Basics of Gray Iron Casting Design

1. Communication Ensures Optimized Design

The one rule that covers every stage of good design is communication. While there are rules that govern how gray iron will solidify and take shape as a cast component, each casting process will affect the metal differently and will offer its own benefits. Before issuing a final drawing, it's imperative to consult a foundry team or patternmaker. The engineer must know how to design a casting that will actually have the requisite strength and functional properties, while a foundry team must be able to make the casting so that it has the strength and functional properties the engineer intended. From a foundry point-of-view, it is more important to receive a component design that is practical and efficient than a "perfect" design that cannot be produced commercially without structural weakness.

Consultation will permit consideration of foundry problems that are likely to be encountered and will promote casting soundness. The time and cost of manufacture also should be considered in the preliminary stages of casting design. Important questions a foundry team can answer are:

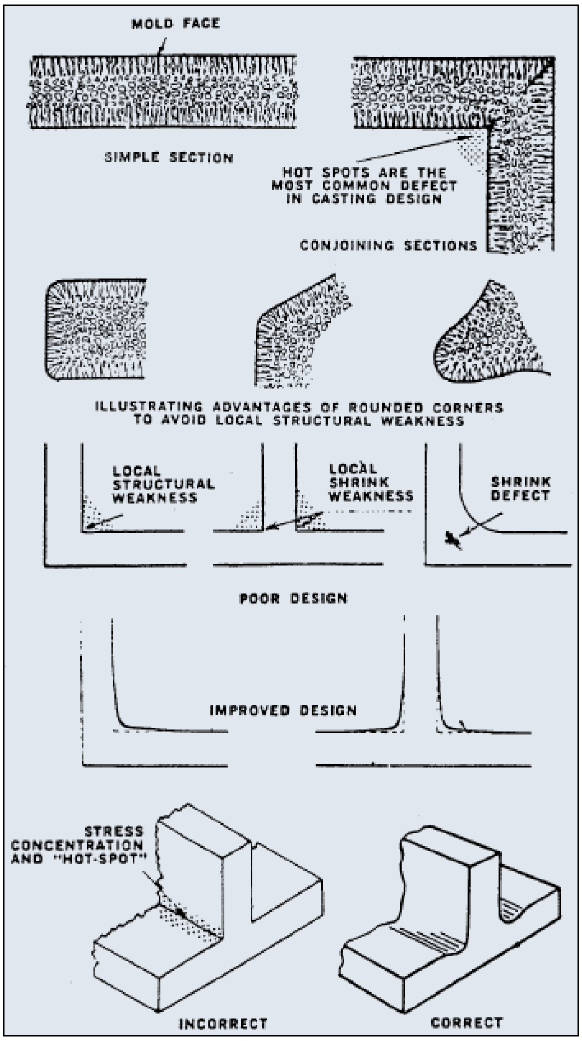
- type of pattern needed;
- metal shrinkage;
- molding method required;
- conditions necessary to make a dependable casting;
- machine finish and dimensional limitations

2. Avoid Sharp Corners and Angles

Solidification of molten metal always proceeds from the mold face, forming unbalanced crystal grains that penetrate into the mass at right angles to the plane of cooling surface. A simple section presents uniform cooling and greatest freedom from mechanical weakness. When two or more sections conjoin, mechanical weakness is induced at the junction and free cooling is interrupted, creating a “hot spot,” the most common defect in casting design.

