

HOMWORK 7.

solutions



PROBLEMS

1. What roles do nucleation and growth play in determining the properties of the alloy(s) you are studying for your second project? What processing parameters affect the rates of nucleation and growth in your alloy(s)? How does varying these parameters provide for different microstructures in your material(s)?

Responses will vary based on project topics. Send me your notes if you'd like some feedback.

2. Pure titanium has two allotropic forms: β -Ti (high temperature) and α -Ti (low temperature). For equilibrium heating conditions, the low temperature α phase transforms to the high temperature β phase at 883 °C (1156K). Let's consider what size of a β -Ti nucleus we would have to form in order for it to be stable at a temperature **just above** the transformation temperature.
 - a. Calculate the critical radius r^* and the activation free energy ΔG^* for a body-centered cubic beta phase nucleus in a superheated alpha titanium matrix at 1165 K. Assume a spherical nucleus (homogeneous nucleation), ΔG_v (1165 K) = -0.095 J/m³, and σ_{sl} = 0.2 J/m².

NOTE: For the surface energy term, I changed σ_{sl} to γ in the following solution.

For homogeneous nucleation of β -Ti in superheated α -Ti,

$$r^* = \frac{-2\gamma}{\Delta G_v} = \frac{-2(0.2 \text{ J/m}^2)}{-0.095 \text{ J/m}^3} = 4.2 \text{ m}$$

$$\Delta G_{\text{hom}}^* = \frac{16\pi}{3} \frac{\gamma^3}{\Delta G_v} = \frac{16\pi}{3} \frac{(0.2 \text{ J/m}^2)^3}{(-0.095 \text{ J/m}^3)^2} = 14.9 \text{ J}$$

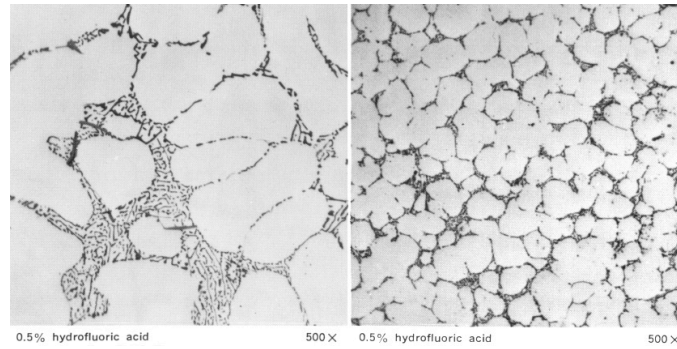
- b. Given your answer in part (a), explain why nucleation of the beta phase is unlikely to occur if you heat the titanium to the 1165 K temperature. What can you do to make nucleation more likely to occur?

Values given in part (a) were calculated at 1165 K, a temperature just 9 K above the equilibrium transformation temperature. At 1165 K, there is little driving force for nucleation of a new phase (β -Ti), especially by homogeneous nucleation processes that get no assistance from surfaces (as in heterogeneous nucleation). For homogeneous nucleation to occur, the radius of stable nuclei must reach a critical size of over **4 meters!** So what would help our β -Ti nucleation to occur? If we increase the temperature substantially (more "superheating"), the volume free energy term (ΔG_v) will get much larger, and the critical radius size and energy barrier for nucleation will get much smaller. Formation of the β -Ti phase would also be assisted by the presence of **surfaces** that could serve as heterogeneous nucleation sites.

3. Look at these cool microstructures from ASM Handbook!

Ah, yes. Cool microstructures.

4. The following two micrographs are from a hypoeutectic (less than 12.6% Si) aluminum-silicon alloy that was melted and poured into two different molds – a sand mold, and a metallic mold.

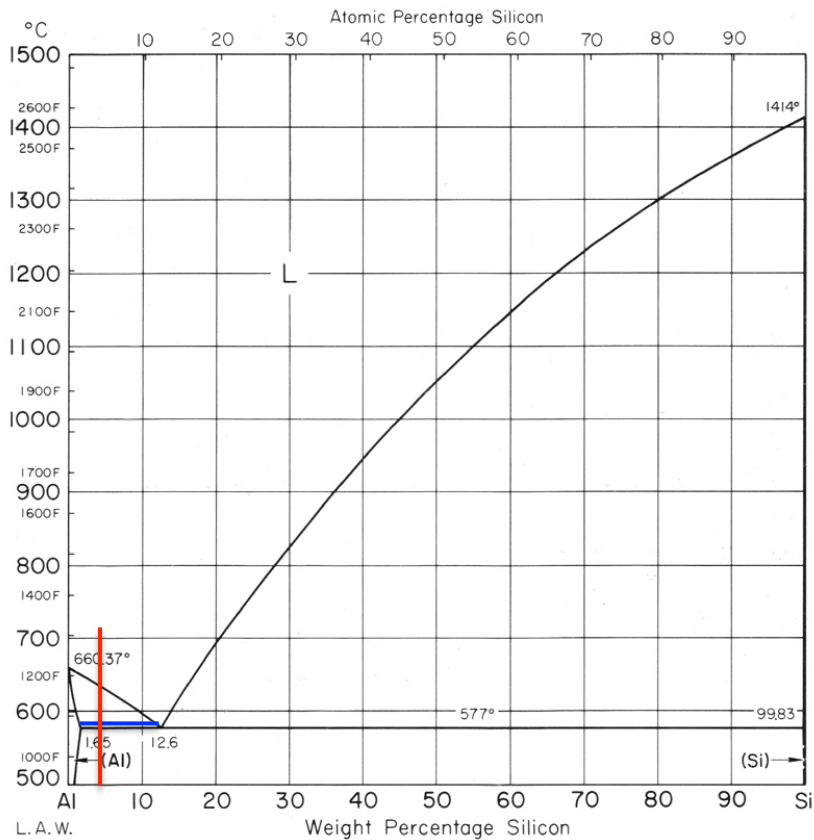


- a. Which photo – left or right – is from the sample that cooled in the metallic mold? How do you know?

