**SAND CASTING**

**Sand casting**, also known as **sand molded casting**, is a metal casting process characterized by using sand as the mold material.

It is relatively cheap and sufficiently refractory even for steel foundry use. A suitable bonding agent (usually clay) is mixed or occurs with the sand. The mixture is moistened with water to develop strength and plasticity of the clay and to make the aggregate suitable for molding. The term "sand casting" can also refer to a casting produced via the sand casting process. Sand castings are produced in specialized factories called foundries.

*Over 70% of all metal castings are produced via a sand casting process.*

**BASIC STEPS IN MAKING SAND CASTINGS**

The basic steps involved in making sand castings are:

1. **Patternmaking.** Patterns are required to make molds. The mold is made by packing molding sand around the pattern. The mold is usually made in two parts so that the pattern can be withdrawn.
   - In horizontal molding, the top half is called the **cope**, and the bottom half is called the **drag**.
   - In vertical molding, the leading half of the mold is called the **swing**, and the back half is called the **ram**.
   - When the patterns withdrawn from the molding material (sand or other), the imprint of the pattern provides the cavity when the mold parts are brought together. The mold cavity, together with any internal cores as required, is ultimately filled with molten metal to form the casting.

2. If the casting is to be hollow, additional patterns, referred to as **core boxes**, are needed to shape the sand forms, or **cores**, that are placed in the mold cavity to form the interior surfaces and sometimes the external surfaces as well of the casting. Thus the void between the mold and core eventually becomes the casting.

3. **Molding** is the operation necessary to prepare a mold for receiving the metal. It consists of ramming sand around the pattern placed in support, or **flask**, removing the pattern, setting cores in place, and creating the gating/feeding system to direct the metal into the mold cavity created by the pattern, either by cutting it into the mold by hand or by including it on the pattern, which is most commonly used.

4. **Melting** and **pouring** are the processes of preparing molten metal of the proper composition and temperature and pouring this into the mold from transfer **ladles**.

5. **Cleaning** includes all the operations required to remove the **gates** and **risers** that constitute the gating/feeding system and to remove the adhering sand, scale, parting fins, and other foreign material that must be removed before the casting is ready for shipment or other processing.
INSPECTION & TESTING

- Inspection follows, to check for defects in the casting as well as to ensure that the casting has the dimensions specified on the drawing and/or specifications.
- Inspection for internal defects may be quite involved, depending on the quality specified for the casting.
- The inspected and accepted casting sometimes is used as is, but often it is subject to further processing which may include heat treatment, painting, rust preventive oils, other surface treatment (e.g., hot-dip galvanizing), and machining.
- Final operations may include electrodeposited plated metals for either cosmetic or operational requirements.

PATTERN

The pattern is the principal tool during the casting process. It is the replica of the object to be made by the casting process, with some modifications. The main modifications are the addition of pattern allowances, and the provision of core prints. If the casting is to be hollow, additional patterns called cores are used to create these cavities in the finished product. The quality of the casting produced depends upon the material of the pattern, its design, and construction. The costs of the pattern and the related equipment are reflected in the cost of the casting. The use of an expensive pattern is justified when the quantity of castings required is substantial.

Functions of the Pattern

1. A pattern prepares a mold cavity for the purpose of making a casting.

2. A pattern may contain projections known as core prints if the casting requires a core and need to be made hollow.

3. Runner, gates, and risers used for feeding molten metal in the mold cavity may form a part of the pattern.

4. Patterns properly made and having finished and smooth surfaces reduce casting defects.

5. A properly constructed pattern minimizes the overall cost of the castings.

Pattern Material

Patterns may be constructed from variety of materials. Each material has its own advantages, limitations, and field of application. Some materials used for making patterns are: wood, metals and alloys, plastic, plaster of Paris, plastic and rubbers, wax, and resins. To be suitable for use, the pattern material should be:

1. Easily worked, shaped and joined

2. Light in weight

3. Strong, hard and durable
4. Resistant to wear and abrasion
5. Resistant to corrosion, and to chemical reactions
6. Dimensionally stable and unaffected by variations in temperature and humidity
7. Available at low cost
   - The usual pattern materials are wood, metal, and plastics. The most commonly used pattern material is wood, since it is readily available and of low weight. Also, it can be easily shaped and is relatively cheap.
   - The main disadvantage of wood is its absorption of moisture, which can cause distortion and dimensional changes.
   - Araldite is the new material for pattern making, which is referring to a range of engineering and structural epoxy, acrylic, and polyurethane adhesives.

A typical pattern attached with gating and risering system

Pattern Allowances

Pattern allowance is a vital feature as it affects the dimensional characteristics of the casting. Thus, when the pattern is produced, certain allowances must be given on the sizes specified in the finished component drawing so that a casting with the particular specification can be made. The selection of correct allowances greatly helps to reduce machining costs and avoid rejections. The allowances usually considered on patterns and core boxes are as follows:

1. Shrinkage or contraction allowance
2. Draft or taper allowance
3. Machining or finish allowance
4. Distortion or camber allowance
5. Rapping allowance

1) Shrinkage or Contraction Allowance

All most all cast metals shrink or contract volumetrically on cooling. The metal shrinkage is of two types:

i. Liquid Shrinkage: it refers to the reduction in volume when the metal changes from liquid state to solid state at the solidus temperature. To account for this shrinkage; riser, which feed the liquid metal to the casting, are provided in the mold.
ii. **Solid Shrinkage**: it refers to the reduction in volume caused when metal loses temperature in solid state. To account for this, shrinkage allowance is provided on the patterns.

The rate of contraction with temperature is dependent on the material. For example, steel contracts to a higher degree compared to aluminum. To compensate the solid shrinkage, a *shrink rule* must be used in laying out the measurements for the pattern. A shrink rule for cast iron is 1/8 inch longer per foot than a standard rule. If a gear blank of 4 inch in diameter was planned to produce out of cast iron, the shrink rule in measuring it 4 inch would actually measure 4 - 1/24 inch, thus compensating for the shrinkage.

<table>
<thead>
<tr>
<th>Material</th>
<th>Dimension</th>
<th>Shrinkage allowance (inch/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grey Cast Iron</td>
<td>Up to 2 feet</td>
<td>0.125</td>
</tr>
<tr>
<td></td>
<td>2 feet to 4 feet</td>
<td>0.105</td>
</tr>
<tr>
<td></td>
<td>over 4 feet</td>
<td>0.083</td>
</tr>
<tr>
<td>Cast Steel</td>
<td>Up to 2 feet</td>
<td>0.251</td>
</tr>
<tr>
<td></td>
<td>2 feet to 6 feet</td>
<td>0.191</td>
</tr>
<tr>
<td></td>
<td>over 6 feet</td>
<td>0.155</td>
</tr>
<tr>
<td>Aluminum</td>
<td>Up to 4 feet</td>
<td>0.155</td>
</tr>
<tr>
<td></td>
<td>4 feet to 6 feet</td>
<td>0.143</td>
</tr>
<tr>
<td></td>
<td>over 6 feet</td>
<td>0.125</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Up to 4 feet</td>
<td>0.173</td>
</tr>
<tr>
<td></td>
<td>Over 4 feet</td>
<td>0.155</td>
</tr>
</tbody>
</table>

**Rate of Contraction of Various Metals**

2) **Draft or Taper Allowance**

By draft is meant the taper provided by the pattern maker on all vertical surfaces of the pattern so that it can be removed from the sand without tearing away the sides of the sand mold.

Figure shows a pattern having no draft allowance being removed from the pattern. In this case, till the pattern is completely lifted out, its sides will remain in contact with the walls of the mold, thus tending to break it.

Figure is an illustration of a pattern having proper draft allowance. Here, the moment the pattern lifting commences, all of its surfaces are well away from the sand surface. Thus the pattern can be removed without damaging the mold cavity.

Draft allowance varies with the complexity of the sand job. But in general, inner details of the pattern require higher draft than outer surfaces. The amount of draft depends upon the length of the vertical side of the pattern to be extracted; the intricacy of the pattern; the method of molding; and pattern material.
Machining or Finish Allowance

The finish and accuracy achieved in sand casting are generally poor. When the casting is functionally required to be of good surface finish or dimensionally accurate, it is generally achieved by subsequent machining. Machining or finish allowances are therefore added in the pattern dimension. The amount of machining allowance to be provided for is affected by the method of molding and casting used viz. hand molding or machine molding, sand casting or metal mold casting. The amount of machining allowance is also affected by the size and shape of the casting; the casting orientation; the metal; and the degree of accuracy and finish required. The machining allowances recommended for different metals is given in Table.

<table>
<thead>
<tr>
<th>Metal</th>
<th>Dimension (inch)</th>
<th>Allowance (inch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast iron</td>
<td>Up to 12</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>12 to 20</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>20 to 40</td>
<td>0.25</td>
</tr>
<tr>
<td>Cast steel</td>
<td>Up to 6</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>6 to 20</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>20 to 40</td>
<td>0.30</td>
</tr>
<tr>
<td>Non-ferrous</td>
<td>Up to 8</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>8 to 12</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>12 to 40</td>
<td>0.16</td>
</tr>
</tbody>
</table>

Machining Allowances of Various Metals

3) Distortion or Camber Allowance

Sometimes castings get distorted, during solidification, due to their typical shape. For example, if the casting has the form of the letter U, V, T, or L etc., it will tend to contract at the closed end causing the vertical legs to look slightly inclined. This can be prevented by making the legs of the U, V, T, or L shaped pattern converge slightly (inward) so that the casting after distortion will have its sides vertical.

