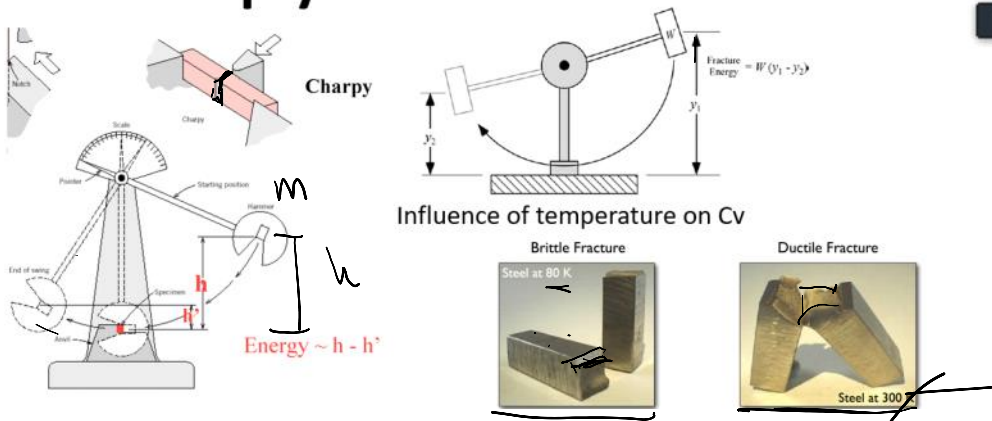
## 2022/08/30

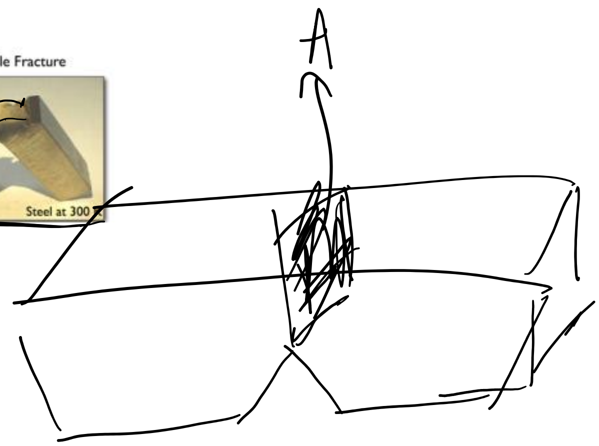
Tuesday, August 30, 2022 2:32 PM

Temperature influence

Testing ductility

# Charpy v-notch test



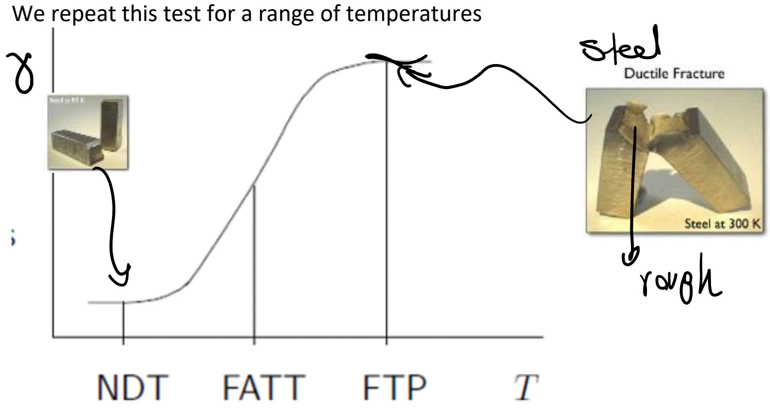

Energy lost = $mg(h-h')$

= fracture energy = $A(2\gamma)$

$\gamma$ → fracture toughness

$$\gamma = \frac{mg(h-h')}{2A}$$

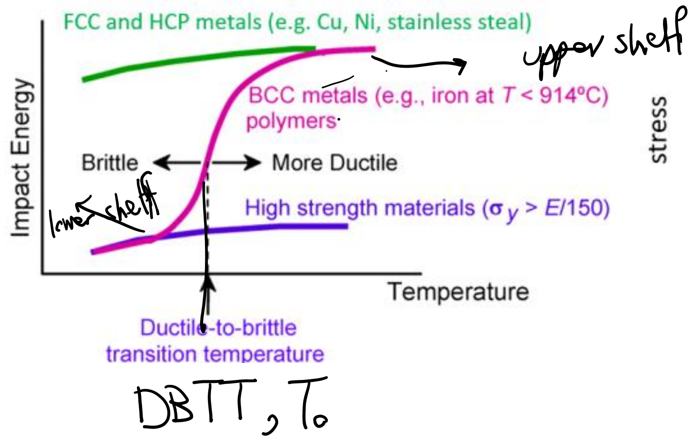
We repeat this test for a range of temperatures

