

## **COURSE: METAL CASTING**

### **Module No. 1: INTRODUCTION**

#### **Lecture No-1**

##### **Scope, Challenges, Focus and History of Casting Process**

###### **Introduction**

The metal casting industry plays a key role in all the major sectors of our economy. There are castings in locomotives, cars, trucks, aircraft, factories, and everywhere. Metal casting is one of the oldest manufacturing methods. In metal casting, metal is melted and poured into a cavity and after solidification of the metal in the cavity, the metal takes the exact shape of the cavity. The solidified object is then taken out from the cavity either by breaking the cavity or taking the cavity apart. The solidified object is called the casting. The cavity is also known as mould. The shape and size of the mould matches with the product requirement. However, depending upon the shape complexity and the metal the size of the mould may differ with the size of the product requirement. the mould into which the molten metal is poured is made of heat resistant material. Sand, being the heat resistant, is the most often used material for making the mould. However, permanent mould made of metal can also be used to cast various products. This process allows to produce the complex parts in one go.

###### **Advantages**

The metal casting process is extensively used in manufacturing because of its many advantages.

1. Very thin sections, because of the flowability of the liquid metal, can be cast by the metal casting process, which otherwise are difficult to produced by other shaping processes.
2. Intricate and complex shapes can be made by this process.
3. Any material that is ferrous or non-ferrous can be cast.
4. The tooling required for casting molds are very simple and inexpensive. As a result, for production of a small lot, it is the ideal process.
5. There are certain parts made from metals and alloys that can only be processed this way.
6. Size and weight of the product is not a limitation for the casting process.

7. Metal casting is a process highly adaptable to the requirements of mass production.

## **Limitations**

1. Dimensional accuracy and surface finish of the castings made by casting processes are a limitation to this technique. Many new casting processes have been developed which can take into consideration the aspects of dimensional accuracy and surface finish. Some of these processes are die casting process, investment casting process, vacuum-sealed molding process, and shell molding process.
2. The metal casting process is a labor intensive process

## **Scope of Metal Casting Industry**

Metal casting process is the oldest manufacturing process. metal cast products find their application in most of the application product and almost all automobile product use cast product(s) as its component. It can be said that Foundry industry is the mother of all industries. In India, There are around 5100 foundries both large as well small units registered in India. Of these, around 3000 units are grey iron foundries, producing about 5.1 million tons of grey iron casting. About 300 foundries are in the large sector. Out of total units, 80 percent are small units, 15 percent are medium- size and only 5 percent are in large sector. In India the scope of metal casting industry is increasing as the government has made tremendous efforts to improve infrastructure including power generation. The efforts will help metal casting industries, which are power extensive industries, to grow.

The knowledge and application of technology in the area of metal casting will help the industries to excel in all of its application areas. The scope of metal casting industry has widen up. It is now-a-days not limited to metal products, but the application of cast product also include, plastic products, composite, civil and building infrastructure development, bridge construction etc. The new initiatives and additional scope of foundry industry will require the skilled manpower in this field. This will enhance the metal casting industry jobs to huge number of metal casting professionals.

## **The Present Challenges to Indian Metal Casting Industries**

- The high cost of technology and related modern equipment
- The cost of energy, which is increasing every time
- High rate of interest on loans
- Industry and Taxation law policies has become a barrier in the growth and export business
- Irregular supply of raw material
- Environment Pollution

## **The Focus of Metal Casting Industries must be on**

- quality not on the quantity with a spirit of producing right first time and every time
- waste reduction and on improving the productivity
- defect prevention not on defect rectification
- competition on pricing as well
- reduction in lead time. there should not be any tolerance on defects or defectives or delays

## **History**

The history of metal casting reaches back almost 5,000 years BC. A brief development of metal casting technology is given below:

**3200 B.C.** A frog made from copper metal, the oldest known casting in existence, was cast in Mesopotamia.

**233 B.C.** Cast iron plowshares are poured in China.

**500 A.D.** Cast crucible steel was first produced in India

**1455** The cast iron pipe to transport the water was used in Dillenburg Castle in Germany.

**1480** The Vannoccio Biringuccio "father of the foundry industry," in Italy is the first man to document the foundry process.

**1709** The first foundry flask for sand and loam molding was created by Englishman Abraham Darby.

**1809** A. G. Eckhardt of Soho, England developed the Centrifugal casting process.

**1896** American Foundrymen's Association (Now American Foundrymen's Society) was formed.

**1897** B.F. Philbrook of Iowa rediscovered the Investment casting process. Though the roots of investment casting process can be traced when bronze dancing girl found at Mohen-jo-daro around 3000 BC .

**1947** The Shell process was invented by J. Croning of Germany during WWII.

**1958** H.F. Shroyer was granted a patent for the full mold process.

**1968** The Coldbox process was introduced by L. Toriello and J. Robins for high production core making.

**1971** The Japanese developed V-Process molding. This method uses unbounded sand and the sand was bind by vacuum.

**1971** Rheocasting was developed at Massachusetts Institute of Technology.

### **Metal Casting History (India)**

**3000 BC** Earliest castings include the 11 cm high bronze dancing girl found at Mohen-jo-daro.

**2000 BC** Iron pillars, arrows, hooks, nails, bowls and daggers or were found in Delhi, Roopar, Nashik and other places.

