Module I

1. Advanced Casting Processes

Other than polymer processing, there are a number of metal casting processes available for industries. Although there are distinct differences between these many casting processes, there are also many common characteristics. For example, in all casting processes, a metal alloy is melted and then poured or forced into a mold where it takes the shape of the mold and is allowed to solidify. Once it has solidified, the casting is removed from the mold. Some castings require finishing due to the cast appearance, tolerance, or surface finish requirements. During solidification, most metals shrink (gray cast iron is an exception) so pattern allowances and proper gating system design is required to get desired shape job.

The casting processes broadly use two basic types of molds, namely, expendable molds (e.g. sand casting) that are destroyed to remove the part, and permanent molds (e.g. die casting) that one mould can be used for many times. Expendable molds are made using either a permanent pattern (e.g. sand casting) or an expendable pattern (e.g. investment casting). Permanent molds, of course, do not require a pattern.

Two of the major advantages for selecting casting as the process of choice for creating a part are the wide selection of alloys available and the ability, as in injection molding, to create complex shapes. However, not all alloys can be cast by all processes.

1.1 CONTINUOUS CASTING

Continuous casting is a technically sophisticated and is a relatively new process in historical terms. Although the continuous strip casting process was developed by Bessemer in 1858, the continuous casting of steel did not gain widespread use until the 1960s. At the recent times, this process is used by the steel industry to produce over 90% of steel in the world today, including plain carbon, alloy, and stainless steel grades.

Continuous casting, also referred to as strand casting, is the process whereby molten metal is solidified into a billet, bloom, or slab for subsequent rolling for subsequent operations. Before the invention of continuous casting, steel was cast into a billet in a separate mould. Now continuous casting is a process used in steel industry to cast a continuous length of metal. Molten metal is cast through a mold, the casting takes the two dimensional profile of the mold but its length is indeterminate. The casting will keep traveling downward, its length increasing with time. New molten metal is constantly supplied to the mold, at exactly the correct rate, to keep up with the solidifying casting. Industrial manufacture of continuous castings is a very precisely calculated operation.

Molten metal is poured into a Tundish from a ladle or metal reservoir. A Tundish is a container that is located above the mold; it holds the liquid metal for the casting. This casting operation uses the gravity force to fill the mold and is placed about 80-90 feet above the ground level to help move along the continuous metal casting. The Tundish is constantly supplied with molten steel to keep the process going. The whole process is controlled to ensure there is smooth flow of molten steel through tundish.

Further, the impurities and slag are filtered in tundish before they move into the mold. The entrance of the mold is filled with inert gases to prevent reaction of molten steel with the gases in the environment like oxygen. The molten metal moves swiftly through the mold and it does not completely solidify in it. The entire mold is cooled with water that flows along the outer surface.
The metal casting moves outside the mold with the help of different sets of rollers. While one set of rollers bend the metal cast, another set will straighten it. This helps to change the direction of flow of the steel slab from vertical to horizontal.

Advantages of Continuous Casting;

(i) The process is cheaper than rolling.
(ii) 100% casting yield.
(iii) The process can be easily mechanized and thus unit labor cost is less.
(iv) Casting surfaces are better.
(v) Grain size and structure of the casting can be easily controlled.

Disadvantages;

(i) Continous and capable cooling of mould is required.
(ii) Just simple shapes can be cast.
(iii) Last capital investment is necessary to set up process.
(iv) Not proper for small scale production.
(v) Require large ground space.

Application;

(i) A great tonnage of continuous casting is done using cast steel.

(ii) Other metals that are continuous casting are copper, aluminum, grey cast iron s, white cast irons, aluminum bronzes, oxygen-free copper, etc.

(i) Metals are cast as ingot for rolling, extrusion, or forging, and long shapes of simple cross section are cast as round, square, hexagonal rods, etc.

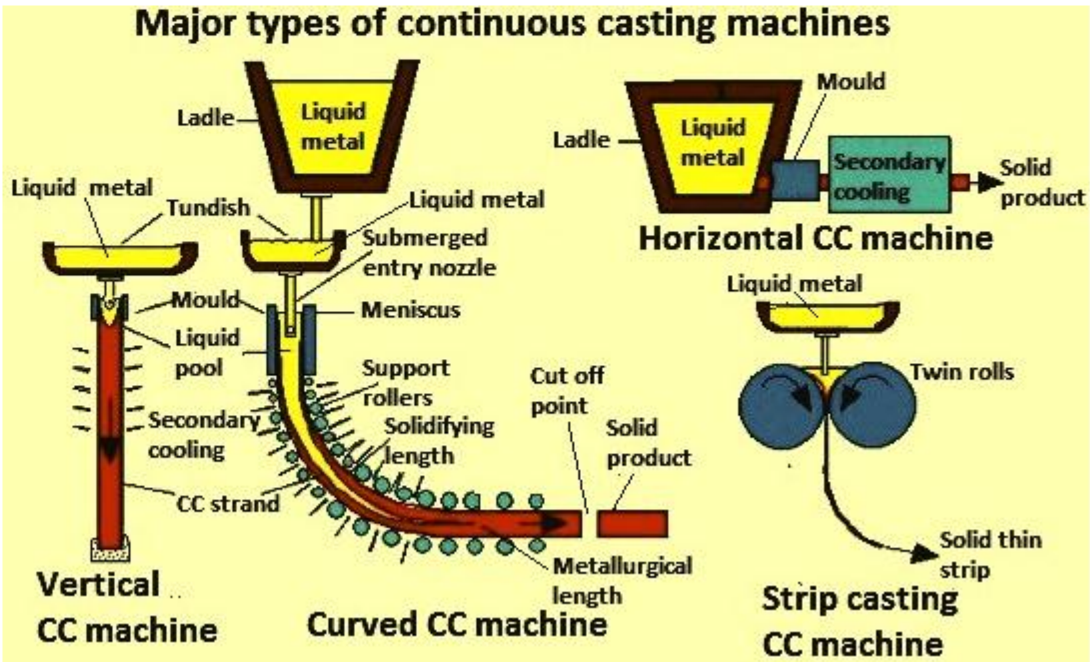

Fig.1.1.1 Continuous casting machines [29]

1.2 DIE CASTING

Like injection molding, die casting is a process in which a molten metal is injected under pressure into a metal mold. The melt then cools and solidifies, conforming to the internal shape of the mold.

As in injection molding, as the part geometry becomes more complex, the cost of the mold increases. Also, as the wall thickness increases, the cycle time required to produce the part also increases. While the thin film, called flashing (Fig.1.2.1), that extrudes out through the spaces between parts of a mold is easily removed by hand in the case of injection-molded parts, the same cannot be said for die-cast parts. Hence, because of the difficulty of flash removal, internal undercuts are not generally die cast. Nevertheless, both injection molding and die casting can economically produce parts of great complexity.

There are two types of die casting machines: a hot chamber machine (Fig.1.2.2) and a cold chamber machine (Fig.1.2.3). Both have four main elements: (1) a source of molten metal, (2) an injection mechanism, (3) a mold, and (4) a clamping system.

In a hot chamber machine, the injection mechanism is submerged in the molten metal (Fig.1.2.2). Because the plunger is submerged in the molten metal, only alloys such as zinc, tin, and lead (which do not chemically attack or erode the submerged injection system) can be used. Aluminum alloys are not suitable for hot chamber machines.

When the die and copper is opened and the plunger retracted the molten metal flows into the pressure chamber (gooseneck). After the mold (die) is closed, the hydraulic cylinder is actuated and the plunger forces the melt into the die at pressures between 14 and 28MPa (2,000-4,000psi). After the melt solidifies, the die is opened, the part ejected, and the cycle repeated.

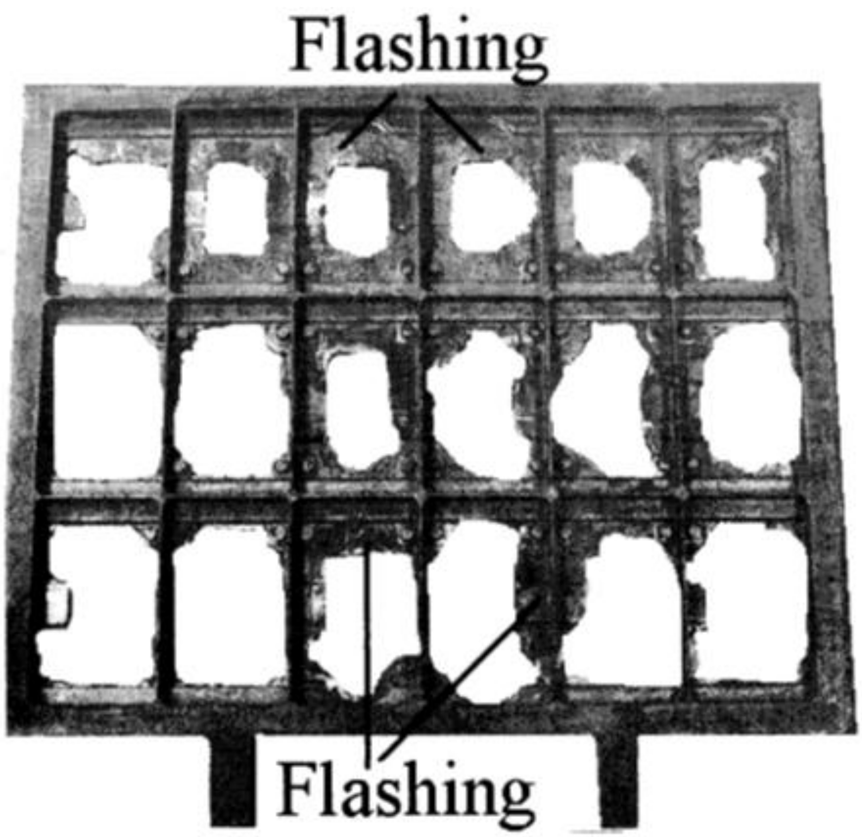

Fig.1.2.1 Die cast part with flashing.

