. Transgranular fracture: Fracture cracks pass through grains. Fracture surface have faceted texture because of different orientation of cleavage planes in grains.

B. Intergranular fracture: Fracture crack propagation is along grain boundaries (grain boundaries are weakened or embrittled by impurities segregation etc.)

trans-granular
Intra-granular

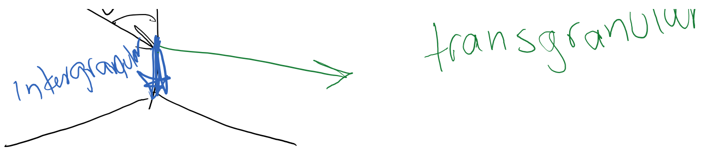


Intergranular fracture



transgranular

θ → 0
weaker-interface }



weaker-interface →
favor intergranular

Contrast in bulk elastic properties also impact this.

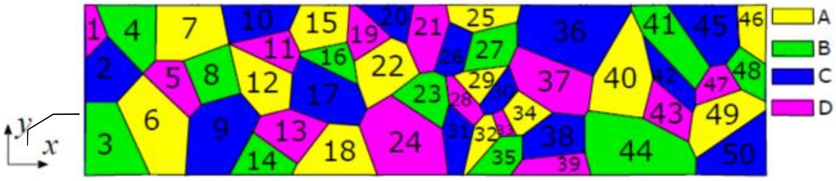
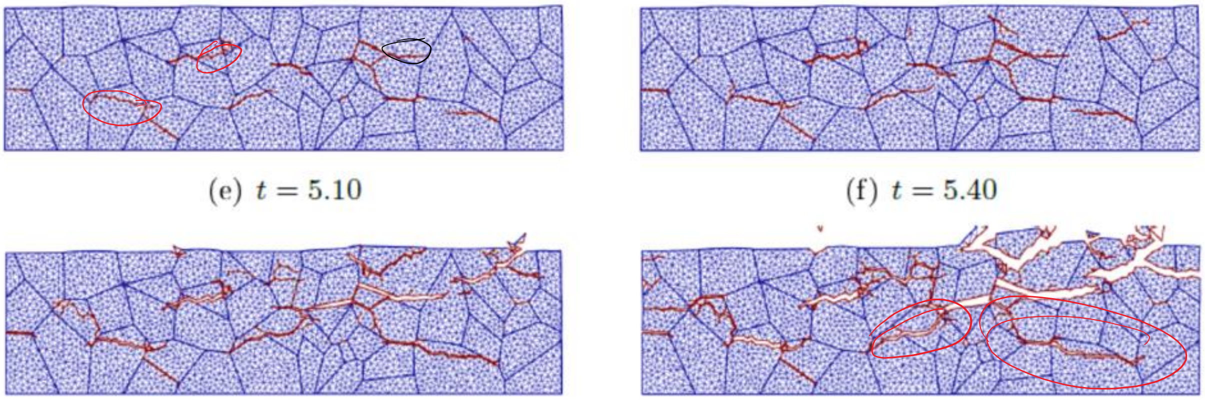


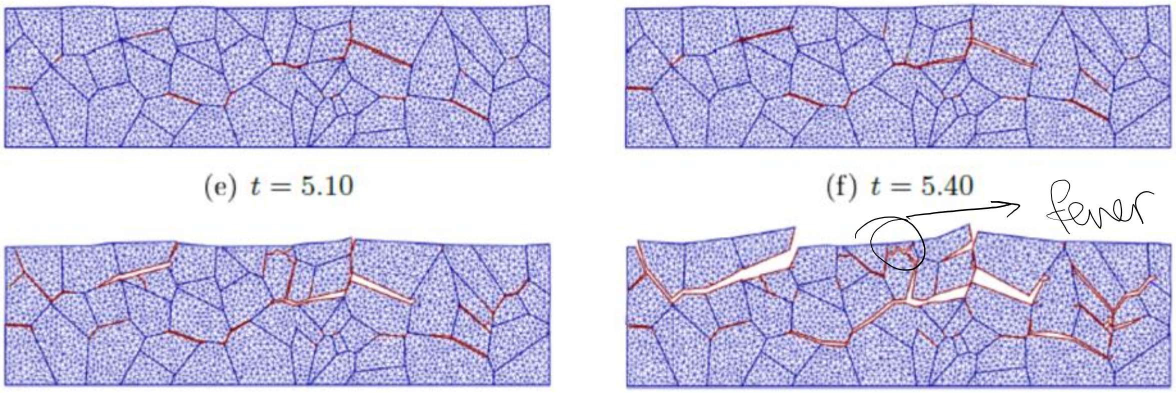
FIGURE 13. The location of 50 grains of materials A, B, C, D in a square domain.