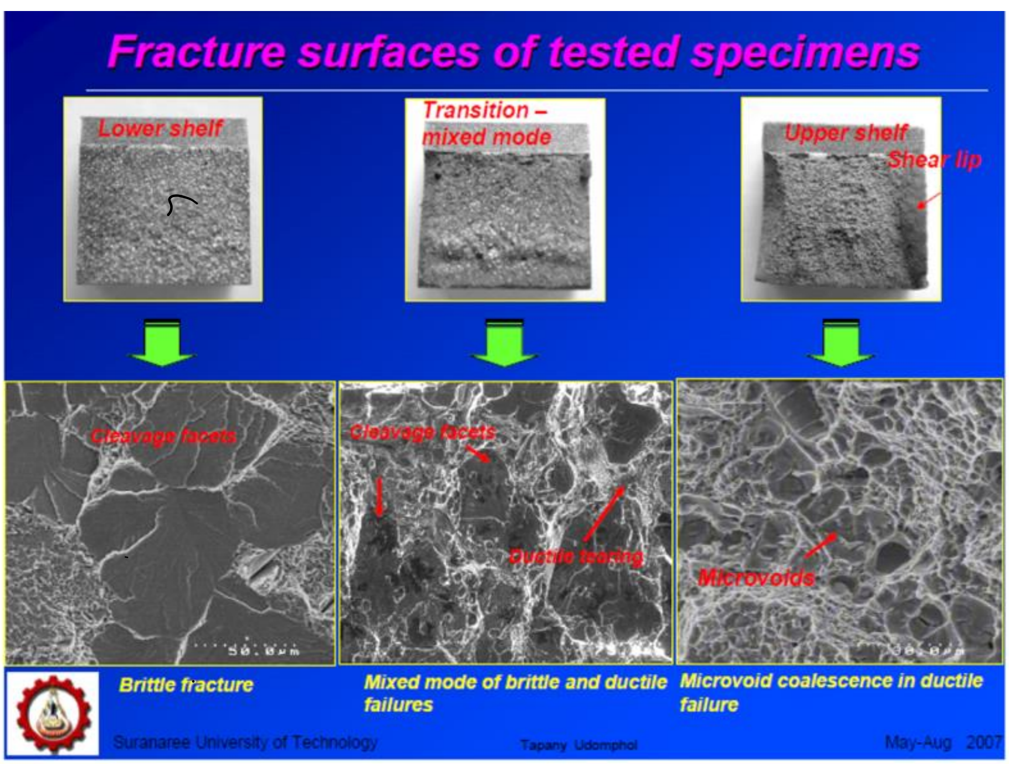



For this material, at low temperature dislocation motion is more inhibited -> less plastic deformation and dissipated energy. The response is more brittle

## 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



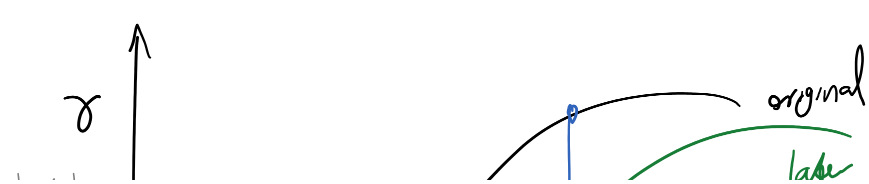



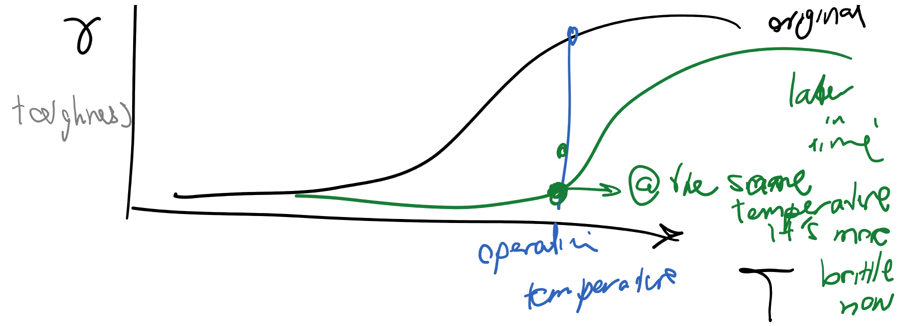

Source: Tapany Udomphol, Suranaree University of Technology
http://eng.sut.ac.th/metal/images/stories/pdf/14_Brittle_fracture_and_impact_testing_1-6.pdf

