Introduction

Steel is the most versatile engineering material available today. Steel can be easily welded and processed and plays a vital role in maintaining the high standard of living enjoyed by the industrialized nations of the world. The versatility of steel can be easily recognized by its applications which range from high strength structural applications to excellent corrosion resistance in aggressive fluids.

The differences between steel castings and its wrought counterparts are principally in the method of production. In the case of wrought steel cast bars, slabs and ingots are mechanically worked to produce sheet, bar, tube and other product forms. However, steel castings are produced in the final product form without any intermediate mechanical working. Steel castings are near net shape products.

Although cast steel accounts for only 10% of the total foundry industry sales, steel castings are used for vitally important components in the mining, railroad, truck, construction, military, and oil and gas industries. The total capacity of the steel casting industry in the United States is approximately 1.6 million tons with a sales value of approximately two billion dollars (US). Steel castings are specified for applications which require weldability, abrasion resistance, high strength, low and high temperature service and corrosion resistance.

There are approximately 300 steel foundries in North America. Due to the diversity of market requirements such as size, tolerances, chemistry, volume, etc., a single foundry cannot serve all of the market and each company will tend to specialize in a portion of the total market. Some of the specialized areas are:

- railroad, construction equipment, truck and mining industries.
- high alloy stainless steel used in corrosion and heat resistant applications or low volume prototype and service parts.

The balance of this chapter indicates chapters which will contain detailed information regarding the casting processes, applications for steel castings and suggestions regarding the use of steel castings.

What Is a Steel Casting?

A steel casting is the product formed by pouring molten steel into a mold cavity. The liquid steel cools and solidifies in the mold cavity and is then removed for cleaning. Heat treating may be required to meet desired properties.

This process provides the near net shape and mechanical properties required by a purchaser to meet his specifications.

Casting Process

The manufacture of steel castings is discussed in this handbook, however, a simplified flow diagram (Figures 1-1 and 1-2) is shown to give an overview of the process steps.

Pattern Equipment

Chapter 11 discusses this important step in the casting process in detail, however, the following points summarize some of the important aspects to be considered.

The dimensional accuracy of a steel casting is dependent on the type and quality of the pattern. The foundry should be responsible for determining the type of pattern which will produce the highest quality part on their equipment.

Types of Patterns

Pattern equipment can be made of wood, metal, wax, plastic, foam, etc. The selection depends on the quantity and size of parts, molding method, casting tolerances required, and cost.

Wood patterns are less costly than other materials, but are suited only for prototypes and limited production. They can easily be converted to plastic if production requirements increase.

Metal patterns are the most costly, but they are required for high volume production. The material can be aluminum, iron, brass, bronze, etc. Cast aluminum is the most commonly used material for medium volume requirements. Metal patterns are also required for both cores and molds produced by the shell process.

Wax patterns are used in the investment, or lost wax, molding process. These processes use dies to form the patterns. The wax patterns are coated with a ceramic slurry to form a shell. The wax is then removed by heat.

Pattern costs will vary considerably depending on material, volume required and tolerance requirements. Consultation with the foundry during the design stage will ensure that the type of pattern equipment necessary will be obtained at the lowest cost.

Foam patterns may be used in the ceramic or bonded sand molding systems. In the ceramic systems they may be substitutes for wax and in the bonded systems inexpensive substitutes for other stronger materials.
Molding Processes

The Molding Processes are discussed in detail in Chapter 13.

**Green sand molding** is the most widely used system and due to mechanization in many green sand foundries, the least expensive process. Water and clay in the sand allows molds to be produced with a high degree of hardness and an accurate mold cavity.

**Shell molding** uses resin bonded sand and a heated pattern to produce a fused sand mold with excellent detail and dimensional accuracy. Energy and material costs are higher than green sand. This process is not suitable for larger castings.

**Chemically bonded molding** uses sand and various chemicals or gases to form a dry hard mold. Dimensional accuracy is good, and the process is suited to all sizes of parts; however, sand reclamation costs are high, and the process is more expensive than green sand.

**Vacuum molding** uses dry unbonded sand. The mold relies on the vacuum for its hardness; the vacuum must be maintained during pouring and cooling. All sizes of parts can be made by this process; accuracy and surface appearance are good.

**Investment casting** (also called “Lost Wax”) uses a wax or foam pattern formed by a very precise metal mold. Several patterns are fixed to a “tree” and then dipped into a ceramic slurry. Successive dipping and drying produces a thick shell of ceramic which becomes the mold. The wax or foam is removed by heat prior to pouring. This process is limited to smaller castings and is generally not competitive unless some machining can be eliminated.

