2020/08/26

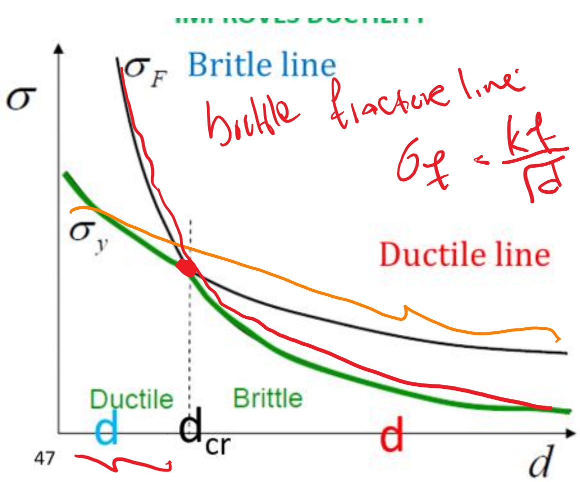
Wednesday, August 26, 2020 1:50 PM

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

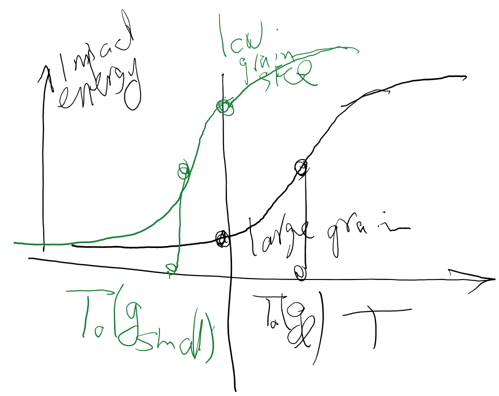
$$\sigma_y = \sigma_0 + \frac{k_y}{\sqrt{d}}$$

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

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



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



smaller grain is expected to lower DBTT :)

More detailed explanation of temperature on ductile and brittle fracture modes

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- initial temperature T —
- decrease temperature by ΔT (T → T-ΔT) ....

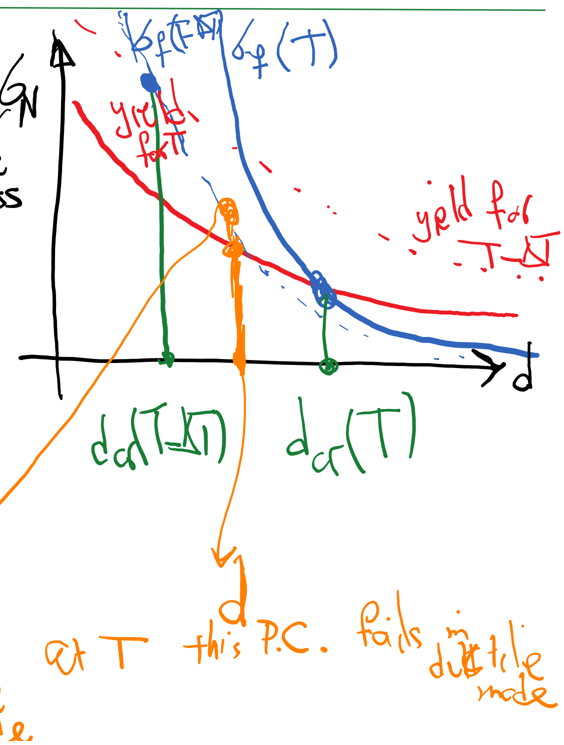
yield: $\sigma_y = \sigma_0 + \frac{k_y}{\sqrt{d}}$ Hall-Petch, $\sigma_0 = Be^{\beta T}$

T ↓ σ_y ↗

brittle fracture: $\sigma_f = \frac{k_f}{\sqrt{d}}$ $k_f = \sqrt{\frac{EG_c}{\pi}}$ → toughness

T ↓ k_f ↓ (G_c ↓)

