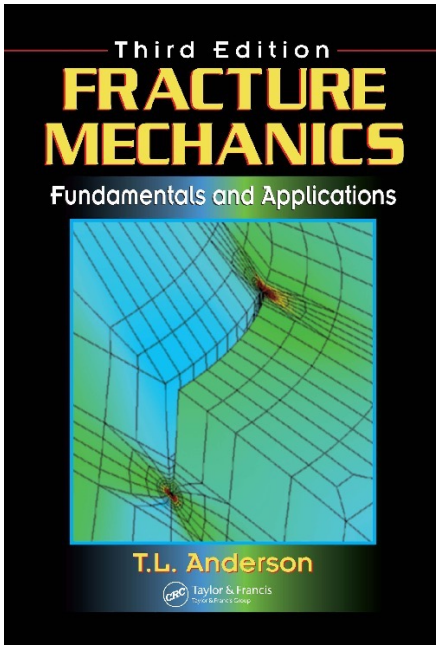
8. 断裂

Dongsheng Wen



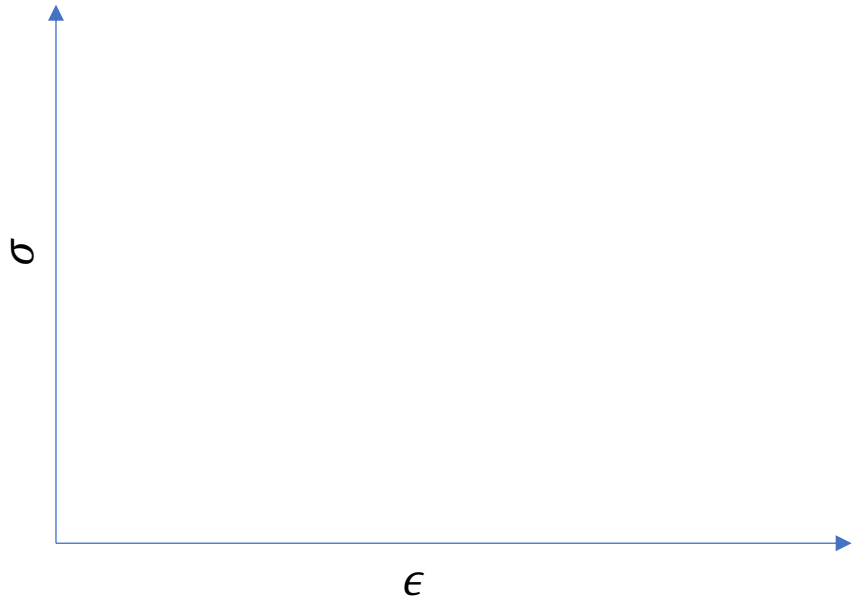
断裂的 ‘名场面’

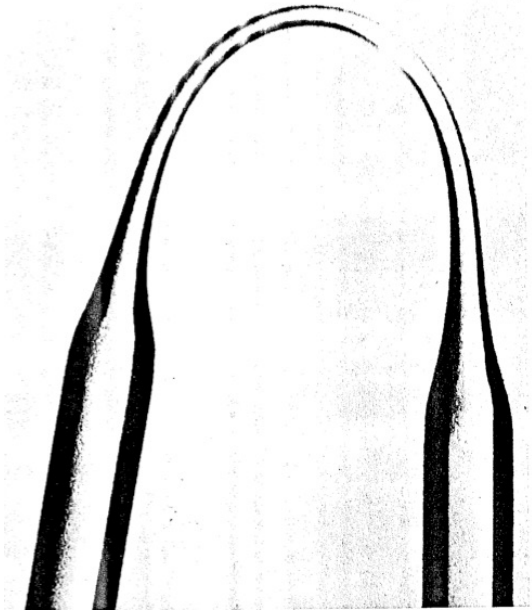
- 英国 vs. 德国
  - 德国的潜艇：U-boat
  - 英国的补给船

英国：

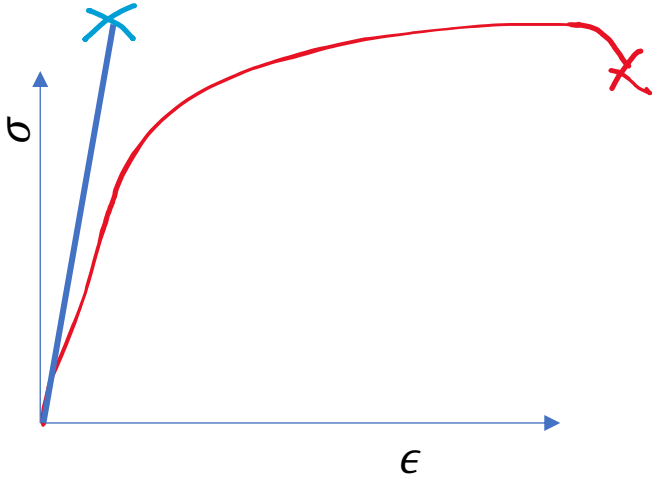
- 1941-1945
  - 英国设计：运输船 1万吨
  - 美国造：2710 艘 (18个船坞)
  - 断裂事故：几百上千次
  - 裂开两半：12 艘
  - 组织研究
- 这事儿的结果：

