Chapter 11

Metal Casting Processes

QUALITATIVE PROBLEMS

11.17 If you need only a few units of a particular casting, which process(es) would you use? Why?

By the student. This is an open-ended question, with many good answers, and the answer given will depend on the applications envisioned by the student. For example, are they considering a zinc die casting or a very large stainless steel part that must be sand cast? In general, the answer depends on the ability to create pattern or mold/die prototypes. If a rapid prototyping system is available (see Chapter 20), a wax blank can be produced relatively easily, and the lost-wax (investment casting) process can be used for small production runs. If a three-dimensional printing system is available, a sand mold can be prototyped directly for sand casting. If the part is too large for investment casting, a pattern plate can be produced for sand casting. If a CNC milling machine (see, for example, Fig. 24.17 on p. 740) is available, a foam or wax pattern can be produced and investment casting or the lost-foam method can be used. Otherwise, sand casting is perhaps the most economical because of the inherent low tooling costs involved.

11.18 What are the reasons for the large variety of casting processes that have been developed over the years? Explain with specific examples.

By the student. There are a large number of acceptable answers depending on the interpretation of the problem by the student. Students may approach this as processes have been application driven, material driven, or economics driven. For example, while investment casting is more expensive than sand casting, closer dimensional tolerances are possible and thus for certain parts, e.g., barrels for handguns, investment casting is preferable. Consider also the differences between the hot- and cold-chamber permanent-mold casting operations. While the hot-chamber process is more automated, thus reducing cost, there are certain disadvantages.

11.19 Why does die casting produce the smallest cast parts?

By the student. Note that because of the high pressures involved in die casting, wall thicknesses less than those attainable by other casting methods are possible.

11.20 What differences, if any, would you expect in the properties of castings made by permanent mold vs. sand casting?

This is an open-ended problem, and a large number of answers are acceptable. Most of the different answers are associated with the students' interpretation of the word 'properties', which can be restricted to mechanical properties or can incorporate design attributes. Examples of answers are that permanent-mold castings generally possess a better surface finish, closer dimensional tolerances, more uniform mechanical properties, and more sound thin-walled sections than sand castings. However, sand castings generally will be of more intricate shapes, larger overall sizes, and (depending upon the alloy) lower in cost than permanent-mold casting.

11.21 Would you recommend preheating the molds used in permanent-mold casting? Would you remove the casting soon after it has solidified? Explain your reasons.

Preheating the molds in permanent-mold casting is advisable in order to reduce the chilling effect of the metal mold, which could lead to low metal fluidity. Also, the molds are heated to reduce thermal damage (fatigue, shock) which may result from repeated contact with the molten metal. Considering casting removal, the casting should be allowed to cool in the mold until there is no danger of distortion or developing defects during shakeout. While this may be a very short period of time for small castings, large castings may require an hour or more.

11.22 Referring to Fig. 11.3, do you think it is necessary to weigh down or clamp the two halves of the mold? Explain your reasons. Do you think that the kind of metal cast, such as gray cast iron vs. aluminum, should make a difference in the clamping force? Explain.

Due to the force exerted on the cope portion of the mold by the molten metal, it is necessary to weigh down or clamp the two halves of the mold. Furthermore, a metal with higher density will exert a higher pressure on the cope; thus, the clamping force depends on the metal cast.

11.23 Explain why squeeze casting produces parts with better mechanical properties, dimensional accuracy, and surface finish than do expendable-mold processes.

The squeeze-casting process involves a combination of casting and forging. The pressure applied to the molten metal by the punch or the upper die keeps the entrapped gases in solution, and thus porosity generally is not found in these products. Also, the rapid heat transfer results in a fine microstructure with good mechanical properties. Due to the applied pressure and the type of die material used, good dimensional accuracy and surface finish are typically obtained for squeeze-cast parts.