The distortion in casting may occur due to internal stresses. These internal stresses are caused on account of unequal cooling of different section of the casting and hindered contraction. Measure taken to prevent the distortion in casting includes:

i. Modification of casting design

ii. Providing sufficient machining allowance to cover the distortion affect

iii. Providing suitable allowance on the pattern, called camber or distortion allowance (inverse reflection)
4) Rapping Allowance

Before the withdrawal from the sand mold, the pattern is rapped all around the vertical faces to enlarge the mold cavity slightly, which facilitate its removal. Since it enlarges the final casting made, it is desirable that the original pattern dimension should be reduced to account for this increase. There is no sure way of quantifying this allowance, since it is highly dependent on the foundry personnel practice involved.

Core and Core Prints

Castings are often required to have holes, recesses, etc. of various sizes and shapes. These impressions can be obtained by using cores. So where coring is required, provision should be made to support the core inside the mold cavity. Core prints are used to serve this purpose. The core print is an added projection on the pattern and it forms a seat in the mold on which the sand core rests during pouring of the mold. The core print must be of adequate size and shape so that it can support the weight of the core during the casting operation. Depending upon the requirement a core can be placed horizontal, vertical and can be hanged inside the mold cavity. A typical job, its pattern and the mold cavity with core and core print is shown in Figure.

![A Typical Job, its Pattern and the Mold Cavity](image)

Types of Pattern

Patterns are of various types, each satisfying certain casting requirements.

A pattern for a part can be made many different ways, which are classified into the following main types:

*Solid pattern* - A solid pattern is a model of the part as a single piece. It is the easiest to fabricate, but can cause some difficulties in making the mold. The parting line and runner system must be determined separately. Solid patterns are typically used for geometrically simple parts that are produced in low quantities.
**Split pattern** - split pattern models the part as two separate pieces that meet along the parting line of the mold. Using two separate pieces allows the mold cavities in the cope and drag to be made separately and the parting line is already determined. Split patterns are typically used for parts that are geometrically complex and are produced in moderate quantities.

**Match-plate pattern** - A match-plate pattern is similar to a split pattern, except that each half of the pattern is attached to opposite sides of a single plate. The plate is usually made from wood or metal. This pattern design ensures proper alignment of the mold cavities in the cope and drag and the runner system can be included on the match plate. Match-plate patterns are used for larger production quantities and are often used when the process is automated.

**Cope and drag pattern** - A cope and drag pattern is similar to a match plate pattern, except that each half of the pattern is attached to a separate plate and the mold halves are made independently. Just as with a match plate pattern, the plates ensure proper alignment of the mold cavities in the cope and drag and the runner system can be included on the plates. Cope and drag patterns are often desirable for larger castings, where a match-plate pattern would be too heavy and cumbersome. They are also used for larger production quantities and are often used when the process is automated.

**Gated Patterns**

A **gated pattern** is a loose pattern that has the gating system included as a part of the pattern. This eliminates the time and inconsistency associated with hand-cutting the gates and runners. Also, since the gating system is designed and fabricated as part of the pattern, the consistency of molten metal flow into the casting and feeding of the casting during solidification is improved. Gated patterns are appropriate for pouring small quantities of castings when quick turn around and low cost are important.

**Parting Line**

By parting line we mean a line or the plane of a pattern corresponding to the point of separation between the cope and drag portions of a sand mold.

Parting lines must be flat or drafted so that the mold can be opened, the pattern removed and then closed for pouring without damage to the sand.

**SURPRISE QUIZ:**

1) **Difference between tolerance and allowance.**
2) **Difference between sprue and runner**
A core is a preformed baked sand or green sand aggregate inserted in a mold to shape the interior part of a casting which cannot be shaped by the pattern.

A core box is a wood or metal structure, the cavity of which has the shape of the desired core which is made therein.

A core box, like a pattern is made by the pattern maker.

Cores run from extremely simple to extremely complicated.

A core could be a simple round cylinder form needed to core a hole through a hub of a wheel or it could be a very complicated core used to core out the water cooling channels in a cast iron engine block along with the inside of the cylinders.

Dry sand cores are for the most part made of sharp, clay-free, dry silica sand mixed with a binder and baked until cured; the binder cements the sand together.

When the metal is poured the core holds together long enough for the metal to solidify, then the binder is finely cooked, from the heat of the casting, until its bonding power is lost or burned out. If the core mix is correct for the job, it can be readily removed from the castings interior by simply pouring it out as burnt core sand. This characteristic of a core mix is called its collapsibility.

The size and pouring temperature of a casting determines how well and how long the core will stay together.

The gases generated within the core during pouring must be vented to the outside of the mold preventing gas porosity and a defect known as a core blow.

Also, a core must have sufficient hot strength to be handled and used properly.

The hot strength refers to its strength while being heated by the casting operation. Because of the shape and size of some cores they must be further strengthened with rods and wires.

A long span core for a length of cast iron pipe would require rodding to prevent the core from sagging or bending upward when the mold is poured because of the liquid metal exerting a strong pressure during pouring.

**BINDERS**

There are many types of binders to mix with core sand. A binder should be selected on the basis of the characteristics that are most suitable for your particular use.

Some binders require no baking becoming firm at room temperature such as rubber cement, Portland cement and sodium silicate or water glass.

In large foundry operations and in some small foundries, sodium silicate is a popular binder as it can be hardened almost instantly by blowing carbon dioxide gas through the mixture.

The sodium silicate/CO\(_2\) process hardens through the following reaction:

\[
Na_2Si_2O_5 \cdot H_2O_{(l)} + CO_{2(g)} \rightarrow SiO_2_{(gel)} + Na_2CO_3 \cdot H_2O_{(glass)}
\]

The silica gel that is formed binds individual sand grains together.
- Oil binders require heating or baking before they develop sufficient strength to withstand the molten metal.
- Sulfite binders also require heating. The most popular of the sulfite binders is a product of the wood pulp industry.
- There are many liquid binders made from starches, cereals, and sugars. They are available under a countless number of trade names.

A good binder will have the following properties:
- Strength
- Collapse rapidly when metal starts to shrink.
- Will not distort core during baking.
- Maintain strength during storage time.
- Absorb a minimum of moisture when in the mold or in storage.
- Withstand normal handling.
- Disperse properly and evenly throughout the sand mix.
- Should produce a mixture that can be easily formed.

**MANUFACTURING OF CORE**

Core sand mixes can be mixed in a Muller or paddle type mixer and in small amounts on the bench by hand.

The core is made by ramming the sand into the core box and placing the core on a core plate to bake.

**Pasted Cores**

Cores can be made in halves and after they are dried, glued together to make the complete core.
**A Three Part Core Box**
This consists of a top, front and back section. The box is assembled and placed top down and clamped. You ram it up, put on a core plate, roll it over, rap it. Remove the top (which forms the negative section in top of the core) then remove the main box from the core as you would any simple split box.

**BALANCE CORE**
This is when the core is supported on one end only and the other unsupported end extends a good way into the mold cavity.

**CHAPLETS**
- Chaplets consist of metallic supports or spacers used in a mold to maintain cores, which are not self-supporting, in their correct position during the casting process.
- They are not required when a pattern has a core print or prints which will serve the same purpose.
- The pattern is drilled, wherever a chaplet is needed.

**CORE BAKING AND CORE OVENS**
- The cores are baked in order to set the binder.
- The usual temperature range for oil bonded cores is from 300 to 450 degrees Fahrenheit. The time required varies with the bulk of the core.
- A large core might take several days to bake or a small core might bake out in an hour or less.
- When an oil core is completely baked the outside is a rich dark brown not black or burned. The core must be cured completely through with no soft centers.
- Another factor which relates to the time and temperature required to properly dry a core, is the type and amount of binder used. Oil binders require hotter and quicker baking.
- The core oven, which is usually a gas fired oven with temperature controls, is equipped with shelves on which to set the core plates and cores for baking.
- The core oven can consist of a square or rectangular brick oven with doors. The bottom of the oven is floor level. The ores are placed on racks which, when full, are rolled into the oven, the oven closed and the cores baked.
MOLDING PROCESS AND MATERIALS

Good castings cannot be made without good molds

- The term molding process refers to the method of making the mold and the materials used.
- The term casting process conveys a broader meaning, often including the molding process, the method of introducing the metal into the mold cavity, or all processes used in making the casting.
- Molding processes have certain features in common.
  1) The use of pattern.
  2) Some type of aggregate mixture comprising a granular refractory and binders.
  3) A means of forming the aggregate mixture around the pattern.
  4) Hardening of aggregate or developing its bond while in contact with the pattern.
  5) Withdrawal of the pattern from the hardened aggregate mold.
  6) Assembly of the mold and core pieces to make a complete mold, metal then being poured into the mold.

CLASSIFICATION OF MOLDING PROCESSES

Molding processes can be classified in a number of ways. Broadly they are classified either on the basis of the method used or on the basis of the mold material used.

