Final Exam

2018. 06. 21. 15:00~17:00, Closed Book
Instructor: Seungtae CHOI

* Note: Translations of some important terminologies into Korean are provided in the parenthesis.

1. (12 points) Please answer to the following questions about yield criterion.
   (a) Explain von Mises yield criterion (항복조건).
   (b) Explain why von Mises stress can be used as a representative value (대표값) for von Mises yield criterion in complicated stress states.
   (c) When the yield strength (항복강도) of a solid is given as σ_Y= 150 MPa, and three principal stresses (주응력) at a point in the solid are given as σ_1= 400 MPa, σ_2=300 MPa, and σ_3= 300 MPa, find out whether yielding occurs at the point or not, and explain why.

   Answer

   (a) The von Mises yield criterion means that yielding of a ductile material begins when the second deviatoric stress invariant J_2 reaches a critical value. The von Mises yield criterion can be also formulated in terms of the von Mises stress or equivalent tensile stress,

$$\sigma_v = \sqrt{\frac{3}{2}\sum_{i=}^{3}\sum_{j=}^{3}\sigma'_{ij}\sigma'_{ij}} = \sqrt{\frac{1}{2}\left[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2\right]}.$$

   In this case, a material is said to start yielding when the von Mises stress reaches a value known as yield strength, σ_Y.

   (b) The von Mises stress is used to predict yielding of materials under complex loading from the results of uniaxial tensile tests. The von Mises stress satisfies the property where two stress states with equal distortion energy have an equal von Mises stress. Because the von Mises yield criterion is independent of the first stress invariant, I_1, it is applicable for the analysis of plastic deformation for ductile materials such as metals, as onset of yield for these materials does not depend on the hydrostatic component of the stress tensor.

   (c) The given stress state is equivalent the sum of two stress states: In stress state I, σ_1= 100 MPa, σ_2= 0 MPa, and σ_3= 0 MPa, and in stress state II, hydrostatic stress , σ_1= σ_2= σ_3= 300 MPa. The hydrostatic stress in the state II does not produce any plastic deformation, and thus the stress state I is only related to yielding. The stress state I is a uniaxial tension with σ_1= 100 MPa, which is less than the yield strength, σ_Y= 150 MPa. Therefore, yield will not occur.

2. (8 points) List up and explain four strengthening mechanisms (강화 혹은 경화 기구) in polycrystalline metals (다결정 금속).

   Answer

   The ability of a metal to deform plastically depends on the ability of dislocations to move. Restricting or hindering dislocation motion renders a material harder and stronger.

1. Grain size reduction

- ✓ Grain boundary (GB) acts as a barrier to dislocation motion.
- ✓ Adjacent grains normally have different orientations.
- ✓ The atomic disorder within a GB region results in a discontinuity of slip planes.
- ✓ Barrier "strength" increases with increasing angle of misorientation.
- ✓ Smaller grain size: more barriers to slip.
- ✓ Dislocations tend to “pile up” at GBs.

2. Solid solution alloying

- ✓ Alloys are stronger than pure metals because impurity atoms that go into solid solution typically impose lattice strains on the surrounding host atoms.
- ✓ Impurity atoms distort the lattice & generate lattice strains.
- ✓ These strains can act as barriers to dislocation motion.
- ✓ Small impurities tend to concentrate at regions of compressive strains near dislocations.
- ✓ Large impurities tend to concentrate at regions of tensile strains near dislocations.

3. Precipitation strengthening

- ✓ Hard precipitates are difficult to shear.
- ✓ Large shear stress needed to move dislocation toward precipitate and shear it.
- ✓ Dislocation “advances” but precipitates act as “pinning” sites.

