Chapter 12

Metal Casting: Design, Materials, and Economics

QUALITATIVE PROBLEMS

12.12 Describe the procedure you would follow to determine whether a defect in a casting is a shrinkage cavity or a porosity caused by gases.

Evidence of which type of porosity is present (gas or shrinkage) can be gained by studying the location and shape of the cavity. If the porosity is near the mold surface, core surface, or chaplet surface, it is most likely to be gas porosity because the air bubbles rise to the surface due to buoyancy, whereas large shrinkage pores are more likely in the casting's bulk. However, if the porosity occurs in an area considered to be a hot spot in the casting, it is most likely shrinkage porosity. Furthermore, gas porosity generally has smooth surfaces and is often, though not always, spherical in shape (inspect, for example, the holes in Swiss cheese and observe how shiny they are). Shrinkage porosity has a more textured and jagged surface and is generally irregular in shape.

12.13 Explain how you would go about avoiding hot tearing.

Hot tearing can be avoided by two methods: (a) change the mold design to decrease the tensile stress that arises upon contraction during solidification, and/or (b) change the mold composition, such that the mold and cores are collapsible under the resulting pressure on them during shrinkage.

12.14 Describe your observation concerning the design changes shown in Fig. 12.1.

Several observations can be made regarding this figure. Figure 12.1a is further emphasized in Fig. 12.2 on p. 326, and shows that hot spots can develop where the section thickness changes abruptly or where corners exist. Figure 12.2b shows how deep cavities should be located on one side of the casting to greatly simplify pattern design as well as removal of the pattern from the sand mold. Due to large temperature gradients (which may form along flat surfaces during cooling) warping may occur. The design of a mold with ribs and serrations shown in Fig. 12.1d can reduce this effect and result in a more sound (not warped) casting. Ribs may be used, for example, on steel flanges at the recessed portion in order to avoid warping of both surfaces with which it is in contact.

12.15 If you need only a few castings of the same design, which three processes would be the most expensive per piece cast?

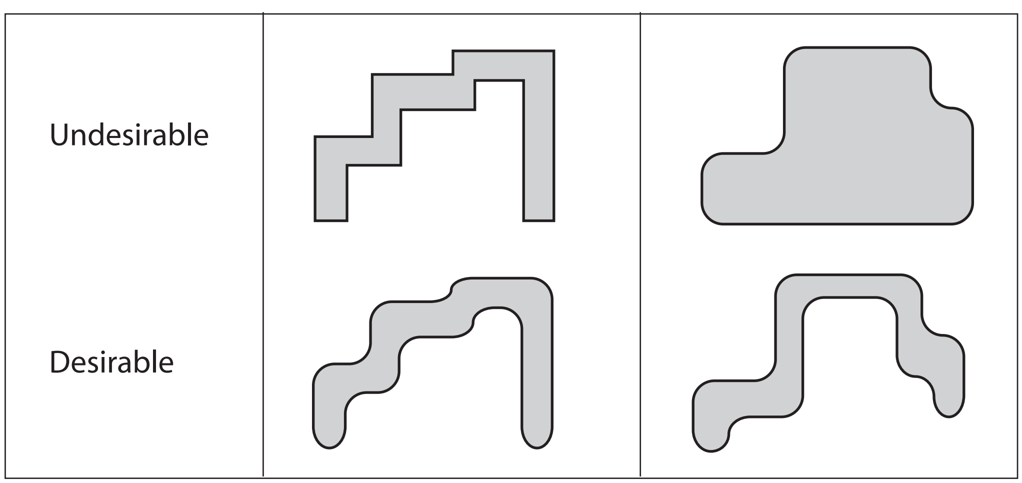
Die casting, shell-mold casting, and centrifugal casting would be the three most expensive processes per piece because these processes involve high equipment costs and a high degree of automation. Both of these factors require large production runs to justify their high cost. The high tooling cost can be mitigated somewhat by rapid tooling technologies, as discussed in Section 20.5 on p. 594. As an interesting comparison, refer to the answer to Problem 11.17 for a discussion regarding the most cost-effective means of producing only a few cast parts.

