Lost Foam Casting

(Full Mould Casting)
(Evaporative Pattern Casting)

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Introduction

The lost foam casting (LFC) is a unique casting method in which ceramic coated polymeric foams are used as the pattern. Generally, loose silica sand is used as the mold material. The presence of the foam pattern in the mold until the moment of casting is the most crucial feature that distinguishes the method from other casting techniques, and therefore the technique is also referred to as the full mold casting. Although the method employs sand as a molding material, it has very different features than conventional sand casting methods. The lack of parting lines in the casts, no need for the draft angle, the elimination of the core concept, and generally, no need for feeders are among these.

On the other hand, the LFC method is not entirely perfect. For instance, gaseous products resulting from the decomposition of the foam during casting can cause back pressure and contamination. But overall, with the investments made by major automotive manufacturers, this casting method has reached an essential point in the industry. The technique has also been a subject and foundation of numerous studies in the scientific area. The fact that the pattern does not need to be removed from the mold is a significant challenge to the conventional casting methods, and this feature will make the LFC method always attractive.

Historical Perspective

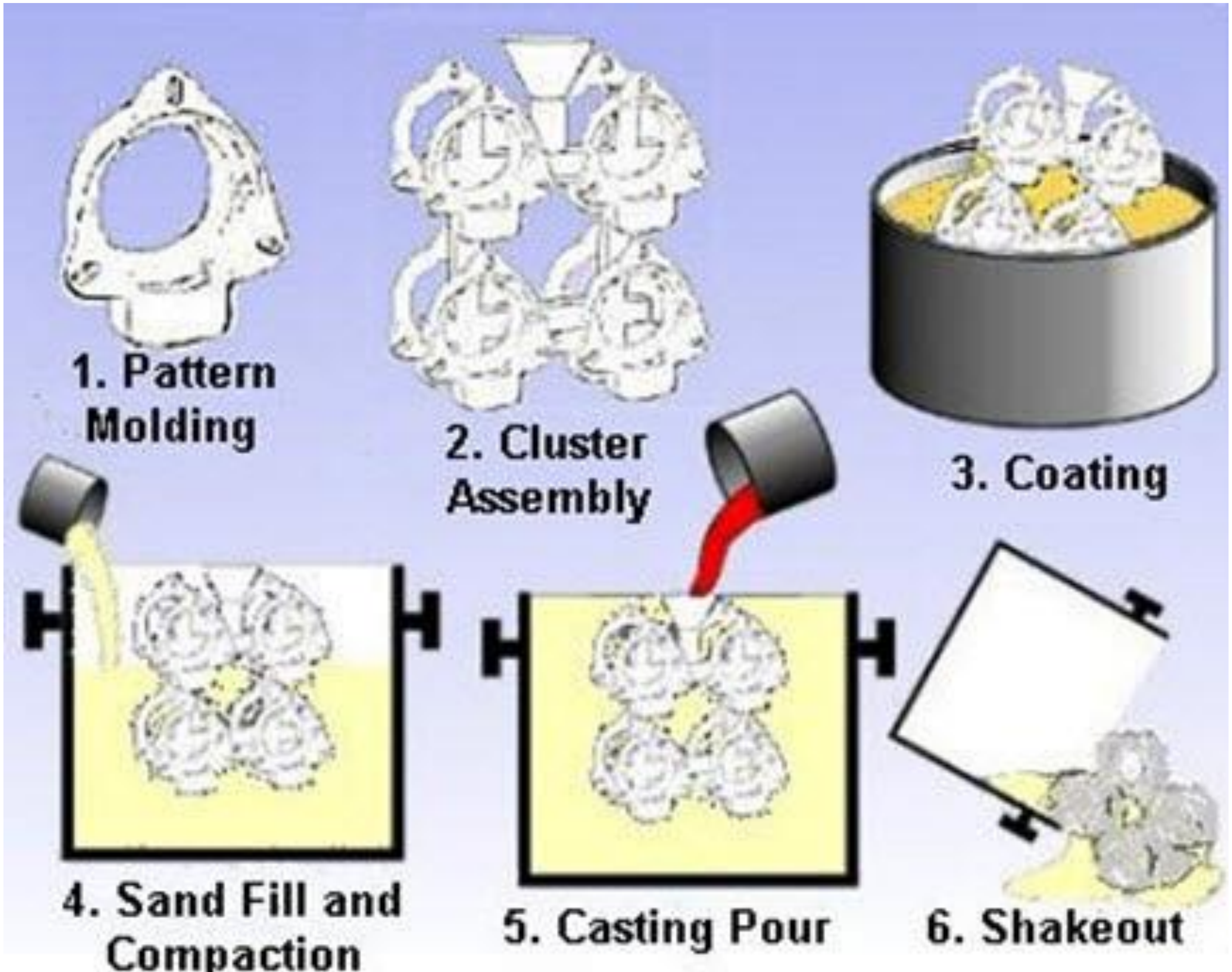
The LFC method was first developed and patented by H. F. Shroyer in 1958. The first applications of the method are also known as the F-process. The polystyrene model material used to be molded without refractory paint by the use of green sand as a molding material during the earlier era of the LFC processing T. R. Smith, in 1964, patented the use of unbonded sand in LFC processes, and this has revolutionized the LFC applications, and this technique is often preferred in today's demands.

