CHAPTER 1

Introduction

Mahi Sahoo
Suraja Consulting Inc.

Alfred Spada
American Foundry Society

A casting is a metal object produced by solidifying molten metal in a mold. The shape of the object is determined by the shape of the mold cavity. The casting process, also known as founding, involves melting metal and pouring it into the mold cavity, which is close to the final dimensions of the finished form. Many types of complex objects ranging in size from a few grams to thousands of kilograms are produced in a metal casting facility. Castings are produced by various casting processes such as sand, permanent mold, investment, and lost foam. While all metals can be cast, the most predominant are iron, steel, aluminum, copper, magnesium, and zinc-based alloys. The science of treating the molten metal and designing the molds for smooth flow of molten metal into the mold cavity to minimize air entrapment are essential parts of casting technology to produce premium quality cast components.

Cast products are different from wrought products. The former are obtained when molten metal solidifies in a desired form. By contrast, wrought products start as cast ingots that are then thermomechanically shaped by different processes such as forging, rolling, and extrusion. In terms of value and volume, metal casting ranks second only to sheet steel in the metal producing industry.

Metal castings are used in more than 90% of all manufactured goods and find a wide range of applications in various sectors such as transportation (automotive, railway, naval, aerospace), mining, forestry, power generation, petrochemical, construction machinery, sporting goods, household appliances, and farm equipment. Typical cast components in major alloys are shown in Fig. 1.1.

Advantages of Casting Process

Certain advantages are inherent in the metal casting processes. These may form the basis for choosing casting as a process to be preferred over other shaping processes. Some of the reasons for the success of the casting process are as follows [1, 2]:

- The most intricate of shapes, both external and internal, may be cast. As a result, many other manufacturing operations such as machining, forging, and welding may be minimized or eliminated.