(i) Classification based on the mold material used:
   (a) Sand molding:
      1. Green sand mold
      2. Dry sand mold,
         - Skin dried mold.
      3. Cement bonded sand mold
      5. Shell mold.
   (b) Plaster molding,
   (c) Metallic molding.

(ii) Classification based on the method used
   (a) Bench molding.            (b) Floor molding,
   (c) Pit molding.              (d) Machine molding.

CLASSIFICATION BASED ON THE MOLD MATERIAL

(a) SAND MOLDING
Molding processes where a sand aggregate is used to make the mold produce by far the largest quantity of castings. Whatever the metal poured into sand molds, the product may be called a sand casting.

i) Green-sand molding: Among the sand-casting processes, molding is most often done with green sand. Green molding sand may be defined as a plastic mixture of sand grains, clay, water, and other materials which can be used for molding and casting processes. The sand is called "green" because of the moisture present and is thus distinguished from dry sand. The basic steps in green-sand molding are as follows:
1. Preparation of the pattern. Most green-sand molding is done with match plate or cope and drag patterns. Loose patterns are used when relatively few castings of a type are to be made. In simple hand molding the loose pattern is placed on a mold board and surrounded with a suitable-sized flask.

2. Making the mold. Molding requires the ramming of sand around the pattern. As the sand is packed, it develops strength and becomes rigid within the flask. Ramming may be done by hand. Both cope and drag are molded in the same way, but the cope must provide for the sprue. The gating-system parts of the mold cavity are simply channels for the entry of the molten metal.

3. Core setting. With cope and drag halves of the mold made and the pattern withdrawn, cores are set into the mold cavity to form the internal surfaces of the casting.

4. Closing and weighting. With cores set, the cope and drag are closed. The cope must usually be weighted down or clamped to the drag to prevent it from floating when the metal is poured.

Because of the nature of green-sand molding and molding sands, the process has certain advantages and limitations. **Advantages are:**

1. Great flexibility as a production process. Mechanical equipment can be utilized for performing molding and its allied operations. Furthermore, green sand can be reused many times by reconditioning it with water, clay, and ether materials. The molding process can be rapid and repetitive.

2. Usually, the meat direct route from pattern to mold ready for pouring is by green-sand molding.

3. Economy, green sand molding is ordinarily the least costly method of molding.

**Limitations in the use of green-sand molding are:**

1. Some casting designs require the use of other casting processes. Thin, long projections of green sand in a mold cavity are washed away by the molten metal or may not even be moldable. Cooling fins on air-cooled-engine cylinder blocks and head are an example. Greater strength is then required of the mold.

2. Certain metals and some castings develop defects if poured into molds containing moisture.

3. The dimensional accuracy and surface finish of green-sand castings may not be adequate.

4. Large castings require greater mold strength and resistance to erosion than are available in green sands.
ii) **Dry-sand Molds**: Dry-sand molds are actually made with molding sand in the green condition. The sand mixture is modified somewhat to favor good strength and other properties after the mold is dried.

Dry-sand molding may be done the same way as green-sand molding on smaller sizes of castings. Usually, the mold-cavity surface is coated or sprayed with a mixture which, upon drying, imparts greater hardness or refractoriness to the mold. The entire mold is then dried in an oven at 300 to 650 F or by circulating heated air through the mold. The time-consuming drying operation is one inherent disadvantage of the dry-sand mold.

**Advantages**
- Dry sand molds are generally stronger than green sand molds and therefore can withstand much additional handling.
- Better dimension control than if they were molded in green sand.
- The improved quality of the sand mixture due to the removal of moisture can result in a much smoother finish on the castings than if made in green sand molds. Where molds are properly washed and sprayed with refractory coatings, the casting finish is further improved.

**Disadvantages**
- This type of molding is much more expensive than green sand molding and is not a high-production process. Correct baking (drying) times are essential.

➤ **Skin-dried Molds**: The effect of a dry-sand mold may be partially obtained by drying the mold surface to some depth, 1/4 to 1 in. Skin drying may be performed by torches or electrical heating elements directed at the mold surface. Skin-dried molds must be poured shortly after drying, so that moisture from the undried sand will not penetrate the dried skin.

iii) **Carbon-Dioxide Gas Molding**
- This process is widely used for rapid hardening the molds & cores made up of green sand.
- The mold making process is similar to conventional molding procedure except the mold material which comprises of pure dry silica sand free from clay, 3-5% sodium silicate as binder and moisture content generally less than 3%.
- A small amount of starch may be added to improve the green compression strength and a very small quantity of coal dust, sea coal, dextrin, wood floor, pitch, graphite and sugar can also be added to improve the collapsibility of the molding sand.
- The prepared molding sand is rammed around the pattern in the mold box and mold is prepared by any conventional technique.
- After packing, carbon dioxide gas at about 1.3-1.5 kg/cm² pressure is then forced all-round the mold surface to about 20 to 30 seconds using CO₂ head or probe or curtain.
- Cores can be baked this way.
- The sodium silicate presented in the mold reacts with CO2 and produce a very hard constituents or substance commonly called as silica gel.

\[ Na_2Si_2O_5 \cdot H_2O_{(l)} + CO_2_{(g)} \rightarrow SiO_2_{(gel)} + Na_2CO_3 \cdot H_2O_{(glass)} \]
This hard substance is like cement and helps in binding the sand grains.

Molds and cores thus prepared can be used for pouring molten metal for production of both ferrous and non-ferrous casting.

The operation is quick, simple require semi-skilled worker.

The evolution of gases is drastically reduced after pouring the thus prepared mould.

This process eliminates mold and core baking oven.

Reclamation of used sand is difficult for this process.

(iv) Cement bonded sand molds.

- A mixture of silica sand containing 8-12% cement and 4-6% water is used.
- When making the mold, the cement-bonded sand mixture must be allowed to harden first, before the pattern is withdrawn. The mold obtained is then allowed to cure for about 3-5 days.
- When the metal is poured, heat causes the water of crystallization of the cement to be driven off, and thus steam must be allowed to pass off through the sand by means of its porosity and suitably distributed vent holes.
- Large castings with intricate shapes, accurate dimensions and smooth surfaces are usually produced by this method.
- The only shortcoming being the long time required for the molding process.

v) Shell Molding

- Shell mold casting is recent invention (Germany during the Second World War) in molding techniques for mass production and smooth finish.
- It is a process in which, a thin mold is made around a heated metallic pattern plate.
- The molding material is a mixture of dry, fine silica sand (clay content should be kept very low), and 3-8% of a thermosetting resin like phenol formaldehyde or silicon grease.
- Conventional dry mixing techniques are used for obtaining the moulding mixture.
- Specially prepared resin coated sands are also used.
- When the molding mixture drops on to the pattern plate, which is heated to a temperature of 35 to 700°F (18 to 375°C), a shell of about 6 mm thickness is formed.
- In order to cure the shell completely, it must be heated to 440 to 650°F (230 to 350°C) for about 1-3 minutes.
- The shell is then released from the pattern plate by ejector pins.
- To prevent sticking of the baked shell to the pattern plate, a silicone release agent is applied to the latter before the molding mixture drops on to it.
Shell molding is suitable for mass production of thin walled, grey cast iron (and aluminum alloy) castings having a maximum weight between 35 and 45 pounds (15 to 20 kg.) However, castings weighing up to 1000 pounds can be made by shell molding on an individual basis.

**Advantages**
(i) High suitable for thin sections like petrol engine cylinder.
(ii) Excellent surface finish.
(iii) Dimensional accuracy of order of 0.002 to 0.003 mm.
(iv) Negligible machining and cleaning cost.
(v) Occupies less floor space.
(vi) Skill-ness required is less.
(vii) Molds formed by this process can be stored until required.
(viii) Better quality of casting assured.
(ix) Mass production.

**Disadvantages**
The main disadvantages of shell molding are:
1. Higher pattern cost.
2. Higher resin cost.
3. Not economical for small runs.
4. Dust-extraction problem.
5. Complicated jobs and jobs of various sizes cannot be easily shell molded.
6. Specialized equipment is required.
7. Resin binder is an expensive material.
8. Limited for small size.

**b) Plaster Molding**
- The mold material in plaster molding is gypsum or plaster of paris.
- To this plaster of paris, additives like talc, fibers, asbestos, silica flour etc. are added in order to control the contraction characteristics of the mold as well as the settling time.
- The plaster of paris is used in the form of slurry.
- This plaster slurry is poured over a metallic pattern confined in a flask.
- The pattern is usually made of brass and it is generally in the form of half portion of job to be cast and is attached firmly on a match plate which forms the bottom of the molding flask.
- Wood pattern are not used because the water in the plaster raises the grains on them and makes them difficult to be withdrawn.
- Some parting or release agent is needed for easy withdrawal of the pattern from the mold.
- As the flask is filled with the slurry, it is vibrated so as to bubble out any air entrapped in the slurry and to ensure that the mold is completely filled up.
- The plaster material is allowed to set, finally when the plaster is set properly the pattern is then withdrawn.
The plaster mold thus produced is dried in an oven to a temperature range between 200-700 degree centigrade and cooled in the oven itself. In the above manner two halves of a mold are prepared and are joined together to form the proper cavity. The necessary sprue, runner etc. are cut before joining the two parts.