12.16 Do you generally agree with the cost ratings in Table 12.6? If so, why?

The cost ratings given in Table 12.6 on p. 337 are based on initial investment (die and equipment) and the labor required to run the processes. The labor cost depends on the extent of process automation. Thus, die casting has a low labor cost (highly automated) and investment casting has a high labor cost (little automation).

12.17 Add more examples to those shown in Fig. 12.2.

By the student. A wide variety of potential examples can be presented. The main consideration is maintaining a uniform section thickness and eliminating corners in order to avoid hot spots. Students should be encouraged to sketch designs that involve varying cross-sections, but also to place chills as an alternative to modifying the shape of the casting. Some examples of these rules are shown in Fig. 12.1c and 12.1e. Some additional designs that attempt to maintain section thickness are shown below:



12.18 Explain how ribs and serrations are helpful in casting flat surfaces that otherwise may warp. Give a specific illustration.

Due to large temperature gradients which may develop along flat surfaces during cooling, warping may be a problem. The design of a mold with ribs and serrations can reduce this effect and result in a more sound (unwarped) casting because these increase the stiffness of the casting and reduce the strain associated with a residual stress. Ribs may be used, for example, on steel flanges at the recessed portion in order to avoid warping of both surfaces with which it is in contact. An illustration of a situation where a rib is beneficial is given in Fig. 12.1d on p. 325.

12.19 Describe the nature of the design changes made in Fig. 12.3. What general principles do you observe in this figure?

Several observations can be made regarding Fig. 12.3 on p. 331, and students are encouraged to think creatively in analyzing these design features. Some of the observations that can be made are:

- In (a), the "poor" design would result in a very thin wall next to the counterbore (which may lead to potential failure), whereas the "good" design eliminates this thin wall.
- In (b), a large flat area may not be acceptable because of casting defects or warpage. The surface can be made much more aesthetically pleasing by incorporating featuers such as serrations and stripling.
- In (c), a radius makes the part much easier to cast; the likelihood of a large pore near the corner is reduced and the mold integrity is improved. Furthermore, a sharp inner corner may create difficulties durign assembly with components that may eb isnerted into the cavity.
- In (d), the "poor" design is difficult to machine (hence costly) into a die; the "good" design is much easier to produce.
- In (e), The "poor" design requires a sharp, knife edge in the die, which could reduce die life. The "good" design eliminates the need for a knife edge in the die.
- In (f), when casting threaded inserts in place, it is good practice to have a length of shank exposed before the threaded section so that the cast metal does not compormise the threads and interfere with their function.

12.20 Note in Fig. 12.4 that the ductility of some cast alloys is very low. Do you think this should be a significant concern in engineering applications of castings? Explain.

The low ductility of some cast alloys shown in Fig. 12.4 on p. 333 should certainly be taken into consideration in engineering applications of the casting. Low ductility will adversely affect properties such as toughness (since the area under the stress-strain curve will be much smaller) and fatigue life. This is particularly significant in applications where the casting is subjected to impact forces.

12.21 Do you think there will be fewer defects in a casting made by gravity pouring versus one made by pouring under pressure? Explain.

When an external pressure is applied, defects such as gas porosity, poor surface finish, and surface porosity are reduced or eliminated. Since gravity pouring does not exert as much pressure as pouring under pressure, gravity pouring generally will produce more defects.

12.22 Explain the difference in the importance of drafts in green-sand casting versus permanent-mold casting.

Draft is provided in a mold to allow the removal of the pattern from the mold without damaging the mold (see, for example, Fig. 11.5 on p. 292). If the mold material is sand and the pattern has no draft (taper), the mold cavity can be damaged upon pattern removal due to the low strength of the sand mold. However, a die made of high-strength steel, which is typical for permanent-mold casting, is not likely to be damaged during the removal of the part; thus smaller draft angles can be employed.