**500 BC** Large scale state-owned mints and processes of metal extraction and alloying have been mentioned in Kautilya's *Arthashastra*

**500 A.D.** Cast crucible steel was first produced in India.

# **COURSE: METAL CASTING**

## **Module No. 1: INTRODUCTION**

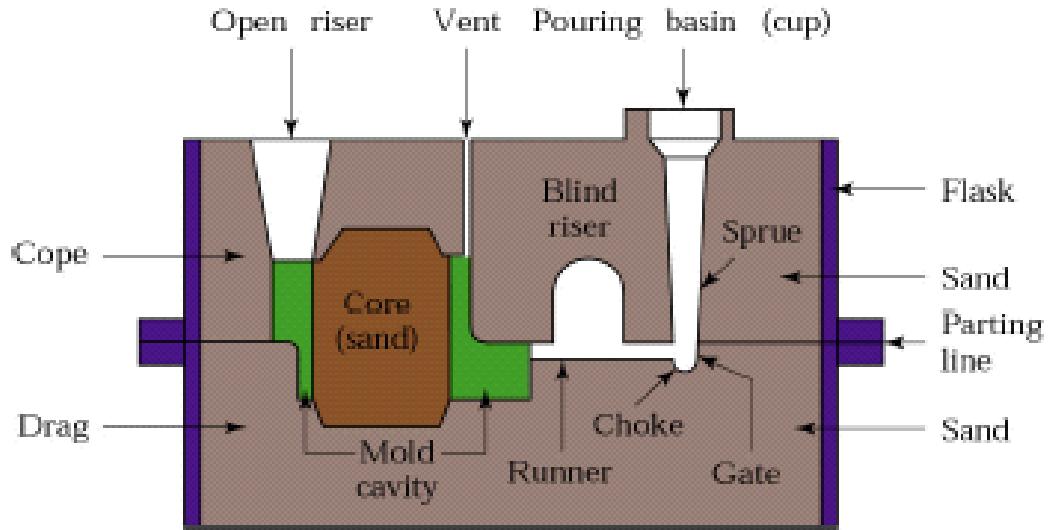
### **Lecture No-2**

#### **Terms and Steps in Sand Casting**

**Casting Terms (Click on the [Fig.1.2.1](#) to view)**

1. **Flask or molding box :** A frame made of metal or wood or plastic, in which the mold is formed. Lower molding flask is known as drag, upper molding flask as cope and intermediate molding flask, used in three piece molding, is known as cheek.
2. **Pattern:** The replica of the object to be cast is known as pattern. The cavity in the mould is created with the help of the pattern.
3. **Parting line:** The dividing line between the two molding boxes that makes up the mold.
4. **Molding sand:** Sand, which is sued for making the mould is called as molding sand. It is a mixture of silica sand, clay, and moisture in appropriate proportions. The molding sand must possess various properties such as permeability, flow ability, cohesive strength, etc.
5. **Facing sand:** In order to give a better surface finish to the casting, a small amount of fine carbonaceous material, known as facing sand, is usually sprinkled on the paring surfaces of the molding boxes.
6. **Core:** The part of mold, made of sand, used to create openings and various shaped cavities in the castings.
7. **Pouring basin:** A funnel shaped cavity at the top of the mold into which the molten metal is poured.
8. **Sprue:** The passage through which the molten metal flows from the pouring basin, and reaches the mold cavity. It controls the flow of metal into the mold.
9. **Runner:** The channel through which the molten metal is carried from the sprue to the gate.
10. **Gate:** A passageway through which the molten metal enters the mold cavity.
11. **Chaplets:** Chaplets are used to support the cores inside the mold cavity. The chaplets are used to prevent the core against buckling or metallostatic pressure.

12. Riser: The shapes of the Risers are like a sprue, which are placed at that part of the casting which is solidified in the last. the risers takes care of the shrinkage of the solidifying metal.
13. Vent: Small opening in the mold to facilitate escape of air and gases.
14. Drag: The bottom half of a horizontally parted mold.
15. Cope: The top half of a horizontally parted mold.
16. Draft: Slight taper given to a pattern to allow drawing from the sand.



**Fig. 1.2.1 : Mold Section showing some casting terms**

### Steps in Making Sand Castings

There are five basic steps in producing a sand castings:

1. Pattern making
2. Core making
3. Mold preparation
4. Melting of metal and its pouring
5. Finishing of casting

## **Pattern making**

The pattern is a physical model of the end product to be produced by metal casting process. It is an replica of the cast product. Several features depending upon the requirement of the end product and the type of metal are added in the pattern with an aim to produce a right casting. The pattern produced is used in the development of the mould to make the cavity in which the molten metal is filled through sprue and ingates.

## **Core making**

Hollow castings can be produced with the help of introducing the core in the cavity produced in the mold. Cores are usually made of sand, which are placed into a mold cavity to form the interior surfaces of castings.

## **Mould preparation**

Mold production is initiated by placing the pattern in the mould box and then the pattern is packed in sand aggregate. The sand aggregate consists of sand, binder and moisture. The sand aggregate is then rammed to make the mould dense and vents are produced, on the top surface of the mould, to let the gases generated after pouring the metal to escape.

## **Melting of metal and its pouring**

The preparation of molten metal for casting is referred to simply as melting and once the metal is melted its is poured in the molding box to produce the casting. however, depending upon the requirement, molten metal may or may not be treated or refined before pouring.

## **Finishing of casting**

After the solidification of casting in the mould, the molding boxes are opened and casting is knocked out from the sand aggregate. The solidified casting needs cleaning as the burned sand aggregate sticks on the casting surface. Also, vent wires, scales etc are need to be removed from the casting.

The flow diagram (generic) to produce a sand casting is shown in Figure 1.2.2.