(e) $t = 5.10$ (f) $t = 5.40$

(g) $t = 5.85$ (h) $t = 6.45$

stronger interface



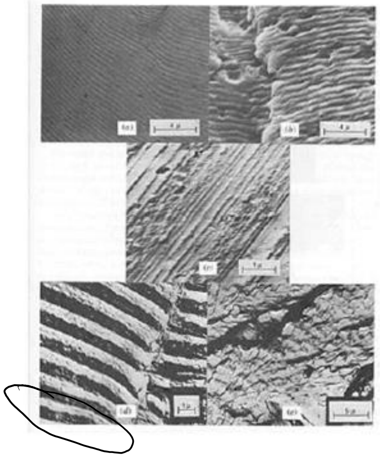
(e) $t = 5.10$ (f) $t = 5.40$

(g) $t = 5.85$ (h) $t = 6.45$

fewer transgranular facture

weaker interface

Fatigue

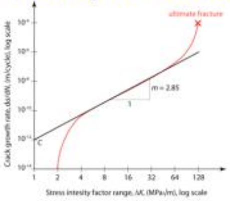


intra-granulair
(or transgranular)
split atom bonds

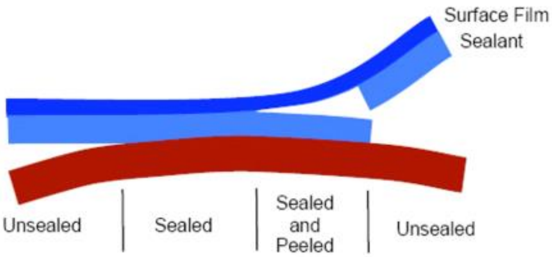
inter-granulair
between grain boundaries

- Cracks grow a very short distance every time

Clam shell structures mark the location of crack tip after each individual cyclic loading



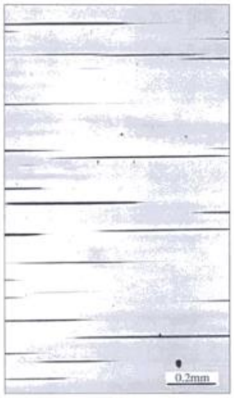
Delamination (De-adhesion)

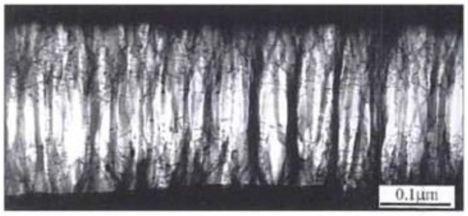


Crazing

- Common for polymers
- sub-micormeter voids initiate

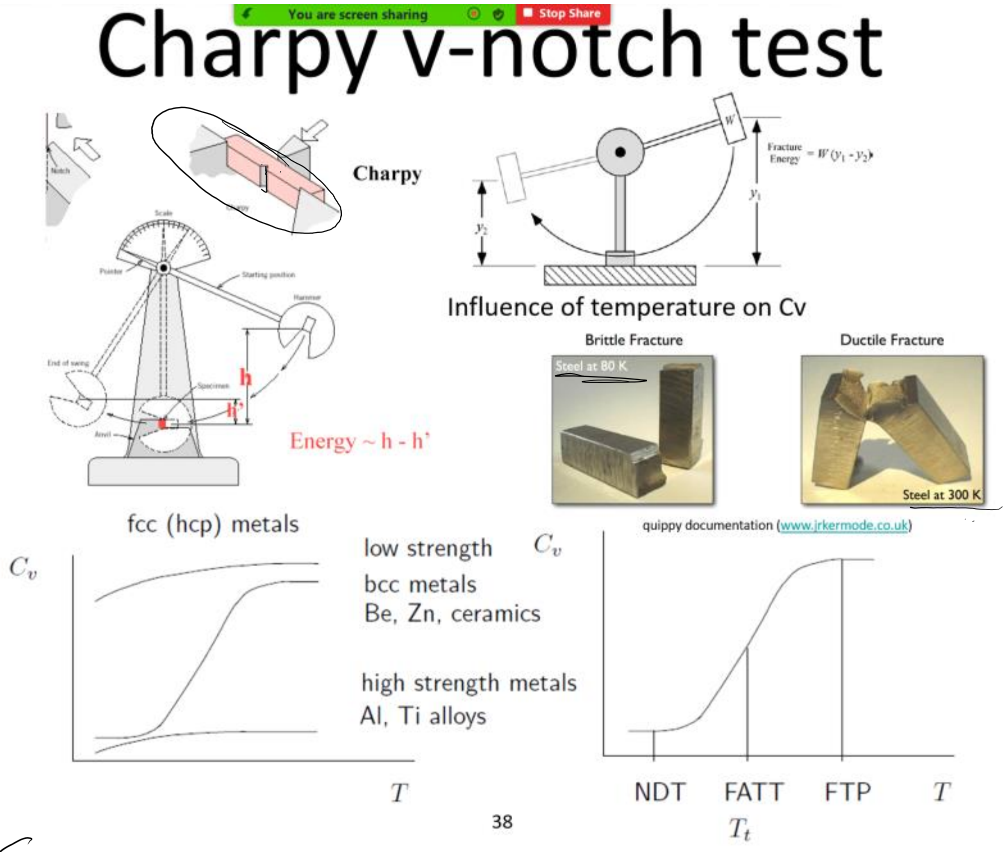
stress whitening because of light reflection from crazes