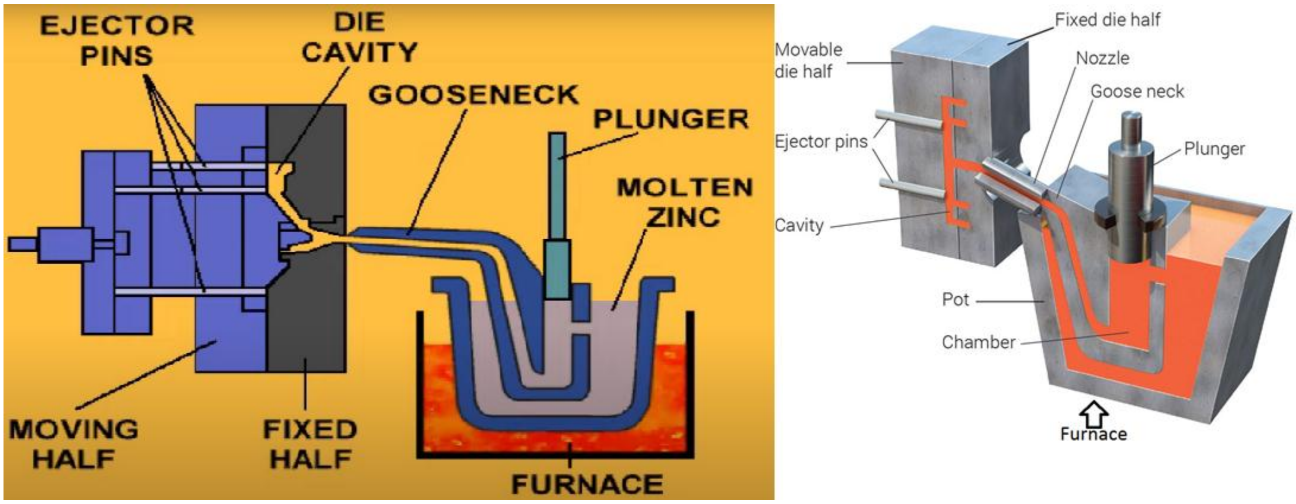

Fig.1.2.2 Hot chamber die casting machine. [28]

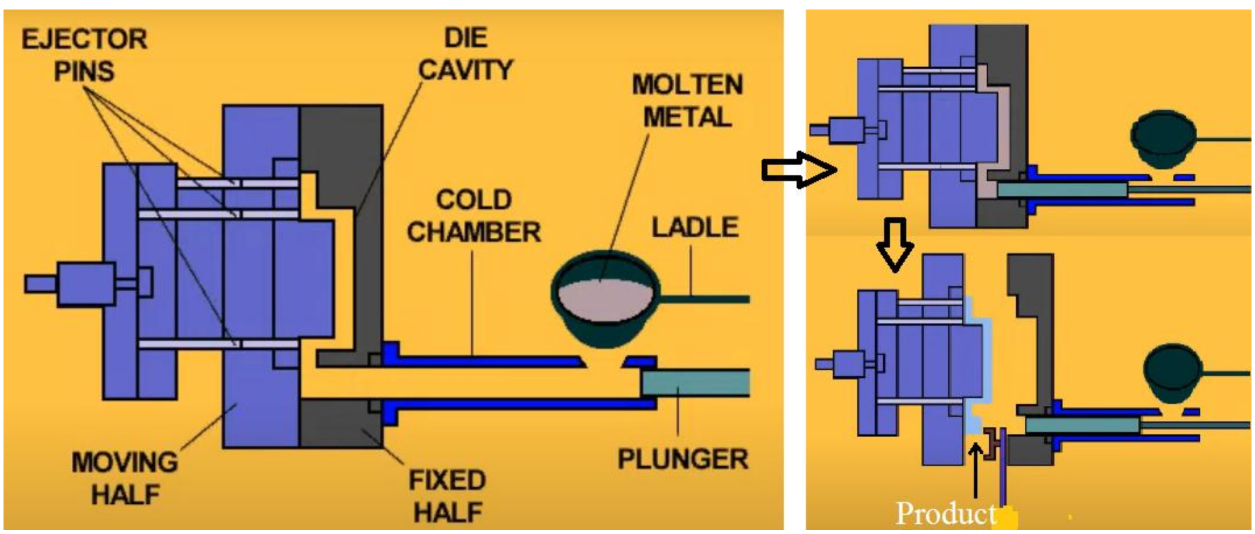

Fig.1.2.3 Cold chamber die casting machine.

Because the higher temperatures used in casting aluminum and copper alloys significantly shorten the life of hot chamber machines, cold chamber machines are often used (Fig.1.2.3). In a cold chamber machine, molten metal from a separate holding furnace is ladled into the cold chamber sleeve after the mold is closed. The melt is then forced into the mold, and after solidification the mold is opened and the part ejected. Injection pressures in this type of machine usually range from 17 to 41MPa (2,500-6,000psi). Pressures as high as 138MPa (20,000psi) are possible.

Since the molds used in die casting are made of steel, only metals with relatively low melting points can be die cast. The vast majority of castings are made of either zinc alloys or aluminum alloys. Zinc alloys are used for most ornamental or decorative objects; aluminum alloys are used for most non-decorative parts.

1.3 PERMANENT MOLD CASTING

In permanent mold casting, also referred to as gravity die casting, molten metal is poured by gravity into a reusable permanent mold made of two or more parts (Fig.1.3.1). This process is closely related to die casting; however, the tolerances and surface finishes achievable by this process are not as good as those obtainable by "pressure" die casting. Because of the high pressures used during filling of the mold during die casting, die casting can produce more complex shapes than achievable via permanent mold casting. Gravity die casting accounts for less than 5 % of all die castings produced.

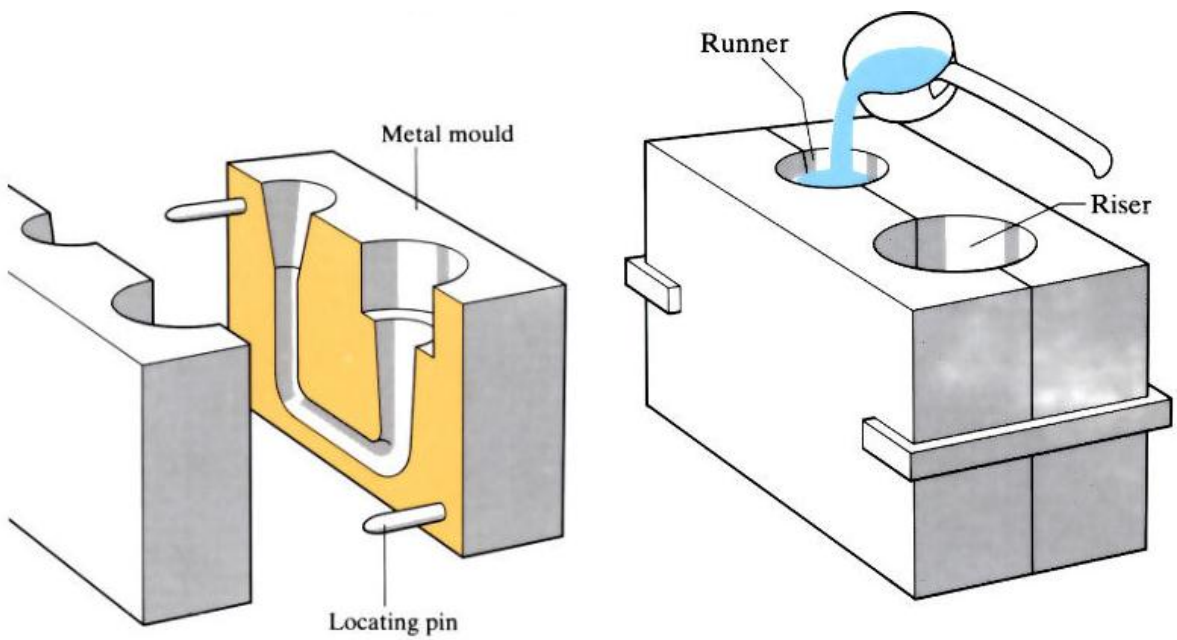

Fig.1.3.1 Permanent mold casting. [25]

1.4 EXPANDABLE MOLD WITH EXPANDABLE PATTERNS

One major difference between the permanent pattern casting methods and the expendable pattern methods is that the expendable pattern is typically always the positive shape of the part. In contrast, permanent patterns are the negative or mirror image to be cast.