12.23 What type of cast iron would be suitable for heavy-machine bases, such as presses and machine tools? Why?

Because of its relatively high strength and excellent castability (which generally means low cost), a pearlitic gray cast iron would probably be most suitable for this application. Note that, as no significant ductility is required for this application, the low ductility of gray irons is of little consequence. An important further advantage is the damping capacity of these cast irons, especially for machine tools (see Section 25.4 on p. 770).

12.24 Explain the advantages and limitations of sharp and rounded fillets, respectively, in casting design.

Sharp corners and fillets should be avoided in casting design because of their tendency to cause cracking and tearing of the casting during solidification. Fillet radii should be large enough to avoid stress concentrations and yet small enough to avoid a low rate of cooling and hot spots that can cause shrinkage cavities in the casting.

12.25 Explain why the elastic modulus, E, of gray cast iron varies so widely, as shown in Table 12.4.

Because the shape, size, and distribution of the second phase, i.e., the graphite flakes, vary greatly for gray cast irons, there is a large corresponding variation of properties attainable. The elastic modulus is one property which is affected by this factor.

12.26 Why are risers not as useful in die casting as compared to sand casting?

The main reasons are the size of typical cast parts and the solidification times involved. Die cast parts generally have smaller sections than sand cast parts; a riser used in die casting will not provide molten metal to the casting because the thin sections solidify and block the flow of molten metal to the remainder of the mold. The solidification rates are important as well; to provide molten metal to the cast shape, the flow rates have to be very high because the casting solidifies so rapidly. Thus, even if a riser is provided in a die casting, the pressure is insufficient to get molten metal to flow where it is needed.

12.27 Describe the drawbacks to having a riser that is (a) too large and (b) too small.

The main drawbacks to having too large of a riser are:

(a) The material in the riser is eventually scrapped and recycled, representing a material loss;

(b) the riser has to be removed, and a larger riser will cost more to machine;

(c) a very large riser increases the solidification time;

(d) the riser may interfere with solidification elsewhere in the casting; and

(e) the extra molten metal may cause buoyancy forces sufficient to separate the mold halves unless they are properly weighted or clamped.

The drawbacks to having too small a riser are mainly associated with defects in the casting, either due to insufficient feeding of liquid metal to compensate for solidification shrinkage, and the development of shrinkage pores because the solidification front is not uniform.

12.28 Why can blind risers be smaller than open-top risers?

Risers are used as reservoirs for a casting in regions where shrinkage is expected to occur, i.e, areas which are the last to solidify. Thus, risers must be made large enough to ensure that they are the last to solidify. If a riser solidifies before the part (it is to feed) does, it is useless. Consequently, an open riser (which is in contact with air) must be larger to ensure it will not solidify first. A blind riser is less prone to this phenomenon, as it is in contact with the mold on all surfaces. Thus, it is slower to cool since the mold increases in temperature and the riser can be located in an area that will cool more slowly; thus, a blind riser may be made smaller.

12.29 If you were to incorporate lettering or numbers on a sand-cast part, would you make them to protrude from the surface or recess them into the surface? What if the part were to be made by investment casting? Explain your answer.

The answer depends on the casting process used. In both processes, letters are commonly machined, and it is easiest to machine recessed letters. In sand casting, a pattern will be machined; the recessed pattern letters will produce sand molds of protruding letters. The parts will then have recessed letters. In investment casting (see Section 19.3 on p. 544), the mold will likely be machined directly; the parts will then have protruding letters.

12.30 The general design recommendations for a well in sand casting (see Fig. 11.3) are that (a) its diameter should be at least twice the exit diameter of the sprue and (b) its depth should be approximately twice the depth of the runner. Explain the consequences of deviating from these guidelines.

(a) Regarding this rule, if the well diameter is much smaller than twice the exit diameter, then the liquid will not fill the well (see Fig. 11.3 on p. 290), and aspiration of the molten metal will result. If the diameter is much larger than twice the exit diameter, the metal may solidify in the well because of longer time there.