**Expendable pattern casting** is also called Lost Foam or Full Mold process and uses a pattern of polystyrene which can be cut from stock or formed in a metal die, depending on volume requirements. The patterns are coated with a ceramic wash. The pattern and polystyrene gating system are embedded in dry sand, and when poured, the polystyrene melts and evaporates. Cores are not required, and capital requirements are low. Dry sand is easily reclaimed compared to other processes. This process produces a clean, tightly tolerated casting. This process is currently in the development phase for steel castings.

**Graphite molding** utilizes graphite molds which are semi-permanent. Dimensional control and surface appearance are excellent. This is a highly specialized process suited mainly to parts like railroad wheels.

**Permanent mold** castings poured into molybdenum molds are severely limited in size.

**Centrifugal molding** produces parts from molten metal poured into rotating molds. Rotation of the mold causes the metal to be held to the inside diameter of the mold. It is ideally suited for pipe and symmetrical configurations.

**Ceramic molding** employs a mixture of refractory materials, hydrolyzed ethyl silicate, and a catalyst which is poured over a pattern. The ceramic shell is stripped before fully setting, then fired, and assembled for pouring. This process produces excellent surface appearance and accuracy and is particularly adapted to turbine blades and manifolds.

Melting and Pouring Operations

Melting and Pouring are summarized here and are detailed in Chapter 14.

Several types of melting furnaces are used in the production of steel castings.

**Electric arc furnaces** (EAF) are responsible for the production of the majority (84%) of steel castings. These units are composed of a steel shell, refractory lining, and a refractory lined roof
with three openings for graphite electrodes. Melting is accomplished by the heat from the electric arc.

The EAF is the most flexible unit for melting steel in that the charge material can be varied and the steel can be refined in the furnace before tapping.

**Electric induction furnaces** are the most common unit for smaller production quantities. The furnace consists of a steel shell with a refractory lining surrounded by a copper coil. Heat is generated by an electric current in the coil.

**Finishing and Heat Treating**

Finishing and Heat Treating are summarized here and are detailed in Chapter 15.

When a casting has cooled, it is shaken out of the mold. Before it can be shipped, it must be finished or cleaned. The first step is an abrasive blast which cleans the surface of all residue of the mold. Then the extraneous metal of the gating system and fins are removed by torch cutting, sawing or grinding. Welding of discontinuities is a common practice in the steel casting industry.

Heat treatment processes may be used to enhance the properties of specific alloys. The scale formed on casting surfaces during heat treatment is removed by abrasive blasting.

Steel castings can be straightened by pressing if warpage occurs during processing. This operation ensures dimensional accuracy of the finished part.

**Pre-machining** or rough machining has become very common in steel foundries. When the customer requires very precise location of finish stock or reduced finish stock the foundry can perform a rough machining operation to provide the desired characteristics.

Many foundries can also supply parts in the finish machined condition.

**Process capability and tolerances** are covered in Chapter 16 and are dependent on many factors. As mentioned earlier, pattern quality, mold material, pre-machining, straightening, etc., can all affect tolerances. The ability to control the casting process is of extreme importance to today’s foundryman, and the supplier of choice can document his programs for the buyer.

**Why Use a Steel Casting?**

The wide range of metallurgical and mechanical properties available in steel castings is discussed in Chapters 17 through 24. Many of the alloys required for severe applications cannot be wrought and must be cast.

All carbon and low alloy steels are readily weldable (Chapter 25). Higher alloy grades such as manganese and stainless steels are routinely welded using appropriate techniques.

Steel castings are readily heat treated by normalizing, annealing, quench and tempering, localized or differential hardening, etc., depending on the mechanical properties required (Chapter 24).

Information on cast high alloy steels is presented in Chapter 20. The corrosion resistance of CF type high alloy cast steels is comparable to wrought 300 series material but the CF grades have a slightly different composition and contain ferrite for improved weldability. Nickel-base alloys are discussed in Chapter 21. The high alloy and nickel-base alloy castings are used in chemical processing plants and corrosive environments.

Wear Resistance of cast steels is reviewed in Chapter 19. It varies from a relatively soft medium carbon steel of .25 percent carbon to the extremely hard “work-hardening” manganese grades and the high chrome irons. Cast steels exhibit superior toughness and impact resistance compared to other materials.

Heat resistant alloys (Chapter 22) are used at temperatures in excess of 1200 °F (649 °C). These materials are usually alloys of iron, chromium, and nickel.

**Fig. 1-3 Total Steel Castings Production (1993)**

**Weight and Size Range.** Steel castings are produced from ounces to over 100 tons and in quantities from one to thousands per order. Each casting will exhibit the chemistry and mechanical properties specified by the buyer.