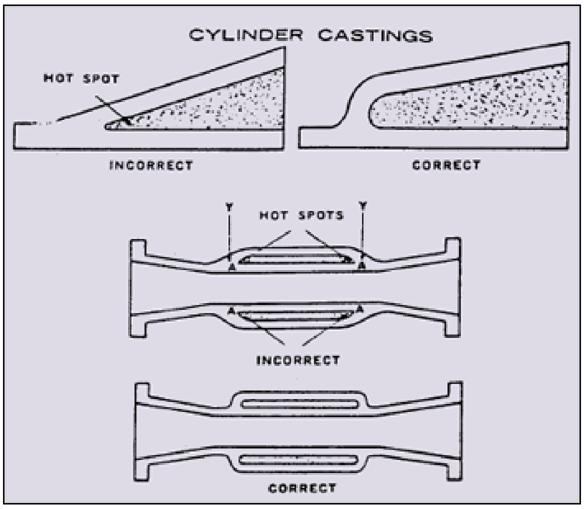
In designing adjoining sections, replace sharp angles with radii and minimize heat and stress concentration. Some examples of improved designs are shown in Fig. 2.

Fig. 2: Designs that incorporate sharp corners will result in structural weaknesses due to localized hot spots at the junctions, however, adding radii that are too large also may result in shrinkage defects (sections that are larger will feed thinner walls, leaving a void in the thick junction). By incorporating small fillet radii, hot spots are avoided, assuring improved strength.



Engine cylinder parts such as steam-jacketed cylinders often are ill-designed with localized casting weaknesses due to sharp corners (Fig. 3). When engineering a cored part, avoid designs that do not have a cooling surface.

Fig. 3: These schematics show how a steam-jacketed cylinder design was improved with rounded junctions.



Streamlining an exterior may result in a heavy section at junctions. Thin, elongated cores forming the cavities within the component result in a heat concentration accentuating the heavy sections. The resulting shrinkage defect causes leakage. A rounded junction will offer uniform strength properties.

3. Avoid Abrupt Section Changes

The difference in relative thickness of adjoining sections should not exceed a ratio of 2:1. If a greater difference is unavoidable, consider a design with detachable parts, like machine tool beds that can be bolted.

When a change in thickness is less than 2:1, it may take the form of a fillet. When the difference is greater, the recommended shift is in the form of a wedge. However, wedge shaped changes in wall thickness should not taper more than 1 in 4. Where a combination of light and heavy sections is unavoidable, use fillets and tapered sections to temper the shifts.

4. Minimize the Number of Sections

A well-designed casting brings the minimum number of sections together at one point. A simple wall section will cool freely from all surfaces, but by adding a section (forming a T), a hot spot is created at the junction, and it will cool like a wall that is 50% larger.

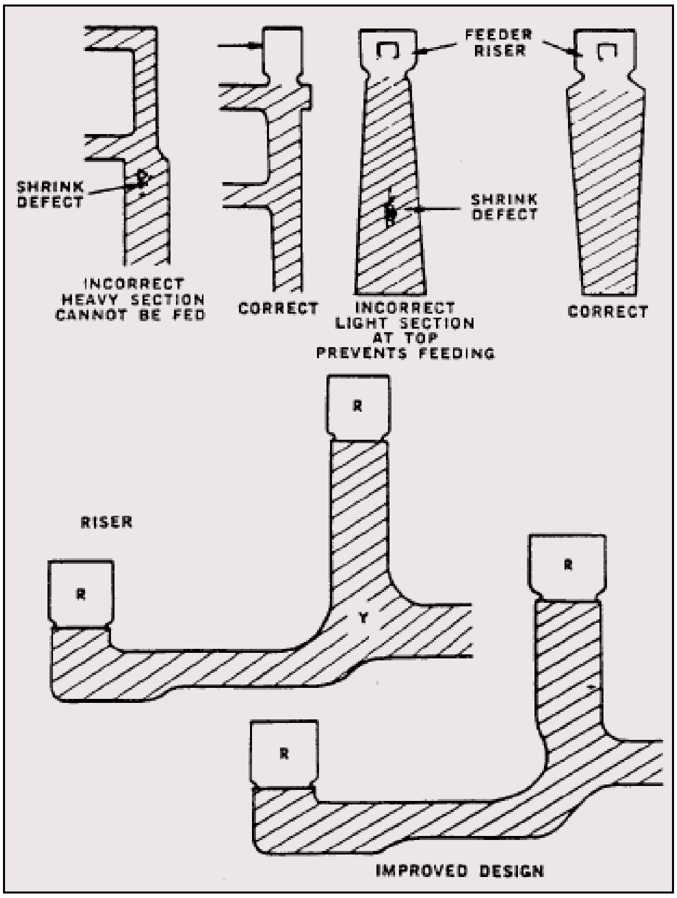
Staggering sections minimizes hot spot effects, thus eliminating weakness and reducing distortion. If staggering is not possible, a cored hole through the center of the junction will help to speed solidification and avoid hot spots (Fig. 4).