Left = sand mold, right = metallic mold. The microstructure on the right is much finer than the one on the left. This indicates that it cooled more quickly (or at a lower temperature). With fast cooling, the diffusion rates are lower, but nucleation rates are higher, which leads to the formation of larger numbers of small grains.

- b. Based on the microstructure, estimate the composition of the Al-Si alloy. The phase diagram is provided below for reference.

Since this is a hypoeutectic alloy, we know that we're going to be working to the left side of the eutectic composition – between 0 and 12.6 weight percent Si. To determine the composition, we need to interpret the microstructure. Take a look at the sand cast microstructure on the left. I'd say that this sample seems to have about 80 % dendrites (large, light blobs) and about 20% of the eutectic solid (speckled regions). Using the lever rule just above the eutectic temperature (see [blue line](#)) to back calculate the composition that would provide for 80 percent (Al) dendrites and 20 percent liquid just prior to solidification, we get a sample composition of about **3.8 weight percent silicon and 96.2 weight percent aluminum** (see [red line](#)).



5. Pure titanium undergoes a crystallographic transformation at 883 °C. Below this temperature, pure titanium has a hexagonal close packed structure known as alpha (α); above it, titanium exists as the body centered cubic beta (β) phase. Addition of certain alloying elements to pure titanium results in significant changes in the phase transformation temperatures and in the stability of the alpha and beta phases. The most common titanium alloy is Ti-6-4, which is composed of titanium with 6 weight percent aluminum and 4 weight percent vanadium. A schematic, pseudo-binary phase diagram for Ti-Al-V alloys is shown below.

a. Based on the schematic Ti-Al-V phase diagram, what phases do you expect to see in room temperature alloys of Ti-6Al-4V?

α and β phases

b. In the four boxes, sketch the expected microstructure in the Ti-6Al-4V alloy. Label the phases in your sketches. Assume furnace (very slow) cooling.

NOTE: You may ignore the “Widmanstätten structure” and “Trace of [110] planes” notes in the following image, and focus on the phases present in the schematic microstructures. Also note that your phase morphology may be different than that shown in the sketches; you could have drawn stripes or globs of alpha in the beta phase...based on the given information, this is fine. In case you’re wondering, the Widmanstätten structure refers to a particular grain morphology in which a product phase nucleates and grows along certain crystallographic directions within the parent phase (in this case, α nucleates and grows in the [110] direction within the β grains). The result is cross-hatched microstructure.

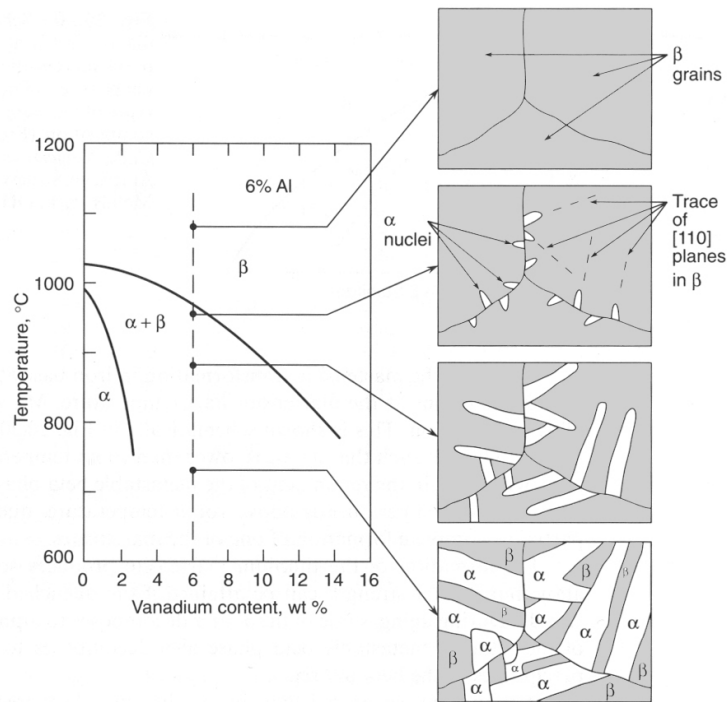


Fig. 20.19 Schematic illustration of the formation of a Widmanstätten structure in a Ti-6Al-4V alloy by cooling slowly from above the beta transus. The final microstructure consists of plates of alpha (white) separated by the beta phase (dark). (From Brooks, C. R., *Nonferrous Alloys*, American Society for Metals, 1984)

c. Would the Ti-6Al-4V alloy provide any property advantages over single-phase alpha alloys? Briefly explain your answer.

Sure! The two phases will provide additional grain/phase boundaries to stop dislocation motion, so we would expect to see higher strength and hardness but lower ductility compared to a single-phase microstructure. It’s likely that, with a little knowledge, experimentation, and research, we could control the morphology of the two phases and form some really hard and strong (or more ductile, if that’s desired) Ti alloys!