COE-C2004 - Materials Science and Engineering

2021-2022 Autumn II

Assignment 6, 12.12.2021

Solutions

1 (5 points)

Density-Property
Extrusion-Processing
Crystalline-Structure
Amorphous-Structure
Elastic Modulus-Property

2 (5 points)

e- Metallic
a- Covalent
c- Van der Waals
a- Covalent
c- Van der Waals

3 (10 points: 2×2 for a + 3×2 for b, -1 point if the symbol is wrong)

(a-1) $[2\bar{3}2]$
(a-2) $(3\bar{2}4)$
(b-1) BCC {110}
(b-2) FCC {100}

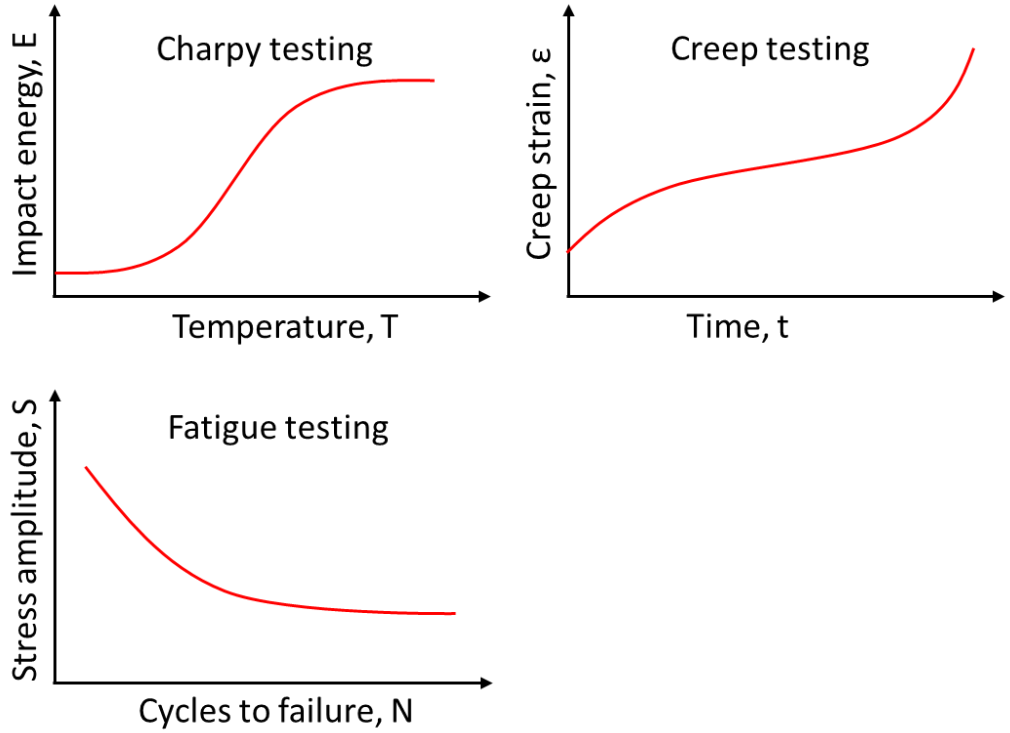
(b-1) The circular cross-sections of the atoms shown form a rectangle when they are connected by lines through their centers. Specifically, the longer edge of the rectangle is larger than the smaller edge by a factor of √2, consistent with the ratio of the rectangular plane that results when a cubic unit cell is cut along {110} plane. The short edges of the rectangle are edges of the cube, so they are <100> directions. The longer edges of the rectangle are the face diagonals of the cube. Note that atoms are touching along <100> directions and there are gaps between the atoms along {110} directions. This is consistent with the simple cubic (SC) structure.
(b-2) The circular cross-sections of the atoms shown form a square when they are connected by lines through their centers. Cubic unit cells cut along {100} planes will feature this shape. The edges of the square are edges of the cube, so they are <100> directions. We see no atoms touching each other along any vectors that lie in the {100} plane. The cubic structure that features no close-packing on cube faces is the body-centered cubic (BCC) structure.

