2016/08/25

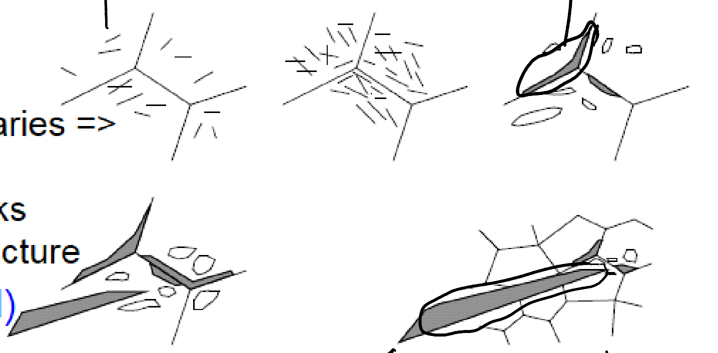
Thursday, August 25, 2016
8:40 AM

Ductile material

Shearing

- Applied stress =>
- Dislocation generation and motion =>
- Dislocations coalesce at grain boundaries =>
- Forming voids =>
- Voids grow to form macroscopic cracks
- Macroscropic crack growth lead to fracture

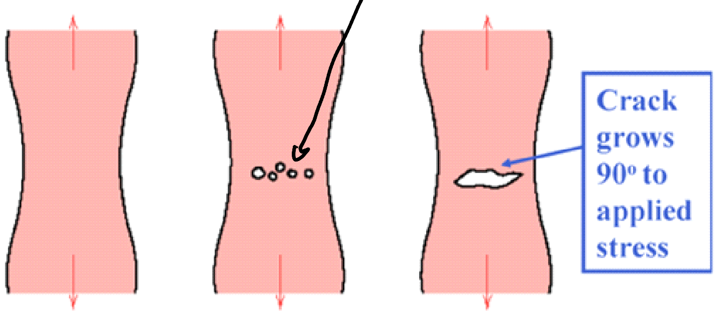
Plastic deformation (ductile material)



dislocation

through collection of dislocations

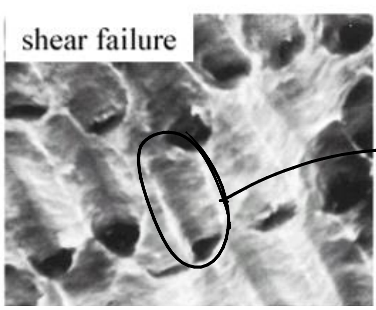
bigger cracks / voids



(a) (b) (c)

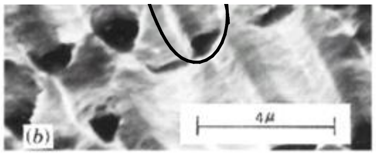
As we can see there are many mechanisms for a ductile material to dissipate energy starting from
dislocation motion and pile up against grain boundaries and corners to
Void formation
Void coalescence
Crack formation

