EMA5001 Lecture 15
Other Issues with Metal Solidification

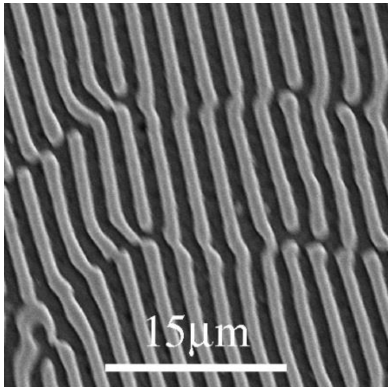
FLORIDA INTERNATIONAL UNIVERSITY

Eutectic Solidification

- L → α + β

- **Classification**
  - Normal
    - Lamellar or other structures
    - Both solid phase has low entropy of fusion
    - Example: Al-Cu
  - Anomalous
    - One of the solid phases has high entropy of fusion (non-metal)
    - Various morphologies
    - Example: Al-Si

67 wt.% Al-33wt% Cu eutectic



http://core.materials.ac.uk/search/detail.php?id=1068

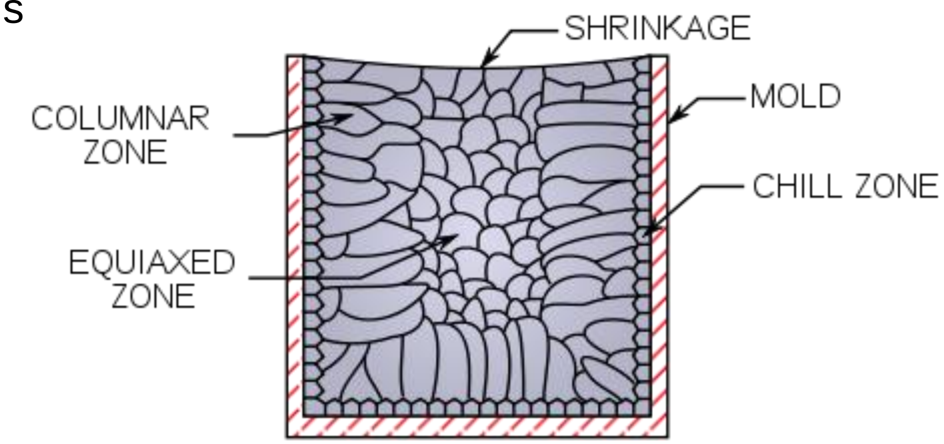
88 wt.% Al-12wt% Si eutectic

http://www.georgesbasement.com/Microstructures/NonFerrousAlloys/Lesson-4/Specimen02.htm

Solidification of Large Ingots

❑Three Regions

- Chill zone - surface equiaxed grains
  - Rapid cooling (Large undercooling ΔT)
  - Full of surface defects as heterogeneous nucleation sites
  - High nucleation rate and smaller grains
  - Stops due to release of latent heat
- Column zone
  - Along direction of heat transfer
- Equiaxed zone in the center
  - Initiated by detached side branches of dendrites



http://en.wikipedia.org/wiki/Casting_(metalworking)

Controlling of Casting Microstructures

❑Controlling of grain size

High nucleation rate leads to greater nucleus density and smaller grains

- Cooling rate
  - Typically higher cooling rate leads to smaller grain size
  - Influenced by casting condition
- Addition of seed for nucleation by alloying
- Mechanical vibration
  - Breaking off the fine equiaxed grains from the mold wall

❑Controlling of zones

Heat transfer impacts the relative distribution of different zones in casting

- Cooling rate
  - Typically higher cooling rate leads to greater column zone
- Cooling direction
  - Cooling in one direction promotes column zone while cooling in all directions promote equiaxed zone
- Foreign impurities
  - Promotes equiaxed zone

Expectations About Solidification (1)

- Understand homogeneous and heterogeneous nucleation including the physical meaning of each terms, the driving force and barrier, the similarities and differences
- Be able to derive critical nucleation size (radius for sphere) and nucleation energy for simple geometry for homogeneous nucleation
- Understand the physical meaning of critical nucleus size and nucleation energy for both homogeneous and heterogeneous nucleation
- Understand the change of critical nucleus size, the largest nucleus size, and nucleation rate in supercooled liquid with respect to undercooling
- Understand the growth of pure solid after nucleation including the major types of growth mechanisms
- Understand the impacts of temperature gradient on stability of the growth front

Expectations About Solidification (2)

- Understand the three simplest scenarios for solidification of binary alloys
- Understand constitutional supercooling
- Understand the mechanism of formation of chill zone, column zone, and equiaxed zone in casting

Class Exercise

- **Assuming during liquid solidification, the nucleus formed are cubes with edge of a,**
  1) Derive the (hypothetical) critical nucleus size a* and critical nucleation energy ΔG^* in this case
  2) Prove that, for the same undercooling, homogeneous nucleation with spherical nucleus is easier to form than cubic nucleus

Class Exercise

❑Solution

Free energy change in nucleation process for cubic nucleus formation

$$\Delta G = -a^3 \Delta G_v + 6a^2 \gamma_{SL}$$

$$\frac{d\Delta G}{da} = -3a^2 \Delta G_v + 12a\gamma_{SL} = 0$$

Therefore, $$a^* = \frac{4\gamma_{SL}}{\Delta G_v}$$

$$\Delta G_v * (cubic) = -\frac{64\gamma_{SL}^3}{\Delta G_v^2} + \frac{96\gamma_{SL}^3}{\Delta G_v^2} = \frac{32\gamma_{SL}^3}{\Delta G_v^2}$$

For the same undercooling, ΔG_v is fixed

For spherical nucleus, $$\Delta G_v * (spherical) = \frac{16\gamma_{SL}^3}{3\Delta G_v^2}$$

$$\Delta G_v * (cubic) = 6\Delta G_v * (spherical)$$

Therefore, it is much easier to form spherical nucleus at the same undercooling

Homework

- **Porter Exercise 4.16 (b and c only)**
- **Given the maximum super cooling of nickel is 319K, nickel melting temperature is 1453 ^{o}C, latent heat is -18.075 kJ/mol, liquid-solid interfacial energy is 2.5x10^{-5} J/cm^{2}, molar volume is 6.6 cm^{3}. Calculate the critical nucleus size and nucleation energy at this undercooling**