CASTING PROCESSES have existed since prehistoric times (see the article “History of Casting” in this Volume). Over the years a wide variety of molding and casting methods have been developed, because the only limitation is human ingenuity. These methods will be introduced and classified in this article. More detailed information on each process can be found in the subsequent articles in this Section.

**Casting Processes (Ref 1)**

Figure 1 shows a simplified flow diagram of the basic operations for producing a sand casting. There are variations from this flow sheet depending on the type of material cast, the complexity of the component shape, and the quality requirements established by the customer. There are also many alternative methods of accomplishing each of these tasks.

The right side of Fig. 1 begins with the task of patternmaking. The article “Patterns and Patternmaking” in this Volume describes in detail the various pattern materials and considerations necessary in producing a quality pattern. A pattern is a specially made model of the component to be produced, used for producing molds.

Generally, sand is placed around the pattern and, in the case of clay-bonded sand, rammed to the desired hardness. In the case of chemical binders, the mold is chemically hardened after light manual or machine compaction. Molds are usually produced in two halves so that the pattern can be easily removed. When these two halves are reassembled, a cavity remains inside the mold in the shape of the pattern. Mold-making equipment and processing are described in the article “Sand Processing” in this Volume.

Internal passageways within a casting are formed by the use of cores. Cores are parts made of sand and binder that are sufficiently hard and strong to be inserted in a mold. Thus, the cores shape the interior of a casting, which cannot be shaped by the pattern itself. The patternmaker supplies core boxes for the production of precisely dimensioned cores. These core boxes are filled with specially bonded core sand and compacted much like the mold itself. Cores are placed in the drag or bottom section of the mold, and the mold is then closed by placing the cope, or top section, over the drag. Mold closing completes the production of the mold, into which the molten metal is then poured. Procedures for making cores are described in detail in the articles “Resin Binder Processes” and “Coring” in this Section.

Casting production begins with melting of the metal (left side, Fig. 1). Molten metal is then tapped from the melting furnace into a ladle for pouring into the mold cavity, where it is allowed to solidify within the space defined by the sand mold and cores. Melting, refining, and pouring of castings are described in the following articles in the Section “Foundry Equipment and Processing” in this Volume:

- “Melting Furnaces”
- “Vacuum Melting and Remelting Processes”
- “Degassing Processes (Converter Metallurgy)”
- “Degassing Processes (Ladle Metallurgy)”
- “Nonferrous Molten Metal Processes”
- “Automatic Pouring Systems”

![Fig. 1](image-url)  
Simplified flow diagram of the basic operations for producing a steel casting. Similar diagrams can be applied to other ferrous and nonferrous alloys produced by sand molding. Source: Ref 1
After it has solidified, the casting is shaken out of the mold, and the risers and gates are removed. Risers (also called “feeders”) are shapes that are attached to the casting to provide a liquid-metal reservoir and control solidification. Metal in the risers is needed to compensate for the shrinkage that occurs during cooling and solidification. Gates are the channels through which liquid metal flows into the mold cavity proper. Heat treatment, cleaning and finishing, and inspection follow. These steps are outlined in the article “Processing of Castings” and in the articles on specific metals and alloys in the Sections “Ferrous Casting Alloys” and “Nonferrous Casting Alloys” in this Volume.

**Classification of Molding and Casting Processes**

Foundry processes can be classified based on whether the molds are permanent or expendable. Similarly, subclassifications can be developed from patterns, that is, whether or not the patterns are expendable. A second subclassification can be based on the type of bond used to make the mold. For permanent molding, processes can be classified by the type of mechanism used to fill the mold. Table 1 provides one possible classification system for the molding and casting processes described in this Section. Permanent pattern, expendable pattern, and permanent mold processes, as categorized in Table 1, are summarized below.

**Permanent Pattern Processes.** As indicated in Table 1, a number of processes use permanent patterns. Of these processes, however, green sand molding is the most prevalent. The typical steps involved in making a casting from a green sand mold are shown in Fig. 2 and described below (Ref 1).

The sequence begins with a mechanical drawing of the desired part. Patterns are then produced and mounted on pattern plates. Both the cope and drag patterns include core prints, which will produce cavities in the mold to accommodate extensions on either end of the core. These extensions fit solidly into the core prints to hold the core in place during pouring. The gate or passageway in the sand mold through which the molten metal will enter the mold cavity is usually mounted on the drag pattern plate. Locating pins on either end of the pattern plates allow for accurate setting the flask over the plate.

Cores are produced separately by a variety of methods. Figure 2 shows the core boxes, which are rammed with a mixture of sand and core binder (see the article “Coremaking” in this Section). If the cores must be assembled from separately made components, they are pasted together after curing. They are then ready to be inserted into the sand mold.