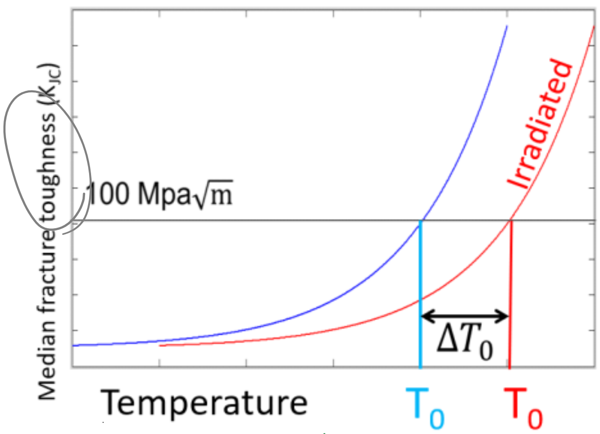
40

There are processes that change Temperature vs. Fracture energy curves

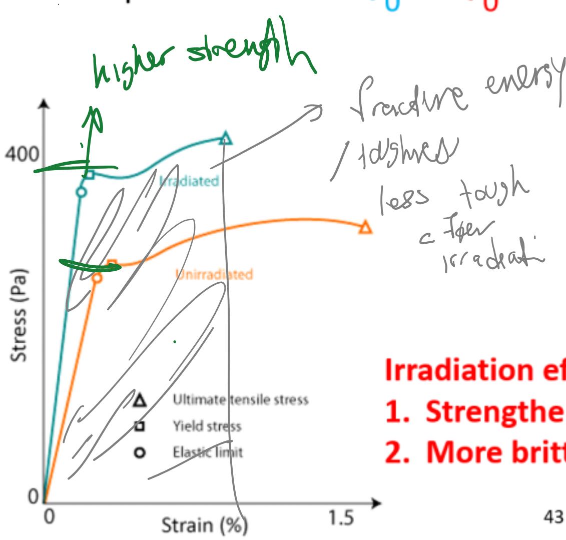
A prime example is irradiation

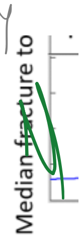





Wallin Master Curve model: K-T shifts to right by $\Delta T_o$ by irradiation

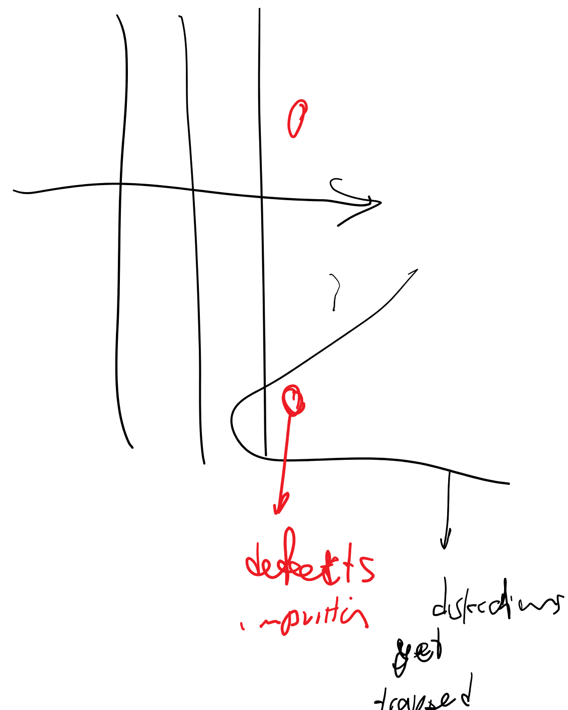



**Irradiation effect:**

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

43

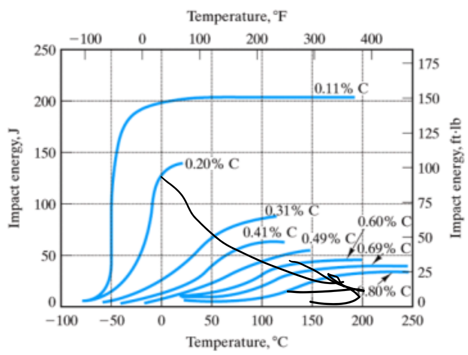


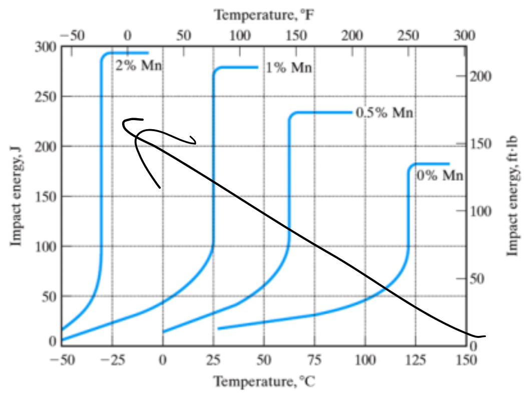

⟹ 1. higher strength
2. lower toughness

# 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.

↓ more brittle



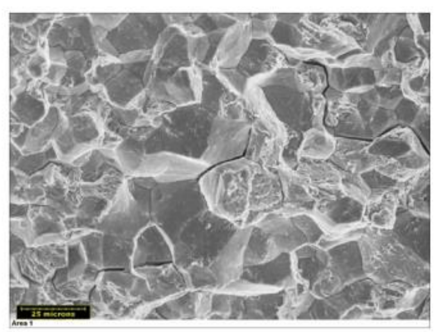




Decrease of DBTT by Mg: formation of manganese-sulfide (MnS) and consumption of some S. It has some side effects