玻璃=脆？
金属=韧？



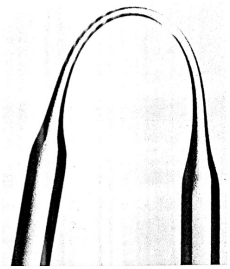


几个问题



- 金属之间有韧性有脆性的区别来自什么？

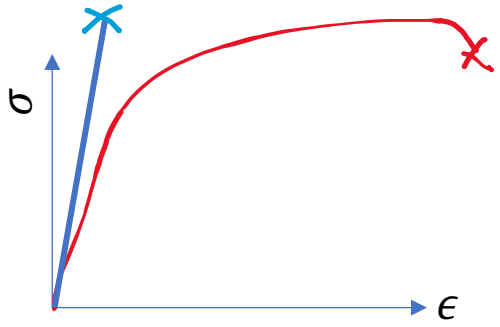
- 为什么陶瓷/玻璃之间会有区别？



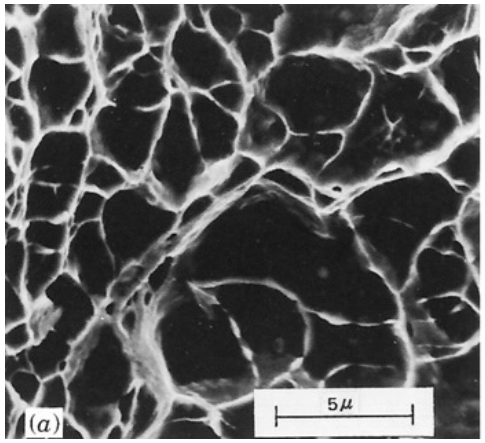
- 为什么船航行到低温海域的时候断了？

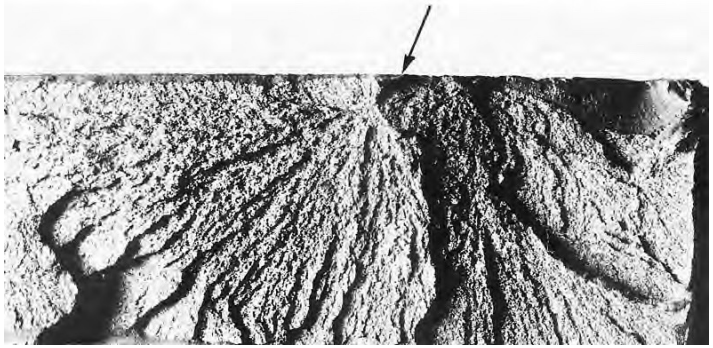
金属之间有韧性有脆性的区别来自什么？

断口的形态

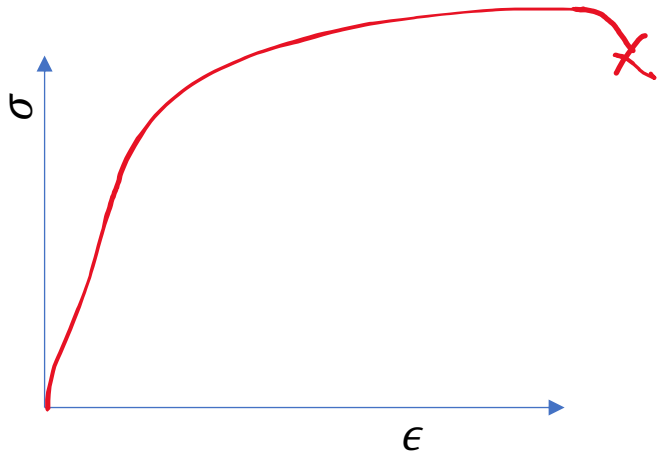


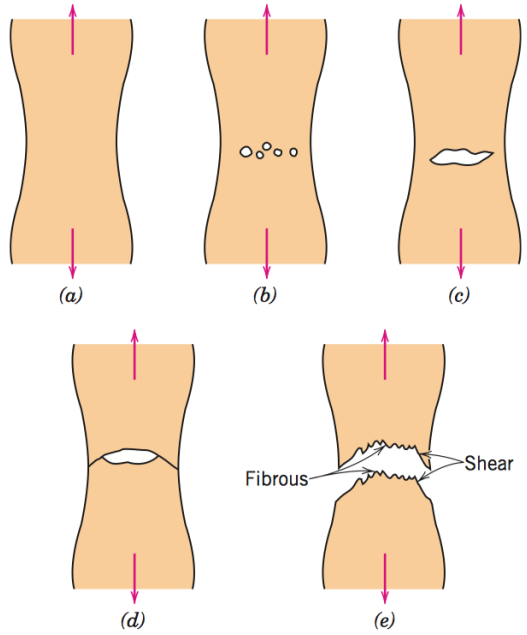
发生大量塑性变形（韧性）的断口 vs. 发生少量塑性变形（脆性）的断口

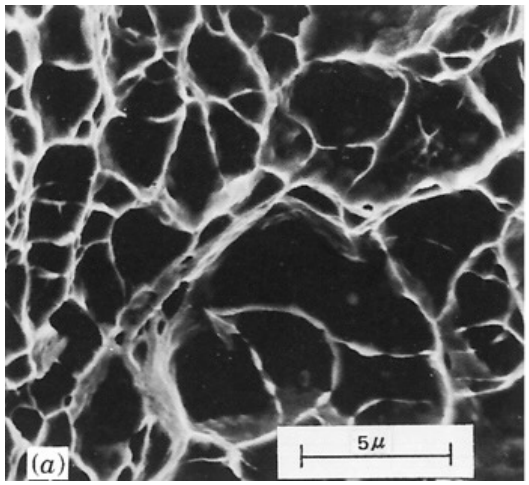




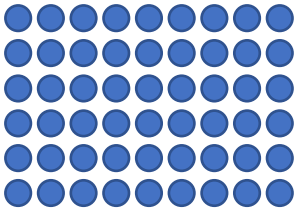
韧性断裂 (Ductile Fracture)

