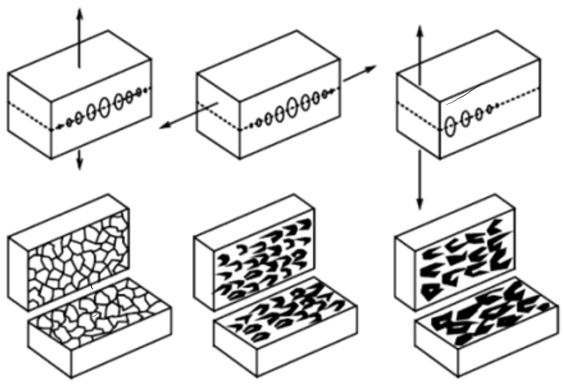
2018/08/27

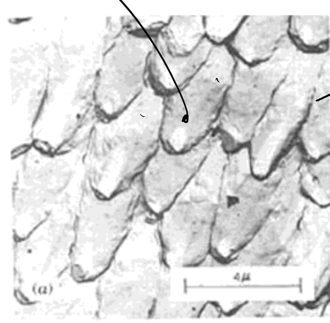
Monday, August 27, 2018 11:25 AM

How does ductile fracture happen?

dislocations pile up against grain boundaries

micro voids are the "seeds" of these conical features





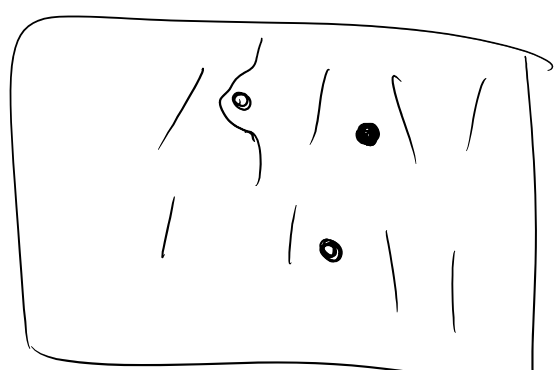
surface of fracture (crack) from ductile fracture

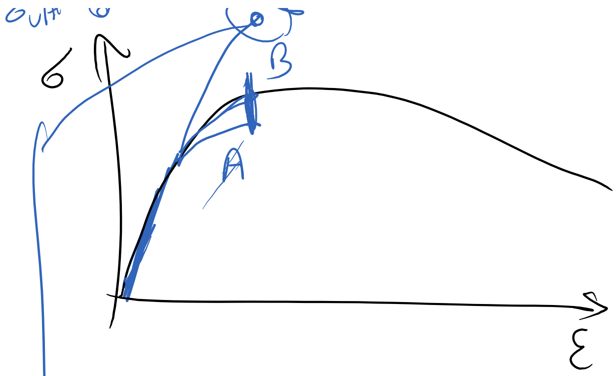
All these processes (dislocation motion, pile-up against grain boundary, microvoid formation, …) contribute to:

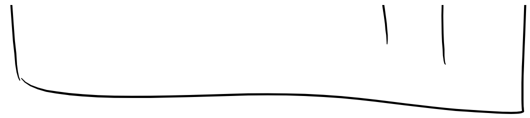
1. Rough fracture surface
2. High fracture energy

