Casting Dimensions (in.)	Solidification Time (min)
0.5 × 8 × 12	3.48
2 × 3 × 10	15.78
2.5 cube	10.17
1 × 4 × 9	8.13

9-13 Find the constants B and n in Chvorinov's rule by plotting the following data on a log-log plot:

Casting Dimensions (cm)	Solidification Time (s)
1 × 1 × 6	28.58
2 × 4 × 4	98.30
4 × 4 × 4	155.89
8 × 6 × 5	306.15

9-14 A 3-in.-diameter casting was produced. The times required for the solid-liquid interface to reach different distances beneath the casting surface were measured and are shown in the following table:

Distance from Surface (in.)	Time (s)
0.1	32.6
0.3	73.5
0.5	130.6
0.75	225.0
1.0	334.9

Determine

(a) the time at which solidification begins at the surface; and

(b) the time at which the entire casting is expected to be solid.

(c) Suppose the center of the casting actually solidified in 720 s. Explain why this time might differ from the time calculated in part (b).

9-15 A 4-in.-diameter aluminum bar solidifies to a depth of 0.5 in. beneath the surface in 5 minutes. After 20 minutes, the bar has solidified to a depth of 1.5 in. How much time is required for the bar to solidify completely?

9-16 Design the thickness of an aluminum alloy casting whose length is 12 in. and width is 8 in., in order to produce a tensile strength of 40,000 psi. The mold constant in Chvorinov's rule for aluminum alloys cast in a sand mold is 45 min/in^2. Assume that data shown in Figures 9-9 and 9-10 can be used.

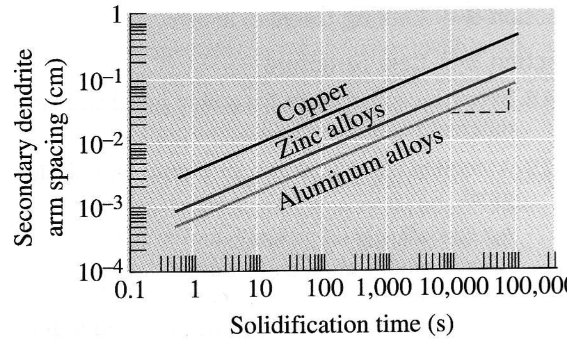

Figure 9-9 (Repeated for Problem 9-16) The effect of solidification time on the secondary dendrite arm spacings of copper, zinc, and aluminum.

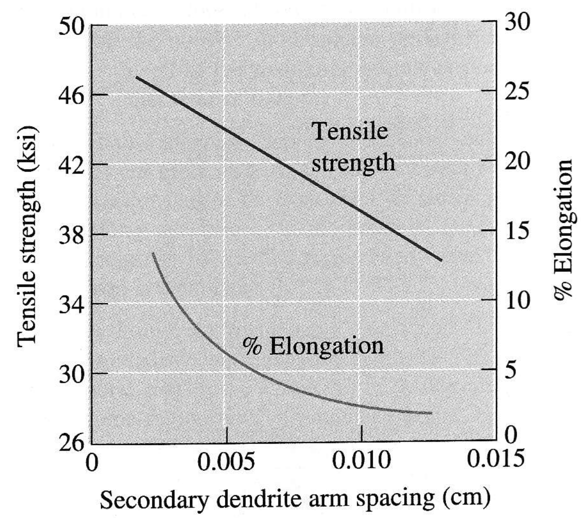

Figure 9-10 (Repeated for Problem 9-16) The effect of the secondary dendrite arm spacing on the properties of an aluminum casting alloy.

9-17 Find the constants c and m relating the secondary dendrite arm spacing to the local solidification time by plotting the following data on a log-log plot:

Solidification Time (s)	SDAS (cm)
156	0.0176
282	0.0216
606	0.0282
1356	0.0374

Section 9-4 Cooling Curves

Section 9-5 Cast Structure

9-18 Sketch a cooling curve for a pure metal and label different regions carefully.

9-19 A cooling curve is shown in Figure 9-21. Determine

(a) the pouring temperature;
(b) the solidification temperature;
(c) the superheat;
(d) the cooling rate, just before solidification begins;
(e) the total solidification time;
(f) the local solidification time; and
(g) the probable identity of the metal.
(h) If the cooling curve was obtained at the center of the casting sketched in the figure, determine the mold constant, assuming that $n = 2$.

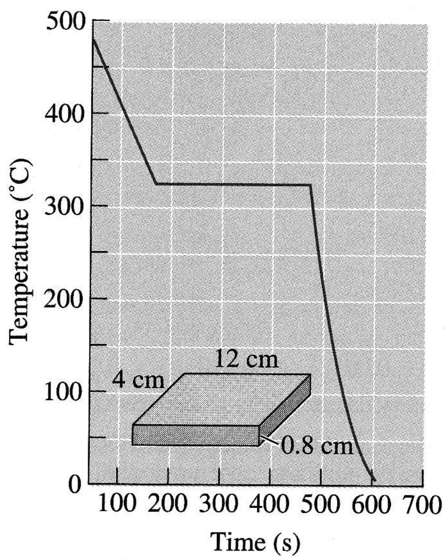

Figure 9-21 Cooling curve (for Problem 9-19).