for ductile fracture



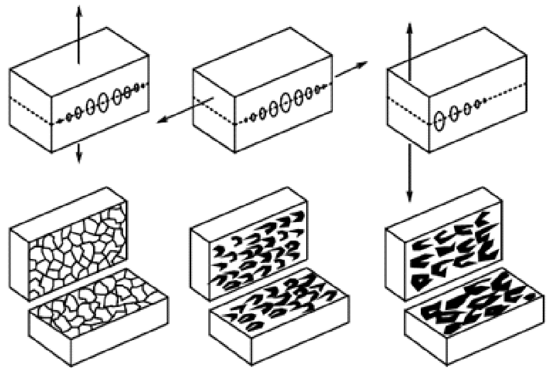
we have these dimple features

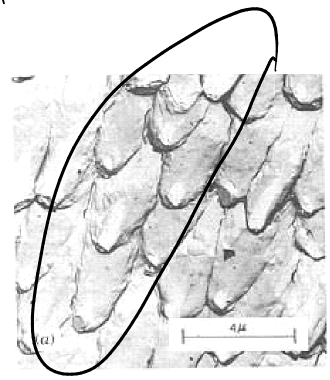
features on



features on crack surfaces for ductile materials

Dough-like or conical features

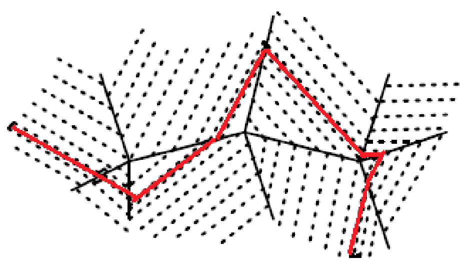


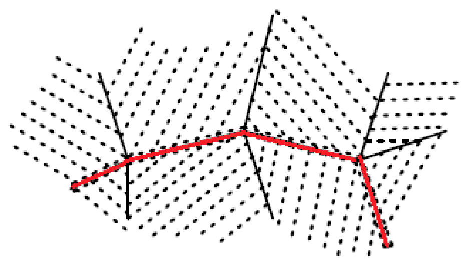


For brittle materials fracture surfaces are much smoother

Cleavage

mostly brittle





intra-granulair

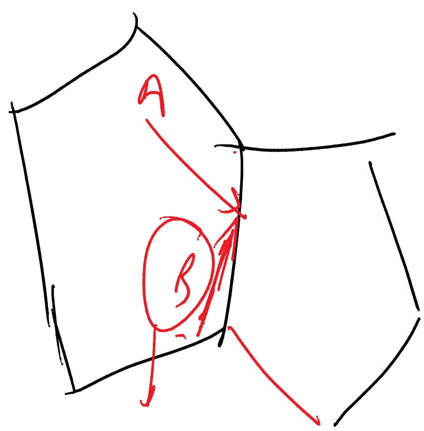
(or transgranular)
split atom bonds

inter-granulair

between grain boundaries

What factors determine what type of fracture occurs:

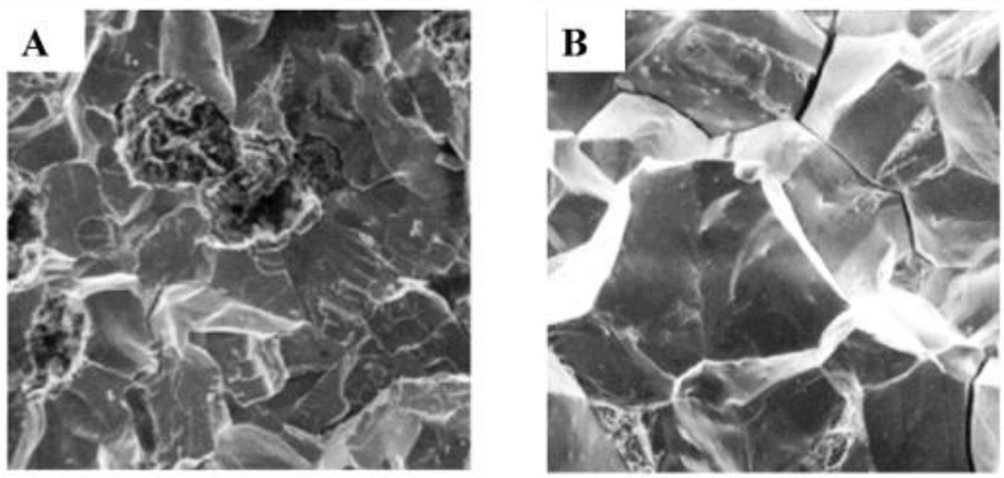
1. Grain boundary energy (bonding)
2. Direction of crack with respect to grain boundaries



more likely than A

to be inter-granular

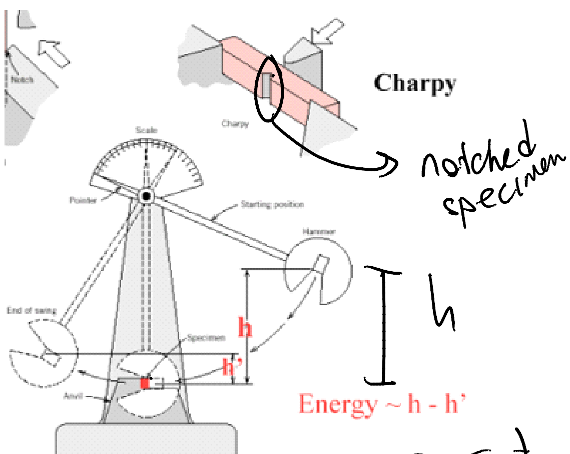
Samples of brittle fracture surface

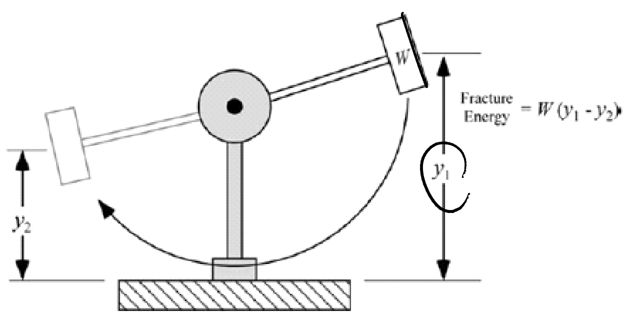


Lecture source:

Ductile to brittle transition

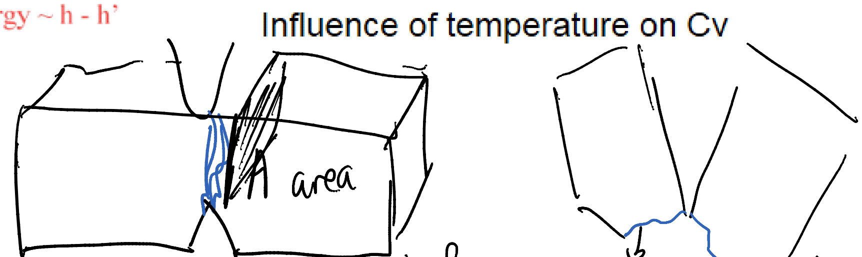
Charpy v-notch test



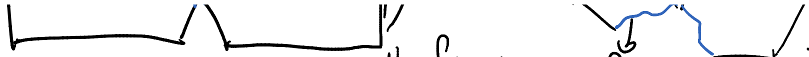


Influence of temperature on Cv

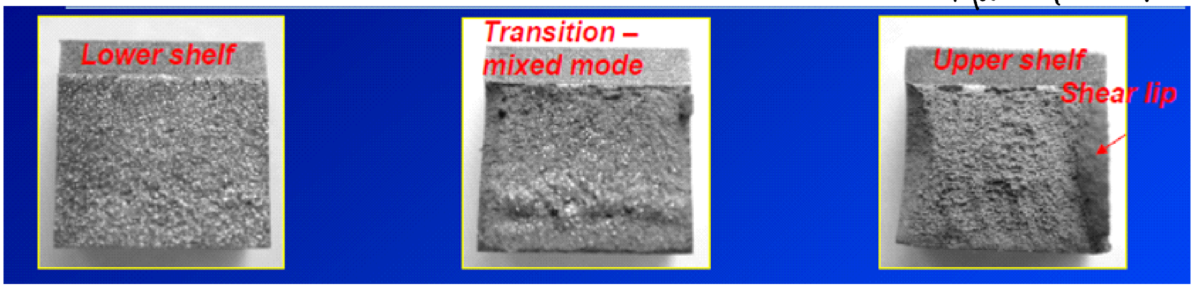
Surfaces of fracture



the fracture surface formation absorbs



the fracture surface formation absorbs energy

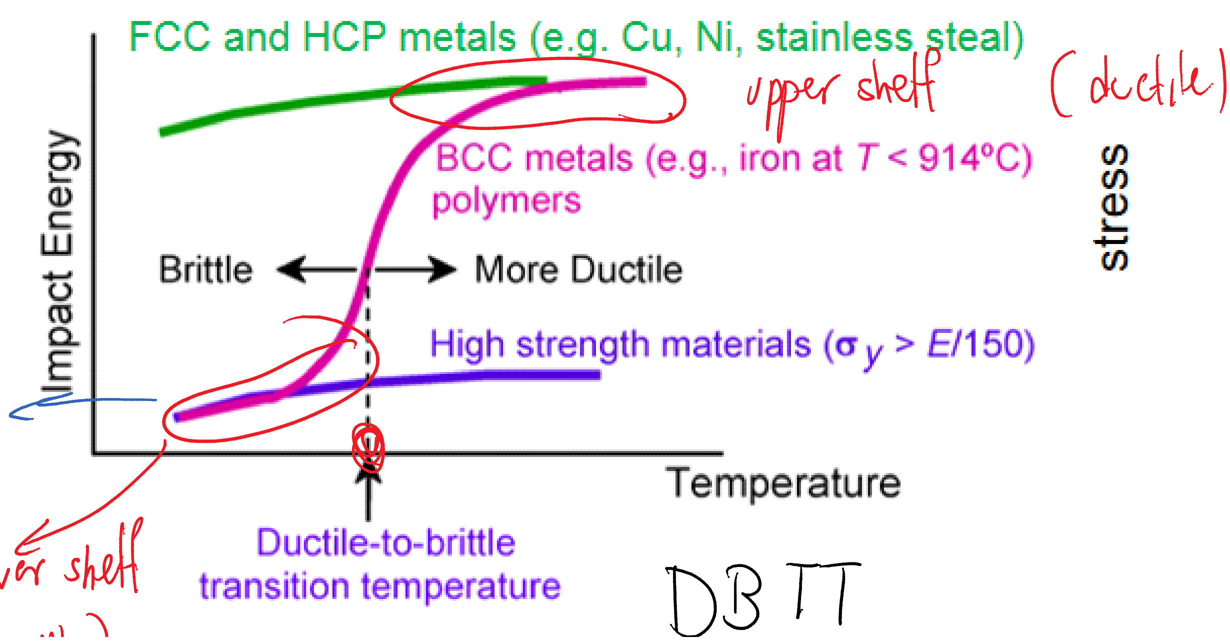


Energy loss = $mg(y_2 - y_1)$ = fracture energy for the specimen = $\mathcal{E}$