4. Strain Hardening

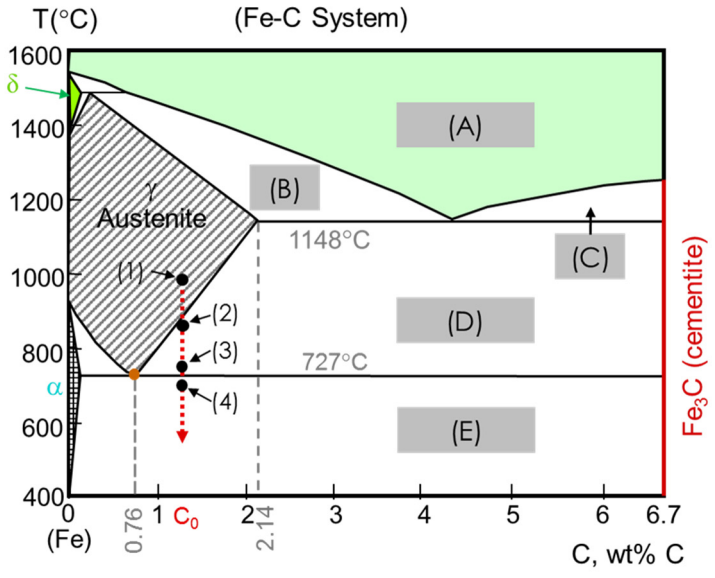
- ✓ Dislocation structures change during plastic deformation (cold working).
- ✓ Dislocations entangle with one another during plastic deformation (cold working).
- ✓ Dislocation motion becomes more difficult.

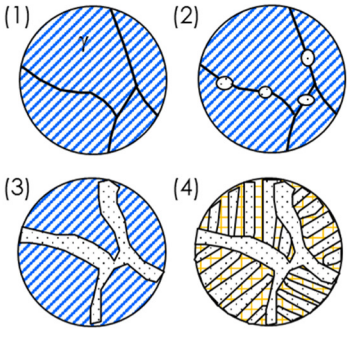
3. (11 points) Please answer to the following questions about the following phase diagram (상태도) of Fe-C system.

(a) Fill out the possible phases in the regions (A)-(E).

(A) L (Liquid) (B) γ (Austenite) + L (Liquid) (C) Fe_3C (Cementite) + L (Liquid)
(D) γ (Austenite) + Fe3C (Cementite) (E) α (Ferrite) + Fe_3C (Cementite)

(b) Draw the microstructures (미세구조) of the hypereutectoid steel (과공석(過共析) 강) (0.76 wt% < C_0 < 2.14 wt%) at the points (1)-(4) shown in the following figure, when it cools down from 1,000 °C to 600 °C.





Please use the following styles for specific phases.

:α (Ferrite)

:γ (Austenite)

:Fe_3C (Cementite)

4. (9 points) Please answer the following questions.
   (a) Explain the creep behavior and stress relaxation behavior (응력이완) of viscoelastic polymers (점탄성 고분자).
   (b) Explain the necking phenomenon (네킹 현상) of a semicrystalline (반정질) polymer in relation with its microstructural change under tensile test.
   (c) Explain a glass transition temperature (유리천이온도).

Answer

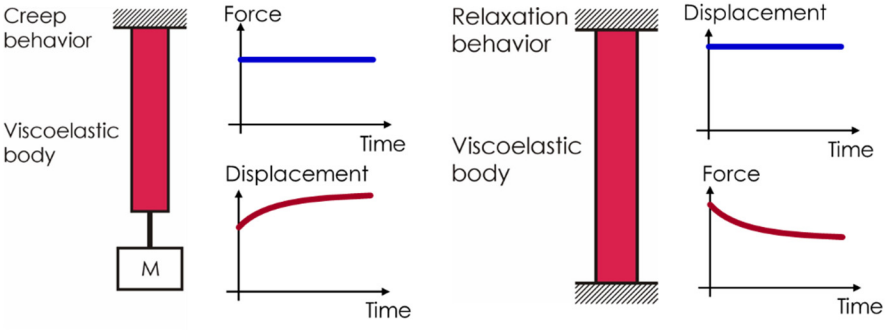
(a) Creep behavior and stress relaxation behavior

*** Creep behavior**

- ✓ Tendency of a solid material to move slowly or deform under the influence of mechanical stresses.
- ✓ Creep occurs as a result of long-term exposure to high levels of stress that are still below the yield strength of the material.