With the expiration of the patent granted by T. R. Smith in 1981, the increase in the use of the method in the automotive industry became noticeable. In the early 1990s, production lines have been established in many automotive companies, especially from Germany and the USA. General Motors, Fiat, and BMW stand out as leading companies in integrating the method into the industry. In the plants where 3xx series Al-Si casting alloys are formed, cylinder block and cylinder head production are realized in a production volume ranging from 5.000 tons to 36.000 tons per year.

Besides, the product range for the LFC method is not limited to automotive parts and aluminum alloys. The method was established in time in the production of pump bodies in infrastructure systems and the shipping industry and has been used for the casting of iron-based and magnesium alloys since the beginning of the 2000s.

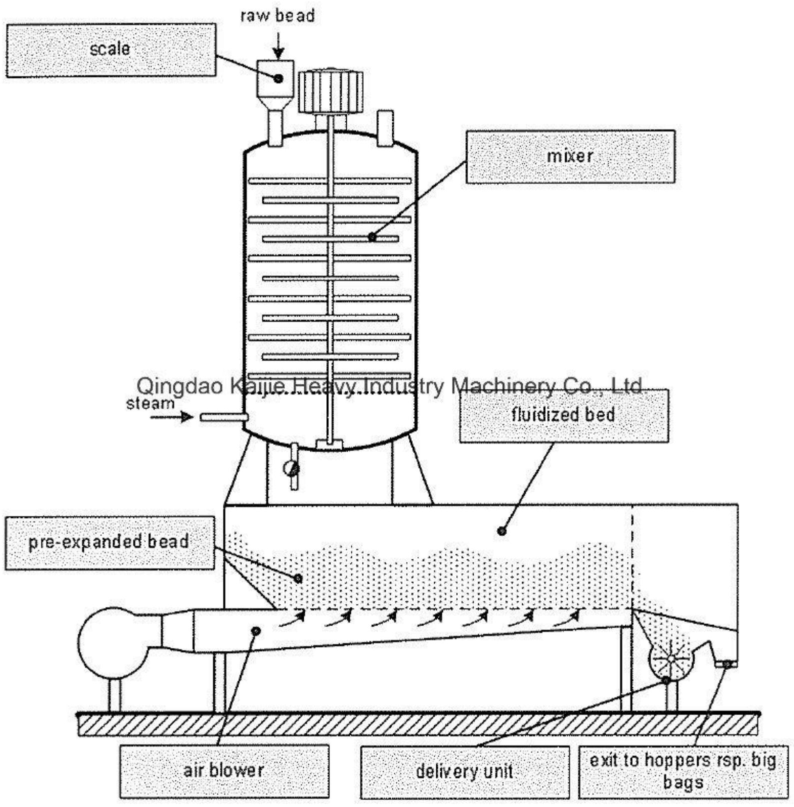
Process stages of the LFC process

- Production of the foam beads (Pre-expansion)
- Pattern making
- Pattern assembly
- Pattern coating
- Moulding
- Casting
- Demoulding and finishing operations.