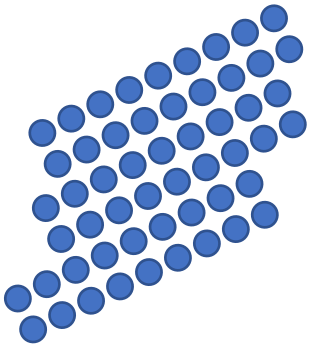


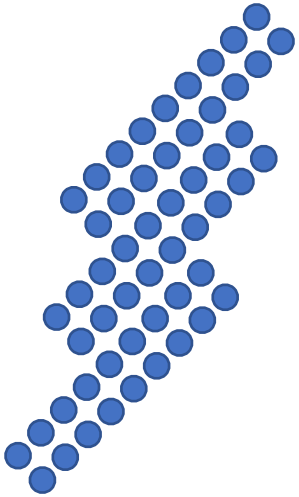


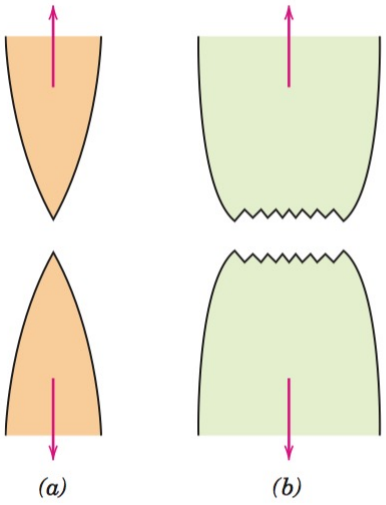


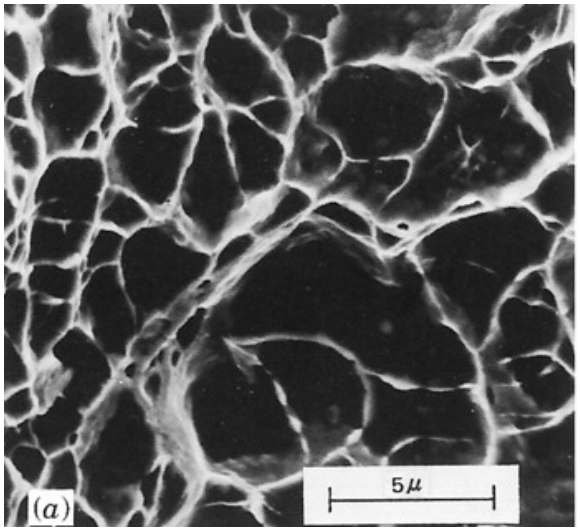
韧性断口的微观



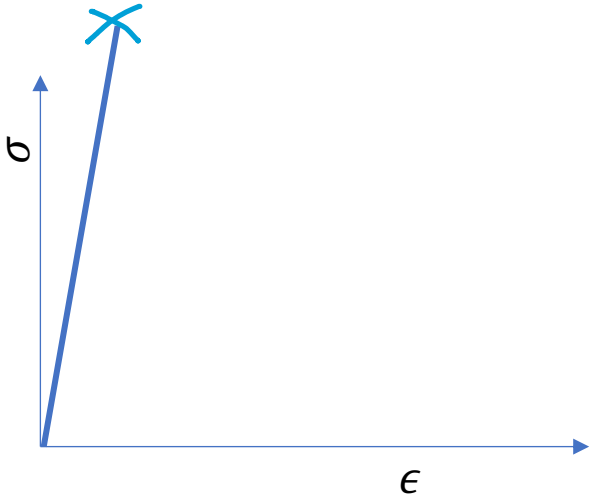


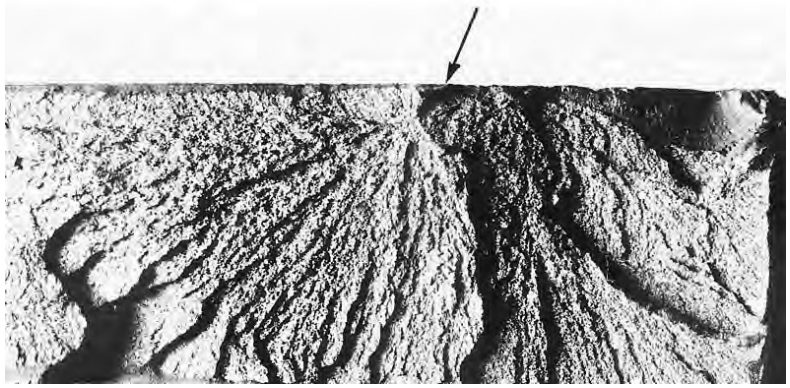


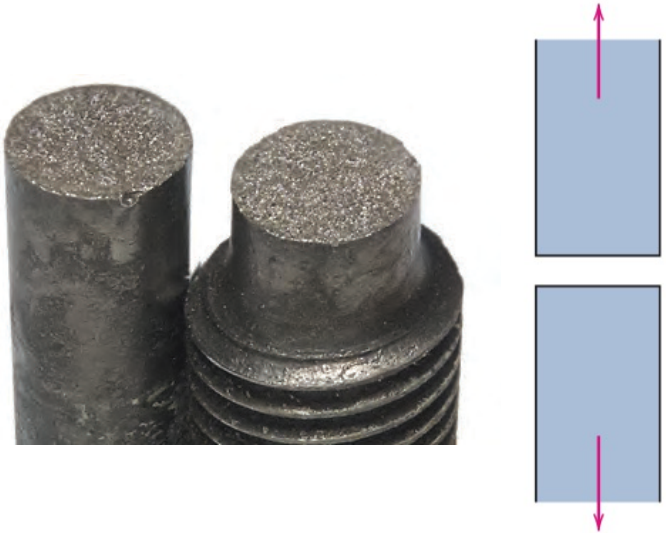




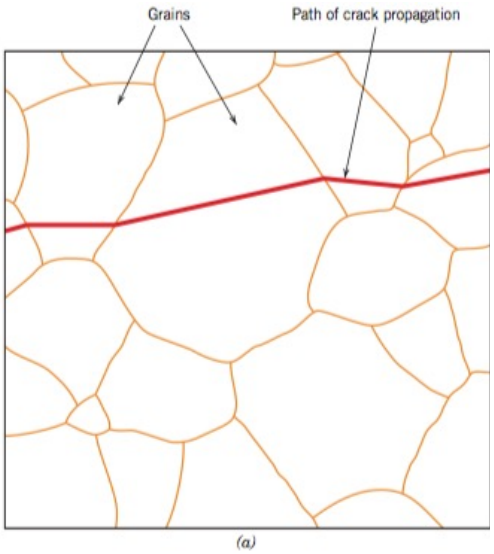
脆性断裂 (Brittle Fracture)