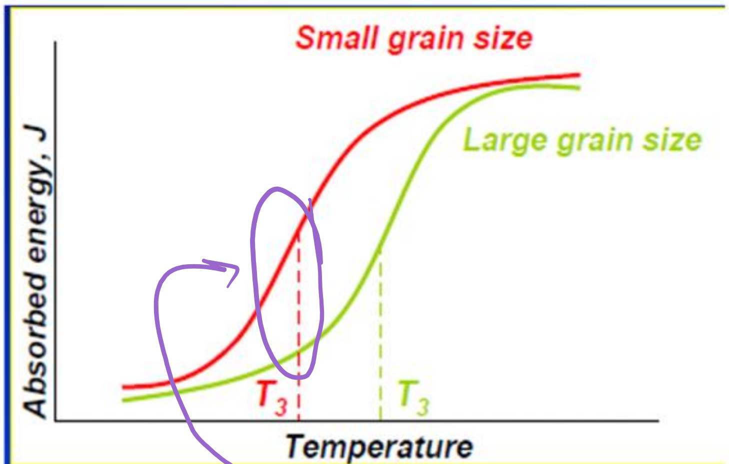
lower temp → more brittle fracture



lower temp -> more brittle fracture

fails in brittle mode ... ductile mode

By decreasing T, d_cr decreases. This is a bad outcome, as for a more limited (now narrower range or small grains) failure will be driven by yielding -> having a ductile fracture.



toughness

$d \searrow \quad C_v \nearrow$

The effect of lower grain size:

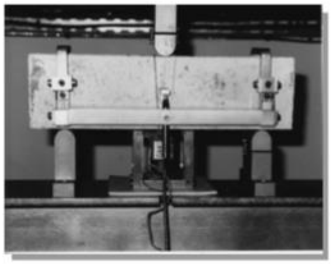
1. As shown in the figure above (and explained through previous equations), lower grain size has higher **toughness**.
2. Lower grain size also results in higher yield stress (~strength)

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

Lowering grain size is the only process we discuss here that at the same size increases toughness and strength! Obviously, in manufacturing the final polycrystalline (P.C.) has certain grain size that has the lowest total energy and in this having bigger grains results in smaller intergranular surfaces and surface energy -> This is why making grains smaller is not trivial.

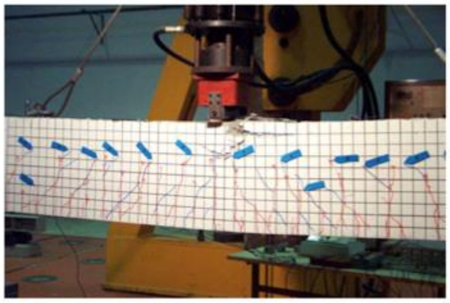
6.Size effect and embrittlement

- Experiment tests: scaled versions of real structures

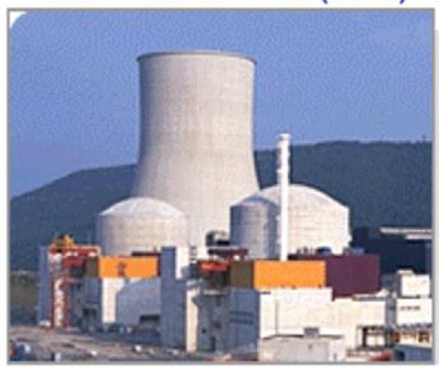


Usual lab tests (10 cm)

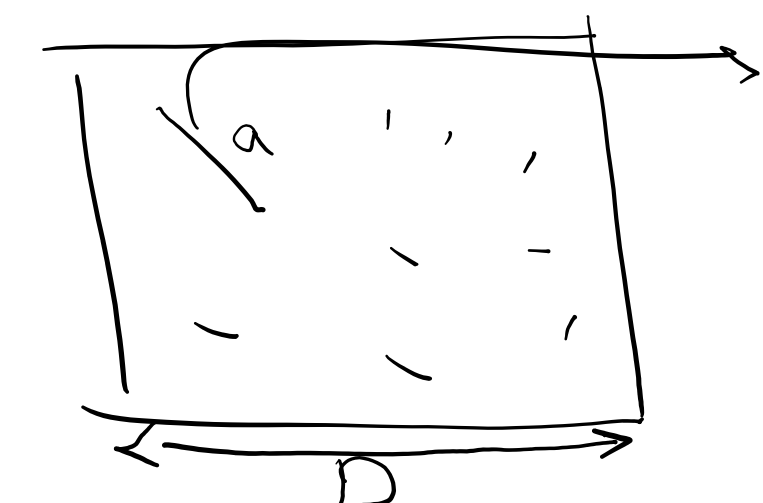
"Usual" structures (10m)



