Casting

Casting is a manufacturing process by which a liquid material such as a suspension of minerals as used in ceramics or molten metal or plastic is introduced into a mould, allowed to solidify within the mould, and then ejected or broken out to make a fabricated part. Casting is used for making parts of complex shape that would be difficult or uneconomical to make by other methods, such as cutting from solid material.

Casting may be used to form hot, liquid metals or meltable plastics (called thermoplastic), or various materials that *cold set* after mixing of components such as certain plastic resins such as epoxy, water setting materials such as concrete or plaster, and materials that become liquid or paste when moist such as clay, which when dry enough to be rigid is removed from the mold, further dried, and *fired* in a kiln or furnace.

Substitution is always a factor in deciding whether other techniques should be used instead of casting. Alternatives include parts that can be stamped out on a punch press or deep-drawn, forged, items that can be manufactured by extrusion or by cold-bending, and parts that can be made from highly active metals.

The casting process is subdivided into two distinct subgroups: expendable and nonexpendable mold casting.

Expendable mold casting

Expendable mold casting is a generic classification that includes sand, plastic, shell, plaster, and investment (lost-wax technique) moldings. This method of mold casting involves the use of temporary, nonreusable molds.

Waste molding of plaster

A durable plaster intermediate is often used as a stage toward the production of a bronze sculpture or as a pointing guide for the creation of a carved stone. With the completion of a plaster the work is more durable (if stored indoors) than a clay original which must be kept moist to avoid cracking. With the low cost plaster at hand the expensive work of bronze casting or stone carving may be deferred until a prosperous patron is found, and as such work is considered to be a technical, rather than artistic processes it may even be deferred beyond the lifetime of the artist.

In waste molding a simple and thin plaster mold, reinforced by sisal or burlap, is cast over the original clay mixture. When cured it is then removed from the damp clay, incidentally destroying the fine details in undercuts present in the clay, but which are now captured in the mold. The mold may then at any later time (but only once) be used to cast a plaster positive image, identical to the original clay. The surface of this "*plaster*" may be further refined and may be painted and waxed to resemble a finished bronze casting.

Sand casting

Sand casting requires a lead time of days for production at high output rates (1-20 pieces/hr-mold), and is unsurpassed for large-part production. Green (moist) sand has almost no part weight limit, whereas dry sand has a practical part mass limit of 2300-2700 kg. Minimum part weight ranges from 0.075-0.1 kg. The sand is bonded together using clays (as in green sand) or chemical binders, or polymerized oils (such as motor oil.) Sand in most operations can be recycled many times and requires little additional input.

Preparation of the sand mold is fast and requires a pattern which can "stamp" out the casting template. Typically, sand casting is used for processing low-temperature metals, such as iron, copper, aluminum, magnesium, and nickel alloys. Sand casting can also be used for high temperature metals where other means would be unpractical. It is said to be the oldest and best understood of all techniques. Consequently, automation may easily be adapted to the production process, somewhat less easily to the design and preparation of forms. These forms must satisfy exacting standards as they are the heart of the sand casting process - creating the most obvious necessity for human control.

Plaster casting (of metals)

Plaster casting is similar to sand molding except that plaster is substituted for sand. Plaster compound is actually composed of 70-80% gypsum and 20-30% strengthener and water. Generally, the form takes less than a week to prepare, after which a production rate of 1-10 units/hr-mold is achieved with items as massive as 45 kg and as small as 30 g with very high surface resolution and fine tolerances.

Once used and cracked away, normal plaster cannot easily be recast. Plaster casting is normally used for nonferrous metals such as aluminium-, zinc-, or copper-based alloys. It cannot be used to cast ferrous material because sulfur in gypsum slowly reacts with iron. Prior to mold preparation the pattern is sprayed with a thin film of parting compound to prevent the mold from sticking to the pattern. The unit is shaken so plaster fills the small cavities around the pattern. The form is removed after the plaster sets.

Plaster casting represents a step up in sophistication and requires skill. The automatic functions easily are handed over to robots, yet the higher-precision pattern designs required demand even higher levels of direct human assistance.

Casting of plaster, concrete, or plastic resin

Plaster itself may be cast, as can other chemical setting materials such as concrete or plastic resin - either using single use *waste* molds as noted above or multiple use *piece* molds, or molds made of small ridged pieces or of flexible material such as latex rubber (which is in turn supported by an exterior mold). When casting plaster or concrete the finished product is, unlike marble, relatively unattractive, lacking in transparency, and so is usually painted, often in ways that give the appearance of metal or stone. Alternatively, the first layers cast may contain colored sand so as to give an appearance of stone. By casting concrete, rather than plaster, it is possible to create sculptures, fountains, or seating for outdoor use. A simulation of high quality marble may be made using certain chemically set plastic resins (for example epoxy or polyester) with powdered stone added for coloration, often with multiple colors worked in. The later is a common means of making attractive washstands, washstand tops and shower stalls, with the skilled working of multiple colors resulting in simulated staining patterns as is often found in natural marble or travertine.