Ductile-to-brittle transition

Low temperatures can severely embrittle steels. The Liberty ships, produced in great numbers during the WWII were the first all-welded ships. A significant number of ships failed by catastrophic fracture. Fatigue cracks nucleated at the corners of square hatches and propagated rapidly by brittle fracture.



Charpy v-notch test

Energy ~ h - h'

Influence of temperature on Cv

quippy documentation (www.jrkermode.co.uk)

fcc (hcp) metals

low strength

bcc metals

Be, Zn, ceramics

high strength metals

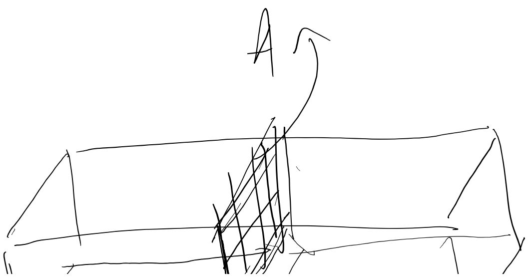
Al, Ti alloys

38

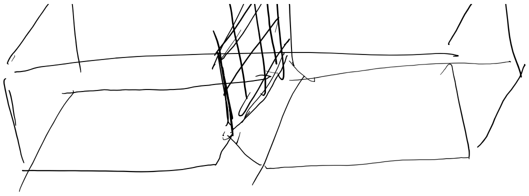
$\mathcal{E}$ = energy lost for the hammer = $m\Delta h = m(h-h')$

$\simeq$ energy for breaking charpy

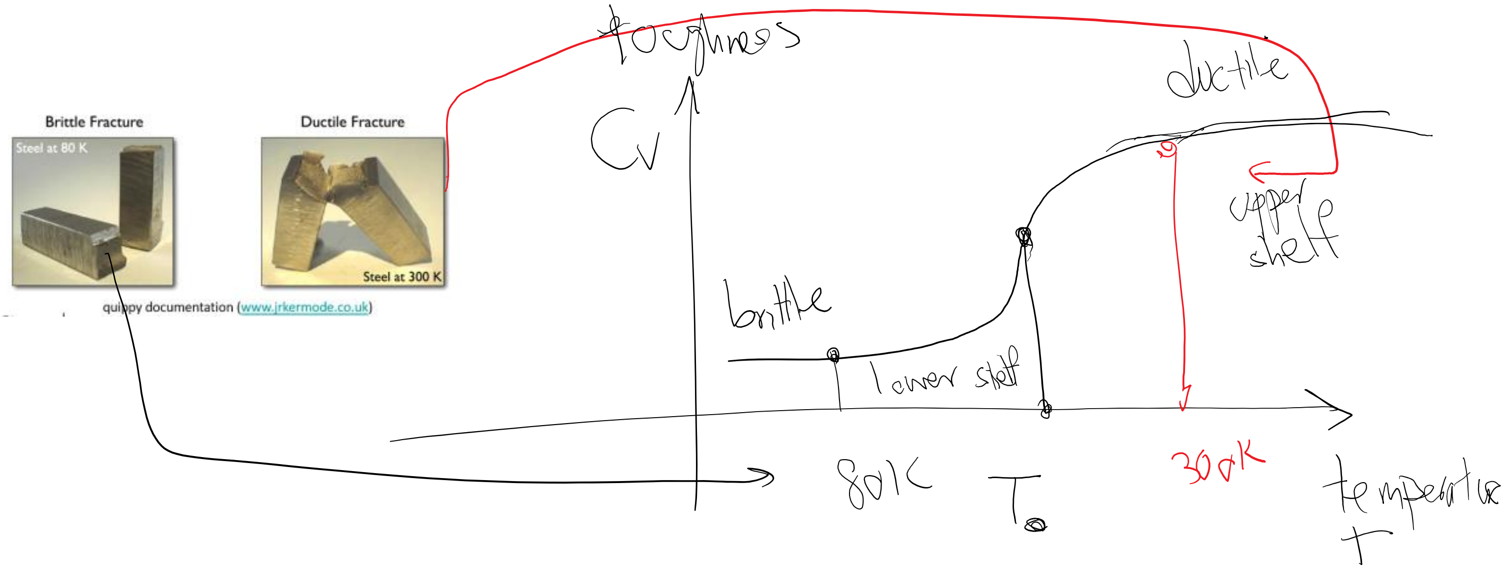
$\Gamma = \frac{\mathcal{E}}{\quad} =$ energy per unit area