Unusual lab tests (1m)



Weibull model & brittle fracture



is quasi-static loading largest crack is in general the most critical for fracture

google Weibull model & weakest link

lowest strength first breaks

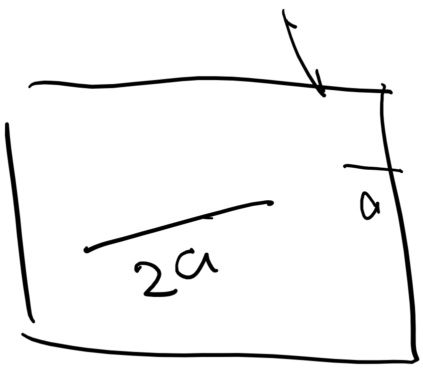
we'll derive this shortly

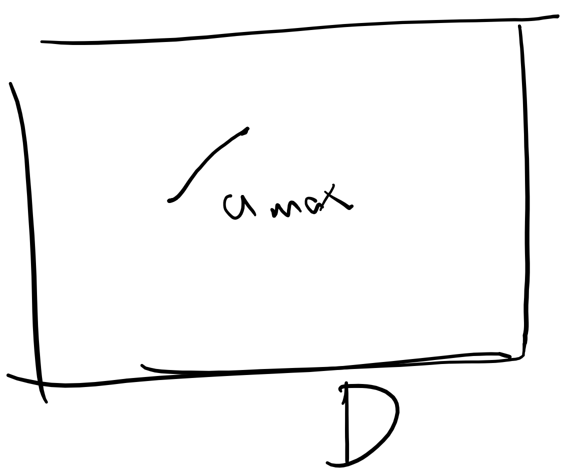
K_{Ic} → fracture toughness
critical stress intensity factor

$$\sigma_{Max} \propto \frac{K_{Ic}}{\sqrt{\pi a}}$$

K_{Ic} → fracture toughness = critical stress intensity factor

$$\sigma_{max} = f \frac{K_{Ic}}{\sqrt{a}}$$





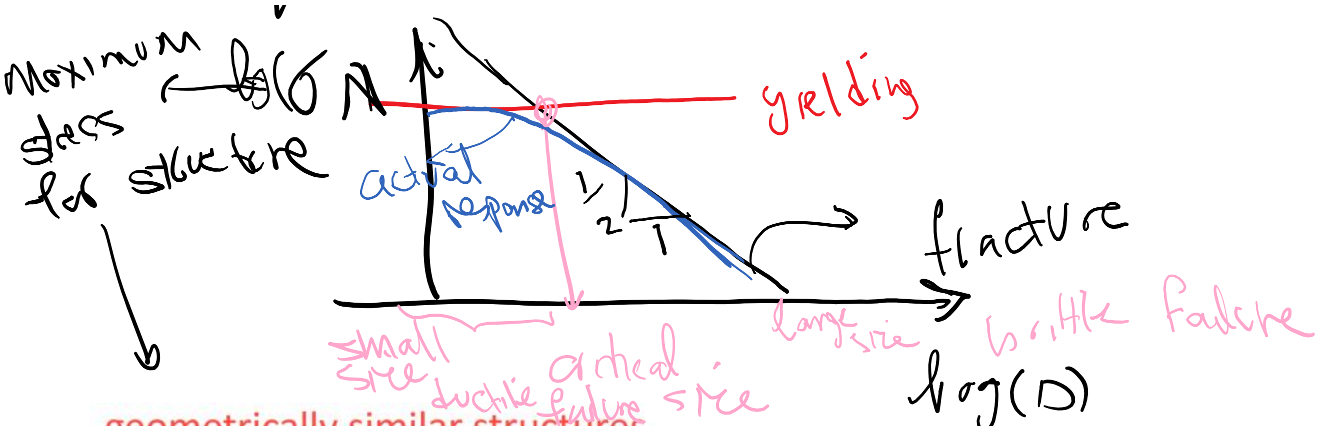
$\sigma_{max\ structure} \cong \sigma_{max}$ for longest crack