**Advantages**

(a) In plaster molding, very good surface finish is obtained and machining cost is also reduced.

(b) Slow and uniform rate of cooling of the casting is achieved because of low thermal conductivity of plaster and possibility of stress concentration is reduced.

(c) Metal shrinkage with accurate control is feasible and thereby warping and distortion of thin sections can be avoided in the plaster molding.

**Limitations**

(a) There is evolution of steam during metal pouring if the plaster mold is not dried at higher temperatures avoid this, the plaster mold may be dehydrated at high temperatures, but the strength of the mold decreases with dehydration.

(b) The permeability of the plaster mold is low. This may be to a certain extent but it can be increased by removing the bubbles as the plaster slurry is mixed in a mechanical mixer.

c) **Metallic Molding**

- Metallic mold is also known as permanent mold because of their long life.
- The metallic mold can be reused many times before it is discarded or rebuilt.
- Permanent molds are made of dense, fine grained, heat resistant cast iron, steel, bronze, anodized aluminum, graphite or other suitable refractoriness.
- The mold is made in two halves in order to facilitate the removal of casting from the mold. Usually the metallic mold is called as dies and the metal is introduced in it under gravity.
- Some times this operation is also known as gravity die casting.
- When the molten metal is introduced in the die under pressure, then this process is called as pressure die casting.
- The mold walls of a permanent mold have thickness from 15 mm to 50 mm.
- The thicker mold walls can remove greater amount of heat from the casting.
- Although the metallic mold can be used both for ferrous and nonferrous castings but this process is more popular for the non-ferrous castings, for examples aluminum alloys, zinc alloys and magnesium alloys.
- Usually the metallic molds are made of grey iron, alloy steels and anodized aluminum alloys.

**Advantages**

(i) Fine and dense grained structure in casting is achieved using such mold.

(ii) The process is economical.

(iii) Because of rapid rate of cooling, the castings possess fine grain structure.
(iv) Close dimensional tolerance is possible.
(v) Good surface finish and surface details are obtained.
(vi) Casting defects observed in sand castings are eliminated.
(vii) Fast rate of production can be attained.
(viii) The process requires less labor.

Disadvantages
(i) The surface of casting becomes hard due to chilling effect.
(ii) High refractoriness is needed for high melting point alloys.
(iii) The process is impractical for large castings.

Applications
1 This method is suitable for small and medium sized casting.
2 It is widely suitable for non-ferrous casting.

CLASSIFICATION BASED ON THE METHOD

i) Bench Molding
This type of molding is preferred for small jobs. The whole molding operation is carried out on a bench of convenient height. In this process, a minimum of two flasks, namely cope and drag molding flasks are necessary. But in certain cases, the number of flasks may increase depending upon the number of parting surfaces required.

ii) Floor Molding
This type of molding is preferred for medium and large size jobs. In this method, only drag portion of molding flask is used to make the mold and the floor itself is utilized as drag and it is usually performed with dry sand.

iii) Pit Molding
Usually large castings are made in pits instead of drag flasks because of their huge size. In pit molding, the sand under the pattern is rammed by bedding-in process. The walls and the bottom of the pit are usually reinforced with concrete and a layer of coke is laid on the bottom of the pit to enable easy escape of gas. The coke bed is connected to atmosphere through vent pipes which provide an outlet to the gases. One box is generally required to complete the mold, runner, sprue, pouring basin and gates are cut in it.

iv) Machine Molding
For mass production of the casting, the general hand molding technique proves uneconomical and inefficient. The main advantage of machine molding, besides the saving of labor and working time, is the accuracy and uniformity of the castings which can otherwise be only obtained with much time and labor. Or even the cost of machining on the casting can be reduced drastically because it is possible to maintain the tolerances within narrow limits on casting using machine molding method.

Molding machines thus prepare the molds at a faster rate and also eliminate the need of employing skilled molders. The main operations performed by molding machines are ramming of the molding sand, roll over the mold, form gate, rapping the pattern and its withdrawal. Most of the molds making operations are performed using molding machines.
STEPS INVOLVED IN MAKING A SAND MOLD

1. Initially a suitable size of molding box for creating suitable wall thickness is selected for a two piece pattern. Sufficient care should also be taken in such that sense that the molding box must adjust mold cavity, riser and the gating system (sprue, runner and gates etc.).

2. Next, place the drag portion of the pattern with the parting surface down on the bottom (ram-up) board.

3. The facing sand is then sprinkled carefully all around the pattern so that the pattern does not stick with molding sand during withdrawn of the pattern.

4. The drag is then filled with loose prepared molding sand and ramming of the molding sand is done uniformly in the molding box around the pattern. Fill the molding sand once again and then perform ramming. Repeat the process three four times.

5. The excess amount of sand is then removed using strike off bar to bring molding sand at the same level of the molding flask height to completes the drag.

6. The drag is then rolled over and the parting sand is sprinkled over on the top of the drag.

7. Now the cope pattern is placed on the drag pattern and alignment is done using dowel pins.

8. Then cope (flask) is placed over the rammed drag and the parting sand is sprinkled all around the cope pattern.

9. Sprue and riser pins are placed in vertically position at suitable locations using support of molding sand. It will help to form suitable sized cavities for pouring molten metal etc.

10. Fill the cope with molding sand and ram uniformly.

11. Strike off the excess sand from the top of the cope.

12. Remove sprue and riser pins and create vent holes in the cope with a vent wire.

13. Sprinkle parting sand over the top of the cope surface and roll over the cope on the bottom board.

14. Rap and remove both the cope and drag patterns and repair the mold suitably if needed and dressing is applied.

15. The gate is then cut connecting the lower base of sprue basin with runner and then the mold cavity.

16. Bake the mold in case of a dry sand mold.

17. Set the cores in the mold, if needed and close the mold by inverting cope over drag.

18. The cope is then clamped with drag and the mold is ready for pouring.
<table>
<thead>
<tr>
<th>Name of process</th>
<th>Pattern type</th>
<th>Molding aggregate</th>
<th>Molding method</th>
<th>Type and development of aggregate bond</th>
<th>Casting weight</th>
<th>Casting intricacy</th>
<th>Casting dimension and smoothness, general case</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green sand...</td>
<td>Wood, plaster, metal; reusable patterns</td>
<td>75% + sand, 3-15% clay and other binders, water; a moist plastic aggregate; reusable</td>
<td>Compaction of sand around pattern, 20-80% reduction in bulk density</td>
<td>Inorganic, green strength due to plastic clay and compaction; dry strength due to water evaporation during casting</td>
<td>Ounces to 1-2 tons</td>
<td>Limited by pattern drawing, no limit with cores</td>
<td>±3/8 in., 250-1000 rms μin.</td>
<td>Most common process</td>
</tr>
<tr>
<td>Dry sand...</td>
<td>Same as above</td>
<td>Same as above</td>
<td>Same as above</td>
<td>Dry strength developed by evaporation of moisture</td>
<td>Heavy castings</td>
<td>Same as above or better</td>
<td>Same as above or better</td>
<td>Baking of mold required, skin drying being a variant of this process</td>
</tr>
<tr>
<td>Core sand...</td>
<td>Same as above, or core boxes and driers</td>
<td>90% + sand, 1-3% core oil or resin, 0.25-1.5% cereal, water</td>
<td>Same as above, core blowing</td>
<td>Organic, polymerization of core oil by baking after removal from core box</td>
<td>Ounces to 500 lb</td>
<td>Same as above</td>
<td>Same as above</td>
<td>Baking of mold required</td>
</tr>
<tr>
<td>Floor and pit molding</td>
<td>Same as above</td>
<td>Same as green sand, with added binder</td>
<td>Same as above</td>
<td>Inorganic, same as green sand, maximum strength due to baking</td>
<td>No limit</td>
<td>No limit</td>
<td>±1/8 in. or less</td>
<td>For very heavy castings</td>
</tr>
<tr>
<td>Process</td>
<td>Pattern Material</td>
<td>Bonding Material</td>
<td>Typical Bonding Method</td>
<td>Typical Properties</td>
<td>Applications</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shell molding</td>
<td>Heated metal pattern</td>
<td>2.5–10.0% thermo-setting resin, balance sand</td>
<td>Free flow of dry sand around pattern or by blowing</td>
<td>Usually less than 250 lb</td>
<td>Limited by pattern drawing, no limit with cores; ± 0.010 in. ± 0.025 in., 100–500 rms μin.</td>
<td>Extensively used for making cores</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂ process</td>
<td>Wood or metal patterns or core boxes</td>
<td>2.0–6.0% sodium silicate binder, balance sand</td>
<td>Compaction of sand around pattern, mechanical or by blowing, then CO₂ gassing</td>
<td>Inorganic bond by chemical reaction of CO₂ and silicate</td>
<td>Ounces to several hundred pounds; Same as above</td>
<td>Similar to dry and core sand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Investment</td>
<td>Wax or plastic, expendable</td>
<td>Slurry with ceramic binder and fine aggregate powder, as ethyl silicate plus silica flour</td>
<td>By dipping pattern in slurry or pouring fluid aggregate around pattern; pattern melted out</td>
<td>Gelling, hydrolysis, or setting of ceramic binder followed by firing</td>
<td>Same as above</td>
<td>Limited to wax patterns that can be ejected from dies and their assemblies; 0.002–0.005 in./in., 10–85 rms μin.</td>
<td>Casting weight usually under 10 lb; heat and corrosion-resistant alloys</td>
<td></td>
</tr>
<tr>
<td>Ceramic molding</td>
<td>Wood, plastic, or metal; reusable</td>
<td>Same as above</td>
<td>Pouring fluid aggregate around pattern; vibration</td>
<td>Same as above</td>
<td>Same as above</td>
<td>Limited to patterns that can be drawn unless flexible patterns are used; Same as above</td>
<td>Heavier castings</td>
<td></td>
</tr>
<tr>
<td>Plaster molding</td>
<td>Metal or plastic patterns</td>
<td>Sand, gypsum binder, and fillers and water</td>
<td>Pouring fluid aggregate around pattern; vibration</td>
<td>Hydration of gypsum followed by drying</td>
<td>Same as above</td>
<td>Same as above</td>
<td>30–50 rms μin., 0.005 in./in. more or less</td>
<td>Aluminum and copper alloy castings mainly</td>
</tr>
</tbody>
</table>
A suitable and workable material possessing high refractoriness in nature can be used for mold making. Thus, the mold making material can be metallic or non-metallic.