9-20 A cooling curve is shown in Figure 9-22. Determine

(a) the pouring temperature;
(b) the solidification temperature;
(c) the superheat;
(d) the cooling rate, just before solidification begins;
(e) the total solidification time;
(f) the local solidification time;
(g) the undercooling; and
(h) the probable identity of the metal.

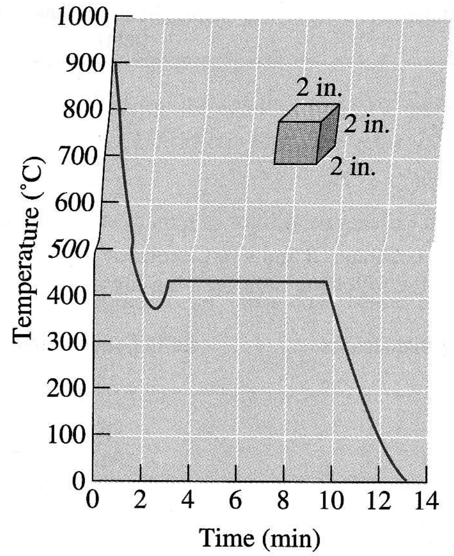

Figure 9-22 Cooling curve (for Problem 9-20).

(i) If the cooling curve was obtained at the center of the casting sketched in the figure, determine the mold constant, assuming that $n = 2$.

9-21 Figure 9-23 shows the cooling curves obtained from several locations within a cylindrical aluminum casting. Determine the local solidification times and the SDAS at each location, then plot the tensile strength versus distance from the casting surface. Would you recommend that the casting be designed so that a large or small amount of material must be machined from the surface during finishing? Explain.

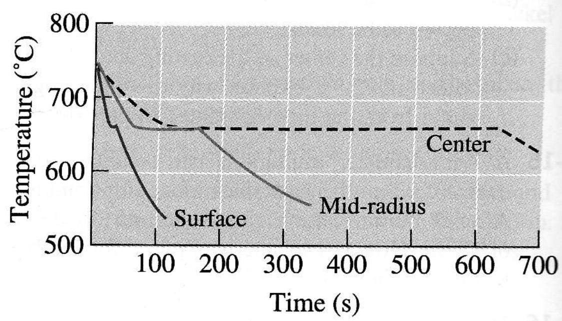

Figure 9-23 Cooling curves (for Problem 9-21).

9-22 Calculate the volume, diameter, and height of the cylindrical riser required to prevent shrinkage in a 4 in. × 10 in. × 20 in. casting if the H/D of the riser is 1.5.

Section 9-6 Solidification Defects

9-23 In general, compared to components prepared using forging, rolling, extrusion, etc., cast products tend to have lower fracture toughness. Explain why this may be the case.

9-24 What is a riser? Why should it be designed so as to freeze after the casting?

9-25 Calculate the volume, diameter, and height of the cylindrical riser required to prevent shrinkage in a 1 in. × 6 in. × 6 in. casting if the H/D of the riser is 1.0.

9-26 Figure 9-24 shows a cylindrical riser attached to a casting. Compare the solidification times for each casting section and the riser and determine whether the riser will be effective.

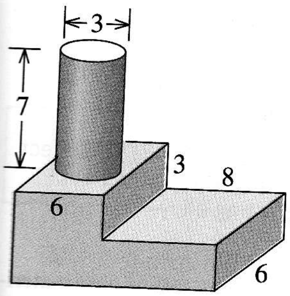

Figure 9-24 Step-block casting (for Problem 9-26).

9-27 Figure 9-25 shows a cylindrical riser attached to a casting. Compare the solidification times for each casting section and the riser and determine whether the riser will be effective.

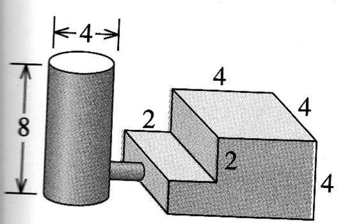

Figure 9-25 Step-block casting (for Problem 9-27).

9-28 A 4-in.-diameter sphere of liquid copper is allowed to solidify, producing a spherical shrinkage cavity in the center of the casting. Compare the volume and diameter of the shrinkage cavity in the copper casting to that obtained when a 4-in. sphere of liquid iron is allowed to solidify.

9-29 A 4-in. cube of a liquid metal is allowed to solidify. A spherical shrinkage cavity with a diameter of 1.49 in. is observed in the solid casting. Determine the percent volume change that occurs during solidification.