Specific energy $\gamma = \dfrac{\mathcal{E}}{2A}$

because we have two fracture surfaces

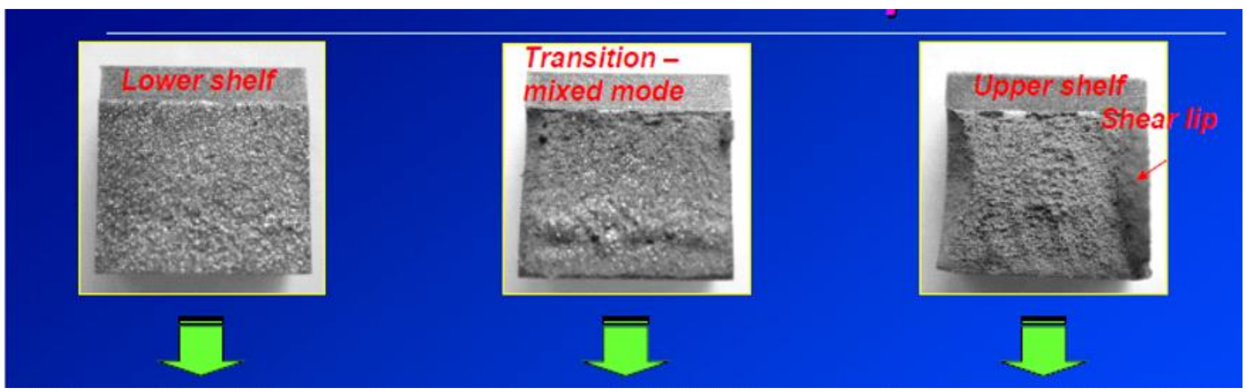
energy needed to create unit area of fracture



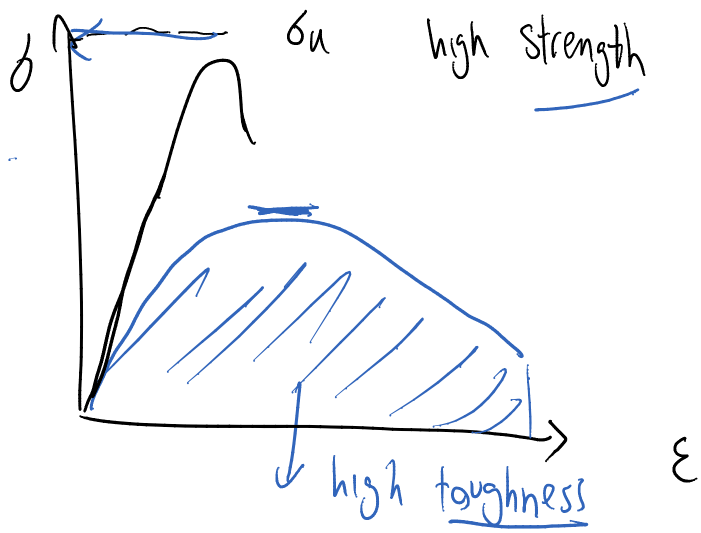
DBTT

(brittle)

To



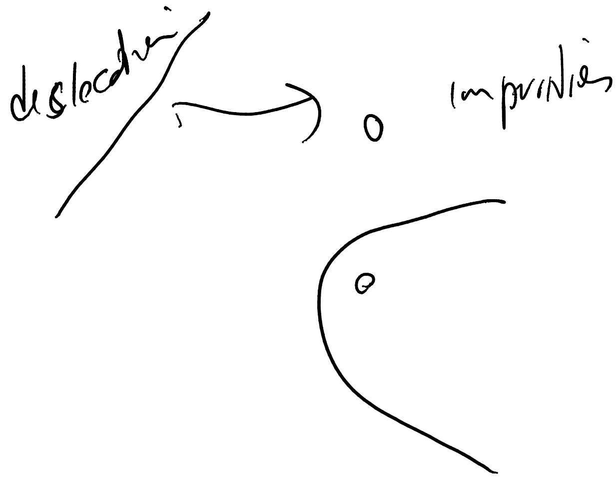
Dilemma in material science



What do you think happens with alloying a material?

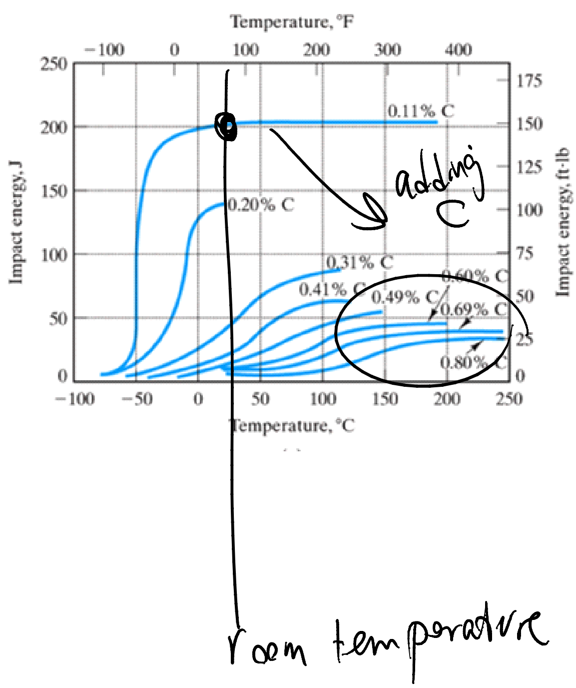
→ Does it increase toughness?