For metallic category, the common materials are cast iron, mild steel and alloy steels.

In the non-metallic group molding sands, plaster of paris, graphite, silicon carbide and ceramics are included.

**But, out of all, the molding sand is the most common utilized non-metallic molding material because of its certain inherent properties namely refractoriness, chemical and thermal stability at higher temperature, high permeability and workability along with good strength. Moreover, it is also highly cheap and easily available.**

**REFRACTORY SANDS**

Different types of refractory sands used for molding are:

(i) Silica sand (ii) Magnesite (iii) Zircon (iv) Silimanite (v) Olivine (vi) Graphite/carbon

- Sand used in foundries must be capable of withstanding very high temperatures and shouldn't collapse under the prevailing load.
- Silica sand is mostly used in foundries because of the following.
  1. It is a very good refractory material and doesn't fuse or soften even at very high temperatures, i.e. 1650°C, when in contact with molten metal.
  2. They can be easily molded into intricate shapes.
  3. They have sufficient porosity or permeability and allow easy escape of gases produced by molten metal and other bonding constituent.
  4. They can be used repeatedly for making molds after addition of some bonding materials.
  5. They are cheap and easily available.
  6. They are chemically immune to molten metals.
  7. They don't decay. Its main drawback is its high coefficient of thermal expansion (above 560T).

**Sources of Molding Sand Molding**

Sand used in foundries is available in (i) River beds. (ii) Sea. (iii) Deserts. (iv) Lakes.

**Types of Molding Sand**

Depending upon the purity and other constituents present, sand is classified into

(i) Natural sand. (ii) Synthetic sand, (iii) loam sand.

(i) **Natural sand:**

- Natural sand is directly used for molding and contains 5-20% of clay as binding material.
- It needs 5-8% water for mixing before making the mold. Many natural sands possess a wide working range of moisture and are capable of retaining moisture content for a long time.
Its main drawback is that it is less refractory as compared to synthetic sand. Many natural sands have weak molding properties. These sands are reconditioned by mixing small amounts of binding materials like bentonite to improve their properties and are known as semi-synthetic sand.

(II) **Synthetic Sands:**

- Synthetic sand consists of silica sand with or without clay, binder or moisture.
- It is a formulated sand i.e. sand formed by adding different ingredients. Sand formulations are done to get certain desired properties not possessed by natural sand.
- These sands have better casting properties like permeability and refractoriness and are suitable for casting ferrous and non-ferrous materials.
- These properties can be controlled by mixing different ingredients.
- Synthetic sands are used for making heavy castings.

(III) **Loam Sand:**

- Loam sand contains many ingredients, like fine sand particles, finely ground refractories, clay, graphite and fiber reinforcements.
- In many cases, the clay content may be of the order of 50% or more.
- When mixed with water, the materials mix to a consistency resembling mortar and become hard after drying.
- Big molds for casting are made of brick framework lined with loam sand and dried.
- Sweeps etc are used for making big castings like big bells by using loam sand.

**Refractory sand grains:** Sand grain size and shape has a marked effect on the properties of molding sand. The specific surface gives a rough idea of the amount of binder needed for molding sand.

**GRAIN SIZE**

- Many properties of molding sand like permeability, adhesiveness, surface fineness, strength, etc, depend upon the grain size and distribution of sand particles.
- The finer the grain size, the finer is the sand as a whole.
- Finely grained sand gives a good surface finish but possesses low permeability.
- Coarse grained sand gives lesser surface finish but imparts good flow ability, good refractoriness and good permeability.
- The green strength of fine sand is higher than coarse sand for the same quantity of ingredients added to it.

**Foundry Sand Grain Shape:** The grain shape of foundry sand has a marked influence on its properties like flow ability, cohesiveness and strength. Generally, four types of grains are present in foundry sand given as follows.

(1) **Rounded Sand Grains:** Rounded sand grains give poor bonding strength as compared to angular sand grains. Too many smooth and rounded sand grains result in sand wash, sand crack and sand scales. These sands also possess greater flow ability.
(II) **Angular Grains:** These grains are produced by breaking of rocks without movement of particles. These are also formed by frost and glacial action. Angular grains have greater bonding strength, lesser flow ability and low permeability than round grain sands. Angular grains have sharp corners and greater contact surface.

(III) **Sub-angular Grains:** As compared to rounded grains, sub-angular grains possess better strength and lower permeability. In comparison to angular grains, they possess lower strength and better permeability.

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**BINDERS USED IN MOLDING SANDS**

- Binders are added to give cohesion to molding sands.
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The following binders are generally added to foundry sand:

(i) Fireclay
(ii) Illite
(iii) Bentonite
   - Sodium montmorillonite
   - Calcium montmorillonite
(iv) Limonite
(v) Kaolinite

(i) **Fireclay:** It is usually found near coal mines. For use in the foundry, the hard black lumps of fireclay are taken out, weathered and pulverized. Since the size of fireclay particles is nearly 400 times greater than the size of bentonite particles, they give poor bonding strength to foundry sand.

(ii) **Illite:** Illite is found in natural molding sands that are formed by the decomposition of micaceous materials due to weathering. Illite possesses moderate shrinkage and poor bonding strength than bentonite.

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CONSTITUENTS OF MOLDING SAND
The main constituents of molding sand involve silica sand, binder, moisture content and additives.

Silica sand
- Silica sand in form of granular quarts is the main constituent of molding sand having enough refractoriness which can impart strength, stability and permeability to molding and core sand.
- Along with silica small amounts of iron oxide, alumina, lime stone, magnesia, soda and potash are present as impurities.
- The chemical composition of silica sand gives an idea of the impurities like lime, magnesia, alkalis etc. present.
- The presence of excessive amounts of iron oxide, alkali oxides and lime can lower the fusion point to a considerable extent which is undesirable.

Moisture
- The amount of moisture content in the molding sand varies generally between 2 to 8 percent.
- This amount is added to the mixture of clay and silica sand for developing bonds.
- This is the amount of water required to fill the pores between the particles of clay without separating them.
- This amount of water is held rigidly by the clay and is mainly responsible for developing the strength in the sand.
- The effect of clay and water decreases permeability with increasing clay and moisture content.
- The green compressive strength first increases with the increase in clay content, but after a certain value, it starts decreasing.

Additives
Additives are the materials generally added to the molding and core sand mixture to develop some special property in the sand. Some common used additives for enhancing the properties of molding and core sands are.

(i) Coal dust
Coal dust is added mainly for producing a reducing atmosphere during casting. This reducing atmosphere results in any oxygen in the poles becoming chemically bound so that it cannot oxidize the metal.

(ii) Dextrin
Dextrin belongs to starch family of carbohydrates. It increases dry strength of the molds.

(iii) Pitch
It is distilled form of soft coal. It can be added from 0.02 % to 2% in mold and core sand. It enhances hot strengths, surface finish on mold surfaces.

(iv) Wood flour
This is a fibrous material mixed with a granular material like sand; its relatively long thin fibers prevent the sand grains from making contact with one another. It can be added from 0.05 % to 2% in mold and core sand. It increases collapsibility of both of mold and core.
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- Loam sand contains many ingredients, like fine sand particles, finely ground refractories, clay, graphite and fiber reinforcements.
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- Many properties of molding sand like permeability, adhesiveness, surface fineness, strength. etc, depend upon the grain size and distribution of sand particles.
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**BINDERS USED IN MOLDING SANDS**

- Binders are added to give cohesion to molding sands.
- Binders provide strength to the molding sand and enable it to retain its shape as mold cavity.
- Binders should be added in optimum quantity as they reduce refractoriness and permeability.
- An optimal quantity of binders is needed, as further increases have no effect on properties of foundry sand.