1. Pattern Molding
2. Cluster Assembly
3. Coating
4. Sand Fill and Compaction
5. Casting Pour
6. Shakeout

Production of the foam beads (Pre-expansion)

Polystyrene is the most widely used and cheapest polymer in pattern production. The polystyrene to be expanded has a molecular weight of 200 $kg.mol^{-1}$ and is impregnated with about 5% pentane as a blowing agent. While the density of the expandable polystyrene in raw form is 640 $kg.m^{-3}$, this value should be reduced to 16-27 $kg.m^{-3}$ to be suitable for foam pattern production. The pre-expansion step is carried out in a steam-heated and stirred chamber. During this process, while the bead grains are softened, the gaseous content expands, and expanded polystyrene (EPS) is produced by the cells formed in each bead grain.



Pre-expander unit for lost foam casting

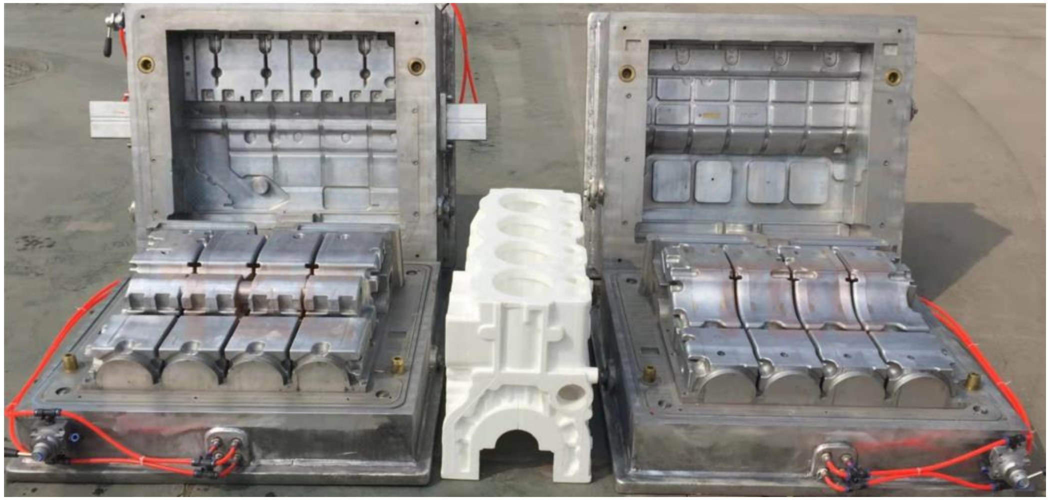
As a result, density decreases with the increase in grain diameter. The pre-expanded grains are allowed to cool and stabilize for 6-12 hours after the treatment. The final foam pattern density depends on the density of the beads obtained by pre-expansion and should remain within the +% 2 limits in the production. In addition to EPS, expanded polymethyl methacrylate (EPMMA) is also used in pattern making. This material is particularly preferred because it reduces carbon-sourced defects in iron and steel castings, the expensiveness of the material and encountered difficulties during the expansion step are the main limitations. Due to these reasons, EPS and EPMMA are more widely used together in iron-based.

Pattern making

The patterns used in the LFC method are produced in two ways: The first is blowing the foam in a closed die, and the second is block foam machining.

Blowing method:

The polystyrene beads, which are cooled and stabilized after the pre-expansion, are filled into the hopper of the pattern molding press. The steps of this process are filling, fusion, cooling, and ejection, respectively. Pattern molding presses typically have a mold placement area of dimensions 800 x 600 mm or 1000 x 700 mm. Foam patterns or pattern components are shaped by final blowing in the pattern dies.




After it is filled, steam is passed through the molds for fusing. There are holes and channels in the molds for steam to enter and exit. Steam heating restarts the expansion process, and the material softens as in pre-expanding. The expanded material fills the air voids; the individual grains merge and form the pattern that takes the form of the mold.

Cooling is usually carried out by spraying water around the mold. If the pattern is removed without cooling, the existing internal pressure in the beads causes the expansion to continue. Due to this fact, the cooling step also has a dimensional determination function. After the pattern has cooled, the mold is opened, and the pattern is pushed out of the mold utilizing ejector pins, which are moved hydraulically or pneumatically. The average cycle time of the entire process is about 1-2 minutes.

After the ejection step, the dimensions of the pattern coming out of the mold change over time. First, there is an increase in dimensions; however, this is followed by shrinkage. This change is a consequence of the diffusion of the pentane and its displacement by the air, which may last for weeks or months. To accelerate the stabilization of the pattern size, the aging process is usually carried out at aged at 65 °C for 4 hours, and the aging process also eliminates the residual moisture that may cause casting defects.