42

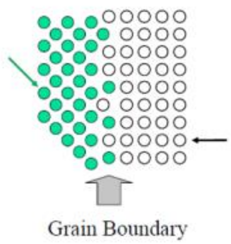
# 4. Hydrogen embrittlement through DBTT

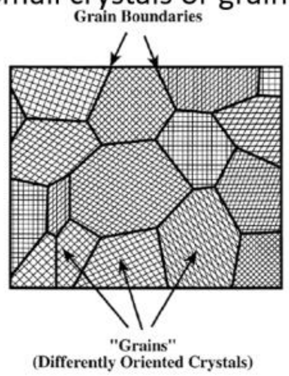
- Hydrogen in alloys drastically reduces ductility in most important alloys:
  - nickel-based alloys and, of course, both ferritic and austenitic steel
  - Steel with an ultimate tensile strength of less than 1000 Mpa is almost insensitive
- A very common mechanism in Environmentally assisted cracking (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.

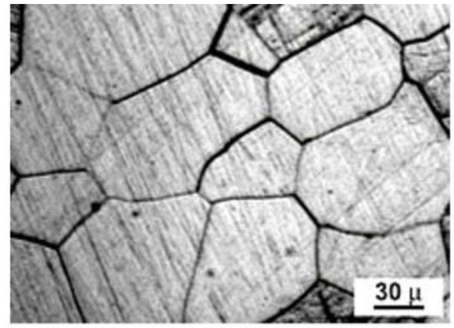


# Grains

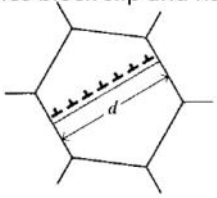
Polycrystalline material:
Composed of many small crystals or grains

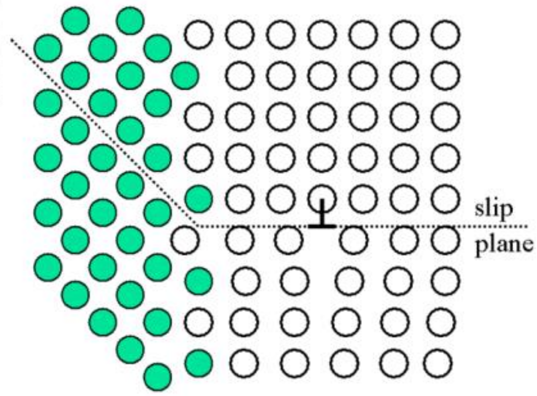



Grain boundary barrier to dislocation motion:
High angle grain boundaries block slip and harden the material



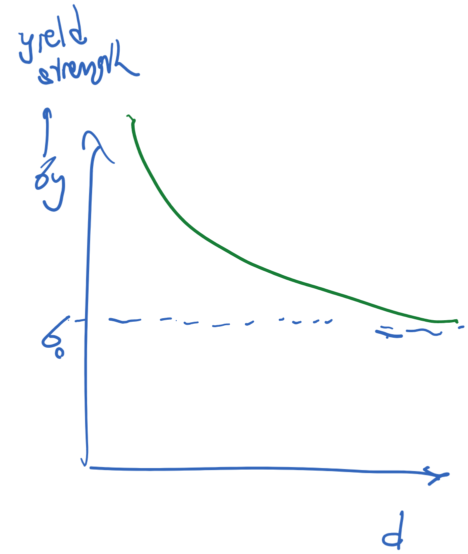

46

Grain size has tremendous impact on ductility of the material

Hall Petch relation

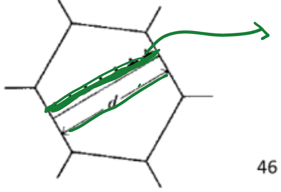
$$\sigma_y(d) = \sigma_0 + \frac{K_y}{\sqrt{d}}$$

Ma yielding of material




Fracture Process

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




46

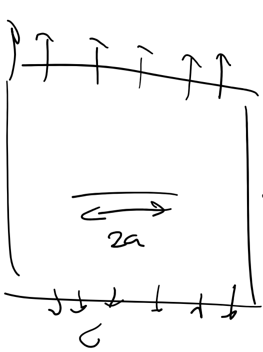
dislocation pile up represents a crack of length d