The following binders are generally added to foundry sand:

1. **Fireclay**
2. **Illite**
3. **Bentonite**
   - Sodium montmorillonite
   - Calcium montmorillonite
4. **Limonite**
5. **Kaolinite**

(i) **Fireclay:** It is usually found near coal mines. For use in the foundry, the hard black lumps of fireclay are taken out, weathered and pulverized. Since the size of fireclay particles is nearly 400 times greater than the size of bentonite particles, they give poor bonding strength to foundry sand.

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CONSTITUENTS OF MOLDING SAND
The main constituents of molding sand involve silica sand, binder, moisture content and additives.

Silica sand
- Silica sand in form of granular quartz is the main constituent of molding sand having enough refractoriness which can impart strength, stability and permeability to molding and core sand.
- Along with silica small amounts of iron oxide, alumina, lime stone, magnesia, soda and potash are present as impurities.
- The chemical composition of silica sand gives an idea of the impurities like lime, magnesia, alkalis etc. present.
- The presence of excessive amounts of iron oxide, alkali oxides and lime can lower the fusion point to a considerable extent which is undesirable.
- The silica sand can be specified according to the size (small, medium and large silica sand grain) and the shape (angular, sub-angular and rounded).

Moisture
- The amount of moisture content in the molding sand varies generally between 2 to 8 percent.
- This amount is added to the mixture of clay and silica sand for developing bonds.
- This is the amount of water required to fill the pores between the particles of clay without separating them.
- This amount of water is held rigidly by the clay and is mainly responsible for developing the strength in the sand.
- The effect of clay and water decreases permeability with increasing clay and moisture content.
- The green compressive strength first increases with the increase in clay content, but after a certain value, it starts decreasing.

Additives
Additives are the materials generally added to the molding and core sand mixture to develop some special property in the sand. Some common used additives for enhancing the properties of molding and core sands are

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(iv) Wood flour
This is a fibrous material mixed with a granular material like sand; its relatively long thin fibers prevent the sand grains from making contact with one another. It can be added from 0.05 % to 2% in mold and core sand. It increases collapsibility of both of mold and core.

**KINDS OF MOULDING SAND**

Molding sands can also be classified according to their use into number of varieties which are described below.

1) **Green sand**
Green sand is also known as tempered or natural sand which is a just prepared mixture of silica sand with 18 to 30 percent clay, having moisture content from 6 to 8%. The clay and water furnish the bond for green sand. It is fine, soft, light, and porous. Green sand is damp, when squeezed in the hand and it retains the shape and the impression to give to it under pressure. Molds prepared by this sand are not requiring backing and hence are known as green sand molds. This sand is easily available and it possesses low cost. It is commonly employed for production of ferrous and non-ferrous castings.

2) **Dry sand**
Green sand that has been dried or baked in suitable oven after the making mold and cores, is called dry sand. It possesses more strength, rigidity and thermal stability. It is mainly suitable for larger castings. Mold prepared in this sand are known as dry sand molds.

3) **Loam sand**
Loam is mixture of sand and clay with water to a thin plastic paste. Loam sand possesses high clay as much as 30-50% and 18% water. Patterns are not used for loam molding and shape is given to mold by sweeps. This is particularly employed for loam molding used for large grey iron castings.

4) **Facing sand**
Facing sand is just prepared and forms the face of the mold, gives surface finish to casting. It is directly next to the surface of the pattern and it comes into contact molten metal when the mold is poured. Initial coating around the pattern and hence for mold surface is given by this sand. This sand is subjected severest conditions and must possess, therefore, high strength refractoriness. It is made of silica sand and clay, without the use of used sand.

5) **Backing sand**
Backing sand or floor sand is used to back up the facing sand and is used to fill the whole volume of the molding flask. Used molding sand is mainly employed for this purpose. The backing sand is sometimes called black sand because that old, repeatedly used molding sand is black in color due to addition of coal dust and burning on coming in contact with the molten metal.

6) **Parting sand**
Parting sand without binder and moisture is used to keep the green sand not to stick to the pattern and also to allow the sand on the parting surface the cope and drag to separate without clinging.

7) **Core sand**
Core sand is used for making cores and it is sometimes also known as oil sand. This is highly rich silica sand mixed with oil binders such as core oil which composed of linseed oil, resin, light mineral oil and other bind materials.
PROPERTIES OF MOULDING SAND

The basic properties required in molding sand and core sand are described as under.

1) Refractoriness
Refractoriness is defined as the ability of molding sand to withstand high temperatures without breaking down or fusing thus facilitating to get sound casting. It is a highly important characteristic of molding sands. Refractoriness can only be increased to a limited extent. Molding sand with poor refractoriness may burn on to the casting surface and no smooth casting surface can be obtained. The degree of refractoriness depends on the SiO2 i.e. quartz content, and the shape and grain size of the particle. The higher the SiO2 content and the rougher the grain volumetric composition the higher is the refractoriness of the molding sand and core sand. Refractoriness is measured by the sinter point of the sand rather than its melting point.

2) Permeability
It is also termed as porosity of the molding sand in order to allow the escape of any air, gases or moisture present or generated in the mold when the molten metal is poured into it. All these gaseous generated during pouring and solidification process must escape otherwise the casting becomes defective. Permeability is a function of grain size, grain shape, and moisture and clay contents in the molding sand. The extent of ramming of the sand directly affects the permeability of the mold. Permeability of mold can be further increased by venting using vent rods.

3) Cohesiveness
It is property of molding sand by virtue which the sand grain particles interact and attract each other within the molding sand. Thus, the binding capability of the molding sand gets enhanced to increase the green, dry and hot strength property of molding and core sand.

4) Green strength
The green sand after water has been mixed into it, must have sufficient strength and toughness to permit the making and handling of the mold. For this, the sand grains must be adhesive, i.e. they must be capable of attaching themselves to another body and therefore, and sand grains having high adhesiveness will cling to the sides of the molding box. Also, the sand grains must have the property known as cohesiveness i.e. ability of the sand grains to stick to one another. By virtue of this property, the pattern can be taken out from the mold without breaking the mold and also the erosion of mold wall surfaces does not occur during the flow of molten metal. The green strength also depends upon the grain shape and size, amount and type of clay and the moisture content.

5) Dry strength
As soon as the molten metal is poured into the mold, the moisture in the sand layer adjacent to the hot metal gets evaporated and this dry sand layer must have sufficient strength to its shape in order to avoid erosion of mold wall during the flow of molten metal.

6) Flowability or plasticity
It is the ability of the sand to get compacted and behave like a fluid. It will flow uniformly to all portions of pattern when rammed and distribute the ramming pressure evenly all around in all directions. Generally sand particles resist moving around corners or projections. In general, flow ability increases with decrease in green strength, an, decrease in grain size. The flow ability also varies with moisture and clay content.
7) Adhesiveness
It is property of molding sand to get stick or adhere with foreign material such sticking of molding sand with inner wall of molding box.

8) Collapsibility
After the molten metal in the mold gets solidified, the sand mold must be collapsible so that free contraction of the metal occurs and this would naturally avoid the tearing or cracking of the contracting metal. In absence of this property the contraction of the metal is hindered by the mold and thus results in tears and cracks in the casting. This property is highly desired in cores.

9) Miscellaneous properties
In addition to above requirements, the molding sand should not stick to the casting and should not chemically react with the metal. Molding sand should be cheap and easily available. It should be reusable for economic reasons. Its coefficients of expansion should be sufficiently low.

SAND TESTING
- Molding sand and core sand depend upon shape, size composition and distribution of sand grains, amount of clay, moisture and additives.
- The increase in demand for good surface finish and higher accuracy in castings necessitates certainty in the quality of mold and core sands.
- Sand testing often allows the use of less expensive local sands. It also ensures reliable sand mixing and enables a utilization of the inherent properties of molding sand.
- Sand testing on delivery will immediately detect any variation from the standard quality, and adjustment of the sand mixture to specific requirements so that the casting defects can be minimized.

Generally the following tests are performed to judge the molding and casting characteristics of foundry sands:

1. Moisture content Test
2. Clay content Test
3. Chemical composition of sand
4. Grain shape and surface texture of sand
5. Grain size distribution of sand
6. Refractoriness of sand
7. Strength Test
8. Permeability Test
9. Flowability Test
10. Shatter index Test
11. Mould hardness Test.

Moisture Content Test
- The moisture content of the molding sand mixture may determine by drying a weighed amount of 20 to 50 grams of molding sand to a constant temperature up to 100°C in a oven for about one hour.
- It is then cooled to a room temperature and then reweighing the molding sand.
- The moisture content in molding sand is thus evaporated.
- The loss in weight of molding sand due to loss of moisture, gives the amount of moisture which can be expressed as a percentage of the original sand sample.
- The percentage of moisture content in the molding sand can also be determined in fact more speedily by an instrument known as a speedy moisture teller.
This instrument is based on the principle that when water and calcium carbide react, they form acetylene gas which can be measured and this will be directly proportional to the moisture content.

This instrument is provided with a pressure gauge calibrated to read directly the percentage of moisture present in the molding sand.

Clay Content Test

The amount of clay is determined by carrying out the clay content test in which clay in molding sand of 50 grams is defined as particles which when suspended in water, fail to settle at the rate of one inch per min.

Clay consists of particles less than 20 micron, per 0.0008 inch in dia.