(b) If the depth of the well is not greater than that of the runner, turbulent metal that first splashed into the well is immediately fed into the casting, leading to aspiration and defects. If the depth is much greater, then the liquid metal stays too long in the well and thus it can solidify prematurely.

12.31 The heavy regions of parts typically are placed in the drag in sand casting and not in the cope. Explain why.

Heavy parts are placed in the drag (see Fig. 11.3 on p. 290) so that the buoyancy force on the cope is reduced. If the buoyancy force becomes high enough, the cope can separate from the drag, resulting in excessive flash in the casting. This requires expensive removal operations such as machining or cropping (see Fig. 14.8 on p. 378 for a similar example).

QUANTITATIVE PROBLEMS

12.32 When designing patterns for casting, patternmakers use special rulers that automatically incorporate solid shrinkage allowances into their designs. For example, a 12-in. patternmaker's ruler is longer than one foot. How long should a patternmaker's ruler be for making patterns for (a) aluminum castings and (b) high-manganese steel?

Referring to Table 12.1 on p. 326, we note that the shrinkage allowance for the two metals are: (a) aluminum alloy = 1.3% and (b) high-manganese steel = 2.6%. From the formula below,

$$L_f = L_o(1 + \text{shrinkage})$$

we find that for aluminum we have

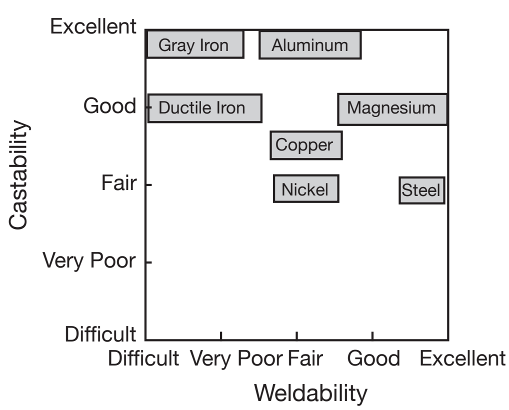
$$L_f = (12.000)(1.013) = 12.156 \text{ in.}$$

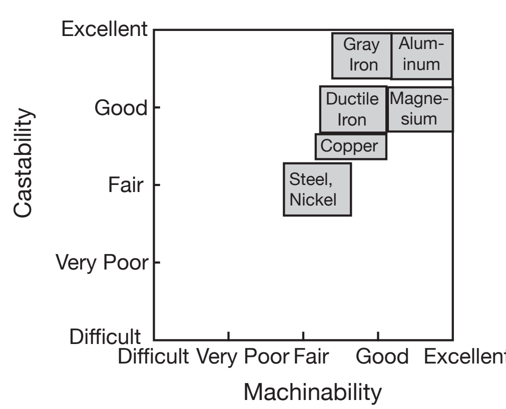
and for high-manganese steel

$$L_f = (12.000)(1.026) = 12.312 \text{ in.}$$

12.33 Using the data given in Table 12.2, develop approximate plots of (a) castability versus weldability and (b) castability versus machinability for at least five of the materials listed in the table.

The plots are as follows:





SYNTHESIS, DESIGN, AND PROJECTS

12.34 List casting processes that are suitable for making hollow parts with (a) complex external features, (b) complex internal features, and (c) both external and internal features. Explain your choices.

By the student. The answers depend on the size of the part under consideration and the materials used. Students should be encouraged to develop solutions based on their experience and training. Although complex features are always difficult to cast, sometimes they can be accomodated. For example, for complex external features:

- Within limits, a pattern plate can create intricate patterns in a sand mold, so sand casting could be suitable.
- Investment casting can utilize any pattern that allows metal to flow into and fill the cavity; these can be rapid prototyped or carved by hand, and can have very intricate external features.
- Shell molding has similar capabilities as sand casting with respect to external features.
- Die casting can produce complex features as long as they do not interfere with ejection of parts from the dies.