Critical Stress Intensity Factor

ignore the factor

$$\sigma_f(d) = (\;)\frac{K_{Ic}}{\sqrt{d}}$$

crack length




$K_I = \sqrt{\pi a}\,\sigma = K_{Ic}$

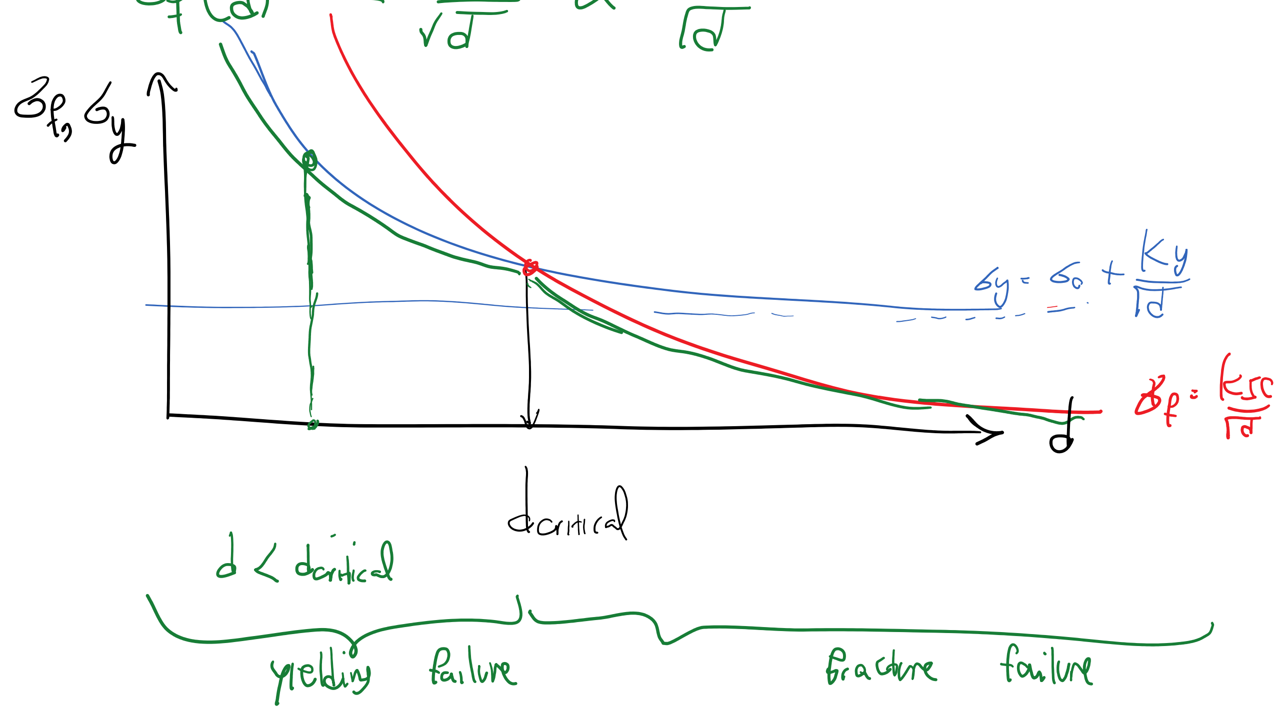
if fails

$\sigma = K_{Ic}$

$\sqrt{\pi d/2}$ $\sqrt{\frac{2}{\pi}}$

$$\sigma_{fracture} = \frac{K_{IC}}{\sqrt{\pi a}}$$

$$\sigma_f(d) = \frac{K_{IC}}{\sqrt{d}} \propto \frac{1}{\sqrt{d}}$$




Making the grains smaller is one of few phenomena / features that increases strength and toughness at the same time

grain size & temperature-sensitive $\sigma_y$, $K_{IC}$ → D→B transition

$$\sigma_y = \sigma_0 + \frac{K_y}{\sqrt{d}} \quad T\nearrow \quad \sigma_y \searrow$$

$(T\searrow \ \sigma_y\nearrow)$

$$\sigma_0 = Be^{-\beta T}$$

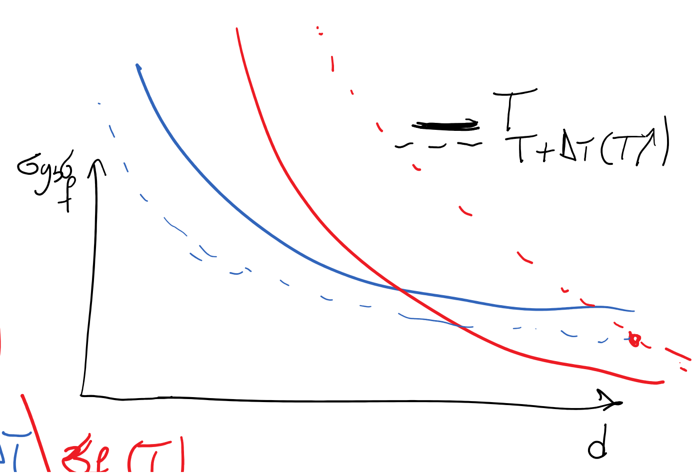
$$\sigma_f = \frac{K_{IC}}{\sqrt{d}} \qquad K_{IC} = \sqrt{\frac{EG}{\pi}}$$