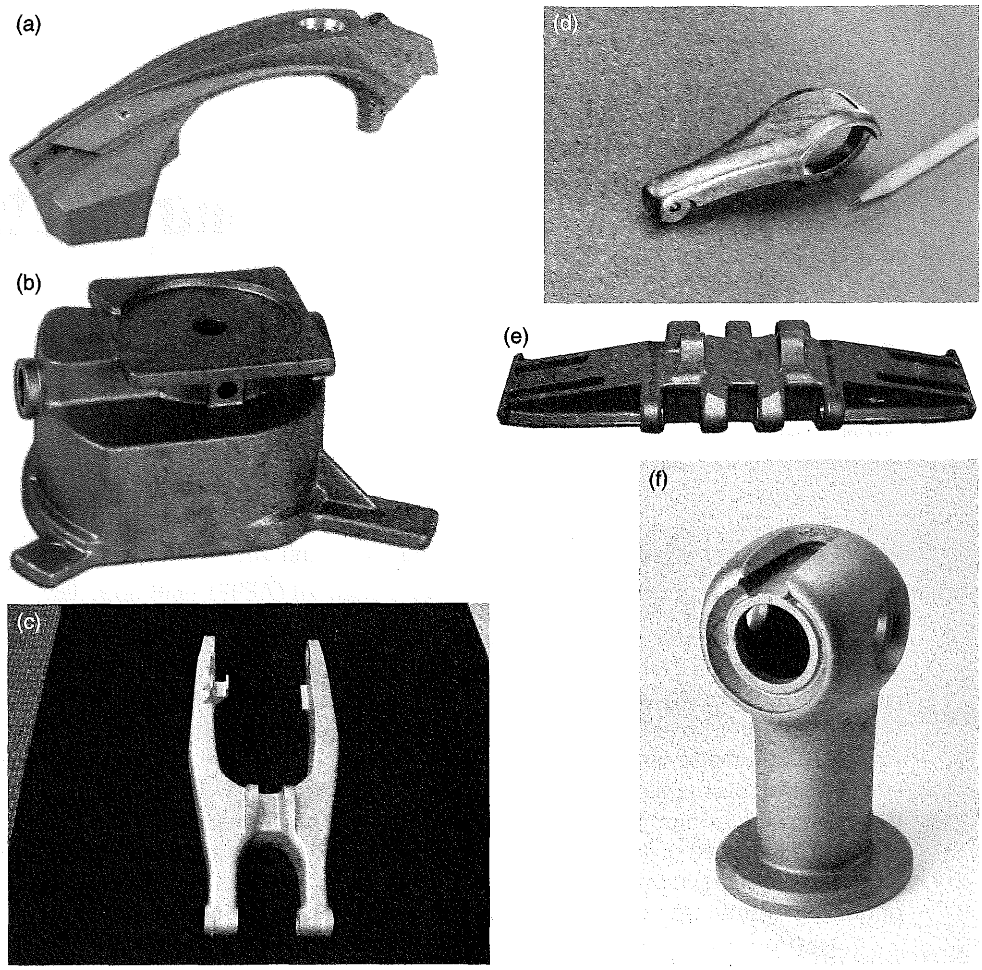


FIGURE 1.1 Typical castings in major alloys. (*a*) This motorcycle frame component was produced via the nobake sand casting process in 356 aluminum with T6 treatment temper. (*b*) The bronze alloy used for this dental suction pump was selected for its high strength, mechanical properties, and wear resistance. (*c*) Produced for a racing motorcycle, this one-piece magnesium casting replaced a three-piece aluminum part. The component is 33% lighter than the original, which impacts the overall performance of the bike. (*d*) This miniature zinc casket arm weighs less than 6 oz. (*e*) This NASA component for the space shuttle crawler transporter, produced with modified 4320 steel alloy via V-process casting, met reduced surface hardness requirements while maintaining high material strength. (*f*) This ductile iron green sand casting is the main structural element of the Spartan hydrant, enclosing and protecting its working parts.

- Because of their metallurgical nature, some metals can only be cast to shape since they cannot be hot-worked into bars, rods, plates, or other shapes from ingot form as a preliminary to other processing. A good example of casting is the family of cast irons which are low cost, extremely useful, and exceed the total of other metals in tonnage cast.

- Casting is a simplified manufacturing process. An object cast as a single piece often would otherwise require multiple manufacturing steps (stamping and welding, for example) to be produced any other way.
- Casting can be a low-cost, high-volume production process, where large numbers of a given component may be produced rapidly. Typical examples are plumbing parts and automotive components such as engine blocks, manifolds, brake calipers, steering knuckles, and control arms.
- Extremely large, heavy metal objects such as pump housings, valves, and hydroelectric plant parts which could weigh up to 200 tons may be cast. These components would be difficult or economically impossible to produce otherwise.
- Some engineering properties such as machinability, bearing, and strength are obtained more favorably in cast metals. In addition, more uniform properties from a directional standpoint can be expected, which is not generally true for wrought products.
- Casting technology has progressed significantly, allowing products to be cast with very thin cross sections, often referred to as "thin-wall-casting"; such capabilities allow designers to reduce the casting weight that is often assumed necessary for production.
- One has to consider the economic advantages of the casting process. In the aerospace industry, some components are still being machined out of forged or rolled pieces despite the fact such pieces can be cast more economically to meet the design criteria, especially with respect to strength and toughness.

In some cases, the casting process may give way to other methods of metal processing. For example, machining produces smooth surfaces and dimensional accuracy not obtainable in any other way; forging aids in developing the ultimate tensile strength and toughness in steel; welding provides a convenient method of joining or fabricating wrought or cast parts into more complex structures; and stamping produces lightweight steel metal parts. Thus the engineer may select from a number of metal-processing methods, singularly or in combination, which is most suited to the needs of his or her work.

The Foundry Industry

The world production of castings for different metals is shown in Table 1.1 for the years 2009 through 2011. It is evident that the world economic recession (2008-09) affected the production of castings. However, as the economy continues to improve, production of castings will increase and the global forecast is for 102 million tons of casting by 2015. China is the largest producer of castings followed by the United States and India. The top 10 countries in the world producing ferrous and nonferrous castings are listed in Table 1.2.