A common feature of ductile fracture is ease of motion of dislocations

by inhibiting dislocation motion plastic deformation reduces



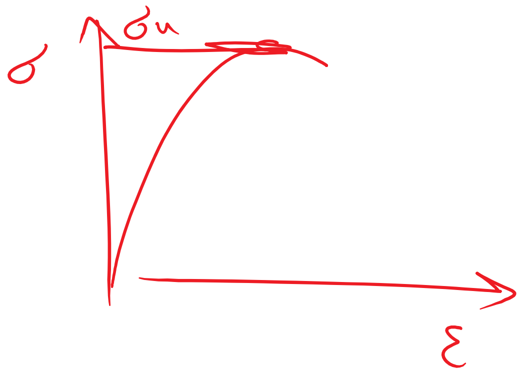


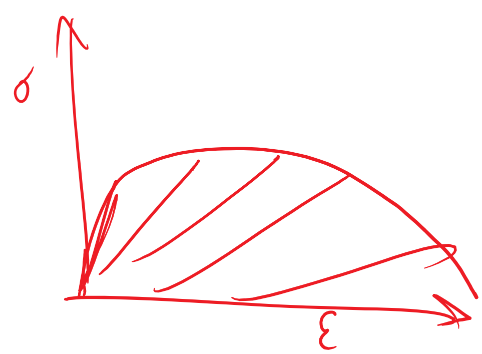


with considerable plastic deformation

↳ by inhibiting dislocations "slip systems" don't easily become activated under high loads → stress can increase further (we take path C in general)

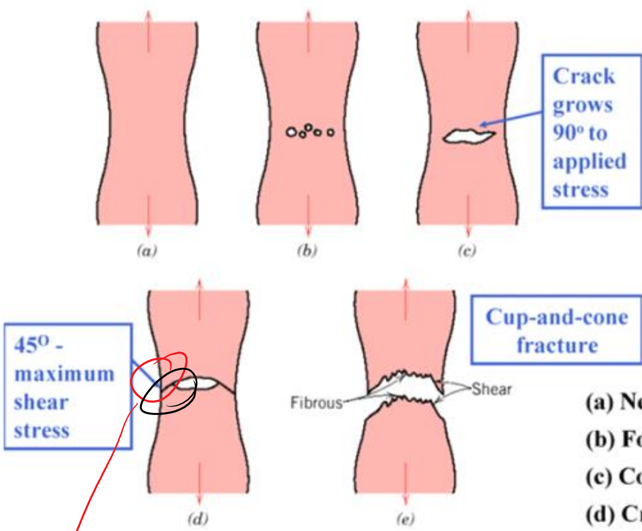
Strength vs toughness





We often gain on one lose on the other by different processes (except one discussed later)

Ductile Fracture (Dislocation Mediated)



(a) Necking

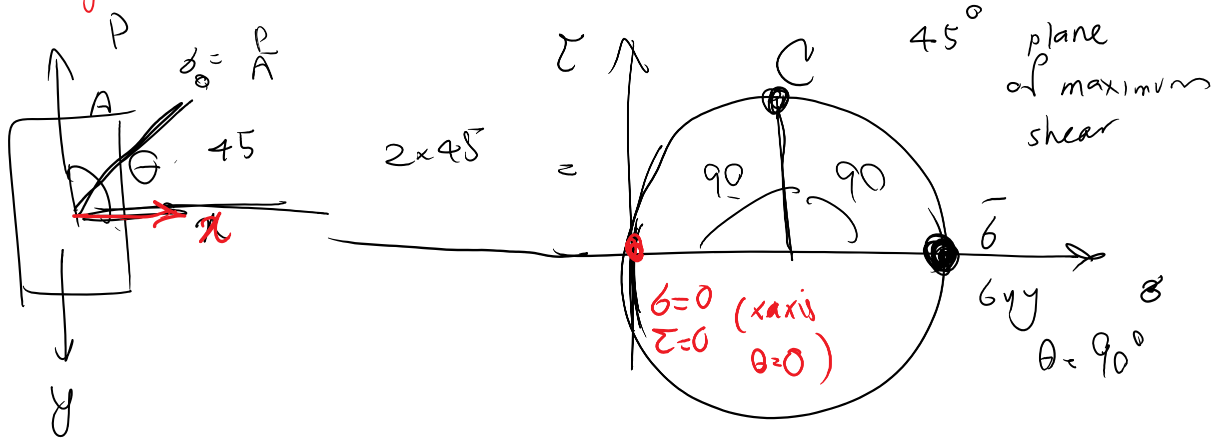
(b) Formation of microvoids

(c) Coalescence of microvoids to form a crack

(d) Crack propagation by shear deformation

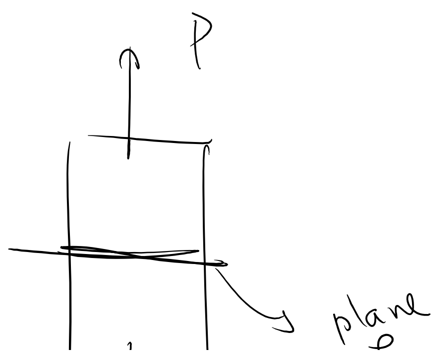
(e) Fracture

→ dislocations are maily activated by shear stress & @ 45° degree we have the maximum shear