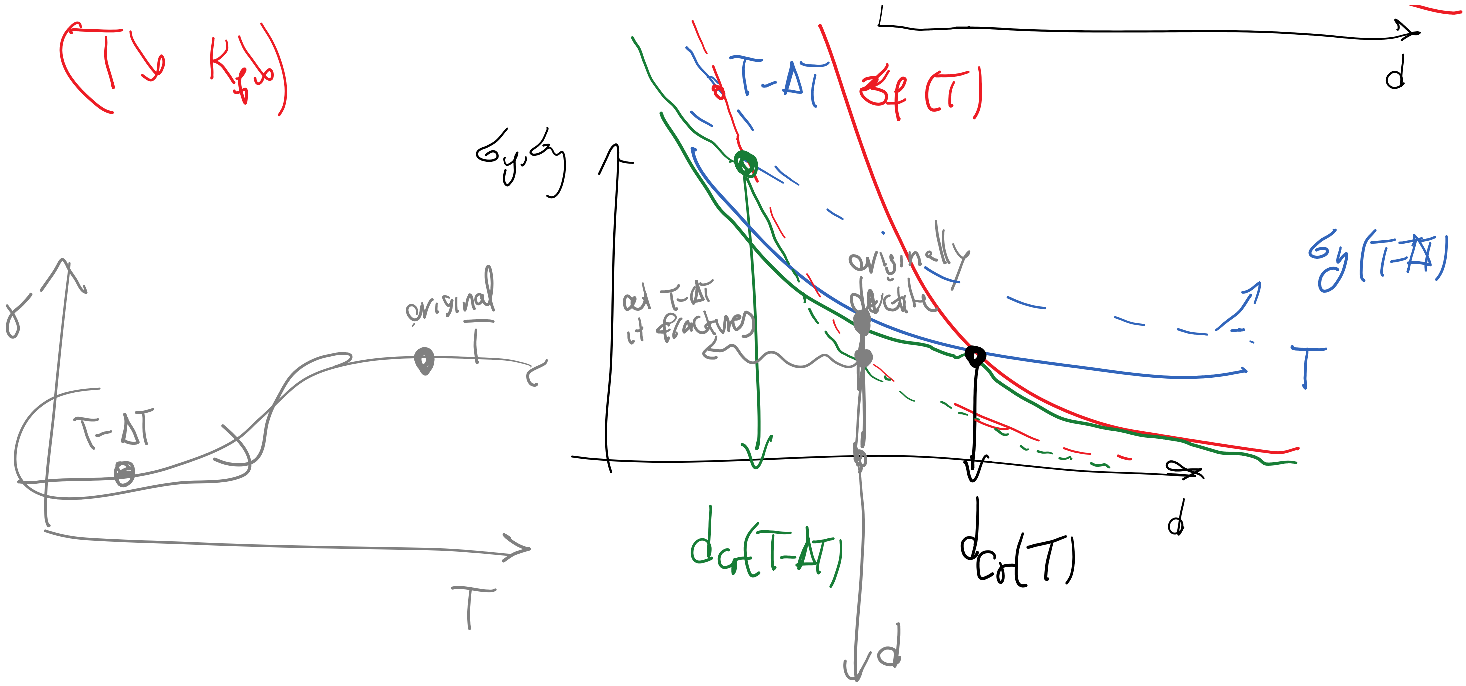
($\gamma$) fracture toughness

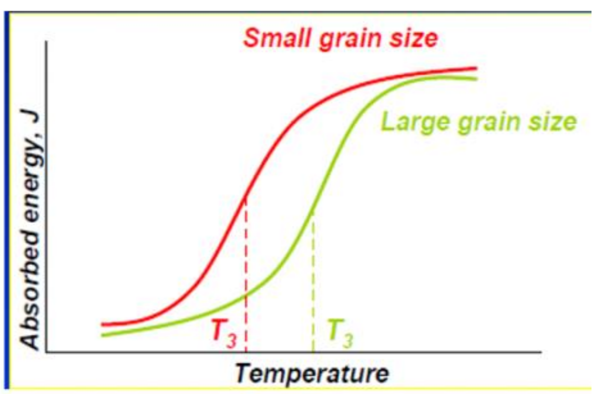
$T\nearrow \ K_f\nearrow$

$(T\searrow \ K_f\searrow)$

$\sigma_f(T-\Delta T)$






# 6.Size effect and embrittlement

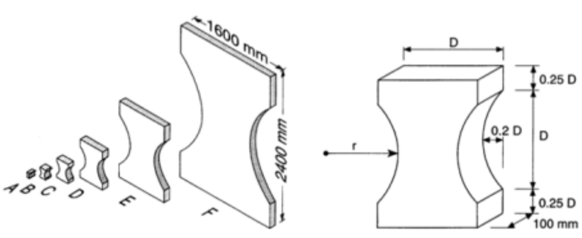
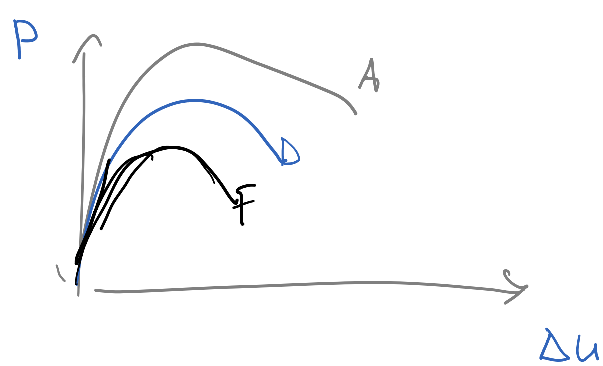
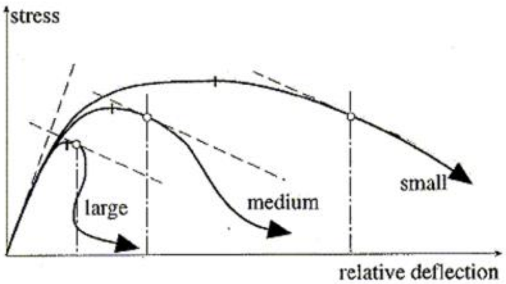
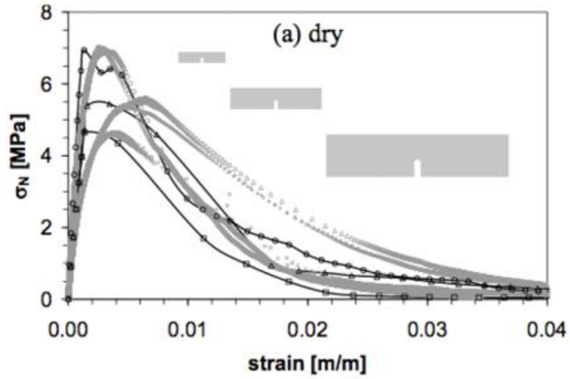