$C_v = \frac{E}{A}$ = energy per unit area to break this material



charpy test <u>toghness</u>



Ductile to brittle transition temperature (DBTT)

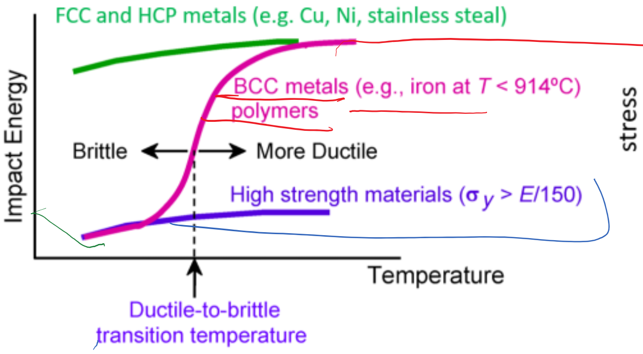
1. Temperature Effects

Temperature decrease => Ductile material can become brittle

BCC metals: Limited dislocation slip systems at low T =>
Impact energy drops suddenly over a relatively narrow temperature range around DBTT.

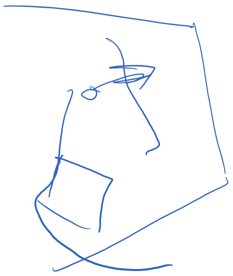
- Ductile to brittle transition temperature (DBTT) or
- Nil ductility transition temperature (T_0)

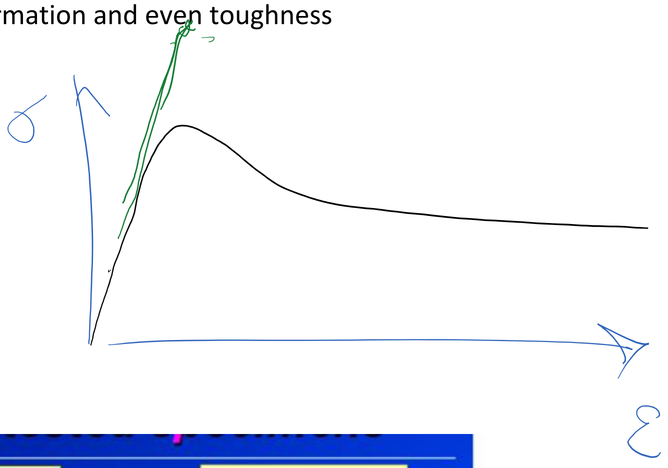
FCC and HCP metals remain ductile down to very low temperatures
Ceramics, the transition occurs at much higher temperatures than for metals