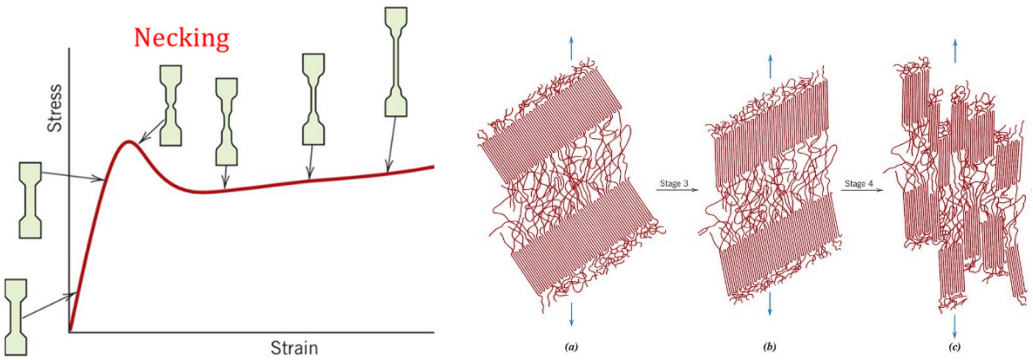
*** Stress relaxation behavior**

- ✓ Stress relaxation is the observed decrease in stress in response to the same amount of strain generated in the structure



(b) Necking phenomenon of a semicrystalline polymer

- ✓ Within the neck, polymer chains become oriented with localized strengthening.



(c) Glass transition temperature

- ✓ The glass transition is the gradual and reversible transition from a hard and relatively brittle "glassy" state into a viscous or rubbery state as the temperature is increased. An amorphous solid that exhibits a glass transition is called a glass.
- ✓ The glass-transition temperature T_g of a material characterizes the range of temperatures over which this glass transition occurs.

* Note: Please select only one answer to the problems 5-34. Two points are allotted to each problem.

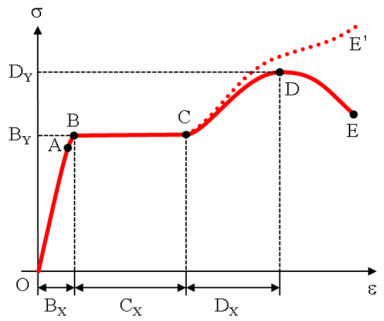
5. Please choose an answer including all the correct statements on the mechanical properties of metals.

Statements
A. In an elastic solid, if the applied load is released, the solid returns to its original shape.
B. The elastic modulus is proportional (비례하는) to the slope of the interatomic force (원자간 힘)-separation curve at equilibrium (평형) spacing.
C. In an elastic solid, the axial elongation (축방향 신장) is accompanied by lateral contraction (측면 수축), and the lateral strain is proportional to the axial strain.
D. Poisson's ratio, ν, of a solid is 0.5, the solid is an incompressible (비압축성의) material.

① A, B, C ② A, B, D ③ B, C, D ④ A, C, D **⑤ A, B, C, D**

6. Please choose an answer best describing the macroscopic mechanical properties of single-crystal (단결정) silicon.
① Anisotropic & Inhomogeneous **② Anisotropic & Homogeneous**
③ Isotropic & Inhomogeneous ④ Isotropic & Homogeneous

7. In the following stress-strain curve of mild steels, please choose an answer correctly listing up the terminologies (용어) of B_Y, D_Y, and the region D_X.
① Tensile strength, yield strength, strain hardening
② Yield strength, tensile strength, strain hardening
③ Tensile strength, yield strength, perfect plastic
④ Yield strength, tensile strength, perfect plastic



8. Please choose an answer including all the correct method(s), with which we can change Young's modulus of polycrystalline metals.

Methods
A. Adding impurity atoms (불순물 원자)
B. Increasing grain sizes by recrystallization (재결정)
C. Increasing dislocation density (전위밀도)

① A ② A, B ③ A, C ④ B, C ⑤ A, B, C

9. Please choose an answer including all the correct statements on the dislocations & strengthening mechanisms of metals.