Steel castings can be joined to other product forms (wrought, forged, etc.) to produce cost-effective fabrications.

**Who Uses Steel Castings?**

Chapter 2 covers the industries who are major users of steel castings and the applications that require the unique properties of cast steel. The generic term “steel” covers a wide range of grades of materials, however, for simplicity two alloy groups are normally considered: Carbon and Low Alloy (C&LA) and High Alloy. High Alloy grades include stainless steels and nickel-base alloys. Austenitic Manganese steels and all other non-stainless steels are usually included in the C&LA group. The total steel casting production in the U.S. excluding high chromium irons is dominated by the C&LA grades (Figure 1-3). The C&LA and High Alloy group markets are shown in Figures 1-4 and 1-5. Some of the larger users are:

- Railroad industry which uses 50% of the total production of steel castings. These parts are used in severe applications such as couplers, draft gears, side frames, bolsters, and wheels.
- Construction machinery manufacturers use about 15% of the steel castings produced each year. The applications here are as varied as the equipment produced. Parts range from end caps on hydraulic cylinders for a small backhoe to transmission housings on large earth-moving machinery.
- Valves and fittings of cast steel account for about 5% of production and are used for the drilling, recovery, transportation, and refining of natural gas and crude oil both on land and offshore. These parts vary in size from a few pounds to many tons. Applications are very severe requiring performance in corrosive liquids at both sub-zero and elevated temperatures. Operating pressures can reach many thousands of p.s.i. in valves and blowout preventers.
- Heavy trucks—both on and off-highway—use about 5% of industry production. Some applications include: axle housings, suspension brackets, wheels, brake parts, axle spindles, differential housings, and fifth wheels.
- Mining industry makes extensive use of steel castings for their extreme requirements of toughness and abrasion resistance both for ore recovery equipment and crushing mills. Both high manganese and other alloy steels are widely used, and these materials can only be produced as castings.
- Numerous other industries use steel castings. These range from food processing and electronics to oil and gas, defense and pulp and paper industries. In fact, castings touch every aspect of our lives.
Cast Steel Compared to Other Cast Metals

Non-ferrous alloys have excellent machinability, and most are lighter than the iron family, but they do not have the strength and toughness required for many severe applications.

Gray Iron is produced more than any other iron alloy. It offers excellent castability and machinability, but it is essentially a brittle material. It is the least expensive of the iron alloys, and the dominant user is the automotive industry.

Ductile Iron, also referred to as nodular iron (or S.G. iron in Europe), is a cast iron which does have some ductility. Applications for this material have grown dramatically in the past 30 years, and it has supplant malleable iron in most cases. Ductile iron has been used for steel applications where weldability and toughness are not required.

Steel Castings Compared to Other Processes

Weldments are produced from ingots which are rolled into common shapes such as bar, plate, "I" beams, tube, etc.

Advantages:
- Mill steel is less expensive than cast or forged parts. There may not be a die or pattern cost, and there are not any size limitations.

Disadvantages:
- If extensive welding is required, the cost increases. Large or complicated parts require expensive fixtures. Rolled or forged materials are anisotropic and exhibit lower ductility when impact is transverse to the direction of working.

Forgings are produced in dies by hammering or pressing to the desired shape. Simple shapes with high volume requirements are good candidates for the forging process, as long as the required part does not have a composition that cannot be mechanically worked. More detailed information on the advantages of steel castings can be found in Chapter 3.

Buying and Specifying Steel Castings

Buying and specifying steel castings are discussed in Chapters 4 and 5. When a steel casting is required to perform a specific engineering function and the specifications have been determined, the next step is to select a supplier for that part. The Steel Founders' Society of America publishes a directory of all foundries in the United States, Canada, and Mexico. This directory lists personnel, capacity, special services, size of parts produced, etc.

Several potential sources should be visited by the quality, engineering, and purchasing departments to audit each facility to determine several qualified sources. A detailed inquiry can be sent to each qualified company. This inquiry should include current engineering drawings showing:

- Machined surfaces
- Material specification (preferably a standard specifying body like ASTM)

Special requirements such as:

- Hardness

- Dimensional tolerances
- Soundness (radiography, N.D.T.)
- Special inspection and tests certification

In addition, the inquiry should show:

- Quantity and delivery required
- Weight (if available)
- Painting, if required
- Name and phone number of person to contact regarding questions on the inquiry
- Shipping destination
- Machining, if required

Treat your foundry supplier as a valued source, not only for castings, but also for advice on:

- Molding methods
- Pattern options
- Metal specifications
- Design assistance for lowest cost