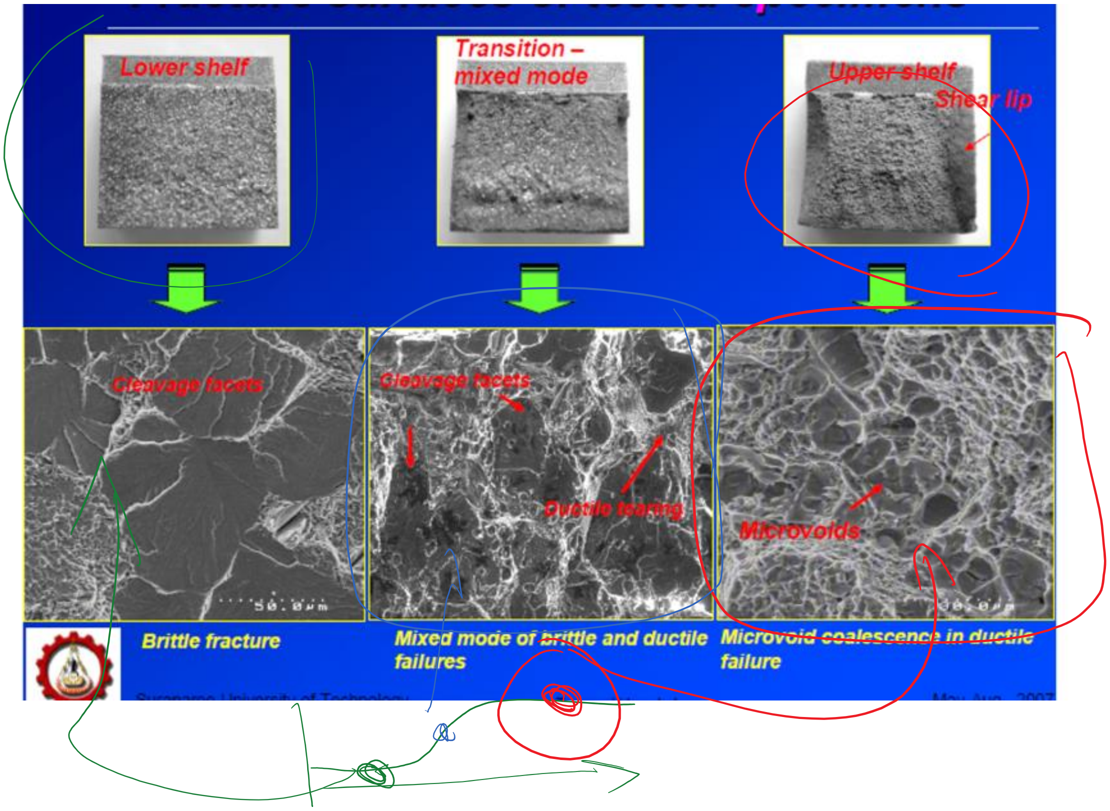


Steel from example above
"Temperature sensitive materials"

- Generally there is a competition between strength and toughness.
- This makes it difficult to have materials that are both tough and high strength (that is improving both at the same time …)
- Reason: When we inhibit dislocation motion, that will increase the strength of the material but adversely decreases its potential for plastic deformation and even toughness






Lower shelf

Transition – mixed mode

Upper shelf

Shear lip

Cleavage facets

Cleavage facets

Ductile tearing

Microvoids

Brittle fracture

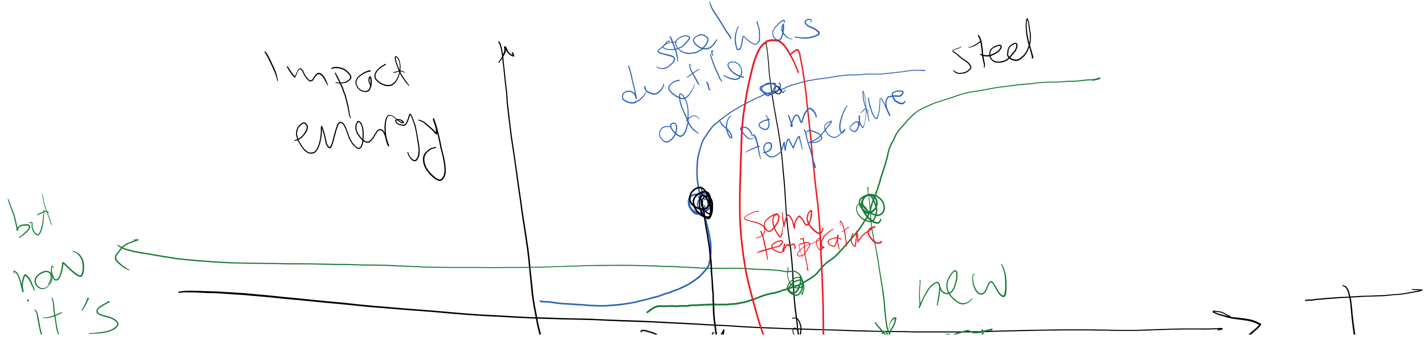
Mixed mode of brittle and ductile failures