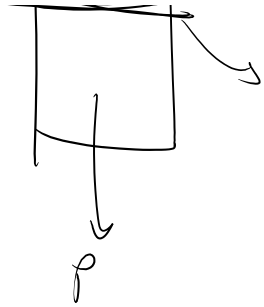


Ductile fracture is shear dominant

Brittle fracture is mostly tensile dominant



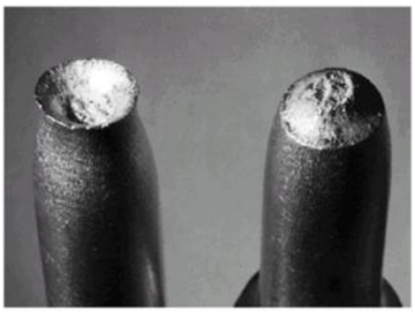
(we expect the specimen



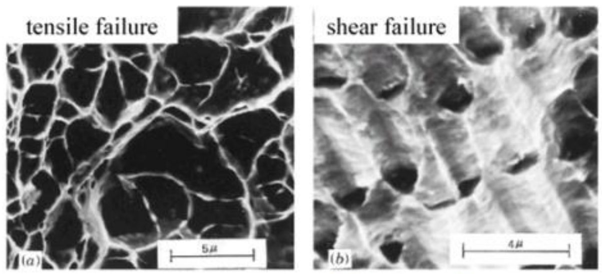
plane of maximum tensile stress

(we expect the specimen to break on this plane if brittle fracture is tensile stress dominant)

Ductile Fracture



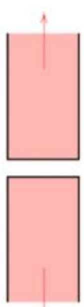
(Cup-and-cone fracture in Al)

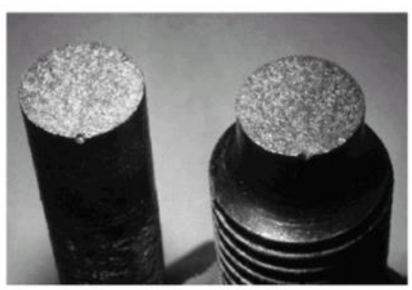


Scanning Electron Microscopy: *Fractographic* studies at high resolution. Spherical "dimples" correspond to microvoids that initiate crack formation.

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).

