Problem Set 1

2. Annealed steel

$E = 200\ GPa$
$d_o = 13\ mm$
$l_o = 50\ mm$
$P_{max} = 67\ kN$
$P_f = 45\ kN$

(a) Tensile strength $= \frac{P_{max}}{\text{area}} = \frac{67\ kN}{\frac{\pi}{4}(13\ mm)^2} = 504.8\ MPa$

(b) Necking occurs after the maximum load. The rate of decrease of load due to decreasing area is greater than the rate of increase of load due to strain hardening. Therefore, load drops off after the initiation of a neck, and the load at fracture is less than the maximum (ultimate) load.

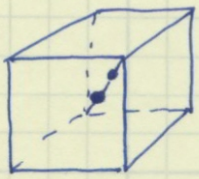
(c) $\sigma = 105\ MPa$

$\therefore \delta = \frac{\sigma}{E} \cdot l_o = \frac{105\ MPa \times 50\ mm}{200\ GPa} = 2.625 \times 10^{-2}\ mm$

—x—

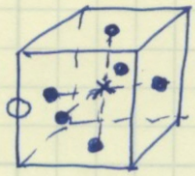
3. Problem 4-1 in Dieter.

(a) FCC



- Tetrahedral site $\left(\frac{1}{4}, \frac{1}{4}, \frac{1}{4}\right)$ is located $\frac{1}{4}$ of the way along the body diagonal from the corner of the cube.
- There are eight corners $\Rightarrow$ there are eight tetrahedral sites, each is located completely within the cube

$\therefore$ # of tetrahedral sites = 8

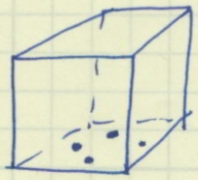


- Octahedral sites are of the type $\left(\frac{1}{2}, \frac{1}{2}, \frac{1}{2}\right)$
- This site is surrounded by six atoms marked by • located at the centers of the six faces of the cubic

- Similar sites exist at the middle of cube edges
  A typical site is shown by the O
- The sites on the edges are shared by 4 unitcells that share the edge.

$\therefore$ number of octahedral sites $= \underset{\text{body center}}{1} + \underset{\text{12 edges}}{\frac{1}{4} \times 12} = \frac{4}{\text{unit cell}}$

(b)



- $\left(\frac{1}{2}, \frac{1}{4}, 0\right)$ — These sites are located on the face of the unit cell.
  - There are 4 such sites per face, shared by two unit cells

$\therefore$ number of sites $= \underset{\text{sites/face}}{\frac{1}{2}} \times 4 \times \underset{\text{faces/cell}}{6} = \frac{12}{\text{unitcell}}$

- $\left(\frac{1}{2}, \frac{1}{2}, 0\right)$ — These sites are at the center of cube faces and are shared between two adjacent unit cells

$\therefore$ # of sites $= \underset{\text{sites/face}}{\frac{1}{2}} \times 1 \times \underset{\frac{\text{faces}}{\text{unitcell}}}{6} = \frac{3}{\text{unit cell}}$

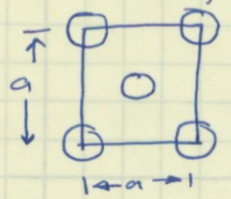
- $\left(\frac{1}{2}, 0, 0\right)$ — These sites are on cube edges

# of sites $= \underset{\text{4 unit cell share an edge}}{\frac{1}{4}} \times 1 \times \underset{\text{12 edge/cell}}{12} = \frac{3}{\text{unitcell}}$

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

4 (a) Copper $a = 3.60\text{Å}$, FCC structure. Find planar density of atoms

(i) (100) plane

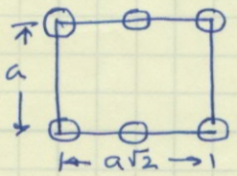


$$\#\text{ of atoms on face} = \underbrace{\frac{1}{4}\times 4}_{\text{corner}} + \underbrace{1}_{\text{center}} = 2$$

$$\text{area of face} = (3.6\times10^{-10}\text{ m})^2$$

$$\therefore \text{density of atoms} = \frac{2}{(3.6\times10^{-10}\text{m})^2} = 1.54\times10^{19}\ \frac{\text{atoms}}{\text{m}^2}$$

(ii) (110) plane

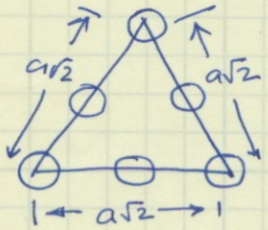


$$\#\text{ of atoms on plane} = \underbrace{\frac{1}{4}\times 4}_{\text{corner}} + \underbrace{\frac{1}{2}\times 2}_{\text{edge}} = 2$$

$$\text{area of plane} = 3.6\times10^{-10}\text{ m} \times 3.6\times10^{-10}\text{ m}\,\sqrt{2}$$

$$\therefore \text{density of atoms} = \frac{2}{(3.6\times10^{-10}\text{ m})^2\sqrt{2}} = 1.09\times10^{19}\ \frac{\text{atoms}}{\text{m}^2}$$

(iii) (111) plane



$$\#\text{ of atoms on plane} = \underbrace{\frac{1}{6}\times 3}_{\text{corner}} + \underbrace{\frac{1}{2}\times 3}_{\text{edge}} = 2$$