$$= \frac{K_{Ic}}{\sqrt{\pi a_{max}}}$$

If $a_{max} \propto D$ → $\sigma_{max} \propto \frac{k}{\sqrt{D}}$ (↓ for fracture)

maximum

welding



geometrically similar structures of different sizes

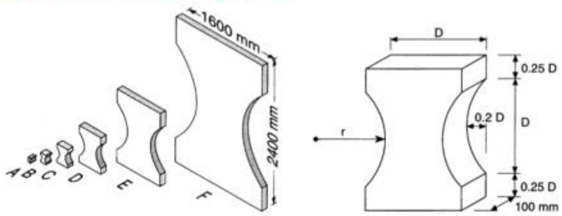


Fig. 1. Specimens with sizes in a scale range of 1:32 and specimen proportions.

type	A	B	C	D	E	F
D [mm]	50	100	200	400	800	1600
r [mm]	36.25	72.5	145	290	580	1160

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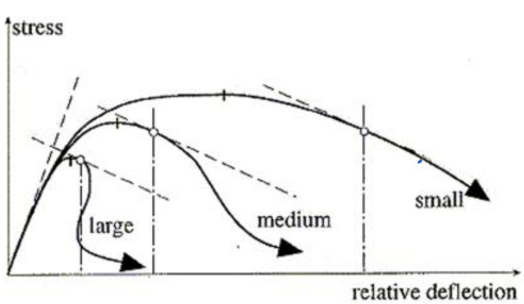
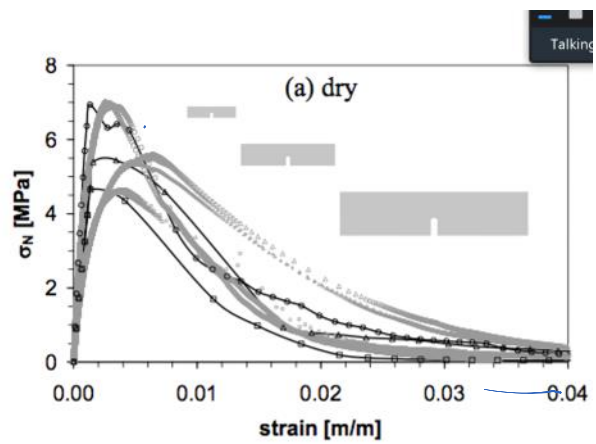


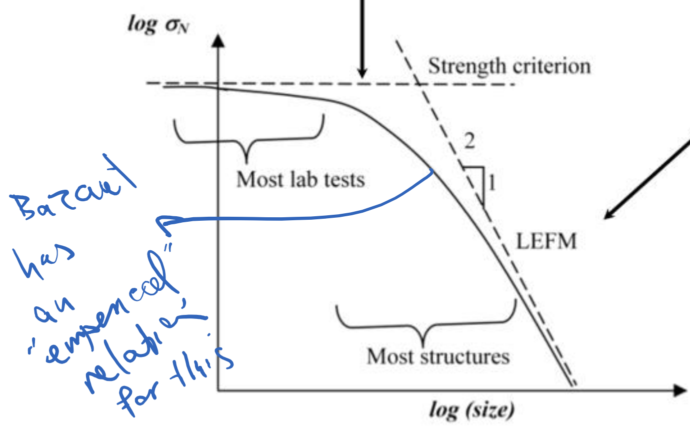


Smaller structures have higher strength and often are more ductile

In short, smaller sizes fail more in ductile mode.