According to U.S. Department of Commerce statistics, metal casting remains 1 of the 10 largest industries when rated on a value-added basis. In the United States, the foundry industry is a $23 billion industry, employing more than 200,000 people

Metal	2009	2010	2011
Gray iron	37,749	43,258	45,870
Ductile iron	29,404	23,451	24,782
Malleable iron	1,013	–	–
Steel	9,070	10,215	10,342
Copper alloys	1,488	1,652	1,799
Aluminum alloys	9,477	10,879	11,319
Magnesium alloys	149	196	181
Zinc alloys	470	528	505
Total	80,895	91,673	98,593

Source: From Spada [3].

Note: Global forecast is for 102 million tons by 2015.

TABLE 1.1 World Production of Castings during 2009 to 2011 (in metric tons)

Country	Castings (in million metric tons)	Number of Casting Plants
China	41.3	30,000
USA	10.33	2,040
India	9.99	4,500
Germany	5.47	612
Japan	4.76	1,612
Russia	4.2	1,350
Brazil	3.34	1,325
Korea	2.34	890
Italy	2.21	1,111
France	2.05	441

Source: From Spada [3].

TABLE 1.2 Global Production of Castings in 2011

(see Table 1.3). As shown below, the 2012 shipments came to $34 billion based on GDP, housing starts, auto, railcar and truck production, construction activity, end-user and supplier interviews. Although the number of foundries is gradually decreasing, it is still a vital part of the manufacturing sector, producing 10.33 million tons of castings for different sectors, as mentioned earlier. At present 77% of the demand for castings in the United States is met by U.S. metalcasters. The lack of capacity in a number of foundries and high cost of production have led to imports from other countries such as China, India, Brazil, Mexico, and other Asian and European countries as shown in Fig. 1.2. In 2009, the United States imported 2.1 million tons of castings.

2,001 metal casting facilities
More than 700 ferrous and 1,300 nonferrous foundries
Employs more than 200,000
80% are small business (less than 100 employees)
2012 shipments: $34 billion
In 1955 and 1991 there were 6,150 and 3,200 plants, respectively
Second in production in the world
Lost approximately 150 plants since the beginning of recession

Source: From Spada [3].

TABLE 1.3 Health of U.S. Metal Casting Industry in 2013

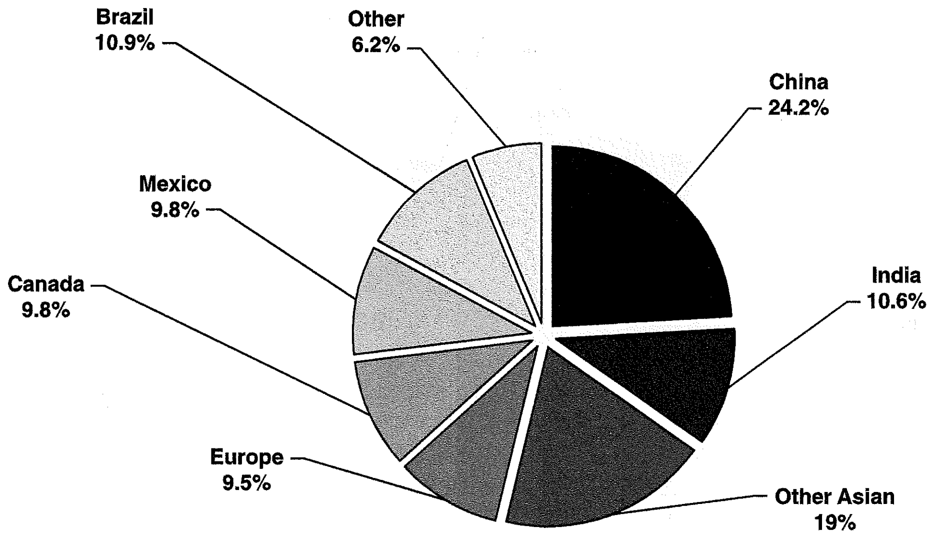


FIGURE 1.2 Import of castings to the United States from other countries. (From Spada [3].)