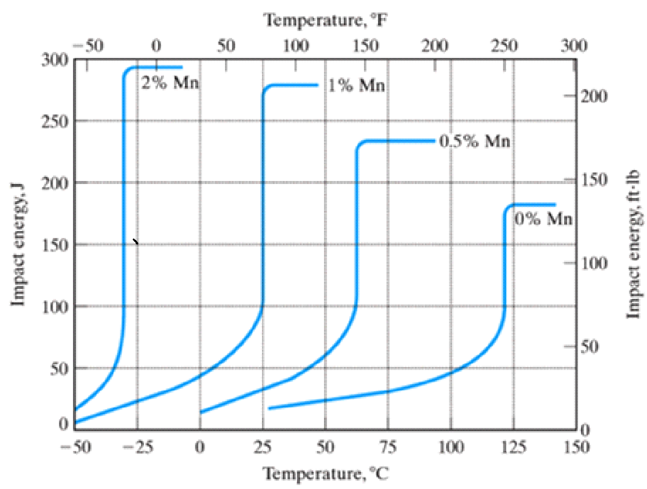
→ " " " strength?



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.

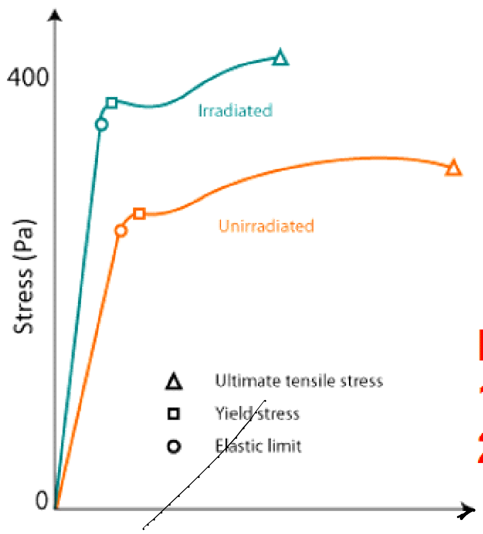


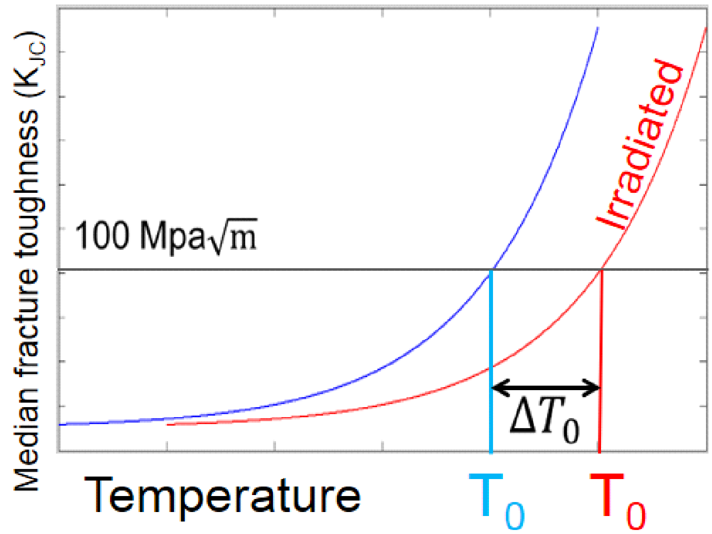


Decrease of DBTT by Mg: formation of manganese-sulfide (MnS) and consumption of some S. It has some side effects

3. Radiation embrittlement through DBTT

- Energetic particles (such as neutron or fission fragments) => knocking atoms out of natural lattice positions changing material property
- T_0 corresponds to $K_{JC} = 100\ MPa\sqrt{m}$
- Wallin Master Curve model: K-T shifts to right by ΔT_o by irradiation