11.24 How would you attach the individual wax patterns on a "tree" in investment casting?

Both the pattern and the tree are locally melted at the contact surface and held together; upon solidification, the surfaces fuse together. This is repeated for each pattern until the "tree" is completed.

11.25 Describe the measures that you would take to reduce core shifting in sand casting.

Core shifting is reduced in a sand mold by core prints, chaplets, or both. Core prints (see Fig. 11.6 on p. 292) are recesses in the pattern to support the core inside the mold. If excessive shifting occurs, chaplets may be used. Chaplets are small metal supports which act both as a spacer for the core to assure proper core location and as an added support to resist shifting.

11.26 You have seen that even though die casting produces thin parts, there is a limit to how thin they can be. Why can't even thinner parts be made by this process?

Because of the high thermal conductivity the metal dies exhibit, there is a limiting thickness below which the molten metal will solidify prematurely before completely filling the mold cavity.

11.27 How are hollow parts with various cavities made by die casting? Are cores used? If so, how? Explain.

Hollow parts and cavities are generally made using unit dies (see Fig. 11.19d on p. 309 and its definition at the bottom of p. 308), although cores also can be used. Core setting occurs mechanically, e.g., for an aluminum tube, as the die closes. A rod, which extends the length of the cavity, is pushed into the mold and the molten metal is then injected. This "core" must be coated with an appropriate parting agent or lubricant to ensure easy ejection of the part without damaging it.

11.28 It was stated that the strength-to-weight ratio of die-cast parts increases with decreasing wall thickness. Explain why.

Because the metal die acts as a chill for the molten metal, the molten metal chills rapidly, forming a fine-grained hard skin (see, for example, Fig. 10.3 on p. 263) with higher strength. Consequently, the strength-to-weight ratio of die-cast parts increases with decreasing wall thickness.

11.29 How are risers and sprues placed in sand molds? Explain with appropriate sketches.

Risers and sprues are usually created from plastic or metal shapes which are produced specifically for this purpose. Thus, a metal sprue is machined to duplicate the desired shape in the mold. This sprue model is then affixed to the pattern plate before the flask is filled with sand. The sand mold is prepared as discussed in the chapter (see Fig. 11.8 on p. 294). When the pattern plate is removed, the riser and sprue patterns are removed at the same time.

11.30 In shell-mold casting, the curing process is critical to the quality of the finished mold. In this part of the process, the shell-mold assembly and cores are placed in an oven for a short period of time to complete the curing of the resin binder. List probable causes of unevenly cured cores or of uneven core thicknesses.

In the production of shell molds and cores, lack of temperature control is often the most probable cause of problems. Unevenly cured cores or uneven core thicknesses are usually caused by furnace- or temperature-control related problems, such as:

(a) Insufficient number of burners or inoperative burners in the curing furnace.

(b) One-half of the core box is higher in temperature that the other half.

(c) Mixture of low- and high-temperature melting-point sands that were improperly blended, thus causing different parts of the core to cure differently.

(d) Temperature controllers not functioning properly.

(e) The core was removed too slowly from the furnace, allowing some of it to be heated longer.

11.31 Why does the die-casting machine shown in Fig. 11.17 have such a large mechanism to close the dies? Explain.

As discussed in the text, the molten metal in die casting is introduced into the mold cavity under great pressure. This pressure has thus a tendency to separate the mold halves, resulting in large flash and unacceptable parts. The large clamp is therefore needed to hold the mold together during the entire casting cycle.

11.32 Chocolate is available in hollow shapes, such as bunnies. What process is used to make these candies?

Thin shells are typically and easily made through slush casting (see Fig. 10.11 on p. 273, and also slush molding, top of p. 555), using split molds. This can be verified by obtaining such a chocolate and breaking it, and observing the interior surface is rather coarse and shows no evidence of having contacted a mold.