Future of the Casting Industry

Worldwide, the aluminum, steel, iron, and copper alloy casting industry is a mature industrial sector, with an established infrastructure, significant metal sources and scrap stream, a large alloy selection and multiple choices for casting process selection. This is not the case for the magnesium casting industry. Magnesium does play an important role in the transportation industry and other industrial applications. Being a structural material with low density and a very high strength to weight ratio, magnesium will reduce vehicle weight, and in turn, reduce greenhouse gas emissions and increase fuel economy. However, at present, it lacks a stronger infrastructure and technical support, including more casting process options, new alloy development with better creep properties at more than 150°C for automotive engine applications, environmentally friendly cover gas for melt protection, and scrap processing technologies. These technical barriers have been discussed in a recent publication on magnesium by the American Foundry Society [4].

The metal casting industry has to be more proactive in adapting new technologies to be competitive. Some of these include

- Enhanced adoption of simulation modeling to optimize casting design
- Vacuum- and pressure-assisted casting process to enhance casting properties
- Automated pouring designed for job shops to improve productivity and quality
- Ablation process for sand casting to achieve sound castings with mechanical properties similar to those permanent mold castings
- Application of rapid prototyping for tool-less casting applications
- Affordable automated grinding systems to improve productivity and reduce cost
- Metal-matrix composite casting including nanoparticle casting

Another important area for the growth of the foundry industry is part consolidation and conversion to castings. Some examples of castings converted from other manufacturing processes are shown in Fig. 1.3.

Education and Training in the Foundry Industry

Casting technology encompasses many branches of science and engineering including physics, chemistry, metallurgy, mechanical engineering, chemical engineering, and computational modeling. Chemical reactions involved in melting of metals and treating of liquid metals, formation of crystal structures, thermodynamic principles as applied to the determination of phase diagrams, design of gating and risering systems, and principles behind grain refinement and heat treatment all deal with some branch of science and engineering. Although there is still a lot of art and craft involved in the casting process, a good understanding of casting technology for the foundry engineer and technologist, mold maker, and pattern maker, would be useful to produce premium quality castings by minimizing casting defects. Application of solidification modeling in the design of gating and risering systems would eliminate the guesswork and contribute to the production of sound castings.

The engineer who designs a casting must have accurate information about the properties of the cast metals to be used. Handbook data may not be useful in the design of components that would lead to low mechanical properties. To provide a foundation for foundry work, course work in the principles of metal casting finds a place in the educational preparation of student engineers. In addition, training offered by casting institutes or societies must incorporate developments in all aspects of metal casting such as alloy development, melting, melt treatment, sand, mold design, and gating and risering design.