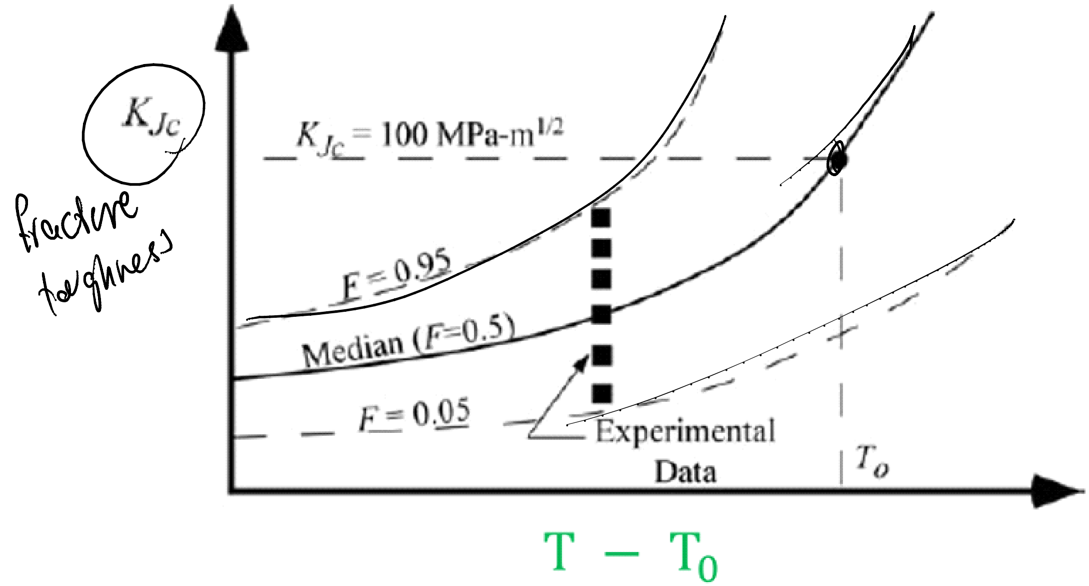


Irradiation effect:

1. Strengthening

2. More brittle

Wallin's Master Curve
Irradiation inceases T_0

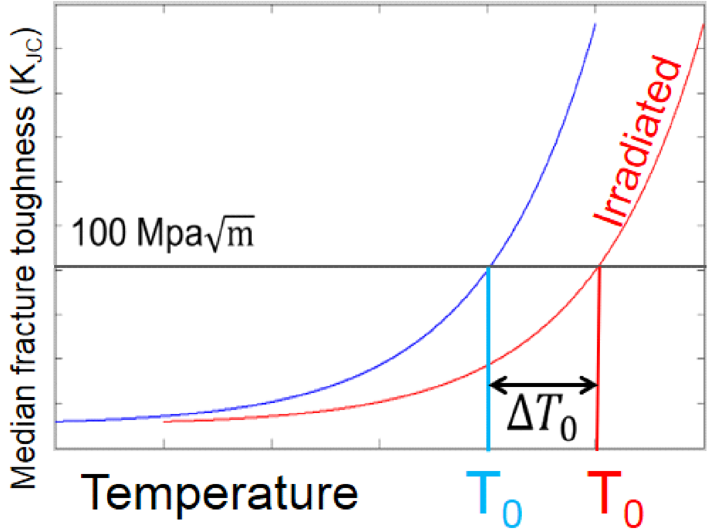


$$K_{Jc(med)} = 30 + 70\exp[0.019(T - T_0)]\,,\mathrm{MPa}\sqrt{\mathrm{m}}$$

$T = T_0$

$K_{Jc} = 100$ this is the definition for T_0

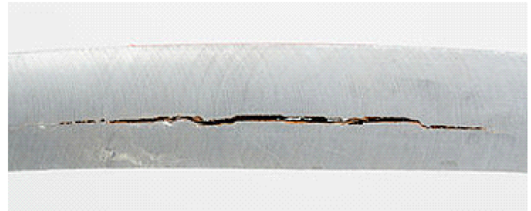
Irradiation increases T0 and shifts the curve to the right (meaning the material becomes more brittle)

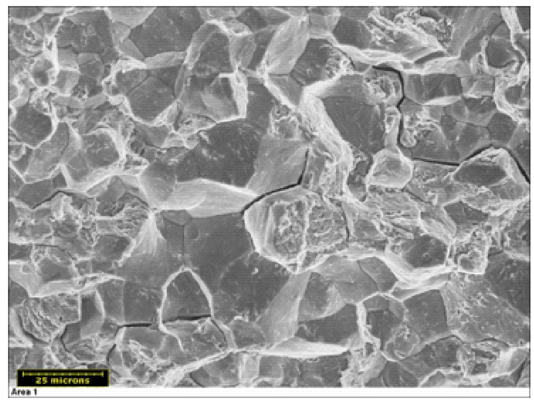


T_0 = function of irradiation level

4. Hydrogen embrittlement through DBT

- 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.