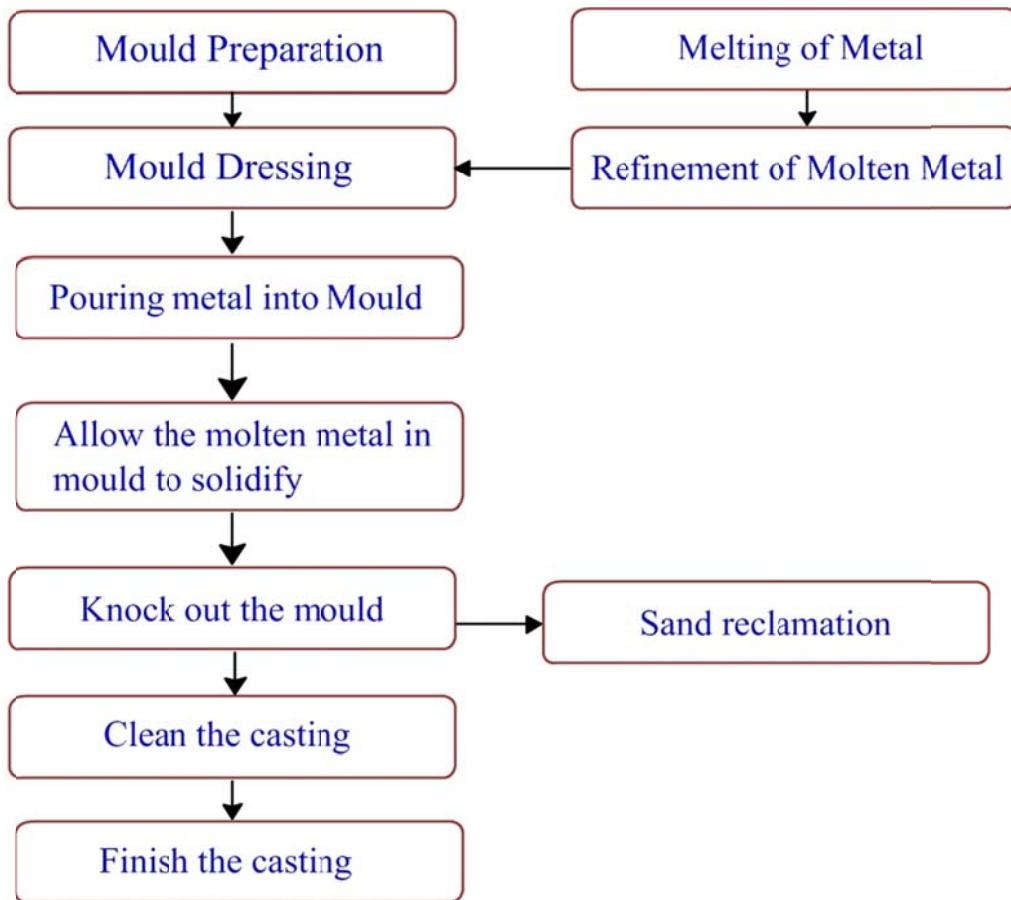


Fig. 1.2.2 The flow diagram (generic) to produce a casting

## **COURSE: METAL CASTING**

### **Module No. 6: PATTERNS**

#### **Lecture No-1**

#### **Patterns: Materials and Functions**

##### **Pattern (Click on [Fig. 6.1.1](#) to view a typical pattern)**

The pattern is not the exact replica of the object to be made by metal casting process but some modifications are provided on the pattern to take care of various process aspects such as shrinkage, hot tear, distortion, stress, core seat etc. For a hollow casting core patterns are needed to produce. The pattern can be made out of various material. The cost of the pattern is reflected on the cost of the casting. hence use of expensive pattern should be limited to the case when a large quantity of castings need to be produced.

##### **Functions of the Pattern**

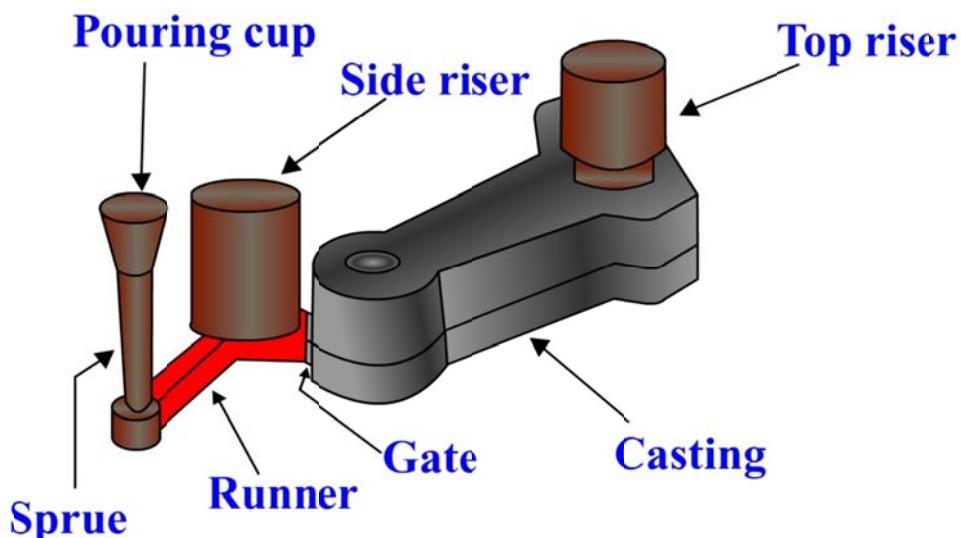
1. A pattern is used to prepares a mold cavity
2. For hollow casting core prints are added to the pattern to support the core in the mould cavity
3. Gates, Riser, and channels may become the part of the casting. however, in most of the cases they are not an integral part of the pattern
4. Efforts should be made to provide all allowances in a proper manner on the pattern and the surface of the pattern need to be made smooth. It results into less casting defects and low cost.
5. A properly constructed pattern minimizes the overall cost of the castings.

