22. 309 Nuclear Materials Engineering Exam #2 SNU-NED May 2004

Closed book, 2hr 1 page spike sheet(A4 size with your name on it)

1.(25) Yield strength(σ_y) of an alloy can be expressed as follows;

$$\sigma_y = \underset{\text{intrinsic}}{\sigma_i} + \Delta\sigma_{ss} + \Delta\sigma_o + \underset{\text{work hard}}{\Delta\sigma_{wh}} + \Delta\sigma_{gb} \quad \text{grain boundaries}$$

where each term on the right hand side represents the strengthening by intrinsic bonding, solid-solution, obstacles, work-hardening, and grain boundaries, respectively.

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a) Explain what determines $\Delta\sigma_{ss}$

b) Explain what determines $\Delta\sigma_o$

c) Given the precipitate density of C(#/m^3), the mean spacing between two adjacent particles on a slip plane is known (although a proof was not given) as $1/\sqrt{C}$. Express $\Delta\sigma_o$ as function of C and b.

d) Explain what determines $\Delta\sigma_{wh}$

e) What is the magnitude of $\Delta\sigma_{gb}$

2.(15) Micro-hardness testing is a useful way to make a rough but non-destructive estimation of yield strength for polycrystalline materials, as long as the indentation area covers at least 30 grains. Excessively large indentation mark can cause crack initiation and hence is undesirable. For a low alloy steel used for heavy section such as reactor pressure vessel, steam generator shell, and most metallic containment wall, yield strength is 200 MPa, and grain size is 10 micrometer.

10^{-6}m

30 grain을 넘는다 ok

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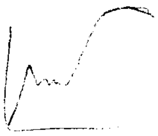
a) If you chose to use Pyramidal micro-indentor with the maximum cross-sectional dimension of 100X100 micrometer, what load should be used in the micro-hardness testing to cover about 30 grains.

H =

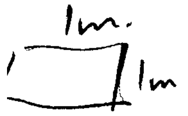
b) When tensile test was made for the material, it showed a yield strength of 200 MPa and then the strength dropped to 190 MPa upon further deformation showing a Lüder's band. Then strength increased with additional deformation and displayed typical necking



and failure at end. Show stress-strain curve for the material.

c) If the hardness is related accurately to the yield strength, how should a ideal stress-strain curve look like?

3. (25) Fracture of key materials in a complex system can lead to catastrophic consequence to a society especially when the system handles high-energy and/or toxic substances, as manifested by the recent Ryongchun explosion in NK.



a) Cleavage fracture occurs along an atomic plane. Assume the mean spacing between the atoms on the cleavage plane of a brittle material is 2 angstrom, and the average bonding energy between two adjacent atoms of a cleavage plane is 4 eV/atom. Then estimate Gc of the material in (kJ/m2.) Note electronic charge is 1.602×10^{-19} Coulomb.

$1 eV = 1.02 \times 10^{-19} J$

b) Most of metals have Gc of 10~1000 kJ/m. How can you explain the high energy required for fracture in metals.

c) Certain metals show a sharp drop in Gc over a narrow temperature range when it is cooled. This phenomenon is called ductile-to-brittle transition. Give an example of this behavior.

d) At a temperature above the ductile-to-brittle transition temperature range, the material showed E= 200 GPa, Gc=150 kJ/m2 and yield strength = 300 MPa. If a plate had a crack size of 5 cm, then what is stress intensity factor(=σ√πa) when applied stress was 100 MPa, as shown in Fig. 1.

e) Sketch stress vs. x in the uncracked section.

Crack tip에
안쪽으로가니

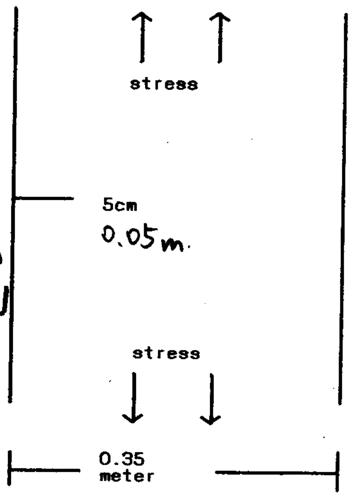
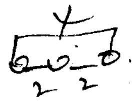


Figure. 1.



$K = \sigma\sqrt{\pi a}$

4.(15) A superconducting magnet in a tokamak fusion reactor experiences oscillating stress with its maximum during an Ohmic induction heating of plasma and minimum at discharge in each burn cycle. The fatigue life of a superconductor with no initial crack is expressed as

$$\Delta\sigma \, N_f^b = C$$

where $\Delta\sigma$ is stress range in MPa, N_f is the cycle to failure, $b = 0.1$ and $C = 632$ MPa(cycle)$^{0.1}$. The superconducting magnet will be cycled 10,000 times between 100 MPa and −100 MPa during the first phase. After then, it will be further cycled 20,000 times between 200 MPa and 0 MPa in the second phase.

a) Determine the fatigue life(N_f) of the superconductor during the first phase condition.

b) Determine the fatigue life(N_f) of the superconductor during the second phase condition. Ultimate tensile strength of the material is 800 MPa.

c) Judge whether or not the materials will survive both phases.

5.(20) If the magnet in Problem 4 was diagnosed to have a crack of 5 cm in the same geometry as shown in Figure 1. Considering safety, it is decided to lower applied stress in a cycle between 50 MPa and zero. The crack growth can be predicted by;

$$da/dN = A\,(\Delta K)^4$$

where $A=2.0 \times 10^{-10}(\mathrm{MPa})^{-4}$m/cycle and da/dN is in m/cycle, stress intensity factor($=\sigma\sqrt{\pi a}$).

a) If fracture toughness is 200 MPa m$^{-1/2}$, what is the critical crack size?

$K_c = \sqrt{E G_c} =$

b) Determine the cycle to failure

c) Draw crack size vs cycle

d) Sketch the fracture surface if the magnet was cycled to the failure and examined under a Scanning Electron Microscope.

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