Fig. 4a - 4b: To prevent uneven cooling, bring the minimum number of sections together or stagger them so that no more than two sections conjoin. When this is not possible, a circular web with adjoining sections is the preferred way to design structures that must intersect (4b).

5. Design for Soundness

Most metals and alloys shrink when they solidify. Therefore, design components so that all members of the parts increase in dimension progressively to one or more suitable areas where feeder heads (risers) can be placed to offset liquid shrinkage (Fig. 1).

Fig. 1: These illustrations portray how design can be used to rectify metal shrinkage defects. To ensure a component is free of shrinkage porosity, design components so that heavier sections are close to risers that can feed liquid metal to them.



6. Employ Uniform Sections

Thicker walls will solidify more slowly, so they will feed thinner walls, resulting in shrinkage voids. The goal is to design uniform sections that solidify evenly. If this is not possible, all heavy sections should be accessible to feeding from risers.

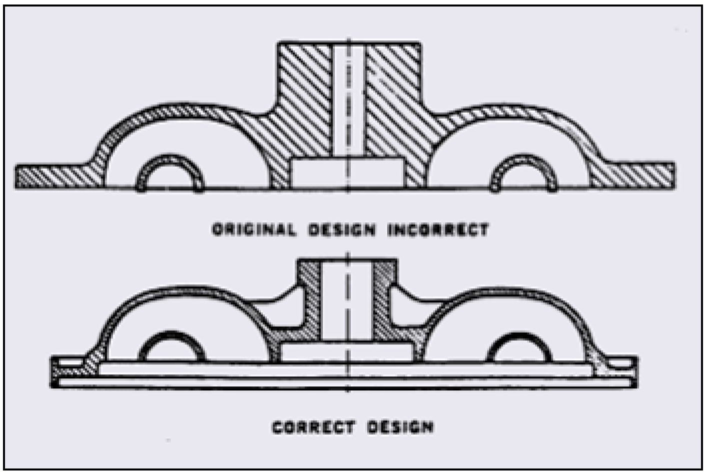
7. Correctly Proportion Inner Walls

Inner sections of castings (resulting from complex cores) cool much slower than outer sections and cause variations in strength properties. A good rule is to reduce inner sections to 0.9 of the thickness of the outer wall.

Avoid rapid section changes because they will result in porosity problems similar to what is seen with sharp angles. Whenever complex cores must be used, design for uniformity of section to avoid local heavy masses of metal.

The inside diameter of cylinders and bushings should exceed the wall thickness of castings. When the inside diameter of a cylinder is less than the wall thickness, it is better to cast the section solid, as holes can be produced by cheaper (and safer) methods than with extremely thin cores.

Fig. 6: To remedy the shrinkage defects in the original design of a hydraulic coupling, excessive metal was removed, resulting in a lighter weight casting with less strain in the light radial veins.