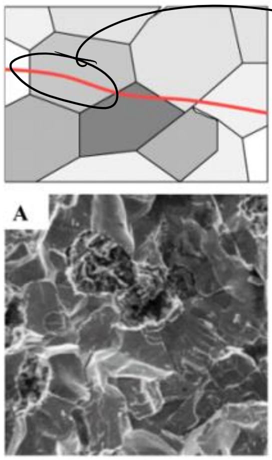


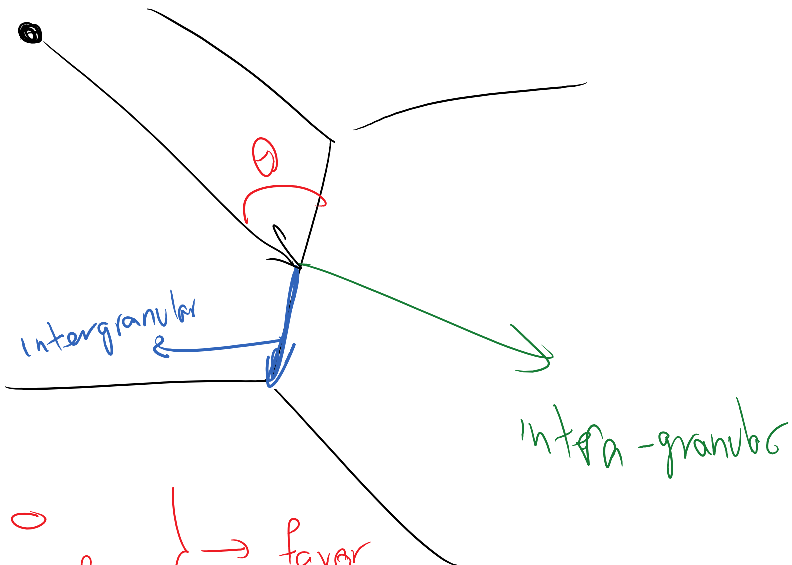


Brittle fracture in a mild steel

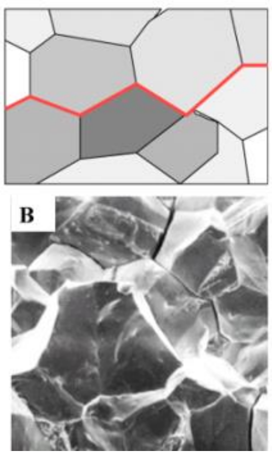
Brittle fracture goes either:

1. Through the grains (intra-granular / trans-granular fracture)





2. Between the grains



θ → 0
weak interface } → favor intergranular

& vice_versa

Contrast in bulk material properties of the grains contribute as well

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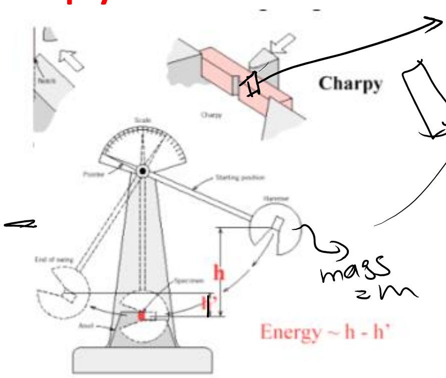
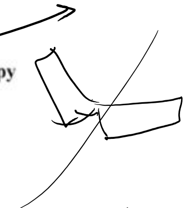
What changes the response of a material from ductile to brittle?

How do measure "toughness" = energy absorption capacity of a material

Charpy v notch test

A effective

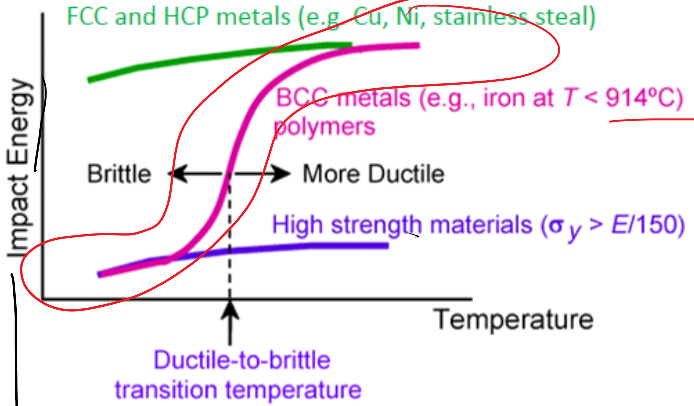




$(h - h')\, mg$ = energy lost

$\frac{\text{energy loss}}{\text{Area}} = \frac{\text{energy}}{\text{area}}$ dissipated by a given material

So we v-notch charpy test we can measure toughness.
Now, what are the factors that change fracture toughness.