Statements
A. Plastic deformation (소성변형) corresponds to the motion of large numbers of dislocations.
B. Dislocation motion is easier in metals rather than in ceramics.
C. Slip planes represent the planes on which dislocations can easily glide.
D. The critical resolved shear stress (분해전단응력), i.e., the minimum resolved shear stress required to initiate slip of dislocations is called as yield stress.

① A, B, C ② A, B, D ③ B, C, D ④ A, C, D ⑤ A, B, C, D

10. When three principal stresses at a point in a solid are given as $\sigma_1 = 100$ MPa, $\sigma_2 = 0$ MPa, and $\sigma_3 = -100$ MPa, please select the normal vector to the slip plane $\boldsymbol{n}$ and the slip direction vector $\boldsymbol{s}$, where the critical resolved shear stress becomes maximum. (Vectors are not normalized.)
① $\boldsymbol{n} = (1, 0, 1)$, $\boldsymbol{s} = (-1, 1, 1)$ ② $\boldsymbol{n} = (1, 1, 0)$, $\boldsymbol{s} = (1, -1, 0)$
③ $\boldsymbol{n} = (1, 0, 1)$, $\boldsymbol{s} = (-1, 0, 1)$ ④ $\boldsymbol{n} = (0, 1, -1)$, $\boldsymbol{s} = (0, 1, 1)$

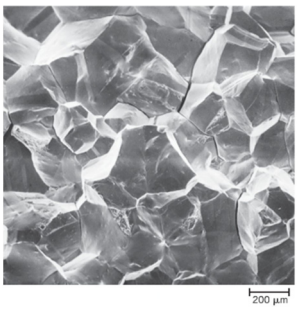
11. Please choose an answer including all the correct statements on the solid-solution (고용체) strengthening.

Statements
A. Large impurities tend to concentrate at regions of compressive strains near dislocations.
B. Small impurities tend to concentrate at regions of tensile strains near dislocations.
C. Alloys are stronger than pure metals because impurity atoms that go into solid solution (고용체) typically impose lattice strains on the surrounding host atoms.

① A, B ② C ③ A, C ④ B, C ⑤ A, B, C

12. Please choose an answer describing the correct sequence of three annealing stages.
① Recrystallization (재결정) → Recovery (회복) → Grain growth (결정립 성장)
② Grain growth → Recovery → Recrystallization
③ Recovery → Recrystallization → Grain growth
④ Grain growth → Recrystallization → Recovery
⑤ Recovery → Grain growth → Recrystallization

13. The following SEM (scanning electron microscope, 전자현미경) image shows a fractured surface of a polycrystalline metal. What kind of fracture can be inferred from the SEM image?
① Transgranular fracture (입내파괴)
② Intergranular fracture (입계파괴)
③ Ductile fracture (연성파괴)
④ Cup-and-cone fracture (컵-원뿔 파괴)



14. Fracture criterion (파괴조건) of linear elastic solids is given as $K_I = K_{IC}$. Please choose an answer describing K_I and K_{IC} correctly.
① K_I = fracture toughness (material property) and K_{IC} = SIF (depending on loading)
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④ K_I = SIF (depending on loading) and K_{IC} = fracture toughness (material property)
* Note: SIF = stress intensity factor (응력강도계수) & fracture toughness (파괴인성)

15. Please choose an answer including all the correct statements on the fracture of solids.

Statements
A. Ductile fracture involves sufficient plastic deformation before fracture.
B. The plastic-zone size at the crack tip depends on the thickness of a compact tension specimen.
C. If temperature increases, materials become more brittle.
D. Hydrogen segregation (수소용질분리) near grain boundaries may cause intergranular fracture.

① A, B ② A, B, C ③ B, C, D ④ A, B, D ⑤ A, C, D

16. Please choose an answer describing the fatigue (피로) phenomenon incorrectly.
① In S-N curve, data are plotted as stress (S) versus the logarithm of the number N of cycles to failure for each of the specimens.
② Below fatigue limit (피로한계), fatigue failure will not occur.
③ Some materials have no fatigue limit.
④ Tensile residual stress (인장잔류응력) increases fatigue life.

