22.14 Final Exam, Spring 2014

(90 minutes), ***Choose 3 out of 4 problems***

March 29, 2014

Show all intermediate work. Define any symbols that you create or use. Solve the problems symbolically, do not bother with final numerical answers. For example, when calculating the angle between the (234) and the $(1\bar{1}0)$ planes, you may leave your answer in the form of $\phi = cos^{-1}\left(\frac{-1}{\sqrt{58}}\right)$, don't bother evaluating the number.

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1) Dislocation Movement: *Dislocation cross slip* is a process whereby a moving screw dislocation can "jump" from one slip system to another, provided that the dislocation gets pinned (stuck) on its original slip plane, and the applied strain is high enough. This means that if a dislocation encounters a barrier on one slip plane, it may move to another slip plane to overcome this barrier.

Assume that a dislocation is moving in the (111) plane in an FCC system. The dislocation encounters a barrier, and cross-slips onto the $(1\bar{1}1)$ system. Calculate the extra factor of shear stress required to move the dislocation from the (111) plane onto the $(1\bar{1}1)$ plane. In other words, how strong does this barrier to dislocation movement have to be?

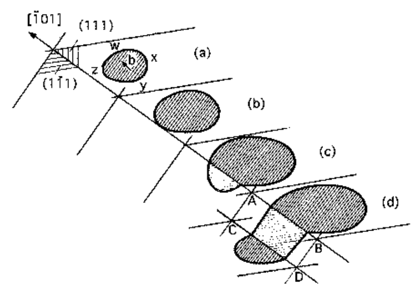


Figure 1: Diagram of dislocation cross slip

2) Radiation Damage Mechanisms: The point defect equations (given below) are fair approximations of radiation defect creation in real materials. In reality, vacancies and interstitials can form *vacancy clusters* and *interstitial clusters*, respectively. These defects have their own mobilities (diffusivities), depending on their *size* (the number of defects they possess).

Rewrite the point defect balance equations, accounting for these two new types of defect clusters (total of 4 types of defects). Account for the fact that a vacancy/interstitial cluster of size n may gain a point defect to become a cluster of size *n+1*, and it may also lose a point defect to become a cluster of size *n-1*, with different rate constants.

3) Stress, Strain, and Crystallinity: Draw side-by-side stress-strain diagrams for a single-crystal and a polycrystalline FCC material, pointing out the origins of each relevant feature of the diagrams. Repeat for a single-crystal and a polycrystalline triclinic material. Explain why the curves for the two crystal systems (FCC and triclinic) appear similar or different, in both the single-crystal and polycrystalline cases.

4) Corrosion Short Answers (NOTE: If you choose this question, you must treat all sub-parts as a single question, to count towards the three you choose):

- Explain how and why blocks of zinc are used to protect ships against corrosion in the ocean.
- Explain why this approach would not work in nuclear reactors, assuming similar materials are used.
- Explain, using the Fe-Cr phase diagram, how to choose the composition of an Fe-Cr alloy for service in high-temperature reactors to avoid accelerated corrosion and mechanical failure. Choose 3-4 representative temperatures, and describe the origins of the limits on Cr composition at each temperature.

Useful Formulas and Diagrams

Miller Index Notation

$$Direction: [hkl] \qquad Plane: (hkl) \qquad Direction\,Family: \langle hkl \rangle \qquad Plane\,Family: \{hkl\}$$

Resolved Shear Stress, Angles Between Crystals

$$\tau_{RSS} = \sigma_{applied} \cos(\theta) \cos(\phi) \qquad \cos(\theta) = \frac{h_1 h_2 + k_1 k_2 + l_1 l_2}{\sqrt{h_1^2 + k_1^2 + l_1^2}\sqrt{h_2^2 + k_2^2 + l_2^2}}$$

Original Point Defect Balance Equations

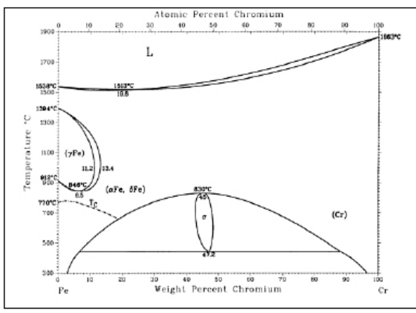
$$\frac{\partial C_{(v,i)}}{\partial t} = K_0 - K_{recomb} C_i C_v - K_{pcp} C_{(i,v)} C_{pcp} - K_{GBs} C_{(i,v)} C_{GBs} - K_{disloc} C_{(i,v)} C_{disloc} + \nabla D_{(i,v)} \nabla C_{(i,v)}$$

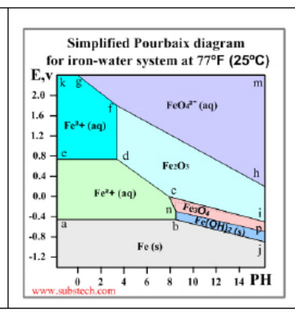
$$"pcp" = incoherent\,precipitates \qquad "GB" = grain\,boundary \qquad "disloc" = dislocations$$

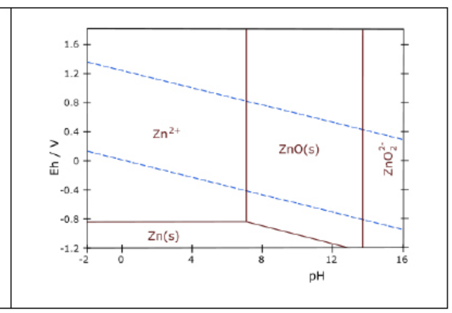
Stress and Strain

$$\sigma_{eng} = E \epsilon_{eng} \qquad \sigma_{true} = \sigma_{eng}(1 + \epsilon_{eng}) \qquad \epsilon_{true} = ln(1 + \epsilon_{eng})$$

Useful Corrosion Diagrams







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