11.33 What are the benefits and drawbacks to heating the mold in investment casting before pouring in the molten metal?

The benefits to heating the mold include: Greater fluidity for detailed parts (in that the molten metal will not solidify as quickly), a possible reduction in surface tension and in viscous friction in the mold, and slower cooling. The main drawbacks to heating the mold are that the mold may not have as high a strength at the elevated temperature, and the metal may be less viscid and becomes turbulent as discussed in Chapter 10. Also, the solidification time will be larger with increased mold preheat, and this can adversely affect production time and process economics as a result.

11.34 The slushy state of alloys refers to that state between the solidus and liquidus temperatures, as described in Section 10.2. Pure metals do not have such a slushy state. Does this mean that pure metals cannot be slush cast? Explain.

The “slushy” state in alloy solidification refers to an intermediate state between liquid and solid. Slush casting involves casting an alloy where the molten metal is poured into the mold, allowed to begin to solidify. The molten portion of the metal is then poured out of the mold, leaving a shell behind. This can be done using pure metals as well as alloys.

11.35 Can a chaplet also be a chill? Explain.

While, in theory, a chaplet can serve as a chill, in practice chaplets rarely do so. Chaplets are intended to support a core or a section of mold. If they are placed in a position to support the core, they may not be in a location that requires a chill. Chaplets have a large footprint, and this helps to transfer heat to the core. However, heat transfer to the core is not an option for faster cooling of the casting; heat instead must be conducted outside of the mold. Therefore, the chaplet cannot usually be considered a chill.

11.36 Rank the casting processes described in this chapter in terms of their solidification rate. That is, which processes extract heat the fastest from a given volume of metal?

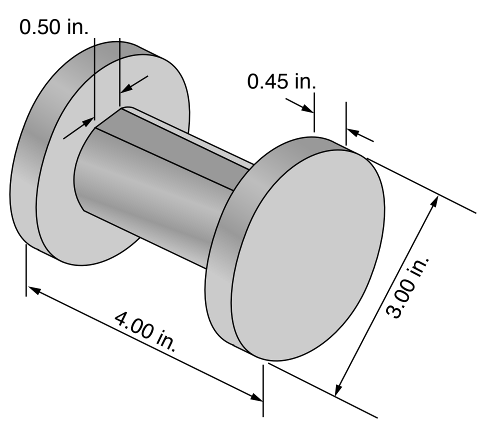
There is, as expected, some overlap between the various processes, and the rate of heat transfer can be modified when desired. However, a general ranking in terms of rate of heat extraction is as follows: Die casting (cold chamber), squeeze casting, centrifugal casting, slush casting, die casting (hot chamber), permanent mold casting, shell mold casting, investment casting, sand casting, lost foam, ceramic-mold casting, and plaster-mold casting.

QUANTITATIVE PROBLEMS

11.37 Estimate the clamping force for a die-casting machine in which the casting is rectangular with projected dimensions of 125 mm x 175 mm (5 in. x 7 in.). Would your answer depend on whether it is a hot-chamber or cold-chamber process? Explain.

The projected area is 35 in^2. For the hot-chamber process and using an average pressure of 2,000 psi, the force is 2,000 x 35 = 70,000 lb. For the cold-chamber process and using a pressure of 6,000 psi, the force is 210,000 lb. Thus, the force depends on the process as well as shape complexity.

11.38 The blank for the spool shown in Figure P11.38 is to be sand cast out of A-319, an aluminum casting alloy. Make a sketch of the wooden pattern for this part, and include all necessary allowances for shrinkage and machining.



