Engineering Materials

Ionic Bonding

$$E_N = E_R + E_A = \int F\,dr \qquad F_N = F_A + F_R = \frac{-m\cdot A}{r^{(m+1)}} + \frac{-n\cdot B}{r^{(n+1)}}$$

$$E_A = \frac{-A}{r} \qquad E_R = \frac{B}{r^n}$$

$$A = \frac{1}{4\pi\,\varepsilon_o}\cdot\left[(z_1\cdot e)\cdot(z_2\cdot e)\right] \qquad \varepsilon_o = 8.85\times 10^{-12}\,\frac{F}{m}$$

z - |# valence electons|

$$e = 1.602\times 10^{-19}\cdot C$$

$$r_o = \left(\frac{A}{n\cdot B}\right)^{\left(\frac{1}{1-n}\right)}$$

Atomic Packing Factors

Simple Cell

$a = 2\cdot R$

$APF = 0.5236$

BCC

$a = \frac{4\cdot R}{\sqrt{3}}$

$APF = 0.68$

FCC

$a = (2\cdot R)\cdot(\sqrt{2})$

$APF = 0.74$

HCP

$a = 2\cdot R$

$c = 1.633\cdot a$

$APF = 0.74$

R - radius of atom

$$V_c = a\cdot b\cdot c$$

$$APF = \frac{n\cdot\frac{4}{3}\cdot\pi\cdot R^3}{V_c} \qquad \rho = \frac{n\cdot A}{V_c\cdot\left(6.023\times 10^{23}\,\frac{atom}{mol}\right)} = \frac{mass}{volume}$$

A - Atomic Weight

n - # atoms in a cell

V_c - Volume of Cell

Diffraction

$$d_{hkl} = \frac{a}{\sqrt{h^2 + k^2 + l^2}}$$

$$\theta = 2\cdot\left[\sin^{-1}\cdot\left(\frac{n\cdot\lambda}{2.\cdot d_{hkl}}\right)\right]$$

n - order

λ - wave length

d_{hkl} - interplanar spacing

θ - diffraction angle

Density

$$LD = \frac{L_c}{L_l}$$

$$PD = \frac{A_c}{A_p}$$

Vacancy Formation

$$N_v = N\cdot e^{\left(\frac{Q_v}{kT}\right)}$$

$$N = \frac{N_A\cdot\rho}{A}$$

T - absolute Temperature

k - Boltzmann's constant

N_A - Avogadro's number

A - atomic weight

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Weight Percent

$$C_1 = \frac{m_1}{m_1 + m_2} \cdot 100 \qquad C_1 = \frac{C'_1 \cdot A_1}{C'_1 \cdot A_1 + C'_2 \cdot A_2} \cdot 100$$

m - mass
n - # moles
A - Atomic weight

Atom Percent

$$C'_1 = \frac{n_{m1}}{n_{m1} + n_{m2}} \cdot 100 \qquad C'_1 = \frac{C_1 \cdot A_2}{C_1 \cdot A_2 + C_2 \cdot A_1} \cdot 100$$

Alloy Density

$$\rho_{ave} = \frac{100}{\left(\frac{C_1}{\rho_1} + \frac{C_2}{\rho_2}\right)} \qquad \rho_{ave} = \frac{C'_1 \cdot A_1 + C'_2 \cdot A_2}{\left(\frac{C'_1 \cdot A_1}{\rho_1} + \frac{C'_2 \cdot A_2}{\rho_2}\right)}$$

Atomic Weight

$$A_{ave} = \frac{100}{\left(\frac{C_1}{A_1} + \frac{C_2}{A_2}\right)} \qquad A_{ave} = \frac{C'_1 \cdot A_1 + C'_2 \cdot A_2}{100}$$

Mass/Unit Volume (Density)

$$C''_1 = \frac{C_1}{\left(\frac{C_1}{\rho_1} + \frac{C_2}{\rho_2}\right)} \cdot 10^3$$