9-30 A 2 cm × 4 cm × 6 cm magnesium casting is produced. After cooling to room temperature, the casting is found to weigh 80 g. Determine

(a) the volume of the shrinkage cavity at the center of the casting; and

(b) the percent shrinkage that must have occurred during solidification.

9-31 A 2 in. × 8 in. × 10 in. iron casting is produced and, after cooling to room temperature, is found to weigh 43.9 lb. Determine

(a) the percent of shrinkage that must have occurred during solidification; and

(b) the number of shrinkage pores in the casting if all of the shrinkage occurs as pores with a diameter of 0.05 in.

9-32 Liquid magnesium is poured into a 2 cm × 2 cm × 24 cm mold and, as a result of directional solidification, all of the solidification shrinkage occurs along the length of the casting. Determine the length of the casting immediately after solidification is completed.

9-33 A liquid cast iron has a density of 7.65 g/cm^3. Immediately after solidification, the density of the solid cast iron is found to be 7.71 g/cm^3. Determine the percent volume change that occurs during solidification. Does the cast iron expand or contract during solidification?

Section 9-7 Casting Processes for Manufacturing Components

9-34 An alloy is cast into a shape using a sand mold and a metallic mold. Which casting will be expected to be stronger and why?

Section 9-8 Continuous Casting, Ingot Casting, and Single Crystal Growth

Section 9-9 Solidification of Polymers and Inorganic Glasses

9-35 Why do most plastics contain amorphous and crystalline regions?

9-36 Explain why silicate glasses tend to form amorphous glasses, however, metallic melts typically crystallize easily.

Section 9-10 Joining of Metallic Materials

9-37 Define the terms brazing and soldering.

Spherulite Spherical-shaped crystals produced when certain polymers solidify.

Superheat The pouring temperature minus the freezing temperature.

Thermal arrest A plateau on the cooling curve during the solidification of a material caused by the evolution of the latent heat of fusion during solidification. This heat generation balances the heat being lost as a result of cooling.

Total solidification time The time required for the casting to solidify completely after the casting has been poured.

Undercooling The temperature to which the liquid metal must cool below the equilibrium freezing temperature before nucleation occurs.

PROBLEMS

Section 9-1 Technological Significance

Section 9-2 Nucleation

9-1 Define the following terms: nucleation, embryo, heterogeneous nucleation, and homogeneous nucleation.

9-2 Suppose that liquid nickel is undercooled until homogeneous nucleation occurs. Calculate

(a) the critical radius of the nucleus required; and
(b) the number of nickel atoms in the nucleus.

Assume that the lattice parameter of the solid FCC nickel is 0.356 nm.

9-3 Suppose that liquid iron is undercooled until homogeneous nucleation occurs. Calculate

(a) the critical radius of the nucleus required; and
(b) the number of iron atoms in the nucleus.

Assume that the lattice parameter of the solid BCC iron is 2.92 Å.

9-4 Suppose that solid nickel was able to nucleate homogeneously with an undercooling of only 22°C. How many atoms would have to group together spontaneously for this to occur? Assume that the lattice parameter of the solid FCC nickel is 0.356 nm.

9-5 Suppose that solid iron was able to nucleate homogeneously with an undercooling of only 15°C. How many atoms would have to group together spontaneously for this to occur? Assume that the lattice parameter of the solid BCC iron is 2.92 Å.

9-6 Calculate the fraction of solidification that occurs dendritically when iron nucleates

(a) at 10°C undercooling;
(b) at 100°C undercooling; and
(c) homogeneously.

The specific heat of iron is 5.78 $J/cm^3 \cdot °C$.

Section 9-3 Growth Mechanisms

9-7 Calculate the fraction of solidification that occurs dendritically when silver nucleates

(a) at 10°C undercooling;
(b) at 100°C undercooling; and
(c) homogeneously.

The specific heat of silver is 3.25 $J/cm^3 \cdot °C$.

9-8 Analysis of a nickel casting suggests that 28% of the solidification process occurred in a dendritic manner. Calculate the temperature at which nucleation occurred. The specific heat of nickel is 4.1 $J/cm^3 \cdot °C$.

9-9 Write down Chvorinov's rule and explain the meaning of each term.

9-10 A 2-in. cube solidifies in 4.6 min. Calculate

(a) the mold constant in Chvorinov's rule; and
(b) the solidification time for a 0.5 in. × 0.5 in. × 6 in. bar cast under the same conditions.

Assume that $n = 2$.

9-11 A 5-cm-diameter sphere solidifies in 1050 s. Calculate the solidification time for a 0.3 cm × 10 cm × 20 cm plate cast under the same conditions. Assume that $n = 2$.

9-12 Find the constants B and n in Chvorinov's rule by plotting the following data on a log-log plot: