22.309 Nuclear Materials Engineering

Final Exam SNU-NED May 31, 2004

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

1(30). An annealed single crystal of pure copper was placed in contact with an annealed single crystal of pure Ni, over a contact area of l_0 x l_0. Both metals have fcc structure with similar lattice parameter.

(a)(10) The couple was heated in a vacuum furnace so that two metal atoms can be mixed at the interface. If an atomic jump distance is defined as r_0 for both metals, derive an expression for Cu or Ni diffusivity.

(b) It is known that the diffusion of both metals occurs only with vacancies. The activation energy of diffusion is therefore consisted of two terms; the energy required for vacancy formation and the energy required for a metal atom to overcome the jump barrier and move to the vacancy nearby. It is determined that vacancy formation energy is fairly constant in fcc to be 1.2 eV/vacancy. If the activation energy of diffusion is measured to be 200 kJ/mole, what is the energy barrier against jumping into the vacancy nearby in eV/atom?

(c) What is the origin of the energy barrier against jumping into the vacancy?

(d) How would the diffusivity changes from (a) above if both metals are cold-worked?

(e) If both metals have polycrystalline structure with nanometer grains (i.e., nanocrystalline structure), how would the diffusivity change from (a) above?

2. (15) A Nb tube having a diameter of 10 μm and wall thickness of 2.5 μm fabricated with Sn core so that tube hole is filled with Sn. Then the fine wire was reacted in solid-state at 700 deg C so that Nb3Sn superconductor can be formed. It is found that Sn preferentially diffuses, by vacancy mechanism, into Nb tube leaving a hole in the tube center (it is called Kirkendall hole)

(a) Estimate the time required for a substantial completion of the solid-state reaction at 700 deg C. The diffusion coefficient for Sn in Nb is given by

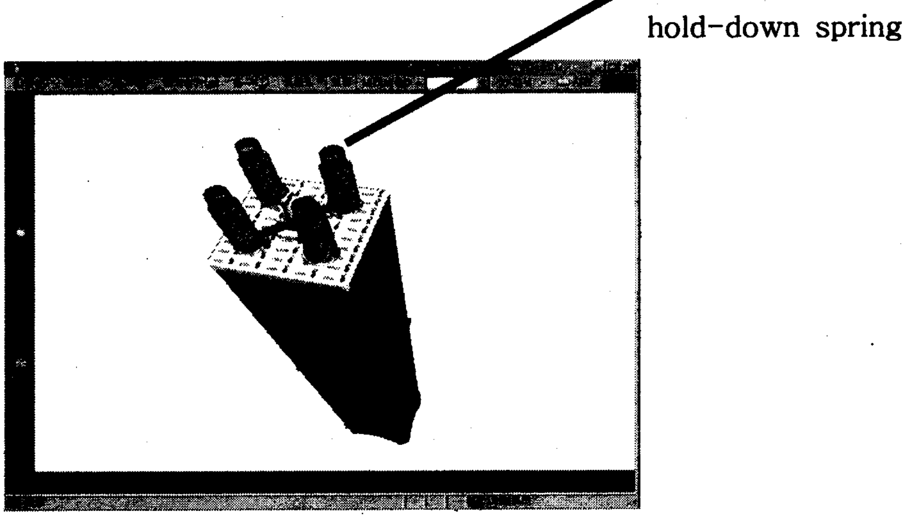
$$D = D_0 e^{-Q/\bar{R}T} \qquad (1)$$

where $\bar{R}$ is the universal gas constant and T is the absolute temperature. The constants D_0 and Q have the values 10 $mm^2 s^{-1}$ and 159 $kJ mol^{-1}$, respectively.

(b) What will be present inside the Kirkendall hole?

(c) It is desired to reduce reaction time so that the risk of furnace failure and resultant financial loss can be lowered. In order to reduce the reaction time without changing the dimensions, what can you propose?

3 (35) In LWR's, nuclear fuels are cooled by high-speed water in the upward direction. The fuels are pushed down by hold-down springs so that thermal expansion can be allowed at a constant compressive force.



A constant load creep testing of a fuel hold-down spring material at an operating temperature showed a steady-state creep behavior between engineering strain and engineering stress as follows;

$$\dot{\varepsilon}_n = A\sigma_n^2 e^{-Q/RT} \qquad (2)$$

where A is a constant, $\bar{R}$ is the universal gas constant and T is the absolute temperature.

(a) If the material having an elastic modulus E is used for the helical spring and then initially a compressive stress (σ_i) was applied within elastic range and then locked in the position. Explain why will the compressive stress in the spring change with time?

(b) (10) Derive an expression for the stress in the spring as function of time starting with Eq. (2).

(c) By initial compression, the spring axial length was decreased by 7% from the original stress-free length of 200 mm at temperature. If the spring was loosened when the compressive stress reached 60% of the initial value, what will be the final stress-free length?

(d) Using the above Eq. (1), derive a new creep equation between true strain rate and true stress.

(e) (10) Draw deformation mechanism map (normalized stress vs. normalized absolute temperature).

4.(20) Dry oxidation and wet corrosion are responsible for the most aging-related failures of complex systems including nuclear power plants. In order to slow these processes and hence to increase the system lifetime, nanoscopic understanding of very thin oxide layers formed on metals is required. Many oxides are n-type semiconductor in which oxygen vacancy is abundant and oxygen diffuses from atmosphere towards metal forming new oxide at the interface between metal and existing oxide.

(a) Draw the pattern of oxide thickness as a function of time for metals with protective oxide in a dry gas containing constant oxygen concentration.

(b) Derive an expression on oxide thickness as function of time and temperature.

(c) If oxygen concentration in the atmosphere is increased linearly with time how would the thickness change with time and temperature?

(d) In wet corrosion, the rate of material oxidation increases significantly over dry oxidation at given temperature. Explain why. Then suggest how the rate can be slowed.

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