When using the expendable pattern method, the part is typically made twice: once in an expendable form of the part (which is disposable) and then as the actual functional metal form of the part. Casting with expendable molds is a very versatile metal-forming process that provides tremendous freedom of design in size, shape, and product quality. Adding expendable patterns to this equation increases the complexity and tolerance of product.

Depending upon the size and application, castings manufactured with the expendable mold process and with expendable patterns increase the tolerance from 1.5 to 3.5 times that of the permanent pattern methods. The two major expendable pattern methods are lost foam and investment casting. A hybrid of these two methods is the Replicast casting process which involves patternmaking with polystyrene (similar to lost foam) but with in a ceramic shell mold (similar to investment casting). These three methods are briefly reviewed here.

1.4.1 Investment Casting Process

Investment casting (also known as ‘lost wax casting’ or ‘precision casting’) has been a widely used process for Centuries. As per [1] Taylor (1983), the principles can be outlined back to 5000 BC when the early man engaged this method to produce elementary tools. As per [2] Barnett (1988), the technology have a great advancement in USA during Second World War, to the need of fastidiousness components with complex geometry. [3] Eddy et al. (1974) reckoned has a different applications and advantages of investment casting process. It is commonly used to manufacturing parts ranging from turbocharger wheels to golf club heads, from electronic boxes to hip replacement implants, general engineering to aerospace engineering and defense outlets.

It explained the basic steps of an investment casting, using abrasive slurry by P.N.Rao [4]. In the investment casting technique, pattern are made of wax, formed by injecting molten wax into a metallic die. Then the pattern or a cluster are gated together to a central wax sprue. The sprued pattern is invested with ceramic or refractory slurry, which is solidified to build a shell around in the wax pattern. The pattern is removed from the shell by melting or combustion process, leaving a hollow void within the shell. Prior of casting, the shells are fired in an oven where intense heat burning out any remaining wax reduce. The resulting shell are hardened by heating, it filled with molten metal. After that molten metal is solidified, the shell is broken and the gates are cut off from the casting to obtain the required shape of component.

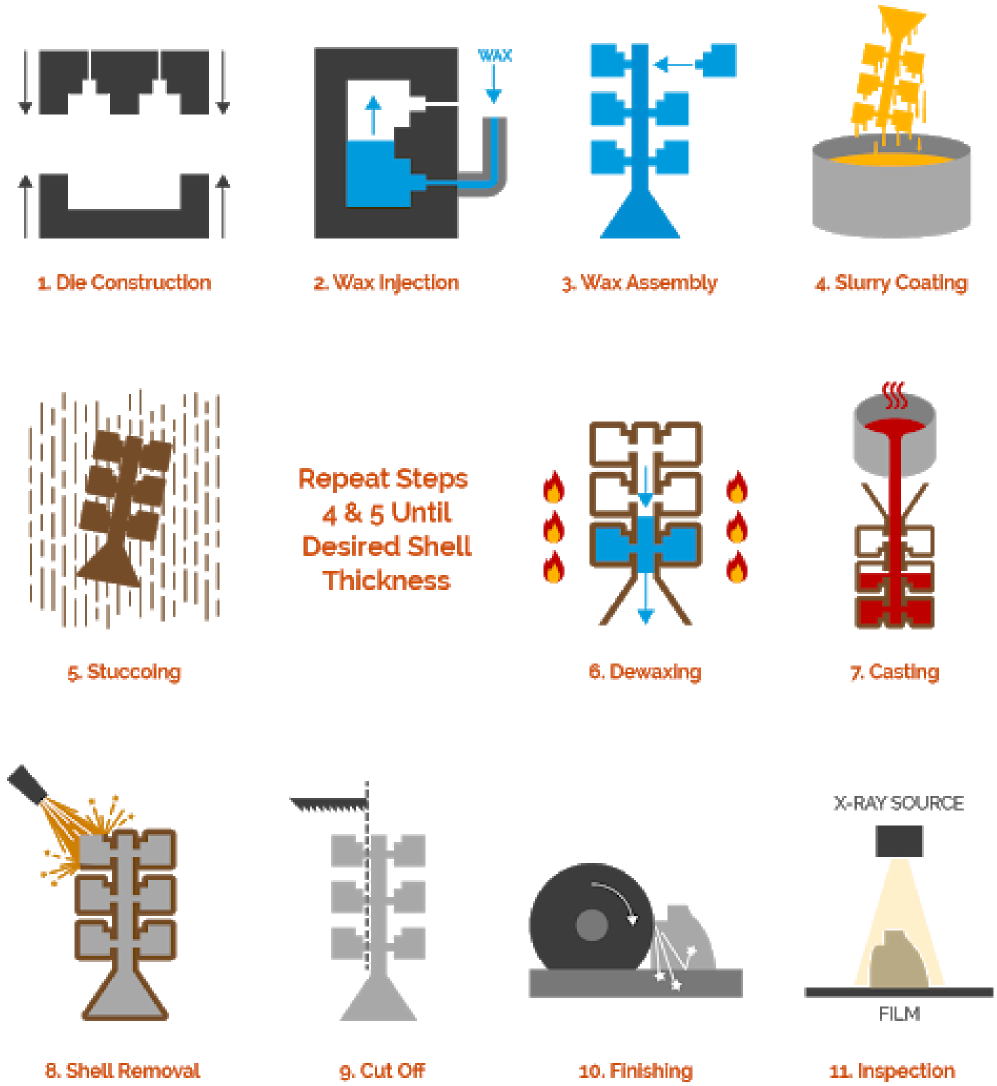

Fig.1.4.1 Investment casting process [27]

Good surface finish is the major advantage of this process. No elaborate and expensive tools are involved in this process. So that shapes are difficult to produce by other casting methods and are very easily possible to be produced by this method. Thin cross sections and intricacies can be made by this processes. Finished machining is considerably reduced on this castings made by this process, making it economical in cost. The process has no metallurgical limitations.
But there is more expensive in this process because of large manual labor involved in the preparations of wax pattern and ceramic slurry. As the shells are delicate, the process is limited by the size and mass obtained. Making intricate and high quality pattern increases the process costs. Steel investment castings is for one-third of the total output by value. Among the non-ferrous alloys, there is a wide range of applications of aluminum and its alloys. Splines, holes, bosses, lettering and even some threads can be successfully cast. Very fine and thin sections can be produced by this process.

1.4.2 Full Mold Process

H.F. Shroyer patented for metal casting on April 15, 1958. In this patent, expanded polystyrene (EPS) block were used by him to machine the pattern and during pouring, it was supported by bonded sand. In the full mold process, the pattern is usually machined from an EPS block and is used to make large kind of castings primarily. Originally this process is also known as 'lost foam process'. The Evaporative pattern casting process (EPC) is a binder less process and no physical bonding is required to bind the sand aggregates. Foam casting techniques has been known by a variety of generic and proprietary names such as in lost foam casting, evaporative pattern casting, cavity-less casting, full mold casting and evaporative foam casting.

The full-mold process (lost foam) is a sand casting method in which polystyrene is used as pattern [5]. The more suitable polymeric materials is to manufacture the patterns are expandable polystyrene and polymethilacrilate, or combination of both [6,7]. The polymer density can vary from 16 to 24 kg/m3. The pattern is covered with refractory coating and inside of mold during metal pouring. As the metal is poured through feeding system, and the metal takes its place, reproducing the exact pattern shape. The gases from the foam burn flee through the sand, crossing the coating layer. The generated gases must travel through the sand easily.

The full-mold process has more advantages compare to other casting methods, especially for high production of difficult shape parts. The patterns are cheap and easy to manufacture, the produced parts are free of lines and exit angles. It possible to reuse the sand [8,9]. The energy consumption is low, as well as operation costs and investments. There is more flexibility for parts design [10]. The production cost cutback with respect to green sand method is around 20–25% for simple parts and 40–45% for complex parts [11].

Since every casting requires a new pattern, it is a costly process. There is a limitation on the minimum section thickness of the pattern. Quality of the casting fully depends upon the quality of the pattern. As the sand is unbounded, during pouring, because of difference evaporation rate of the metal and flow rate of the metal, sand falls down in the cavity generated. Hence, defective casting. The foam is 92% C by weight, the lost foam process is unsuitable for the majority of steel alloys.