4 (12 points: 2×6)

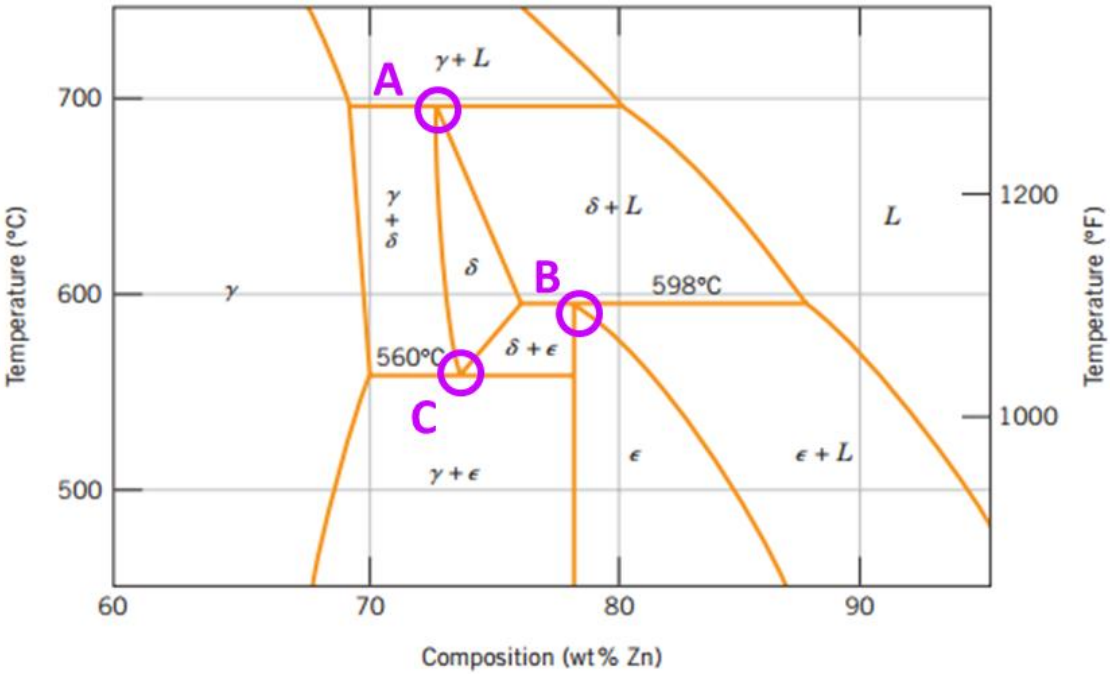
1-Vacancy, 2-Interstitial foreign atom, 3-Substitutional foreign atom, 5-Dislocation, 6-Decorated dislocation (dislocation with interstitial foreign atoms segregation at the dislocation core), 7-Grain boundary.

Prof. Dr.-Ing. Junhe Lian junhe.lian@aalto.fi Tel.: +358 50 477 0765
Adv. Manufacturing and Materials | Department of Mechanical Engineering | School of Engineering | Aalto University
Mail address: P.O. Box 14200, FI-00076 Aalto, Finland; Visiting address: Puumiehenkuja 3, 02150 Espoo, Finland

5 (9 points: 3 figures + 6 axis titles)



6 (9 points: 3 reaction names and markers or values + 3 functions ×2)



A: peritectic reaction: $L + \gamma \Leftrightarrow \delta$ (Temperature=680°C-700°C, wt% Zn =72%-74%.)

B: peritectic reaction: $L + \delta \Leftrightarrow \varepsilon$ (Temperature=598°C, wt% Zn =76%-78%.)

C: eutectoid reaction: $\delta \Leftrightarrow \gamma + \varepsilon$ (Temperature=560°C, wt% Zn =73%-75%.)

Prof. Dr.-Ing. Junhe Lian junhe.lian@aalto.fi Tel.: +358 50 477 0765
Adv. Manufacturing and Materials | Department of Mechanical Engineering | School of Engineering | Aalto University
Mail address: P.O. Box 14200, FI-00076 Aalto, Finland; Visiting address: Puumiehenkuja 3, 02150 Espoo, Finland

7 (15 points)

This problem asks for us to determine to what temperature a cylindrical rod of 1025 steel 75.00 mm long and 10.000 mm in diameter must be cooled from 25 °C in order to have a 0.008 mm reduction in diameter if the rod ends are maintained rigid. There will be two contributions to the diameter decrease of the rod; the first is due to thermal contraction (which will be denoted as Δd_1), while the second is from Poisson's lateral contraction as a result of elastic deformation from stresses that are established from the inability of the rod to contract as it is cooled (denoted as Δd_2).