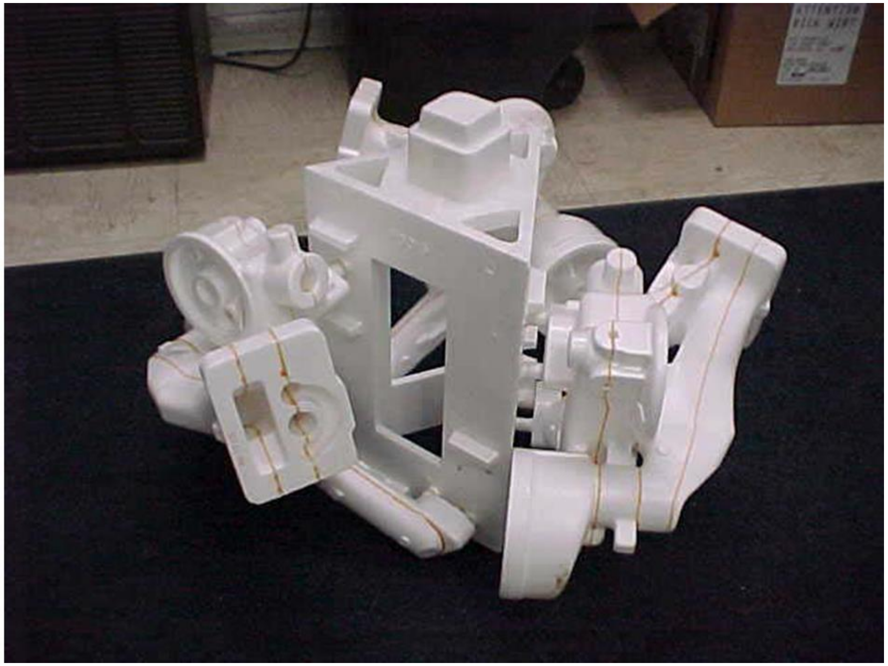
Machining method:

This method uses semi-finished foam materials which are blown in block or plate-shaped molds. This method is generally preferred for large parts. The pattern or pattern components of such parts are so large that they cannot be blown in molding presses. Also, the blowing technique is suitable for high volume mass production in individual aluminum molds. However, the production volume of the large parts is generally low, and it is more economical to process patterns from blocks. This technique is also widely used in prototype pattern production. Machining is carried out on CNC milling machines or hot wire cutters specially designed for this purpose. Instead of inflated foam blocks, extruded foam blocks can also be processed to produce patterns.


RAPID CNC
RAPID CNC

Pattern assembly

In the LFC method, the joining of pattern parts is usually done using wax or silicone-based adhesives. Industrially, mostly hot liquid adhesives are preferred. The application temperature and chemical structure of the adhesive should not damage the foam pattern's shape and dimensional integrity after the application. Evaporation rate and ash content should be similar to the values of the pattern material to avoid casting defects. The adhesive used should not break or separate during coating, transportation, and molding steps. Joining operations can be performed manually; however, automatic and semi-automatic systems are also used to increase production speed and quality. In these systems, special glue printing-machines are used which apply the hot adhesive to the surface in a fast and precise manner.