17. Please choose an answer including all the correct statements on creep behavior.

Statements

A. Creep represents time-dependent and permanent deformation (영구변형) of materials when subjected to constant load or stress.
B. In the secondary creep stage, strain rate ($\Delta\varepsilon/\Delta t$) is constant.
C. In the secondary creep stage, strain rate ($\Delta\varepsilon/\Delta t$) may increase if temperature increases.
D. In creep, time to rupture (파단시간) decreases as stress increases.

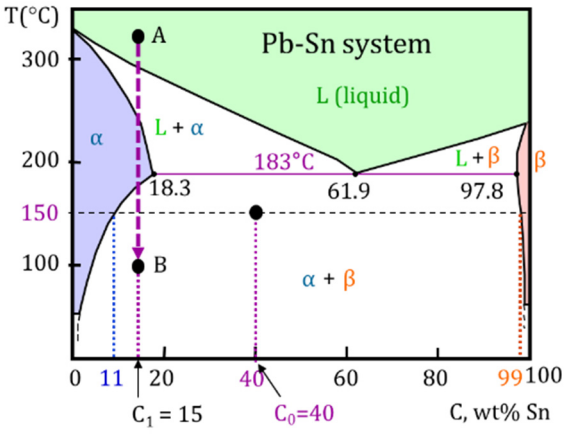
① A, B, C ② A, B, D ③ B, C, D ④ A, C, D ⑤ A, B, C, D

18. Please choose an answer incorrectly connecting terminology into its meaning about phase diagrams (상태도).
① Phase (상) – A homogeneous portion of a system that has uniform physical and chemical characteristics
② Component (성분) – The elements or compounds which are present in the alloy
③ Mixture (혼합물) – A system composed of two or more elements
④ Solubility limit (용해한도) – A maximum concentration of solute atoms that may dissolve in the solvent to form a solid solution

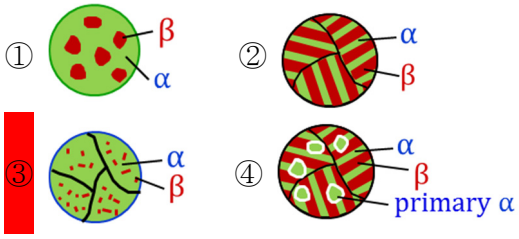
19. Please choose a statement correctly describing binary isomorphous system (2원 전율고용체계).
① Cu-Ag system belongs to binary isomorphous system.
② One component is completely soluble in another component.
③ Melting temperature is independent of the concentration.
④ Liquid and solid phases cannot coexist.

20. Please choose a terminology representing 2-component system having a special composition with a mininum melting temperature.
① Binary isomorphous system
② Binary eutectic system (2원 공정계)
③ Hypereutectoid system (과공석계)
④ Intermetallic compounds (금속 간 화합물)

21. For a 40 wt% Sn-60 wt% Pb alloy at 150°C as shown in the following figure, choose an answer correctly representing the β phase composition and its weight fraction.
① $C_\beta = 97.8$ wt% Sn, $W_\beta = 0.67$
② $C_\beta = 97.8$ wt% Sn, $W_\beta = 0.33$
③ $C_\beta = 99.0$ wt% Sn, $W_\beta = 0.67$
④ $C_\beta = 99.0$ wt% Sn, $W_\beta = 0.33$



22. For a 15 wt% Sn-85 wt% Pb alloy cooling down from the state A to the state B (about 100°C) as shown in the figure, please choose a possible microstructure at the state B.



23. Please choose an answer incorrectly connecting terminology into its example about reactions.
① Eutectic reaction (공정반응) – liquid transforms to two solid phases.
② Eutectoid reaction (공석반응) – one solid phase transforms to another solid phase.
③ Peritectic reaction (포정반응) – liquid and one solid phase transform to a second solid phase.