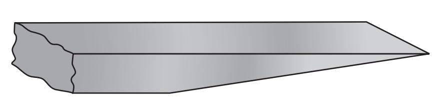
Internal features are more difficult to produce; however, the following are possible:

- In sand casting, a core with complex features can be used when necessary.
- In investment casting, internal features can be produced as long as they can be reproduced on the pattern.

When both are featuers are required, sand or investment casting may be suitable.

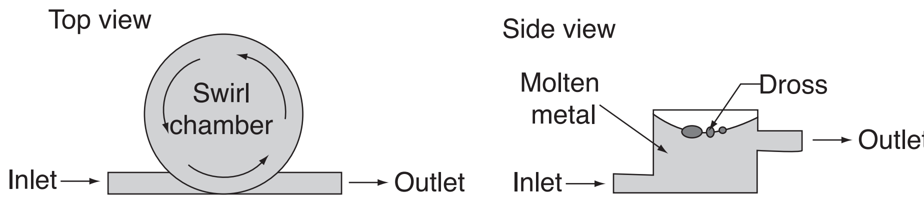
12.35 Small amounts of slag and dross often persist after skimming and are introduced into the molten metal flow in casting. Recognizing that slag and dross are less dense than the molten metal, design mold features that will remove small amounts of slag before the metal reaches the mold cavity.

There are several trap designs in use in foundries. An excellent discussion of dross trap design is given in J. Campbell, *Castings*, 1991, Reed Educational Publishers, pp. 53-55. A conventional and effective dross trap is the following design:

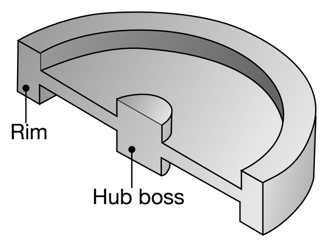


The design is based on the principle that a trap at the end of a runner will capture the first material through the runner and keep it away from the gates. The design shown above is a wedge-type trap. Metal entering the runner contacts the wedge, and the leading front of the metal wave is chilled and attaches itself to the runner wall, and thus it is kept out of the mold cavity. The wedge must be designed to avoid reflected waves that would recirculate the dross or slag.

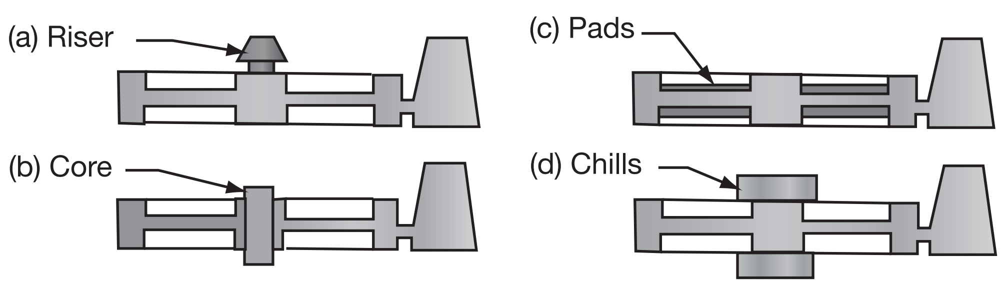
The following design is a swirl trap, which is based on the principle that the dross or slag is less dense than the metal. The metal enters the trap off of the center, inducing a swirl in the molten metal as the trap is filled with molten metal. Since it is much less dense than the metal, the dross or slag remains in the center of the swirl trap. Since the metal is tapped from the outside periphery, dross or slag is excluded from entering the casting.



12.36 For the cast metal wheel illustrated in Figure P12.36, show how (a) riser placement, (b) core placement, (c) padding, and (d) chills may be used to help feed molten metal and eliminate porosity in the isolated hub boss.



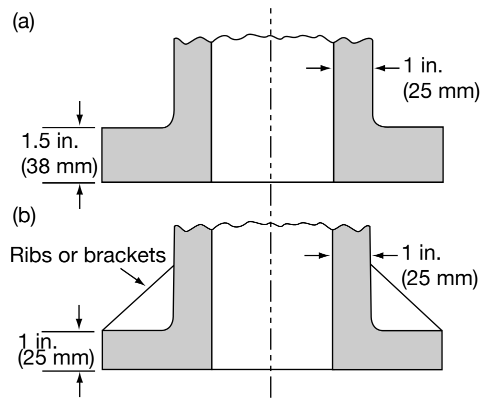
Four different methods are shown below.



