Guide to Casting and Molding Processes

Understanding the ‘metalcasting’ basics can help you design for manufacturability and utilize processes that meet your specific requirements.

An ECS Staff Report

> **Considerations for Selecting a Casting Process**
> - Required quality of the casting surface
> - Required dimensional accuracy of the casting
> - Number of castings required per order
> - Type of pattern and corebox equipment needed
> - Cost of making the mold(s)
> - How the selected process will affect the design of the casting

The versatility of metalcasting is demonstrated by the number of casting and molding processes currently available. This wide range of choices offers design engineers and component users enormous flexibility in their metalforming needs (Fig. 1).

Each process offers distinct advantages and benefits when matched with the proper alloy and application. When reviewing these processes and determining which best suits your needs, consider the following:

- required surface quality;
- required dimensional accuracy;
- type of pattern/corebox equipment;
- cost of making the mold(s);
- how the selected casting process will affect the design of the casting.

Molding processes can be broken into four general categories: sand casting processes; permanent mold processes; ceramic processes; and rapid prototyping. Following is a look at the most common casting processes.

SAND CASTING PROCESSES

Fundamentally, a mold is produced by shaping a refractory material to form a cavity of desired shape such that molten metal can be poured into the cavity. The mold cavity needs to retain its shape until the metal has solidified and the casting is removed. This sounds easy to accomplish, but depending on the choice of metal, certain characteristics are demanded of the mold. When granular refractory materials, such as silica, olivine, chromite or zircon sands, are used, the mold must be:

- strong enough to sustain the weight of the molten metal;
- constructed to permit any gases formed within the mold or mold cavity to escape into the air;