Pattern coating

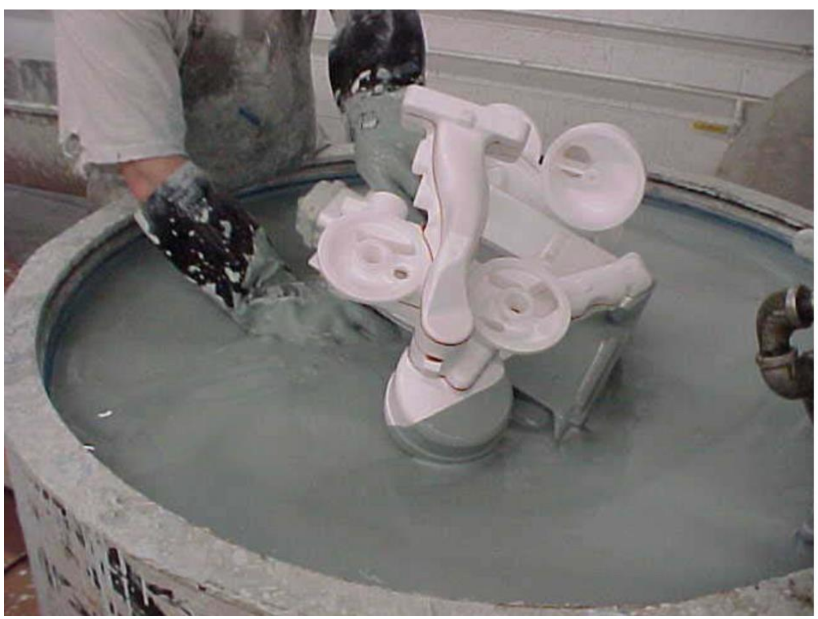
Although it is possible to make some castings without coating, the refractory coating is an essential requirement in the LFC method. This special coating has two vital functions. First, it acts as a barrier between the smooth pattern surface and coarse sand. Thus, it prevents the mold from collapsing during casting and prevents the deterioration of the surface quality with maintaining dimensional stability. The second function is providing a controlled permeability, allowing the gas products formed by evaporation of the foam pattern to escape away from the casting into the sand through the coating. The gas permeability of the coating determines the escaping rate of the decomposition product gases and air through the liquid metal - foam interface during the casting process. As a result, it determines the rate of liquid metal – foam replacement.

If the gas permeability is too low, high backpressure builds up at the liquid metal - foam interface, reducing the speed of metal progression, which may result in misrun defects. If the gas permeability is too high, turbulence may occur on the liquid metal front, and the liquid polymer products may be trapped in the metal, causing pyrolysis defects. In addition, the thermal conductivity and heat capacity of the coating affect the cooling and solidification behavior of the alloy. Low permeability coatings are preferred for aluminum castings with a high surface area to volume ratio, for example, the intake manifolds. Thick cross-section aluminum and other non-ferrous castings require medium or high permeability coatings. Iron-based castings generally require higher permeability coatings than non-ferrous ones.

The ceramic content of the coating may be silica, mica, alumina, zircon, or olivine. Silica is highly preferred because of its low cost. The use of zircon and olivine based coatings is not common. The solvent options for the coating materials are limited because the solvent must be compatible with the foam pattern. Hydrocarbon and chlorine-containing solvents can be aggressive to most widely used pattern materials such as EPS. Because of this situation, the majority of coatings to be found as water-based.

The application of the refractory coating on the foam pattern can be made by dipping, spraying, brushing, or flow coating methods. Generally, small and medium-sized parts are coated by dipping method, while other methods are preferred for large parts.

The average thickness of the dried layer is between 0.2 - 0.3 mm. Following the coating, the drying step is carried out. The drying step may be carried out for 24 hours under ambient conditions or in a shorter time in an oven or a heated room. This accelerated drying technique is carried out at 50-65 °C for 2-6 hours. In very high volume production, microwave heating can also be used.