##### **Pattern Material**

The pattern can be made out of various material. Some of the materials used for making the patterns are wood, metals and alloys, plastic, plaster of Paris, plastic and rubbers, wax, and resins. the every material has its own advantages and disadvantages of being used as a pattern. In general the pattern material should posses the following characteristics:

1. Light in weight
2. Can be worked, shaped, and joined easily
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 wood is the most favorable pattern material because of its availability in abundance and low weight. Also, it can be easily shaped and is relatively cheap. The main disadvantage of wood is that it absorbs moisture, as a result there is possibility of distortion and dimensional changes in the pattern. Hence, if wood is being used as a pattern material, the wood need to be properly seasoned.



**Fig. 6.1.1: A typical pattern attached with gating and risering system**

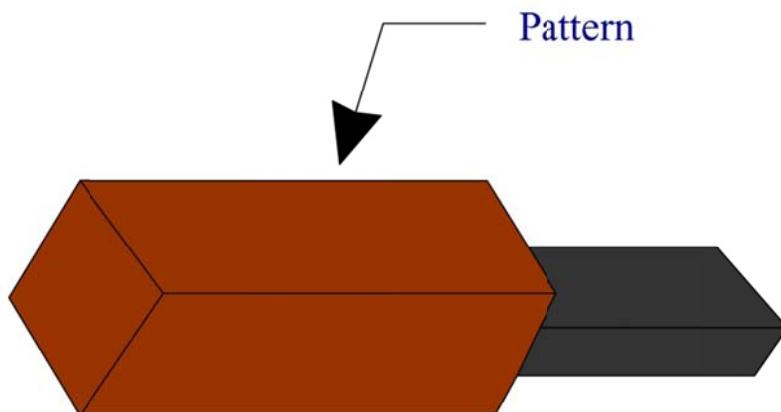
### Types of Pattern

Various types of patterns are being used in metal casting.

1. Single piece pattern
2. Split or two piece pattern
3. Match plate pattern
4. Cope and drag pattern
5. Gated pattern
6. Sweep pattern
7. Skeleton pattern
8. Loose Piece Pattern

### **Single Piece Pattern**

The single piece or one piece pattern is the most inexpensive of all types of patterns. This type of pattern is used where the object is simple and does not create any withdrawal problems. For prototype development a single piece pattern is most frequently used. This type of pattern is expected to be entirely in the drag and one of the surface is expected to be flat which is used as the parting plane. A typical one-piece pattern is shown in Fig.6.1.2

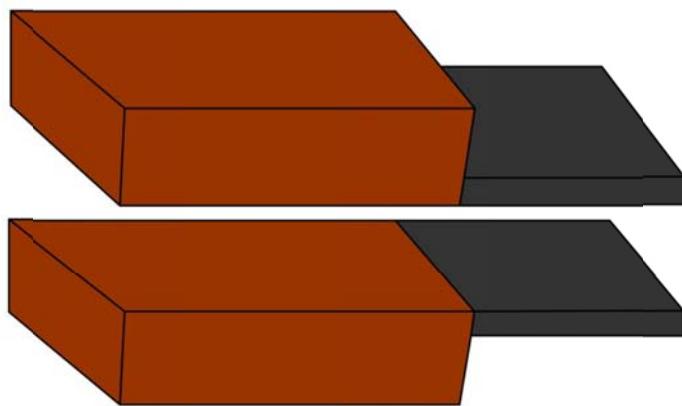


**Fig. 6.1.2: A Typical One Piece Pattern**

### **Split or Two Piece Pattern**

Two piece pattern is most common in metal casting industries. The pattern is split along the parting surface, the position of split is determined by the shape of the casting. One half of the

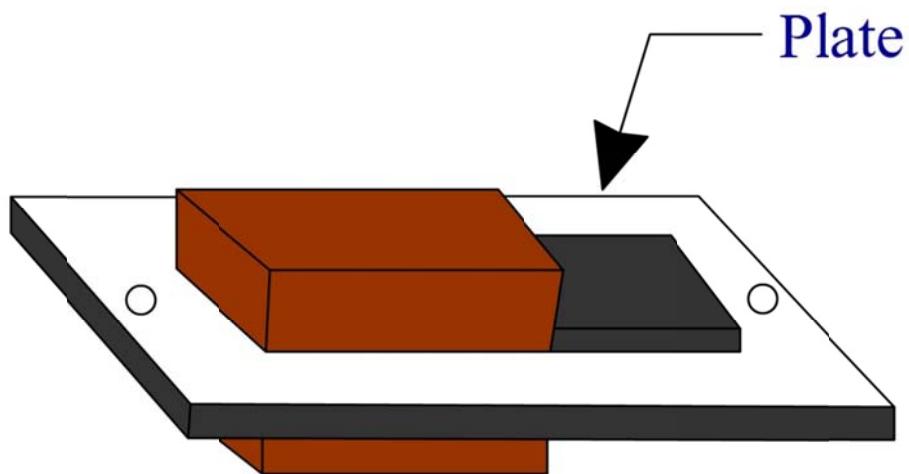
pattern is molded in drag and the other half in cope. The two halves of the pattern must be aligned properly by making use of the dowel pins, which are fitted, to the cope half of the pattern. These dowel pins match with the precisely made holes in the drag half of the pattern. A typical two piece or split pattern is shown in Fig.6.1.3