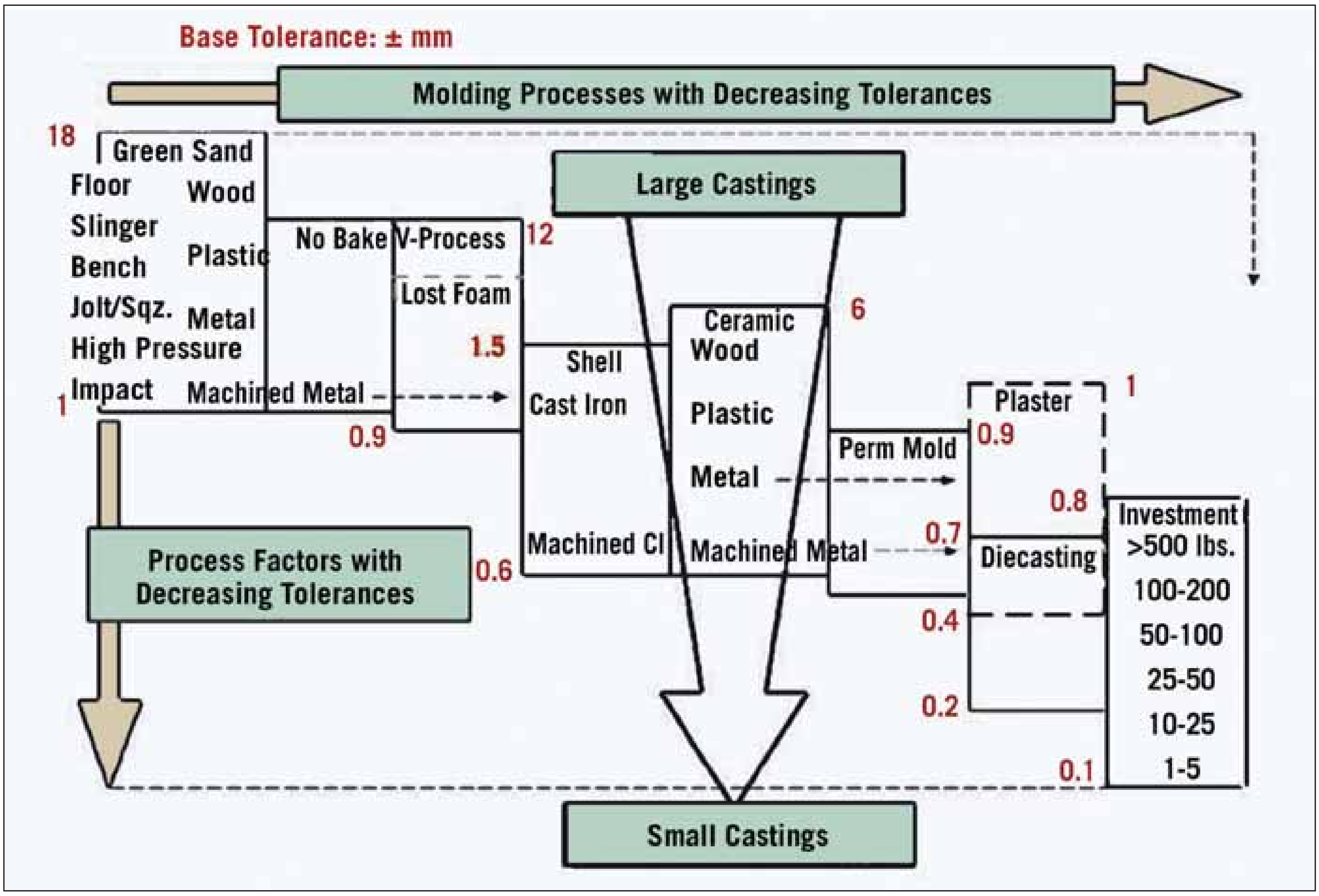


Fig. 1. Shown here is a comparison of the various molding and casting processes. The chart shows common molding processes and how effective each is at obtaining tight tolerances. It also shows which processes are better suited toward producing larger components. The data is provided as a guideline; the actual tolerances achieved can vary depending on the metalcasting facility’s capabilities.

In the nobake molding process, refractory sand is coated with binder and a liquid catalyst. As the binder and catalyst combine, a chemical reaction hardens the sand. Shown above is the application of the refractory coating.

- resistant to the erosive action of molten metal during pouring and the high heat of the metal until the casting is solid;
- collapsible enough to permit the metal to contract without undue restraint during solidification;
- able to cleanly strip away from the casting after the casting has sufficiently cooled;
- economical, since large amounts of refractory material are used.

Green Sand Molding

The most common method used to make metal castings is green sand molding. In this process, granular refractory sand is coated with a mixture of bentonite clay, water and, in some cases, other additives (Fig. 1). The additives help to harden and hold the mold shape to withstand the pressures of the molten metal.

The green sand mixture is compacted by hand or through mechanical force around a pattern to create a mold. The mechanical force can be induced by slinging, jolting, squeezing or by impact/impulse.

The following points should be taken into account when considering the green sand molding process:

- for many metal applications, green sand processes are the most cost-effective of all metal forming operations;
- these processes readily lend themselves to automated systems for high-volume work as well as short runs and prototype work;
- in the case of slinging, manual jolt or squeeze molding to form the mold, wood or plastic pattern materials can be used. High-pressure, high-density molding methods almost always require metal pattern equipment;
- high-pressure, high-density molding normally produces a well-compacted mold, which yields better surface finishes, casting dimensions and tolerances;
- the properties of green sand are adjustable within a wide range, making it possible to use this process with all types of green sand molding equipment and for a majority of alloys poured.

Chemically Bonded Molding Systems

This category of sand casting processes is widely used throughout the metalcasting industry because of the economics and improved productivity each offers. Each process uses a unique chemical binder and catalyst to cure and harden the mold and/or core. Some processes require heat to facilitate the curing mechanism, though others do not.