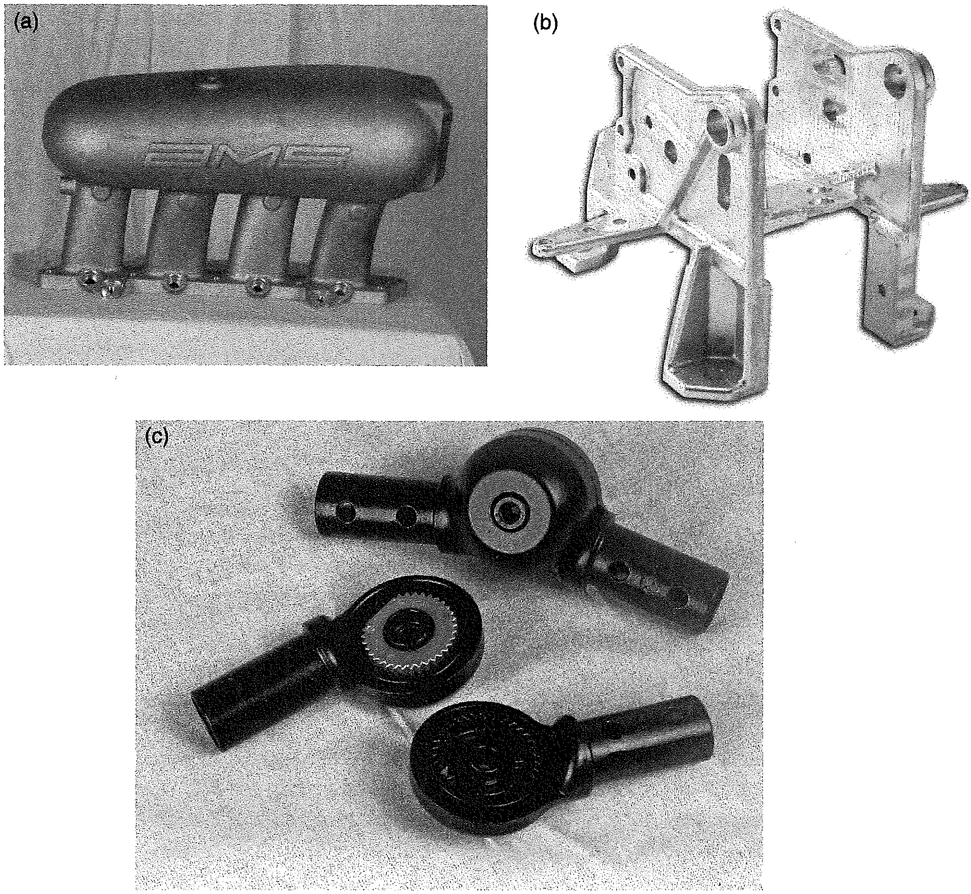


Figure 1.3 Examples of part consolidation and conversion. (*a*) This four-cyclinder intake manifold was cast in A356 aluminum via the green sand casting process. The casting was converted from a sheet metal weldment by Eagle Aluminum Cast Products, Muskegon, MI. The manifold is designed for the high-performance automotive aftermarket, specifically the Mitsubishi Evolution. (*b*) This steering/linkage assembly was cast in brass via the permanent mold casting process. The casting was converted from a multipiece weldment by Piad Precision Casting Corp., Greensburg, PA. The assembly is used in a pallet truck application and delivered the customer a 10% weight reduction over the weldment. (*c*) This locking hinge assembly was cast in 4140 steel via the investment casting process. The casting was converted from an aluminum fabrication by Signicast Investment Castings, Hartford, WI. The locking hinge fits on a wheelchair and is more durable than its aluminum counterparts. (From Spada [3].)

References

1. R. W. Heine, C. R. Loper, Jr., and P. C. Rosenthal, *Principles of Metal Casting*, McGraw-Hill Book Company, New York, 1967.

Casting Terms

1. Flask: A metal or wood frame, without fixed top or bottom, in which the mold is formed. Depending upon the position of the flask in the molding structure, it is referred to by various names such as drag - lower molding flask, cope - upper molding flask, cheek - intermediate molding flask used in three piece molding.

2. Pattern: It is the replica of the final object to be made. The mold cavi ty is made with the help of pattern.

3. Parting line: This is the dividing line between the two molding flasks that makes up the mold.

4. Molding sand: Sand, which binds strongly without losing its permeability to air or gases. It is a mixture of silica sand, clay, and moisture in appropriate proportions.

5. Facing sand: The small amount of carbonaceous material sprinkled on the inner surface of the mold cavity to give a better surface finish to the castings.

6. Core: A separate part of the mold, made of sand and generally baked, which is used to create openings and various shaped cavities in the castings.

7. Pouring basin: A small funnel shaped cavity at the top of the mold into which the molten metal is poured.

8. Sprue: The passage through which the molten metal, from the pouring basin, reaches the mold cavity. In many cases it controls the flow of metal into the mold.