Shell molding

Shell molding is also similar to sand molding except that a mixture of sand and 3-6% resin holds the grains together. Set-up and production of shell mold patterns takes weeks, after which an output of 5-50 pieces/hr-mold is attainable. Aluminium and magnesium products average about 13.5 kg as a normal limit, but it is possible to cast items in the 45-90 kg range. Shell mold walling varies from 3-10 mm thick, depending on the forming time of the resin.

There are a dozen different stages in shell mold processing that include:

1. Initially preparing a metal-matched plate
2. Mixing resin and sand
3. Heating pattern, usually to between 505-550 K
4. Inverting the pattern (the sand is at one end of a box and the pattern at the other, and the box is inverted for a time determined by the desired thickness of the mill)
5. Curing shell and baking it
6. Removing investment
7. Inserting cores
8. Repeating for other half
9. Assembling mold
10. Pouring mold
11. Removing casting
12. Cleaning and trimming.

The sand-resin mix can be recycled by burning off the resin at high temperatures.

Investment Casting

Investment casting (lost-wax casting) is a process that has been practised for thousands of years, with lost wax process being one of the oldest known metal forming techniques. From 5000 years ago, when bees wax formed the pattern, to today’s high technology waxes, refractory materials and specialist alloys, the castings ensure high quality components are produced with the key benefits of accuracy, repeatability, versatility and integrity.

The process is suitable for repeatable production of net shape components, from a variety of different metals and high performance alloys. Although generally used for small castings, this process has been used to produce complete aircraft door frames, with steel castings of up to 300 kg and aluminium castings of up to 30 kg. Compared to other casting processes such as die casting or sand casting it can be an expensive process, however the components that can be produced using investment casting can incorporate intricate contours, and in most cases the components are cast near net shape, so requiring little or no rework once cast.

Nonexpendable mold casting

Tin soldiers being cast in German molds from the early 20th century. The two mold halves are clamped together, and the metal (an alloy of tin and lead, heated to approx. 300 °C) is poured into the mold. When the metal has solidified, the mold is cracked open. Sprues (pouring channels) and extraneous flash (metal that has penetrated cracks and air channels in the mold) are seen in the third image, and have been removed from the castings in the last image.

Nonexpendable mold casting differs from expendable processes in that the mold need not be reformed after each production cycle. This technique includes at least four different methods: permanent, die, centrifugal, and continuous casting.

Permanent mold casting

Permanent mold casting (typically for non-ferrous metals) requires a set-up time on the order of weeks to prepare a steel tool, after which production rates of 5-50 pieces/hr-mold are achieved with an upper mass limit of 9 kg per iron alloy item (cf., up to 135 kg for many nonferrous metal parts) and a lower limit of about 0.1 kg. Steel cavities are coated with a refractory wash of acetylene soot before processing to allow easy removal of the workpiece and promote longer tool life. Permanent molds have a limited life before wearing out. Worn molds are either refinishing or replacement. Cast parts from a permanent mold generally show 20% increase in tensile strength and 30% increase in elongation as compared to the products of sand casting.

The only necessary input is the coating applied regularly. Typically, permanent mold casting is used in forming iron, aluminum, magnesium, and copper based alloys. The process is highly automated.

Die casting

Die casting is the process of forcing molten metal under high pressure into mold cavities (which are machined into dies). Most die castings are made from nonferrous metals, specifically zinc, copper, and aluminum based alloys, but ferrous metal die castings are possible. The die casting method is especially suited for applications where a large quantity of small to medium sized parts are needed with good detail, a fine surface quality and dimensional consistency.

Centrifugal casting

Centrifugal casting is both gravity- and pressure-independent since it creates its own force feed using a temporary sand mold held in a spinning chamber at up to 900 N (90 *g*). Lead time varies with the application. Semi- and true-centrifugal processing permit 30-50 pieces/hr-mold to be produced, with a practical limit for batch processing of approximately 9000 kg total mass with a typical per-item limit of 2.3-4.5 kg.

Industrially, the centrifugal casting of railway wheels was an early application of the method developed by German industrial company Krupp and this capability enabled the rapid growth of the enterprise.

Small art pieces such as jewelry are often cast by this method using the lost wax process, as the forces enable the rather viscous liquid metals to flow through very small passages and into fine details such as leaves and petals. This effect is similar to the benefits from vacuum casting, also applied to jewelry casting.