24. Please choose an answer incorrectly connecting the phase of Fe-C system into its crystal structure.
① Ferrite (α) – BCC (body-centered cubic, 체심입방)
② Austenite (γ) – FCC (face-centered cubic, 면심입방)
③ Ferrite (δ) – BCC (body-centered cubic, 체심입방)
④ Pearlite – alternating layers of α (ferrite) and martensite phases
⑤ Martensite – BCT (body centered tetragonal, 체심정방)

25. Please choose an answer listing microstructures of Fe-C alloys from high strength to low strength.
① Martensite > Bainite > Fine pearlite > Coarse pearlite > Spheroidite
② Martensite > Bainite > Coarse pearlite > Fine pearlite > Spheroidite
③ Bainite > Spheroidite > Martensite > Fine pearlite > Coarse pearlite
④ Bainite > Spheroidite > Martensite > Coarse pearlite > Fine pearlite
⑤ Spheroidite > Bainite > Martensite > Coarse pearlite > Fine pearlite

26. Please choose a terminology representing the thermodynamic potential (열역학 포텐셜) that is minimized when a system reaches chemical equilibrium at constant pressure and temperature.
① Gibbs free energy ② Helmholtz free energy
③ Enthalpy ④ Internal energy

27. Please choose an answer including all the correct statements on the martensite phase of iron-carbon alloys.

Statements
A. A non-equilibrium single-phase structure from a diffusionless transformation (무확산 변태) of austenite.
B. Body centered tetragonal (BCT) crystal structure
C. Platelike or needlelike appearance.
D. A supersaturated solid solution (과포화 고용체) that is capable of rapidly transforming to other structures if heated to temperatures at which diffusion rates become appreciable.

① A, B, C ② A, B, D ③ B, C, D ④ A, C, D ⑤ A, B, C, D

28. Please choose an answer incorrectly stating what happens in stress-strain curve of thermoplastics when temperature increases.
① Young's modulus decreases. ② Tensile strength decreases.
③ Ductility increases. ④ Thermoplastics become brittle.

29. Please choose an answer including all the correct statements on the viscoelastic deformation (점탄성 거동) of polymers.

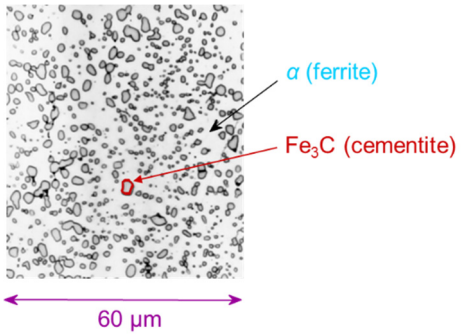
Statements
A. A polymer can exhibit all intermediate range (중간 범위) of properties between an elastic solid and a viscous liquid.
B. Viscoelastic materials possess a memory (fading) of past events.
C. Two types of viscoelastic behavior are creep and stress relaxation.

① A, B ② A, C ③ B, C ④ A, B, C

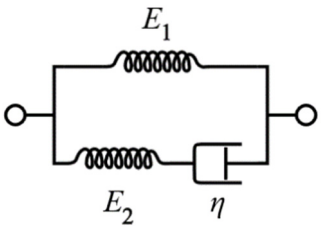
30. Please choose a terminology representing the observed decrease in stress in response to the same amount of strain generated in the structure.
① Creep behavior ② Stress relaxation behavior
③ Yielding behavior ④ Necking behavior

31. Please choose a method to increase the fatigue life (피로수명) of solids.
① Quenching (담금질) ② Shot peening ③ Annealing

32. Please choose a microstructure of iron-carbon alloys corresponding to the following picture.
① Martensite
② Spheroidite
③ Pearlite
④ Cementite
⑤ Austenite



33. Please choose a viscoelastic model representing the spring-dashpot system as shown in the following figure.
① Maxwell model
② Kelvin-Voigt model
③ Standard linear solid model



34. Please choose a stage of tensile test, at which semicrystalline thermoplastics can have the microstructure as shown in the following figure. ④