Grain Size

$$N = 2^{n-1}$$

N - # grains/inch
n - grain size

$$n = 1 + \frac{\log(N)}{\log(2)}$$

$$\mathrm{GrainDiameter} = \frac{\left(\sqrt{N}\right)^{-1}}{\mathrm{magnification}}$$

$$\mathrm{GrainSize} = \frac{\left(\frac{\mathrm{linelength}}{\mathrm{grains}}\right)}{\mathrm{magnification}}$$

Dislocation Vector

$$\vec{b} = \frac{a}{2}\,[hkl]$$

[hkl] - direction with greatest line density

$$|b| = \frac{a}{2} \cdot \sqrt{h^2 + k^2 + l^2}$$

Steady State Diffusion

$$J = \frac{M}{At}$$

M - # atoms

$$J = -D \cdot \frac{C_a - C_b}{X_a - X_b} \qquad J = -D \cdot \frac{\Delta C}{\Delta X}$$

J - Diffusion Flux
D - Diffusion Coefficient
D_o - Pre-exponential
A - area
t - time
ΔX - diffusion distance
C - concentration

Non-Steady State Diffusion

$$D = D_o \cdot e^{\left(\frac{-Q_d}{R \cdot T}\right)}$$

$$K = 8.62 \cdot 10^{-5} \cdot \frac{eV}{atom \cdot K}$$

$$R = 8.31 \cdot \frac{J}{mol \cdot K}$$

$$C_x = \frac{C_1 + C_2}{2} - \frac{C_1 - C_2}{2} \cdot \mathrm{erf}\left(\frac{x}{2\sqrt{Dt}}\right)$$

$$\frac{C_x - C_o}{C_s - C_o} = 1 - \mathrm{erf}\left(\frac{x}{2 \cdot \sqrt{D \cdot t}}\right)$$

C_1 - initial concentration in block 1
C_2 - initial concentration in block 2
C_x - desired concentration
C_o - initial concentration
C_s - surface concentration

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$\sigma = \frac{P}{A_o}$ $\quad \sigma = E \cdot \varepsilon$ $\quad \varepsilon = \frac{\Delta L}{L_o}$ $\quad \frac{L}{L_o} = \frac{A_o}{A}$

$\sigma_T = \frac{P}{A_i}$ $\quad \sigma_T = \sigma(1+\varepsilon)$ $\quad \varepsilon_T = \ln\left(\frac{L_i}{L_o}\right)$

$\sigma_T = K \cdot \varepsilon_T^{\,n}$ $\quad \sigma_w = \frac{\sigma_y}{N}$ $\quad \varepsilon_T = \ln(1+\varepsilon)$

N - safety factor

TS = $\sigma_{necking}$

$TS_{MPa} = 3.45 \cdot HB$

$TS_{psi} = 500 \cdot HB$

$E = 2G(1+\nu)$

$\tau = G \cdot \gamma$ $\quad \tau = \frac{P}{A_o}$ $\quad \nu = \frac{-\varepsilon_x}{\varepsilon_z}$ $\quad \nu = \frac{-\varepsilon_y}{\varepsilon_z}$

$U_r = \frac{\sigma_y^{\,2}}{2 \cdot E} = \frac{1}{2} \cdot \sigma_y \cdot \varepsilon_y$ $\quad \%EL = \left(\frac{L_f - L_o}{L_o}\right) \cdot 100$

$\%RA = \left(\frac{A_o - A_f}{A_o}\right) \cdot 100$

$$E = \left(\frac{dF}{dr}\right)_{r_o} \qquad E = \frac{-2A}{\left(\frac{A}{n \cdot B}\right)^{\left(\frac{3}{1-n}\right)}} + \frac{n \cdot B(n+1)}{\left(\frac{A}{n \cdot B}\right)^{\left(\frac{n+2}{1-n}\right)}}$$

σ_T - true stress
σ - engineering stress
ε_T - true strain
ε - strain
τ - shear stress
L - length
A - area
E - modulus of elasticity
G - shear modulus
υ - poison's ratio
P - load
K, n - material constants
U_r - modulus of resilience
(strain energy)
RA - reduction of area
EL - ductility
TS - tensile strength

Brinell hardness

$$HB = \frac{2 \cdot P}{\pi \cdot D \cdot \left(D - \sqrt{D^2 - d^2}\right)}$$

P - load (500 Kg)
D - diameter of sphere (mm)
d - diameter of indentation (mm)

