Nuclear Materials Engineering

Problem 1. (10 min) An alloy has the composition 50 wt % Ni – 30 wt % Fe – 15 wt % W – 5 wt % C. What is the composition of this same alloy in atom percent?

M_{Ni} = 58.69 g/mol
M_{Fe} = 55.85 g/mol
M_{W} = 183.84 g/mol
M_{C} = 12.01 g/mol

Problem 2. (15 min) As a fuel designer, compare the benefits and weaknesses of oxide, metal, and nitride nuclear fuels with respect to at least two material properties. Specify the type of reactor that these fuels may be best suited for.

Problem 3. (10 points) An element is introduced into an iron based alloy as a solute. It is oversized, which means it causes outward relaxation for neighboring atoms.

a) (5 min) Which type of defects (interstitial vs. vacancy) prefer to bind with this solute to form defect-solute complex? Why?

b) (5 min) For radiation induced segregation, will this element tend to migrate toward (enrichment) or away from (depletion) grain boundaries? Why?

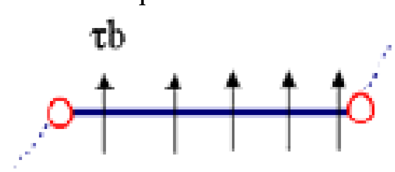
Problem 4. (20 points) An energetic particle created by neutron recoil will lose its energy in fuel and cladding through electronic and nuclear stopping mechanisms.

a) (10 min) Briefly explain the electronic and nuclear stopping mechanisms.

b) (5 min) Roughly plot the stopping power for electronic and nuclear stopping of the particle as a function of kinetic energy from 100 eV to 10 MeV.

c) (5 min) Mark the region on your plot where the energetic particle is most efficient at creating displacements.

Problem 5. (10 points) The Frank-Read process is a mechanism that describes how new dislocations are generated under an applied stress. The figure below shows the initial position when a shear stress (τ_b) is applied in the slip plane acting on a dislocation segment which is firmly anchored at two points. Use a series of schematic drawings to predict subsequent evolution of multiple dislocations.



Problem 6. (20 points)

a) (5 min) What is creep?

b) (5 min) If a very fine grain size is introduced into a cladding material, what changes are expected in the creep resistance? Briefly explain why.

c) (10 min) If the average secondary creep rate for a metal alloy under a tensile stress of 7 MPa varies with temperature according to the table below, what is the creep activation energy (KJ/mol)? (Assume the creep mechanism is governed by an empirical Arrhenius relationship, R = 8.314 J/mol-K)

Temperature	Creep Rate, $\dot{\varepsilon}$
700 ºC	7.5×10^{-7} s^{-1}
725 ºC	1.2×10^{-6} s^{-1}

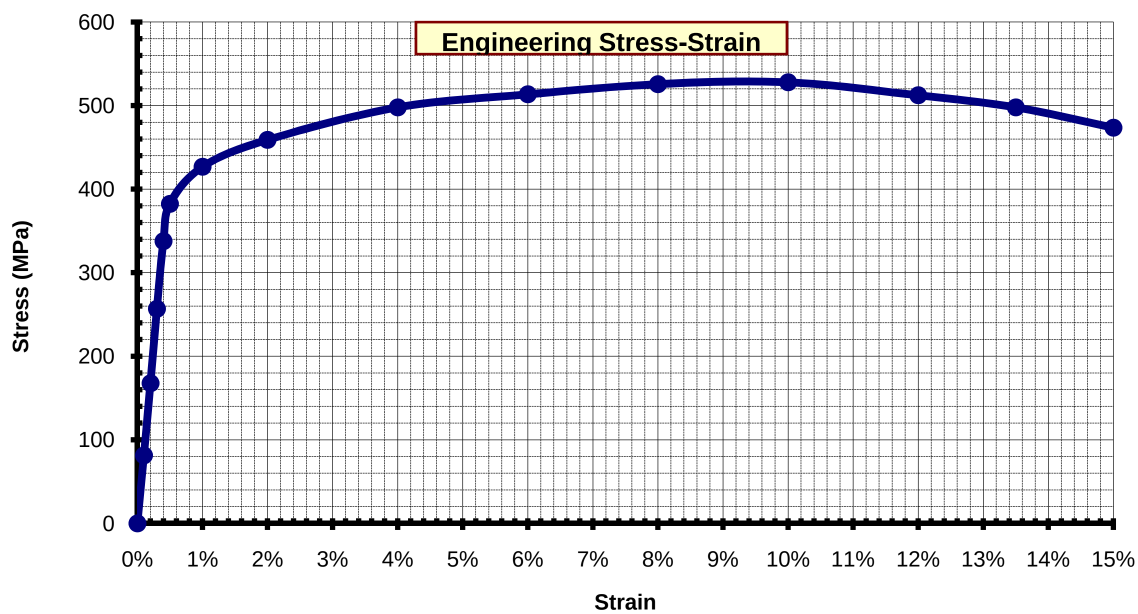
Problem 7. (20 min)

a) (5 min) The stress-strain curve given below is for a hypothetical metal. Estimate the modulus of elasticity, yield stress (0.2% offset), and ultimate tensile strength.