$$\sigma_N = f_t = f_t(D)^0$$

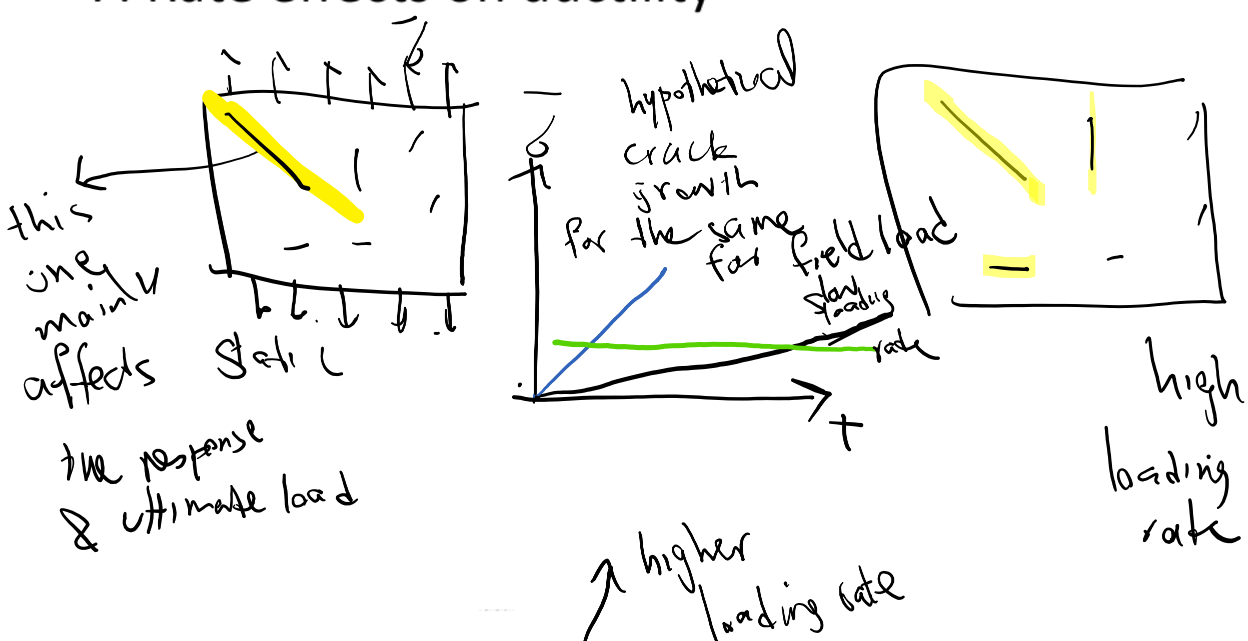
$$\sigma_N = \frac{K_{Ic}}{\sqrt{\pi a}} = \frac{K_{Ic}}{\sqrt{\pi c_N D}}$$

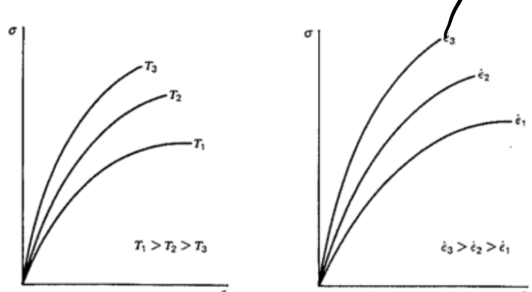


Larger size ⇨ More brittle

For very small structures the curve approaches the horizontal line and, therefore, the failure of these structures can be predicted by a strength theory. On the other hand, for large structures the curve approaches the inclined line and, therefore, the failure of these structures can be predicted by LEFM.

7. Rate effects on ductility





Strain rate ↗ similar to T ↘

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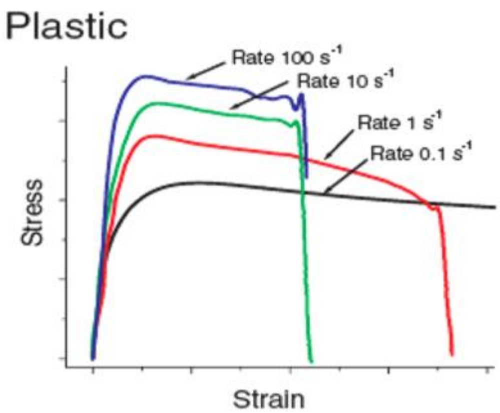

Strain rate ↗ ⇨ DBTT ↗ (more brittle in impact)