Microvoid coalescence in ductile failure

Suranaree University of Technology

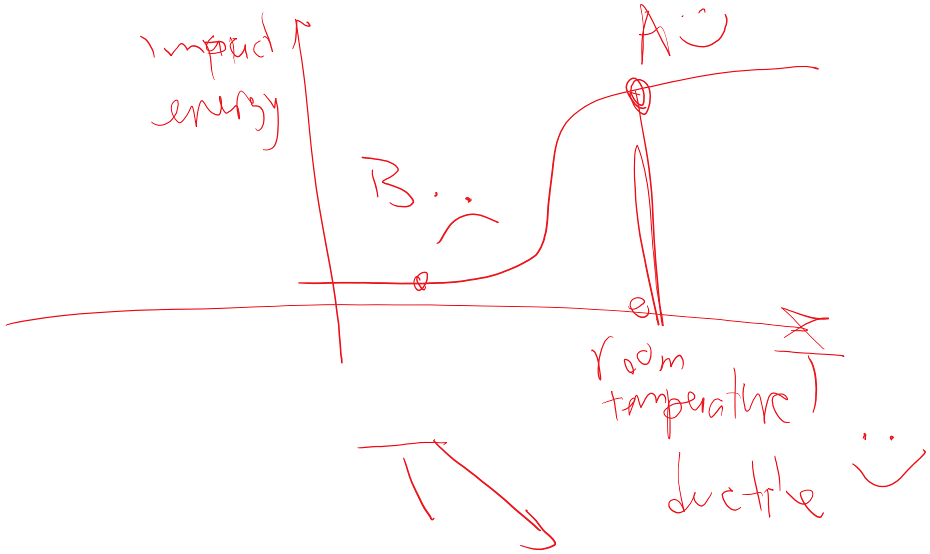
May-Aug 2007

- We observed that for some materials temperature can significantly change impact energy.
- Any process that changes DBTT also indirectly changes material response between ductile and brittle.



T_0 / DBTT ↗

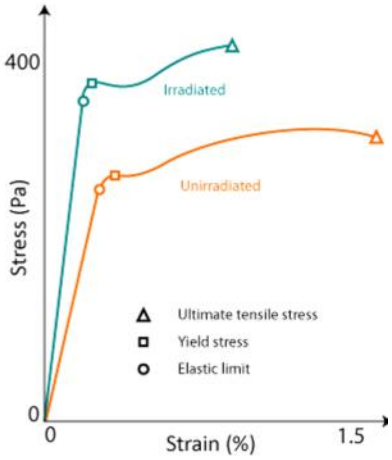
material becomes more brittle



FOR temperature sensitive materials:

- There can be many factors that shift T0 (DBTT) to higher temperatures.
- This is a bad thing from ductility / toughness perspective as in a wider range of temperatures the material is brittle.

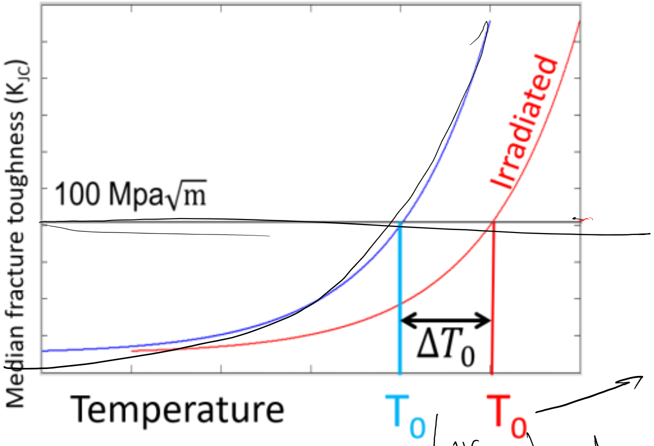
- Radiation is one phenomena that makes the material more brittle and in this process shifts T0 to higher temperature.
- The reason for embrittlement is higher inhibition of dislocation motion by impurities and particulates that are induced by radiation.