This process is suitable for non-ferrous alloys and irons. It is used for making automotive components (cylinder heads, engine blocks, inlet manifolds, heat exchanger, and crank shaft). It is used in marine, aerospace and construction industries.

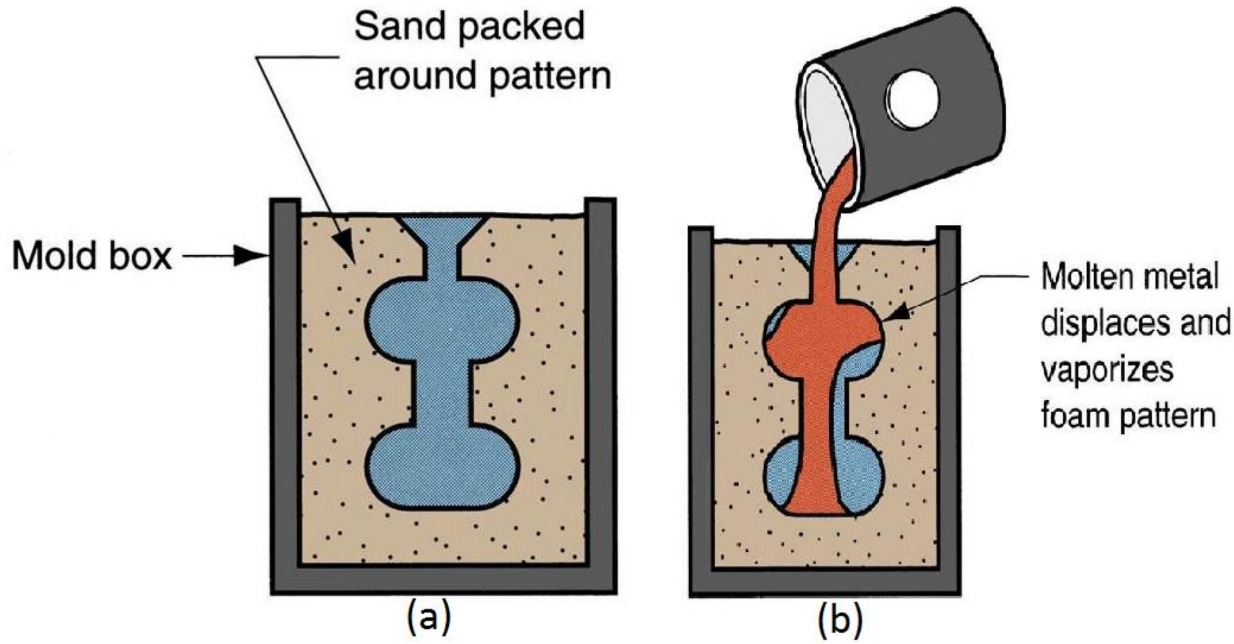

Fig.1.4.2 Full mould casting

1.4.3 Ceramic Shell Casting – Replicast:

The Replicast process can be best characterized as a hybrid of the investment casting process and expanded polystyrene (EPS) as in lost foam. [12] Ashton et al. (1984) developed the ceramic shell casting process based on the foam pattern, researchers and precise casting production enterprises has already recognized its advantages over lost wax casting and lost foam casting, and have mainly employed as a solution to carburization of low-carbon steel castings produced in the lost foam process.

First of all, the foam pattern is based on the part shape is prepared as prototype, and the thin shell with fewer layers is fabricated using the shell fabrication technology and investment casting outside the foam prototype. After the foam prototype is removed, the shell is taken to be roasted. Following the boxing and modelling, the molten metal is poured and solidified under vacuum and air pressure at a level.

In this foam pattern has higher dimensional accuracy and much lighter weight, in this new process can be used to produce large precise castings. Furthermore, the shells are very thin because of the loose-sand uniting vacuum was employed to further reinforce it, thus the production cycle of shells can be significantly shortened. This new shell casting process also over in lost foam casting process. In as much as the foam prototypes are removed before pouring, the filling capacity of molten metal can be improved, especially for non-ferrous metals, and carburization of low-carbon steel castings would also be eliminated. Air emissions are easier to control than with lost foam. This application of a vacuum during casting allows improved fill-out of molding.

The support provided by the ceramic shell during casting allows large, thin shells to be easily poured. Sand inclusions and other sand mold-related defects can be virtually eliminated. As with investment and lost foam casting, there are no cores or parting lines, high dimensional accuracy, and excellent surface finish. The ceramic shell does not have a thick as for shell casting. The technique minimizes dust emissions from molding and finishing, as compared to sand molding.

In the lost wax casting process, wax can be retain in its common name of ‘precision casting process’ only for very small castings. Since the surface quality of the foam pattern is much poor when compared to that wax casting, the shell fabricated outside the foam pattern would produce a relatively higher surface roughness of the casting, which has been verified by [16] Kumar et al. (2007) and Li et al. (1998). This has consequently hundreds of application in this new shell casting process in the precise casting field. However, it was verified by Campbell (2000) and Bonilla et al. (2001) that, for large castings, the process becomes no better than low technology sand castings.

Wang et al. (2007) and Wen et al. (2009) reported that the rapid development of aerospace and automotive industry [13], the demand for complicated and thin-walled aluminium and magnesium alloy precision castings increases market due to their high strength-to-weight ratio and lightweight. [14] Liao et al. (2009) introduced vacuum and low-pressure casting process into primary ceramic shell process to produce magnesium alloy and aluminium precision castings, which could eliminating pore and shrinkage defects as present in lost foam castings. As presented by [15] Jiang et al. (2010). Table 1 compares replicast with investment casting process.

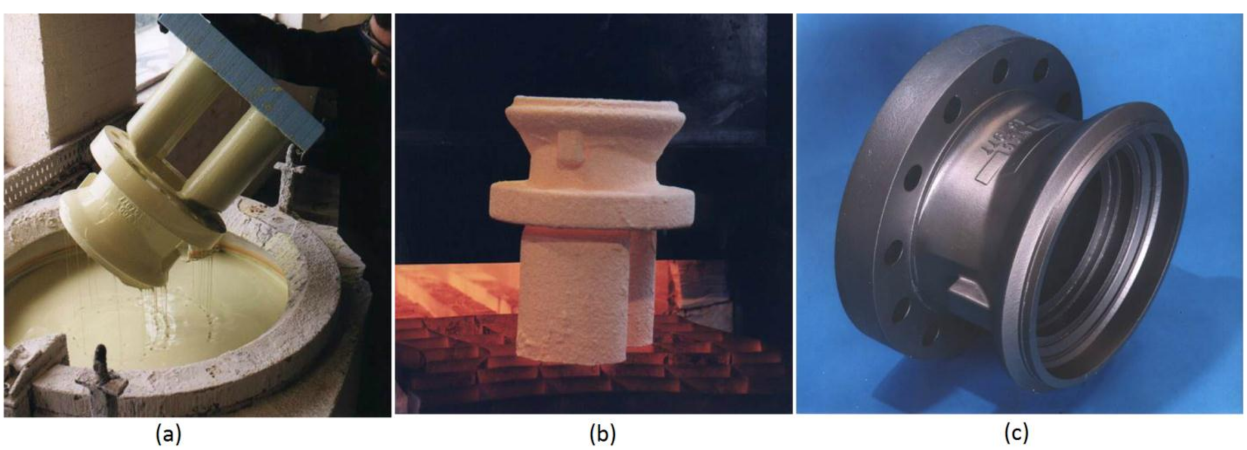

Fig.1.4.3 Replicast process [26]

1.4.4 SEMI-SOLID METAL PROCESSING

Semi solid metal processing, also known as semisolid metal casting, semisolid forming, or semisolid metal forging, is a special die casting process wherein a partially solidified metal slurry (typically, 50% liquid/50% solid instead of fully liquid metal) is injected into a die cavity to form a die-cast type of component. It was discovered that when the dendritic structure of a partially solidified Sn-15wt%Pb alloy was fragmented by shear in a Couette viscometer, it results in a globular structure.

The apparent viscosity of the globular structure was dramatically lower than that of the dendritic, and the slurry is formed has fluidity approximating that of machine oil. That semisolid material has rest held its shape like a solid; however, when a shear stress was applied, it became fluid to be injected into a die casting this property is known as thixotropy. The key to SSM processing is to generate a semisolid metal slurry that contains a globular primary phase (surrounded by the enriched liquid phase) and exhibits thixotropic behavior. That is, the viscosity of the slurry decreases continuously under shear deformation, whereas the viscosity value can be recovered once the shear action ceases. There are three major semisolid processing routes: **thixocasting**, **rheocasting**, and **Thixomolding**, and several variations within those.