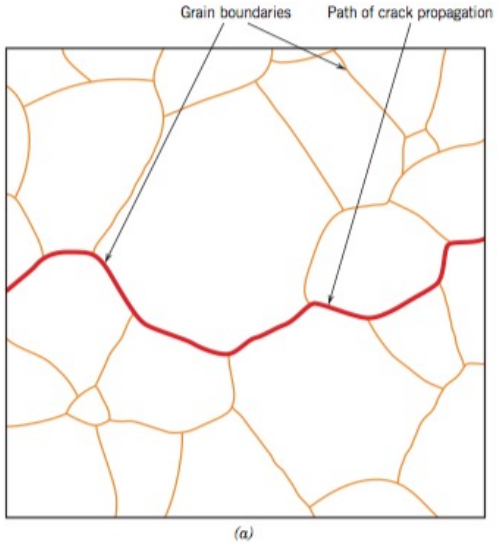


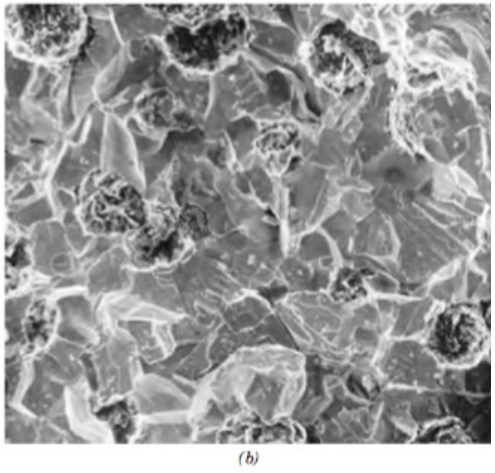


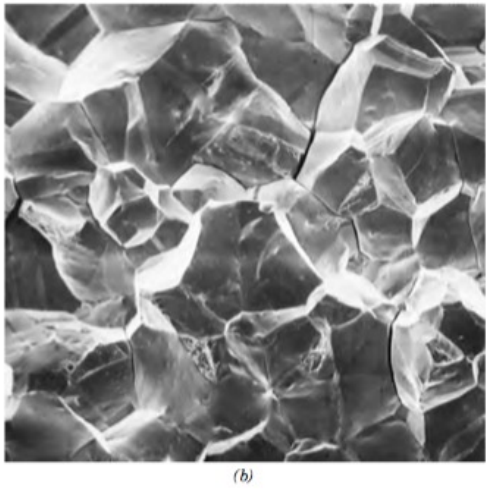


脆性断口 – 穿晶和沿晶


Grains
Path of crack propagation
(a)

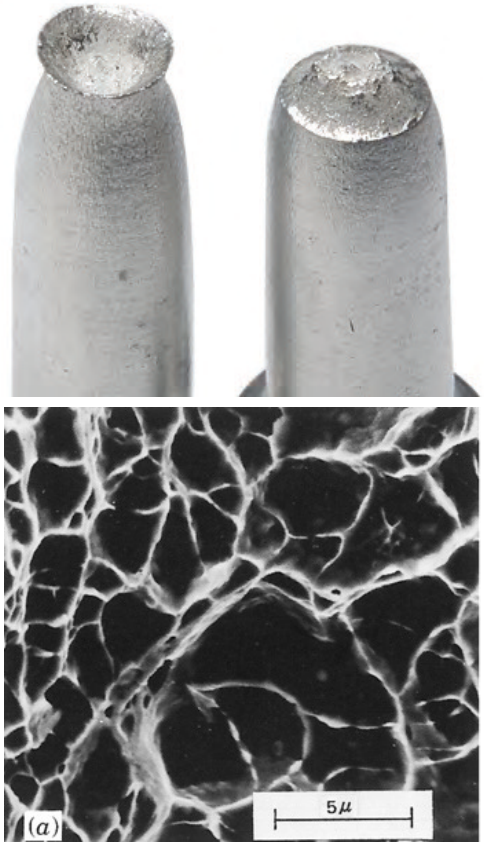

Grain boundaries
Path of crack propagation
(a)


(b)

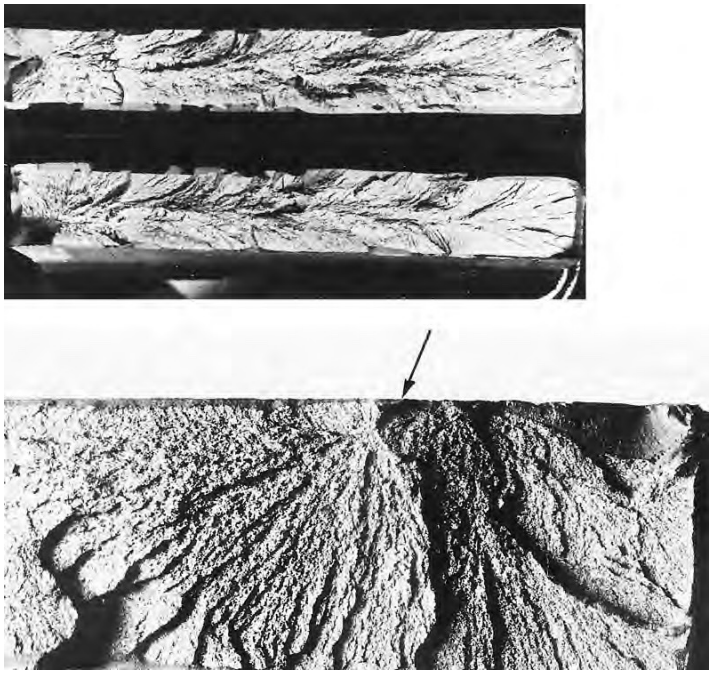

(b)

断口的形态

发生大量塑性变形（韧性）的断裂　　vs.　　发生少量塑性变形（脆性）的断裂。



?

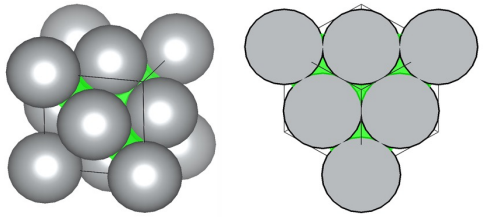


FCC, BCC 和 HCP的滑移系有多少？

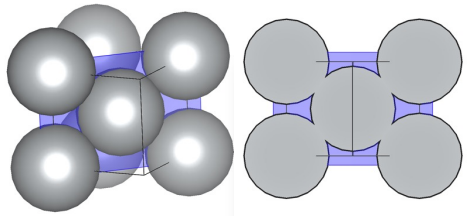
还记得密排面和密排方向吗？

- 密排面 (close-packed planes)

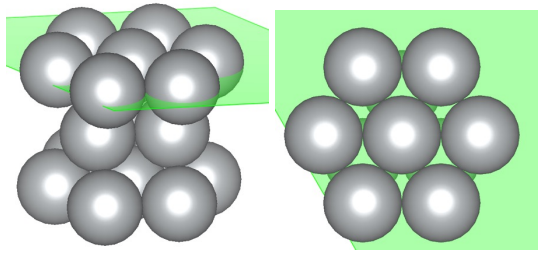
FCC - {111}



BCC – 无
稍微密一点的 {110}

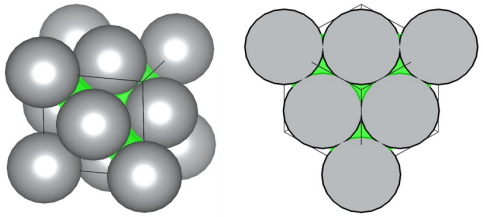


HCP-{0001}

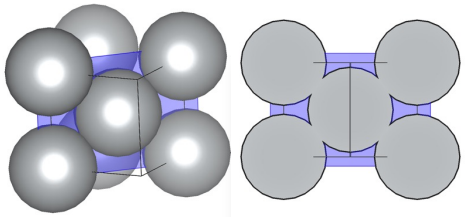


- 密排方向 (close-packed directions)