The sketch for a typical green-sand casting pattern for the spool is shown below. A cross-sectional view is also provided to clearly indicate shrinkage and machining allowances, as well as the draft angles (see p. 326 for the required information). The important elements of this pattern are as follows (dimensions in inches):

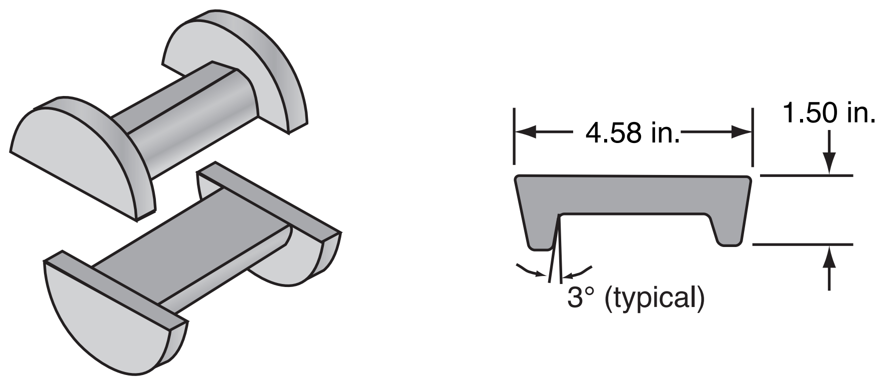
(a) Two-piece pattern.

(b) Locating pins will be needed in the pattern plate to make sure these features align properly.

(c) Shrinkage allowance = 5/32 in./ft.

(d) Machining allowance = 1/16 in.

(e) Draft = 3°.



11.39 Repeat Problem 11.38 but assume that the aluminum spool is to be cast using expendable-pattern casting. Explain the important differences between the two patterns.

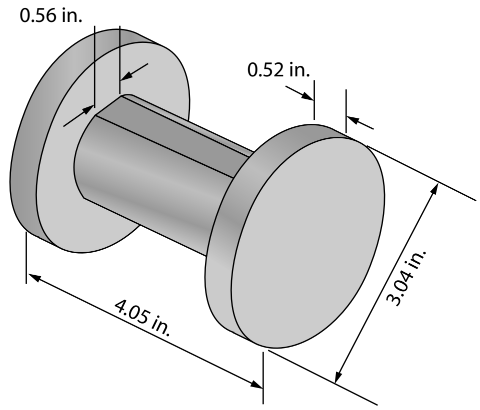
A sketch for a typical expendable-pattern casting is shown below. A cross-sectional view is also provided to clearly show the differences between green-sand (from Problem 11.38) and evaporative-casting patterns. There may be some variation in the patterns produced by students depending on which dimensions are assigned a machining allowance. The important elements of this pattern are as follows (dimensions in inches.):

(a) One-piece pattern, made of polystyrene.

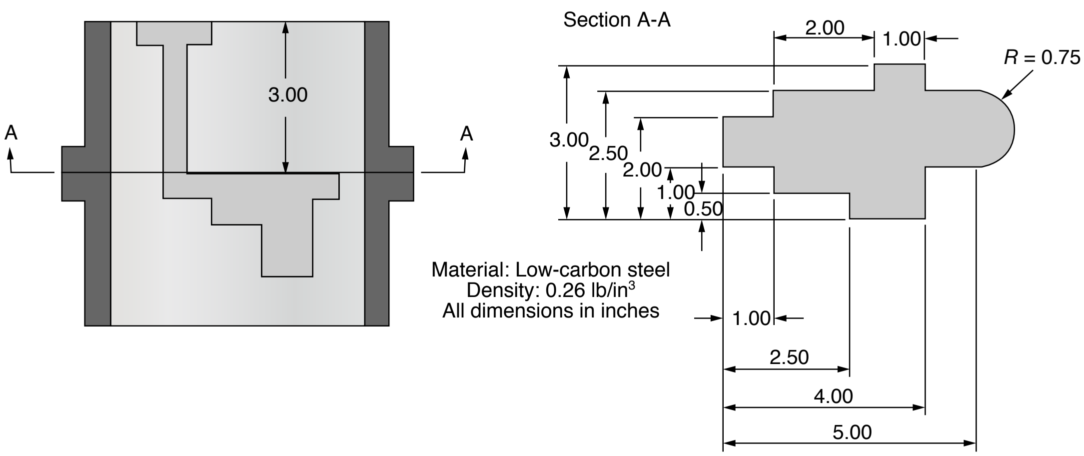
(b) Shrinkage allowance = 5/32 in./ft

(c) Machining allowance = 1/16 in.