Fig. 1. Specimens with sizes in a scale range of 1:32 and specimen proportions.




Smaller samples like grain size is the other feature that makes the material tougher and higher strength



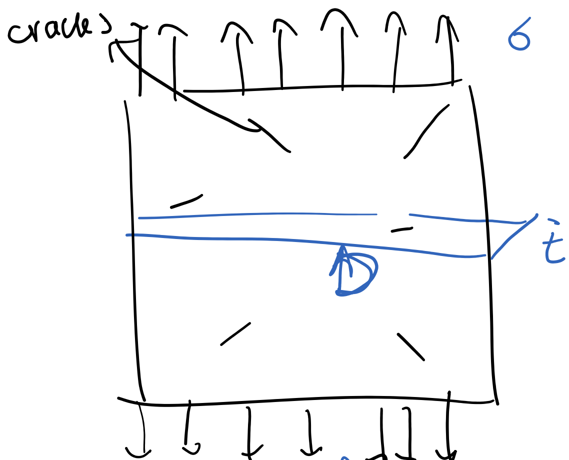




Failure mechanisms

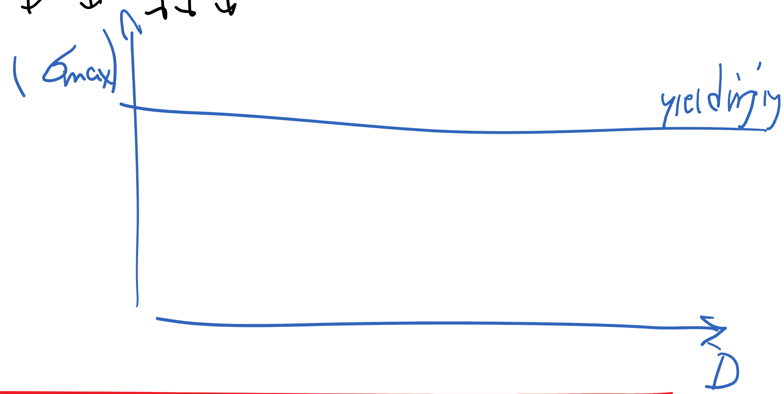
① yielding

$(\sigma_{max})_{yielding} A = \sigma_y A$

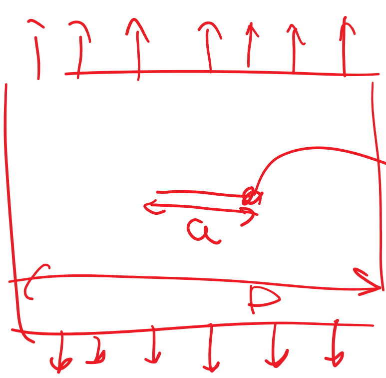
$$(\sigma_{max})_{yielding} = \sigma_y$$