Grain Fineness Test

The AFS Grain Fineness Number (AFS-GFN) is one means of measuring the grain fineness of a sand system.

GFN is a measure of the average size of the particles (or grains) in a sand sample. The grain fineness of molding sand is measured using a test called sieve analysis.

The test is carried out in power-driven shaker consisting of number of sieves fitted one over the other.

1. A representative sample of the sand is dried and weighed, then passed through a series of progressively finer sieves (screens) while they are agitated and tapped for a 15-minute test cycle. The series are placed in order of fineness from top to bottom.

2. The sand retained on each sieve (grains that are too large to pass through) is then weighed and recorded.

3. The weight retained on each sieve is carried out through calculations to get the AFS-GFN.

Refractoriness Test

The refractoriness of the molding sand is judged by heating the A.F.S standard sand specimen to very high temperatures ranges depending upon the type of sand.

The heated sand test pieces are cooled to room temperature and examined under a microscope for surface characteristics or by scratching it with a steel needle.

If the silica sand grains remain sharply defined and easily give way to the needle. Sintering has not yet set in.

In the actual experiment the sand specimen in a porcelain boat is placed into an electric furnace. It is usual practice to start the test from 1000°C and raise the temperature in steps of 100°C to 1300°C and in steps of 50° above 1300°C till sintering of the silica sand grains takes place.

At each temperature level, it is kept for at least three minutes and then taken out from the oven for examination under a microscope for evaluating surface characteristics or by scratching it with a steel needle.
Strength Test
This is the strength of tempered sand expressed by its ability to hold a mold in shape. Sand molds are subjected to compressive, tensile, shearing, and transverse stresses.

The green compressive strength test and dry compressive strength is the most used test in the foundry.

- **Compression tests**
  - A rammed specimen of tempered molding sand is produced that is 2 inches in diameter and 2 inches in height.
  - The rammed sample is then subjected to a load which is gradually increased until the sample breaks.
  - The point where the sample breaks is taken as the compression strength.

- **Shear tests**
  - The compressive loading system is modified to provide offset loading of the specimen.
  - Under most conditions the results of shear tests have been shown to be closely related to those of compression tests, although the latter property increases proportionately more at high ramming densities.

- **The tensile test**
  - A special waisted specimen is loaded in tension through a pair of grips.

- **The transverse test**
  - A plain rectangular specimen is supported on knife edges at the ends and centrally loaded to fracture.

*Tensile and transverse tests are commonly applied to high strength sands, the conditions being especially relevant to the stresses incurred in cores during handling and casting*
Permeability Test

- Permeability is determined by measuring the rate of flow of air through a compacted specimen under standard conditions.
- A cylinder sand sample is prepared by using rammer and die. This specimen (usually 2 inch dia & 2 inch height) is used for testing the permeability or porosity of molding and the core sand. The test is performed in a permeability meter consisting of the balanced tank, water tank, nozzle, adjusting lever, nose piece for fixing sand specimen and a manometer. The permeability is directly measured.
- Permeability number \( P \) is volume of air (in cm\(^3\)) passing through a sand specimen of 1 cm\(^2\) cross-sectional area and 1 cm height, at a pressure difference of 1 gm/cm\(^2\) in one minute.

\[
P = \frac{Vh}{atp}
\]

Where, \( P \) = permeability
- \( v \) = volume of air passing through the specimen in c.c.
- \( h \) = height of specimen in cm
- \( p \) = pressure of air in gm/cm\(^2\)
- \( a \) = cross-sectional area of the specimen in cm\(^2\)
- \( t \) = time in minutes.

Shatter Index Test

- In this test, the A.F.S. standard sand specimen is rammed usually by 10 blows and then it is allowed to fall on a half inch mesh sieve from a height of 6 ft.
- The weight of sand retained on the sieve is weighed.
- It is then expressed as percentage of the total weight of the specimen which is a measure of the shatter index.

Mold Hardness Test

- This test is performed by a mold hardness tester.
- The working of the tester is based on the principle of Brinell hardness testing machine.
- In an A.F.S. standard hardness tester a half inch diameter steel hemispherical ball is loaded with a spring load of 980 gm.
- This ball is made to penetrate into the mold sand or core sand surface.
- The penetration of the ball point into the mold surface is indicated on a dial in thousands of an inch.
- The dial is calibrated to read the hardness directly i.e. a mold surface which offers no resistance to the steel ball would have zero hardness value and a mold which is more rigid and is capable of completely preventing the steel ball from penetrating would have a hardness value of 100.
- The dial gauge of the hardness tester may provide direct readings.

Compactability and flowability

- The compactability test is widely accepted as both simple to perform and directly related to the behavior of sand in molding, particularly when involving squeeze compaction.
- A fixed volume of loose sand is compacted under standard conditions and the percentage reduction in volume represents the compactability.
SAND CONDITIONING

Natural sands are generally not well suited for casting purposes. On continuous use of molding sand, the clay coating on the sand particles gets thinned out causing decrease in its strength.

Thus proper sand conditioning accomplish uniform distribution of binder around the sand grains, control moisture content, eliminate foreign particles and aerates the sands.

Therefore, there is a need for sand conditioning for achieving better results.

- The foreign materials, like nails, hard sand lumps and metals from the used sand are removed. For removing the metal pieces, particularly ferrous pieces, the sand from the shake-out station is subjected to magnetic separator, which separates out the iron pieces, nails etc. from the used sand.

- Next, the sand is screened in riddles which separate out the hard sand lumps etc. These riddles may be manual as well as mechanical. Mechanical riddles may be either compressed air operated or electrically operated. But the electrically operated riddles are faster and can handle large quantities of sand in a short time.

- After all the foreign particles are removed from and the sand is free from the hard lumps etc., proper amount of pure sand, clay and required additives are added to for the loss because of the burned, clay and other materials. As the moisture content of the returned sand known, it is to be tested and after knowing the moisture the required amount of water is added.

- There are two methods of adding clay and water to sand. In the first method, first water is added to sand follow by clay, while in the other method, clay addition is followed by water. It has been suggested that the best order of adding ingredients to clay bonded sand is sand with water followed by the binders. In this way, the clay is more quickly and uniformly spread on to all the sand grains. An additional advantage of this mixing order is that less dust is produced during the mulling operation.

- Now these things are mixed thoroughly in a mixing muller. The main objectives of a mixing muller is to distribute the binders, additives and moisture or water content uniformly all around each sand grain and helps to develop the optimum physical properties by kneading on the sand grains. Inadequate mulling makes the sand mixture weak which can only be compensated by adding more binder.

- The final step in sand conditioning is the cooling of sand mixture because of the fact that if the molding sand mixture is hot, it will cause molding difficulties
The mechanism of solidification of metals/alloys and its control for obtaining sound castings is the most important problem of foundry men.

- As soon as the molten metal is poured in a sand mold, the process of solidification starts.
- During solidification, cast form develops **cohesion** and acquires structural characteristics.
- The mode of solidification affects the properties of the castings because a casting acquires a metallographic structure which is determined during solidification.
- The metallographic structure consists of
  - **Grain size, Shape and orientation**
  - **Distribution of alloying elements.**
  - **Underlying crystal structure and its imperfections.**
- Besides structure, the soundness of a casting also depends upon the solidification mechanism.
- Soundness implies the degree of true **metallic continuity** and a casting will be sound if volume shrinkage accompanying the change of state of melt to solid is compensated by liquid metal with the help of riser, etc.
- Volume shrinkage or volume contraction occurs during three stages and thus contraction or shrinkage is of three types.
  1. **Liquid Contraction (shrinkage):** it occurs when the metal is in liquid state.
  2. **Solidification Contraction (shrinkage):** it occurs during the change from liquid (melt) to solid.
  3. **Solid Contraction (shrinkage):** it occurs when metal is solid i.e. after solidification. They do not influence shrinkage defects.
Solidification
- In pure metals and eutectic alloys takes place at constant temperature.
- In solid solution alloys proceeds over a temperature range.

Solidification occurs
- By the nucleation of very small crystals.
- Which grow under the thermal and crystallographic conditions existing during solidification.

- **Grain growth** stops when complete melt has been solidified.

- The relative rates and location of nucleation and growth phenomenon within the melt decides final structure of the solid and establishes whether solidification is directional or it takes place in a discrete manner throughout the melt.

Changes that occur are:

i) **Superheat** must be removed from the metal. Super heat is basically that heat which must be removed before solidification begins.

ii) **Latent heat of fusion** is also evolved; this must be transferred to the surrounding mold before complete solidification can be achieved.

iii) Finally solid metal transfers heat to the mold, and then to the atmosphere as it cools to room temperature.

CONCEPT OF SOLIDIFICATION OF METALS

- A metal in molten states possess high energy. As the melt cools, it loses energy to form crystals.

- Since heat loss is more rapid near mold walls than any other place, first submicroscopic metal crystallites called nuclei form here.

- Melt experiences difficulty in starting to crystallites if no nuclei in the form of impurities are present to start crystallization.

- However in such conditions melt undercools and thus nuclei or seed crystals form.

- Nuclei formed as above tend to grow at the second stage of solidification.

- The crystal growth proceeds with release of energy at crystal melt interface.
The crystal growth occurs in a dendritic manner.