9. Runner: The channel through which the molten metal is carried from the sprue to the gate.

10. Gate: A channel through which the molten metal enters the mold cavity.

11. Chaplets: Chaplets are used to support the cores inside the mold cavity to take care of its own weight and overcome the metallostatic force.

12. Riser: A column of molten metal placed in the mold to feed the castings as it shrinks and solidifies. Also known as "feed head".

13. Vent: Small opening in the mold to facilitate escape of air and gases.

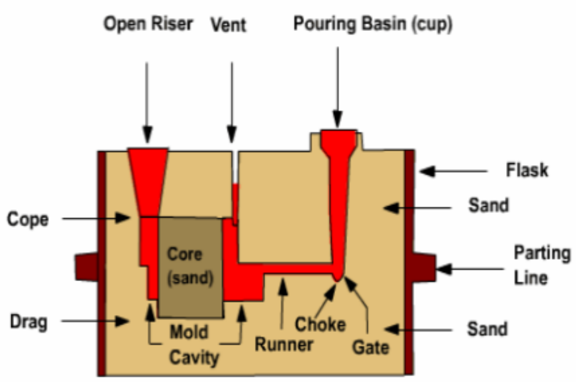
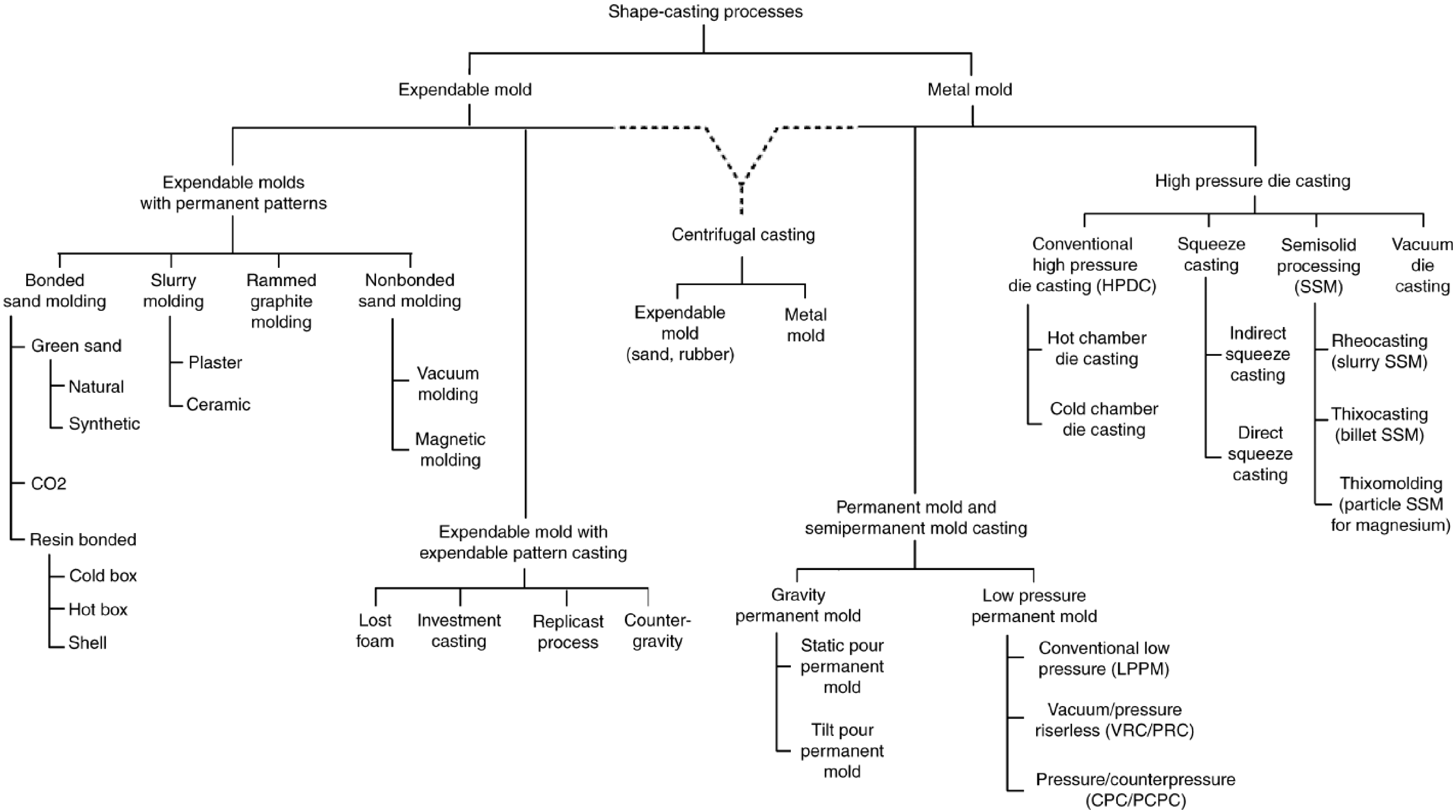


