Spring 2020: Mechanical Properties Materials Science (MPMS)

Take Home Exam IY: (Diffusional Deformation at High Temperature)
Given out on Monday 04/27/2020, due on Monday 05/04/2020

SOLUTIONS

1. A polycrystal is assumed to be constructed from simple cubes. Each cube contains 10^6 atoms. The crystal is pulled in uniaxial tension, so that boundaries with a horizontal orientation are under the applied stress, while the vertically oriented boundaries are stress free.

(i) Calculate the strain that would be produced by the transport of 1000 atoms from every vertical grain boundary into the adjacent horizontal grain boundary.

(ii) Now assume that the atoms are transported at the rate of 1000 atoms per second. What will be the strain rate of the deformation of the polycrystal.

Hint: You should not have to consider the volume of atoms (Ω).

(i)The crystal is a cube of 100 x 100 x 100 atoms. The surface of a face contains 100x100 atoms. Since four faces feed one horizontal face the total number of atoms transported per grain is equal to 4×10^3. The addition of one atom layer would require 10^4 atoms, which would produce a strain of 1% since one layer has one hundredth the height of the cube. Therefore 0.4 atom layer will produce a strain of 0.4%.

The strain rate will be 0.004 per second.

2. Explain why the equation for strain rate for diffusional deformation by boundary diffusion in polycrystals with a grain size, d, given by

$$\eta = \frac{\sigma}{\dot{\varepsilon}} = \frac{k_B T d^3}{4\Omega\delta_{gb} D_{gb}}$$

reduces to the Stokes Einstein equation for the viscosity of amorphous materials such as glasses and liquids,

$$\eta_{StokesEinstrai} = \frac{\sigma}{\dot{\varepsilon}} = \frac{k_B T}{6\pi\Omega^{1/3} D_{glass}}$$

Note the difference in the numerical parameter of 6π instead of 4.

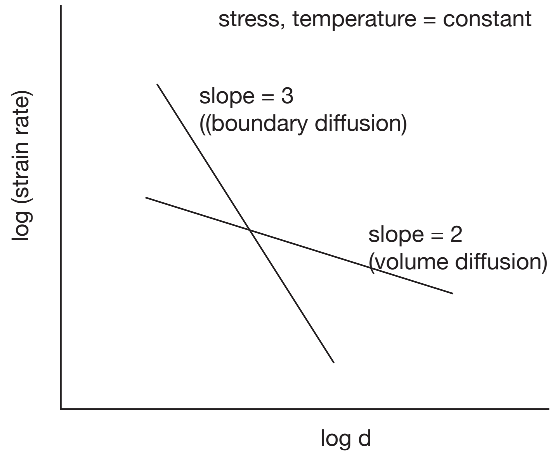
Give a possible explanation for this discrepancy.

(i) assume that the grain size becomes equal to the size of one atom, that is $d = \Omega^{1/3}$. At the same time we assume that the width of the boundary is approximately equal to the atom size, that is $\delta_{gb} = \Omega^{1/3}$, which gives the answer.

(ii) one reason for the discrepancy is that $\delta_{gb} > \Omega^{1/3}$ but that difference still cannot account for the factor of $(6\pi/4) = 1.5\pi$. The difference probably lies in the approximations made in the analysis for the diffusional creep, for example in the estimate of the cross section of diffusion and the diffusion distance.

3. (i) Write a short essay (less than 100 words) on the ramification of the grain size in the mechanisms of diffusional deformation.

(ii) Why does a small grain size promote superplastic deformation?



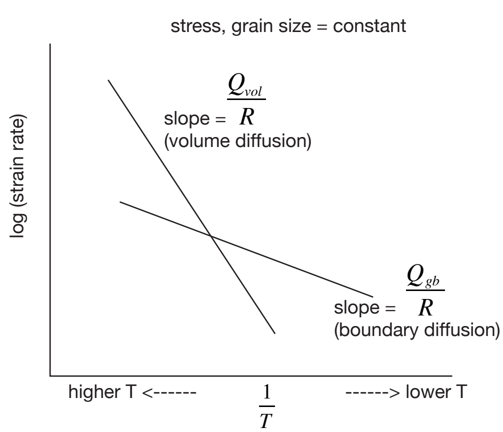
Note that boundary diffusion is dominant for smaller grain size because of the higher slope, that is from d^{-3} dependence.

Superplastic deformation implies high strain rate which is favored by the smaller grain size.

4. We have discussed two mechanisms of diffusional deformation, one by boundary diffusion and the other by volume diffusion. The activation energy for volume diffusion is higher than the activation energy for boundary diffusion. For example see

H. J. Frost "Deformation Mechanism Maps" (the link is given just above on this webpage)

Which mechanism would you expect to dominate at higher temperatures, and why?



Since volume diffusion has a higher activation energy it is dominant at the higher temperature.