

Homework 5 Advanced Thermodynamics Due Monday September 26, 2022

Seede R, Ye J, Whitt A, Trehern W, Elwany A, Arroyave R, Karaman I, *Effect of composition and phase diagram features on printability and microstructure in laser powder bed fusion: Development and comparison of processing maps across alloy systems* Add. Man. **47** 102258 (2021) consider four nickel super alloys that are used for powder bed fusion additive manufacturing (AM) (3d printing). In this process a layer of metal powder is deposited followed by melting of a structural layer using a laser to form a solid metal layer. After many layers are deposited the excess metal powder is removed and a 3d part has been created. Control of the crystalline phases and their structure during the AM process is important to the final properties.

- a) Figure 1 shows the phase diagram for the four alloys, the red dashed lines indicating the compositions chosen for this paper. Why does the Cu-Ni phase diagram appear much simpler than the other phase diagrams? Seede indicates that the alloy systems were chosen to demonstrate binary isomorphous, weak solute partitioning, strong solute partitioning, and eutectic alloying conditions. Explain how this is exhibited in the phase diagrams and compositions chosen (red, dashed lines) in Figure 1.
- b) Identify intermetallic phases, eutectic, peritectic, monotectic, and syntectic reactions in Figure 1. Indicate where congruent and incongruent melting occurs. Explain what a Laves phase is and where it exists in these phase diagrams. Where does the delta phase exist? (Refer to Amato KN, Gaytan SM, Murr LE, Martinez E, Shindo PW, Hernandez J, Collins S, Medina F, *Microstructures and mechanical behavior of Inconel 718 fabricated by selective laser melting* Acta Met. **60** 2229-2239 (2012).)
- c) The processing diagrams in Figures 2 and 3 indicate the optimal conditions for AM. Using the phase diagrams, describe the reason that balling occurs at high scan speeds while keyholing occurs at slow scan speeds. Describe the reason for the shape of the “Lack of Fusion” envelope. (Refer to DebRoy T, Wei HL, Zuback JS, Mukherjee T, Elmer JW, Milewski JO, Beese AM, Wilson-Heid A, De A, Zhang W, *Additive manufacturing of metallic components – Process, structure and properties* Prog. Mat. Sci. **92** 112-224 (2018).)
- d) Figures 4, 5 and 7, 8 and 9 show the morphology resulting from the laser melting. Use the phase diagram to describe the origin of the structures seen in these micrographs.
- e) Download the Thermocalc program from the link on the webpage. (You can also use OPEN CALPHAD on a PC). If you use Thermocalc follow the procedure on the webpage https://www.youtube.com/watch?v=hbhWAUwydDg&feature=emb_rel_end to determine the carbon iron phase diagram at 1 bar. Make a plot from 0 to 10 percent carbon with increments of 1 percent for 500 to 3000°C. Recalculate the phase diagram at 10 bar and compare the two phase-diagrams.