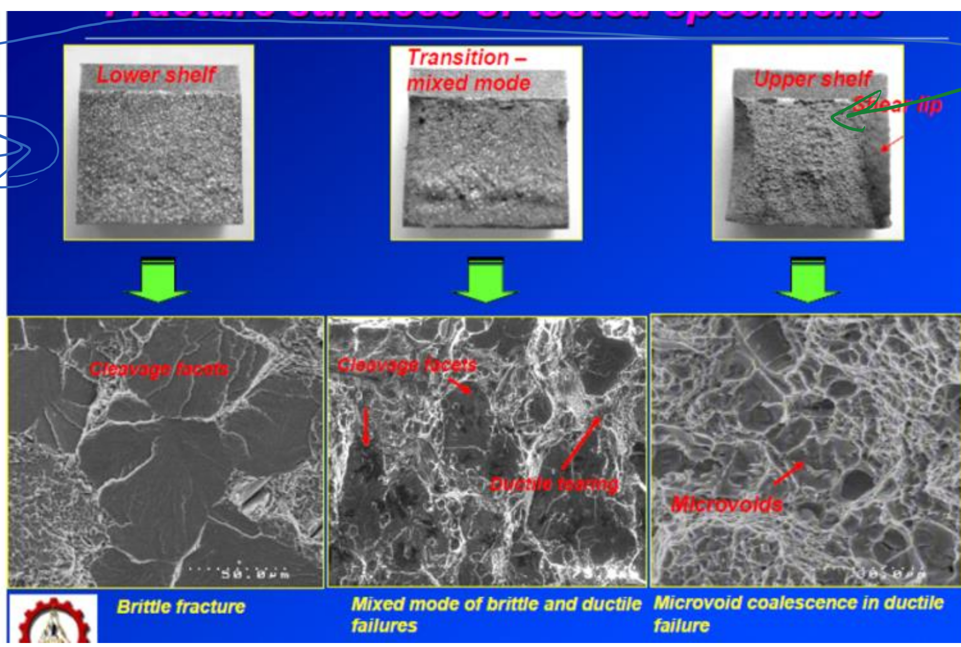


always ductile

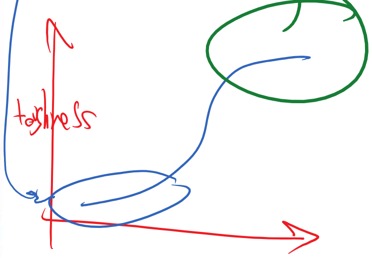
temperature-sensitive material (for f. toughness)