Lecture source:
Prof. Leonid Zhigilei, http://people.virginia.edu/~lz2n/mse209/index.html
MSE 2090: Introduction to Materials Science Chapter 8, Failure
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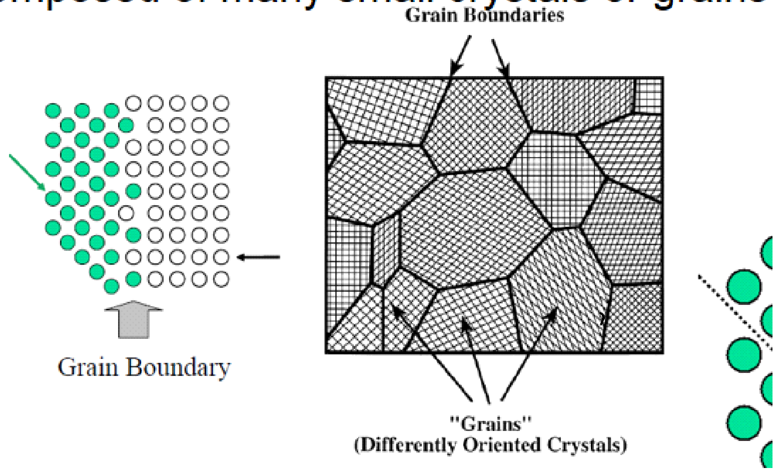
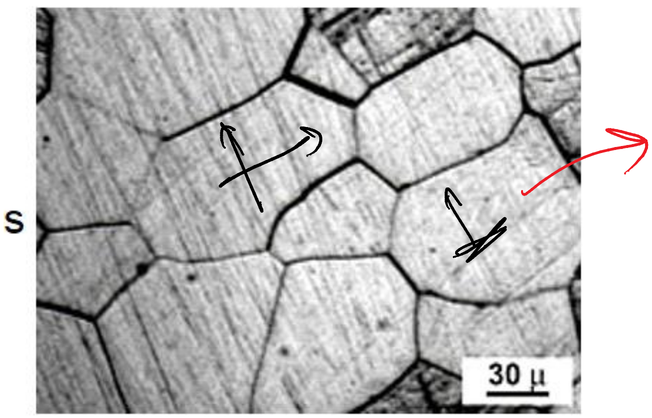
Next aspect that changes ductility is grain structure

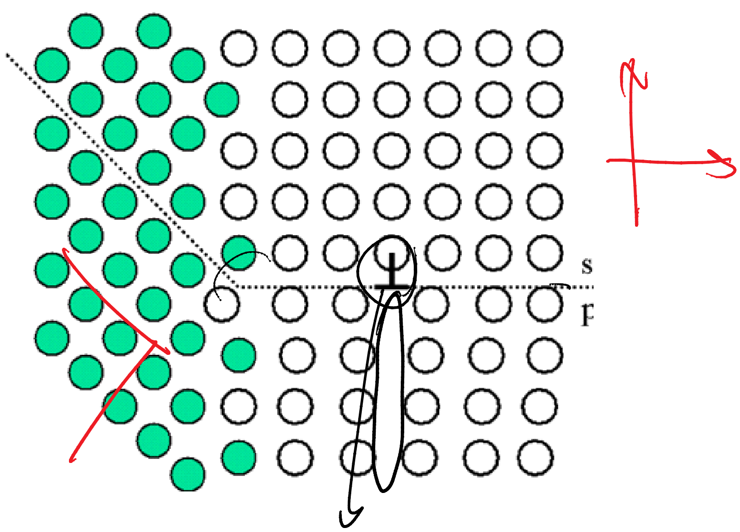
Introduction to grain structure
Please read the notes from Zhigilei on grain structures

Polycrystalline material:
Composed of many small crystals or grains





anisotropic material



different orientation of lattice

dislocation

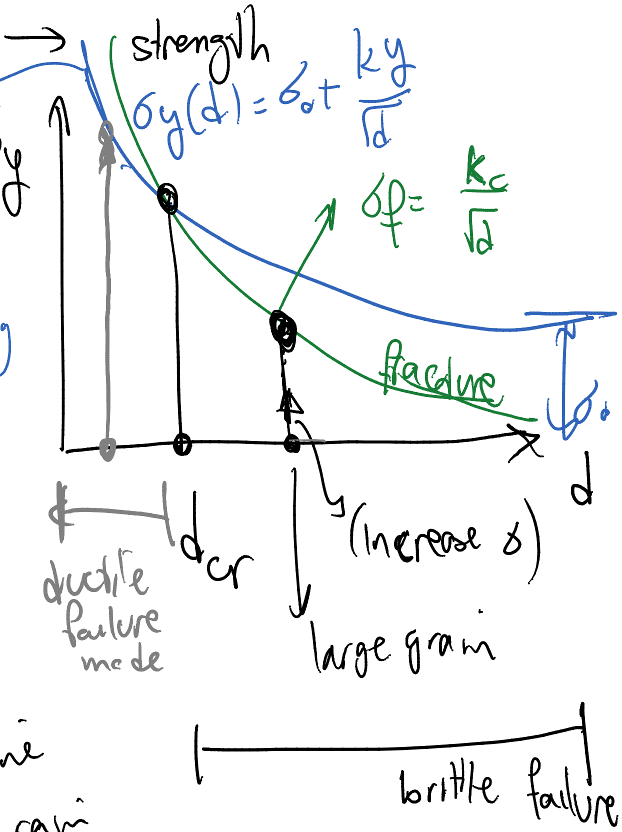
How does the grain size change the ductility and strength of a material?