According to the definition of thermal extension coefficient, the magnitude of Δd_1 may be computed using:

$$\Delta d_1 = d_0 \alpha_l (T_f - T_0)$$ Eq.1 (1 point)

Then, Δd_2 is related to the transverse strain (ε_x) according to:

$$\frac{\Delta d_2}{d_0} = \varepsilon_x$$ Eq. 2 (1 point)

Also, transverse strain and longitudinal strain (ε_z) are related according to:

$$\varepsilon_x = -\nu \varepsilon_z$$ Eq. 3 (1 point)

where ν is Poisson's ratio.

Furthermore, the longitudinal strain is related to the modulus of elasticity:

$$\varepsilon_z = \frac{\sigma}{E}$$ Eq. 4 (1 point)

In addition, thermal stress is equal to:

$$\sigma = E\alpha_l (T_0 - T_f)$$ Eq. 5 (1 point)

Combine Eqs. 2 – 5:

$$\frac{\Delta d_2}{d_0} = -\frac{\nu E \alpha_l (T_0 - T_f)}{E} = -\nu \alpha_l (T_0 - T_f)$$

$$\Delta d_2 = -d_0 \nu \alpha_l (T_0 - T_f)$$ (2 points)

The total Δd is

$$\Delta d = \Delta d_1 + \Delta d_2 = d_0 \alpha_l (T_f - T_0) + d_0 \nu \alpha_l (T_f - T_0) = d_0 \alpha_l (T_f - T_0)(1 + \nu)$$ (2 points)

The Poisson's ratio can be calculated according to:

$$G = E/2(1 + \nu)$$ Eq. 6 (1 point)

$$\nu = \frac{E}{2G} - 1 = \frac{208\ \text{GPa}}{2*80\ \text{GPa}} - 1 = 0.3$$ (2 points)

Therefore,

$$-(0.008\ \text{mm}) = (10.000\ \text{mm})\left[12.0 \times 10^{-6}\ (°\text{C})^{-1}\right](T_f - 25°C)(1 + 0.30)$$ (1 point)

Solving the above expression for T_f:

T_f = -26.3 °C (2 points)

8. (5 points × 4 = 20, without description/explanation:10 points)

Electrical conductivity σ: the proportionality constant between current density and applied electric field; also, a measure of the ease with which a material is capable of conducting an electric current (unit: $(\Omega \cdot m)^{-1}$).

$\sigma_{\text{metals}} > \sigma_{\text{ceramics}} \sim > \sigma_{\text{polymers}}$: Metals have the free electrons as charger carrier and there is an overlap of an empty band and a filled band, that makes metals have the largest electrical conductivity on the order of $10^7\ (\Omega \cdot m)^{-1}$. Ceramics and polymers are electrical insulators with very low

Prof. Dr.-Ing. Junhe Lian junhe.lian@aalto.fi Tel.: +358 50 477 0765
Adv. Manufacturing and Materials | Department of Mechanical Engineering | School of Engineering | Aalto University
Mail address: P.O. Box 14200, FI-00076 Aalto, Finland; Visiting address: Puumiehenkuja 3, 02150 Espoo, Finland

conductivities, ranging between 10^{-10} and 10^{-20} $(\Omega \cdot m)^{-1}$, as the bandgap between the filled valence band and empty conduction band is relatively wide in insulators.

Heat capacity C is a property that is indicative of a material's ability to absorb heat from the external surroundings; it represents the amount of energy required to produce a unit temperature rise (unit: J/mol·K). **Specific heat** represents the heat capacity per unit mass (unit: J/kg·K). There are two ways in which this property may be measured, according to the environmental conditions accompanying the transfer of heat. One is the heat capacity while maintaining the specimen volume constant C_v; the other is for constant external pressure, which is denoted C_p. The magnitude of C_p is almost always greater than C_v. However, this difference is very slight for most solid materials at room temperature and below. $C_{\text{polymers}} > C_{\text{ceramics}} \sim > C_{\text{metals}}$: In most solids, the principal mode of thermal energy assimilation is by the increase in the vibrational energy of the atoms. Again, atoms in solid materials are constantly vibrating at very high frequencies and with relatively small amplitudes. Rather than being independent of one another, the vibrations of adjacent atoms are coupled by virtue of atomic bonding. These vibrations are coordinated in such a way that traveling lattice waves are produced. Other energy-absorptive mechanisms also exist that can add to the total heat capacity of a solid. In most instances, however, these are minor relative to the magnitude of the vibrational contribution. There is an electronic contribution in that electrons absorb energy by increasing their kinetic energy. However, the electronic contribution is ordinarily insignificant.