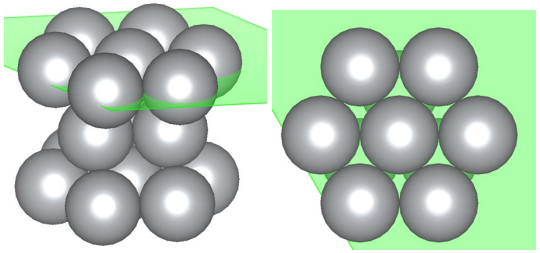
FCC – $< 1\bar{1}0 >$



BCC – $< 1\bar{1}1 >$



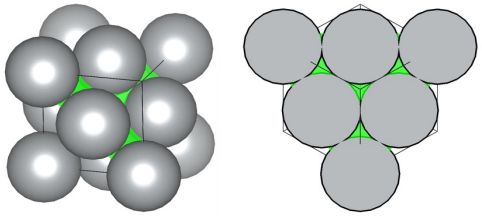
HCP - $<11\bar{2}0>$



FCC, BCC 和 HCP的滑移系有多少？

算算FCC有几个滑移系？

FCC - $\{111\} < 1\bar{1}0 >$

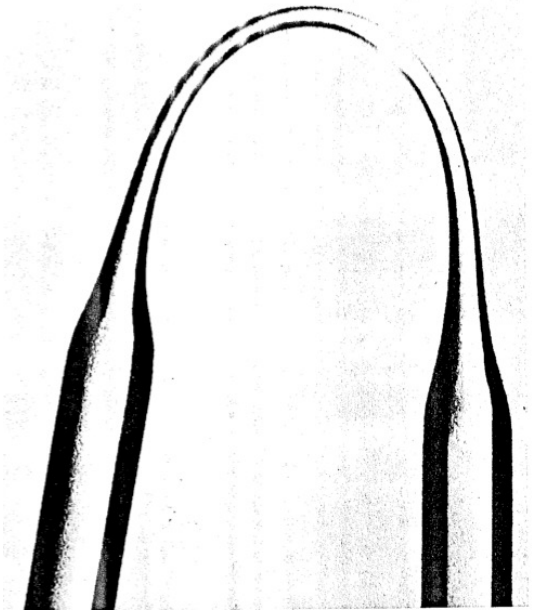


密排面和密排方向只能告诉你一个理论大概！！！

Metals	*Slip Plane*	*Slip Direction*	*Number of Slip Systems*
	Face-Centered Cubic		
Cu, Al, Ni, Ag, Au	$\{111\}$	$\langle 1\bar{1}0 \rangle$	12
	Body-Centered Cubic		
α-Fe, W, Mo	$\{110\}$	$\langle \bar{1}11 \rangle$	12
α-Fe, W	$\{211\}$	$\langle \bar{1}11 \rangle$	12
α-Fe, K	$\{321\}$	$\langle \bar{1}11 \rangle$	24
	Hexagonal Close-Packed		
Cd, Zn, Mg, Ti, Be	$\{0001\}$	$\langle 11\bar{2}0 \rangle$	3
Ti, Mg, Zr	$\{10\bar{1}0\}$	$\langle 11\bar{2}0 \rangle$	3
Ti, Mg	$\{10\bar{1}1\}$	$\langle 11\bar{2}0 \rangle$	6