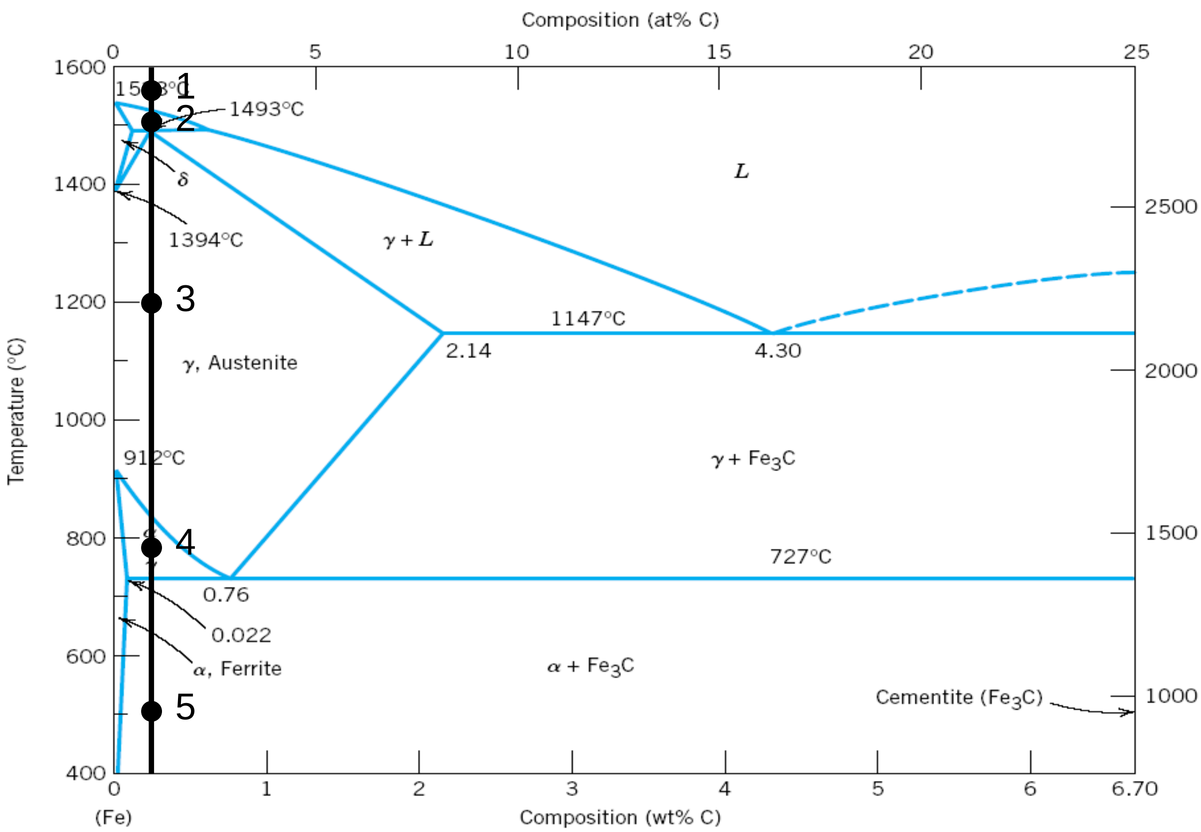
b) (5 min) Explain why dislocation motion is important to plastic deformation.

c) (5 min) Draw a 2-D sketch of an edge dislocation in a simple cubic lattice. Indicate the location of the dislocation "core" (the center) with the appropriate symbol and show the burgers vector.

d) (5 min) Sketch an FCC unit cell. What is the direction of the most favorable burgers vector for dislocation glide in a slip plane, $\vec{b}$, (expressed as a family of directions) and what is the magnitude of $|\vec{b}|$ (expressed in terms of the unit cell parameter a)?



Problem 8. (15 min) Assume you have a liquid Fe-C alloy with ~0.3 wt % carbon at 1600°C. Assume slow, equilibrium cooling and sketch the phases present at the five points indicated on the phase diagram. (use the circles provided below).



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