(d) No draft angles are necessary.



11.40 In sand casting, it is important that the cope mold half be weighted down with sufficient force to keep it from floating when the molten metal is poured in. For the casting shown in the figure below, calculate the minimum amount of weight necessary to keep the cope from floating up as the molten metal is poured in. (Hint: The buoyancy force exerted by the molten metal on the cope is dependent on the effective height of the metal head above the cope.)



The cope mold half must be heavy enough or be weighted sufficiently to keep it from floating when the molten metal is poured into the mold. The buoyancy force, F, on the cope is exerted by the metallostatic pressure (caused by the metal in the cope above the parting line) and can be calculated using the formula

$$F = pA$$

where p is the pressure at the parting line and A is the projected area of the mold cavity. The pressure is

$$p = wh = (0.26 \text{ lb/in}^3)(3.00 \text{ in.}) = 0.78 \text{ psi}$$

The projected mold-cavity area can be calculated from the dimensions given on the right figure in the problem, and is found to be 10.13 in^2. Thus the force F is

$$F = (0.78)(10.13) = 7.9 \text{ lb}$$

11.41 If an acceleration of 100 g's is necessary to produce a part in true centrifugal casting, and the part has an inner diameter of 10 in., a mean outer diameter of 14 in., and a length of 25 ft, what rotational speed is needed?

The angular acceleration is given by $\alpha = \omega^2 r$. Recognizing that the largest force is experienced at the outside radius, this value for r is used in the calculation:

$$\alpha = \omega^2 r = 100 \text{ g} = 3220 \text{ ft/s}^2$$

Therefore, solving for ω,

$$\omega = \sqrt{\alpha/r} = \sqrt{\left(3220 \text{ ft/s}^2\right)/(0.583 \text{ ft})} = 74 \text{ rad/s} = 710 \text{ rpm}$$

11.42 A jeweler wishes to produce twenty gold rings in one investment casting operation. The wax parts are attached to a wax central sprue of 0.5 in. diameter. The rings are located in four rows, each 0.5 in. from the other on the sprue. The rings require a 0.125-in. diameter, 0.5-in. long runner to the sprue. Estimate the weight of gold needed to completely fill the rings, runners, and sprues. The specific gravity of gold is 19.3.

The particular answer will depend on the geometry selected for a typical ring. Let's approximate a typical ring as a tube with dimensions of 1 in. outer diameter, 5/8 in. inner diameter, and 3/8 in. width. The volume of each ring is then 0.18 in^3, and a total volume for 20 rings of 3.6 in^3. There are twenty runners to the sprue, so this volume component is

$$V = 20\left(\frac{\pi}{4}d^2\right)L = 20\left(\frac{\pi}{4}(0.125 \text{ in.})^2\right)(0.5 \text{ in.}) = 0.123 \text{ in}^3$$

The central sprue has a length of 1.5 in., so that its volume is

$$V = \frac{\pi}{4}d^2 L = \frac{\pi}{4}(0.5 \text{ in.})^2(1.5 \text{ in.}) = 0.29 \text{ in}^3$$

The total volume is then 4.0 in^3, not including the metal in the pouring basin, if any. The specific gravity of gold is 19.3, thus its density is $19.3(62.4 \text{ lb/ft}^3) = 0.697 \text{ lb/in}^3$. Therefore, the jeweler needs 2.79 lb. of gold.

11.43 Assume that you are an instructor covering the topics in this chapter, and you are giving a quiz on the numerical aspects to test the understanding of the students. Prepare two quantitative problems and supply the answers.