Thermal expansion coefficient (α_l or α_v): The fractional change in length divided by the change in temperature. Most solid materials expand upon heating and contract when cooled. The linear coefficient of thermal expansion is a material property that is indicative of the extent to which a material expands upon heating and has units of reciprocal temperature, $1/℃$, **or** $1/F$**.**

$\alpha_{l_{\text{polymers}}} > \alpha_{l_{\text{metals}}} > \alpha_{l_{\text{ceramics}}}$: for each class of materials (metals, ceramics, and polymers), the greater the atomic bonding energy, the deeper and narrower this potential energy trough. As a result, the increase in interatomic separation with a given rise in temperature will be lower, yielding a smaller value of α_l.

Thermal conductivity k: for steady-state heat flow, the proportionality constant between the heat flux and the temperature gradient (unit: W/m·K). Also, a parameter characterizing the ability of a material to conduct heat. Thermal conduction is the phenomenon by which heat is transported from high- to low-temperature regions of a substance. The property that characterizes the ability of a material to transfer heat is thermal conductivity.

$k_{\text{metals}} > k_{\text{ceramics}} > k_{\text{polymers}}$: Heat is transported in solid materials by both lattice vibration waves (phonons) and free electrons. In high-purity metals, the electron mechanism of heat transport is much more efficient than the phonon contribution because electrons are not as easily scattered as phonons and have higher velocities. Furthermore, metals are extremely good conductors of heat because relatively large numbers of free electrons exist that participate in thermal conduction. The thermal conductivity values of metals generally range between about 20 and 400 W/m·K. Nonmetallic materials are thermal insulators in as much as they lack large numbers of free electrons. Thus the phonons are primarily responsible for thermal conduction. Again, the phonons are not as effective as free electrons in the transport of heat energy as a result of the very efficient phonon scattering by lattice imperfections. Besides, for polymers, energy transfer is accomplished by the vibration and rotation of the chain molecules. The magnitude of the thermal conductivity depends on the degree of crystallinity; a polymer with a highly crystalline and ordered structure will have greater conductivity than the equivalent amorphous material. This is due to the more effective coordinated vibration of the molecular chains for the crystalline state.

Prof. Dr.-Ing. Junhe Lian junhe.lian@aalto.fi Tel.: +358 50 477 0765
Adv. Manufacturing and Materials | Department of Mechanical Engineering | School of Engineering | Aalto University
Mail address: P.O. Box 14200, FI-00076 Aalto, Finland; Visiting address: Puumiehenkuja 3, 02150 Espoo, Finland

9 (15 points)

(1) True
(2) True
(3) False, Before and after an edge dislocation has passed through some region of a crystal, the atomic arrangement is ordered and perfect. It is only during the passage of the extra half-plane that there is disorder.
(4) False, $G = \frac{E}{2(1+\nu)} = \frac{E}{2(1+0.3)} = 0.38E$
(5) False, The burger vector of an edge dislocation is perpendicular to its dislocation line.
(6) True
(7) True
(8) False, Generally, there is no distinct ductile-brittle transition behavior of HCP and FCC metals, as they have the most-close packing structure and their dislocation slip activation is not sensitive to temperature.
(9) False, Large supercooling will lead to a larger temperature gradient and more grain nucleation sites, which further results in smaller grain size than small supercooling.
(10) True
(11) True
(12) True
(13) False, Free electrons play a role in thermal conduction, not expansion.
(14) True
(15) False, Grain boundaries are deleterious to the performance of electronic phenomena. Besides, the thermal conductivity of a single crystal is also greater than that of the polycrystalline material because both phonons and free electrons are scattered at grain boundaries; thus, the efficiency of thermal transport and electrical conductivity is lower for the polycrystalline material.

Due date: 18:00, 12.12.2021.
Contact: MyCourses 'General discussion' channel

Prof. Dr.-Ing. Junhe Lian junhe.lian@aalto.fi Tel.: +358 50 477 0765
Adv. Manufacturing and Materials | Department of Mechanical Engineering | School of Engineering | Aalto University
Mail address: P.O. Box 14200, FI-00076 Aalto, Finland; Visiting address: Puumiehenkuja 3, 02150 Espoo, Finland