Dendritic growth takes place by the evolution of small arms on the original branches of individual dendrites.

These solid dendrites give rise to grains.

(a) **Slow cooling** makes the dendrites to grow long whereas **fast cooling** causes short dendrite growth.

(b) Since eventually dendrites become grains, slow cooling results in large grain structure and fast cooling in small grain structure in the solidified metal.

As solidification proceeds, more and more arms grow on an existing dendrite and also more and more dendrites form until the whole melt is crystallized.

Dendrite arms grow because metal atoms attach themselves to the solid dendrite.

Atoms arrange themselves in a three dimensional pattern which is repeated many times during the crystal growth.

This unit of repetition is called a Unit cell. Unit cells arrange themselves in straight lines.

Straight lines thus formed in geometric pattern at right angles to each other produce dendritic structure.

Dendrite grow outward until they contact the neighboring dendrite and generate grain boundaries i.e. boundaries between crystals or grains.

Quiet likely that the dendrite arms become thickened and ultimately a solid crystal or grain may remain with no indication of dendritic growth.
SOLIDIFICATION OF PURE METALS

- Pure metals generally possess
  - Excellent thermal and electrical conductivity (e.g., Cu and Al)
  - Higher ductility, higher melting point, lower yield point and tensile strength
  - Better corrosion resistance as compared to alloys

- Pure metals melt and solidify at a single temperature which may be termed as Melting Point or Freezing Point, it is in solid state.

- Above freezing point the metal is liquid and below freezing point, it is in solid state.

- If number of temperature measurements are taken at different times, while pure metal is cooled under equilibrium conditions from the molten state till it solidifies, a Time-Temperature plot will be obtained.

1. Liquid metal cools from A to B.
2. From B to C, the melt liberates latent heat of fusion; temperature remains constant.
3. The liquid metal starts solidifying at B and it is partly solid at any point between B and C and at C the metal is purely solid.
4. From C to D, the solid metal cools and tends to reach room temperature.
5. The slopes of AB and CD depend upon the specific heats of liquid and solid metals respectively.

If a pure metal cools rapidly or even otherwise when it is very pure and does not contain at all impurity as nucleus to start crystallization.

1. Nucleation of solid does not start at point B (i.e. normal solidification temperature) but it does so at C i.e after the liquid metal has supercooled. This phenomenon is known as supercooling or undercooling.
2. Besides pure metals, supercooling may occur in alloys also, e.g., Gray cast iron.

**Undercooling** - The temperature to which the liquid metal must cool below the equilibrium freezing temperature before nucleation occurs.

**Recalscence** - The increase in temperature of an undercooled liquid metal as a result of the liberation of heat during nucleation.
Thermal arrest - A plateau on the cooling curve during the solidification of a material caused by the evolution of the latent heat of fusion during solidification.

Total solidification time - The time required for the casting to solidify completely after the casting has been poured.

Local solidification time - The time required for a particular location in a casting to solidify once nucleation has begun.

- When pure metals (and some eutectic alloys) are allowed to solidify in a mold, the portion of molten metal next to the mold wall begins to solidify.

- The metal solidifies in the form of a solid skin and then the liquid metal tends to freeze onto it.

- The solid skin progresses towards the center of the mold from all the mold walls.

- As the successive layers of molten metal build up in the form of solid skin or as the solid metal wall thickness increases, the liquid level in the mold falls because of solidification shrinkage.
SOLIDIFICATION OF AN ALLOY

- The alloys normally solidify in a temperature range

NUCLEATION

- Nucleation is the beginning of a phase transformation
- Nucleation is marked by the appearance in the molten metal of tiny regions called nuclei of the new phase which grow to solid crystals (by further deposition of atoms) until the transformation is complete.

- Nucleation may involve
  - The assembly of proper kinds of atoms
  - Structural change into one or more unstable intermediate structures
  - Formation of critical sized particle (i.e. nuclei) of the new (i.e. solid) phase
1) **HOMOGENOUS or SELF NUCLEATION**

- Formation of a critically sized solid from the liquid by the clustering together of a large number of atoms at a high undercooling (without an external interface).
- Homogenous nucleation is one occurring in perfectly homogeneous materials such as pure liquid metals.
- Nucleation of the super cooled grains depends upon two factors:

**Factor A**

1. The free energy available from the solidification process; which depends upon the volume of the particle formed.
2. The replacement of old phase (i.e. molten metal) by the new (i.e. solid) phase accompanies a free energy decrease per unit volume and this contribute to the stability of the region (new phase).
3. In case of spherical particle, if the temperature is suddenly dropped below the freezing point, the free energy change per unit volume of metal transformed (i.e. solidified) will be

$$
\frac{4}{3} \pi r^3 \Delta G_v
$$

and it is negative (because free energy decreases); \( r \) is the radius of the particle.

**Factor B**

1. The second factor is the energy required to form a liquid-solid interface.
2. Particles formed, in the melt have some surface area. Solid-liquid phases possess a surface in between the two. Such a surface has a positive free energy per unit area associated with it.
3. The creation of a new interface (surface) is associated with free energy increase proportional to the surface area of the particle and this free energy increase is equal to

$$
4\pi r^2 \gamma
$$

- Thus total free energy change for a particle of radius \( r \),

$$
\Delta G_T = -\frac{4}{3} \pi r^3 \Delta G_v + 4 \pi r^2 \gamma
$$

![Diagram](image)

**Surface Free Energy** - destabilizes the nuclei (it takes energy to make an interface)

**Volume (Bulk) Free Energy** - stabilizes the nuclei (releases energy)

\( r^* = \text{critical nucleus: nuclei } < r^* \text{ shrink; nuclei } > r^* \text{ grow (to reduce energy)} \)
As the particle radius increases, the free energy, also increases till the particle grows to a critical radius and thereafter an increase in particle radius accompanies with decrease in free energy and so much so that the free energy becomes negative also.

Particles having radius less than the critical radius tend to redissolve and thus lower the free energy. Such particles are known as EMBRYOS.

Particles having radius greater than the critical radius tend to grow and also lower the free energy. Such particles are known as NUCLEI.

The critical particle size must be created before the nucleus is stable for a particular supercooling temperature.

\[
\begin{align*}
r^* &= \frac{-2\gamma T_m}{\Delta H_S \Delta T} \\
\gamma &= \text{surface free energy} \\
T_m &= \text{melting temperature} \\
\Delta H_S &= \text{latent heat of solidification} \\
\Delta T &= T_m - T = \text{supercooling}
\end{align*}
\]

Note: \(\Delta H_S\) = strong function of \(\Delta T\) \\
\(\gamma\) = weak function of \(\Delta T\)

\[r^* \text{ decreases as } \Delta T \text{ increases}\]

For typical \(\Delta T\), \(r^*\) ca. 100Å

**Numericals**

Calculate the size of the critical radius of atoms in the critical nucleus when solid copper forms by homogeneous nucleation

\[
\Delta T = 236^\circ C \quad T_m = 1085 + 273 = 1358 \text{ K}
\]

\[
\Delta H_f = 1628 \text{ J/cm}^3
\]

\[
\sigma_{sl} = 177 \times 10^{-7} \text{ J/cm}^2
\]

\[
r^* = \frac{2\sigma_{sl} T_m}{\Delta H_f \Delta T} = \frac{(2)(177 \times 10^{-7})(1358)}{(1628)(236)} = 12.51 \times 10^{-8} \text{ cm}
\]
2) HETEROGENEOUS NUCLEATION

- Heterogeneous nucleation occurs at surfaces, imperfections, severely deformed regions, etc. which lowers the critical free energy.
- In molten metals (castings) usually foreign particles are present as impurities which lower the liquid solid interface energy and help in nucleation and thereby reduce the amount of undercooling needed to actuate nucleation.
- The basic requirement for heterogeneous nucleation lies in the ability of the liquid metal to wet the foreign particles.

A solid forming on an impurity can assumed the critical radius with a smaller increase in the surface energy. Thus, heterogeneous nucleation can occur with relatively low undercoolings

- After the initial nuclei are formed.
  1. More solid may be deposited upon the first nuclei or
  2. More nuclei may form, or
  3. A different phase may occur in the melt.
- There is either very little or no supercooling at all in heterogeneous nucleation.

GROWTH

- Growth follows nucleation.
- Growth process determines the final crystallographic structure of the solid.
- The mode of growth of individual grains as well as the general mass of the solid depends upon the thermal conditions prevalent in the solidification zone and the constitution of the alloy.
- Growth may be defined as the increase of the nucleus in size.
- The nuclei grow by additions of atoms.
- The nuclei reduce their total free energy by continuous growth
- During growth, material is transferred by diffusion.
  a) Through the old phase (i.e. liquid metal)
  b) Across the liquid-solid interface.
  c) Into the nucleus
- Growth starts on the grains already formed.
- The growth is controlled by the rate of heat transfer from the casting, since there is a temperature gradient towards the casting surface, the growth occurs in a direction opposite to heat flow, i.e towards the center of the melt.

![Diagram of nucleation and growth in a casting](image)

Development of the ingot structure of a casting during solidification: (a) Nucleation begins, (b) the chill zone forms, (c) preferred growth produces the columnar zone, and (d) additional nucleation creates the equiaxed zone.