Gas Catalyzed or Coldbox Systems—Coldbox systems utilize a family of binders where the catalyst is not added to the sand mixture. Catalysts in the form of a gas or vapor are added to the sand and resin com-

This automated molding loop is used to automatically produce nobake molds. The loop is among the largest in production in North America.

ponent so the mixture will not cure until it is brought into contact with a catalyst agent. The sand-resin mixture is blown into a corebox to compact the sand, and a catalytic gas or vapor is permeated through the sand mixture, where the catalyst reacts with the resin component hardening the sand mixture almost instantly. Any sand mixture that has not come into contact with the catalyst is still capable of being cured, so many small cores can be produced from a large batch of mixed sand.

This robot coldbox core and mold making cell is composed of 11 robot arms and gantries designed to automatically produce, assemble and refractory coat components. It requires two operators for inspection purposes.

Several coldbox processes exist, including phenolic urethane/amine vapor, furan/SO_2, acrylic/SO_2 and sodium silicate/CO_2. In general, coldbox processes offer:

- good dimensional accuracy of the cores because they are cured without the use of heat;
- excellent surface finish of the casting;
- excellent characteristics for high-production runs since production cycles are short;
- excellent core and mold shelf life.

***Shell Process*—**In this process, sand is pre-coated with a phenolic novalac resin containing a hexamethylenetetramine catalyst. The resin-coated sand is dumped, blown or shot into a metal corebox or over a metal pattern that has been heated to 450-650F (232-343C). Shell molds are made in halves that are glued or clamped together before pouring. Cores, on the other hand, can be made whole, or, in the case of complicated applications, can be made of multiple pieces glued together.

Benefits of the shell process include:

- an excellent core or mold surface, resulting in good casting finish;
- good dimensional accuracy in the casting because of mold rigidity;
- storage for indefinite periods of time, which improves just-in-time delivery;
- high-volume production;
- selection of refractory material other than silica for specialty applications;
- a savings in materials usage through the use of hollow cores and thin shell molds.

***Nobake or Airset Systems*—**In order to improve productivity and eliminate the need for heat or gassing to cure mold and core binders, a series of resin systems referred to as nobake or airset binders was developed.

In these systems, sand is mixed with one or two liquid resin components and a liquid catalyst component. As soon as the resin(s) and catalyst combine, a chemical reaction begins to take place that hardens (cures) the binder. The curing time can be lengthened or shortened based on the amount of catalyst used and the temperature of the refractory sand.

The mixed sand is placed against the pattern or into the corebox. Although the sand mixtures have good flowability, some form of compaction (usually vibration) is used to provide densification of the sand in the mold/core. After a period of time, the core/mold has cured sufficiently to allow stripping from the corebox or pattern without distortion. The cores/molds are then allowed to sit and thoroughly cure. After curing, they can accept a refractory wash or coating that provides a better surface finish on the casting and protects the sand in the mold from the heat and erosive action of the molten metal as it enters the mold cavity.

Vertically parted molding machines, normally used for high-production runs, are automated and compact molding sand by squeezing.

The nobake process provides positive features, such as:

- the capability to use wood, and in some cases, plastic patterns and coreboxes.
- good casting dimensional tolerances due to the rigidity of the mold;
- good casting finishes;
- typically easy shakeout (the separation of the casting from the mold after solidification is complete);
- the abiliy to store cores and molds indefinitely.

Unbonded Sand Processes

Unlike the sand casting processes that use various binders to hold the sand grains together, two unique processes use unbonded sand as the molding media. These include the lost foam process and the less common V-Process.

***Lost Foam Casting*—**In this process, the pattern is made of expendable polystyrene (EPS) beads. For high-production runs, the patterns can be made by injecting EPS beads into a die and bonding them together using a heat source, usually steam. For shorter runs, pattern shapes are cut from sheets of EPS using conventional woodworking equipment and then assembled with glue. In either case, internal passageways in the casting, if needed, are not formed by conventional sand cores but are part of the mold itself.