Vickers micro-hardness

$$HV = \frac{1.845 \cdot P}{d_1^{\,2}}$$

P - load
d_1 - diagonal length (mm)

Knoop micro-hardness

$$HK = \frac{14.2 \cdot P}{L^2} \qquad \frac{L}{b} = 7.11 \qquad \frac{b}{t} = 4.0$$

L - long diagonal distance (mm)
b - short diagonal distance (mm)
t - depth of indentation (mm)

$\tau_r = \sigma \cdot \cos(\phi) \cdot \cos(\lambda)$

$\sigma_y = \frac{\tau_{crss}}{(\cos(\phi) \cdot \cos(\lambda))_{max}}$

τ_r - resolved shear stress
ϕ - < between slip direction and axial load
λ - < between normal to slip plane and axial load

$d^n - d_o^{\,n} = k \cdot t$ $\quad$ n, k - constants, n=2

$\ln(d) = A + B \cdot \ln(t)$ $\quad$ A, B - constants

$\sigma_y = \sigma_o + \frac{k_y}{\sqrt{d}}$ $\quad$ d - average grain diameter
σ_o, k_y - constants

$\tau_{crss} = \tau_o + A \cdot \sqrt{\rho\, d}$

$\%CW = \left(\frac{A_o - A_d}{A_o}\right)100$

τ_{crss} - critical resolved shear stress
A - atomic weight
CW - cold work
ρ_d - dislocation density
τ_o - constant

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$$\cos(\phi) = \frac{(h \cdot u + k \cdot v + l \cdot w)}{\sqrt{h^2 + k^2 + l^2} \cdot \sqrt{u^2 + v^2 + w^2}}$$

ϕ - angle between vectors

Mass Fraction

$$W_1 = \frac{C_2 - C_o}{C_2 - C_1} \qquad W_2 = \frac{C_1 - C_o}{C_2 - C_1}$$

Volume Fraction

$$V_\alpha = \frac{v_\alpha}{v_\alpha + v_\beta} = \frac{\frac{W_\alpha}{\rho_\alpha}}{\frac{W_\alpha}{\rho_\alpha} + \frac{W_\beta}{\rho_\beta}} \qquad W_\alpha = \frac{V_\alpha \cdot \rho_\alpha}{V_\alpha \cdot \rho_\alpha + V_\beta \cdot \rho_\beta}$$

$$W_E = \frac{C_o - C_\alpha}{C_E - C_\alpha} \qquad W_\alpha' = \frac{C_E - C_o}{C_E - C_\alpha}$$

$$W_{\alpha E} = W_\alpha - W_\alpha'$$

$$W_\alpha = \frac{C_\beta - C_o}{C_\beta - C_\alpha} \qquad W_\beta = \frac{C_o - C_\alpha}{C_\beta - C_\alpha}$$

Conversions / Constants

$$N_A = 6.023 \times 10^{23} \cdot \frac{\text{atoms}}{\text{mol}}$$

$${}^oK = {}^oC + 273.15$$

$${}^oR = {}^oF + 459.67$$

$$k = 1.38 \times 10^{-23} \cdot \frac{J}{\text{atom} \cdot {}^oK}$$

$$1 \cdot F = \frac{s^2 \cdot C^2}{Kg \cdot m^2}$$

$$k = 8.62 \times 10^{-5} \cdot \frac{eV}{\text{atom} \cdot {}^oK}$$

$$eV = 1.6 \times 10^{-19} \cdot N \cdot m$$

$$R = k = 8.31 \frac{J}{\text{mol} \cdot {}^oK}$$

$$\text{amu} = \frac{g}{\text{mol}}$$

$$\sigma_m = \sigma_a = \frac{\sigma_{max} - \sigma_{min}}{2}$$

σ_a - stress amplitude

σ_m - mean stress

$$\dot{\varepsilon}_s = k_1 \sigma^n$$

$\dot{\varepsilon}_s$ - steady state creep

$$\dot{\varepsilon}_s = k_2 \sigma^n e^{\left(\frac{-Q_c}{RT}\right)}$$

$$P + F = C + N$$

components

variables

Freedom

P # phases