Figure 1 : Mold Section showing some casting terms

	Alloy Group	Main Alloy Types	Important Alloying Elements
Ferrous	**Cast Iron**	Grey Cast Iron White Cast Iron Nodular Cast Iron Malleable Cast Iron	C, Si, P, Ni, Cr…
	Steel	Carbon Steels and Low Alloy Steels. High Alloy Steels (Stainless Steels)	C, Mn, Cr, Ni, Mo…
Non-Ferrous	**Copper Alloys**	Brass and Bronze	Zn, Sn, P, Pb, Ni, Al, Fe, Mn, Si…
	Aluminum Alloys	Cast Alloys	Si, Cu, Mg, Mn, Zn, Ni…
	Magnesium Alloys	Cast Alloys	Al, Zn, Zr, Mn…
	Zinc Alloys		Al, Mg, Cu…
	Nickel Alloys		
	Others	Pb, Sn,Co alloys. Magnet alloys	Sn, Pb, Sb, Cu, Cr, Ni, Mo, Co, W, Nb, Fe, Al, Ti…


Shape-casting processes
Expendable mold
Metal mold
Expendable molds with permanent patterns
Centrifugal casting
High pressure die casting
Bonded sand molding
Slurry molding
Rammed graphite molding
Nonbonded sand molding
Green sand
Natural
Synthetic
CO2
Resin bonded
Cold box
Hot box
Shell
Plaster
Ceramic
Vacuum molding
Magnetic molding
Expendable mold (sand, rubber)
Metal mold
Conventional high pressure die casting (HPDC)
Squeeze casting
Semisolid processing (SSM)
Vacuum die casting
Hot chamber die casting
Cold chamber die casting
Indirect squeeze casting
Direct squeeze casting
Rheocasting (slurry SSM)
Thixocasting (billet SSM)
Thixomolding (particle SSM for magnesium)
Expendable mold with expendable pattern casting
Lost foam
Investment casting
Replicast process
Counter-gravity
Permanent mold and semipermanent mold casting
Gravity permanent mold
Low pressure permanent mold
Static pour permanent mold
Tilt pour permanent mold
Conventional low pressure (LPPM)
Vacuum/pressure riserless (VRC/PRC)
Pressure/counterpressure (CPC/PCPC)

BASIC STEPS IN MAKING SAND CASTINGS

Practically all the detailed operations that enter into the making of sand castings may be categorized as belonging to one of five fundamental steps of the process:

1. Patternmaking (including core boxes)
2. Coremaking
3. Molding
4. Melting and pouring
5. Cleaning

The details and technical processes involved in each of the above operations are the source of the foundryman's principal problems, other than personnel and marketing. The integration of the various steps to produce a casting is briefly summarized for the benefit of those unfamiliar with the foundry. The processes, and the equipment, are illustrated in part in Fig. 1.1.