TABLE 1 : Comparison of investment casting, Full mold process and replicast Process

Feature	**Investment casting**	**Full mold process**	**Replicast process**
Pattern	Softened wax is injected at high pressure into a metal tool. The wax is subject to shrinkage and deformation, and it is expensive and heavy. It is reclaimable to some degree.	Pattern is made from polystyrene foam and Injected into aluminium tool	Partially expanded EPS beads are blown into aluminium tooling and completely expanded. Finished patterns are lightweight, have high density, and provide good surface finish and excellent dimensional accuracy.
Shell	Successive coats of refractory slurry and stucco are applied. Five to ten coats are required completed shells are often heavy and difficult to handle. Firing at 1000^{o}C for 20 min removes the residual wax and hardens the shell.	No shell is prepared but coated with primary refractory paint	Successive coats of refractory slurry and stucco are applied. Three or four coats are required, resulting in a relatively light and easy-to-handles shell. Firing at 925–1000^{o}C for 5 min removes the EPS pattern and hardens the shell

Pouring	Metal is frequently poured into hot, unsupported shells, breakage is possible.	The polystyrene foam pattern left in Sand mold is decomposed by the molten metal. The metal replaces the foam pattern, exactly duplicating all of the features of the pattern	Thin ceramic shell is surrounded by loose sand vibrated to maximum bulk density, and the vacuum is applied during pouring to prevent shell breakage.
Applications	Suitable for all alloys. Less suited for heavy section components.	Suitable for non-ferrous alloys and irons (preferably aluminum) Not suitable for steel.	Suitable for all alloys. Not ideal for very thin section parts (e.g. <2mm).
Manufacturability	Medium productivity with outstanding dimensional control.	Less productivity	Very less productivity

Thixocasting:

Thixocasting consists of two separate stages: the production of billet feedstock having the appropriate globular structure, and reheating of billets to the semisolid temperature range, followed by the die casting operation. The thixocasting route starts from a non-dendritic solid precursor material that is specially prepared by manufacturer, using continuous casting methods. Upon reheating this material into the mushy (two-phase) zone, a thixotropic slurry is formed, which is the feedstock for the semisolid casting operation. There are three major processing methods to make thixocasting feedstock which can be reheated to the semisolid region to develop the fully globular structure for forming into SSM parts.

The advantages of thixocasting are exceptional part quality extremely because of low levels of shrinkage or gas porosity, excellent leak tightness and weldability. Excellent mechanical properties (T5 heat treated thixocasting parts are able to achieve properties typically found in T6 heat treated permanent mold castings). Fast cycle times. Long die life because of limited thermal shock to the tooling and less heat checking. Near-net shape because of low draft angles possible, reduced machining stock compared to competitive casting processes

The thixocasting machines incorporate larger injection cylinders with additional hydraulic multiplication systems, as well as thicker platens and larger-diameter tie bars to accommodate the high injection forces. Due to the extra material costs and engineering necessary to achieve the higher injection forces and velocity control, these specialized thixocasting machines are more expensive than conventional die-casting machines.

Rheocasting:

Rheocasting (also known as slurry-on-demand), the liquid state is the beginning point, and a thixotropic slurry is formed directly from the melt via special thermal treatment/management of the solidifying system [17]. The rheocasting method is favored over thixocasting because there is no premium added to the billet cost, and the scrap recycling issues are alleviated.

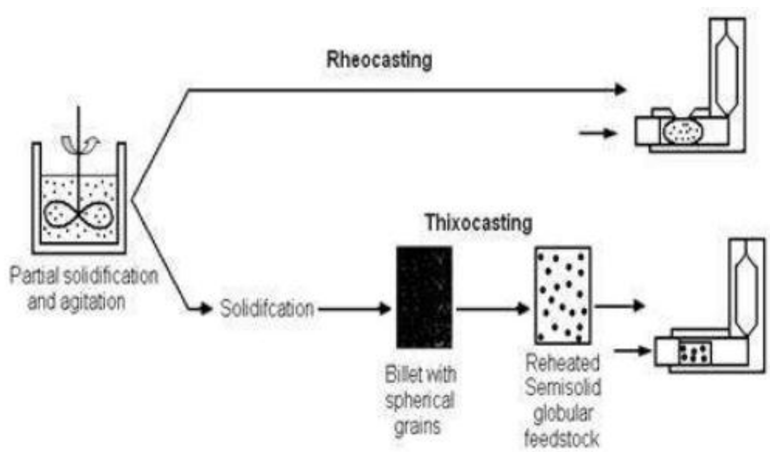

Fig.1.4.4 Rheocasting and Thixocasting process

Thixomolding (Magnesium Pellets)

Thixomolding process uses solid chips or pellets of conventionally solidified magnesium alloys that are fed into a heated injection system containing a reciprocating screw. Upon heating, the metal chips are converted by the shear action of the screw into a thixotropic, low-solid-content slurry (solid fraction less than 0.3), which is fed into the shot accumulator by the rotating screw. Once the accumulation chamber is filled, the slurry is injected in the mold.

A major advantage of the process is that it effectively combines both slurry making and slurry injecting into a one step process, leading to high productivity and energy savings. In addition, the process avoids the safety problems usually associated with melting, handling, and die casting molten magnesium. Thixomolding is successfully implemented in some of magnesium alloys. Table 2 provides a comparison of semi-solid metal process.

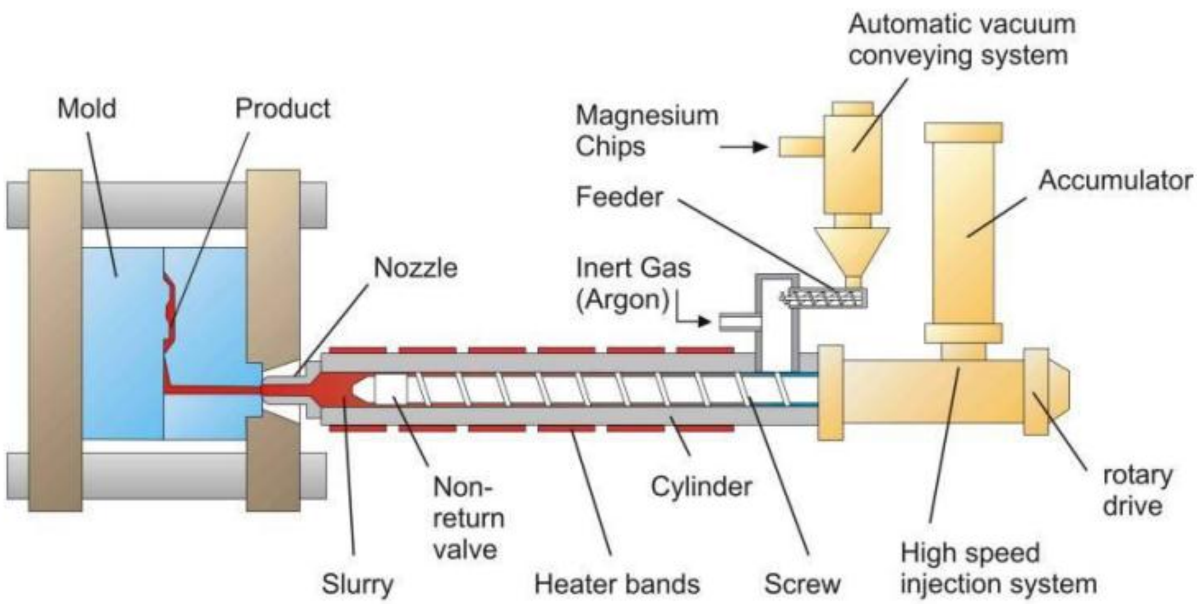

Fig. 1.4.5 Thixomolding setup

TABLE 2 Comparison of Semi-solid metal process

Thixocasting	**Rheocasting**	**Thixomolding**
Thixocasting begins with a non-dendritic solid precursor of material that is specially prepared by the manufacturer using continuous casting methods	Rheocasting starts with material in the liquid state, and the thixotropic slurry is formed directly from the melt via special thermal treatment/management of the system	Thixomolding process uses solid chips or pellets of conventionally solidified magnesium alloys that are fed into a heated injection system
Upon reheating the material into the mushy (i. e., two-phase) zone, thixotropic slurry forms and becomes the feed for the casting operation	The slurry is subsequently fed into the die cavity.	Upon heating, the metal chips are converted by the shear of the screw into a thixotropic, low-solid-content slurry which is fed into the shot accumulator by the rotating screw. Once the accumulation chamber is filled.
No prior treatment is required	It is favored in that there is no premium added to the billet cost, and the scrap recycling issues are alleviated	A major advantage of the process is that it effectively combines both slurry making and slurry injecting into a one step process, leading to high productivity and energy savings. In

		addition, the process avoids The safety problems usually associated with melting, handling, and die casting molten magnesium.

1.4.5 NO-BOND SAND MOLDING PROCESS

Sand molding processes are classified according to the way in which the sand is held (bonded). Most sand casting employs green sand molds, which are made of sand, clay, and additives. Binders are also used to strengthen the cores, which are the most fragile part of mold assembly. However, some molding processes do not use binders [18]. Instead, the sand or mold aggregates are held together during pouring by the pattern itself (as in lost-foam casting) or by the use of an applied force (as in vacuum molding and magnetic molding described here). No-bonded molding processes involve free-flowing mold particles and do not require binders, mulling equipment, or mold additives.