Continuous casting

Continuous casting is a refinement of the casting process for the continuous, high-volume production of metal sections with a constant cross-section. Molten metal is poured into an open-ended, water-cooled copper mould, which allows a 'skin' of solid metal to form over the still-liquid centre. The strand, as it is now called, is withdrawn from the mould and passed into a chamber of rollers and water sprays; the rollers support the thin skin of the strand while the sprays remove heat from the strand, gradually solidifying the strand from the outside in. After solidification, predetermined lengths of the strand are cut off by either mechanical shears or travelling oxyacetylene torches and transferred to further forming processes, or to a stockpile. Cast sizes can range from strip (a few millimetres thick by about five metres wide) to billets (90 to 160 mm square) to slabs (1.25 m wide by 230 mm thick). Sometimes, the strand may undergo an initial hot rolling process before being cut.

Continuous casting is used due to the lower costs associated with continuous production of a standard product, and also increases the quality of the final product. Metals such as steel, copper and aluminium are continuously cast, with steel being the metal with the greatest tonnages cast using this method.

Cooling rate

The rate at which a casting cools affects its microstructure, quality, and properties.

The cooling rate is largely controlled by the molding media used for making the mold. When the molten metal is poured into the mold, the cooling down begins. This happens because the heat within the molten metal flows into the relatively cooler parts of the mold. Molding materials transfer heat from the casting into the mold at different rates. For example, some molds made of plaster may transfer heat very slowly, while a mold made entirely of steel would transfer the heat very fast. This cooling down ends with (solidification) where the liquid metal turns to solid metal.

Intermediate cooling rates from melt result in a dendritic microsturcture. Primary and secondary dendrites can be seen in this image.

At its basic level a foundry may pour a casting without regard to controlling how the casting cools down and the metal freezes within the mold. However, if proper planning is not done the result can be gas porosities and shrink porosities within the casting. To improve the quality of a casting and engineer how it is made, the foundry engineer studies the geometry of the part and plans how the heat removal should be controlled.

Where heat should be removed quickly, the engineer will plan the mold to include special heat sinks to the mold, called chills. Fins may also be designed on a casting to extract heat, which are later removed in the cleaning (also called fettling) procees. Both methods may be used at local spots in a mold where the heat will be extracted quickly.

Where heat should be removed slowly, a riser or some padding may be added to a casting. A riser is an additional larger cast piece which will cool more slowly than the place where is it attached to the casting.

Generally speaking, an area of the casting which is cooled quickly will have a fine grain structure and an area which cools slowly will have a coarse grain structure.

Shrinkage

Castings shrink when they cool. Like nearly all materials, metals are less dense as a liquid than a solid. During solidification (freezing), the metal density dramatically increases. This results in a volume decrease for the metal in a mold. Solidification shrinkage is the term used for this contraction. Cooling from the freezing temperature to room temperature also involves a contraction. The easiest way to explain this contraction is that is the reverse of thermal expansion. Compensation for this natural phenomenon must be considered in two ways.

Solidification shrinkage

The shrinkage caused by solidification can leave cavities in a casting, weakening it. Risers provide additional material to the casting as it solidifies. The riser (sometimes called a "feeder") is designed to solidify later than the part of the casting to which it is attached. Thus the liquid metal in the riser will flow into the solidifying casting and feed it until the casting is completely solid. In the riser itself there will be a cavity showing where the metal was fed. Risers add cost because some of their material must be removed, by cutting away from the casting which will be shipped to the customer. They are often necessary to produce parts which are free of internal shrinkage voids. One method that assists in keeping the metal molten in the riser longer is the utilisation of an exothermic sleeve. http://www.gw-svr-a.org.uk/4566_castings.html

Sometimes, to promote directional solidification, chills must be used in the mold. A chill is any material which will conduct heat away from the casting more rapidly that the material used for molding. Thus if silica sand is used for molding, a chill may be made of copper, iron, aluminum, graphite, zircon sand, chromite or any other material with the ability to remove heat faster locally from the casting. All castings solidify with progressive solidification but in some designs a chill is used to control the rate and sequence of solidification of the casting.

Patternmaker's shrink (thermal contraction)

Shrinkage after solidification can be dealt with by using an oversized pattern designed for the relevant alloy. Pattern makers use special "contraction rulers" (also called "shrink rules") to make the patterns used by the foundry to make castings to the design size required. These rulers are 1 - 6% oversize, depending on the material to be cast. These rulers are mainly referred to by their actual changes to the size. For example a 1/100 ruler would add 1 mm to 100 mm if measured by a "standard ruler" (hence being called a 1/100 contraction ruler). Using such a ruler during pattern making will ensure an oversize pattern. Thus, the mold is larger also, and when the molten metal solidifies it will shrink and the casting will be the size required by the design, if measured by a standard ruler. A pattern made to match an existing part would be made as follows: First, the existing part would be measured using a standard ruler, then when constructing the pattern, the pattern maker would use a contraction ruler, ensuring that the casting would contract to the correct size.