The mold is made by placing a flask (an open metal box) over the cope pattern plate. Before molding can begin, risers are added to the pattern at predetermined points to control solidification and supply liquid metal to the casting to compensate for the shrinkage that takes place during cooling and solidification. Thus, any shrinkage voids form in the risers, and the casting will be sound. A hole or holes (called sprues) must also be formed in the cope section of the mold to provide a channel through which the molten metal can enter the gating system and the mold cavity.

The cope half of the mold is produced by ramming sand into the flask, which is located on the pattern plate with pins. The flask full of sand is then drawn away from the pattern board, and the riser and sprue pieces removed.

A flask is subsequently placed over the drag pattern plate using the locating pins on the plate. Sand is rammed around the pattern, and a bottom board is placed on top of the flask full of sand. The pattern, flask, and bottom board are then molded over 180°, and the pattern is withdrawn.

The completed core is set into the core prints in the drag half of the mold and the cope half of the mold is set on top of the drag. Proper alignment of the mold cavity in the cope and drag portions of the mold is ensured by the use of closing pins, which align the two flasks. The flasks can be clamped together, or weights can be placed on top of the cope, to counteract the buoyant force of the liquid metal, which would otherwise tend to float the cope off the drag during pouring.

Metal is then poured into the mold cavity through the sprue and allowed to solidify. The casting is shaken from the sand and appears as shown in Fig. 2, with the sprue, gating system, and risers attached. Following shakeout, the flasks, bottom boards, and clamps are cycled back to the molding station while the casting is moved through the production process. When the gates and risers are removed from the casting, they are returned to the furnace to be remelted. After cleaning, finishing, and heat treating, the castings are ready for shipment.

**Expendable pattern processes use poly- styrene patterns (lost foam casting and Replicast process) or wax patterns (see discussion below on investment casting). Both of these foundry processes are increasing in use.**

The investment casting process has been known for at least 6000 years, but its use for the production of commercial castings has grown considerably during the second half of the 20th century. The process is also referred to as the lost wax process and as precision casting. The term precision implies high accuracy of dimensions and tight tolerances. Investment casting also yields smoother, high-integrity surfaces that require little or no machining, depending on the application.
The basic steps involved in making a casting from a green sand mold are as follows:

- Production of heat-disposable patterns, usually made of wax or wax/resin mixtures
- Assembly of these patterns onto a gating system
- Investing, or covering, the pattern assembly with ceramic to produce a monolithic mold
- Melting out the pattern assembly to leave a precise mold cavity
- Firing the ceramic mold to remove the last traces of the pattern material, to fire the ceramic and develop the high-temperature bond, and to preheat the mold ready for casting
- Casting (pouring)
- Shakeout, cutoff, and finishing

These basic process steps are outlined schematically in Fig. 3. Detailed information on each of these processing steps can be found in the article “Investment Casting” in this Section.

Although it has a wide variety of applications, investment casting is particularly favored for the production of parts for gas turbine blades and vanes (nickel and cobalt alloys) and aircraft structural components (titanium, superalloys, and 17-4 PH stainless steel). The application of directional solidification (DS) and single-crystal (SC) technology to investment casting has also increased interest and use. Detailed information on developments in DS/SC technology can be found in the following articles in this Volume:

- “Solidification of Single-Phase Alloys”
- “New and Emerging Processes” (see the section “Directional and Monocrystal Solidification”)
- “Vacuum Melting and Remelting Processes”
- “Nickel and Nickel Alloys”

Examples of investment castings for critical applications are shown in Fig. 4(a) to 4(c). Permanent mold processes involve the use of metallic (ferrous) or solid graphite molds. On a volume basis, die casting, centrifugal casting, and permanent mold (gravity die) casting are the most important. Each of these is covered in detail in this Section. As indicated in Table 1, however, a number of hybrid processes, such as squeeze casting and semisolid metal processing have been developed that use permanent molds. Figure 5 shows a flowchart
of operations for the rheocast method of semisolid casting. This process involves vigorous agitation of the melt during the early stages of solidification to break up the solid dendrites into small spherulites. The benefits provided by semisolid forming processes, as well as the microstructures produced by these methods, are discussed in the articles "New and Emerging Processes" (see the section on "Semisolid Metal Casting and Forging") and "Zinc and Zinc Alloys" in this Volume.

REFERENCE

SELECTED REFERENCES
- E.L. Kotzin, Metalcasting & Molding Processes, American Foundrymen's Society, 1981
- Molding Methods and Materials, American Foundrymen's Society, 1962
**Classification of Processes/Foundry Operations / 207**

**Fig. 4(a)** Directionally solidified land-based turbine blades made from investment cast nickel-base superalloys. Courtesy of Howmet Corporation, Whitehall Casting Division.

**Fig. 4(b)** Radial and axial turbine wheels made from investment cast Mar-M-247 nickel-base superalloy. Courtesy of Howmet Corporation, Whitehall Casting Division.

**Fig. 4(c)** Investment cast turbine blade with convex wall removed showing complex core.

**Fig. 5** Rheocast process. Source: M.C. Flemings, Massachusetts Institute of Technology.