The polystyrene pattern is coated with a refractory coating, which covers both the external and internal surfaces. With the gating and risering system attached to the pattern, the assembly is suspended in a one-piece flask, which is then placed onto a compaction or vibrating table. As the dry, unbonded sand is poured into the flask and pattern, the compaction and vibratory forces cause the sand to flow and densify. The sand flows around the pattern and into the internal passageways of the pattern.

As the molten metal is poured into the mold, it replaces the EPS pattern, which vaporizes. After the casting solidifies, the unbonded sand is dumped out of the flask, leaving the casting with an attached gating system.

With larger castings, the coated pattern is covered with a facing of chemically bonded sand. The facing sand is then backed up with more chemically bonded sand.

The lost foam process offers the following advantages:

- no size limitations for castings;
- improved surface finish of castings due to the pattern's refractory coating;
- no fins around coreprints or parting lines;
- in most cases, separate cores are not needed;
- excellent dimensional tolerances.

V-Process – In the V-Process, the cope and drag halves of the mold are formed separately by heating a thin plastic film to its deformation point. It is then vacuum-formed over a pattern on a hollow carrier plate.

The process uses dry, free-flowing, unbonded sand to fill the special flask set over the film-coated pattern. Slight vibration compacts the fine grain sand to its maximum bulk density. The flask is then covered with a second sheet of plastic film. The vacuum is drawn on the flask, and the sand between the two plastic sheets becomes rigid.

The cope and drag then are assembled to form a plastic-lined mold cavity. Sand hardness is maintained by holding the vacuum within the mold halves at 300-600 mm/Hg. As molten metal is poured into the mold, the plastic film melts and is replaced immediately by the metal. After the metal solidifies and cools, the vacuum is released and the sand falls away.

PERMANENT MOLD CASTING

At least three families of molding and

In high-production lost foam casting, foam patterns are molded and assembled on a cluster, coated with a refractory, placed in a flask and surrounded with unbonded sand. Molten metal then is poured over the pattern and evaporates the foam.

In the diecasting process, metal is ladled into shot sleeves and forced under extreme pressure into the permanent mold or die.

casting processes can be categorized as permanent mold processes. These include diecasting (high-pressure diecasting), low-pressure permanent mold casting and permanent mold casting. Unlike sand casting processes, in which a mold is destroyed after pouring to remove the casting, permanent mold casting uses the mold repeatedly.

Diecasting—Diecasting is used to produce small- to medium-sized castings at high-production rates. The metal molds are coated with a mold surface coating and preheated before being filled with molten metal. Premeasured amounts of molten metal are forced from a shot chamber into the permanent mold or die under extreme pressure (greater than 15,000 psi).

Castings of varying weights and sizes can be produced. Nearly all die castings are produced in nonferrous alloys with limited amounts of cast iron and steel castings produced in special applications.

Die castings and the diecasting process are suitable for a wide variety of applications in which high part volumes are needed. Benefits include:

- excellent mechanical properties and surface finish;
- dimensional tolerances of 0.005-0.01 in.;
- recommended machining allowances of 0.01-0.03 in.;
- thin-section castings.

Permanent Mold Casting (Gravity Diecasting)—Another form of permanent mold casting is when the molten metal is poured into the mold, either directly or by tilting the mold into a vertical position. In this process, the mold is made in two halves from cast iron or steel. If cores are to be used, they can be metal inserts, which operate mechanically in the mold, or sand cores, which are placed in the molds before closing (semi-permanent molding).

The mold halves are preheated and the internal surfaces are coated with a refractory. If static pouring is to be used, the molds are closed and set into the vertical position for pouring; thus, the parting line is in the vertical position. In tilt pouring, the mold is closed and placed in the horizontal position at which point molten metal is poured into a cup(s) attached to the mold. The mold then is tilted to the vertical position, allowing the molten metal to flow out of the cup(s) into the mold cavity.

The various permanent mold techniques—static pour and tilt pour—offer a

When design engineers are discussing the most efficient molding method to obtain the cast components, they must be familiar with what alloys will be used. Aluminum, shown above during a pouring operation, is a versatile material that can be cast in most types of molds.