V-Process:

The vacuum-sealed molding process allows molders to make complex molds using dry, unbounded, and freely flowing sand. Molds are sealed by using plastic films along the top and bottom sand surfaces of the cope and the drag molds and then vacuum applied to the sand medium of cope and drag [19]. The plastic film along with top of the drag mold and the bottom of cope mold is softened by heating and formed on an appropriate pattern to produce the hollow cavity for the finished mold. The control factors of the V-process are may affect the quality of the castings and the molding sand, vibration frequency, vibrating time, degree of vacuum imposed, and pouring temperature.

The advantage of the V-process is that the use of vacuum to maintain the mold eliminates the requirement for a sand binder. Consequently, no sand mixing system is required, and the machinery for shakeout and sand reclamation are therefore less costly to installing and operate. Additional benefits for V-process molding include reduced requirements for sand control and lower fume and dust generation [20]. V-process mold will also retain heat longer, slowing solidification, due to presence of no moisture in the mold sand.

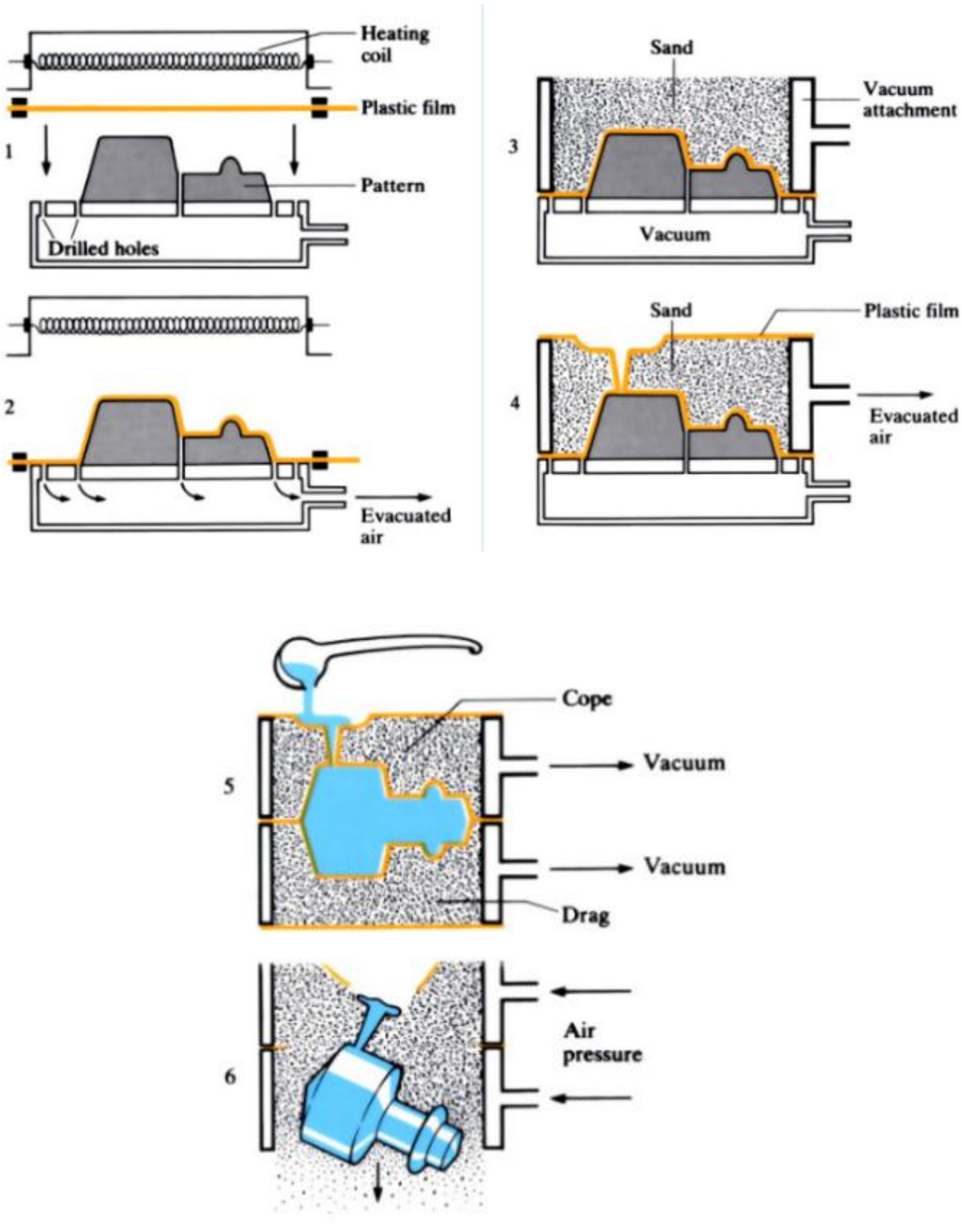

Fig.1.4.5 V-Process [25]

Magnetic Molding:

Based on a concept similar to the lost-foam process using an expandable polystyrene (EPS) pattern, magnetic molding was developed. In initial development of the magnetic molding process took place at the same time as the lost-foam process, but it has never achieved the same level of industrial development as the lost-foam method [21]. The magnetic molding process involves a coated EPS pattern that is surrounded by a mold material of magnetic iron or steel shot (instead of sand as in lost foam). After the EPS pattern is positioned in the flask and encased with magnetic shot particles (between 0.1 and 1.0 mm, or 0.004 and 0.04 in., in diameter), the mold is compacted further by periodic vibrating and/or tilting. The mold is then made rigid by the application of a magnetic field prior to pouring the molten metal. Evolving gases are drawn off through the base of the flask. The magnetic field is turned off after solidification and cooling, resulting in immediate shakeout. The free-flowing magnetic shot molding material is returned to its point of origin after cooling, dedusting, and metal splash removal.

Advantages of the magnetic molding, like other no-bond methods, include the absence of a chemical binder, reductions in dust and noise levels, full mechanization or automation of the process, and the elimination of normally used molding activities (such as ramming and jolting). The increased heat conductivity of the iron or steel molding material also results in a finer grain structure in the cast metal. Another advantage is that a piece mold can be produced without a joint line.

Magnetic molding using irons, carbon and low-alloy steels, high-chromium steels, and copper-base alloys are under research.

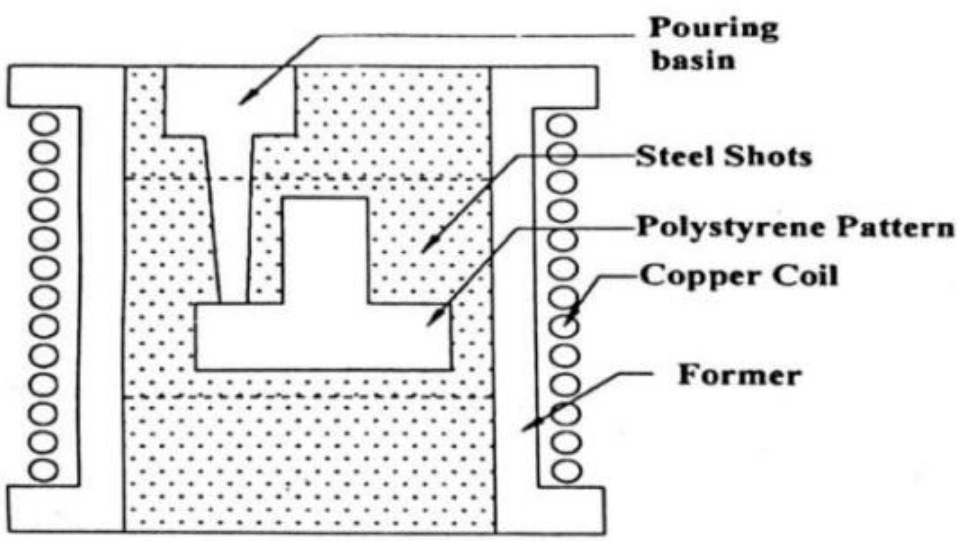

Fig.1.4.6 Magnetic molding setup

1.5 Plastic Materials Processing

Polymers are natural or synthetic resins or their compound which can be molded, extended, cast or used as films or coatings. Naturally occurring polymers – those derived from plants and animals – are in use for many centuries; these materials include wood, rubber, cotton, wool, leather, and silk. Modern scientific research tools facilitated the determination of the molecular structures of this group of materials, and the development of numerous polymers, which could be synthesized from small organic molecules. The synthetics can be produced inexpensively, and their properties may be managed to the degree that many are superior to their natural counterparts. In many applications, metal and wood parts are replaced by plastics, which have satisfactory properties, longer durability and can be produced at a lower cost.

Polymers are most commonly classified as (a) thermoplastics and (b) thermosetting polymer.