**Fig. 6.1.3 : A Typical Two Piece Pattern**

#### **Match Plate Pattern**

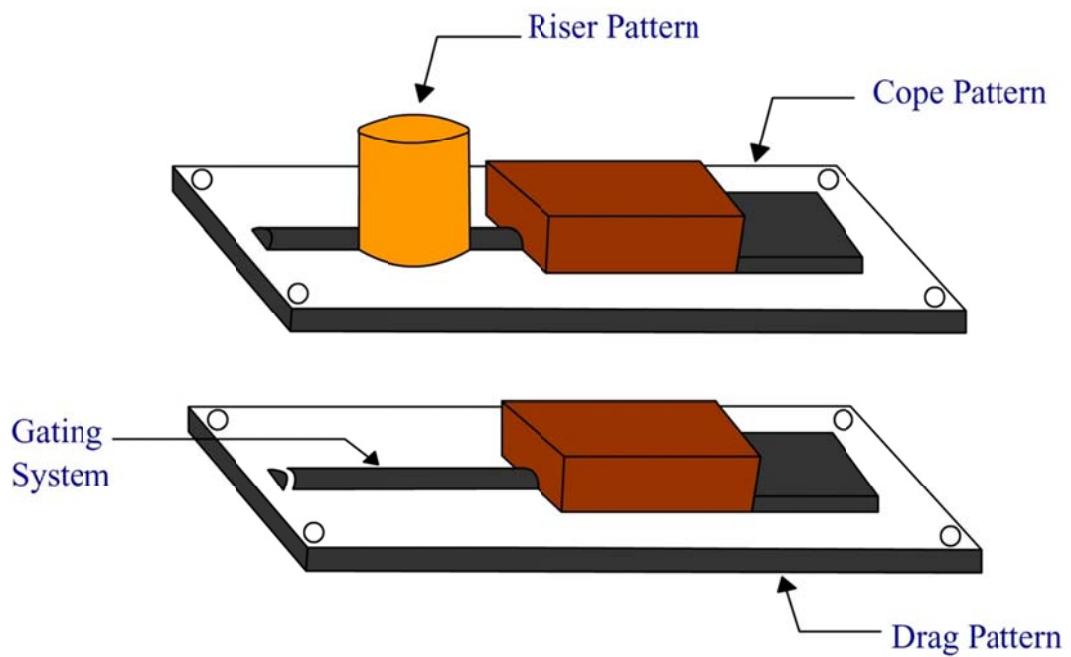
When there is requirement of large scale production of a small size casting, match plate pattern is a viable alternative. match plate pattern requires less time to adjust the location of the pattern in cope and drag. the cope and drag portion of pattern is mounted on a the opposite of wood or metal plate. Both the drag and cope can be prepared simultaneously by the use of the match plate pattern. A typical match plate pattern is shown in Fig. 6.1.4.



**Fig. 6.1.4 A Typical Match Plate Pattern**

#### Cope and Drag Pattern

The cope and drag parts of the pattern are mounted on a separate plate of wood or metal. Two different workers can use the individual pattern plate to produce the respective molding box, thus reducing the time for entire mould production. A typical match plate pattern is shown in Fig.6.1.5.



**Fig. 6.1.5 A Typical Cope and Drag Pattern**

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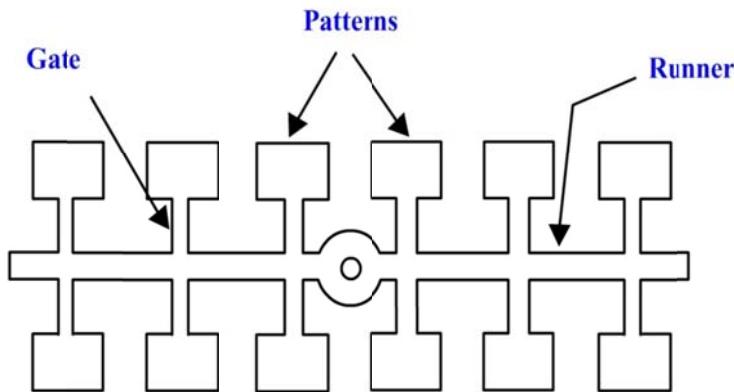
### **Module No. 6: PATTERNS**

#### **Lecture No-2**

#### **Pattern types and Design Considerations**

##### **Gated Pattern**

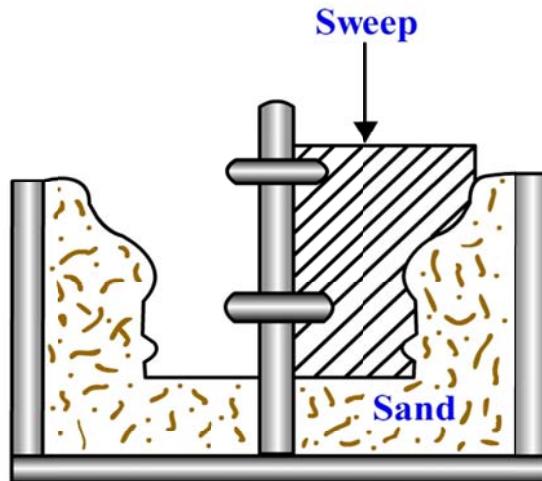
Many times it is desired to produce the multiple small parts in one go. In such case, small part cavities are created in one mould and these cavities are joined by the system of runners and gates. This arrangement helps to achieve higher productivity. Such type of pattern system is known as gated pattern. A typical gated pattern is shown in Fig.6.2.1.



**Fig. 6.2.1 A Typical Gated Pattern**

##### **Sweep Pattern**

For axi-symmetrical castings such as bells, the full cavity of the casting can be created by sweeping the pattern around the spindle. The pattern is a part of the full shape of the end product. Such patterns are known as sweep pattern and are preferred for producing large symmetrical shaped castings. A typical sweep pattern is shown in Fig.6.2.2.