8. Fillet All Sharp Angles

Fillets (round-end corners) have three functional purposes:

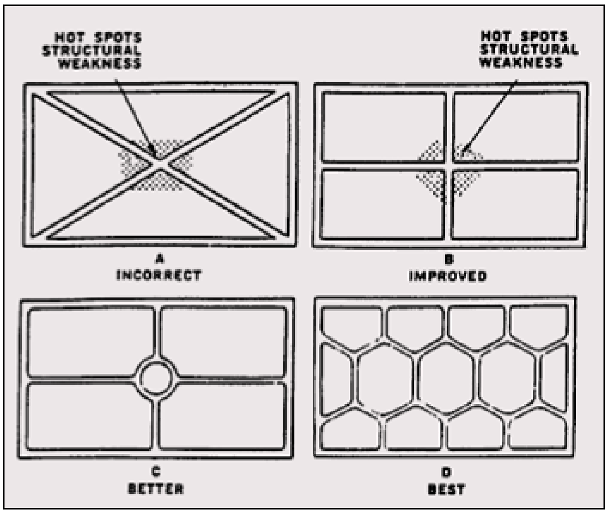
- to reduce the stress concentration in a casting in service;
- to eliminate cracks, tears and draws at reentry angles;
- to make corners more moldable by eliminating hot spots.

The number of fillet radii in one pattern should be the minimum possible, preferably only one. To fulfill engineering stress requirements and reduce stress concentration, relatively large fillets may be used with radii equaling or exceeding casting section. Fillets that are too large are undesirable—the radius of the fillet should not exceed half the thickness of the section joined.

To avoid a section size that is too large at an "L" junction, round an outside corner to match the fillet on the inside wall. Where this is not possible, consideration must be given to which is more vital: the engineered design or the possible casting defect.

In the case of a "V" or "Y" sections and other angular forms, always design them so that a generous radius eliminates localization of heat.

Fig. 7a - 7d: In 7a, walls meet at acute angles, creating hot spots. The best design is 7d in which honeycombing produces uniform cooling conditions, assuring improved strength with minimal risk of distortion and structural weakness.



9. Maximize Design of Ribs and Brackets

Ribs have two functions: to increase stiffness and to reduce weight. If they are too shallow or too widely spaced, they can be ineffective. The thickness of ribs should approximate 80% of the adjoining thickness and should be rounded at the edge. In other words, thin ribs should be avoided when joined to a heavy section or they may lead to high stresses and cracking. The design preference is for the ribs to be deeper than they are thick; the ribs should solidify before the casting section they adjoin. In addition, the space between ribs should prevent any localized accumulation of metal.

In general, ribs in compression offer a greater safety factor than ribs in tension. However, castings having thin ribs or webs in compression may require design changes to provide necessary stiffening and avoid buckling.

Avoid cross ribs or ribbing on both sides of a casting. Cross ribbing creates hot spots and makes feeding difficult. Instead, design cross-coupled ribs in a staggered double "T" form. Avoid complex ribbing, which complicates molding, hinders uniform solidification and creates hot spots. Consequently, ribs are only preferable when the casting wall cannot be made strong or stiff enough on its own.

Ribs meeting at acute angles also may cause molding difficulties, increase costs and aggravate the risk of casting defects. "Honeycombing" often will provide increased strength and stiffness without creating hot spots (Fig. 7).

Brackets carrying offset loads introduce bending moments—localized and in the body of the casting. As a remedy, taper "L"-shaped brackets and make the length of contact with the main casting as ample as possible. As another option, brackets may frequently be cast separately and then attached, simplifying molding.

A ribbed bracket will offer a stiffness advantage, but avoid heat concentration by providing cored openings in webs and ribs. Such openings should be as large as possible, and consistent with strength and stiffness. Avoid rectangular-shaped cored holes in ribs or webs; use oval-shaped holes with the longest dimension in the direction of the stresses.

10. Avoid Using Bosses, Lugs, and Pads

Bosses and pads increase metal thickness, create hot spots and cause open grain or draws. If they must be incorporated into a design, blend them into the casting by tapering or flattening the fillets.

Bosses should not be used in casting design when the surface to support bolts may be obtained by milling or countersinking. In addition, a continuous rib instead of a series of bosses will permit shifting hole location.