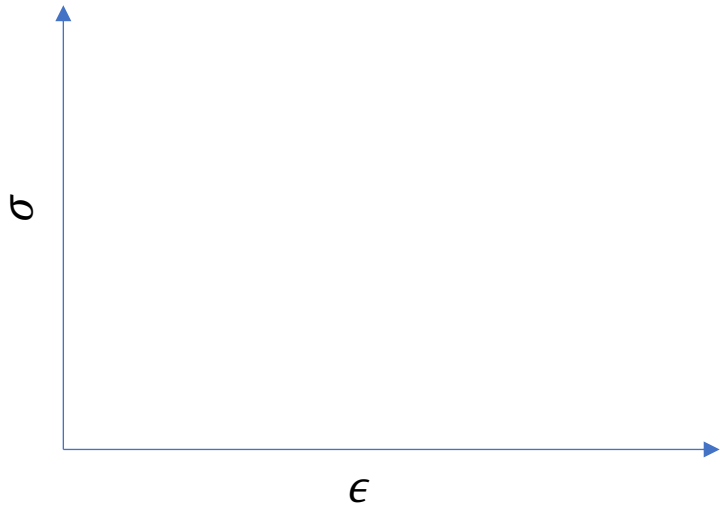
脆性断裂的另一个思考。。。

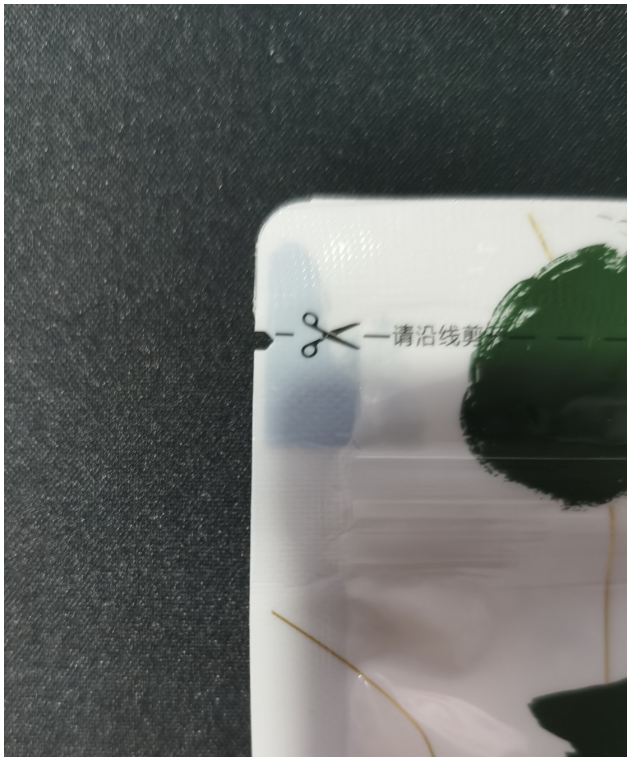
除开晶体结构，玻璃之间为什么会有区别？

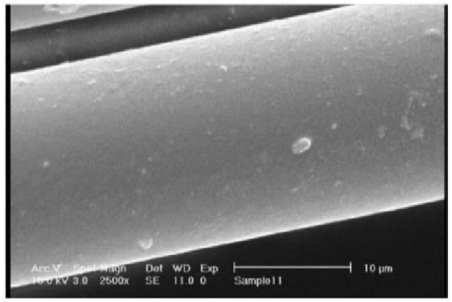


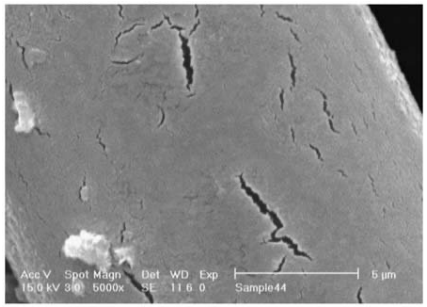
断裂和裂纹的关系?

撕零食袋儿



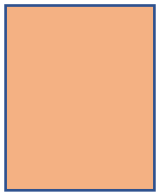




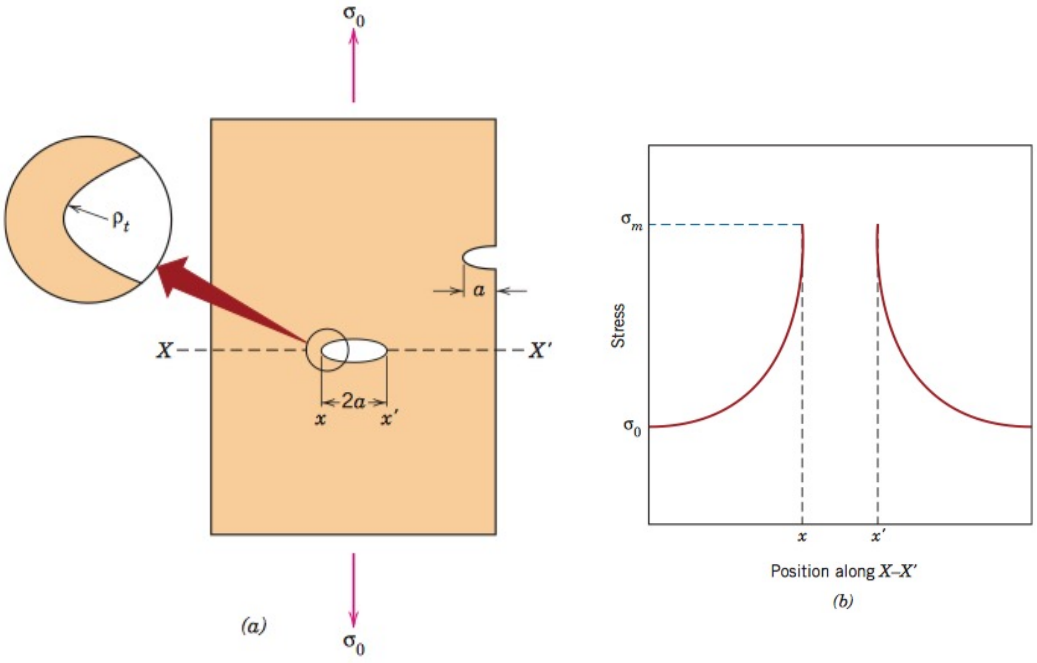


Shokrieh, M.M., Nasir, V. and Karimipour, H., 2012. Strength behavior and crack-formation mechanisms of E-glass fiber exposed to sulfuric acid environment. *Journal of composite materials*, *46*(7), pp.765-772.

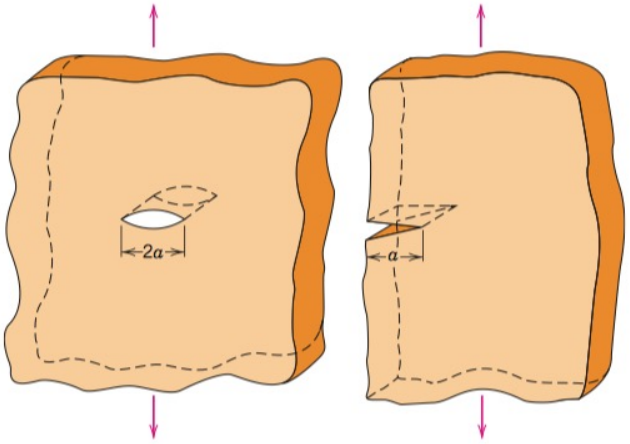
裂纹的害处：
应力集中 (Stress concentration)

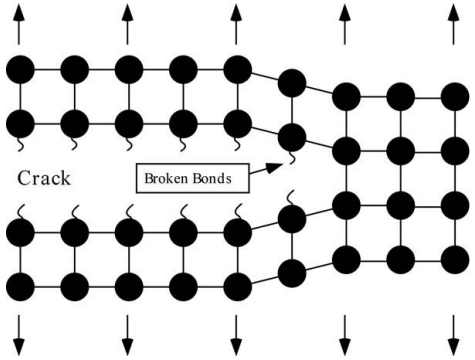


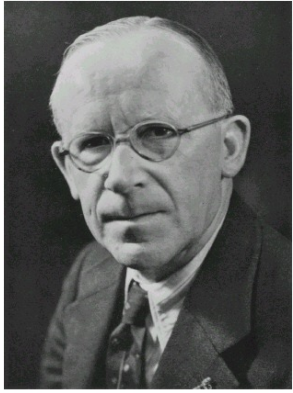
$$\sigma_m = 2\sigma_0\left(\frac{a}{\rho_t}\right)^{1/2}$$