In the investment casting process, wax patterns are produced in dies and assembled. They are then "invested" with ceramic to produce a monolithic mold. The pattern then is melted to leave a precise mold cavity.

variety of advantages for a range of metal-forming applications. Benefits include:

- superior mechanical properties because the metal mold acts as a chill;
- uniform casting shape and excellent dimensional tolerances because molds are made of metal;
- excellent surface finishes;
- high-production runs;
- the ability to selectively insulate or cool sections of the mold, which helps control the solidification and improves overall casting properties.

Low-Pressure and/or Vacuum Permanent Mold Casting (LPPM)—In this process, low pressure is used to push the molten metal (and/or a vacuum is used to draw the metal) into the mold through a riser tube as the furnace is below the mold cavity. The amount of pressure, from 3-15 psi, depends on the casting configuration and the quality of the casting desired. When internal passageways are required, they can be made by either mechanically actuated metal inserts or sand cores. The goal of this process is to control the molten metal flow as much as possible to ensure a tranquil fill of the mold cavity.

Nearly all of the LPPM castings produced are made of aluminum, other light alloys and, to a lesser extent, some copper-base alloys. Because it is a highly controllable process, LPPM offers the following advantages:

- when molten metal is fed directly into the casting, excellent yields are realized, and the need for additional handwork is reduced;
- odd casting configurations and tooling points for machining can be placed in areas where gates and risers normally would be placed;
- the solidification rate in various sections of the casting can be controlled through selective heating or cooling of the mold sections, thus offering excellent casting properties;
- surface finish of castings is good to excellent.

CERAMIC & PLASTER PROCESSES

This family of casting processes is unique in that ceramic and plaster are used as molding media. These processes offer a high degree of precision in regard to dimensions as well as excellent surface finishes.

Investment Casting—The investment casting process was one of the first processes used to produce metal castings. The process has been described as the lost wax process, precision casting and investment casting. The latter name generally has been accepted to distinguish the present industrial process from artistic, medical and jewelry applications.

The basic steps of the investment casting process are:

1. Production of heat-disposable wax or plastic patterns;
2. Assembly of those patterns onto a gating system;
3. "Investment," or covering of the pattern assembly with ceramic to produce a monolithic mold;
4. Melting of the pattern assembly to leave a precise mold cavity;
5. Firing of the ceramic mold to remove the last traces of the pattern material while developing the high-temperature bond and preheating the mold ready for casting;
6. Pouring;
7. Knockout, cutoff and finishing.

The patterns are produced in dies via injection molding. For the most part, the patterns are made of wax; however, there are patterns that are made of plastic or polystyrene. Because the tooling cost for individual wax patterns is high, investment casting normally is used when high volumes are required. When cores are required, they are made of soluble wax or ceramic materials.

The ceramic shell is built around a pattern/gating assembly by repeatedly dipping the "tree" into a thin refractory slurry. After dipping, a refractory aggregate, such as silica, zircon or aluminum silicate sand, is rained over the wet slurry coating. After each dipping and stuccoing is completed, the assembly is allowed to thoroughly dry before the next coating is applied. Thus, a shell is built up around the assembly. The required thickness of this shell is dependent on the size of the castings and temperature of the metal to be poured. After the ceramic shell is complete, the entire assembly is placed into an autoclave oven to melt and remove a majority of the wax.

In investment casting, the pattern is covered with ceramic to produce a monolithic mold. When the wax pattern is melted, a precise mold cavity is formed.

The majority of investment castings weigh less than 5 lbs., but there is a trend to produce larger castings in the 10-30-lb. range. Castings weighing up to 800 lbs. have been poured in this process. Some of the advantages of investment casting include:

- excellent surface finishes;
- tight dimensional tolerances;
- elimination or reduction of machining.
- ability to produce titanium castings as well as the other superalloys.