Thermoplastic Materials

The polymeric materials which soften on the application of heat with or without pressure, but require cooling to set them to shape are called Thermoplastic Materials. These can be heated and cooled any number of times, but should not be heated above the decomposition temperature. These polymers primarily include long chain straight molecule and the chains are held close to each other by secondary weak forces. Upon heating, these secondary forces are reduced and sliding can occur easily thereby allowing visco-plastic flow and ease in molding. These polymers are characterized with low melting temperature and lesser strength compared to the thermo setting plastic. Some important thermoplastic materials are Polythene, Polyvinyl chloride, Polystyrene etc.

Thermosetting Materials

Polymers which require heat and pressure to mold them into shape and become permanently hard during shaping are called Thermosetting Materials. These materials cannot be re- softened once they are set and hardened. Thermosetting polymers typically include crosslinked molecular chains and hence, are ideal for making components which require rigidity, strength and resistance to heat. Due to cross linking, thermosetting polymers are hard, tough, non-swelling and brittle, and cannot be softened and remolded as thermoplastic materials. Some important thermoplastic materials are Phenol Formaldehyde, Epoxy Resins, and Polyesters etc

Manufacturing process used with polymers take advantage of the unique visco-plastic flow properties of polymers. Compared with the metals, the flow stress is much lower and highly strain rate dependent, the viscosity is much higher, and formability is much greater. As viscosity is high, it is not possible to pour the liquid polymer in a die. It is essential to force the polymer to take the die shape perfectly. Some of the common manufacturing processes of polymers

1.5.1 Injection Moulding Process

Injection moulding is the most widely used polymeric fabrication process. It evolved from metal die casting, however, unlike molten metals, polymer melts have a high viscosity and cannot simply be poured into a mould. Instead a large force must be used to inject the polymer into the hollow mould cavity. More melt must also be packed into the mould during solidification to avoid shrinkage in the mould. The injection moulding process is primarily a sequential operation that results in the transformation of plastic pellets into a moulded part. Identical parts are produced through a cyclic process involving the melting of a pellet or powder resin followed by the injection of the polymer melt into the hollow mould cavity under high pressure.

Injection Moulding Machine

An injection moulding machine produces components by injection moulding process. Most commonly used machines are hydraulically powered in-line screw machines, although electric machines are appearing and will be more dominant in the market in near future. The main units of a typical injection moulding machine are the clamping unit, the plasticizing unit, and the drive unit; they are shown in Fig. 2.1. The clamping unit holds the mould. It is capable of closing, clamping, and opening the mould. Its main components are the fixed and moving plates, the tie bars and the mechanism for opening, closing and clamping. The injection unit or plasticizing unit melts the plastic and injects it into the mould. The drive unit provides power to the plasticizing unit and clamping unit.

Injection moulding machines are often classified by the maximum clamp force that the machine can generate. This is the force that pushes the two mold halves together to avoid opening of the mould due to internal pressure of the plastic melt in the mould. The clamping force of typical injection moulding machines range from 200 to 100,000 kN.

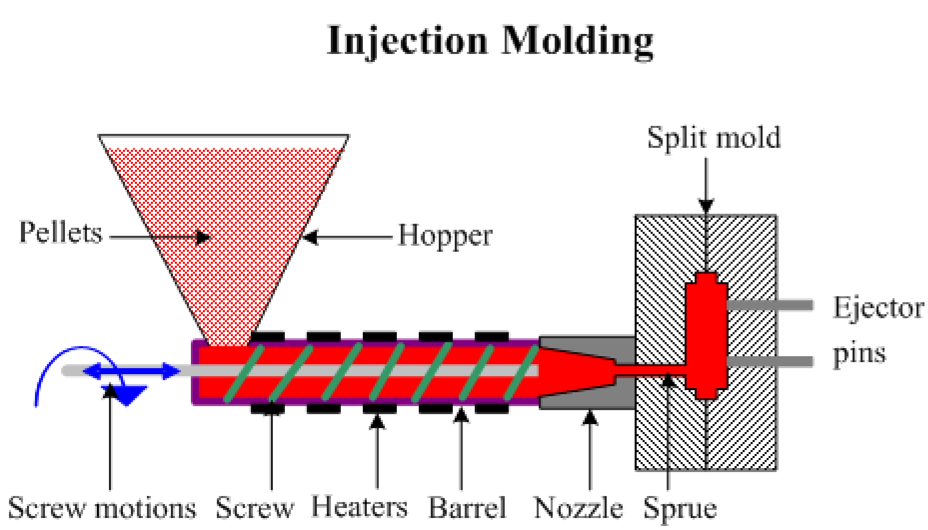

Fig.1.5.1 Injection Moulding Machine [23]

1.5.2 Extrusion

Extrusion is one of the few continuous plastic processes, which is used to produce sheet, film, long length with a profiled cross section and fiber. The chief concern with extrusion of polymers is the die swell and the orientation. In die swell, the extrudate swells to a size greater than the die from which it just exited. Thus the design must compensate for the swell. Polymer molecules become highly oriented in one or two directions as a result of the strongly oriented flow inherent in the extrusion process. Control of orientation can improve the property of the material.

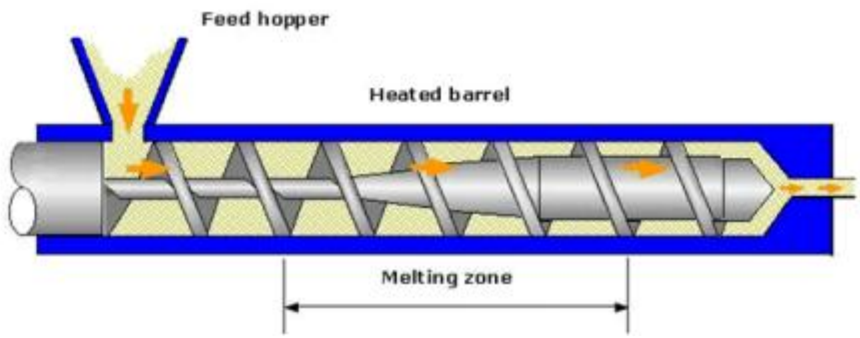

Fig.1.5.2 Schematic set-up of Polymer Extrusion [22]

1.5.3 Blow Molding

In blow molding, a hot tube of plastic material is placed between two halves of the mold. The mold is then closed and air or inert gas is blown at a pressure of 20 – 40 MPa which expands the hot tube outward to fill the mold cavity. The part cools, hardened and is ejected from mold. The process produces a part that is dimensionally defined on its external dimension. The process does not lend itself to incorporate design details such as holes, corners, narrow ribs, etc. The blow molding process is very fast and can produce part very economically. The process can be accomplished manually or by semi-automatic or automatic machines

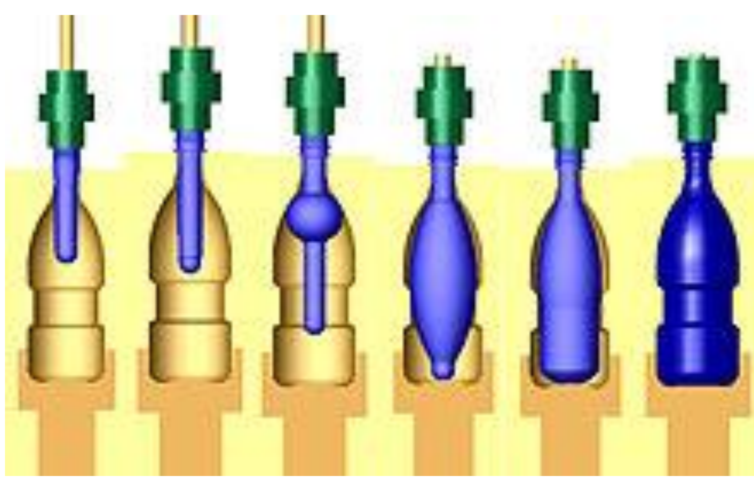

Fig.1.5.3 Schematic set-up for Blow Molding of Polymer [22]

1.5.4 Compression Molding

In this technique, a preform of a typical polymer is placed in a heated mold cavity and a plunger applies pressure to force the polymer to fill the mold cavity. The material is then allowed to cure and ejected from the mold. As the amount of flow is much lesser than the same used in injection molding, the level of residual stress in the part is low. Parts made in this way would have sprues and runners which must be trimmed.