**Fig. 6.2.2 A Typical Sweep Pattern**

### Skeleton Pattern

As the name of the pattern suggest, this type of pattern are made of strips of wood or plastic. These strips are used for building the Skeleton of the pattern giving the correct shape and size of the pattern. Around and inside Skeleton of pattern molding sand is packed. This type of pattern is used for very large casting. A typical Skeleton pattern is shown in Fig.6.2.3.

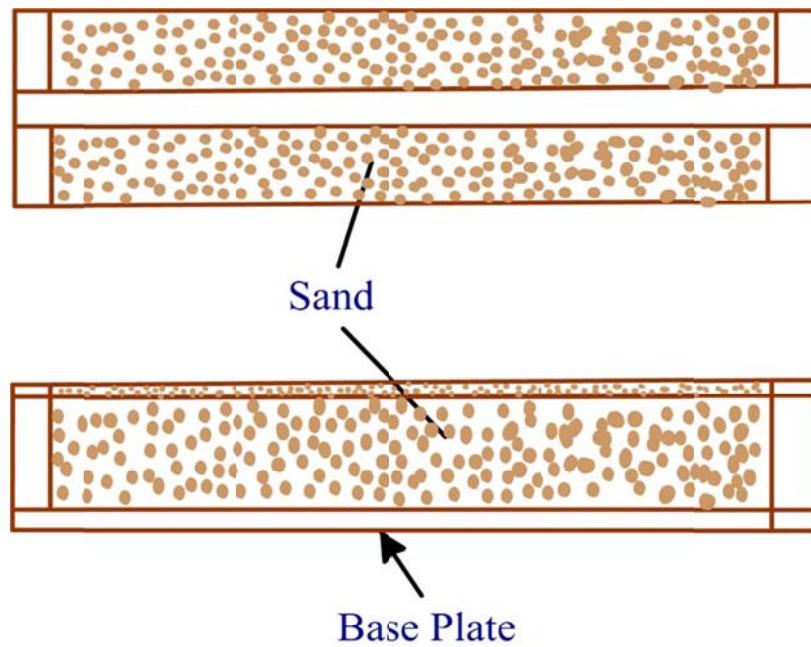
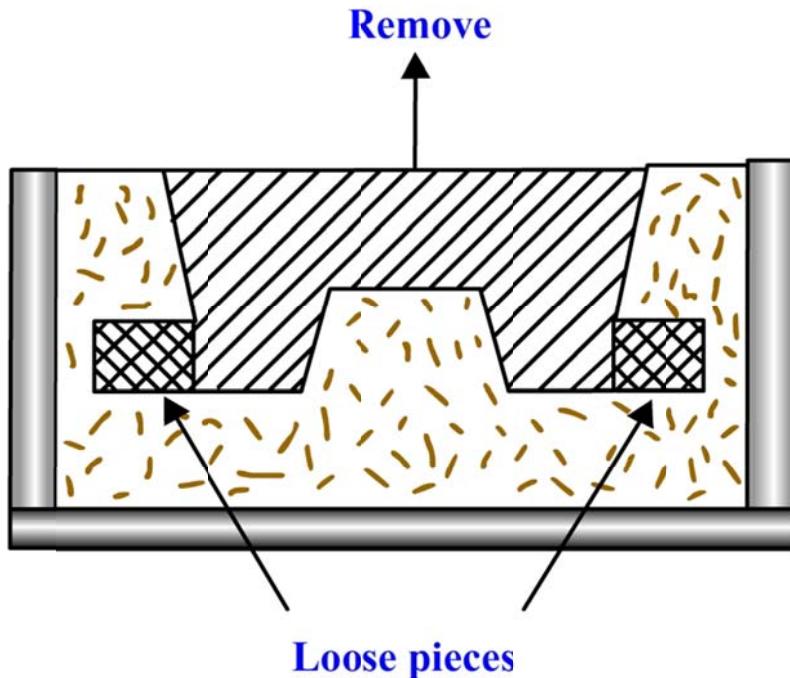


Fig. 6.2.3 A Typical Skeleton Pattern

### Loose Piece Pattern

Sometimes loose pieces need to be added with the pattern. These loose piece help to facilitate the pattern withdrawal from the mould. This type of pattern is used when the casting has projection, or undercuts. the projections and undercuts may create hindrance in the withdrawal of the pattern from the mould. Hence loos piece pattern is sued in such cases. A typical loose piece pattern is shown in Fig. 6.2.4.



**Fig. 6.2.4 A Typical Loose Piece Pattern**

### Pattern Design Considerations

#### Pattern Allowances

The liquid metal on solidification undergoes various type of shrinkages. this shrinkage may be because of metal characteristics and also may be because of pattern, gating, and risering design. The shrinkage affects the dimensional accuracy needed in the final casting. Hence, in order to get a correct casting, various allowance called pattern allowances need to put on the pattern before making the mold and subsequent pouring in the mould cavity.

Similarly the pattern allowances are also need to be provided on the core patterns. 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

### **Shrinkage or Contraction Allowance**

The metal when solidifies shrinks volumetrically. The metal shrinkage is of two types:

i. **Liquid shrinkage:**

After pouring the liquid metal in a mould, metal starts solidifying. When metal solidifies from liquid state to solidus temperature, there is reduction in volume of the liquid metal. This reduction is known as liquid shrinkage. The reduction in volume is compensated by the riser, which stores liquid metal and the metal in riser remains liquid later than that of metal in cavity.

ii. **Solid shrinkage:**

Once the casting is solidified in the mould cavity, the contraction in volume, when the temperature of the casting moves from solidus to room temperature, of the casting occurs. This contraction in volume is taken care by providing the shrinkage allowances in the pattern.

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. The various rate of contraction of various materials are given in [Table 6.2.1](#).