Irradiation effect:

1. **Strengthening**
2. **More brittle**

- Energetic particles (such as neutron or fission fragments) => knocking atoms out of natural lattice positions changing material property

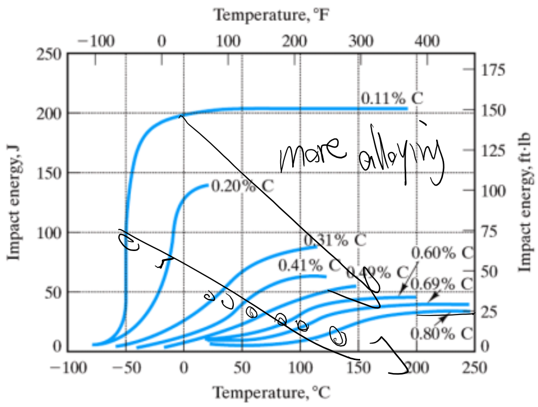


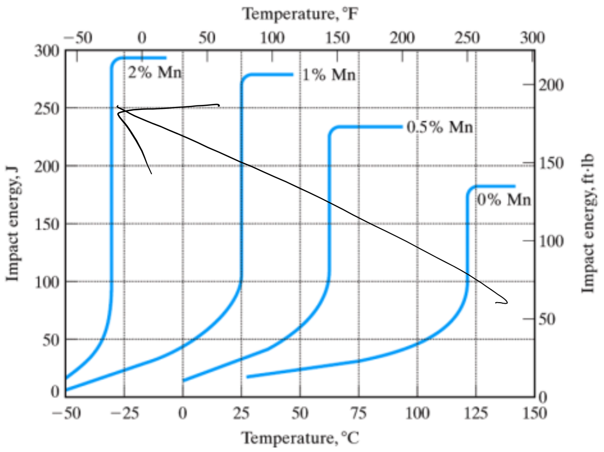
older material

(irradiat~ ..)

2. Impurities and alloying effect on DBTT

- Alloying usually increases DBTT by inhibiting dislocation motion. They ar generally added to increase strength or are (an unwanted) outcome of th processing
- For steal P, S, Si, Mo, O increase DBTT while Ni, Mg decease it.





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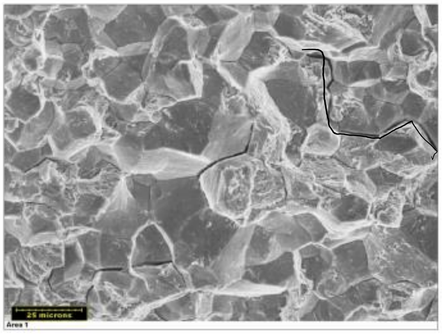
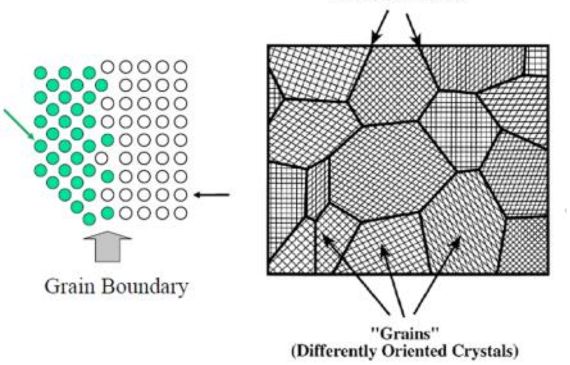
4. Hydrogen embrittlement through DBTT

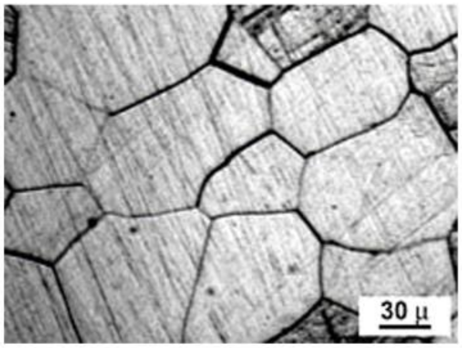
- Hydrogen in alloys drastically reduces ductility in most important alloys:
  - nickel-based alloys and, of course, both ferritic and austenitic steel
  - Steel with an ultimate tensile strength of less than 1000 Mpa is almost insensitive
- A very common mechanism in Environmentally assisted cracking (EAC):
  - High strength steel, aluminum, & titanium alloys in aqueous solutions is usually driven by hydrogen production at the crack tip (i.e., the cathodic reaction)
  - Different from previously thought anodic stress corrosion cracking(SCC)
- Reason (most accepted)
  - Reduces the bond strength between metal atoms => easier fracture.