断裂强度和裂纹的关系

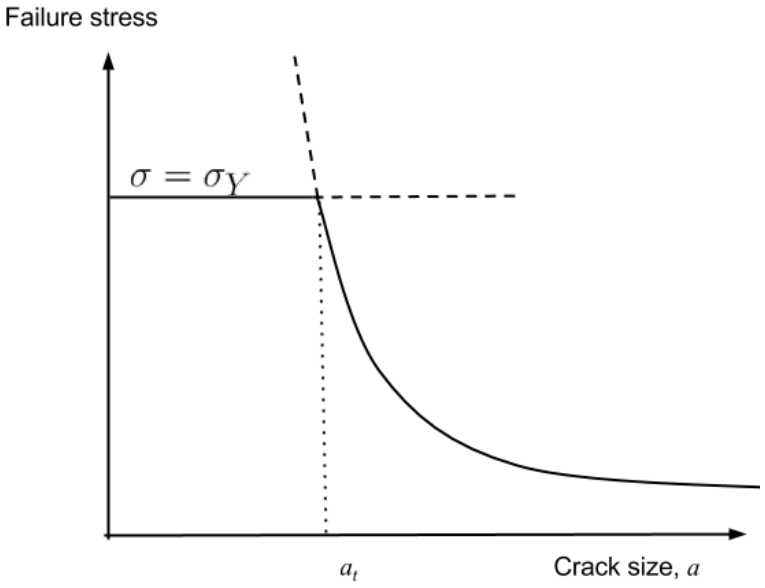






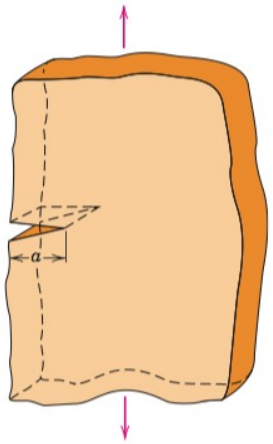
Alan Arnold Griffith FRS.
(Reproduced with permission from the Royal Society.)

$$\sigma_c = \left(\frac{2E\gamma_s}{\pi a}\right)^{\frac{1}{2}}$$



小练习

$$\sigma_c = \left(\frac{2E\gamma_s}{\pi a}\right)^{\frac{1}{2}}$$



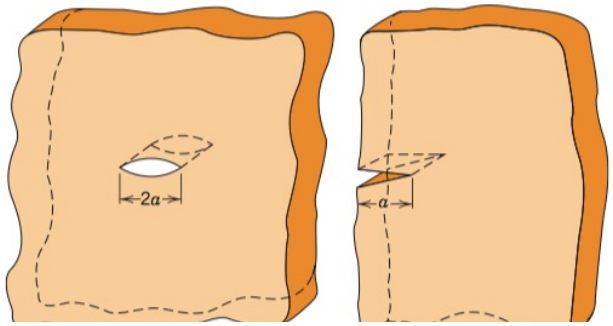
一块玻璃在受拉伸的状态，拉伸强度是40MPa，如果它的表面能是0.3J/m^2，杨氏模量 E = 69 GPa，多大的裂缝会让它无屈服断裂？

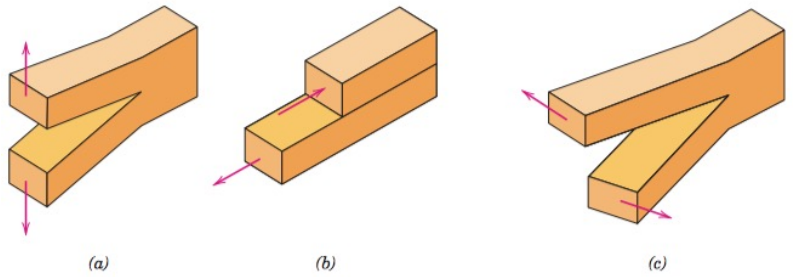
断裂韧性 (Fracture Toughness)

$$\sigma_c = \left(\frac{2E\gamma_s}{\pi a}\right)^{\frac{1}{2}}$$

$$\mathrm{K}_c = Y\sigma_c\sqrt{\pi a}$$

$$\mathrm{K}_{Ic} = Y\sigma_c\sqrt{\pi a}$$





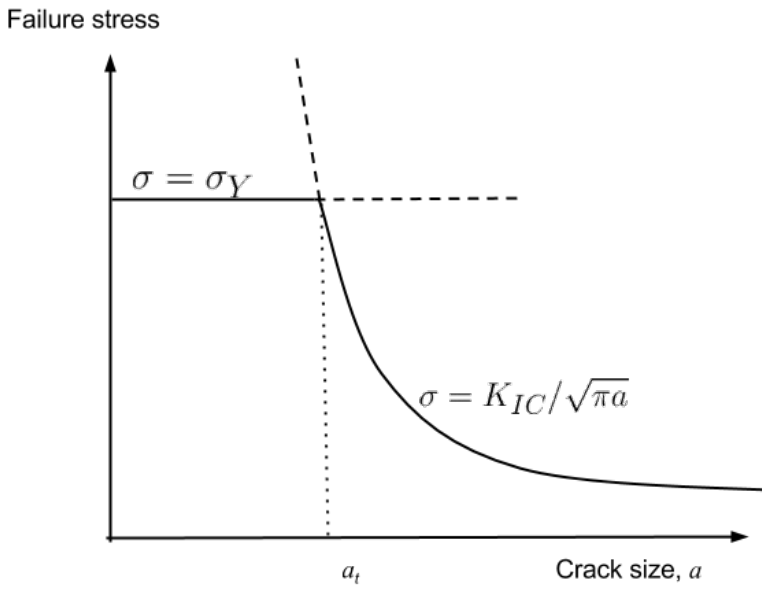
一些材料的断裂韧性

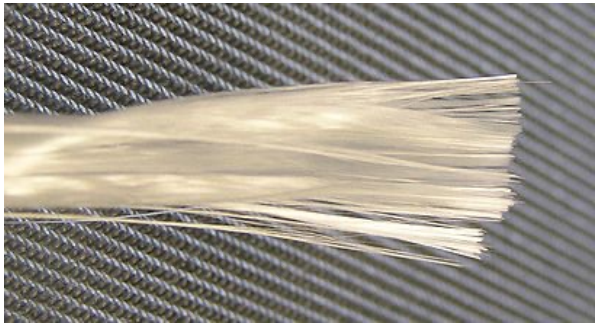
Material	Yield Strength MPa	Yield Strength ksi	K_{Ic} $MPa\sqrt{m}$	K_{Ic} $ksi\sqrt{in.}$
Metals				
Aluminum Alloy[a] (7075-T651)	495	72	24	22
Aluminum Alloy[a] (2024-T3)	345	50	44	40
Titanium Alloy[a] (Ti-6Al-4V)	910	132	55	50
Alloy Steel[a] (4340 tempered @ 260°C)	1640	238	50.0	45.8
Alloy Steel[a] (4340 tempered @ 425°C)	1420	206	87.4	80.0
Ceramics				
Concrete	—	—	0.2–1.4	0.18–1.27
Soda-Lime Glass	—	—	0.7–0.8	0.64–0.73
Aluminum Oxide	—	—	2.7–5.0	2.5–4.6
Polymers				
Polystyrene (PS)	—	—	0.7–1.1	0.64–1.0
Poly(methyl methacrylate) (PMMA)	53.8–73.1	7.8–10.6	0.7–1.6	0.64–1.5
Polycarbonate (PC)	62.1	9.0	2.2	2.0