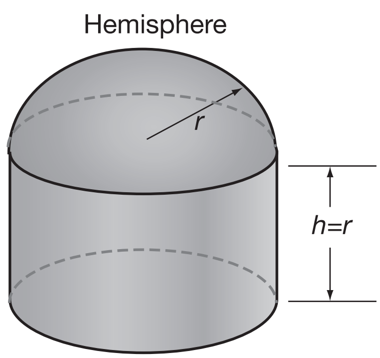
By the student. This is a challenging, open-ended question that requires considerable focus and understanding on the part of the students, and has been found to be a very valuable homework problem.

SYNTHESIS, DESIGN, AND PROJECTS

11.44 Make a list of the mold and die materials used in the casting processes described in this chapter. Under each type of material, list the casting processes that are employed, and explain why these processes are suitable for that particular mold or die material.

- Sand: Used because of its ability to resist very high temperatures, availability, and low cost. Used for sand, shell, expanded-pattern, investment, and ceramic-mold casting processes.
- Metal: Such as steel or iron. Result in excellent surface finish and good dimensional accuracy. Used for die, slush, pressure, centrifugal, and squeeze-casting processes.
- Graphite: Used for conditions similar to those for metal molds; however, lower pressures are tolerable for this material. Used in pressure- and centrifugal-casting processes.
- Plaster of paris: Used in the plaster-mold casting process in the production of small components, such as fittings and valves.

11.45 The optimum shape of a riser is spherical to ensure that it cools more slowly than the casting it feeds. However, spherically-shaped risers are difficult to cast. (a) Sketch the shape of a blind riser that is easy to mold, but also has the smallest possible surface area-to-volume ratio. (b) Compare the solidification time of the riser in part (a) to that of a riser shaped like a right circular cylinder. Assume that the volume of each riser is the same and that, for each, the height is equal to the diameter. (See the example in Section 10.3.4.)



A sketch of a blind riser that is easy to cast is shown above, consisting of a cylindrical and a hemispherical portion. Note that the height of the cylindrical portion is equal to its radius (so that the total height of the riser is equal to its diameter). The volume, V, of this riser is

$$V = \pi r^2 h + \left(\frac{1}{2}\right)\left(\frac{4\pi r^3}{3}\right) = \left(\frac{5\pi r^3}{3}\right)$$

Letting V be unity, we have $r = (3\pi/5)^{1/3}$. The surface area A of this riser is

$$A = 2\pi rh + \pi r^2 + (1/2)(4\pi r^2) = 5\pi r^2 = 5\pi(3\pi/5)^{2/3} = 5.21$$

Thus, from Eq. (10.7) on p. 272, the solidification time, t, for the blind riser will be

$$t = C(V/A)^2 = C(1/5.21)^2 = 0.037C$$

From Example 10.1 on p. 274, we know that the solidification time for a cylinder with a height equal to its diameter is $0.033C$. Thus, the blinder riser in (a) will cool a little slower.

11.46 Sketch an automated casting line consisting of machienry, conveyors, robots, sensors, etc., that could automatically perform the expendable-pattern casting process.

By the student. Several designs for an automated casting line could be developed. The student should consider the proper sequence of operations and place the required machinery in a logical and efficient order, including material handling capability.

11.47 Which of the casting processes would be most suitable for making small toys? Why?

Small toys, such as metal cars, are produced in large quantities so that the mold cost is spread over many parts. Referring to Table 11.1 on page 262, to produce the intricate shapes needed at large quantities reduces the options to investment casting and die casting. Since the parts are nonferrous, die casting is the logical choice.

11.48 Describe the procedures that would be involved in making a large bronze statue. Which casting process(es) would be suitable? Why?

By the student. Very large statues, such as those found in parks and museums, are produced in a number of methods. One is by first manufacturing or sculpting a blank from wax and then using investment casting. Another involves producing a plaster mold from a wax or wooden blank, which is closely related to plaster mold and investment casting.

11.49 Write a brief report on the permeability of molds and the techniques that are used to determine permeability.

By the student. Good sources for such a literature search are machine tool design handbooks and texts on casting operations. Permeability suggests that there is a potential for material to penetrate into the porous mold material. This penetration can be measured through a number of experimental setups, such as using a standard sized slug or shape of sand, and applying a known pressure to one side and measuring the flow rate through the sand.