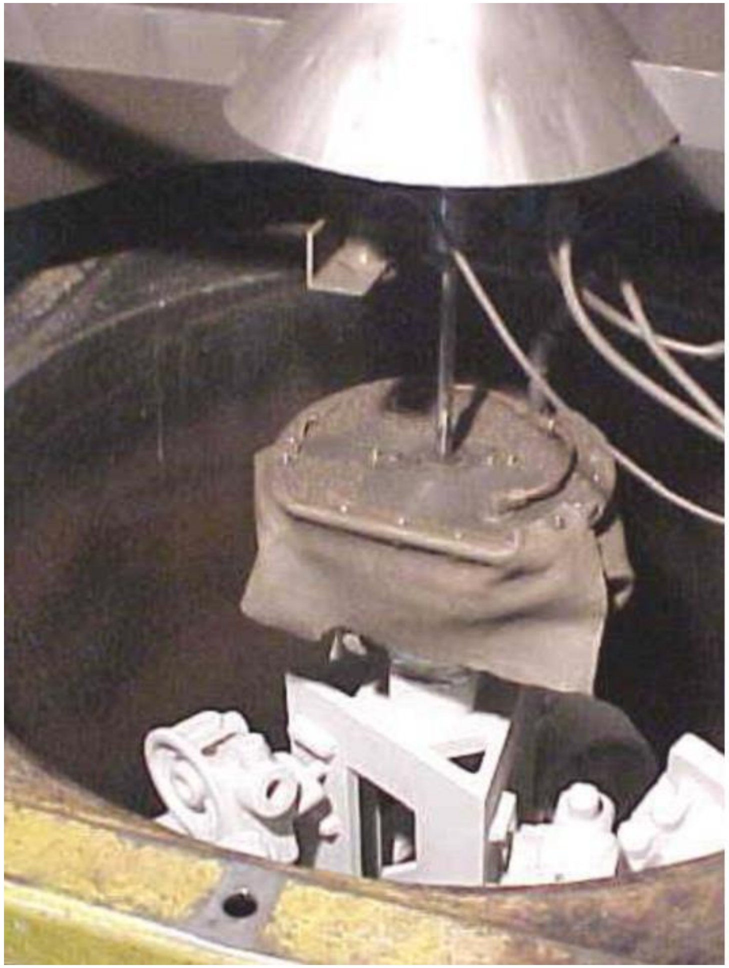


Moulding

One of the most important features of the modern LFC method is that the molds made with loose sand. However, in some cases, bonded sand may be used partially or completely in the mold, making to support the large molds. Coarse spherical silica sand is commonly preferred in the LFC molds. Some foundries use olivine or synthetic mullite sand with low thermal expansion. Coarse sand is required for high permeability, as the evaporating gas must rapidly dissipate. As the pattern coating is used, coarse sand does not reduce the surface quality. Generally, AFS 35 – 3 screen distribution size sand is preferred for iron-based castings; on the other hand, AFS 45 – 3 screen distribution is preferred for non-ferrous castings.

One-piece steel boxes are generally used for molding step. Coated and dried foam patterns are placed in a box pre-filled with a sand bed with a thickness of 25-75 mm. Following this step, the loose sand is filled to the molding box with a sprinkler system. The sprinkler system ensures that the sand is filled at the same height and prevents any damage to the delicate model. Mechanical vibration is applied for proper compaction during and after the sand filling step. The amplitude and frequency of the applied vibration may be within a wide range to provide the necessary compression. The vibration duration must also be sufficient to ensure that all gaps in the interior and exterior of the pattern are filled.

In order to maintain the permeability, fine particles accumulated in the sand must be separated by sieving. Some foundries apply thermal reclamation to the sand. Evaporated polymeric foam products are dispersed in the sand and condense near the cast part. These residues adversely affect the flowability, compressibility, and permeability of the sand. Sand can be removed from this type of residue by the thermal reclamation process. A vital element for molding is to allow the sand to cool sufficiently in the cycle before the next use. If the temperature is above 50 °C when sand is filled to the box, the foam pattern inevitably will be damaged.