Patternmaking

Patterns are required to make molds. The mold is made by packing some readily formed plastic material, such as molding sand, around the pattern, as illustrated in Fig. 1.1. When the pattern is withdrawn, its imprint provides the mold cavity, which is ultimately filled with metal to become the casting. Thus molding requires, first, that patterns be made. A pattern, as shown in Fig. 1.1, may be simply visualized as an approximate replica of the exterior of a casting. If the casting is to be hollow, as in the case of a pipe fitting, additional patterns, referred to as core boxes, are used to form the sand that is used to create these cavities.

Coremaking

Cores are forms, usually made of sand, which are placed into a mold cavity to form the interior surfaces of castings. Thus the void space

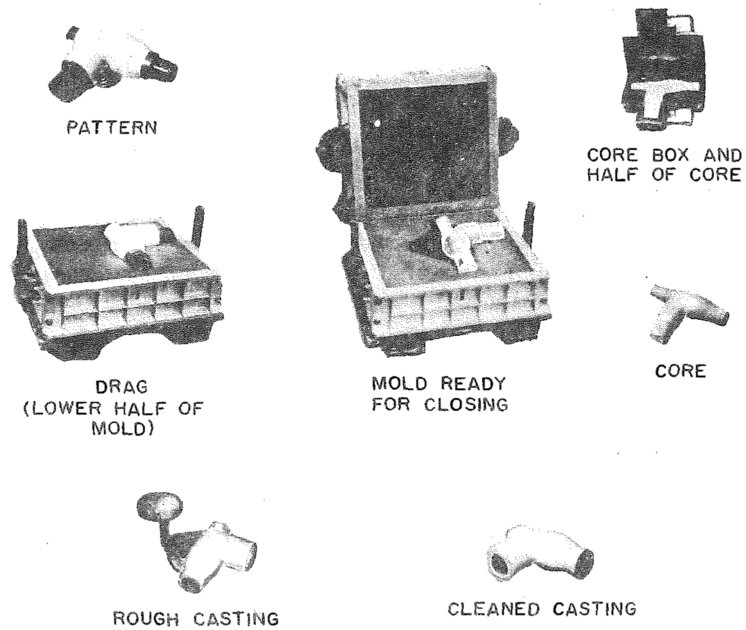


Fig. **1.1** Elements in making a casting. Top half of mold, cope; bottom half, drag.

between the core and mold-cavity surface is what eventually becomes the casting. A core and core box for a mixing valve are shown in Fig. 1.1. Cores are ordinarily made separately from molds in a designated area of the foundry referred to as a core room. They are then transported to the molding department to be placed in the molds. Core boxes are required to produce cores, so that this operation is again dependent on the pattern department.

Molding

Molding consists of all operations necessary to prepare a mold for receiving molten metal. Molding usually involves placing a molding aggregate around a pattern held within a supporting frame, withdrawing the pattern to leave the mold cavity, setting the cores in the mold cavity, and finishing and closing the mold. The mold is then ready for pouring. A finished mold ready for closing is illustrated in Fig. 1.1.

Melting and Pouring

The preparation of molten metal for casting is referred to simply a *melting*. Melting is usually done in a specifically designated area of th foundry, and the molten metal is transferred to the molding area wher the molds are poured.

Cleaning

Cleaning refers to all operations necessary to the removal of sand, scal and excess metal from the casting. The casting is separated from th molding sand and transported to the cleaning department. Burned-o sand and scale are removed to improve the surface appearance of th casting. Excess metal, in the form of fins, wires, parting-line fins, an gates, is cut off. Defective castings may be salvaged by welding o other repair. Inspection of the casting for defects and general qualit follows. The casting is then ready for shipment or further processing for example, heat-treatment, surface treatment, or machining. A rougl mixing-valve casting and a cleaned casting are shown in Fig. 1.1.

The preceding paragraphs have briefly summarized the basic steps i the foundry process. There are, of course, other steps, not discussed which are exceedingly important in some foundries. For example, witl certain alloys, every casting must be given a heat-treatment. The mor specialized steps peculiar to certain kinds of foundries and alloys wil be considered separately in later chapters.