<b>Material</b>	<b>Dimension</b>	<b>Shrinkage allowance (mm/mm)</b>
Grey Cast Iron	Up to 610 mm	0.010
	610 mm to 1220 mm	0.009

	over 1220 mm	0.007
Cast Steel	Up to 610 mm	0.021
	610 mm to 1830 mm	0.016
	over 1830 mm	0.013
Aluminum	Up to 1220 mm	0.013
	1220 mm to 1830 mm	0.012
	over 1830 mm	0.010
Magnesium	Up to 1220 mm	0.014
	Over 1220 mm	0.013

**Table 6.2.1 Rate of Contraction of Various Metals**

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### **Module No. 6: PATTERNS**

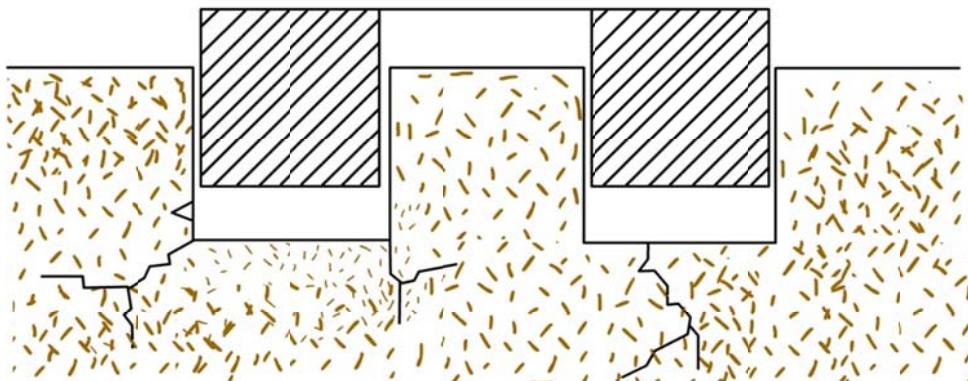
#### **Lecture No-3**

##### **Allowances and Guidelines in Pattern Making**

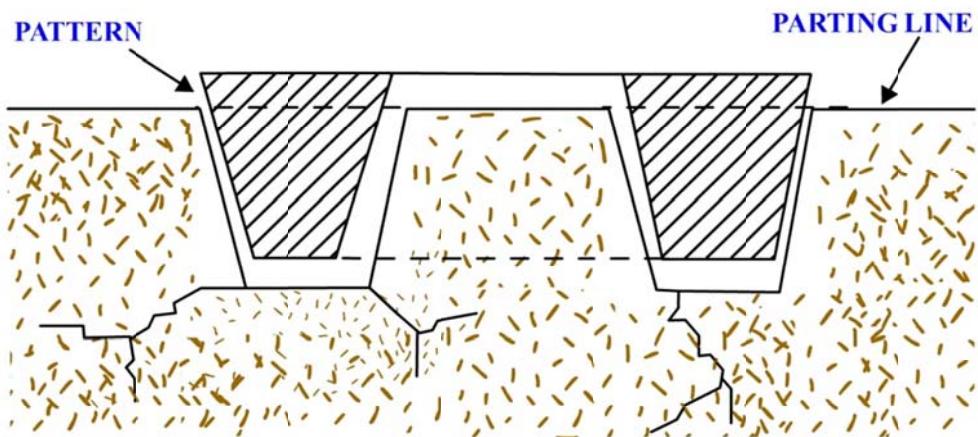
###### **Draft or Taper Allowance**

All the vertical surfaces of the pattern is provided with a taper allowance so that the pattern can be removed safely from the molding sand without tearing away the sides of the sand. This taper allowance is also known as draft allowance. [Fig. 6.3.1 \(a\)](#) shows a pattern having no taper allowance. In this case, till the pattern is completely lifted out, its vertical sides will remain in contact with the vertical walls of mold, thus tending to break it. [Fig. 6.3.1 \(b\)](#) is represents a pattern with taper allowance. In this case the mould wall does not break when the pattern is lifted out of the mould.

As a guideline, when the taper allowance is provided on the inner surfaces of the pattern, the allowance is generally higher than that of allowance which is provided on the outer surface. Also, the amount of taper allowance depends upon the length of the vertical side of the pattern to be removed from the molding sand. Table 6.3.1 provides a general guide lines for the draft allowance.



**Fig. 6.3.1 (a) Pattern Having No Draft on Vertical Edges**



**Fig. 6.3.1 (b) Pattern Having Draft on Vertical Edges**

Pattern material	Height of the given surface (mm)	Draft angle (External surface)	Draft angle (Internal surface)
Wood	25	3.00	3.00
	25 to 50	1.50	2.50
	50 to 100	1.00	1.50
	100 to 200	0.75	1.00
	200 to 800	0.50	1.00
Metal and plastic	25	1.50	3.00
	25 to 50	1.00	2.00
	50 to 100	0.75	1.00
	100 to 200	0.50	1.00
	200 to 800	0.50	0.75

**Table 6.3.1 Draft Allowances of Various Metals**

### Machining or Finish Allowance

The allowance provided on the pattern to take care of dimensional accuracy and surface finish of the end product is known as machining or finish allowance. Sand castings provide, in general, poor surface finish. In order to achieve the desired surface finish, the casting need to be machined. The allowance to take care of extra metal removed to achieve the surface finish is called the machining allowance. the machining or finish allowance depends upon the type of molding process, method of molding, shape and size of the casting, orientation of the different surfaces of the pattern in the cavity, degree of

finish desired, and metal of the end product. The machining allowances recommended for different metal is given in [Table 6.3.2](#).