Grains

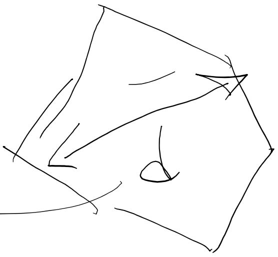
Polycrystalline material:
Composed of many small crystals or grains





We want to understand the effect of grain size on yield strength and toughness

A) Hall-Petch effect: Yield strength as a function of grain size:



ave. grain size

$$\sigma_y = \sigma_0 + \frac{k_y}{\sqrt{d}}$$

material parameters

$d \searrow \qquad \sigma_y \nearrow$

B) Fracture mode

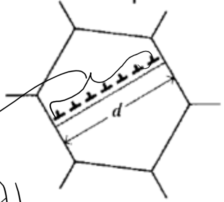
$$\sigma = \frac{K_{Ic}}{\sqrt{a}}$$

fracture toughness

half crack length

we will derive this later

Grain boundary barrier to dislocation motion:
High angle grain boundaries block slip and harden the material

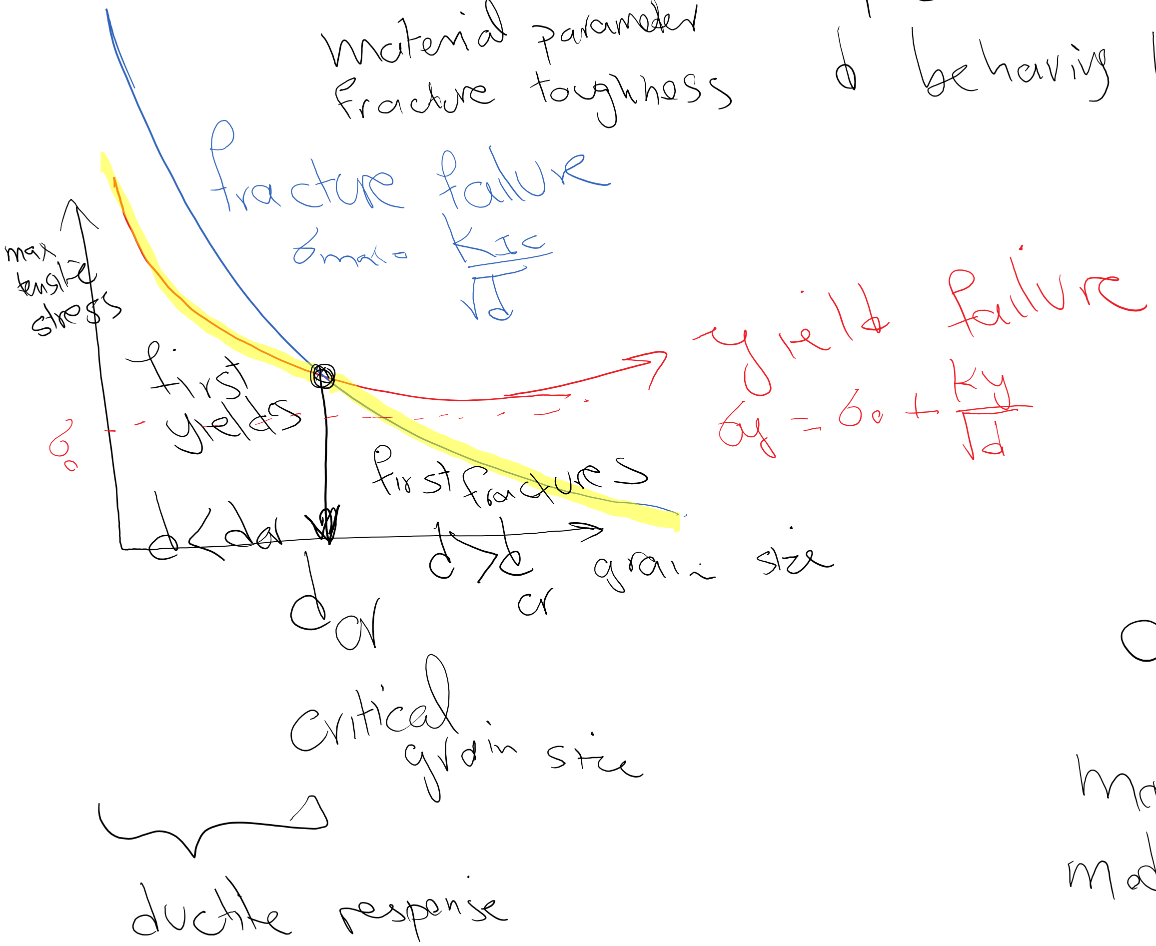


Similar to a crack of length d

$$\boxed{\sigma_{max} = \frac{K_{Ic}}{\sqrt{d}}}$$

maximum stress for a grain by dislocations of length d behaving like a crack

material parameter fracture toughness



d ↓

more ductile mode of failure