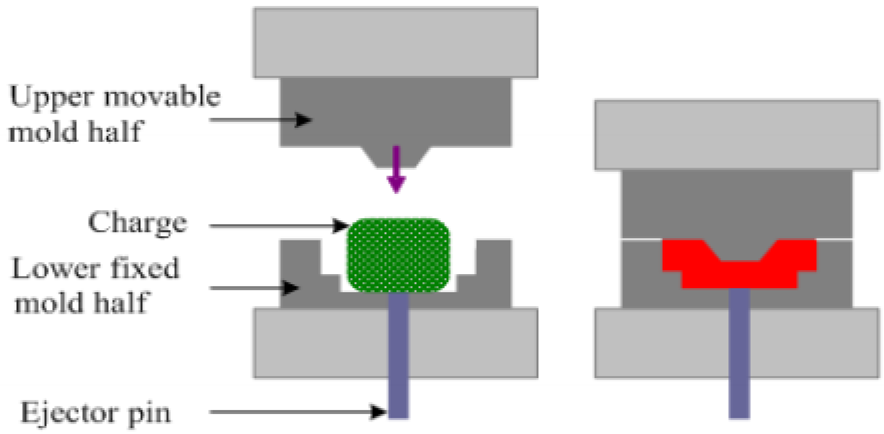

Fig.1.5.4 Schematic set-up of Compression Molding of polymers [23]

1.5.5 Thermoforming

Thermoforming refers to heating a sheet of plastic material until it becomes soft and flexible and then forming it either by vacuum, by air pressure or between matching mold halves. Following are the typical sequences used in thermoforming of polymers.

- A sheet of thermoplastic material is placed over a die and heated until it becomes soft.
- A vacuum is then created inside the die cavity which draws down the heated plastic sheet into the shape of the die.
- The material is then cooled, the vacuum is released and the final product is taken out. Traditionally, thermoforming is done with only a single mold, but for more precise control of dimension two matching mold halves are used.

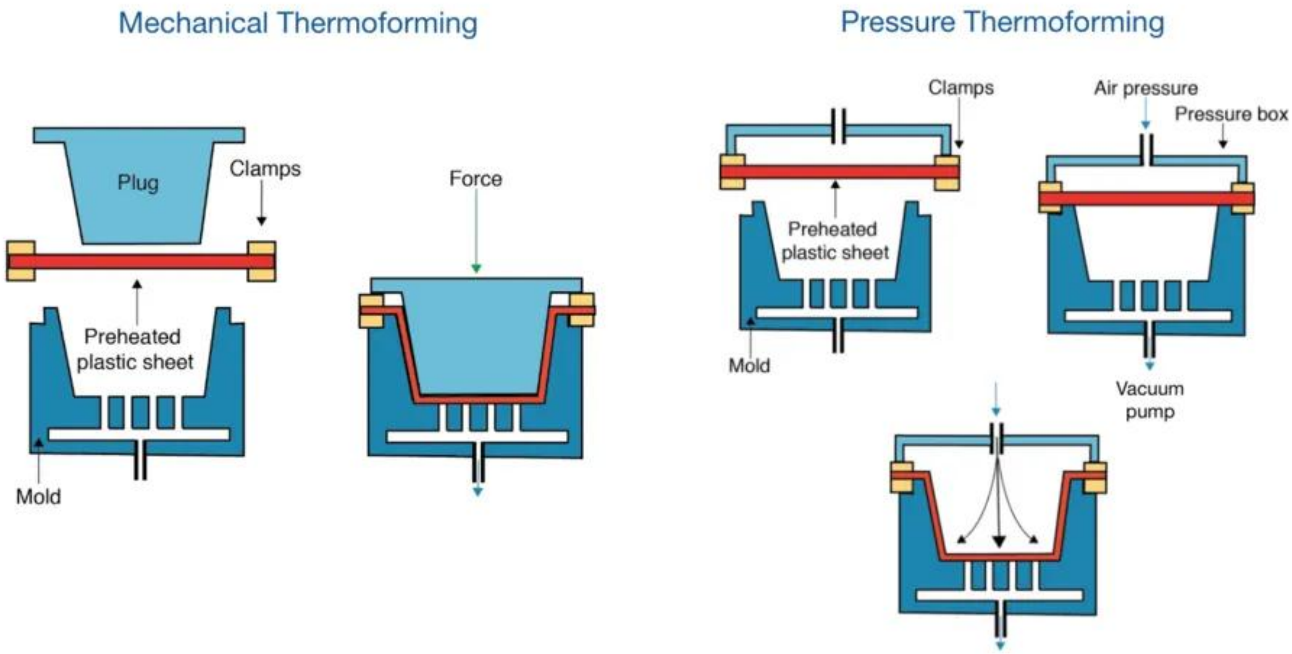

Fig. 1.5.5 Schematic set-up of Thermoforming Process [24]

REFERENCES:

1. Taylor, P.R., 1983. An illustrated history of lost wax casting. In: Proceedings of the 17th Annual BICTA Conference

2. Barnett, S.O., 1988. Investment casting—the multi-process technology. Foundry Trade Journal 11 (3), pp. 33–37.
3. Eddy, W.P., Barbero, R.J., Dieters, W.I., Esarey, B.J., Frey, L., Gros, J.R., 1974. In: Lyman, T. (Ed.), Investment Casting. American Society for Metals, Ohio, pp. 237–261.
4. Manufacturing Technology, Volume 1. Front Cover. P. N. Rao. Tata McGraw-Hill Education
5. S. Shivkumar, X. Yao, M. Makhlouf, Polymer–melt interactions during casting formation in the lost foam process, Scripta Metall. Mater. 33 (1995) pp. 39–46 (Number 1.3946).
6. T.S. Piwonka, A comparison of lost pattern casting processes, Foundry T. J. 164 (1990) pp. 626–631.
7. R.H. Immel, Expandable polystyrene and its processing into patterns for the evaporative casting process, AFS Trans. 87 (1979) pp.545– 550.

8. A.J. Clegg, Expanded-polystyrene molding a status report, Foundry T. J. 159 (1985) pp.177–196.
9. M.R. Barone, D.A. Caulk, A foam ablation model for lost foam casting of aluminium, Int. J. Heat Mass Transfer 48 (2005) pp. 4132–4149.
10. J.R. Brown, Processos de Fundic¸ ˜ao a Poliestireno, Atual Est´agio de Desenvolvimento, 40 Conbrafund, S˜ao Paulo, 1984, pp. 129– 136.
11. R. Bailey, Understanding the evaporative pattern casting process (EPC), Mod. Cast. (1982) pp. 58–72.
12. Ashton, M.C., Sharman, S.G., Brookes, A.J., 1984. Replicast CS (ceramic shell) process. Mater. Des. 5 (2), pp. 66–67.
13. Wang,Y.C., Li, D.Y., Peng, Y.H., 2007. Numerical simulation of low pressure die casting of magnesium wheel. Int. J. Adv. Manuf. Technol. 32 (3–4), pp. 257–264.
14. Liao, D., Fan, Z., Jiang, W., 2009. Study on thin-wall and low-roughness ceramic shell mould based on EPS process. Foundry 58 (12), pp.1220–1223.
15. Jiang, W., Fan, Z., Liao, D., Zhao, Z., Dong, X., 2010. Preparation process of compound shell for lost foam casting based on foam pattern prototypes. Special Casting Nonferrous Alloys 30 (2), pp. 161–163.
16. Kumar, S., Kumar, P., Shan, H.S., 2007. Effect of evaporative pattern casting process parameters on the surface roughness of Al–7% Si alloy castings. J. Mater. Process. Technol. 182 (2–3), pp. 615–623.
17. O. Ludwig, C.-L. Martin, J.-M. Drezet, and M. Sue´ry, Rheological Behaviour of Al-Cu Alloys During Solidification: Constitutive Modelling, Experimental Identification and Numerical Study, Met. Mater. Trans., Vol 36A, 2005, pp. 1525–1535
18. M.C. Flemings, Semi-Solid Processing — The Rheocasting Story, Test Tube to Factory Floor: Implementing Technical Innovations, Proceedings of the Spring Symposium, May 22, 2002, Metal Processing Institute, Worcester Polytechnic Institute, Worcester, MA, 2003
19. Y. Kubo, K. Nakata, and P.R. Gouwens, Molding Unbonded Sand with Vacuum— The V-Process, Trans. AFS, Vol 81, 1973, pp 529–544
20. T. Miura, Casting Production by V-Process Equipment, Trans. AFS, Vol 84, 1976 p 233–236
21. P.-M. Geffroy et al., Thermal and Mechanical Behavior of Al-Si Alloy Cast Using Magnetic Molding and Lost-Foam Processes, Metall. Mater. Trans. A, Vol 37, Feb 2006, pp. 441–447
22. https://en.wikipedia.org/wiki/Blow_molding#/media/File:Blow_molding_process.jpg
23. www.substech.com
24. https://bioplasticsnews.com/
25. www.open.edu/openlearn
26. https://castingstechnology.com/products-and-services/casting-producers/cti-technologies/replicast/

27. http://americancastingco.com/investment-casting-process/
28. https://www.engineeringclicks.com/die-casting/pressure-die-casting-pdc/
29. http://ccc.illinois.edu/
30. John A Schey, Introduction to Manufacturing Processes, 3rd
31. G Dieter, Engineering Design - A Materials and Processing Approach, McGraw Hill, NY, 2000. Edition, Mcgraw Hill, Singapore, 2000.
32. William D. Callister, Material Science and Engineering: An Introduction, 6th
33. Edition, Wiley Students Edition, 2009.