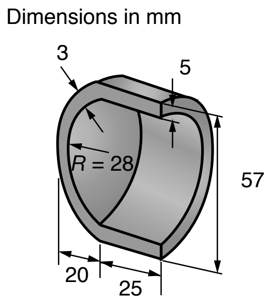
11.50 Light metals are commonly cast in vulcanized rubber molds. Perform a literature search and describe the mechanics of this process.

By the student. The basic mechanics are that an elastomer in a container is used along with a blank of the desired part. The elastomer is compressed against the blank, the container is clamped against the part and then the elastomer is vulcanized (see Section 7.9 on p. 214) and maintains its shape. This is restricted to light metals because the rubber molds would chemically degrade at the casting temperatures for other metals. A complete description is given in Gonicberg, J.A., and Ritch, M.L., *Principles of Centrifugal Rubber Mold Casting*, Providence, A.J. Oster Co., 1980.

11.51 It is sometimes desirable to cool metals more slowly than they would if the molds were maintained at room temperature. List and explain methods you woulod use to slow down the cooling process.

The cooling process can be slowed, first by cooling the mold in a room at elevated temperature. This is similar to the single-crystal casting technique shown in Fig. 11.30 on page 290. In addition, one could place a container, such as a steel drum, around the mold to slow the convected heat transfer to the ambient air. One could also reheat the mold at some stage during the cooling cycle, perhaps even with a simple approach as with a gas torch.

11.52 The part shown below is a hemispherical shell used as an acetabular (mushroom shaped) cup in a total hip replacement. Select a casting process for this part and provide a sketch of all the patterns or tooling needed if it is to be produced from a cobalt-chrome alloy.



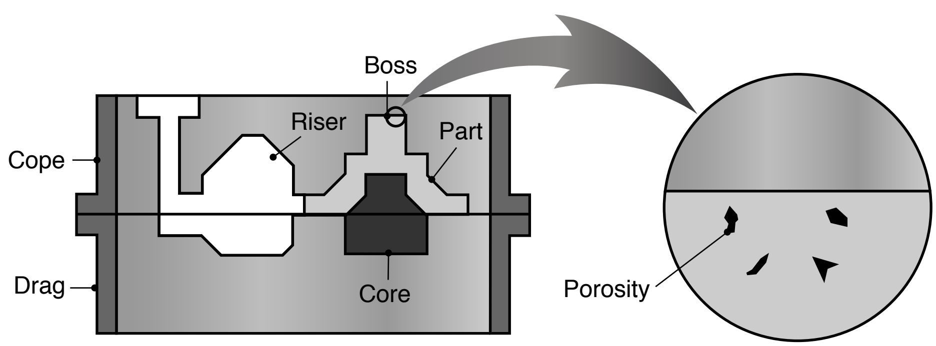
By the student. Various answers are possible, depending on the student's estimates of production rate and equipment costs. In practice, such a part would be produced through an investment-casting operation, where the individual parts with runners are injection molded and then attached to a central sprue. The tooling that would be needed include:

(a) A mold for injection molding of wax into the cup shape.

(b) Templates for placement of the cup shape onto the sprue, in order to assure proper spacing for evenly controlled cooling.

(c) Machining fixtures. It should also be noted that the wax pattern will be larger than the desired casting, because of shrinkage as well as the incorporation of a shrinkage allowance.

11.53 Porosity developed in the boss of a casting is illustrated in the figure below. Show that this problem can be eliminated by simply repositioning the parting line of this casting.



Note in the figure below that the boss is at some distance from the blind riser; consequently, the boss can develop porosity as shown because of a lack of supply of molten metal from the riser. The sketch below shows a repositioned parting line that would eliminate porosity in the boss. Note that the boss can now be supplied with molten metal as it begins to solidify and shrink.