Ki Computed using quasistatic relations (Anderson p.178)

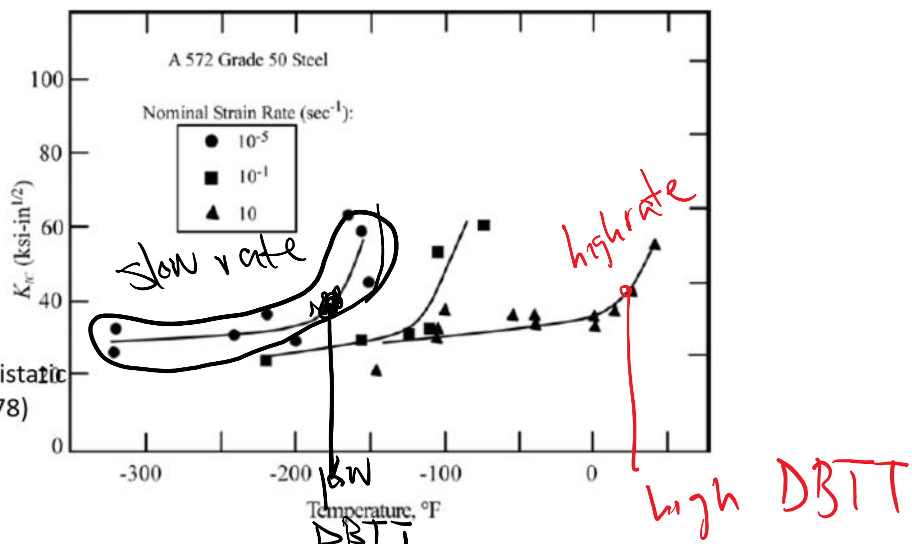

FIGURE 4.5 Effect of loading rate on the cleavage fracture toughness of a structural steel. Taken from Barsom, J.M., "Development of the AASHTO Fracture Toughness Requirements for Bridge Steels." *Engineering Fracture Mechanics*, Vol. 7, 1975, pp. 605–618.

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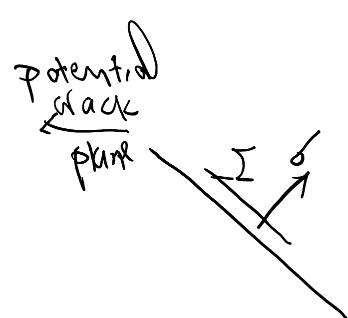
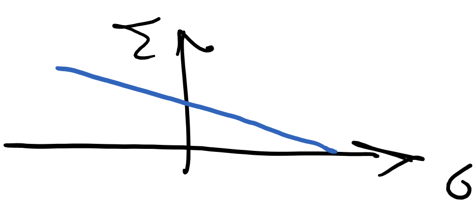
8. Triaxial stress and confinement

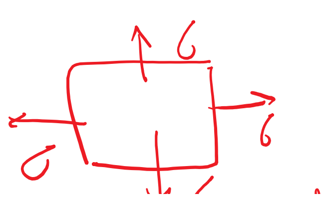
Triaxial stress state generally make the failure more brittle.