Ceramic Molding—Generally, these processes employ a mixture of graded refractory fillers that are blended to a slurry consistency. Various refractory materials can be used as filler material. The slurry then is poured over a pattern that has been placed in a container.

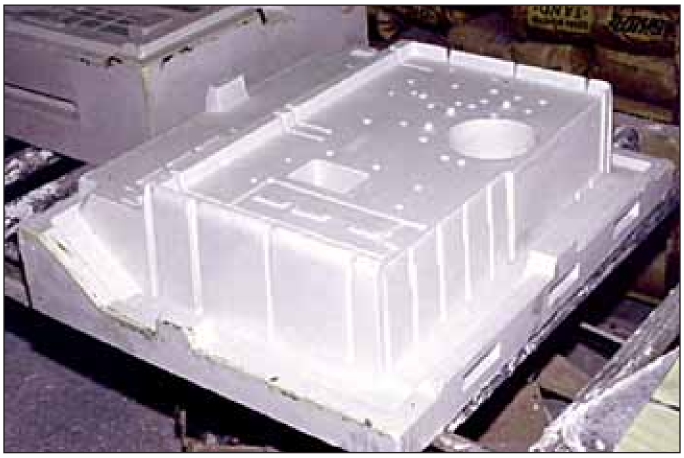
First, a gel is formed in a pattern and stripped from the mold. The mold then is heated to a high temperature until it becomes rigid. After the molds cool, molten metal is poured into them, with or without preheating.

The ceramic molding processes have proven effective with smaller size castings in short- and medium-volume runs. At the same time, these processes offer castings with excellent surface finish and good dimensional tolerances.

Plaster Molding—Plaster molding is used to produce castings of the lower melting temperature metals, such as the aluminum alloys. In the process, a slurry containing calcium sulfate, sometimes called gypsum, is poured into a flask that contains the pattern. After the slurry has set, the pattern and flask are removed, and the drying cycle to remove the moisture from the mold begins.

After the mold has cooled, the cores and mold are assembled. After assembly, most molds are preheated before pouring. Because these molds have very poor permeability, in many cases, vacuum-assistance or pressure is required during pouring.

The plaster mold processes are well-suited for short run and prototype work with the lower temperature alloys, particularly aluminum.



Rubber Plaster Mold casting helps save in production time and tooling costs with reusable rubber molds.

RAPID PROTOTYPING

Rapid prototyping (RP) is a general name that encompasses numerous methods used to fabricate objects from CAD data. There are a number of different RP processes, and new developments are constantly being made.

RP most commonly is used with investment casting, sand casting and plaster molding to produce actual cast parts to test for form, fit and function as well as determine the approximate final properties of the cast parts.

Investment Casting—RP models for investment casting are created by converting a 3-D CAD model into an .STL file. The file then is "printed" three-dimensionally using either photopolymer, thermopolymer, polystyrene or other materials, depending on the RP method. The prototype models then can be attached to a gating system and processed through typical investment casting to produce cast prototype parts.

Sand Casting—In sand casting, RP-generated parts can be used as patterns for fabricating a sand mold. RP processes that use a material similar to wood are common. The molds are created in a fraction of the time and then affixed to the pattern board before sand is packed around to create half of a mold cavity.

To save even more time, RP processes can be used to directly fabricate molds and cores. These processes build the cores and molds layer-by-layer by fusing either polymer-bonded sand together or using a wide-area inkjet to bond the sand. The molds and cores also may be created by forming a block of sand and machining out the cavity.

Plaster Molding—RP often is used with plaster molding processes to circumvent or transition to the production of hard tooling. This is accomplished by creating a rubber mold from an RP-generated pattern (similar to sand casting). The rubber mold then is used to create plaster molds for casting production. Plaster casting often serves as a precursor to diecasting production while the hard tool is being made.

A final form of RP worth mentioning is the use of CNC machining to create individual parts, tooling or dies, or to take blocks of sand and machine them to create prototype sand molds. *ECS*