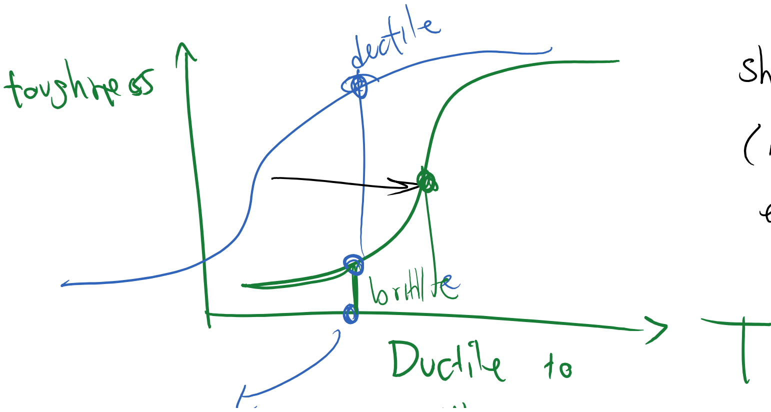
always brittle

measured by charpy test



upper shelf





shifting DBTT → (increasing it) effectively makes the material more brittle

Ductile to Brittle Transition temperature (DBTT) → T more brittle

from temperature

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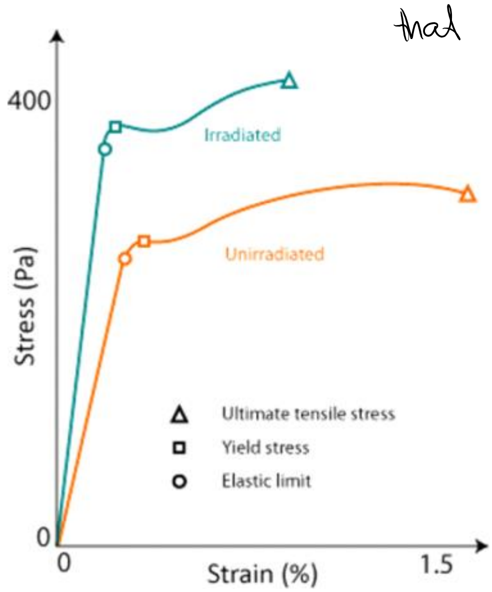
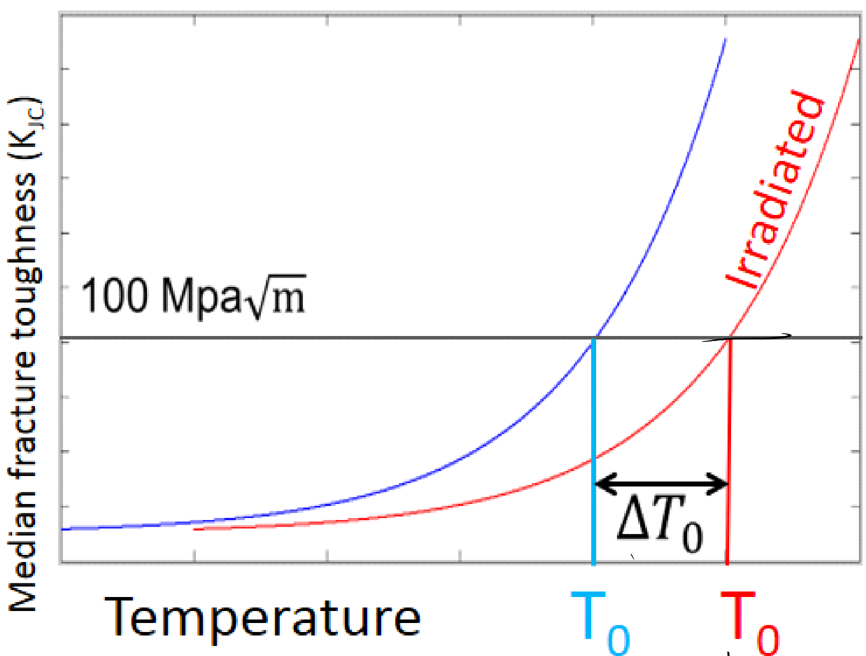
2. Irradiation → creates voids and high stiffness regions that inhibit dislocation motion

→ higher strength, lower toughness



One way to model brittle transition by irradiation is the Wallin Master curve:



↓ higher radiation

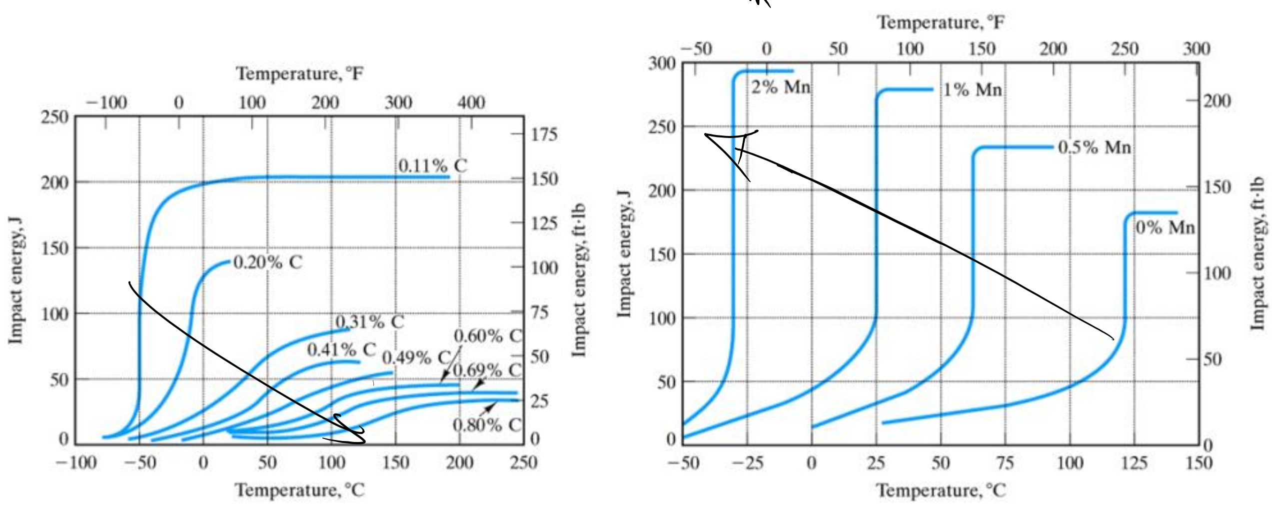
↓ higher radiation

T_0 = function of radiation

2. Impurities and alloying effect on DBTT

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

+Mn



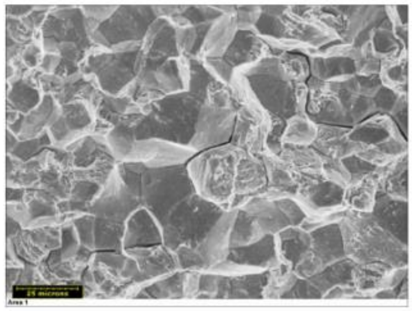
lower max toughness

& T_0 →

both are bad

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.



5. The effect of grain size on ductility

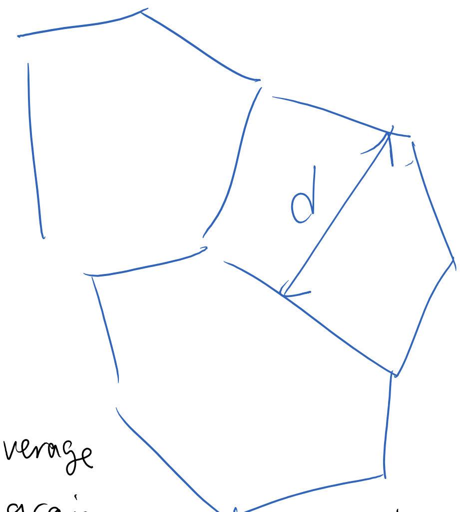
Hall petch effect:

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

σ_y → yield stress

σ_0, k_y → material parameters

d → average grain size



Failure mode 2: Fracture

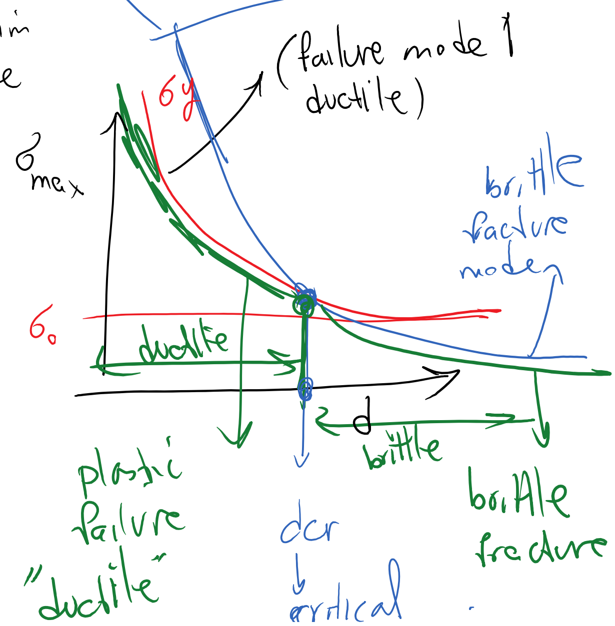
$$\sigma \propto \frac{K}{\sqrt{a}}$$

K → fracture toughness

a → crack length

$$\rightarrow \sigma_{max} = \frac{K_c}{\sqrt{\ }}$$

K_c → material toughness



→ $\sigma_{max} = \frac{K_c'}{\sqrt{d}}$

"ductile" → critical grain size

fracture

the pile up of dislocations effectively "acts" like a crack