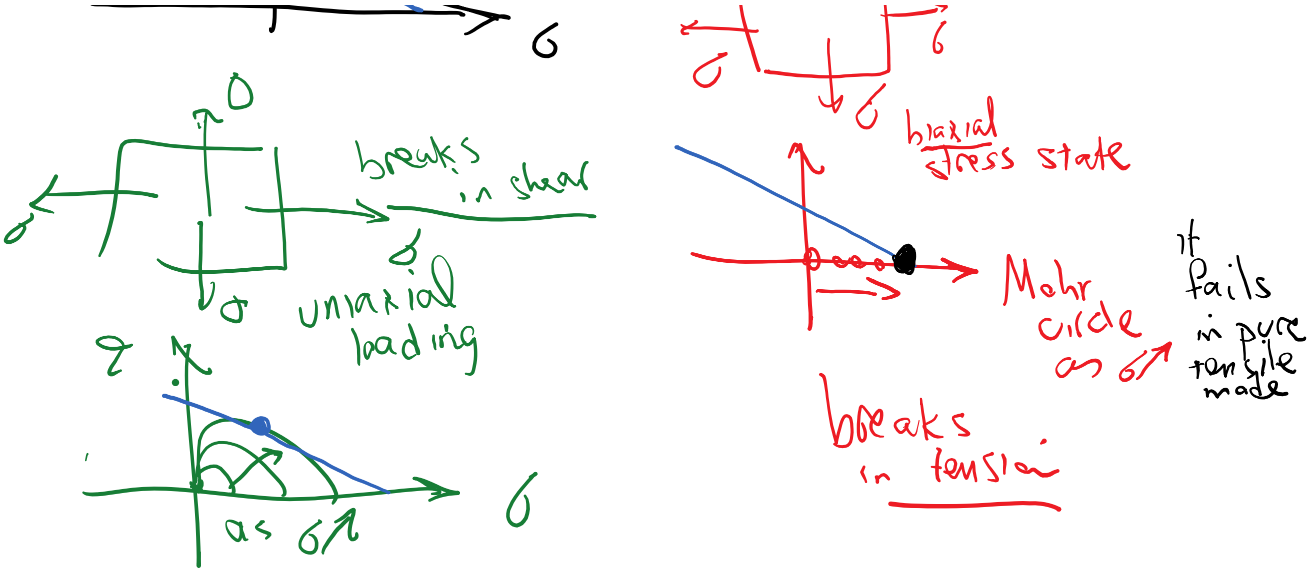
Example

Mohr - Coulomb (MC) failure criterion



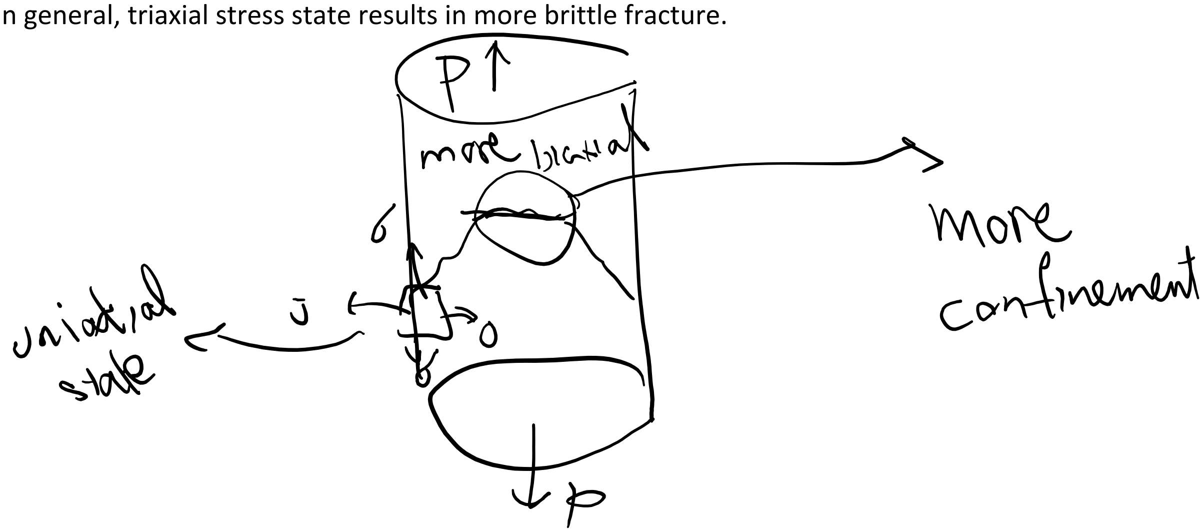






Failure mode changes by uniaxial and biaxial stress state as the example above shows that.

In general, triaxial stress state results in more brittle fracture.



Ductile to brittle transition

Often hardening (increasing strength) reduces ductility
Phenomena affecting ductile/brittle response

1. T (especially for BCC metals and ceramics)
2. Impurities and alloying
3. Radiation
4. Hydrogen embrittlement
5. Grain size
6. Size effect
7. Rate effect
8. Confinement and triaxial stress state

Decreasing grain size is the only mechanism that hardens and promotes toughness