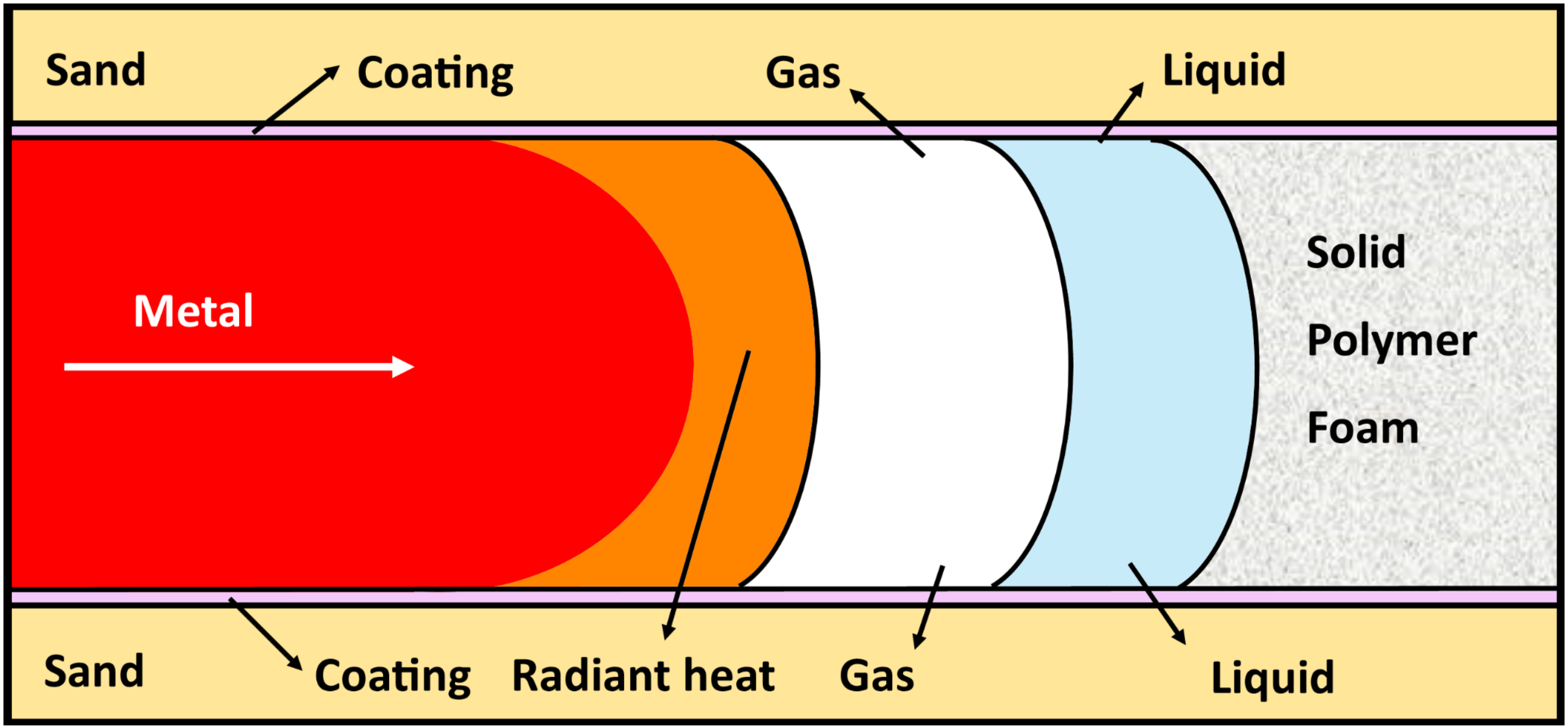
Casting

In the LFC method, filling the mold with liquid metal is no different from other casting methods. Casting should be performed at a speed in which the pouring basin and sprue will remain continuously filled by ensuring the continuity of the flow. In this way, the metallostatic pressure is kept constant on the liquid metal front, gas and slag are prevented from entering the mold, and the collapse of the sprue is avoided, and the liquid metal can reach the whole mold. The casting temperature is critical and should be controlled more stringently than other casting methods.

The recommended casting temperature ranges for aluminum alloys, copper alloys (brass and bronze), and gray cast iron castings are 705 - 790 °C, 1040 - 1260 °C, and 1370 - 1455 °C, respectively. Mainly the process is performed by gravity, and however, vacuum support can also be used. For the vacuum support, the mold box is connected to the vacuum pump by a hose from its base and covered with a polymeric film above. Vacuum suction helps to remove harmful decomposition products and prevent casting defects. After the casting and solidification stages, the mold is transferred to the tip over zone, and since the binder is not used, the cast part is separated from the sand by simply overturning the box.

Flow of Liquid Metal in LFC

In this method, the fact that the pattern is in the mold and the necessity of liquid metal to replace it makes the metal flow very different from all other casting methods. Liquid and gaseous polymer zones are formed at the interface as soon as the liquid metal contacts the solid foam. The width and proportion of the gaseous and liquid zones at the interface depend on the temperature of the liquid metal. At relatively low casting temperatures (casting of Al and Mg alloys), the gaseous zone is relatively narrow. The high casting temperature of iron-based alloys causes this zone to expand considerably. For this reason, vacuum support in the LFC method is particularly useful for castings of iron-based alloys.


Sand
Coating
Gas
Liquid
Metal
Solid
Polymer
Foam
Sand
Coating
Radiant heat
Gas
Liquid

Controlled backpressure in front of the liquid metal front is also useful. In this way, the interface proceeds with a smooth profile, preventing turbulence and allowing sufficient time for liquid or gaseous decomposition products to move away from the coating.

As the liquid metal front proceeds, the temperature decrease at this point creates a significant temperature gradient backward, which greatly contributes to the formation of directional solidification. As a result, feeder dimensions may be reduced or may not need to be used at all most of the time.

Video links

- https://www.youtube.com/watch?v=GYht8qVcbUs
- https://www.youtube.com/watch?v=u3GOV4_Vn3U
- https://www.youtube.com/watch?v=MNJt0a8Pn20&t
- https://www.youtube.com/watch?v=PIFuuxWC9rY
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