$A = Dt$




Fracture




geometric factor

$K = f\sqrt{\pi a}\,\sigma$ → far field stress

fracture initiates when

$K = K_{IC} \rightarrow \sigma_{fracture}(f\sqrt{\pi a}) = K_{IC}$

$$\sigma_{fracture} = \frac{K_{IC}}{f\sqrt{\pi a}}$$

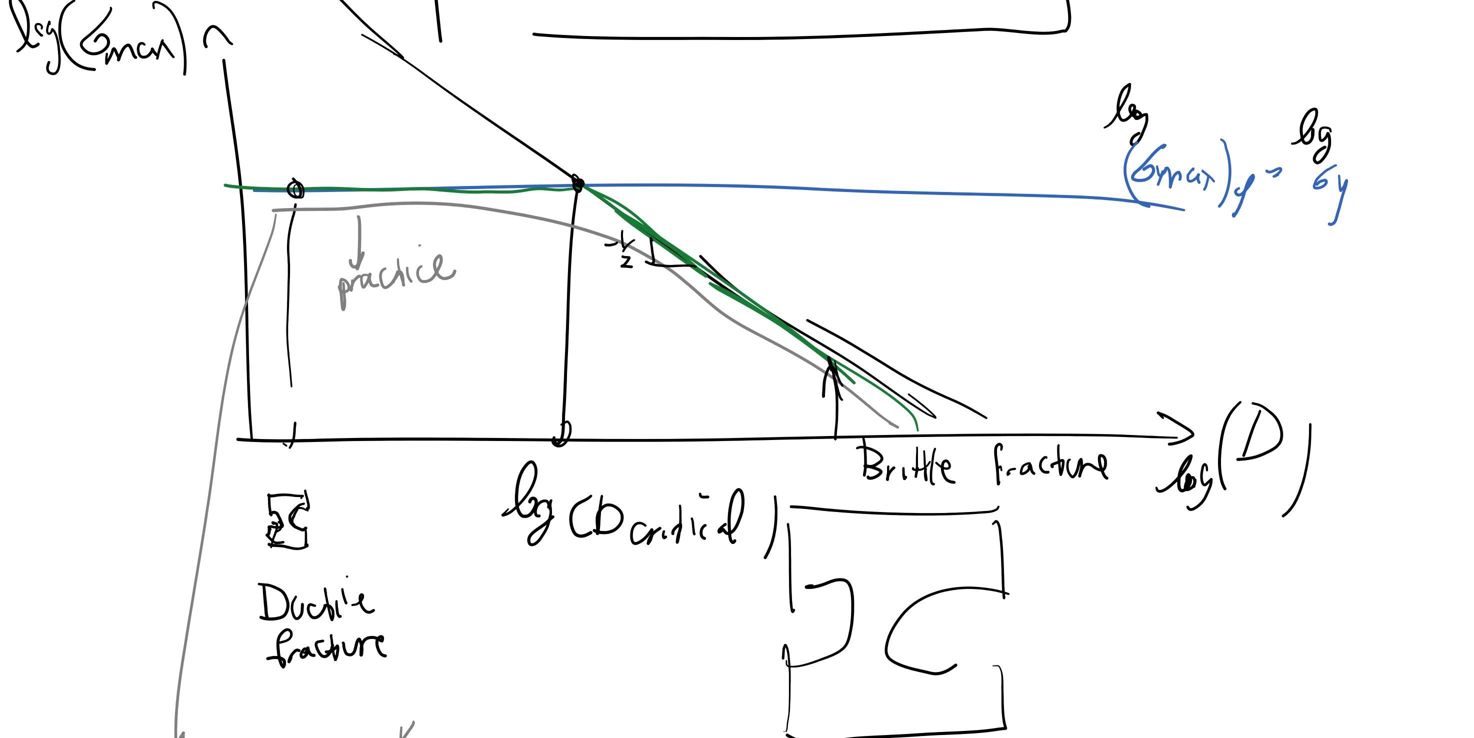
$$\sigma_{fracture} = \frac{K_{IC}}{f\sqrt{\pi a}}$$

Worse case

$$a \propto D$$

$$\sigma_{fracture} \propto \frac{1}{\sqrt{D}}$$

$$\log \sigma_f = C - \tfrac{1}{2}\log D$$




$$\sigma_z = \frac{\sigma_0}{\sqrt{1 + D/D_{crit}}}$$

Bazant