12.37 Assume that the introduction to this chapter is missing. Write a brief introduction to highlight the importance of the topics covered in it.

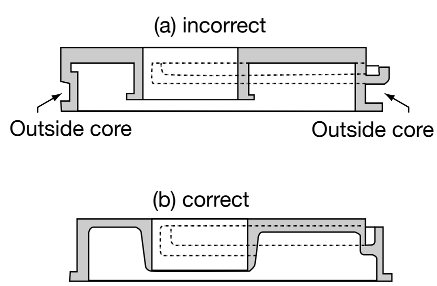
By the student. The most challenging aspect of this problem is to make the introduction sufficiently brief.

12.38 In Fig. P12.38, the original casting design shown in (a) was modified to the design shown in (b). The casting is round and has a vertical axis of symmetry. As a functional part, what advantages do you think the new design has over the old one?



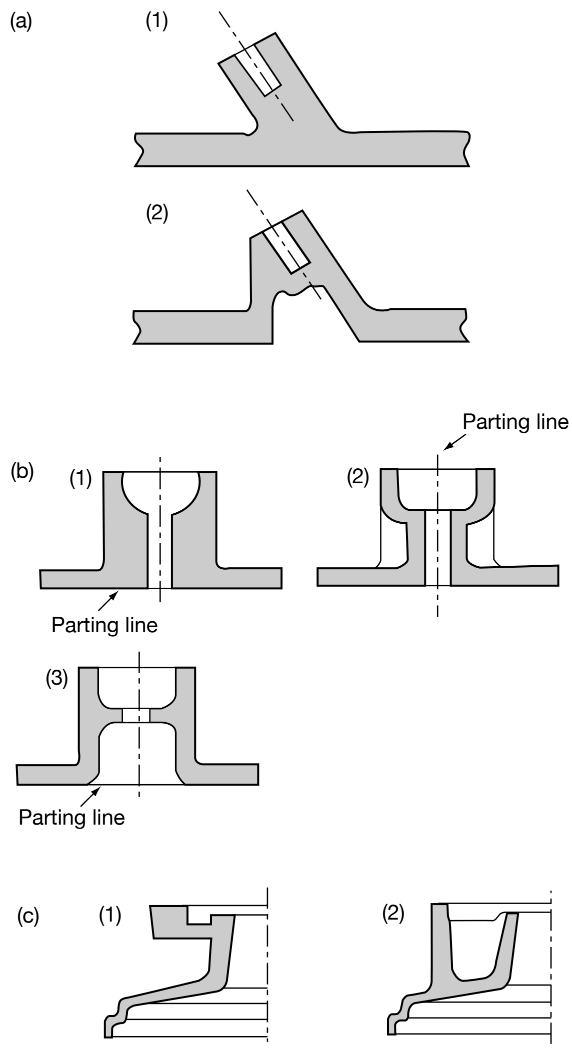
By the student. There are a number of advantages, including the fact that the part thickness is more uniform, so that large shrinkage porosity is less likely, and the ribs will control warpage due to thermal stresses as well as increase joint stiffness. This redesign illustrates the recommendations given in Figs. 12.1 and 12.2 on pp. 325-326.

12.39 An incorrect and a correct design for casting are shown Fig. P12.39. Review the changes made and comment on their advantages.



By the student. The main advantage of the new part is that it can be easily cast without using an external core. The original part requires two such cores because the shape is such that it cannot be obtained in a sand mold without using cores.

12.40 Three sets of designs for die casting are shown in Fig. P12.40. Note the changes made to die design 1 and comment on the reasons.



By the student. There are many observations, usually with the intent of minimizing changes in section thickness, eliminating inclined surfaces to simplify mold construction, and to orient flanges so that they can be easily cast.