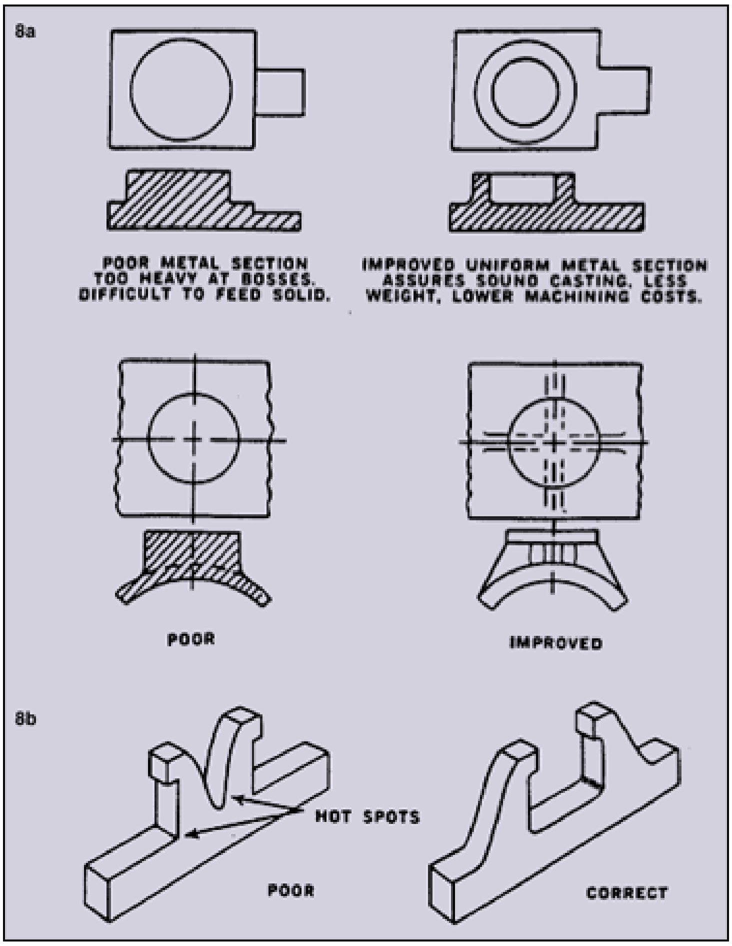
The thickness of bosses and pads preferably should be less than the thickness of the casting section they adjoin but thick enough to permit machining without touching the casting wall. Where a casting section is light and does not permit this, following these minimum recommended heights can serve as a guide:

1. if the casting length is less than 1.5 ft, the height of the boss should be at least 0.25 in.;
2. if the casting is 1.5-6 ft, the boss should be at least 0.75 in.;

3. if the casting is more than 6 ft, the boss should be 1 in. When there are several lugs and bosses on one surface, they should be joined to facilitate machining.

When there are several lugs and bosses on one surface, they should be joined to facilitate machining. A panel of uniform thickness (instead of many pads at varying heights) will simplify machining. In large castings, pouring a metal section that is too heavy at the bosses is difficult to feed. A better design is to make the walls of the boss at uniform thickness to the casting walls (Fig. 8a - 8b).

Fig. 8a - 8b: By designing a uniform metal section at the boss (essentially removing unnecessary material at the center of the boss), both weight and machining costs are reduced. In addition, to avoid heat concentration, spread lugs.



Visualize the Casting in the Mold

It can be difficult to follow all section changes and shapes from a blueprint. By creating a three-dimensional drawing or constructing a small model, an engineer can study how the metal will enter the mold, discover how solidification proceeds and define how parts must be fed to assure casting soundness.

A model to scale or a full-size pattern can be used later to help the designer see how cores must be designed, placed or omitted. It also will help the foundry to determine how to mold the casting, detect casting weakness (shrinks and cracks), where to place gates and risers, and answer other questions affecting casting soundness, cost and delivery