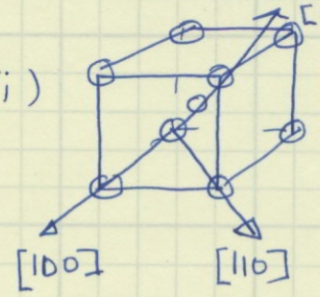
$$\text{area of plane} = \frac{1}{2}\,a\sqrt{2}\cdot a\sqrt{2}\sin 60 = \frac{\sqrt{3}}{2}\,a^2$$

$$\therefore \text{density of atoms} = \frac{2}{\frac{\sqrt{3}}{2}(3.6\times10^{-10}\text{ m})^2} = 1.78\times10^{19}\ \frac{\text{atoms}}{\text{m}^2}$$

(b) Fe $a = 0.287$ nm BCC structure

Find linear density of atoms

(i)



[100] direction → $\frac{1\text{ atoms}}{\text{edge}} = \frac{1\text{ atom}}{0.287\times10^{-9}\text{ m}}$

$= 3.48\times10^{9}$ atoms/m

[110] direction → $\frac{1\text{ atom}}{\text{face diagonal}} = \frac{1\text{ atom}}{(0.287\times10^{-9}\sqrt{2}\text{ m})}$

$= 2.46\times10^{9}$ atoms/m

[111] direction → $\frac{2\text{ atom}}{\text{body diagonal}} = \frac{2}{(0.287\times10^{-9}\sqrt{3}\text{ m})} = 4.023\times10^{9}\ \frac{\text{atoms}}{\text{m}}$

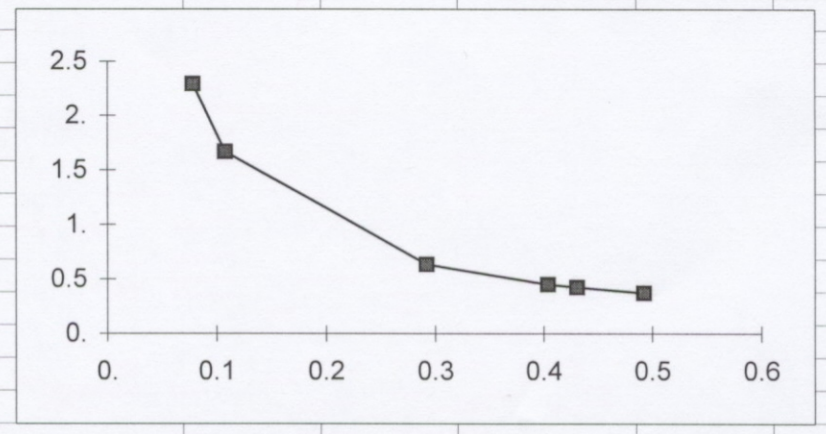
22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS
AMPAD

Area=122 mm^2

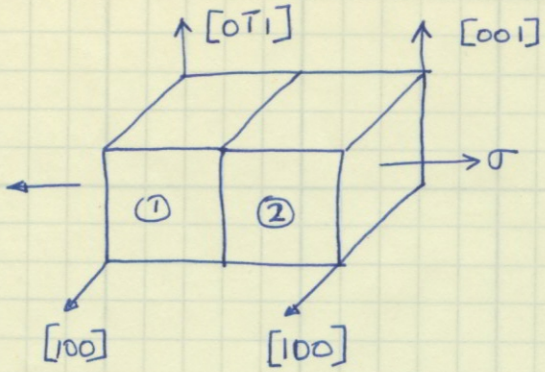
Load P (g)	90-phi (deg)	lambda (deg)	m=cos(phi) x cos(lambda)	sigma= P/A (MPa)	Tau-c= m.sigma (MPa)
20730	6.5	18	0.1077	1.6669	0.1795
7870	19.5	29	0.292	0.6328	0.1848
5280	30	30.5	0.4308	0.4246	0.1829
4600	40	40	0.4924	0.3699	0.1821
5600	61	62.5	0.4039	0.4503	0.1819
28500	85	85.5	0.0782	2.2917	0.1791

Deformation occurs at the same value of the resolved shear stress Tau-c of about 0.18 MPa for all orientations
This verifies Schmid's law

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6.



Slip systems in the simple cubic system are

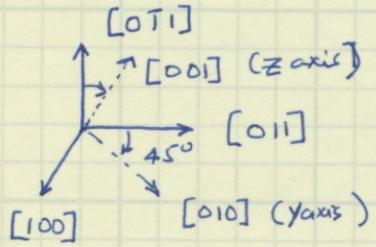
ⓐ (001) [100]
ⓑ (001) [010]
ⓒ (010) [100]
ⓓ (010) [001]
ⓔ (100) [010]
ⓕ (100) [001]

For crystal ②

- Loading direction is [010]
- This direction is perpendicular to the slip direction of slip systems ⓐ, ⓒ, ⓓ, ⓕ i.e. $\lambda = 90°$
- This direction lies in the slip plane of slip systems ⓑ and ⓔ i.e. $\phi = 90°$

∴ The Schmid factor $m = \cos\phi \cos\lambda = 0$ for all systems and crystal ② will not undergo slip.

For crystal ①



- The loading direction is [011]
- This direction is perpendicular to the slip direction of slip systems ⓐ and ⓒ i.e. $\lambda = 90°$
- This direction lies in the plane of slip systems ⓔ and ⓕ i.e. $\phi = 90°$
- Slip systems ⓑ and ⓓ are oriented with their slip directions and slip plane normals at 45° to the loading direction.

∴ crystal ① will undergo slip.