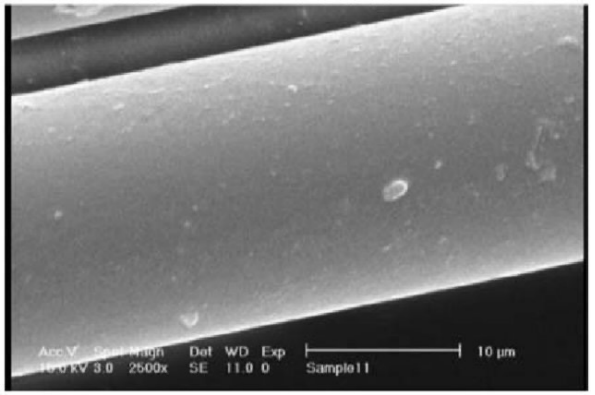
[a] **Source:** Reprinted with permission, *Advanced Materials and Processes,* ASM International, © 1990.

By Peter Dazeley

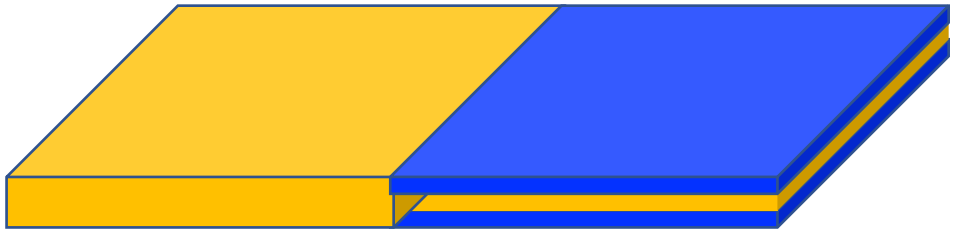
利用断裂强度来设计材料 （1）

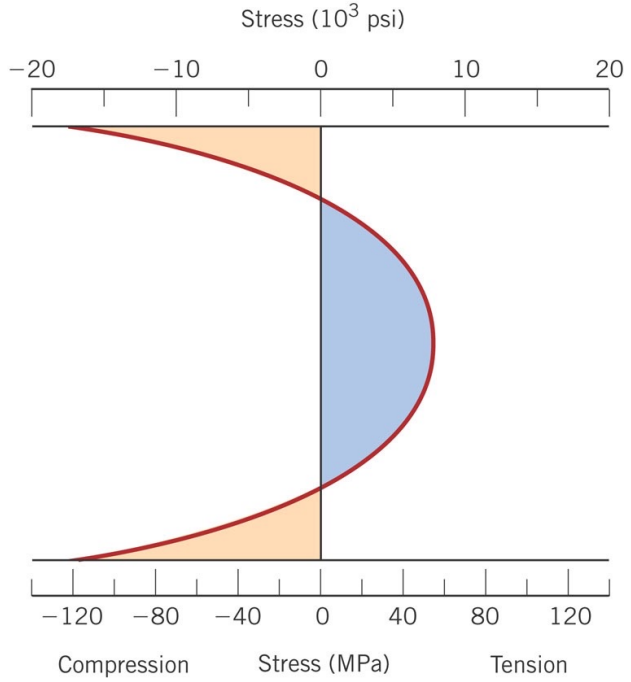




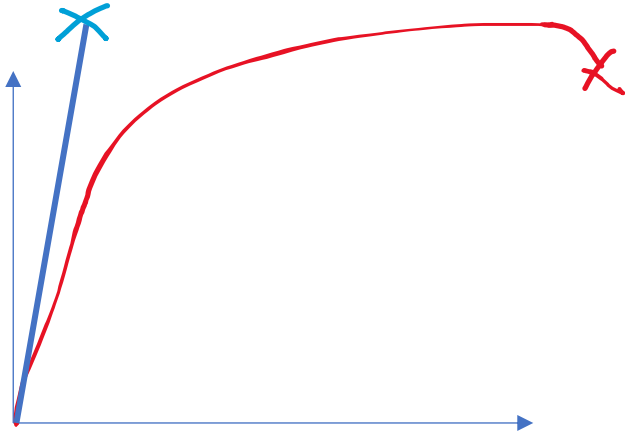


利用断裂强度来设计材料 （2）



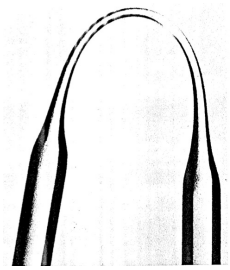


几个问题



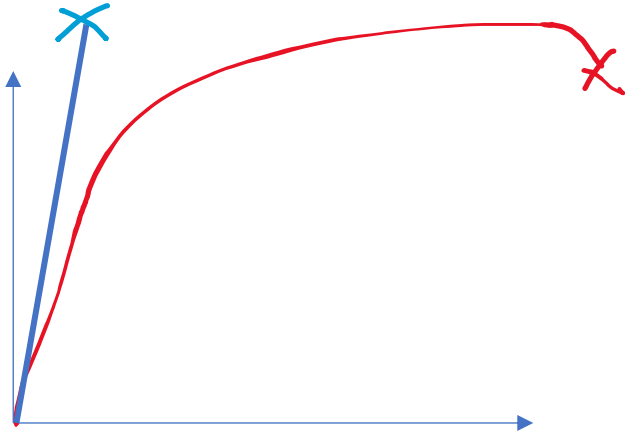
- 金属之间有韧性有脆性的区别来自什么？

- 为什么陶瓷/玻璃之间会有区别？



课后思考：
金属和陶瓷之间的韧性塑性巨大差别是为什么？
- 化学键
- 结构
- 致密度

几个问题



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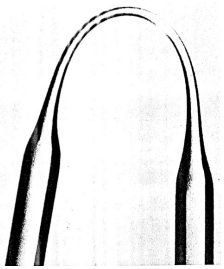

- 为什么船航行到低温海域的时候断了？

8.1 材料的硬脆转变