5. Grain size

- In BCC metals, brittle fracture can be initiated by dislocation glide within a crystalline grain
- Yield stress depends on grain size (Hall-Petch law)

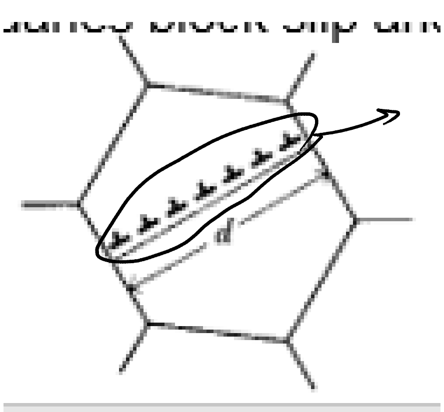
$$\sigma_y = \sigma_0 + \frac{k_y}{\sqrt{d}}$$

yield stress



d ↘ σ_y ↗

it's good to have smaller grains for higher σ_y



dislocation line within a grain

"approximate this with a crack"

$\ell \propto d$

crack length

applied stress

$$K = \sigma\sqrt{2\pi\ell}_{b,d} = K_c$$

$K = \sigma\sqrt{\pi a}$ ... $b.d$ $= K_c$

stress intensity factor

when fracture happen

$K = K_c$

fracture toughness

$\sigma\sqrt{d} \propto K_c \Rightarrow$

$$\sigma \propto \frac{K_c}{\sqrt{d}}$$

stress needed to cause the dislocation pile-up in the grain (modeled by a crack) to be activated and propagate as a crack

- Yield stress depends on grain size (Hall-Petch law)

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

$\sigma_y \uparrow \Rightarrow$ toughness ("energy absorption") $\uparrow$

- Dislocation pile-up acts as crack with size ≈d =>
- Stress to cause brittle fracture is

$$\sigma_f = \frac{k_f}{\sqrt{d}},\ k_f = \sqrt{\frac{EG_c}{\pi}}$$

$\uparrow$ σ

- **Small grain size =>**
  1. **Lower DBTT (more ductile)**
  2. **Increases thoughness**

⇨

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ONLY STRENGTHING MECHANISM THAT IMPROVES DUCTILITY

Britle line

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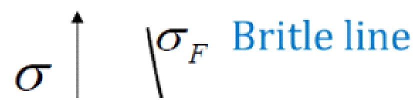
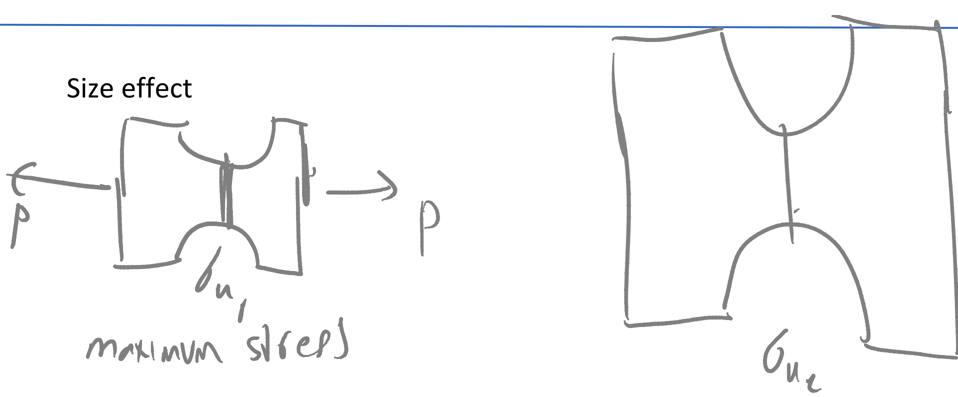
- **Grain boundaries have higher energies (surface energy) ⇨ Grains tend to diffuse and get larger to lower the energy**



- Heat treatments that provide grain refinement such as air cooling, recrystallisation during hot working help to lower transition temperature.

Size effect



A) $\sigma_{u_1} = \sigma_{u_2}$

B) $\sigma_{u_1} < \sigma_{u_2}$

C) $\sigma_{u_1} > \sigma_{u_2}$

smaller structures have higher strength!

This phenomenon is insignificant for ductile materials but very important for brittle materials

That is, for brittle materials as size increases so does fracture strength