Metal	Dimension (mm)	Allowance (mm)
Cast iron	Up to 300	3
	300 to 500	5
	500 to 1000	6.25
Cast steel	Up to 150	3
	150 to 500	6.25
	500 to 1000	7.50
Non ferrous	Up to 200	2.25
	200 to 300	3
	300 to 1000	4

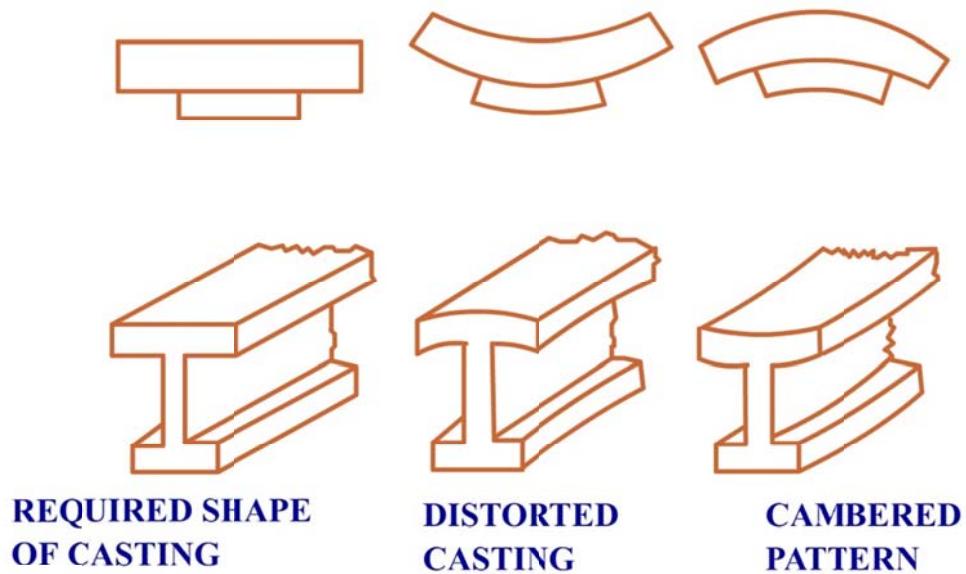
**Table 6.3.2 Machining Allowances of Various Metals**

### Distortion or Camber Allowance

The distortion in casting can also happen due to its 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 (Fig. 6.3.2). This allowance is known as distortion allowance.

The distortion in the casting, because of the shape of the casting may occur due to internal stresses, which are developed due to unequal cooling of different section of the casting and hindered contraction. Measure taken to prevent the distortion in casting include:

- 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 deflection)



**Fig. 6.3.2 Distortions in Casting**

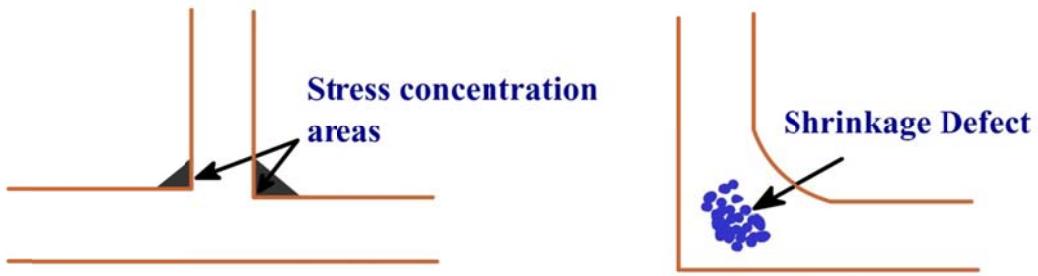
### Rapping Allowance

When a pattern is removed from the molding sand aggregate, the pattern is rapped all around its vertical sides. This rapping of the pattern is done to enlarge the mould cavity on its vertical sides so that the pattern removal from the mould becomes smooth. 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. It is a negative allowance and is to be applied only to those dimensions that are parallel to the parting plane.

### Some Guidelines for Making Patterns

1. Always try to avoid sharp angles and corners

Sharp angles and corner may result into either the internal shrinkage or tearing (stress concentration) at the corner points of the casting after the solidification as shown in 6.3.3. Hence, corner and sharp angles are provided with radii or while making mould, chills are provided and risers on such sections may be provided as indicated in 6.3.4.

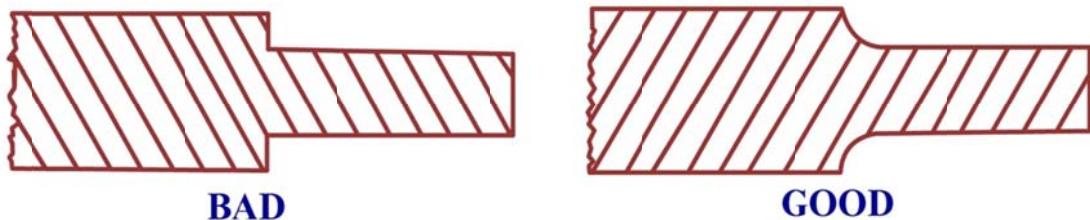


**Fig. 6.3.3 a and b Poor designs in patterns**



**Fig. 6.3.4 a and b Improved design in patterns**

2. Always avoid abrupt section thickness as shown in fig. 6.3.5



**Fig. 6.3.5 Different cross section designs**

3. Always try to design the section as uniform in thickness (section) as possible
4. Always avoid the section of casting of shapes as U, V, T, or L. If needed provide the reverse camber allowance as discussed above.

## **COURSE: METAL CASTING**

### **Module No.7: TESTING OF SAND**

#### **Lecture No-1**

#### **Sand composition, testing and material properties**

#### **Molding Sand Composition**

The main ingredients of any molding sand are:

- Base sand,
- Binder, and
- Moisture

#### **Base Sand**

The major component of a molding sand is the base sand. Silica sand is most commonly used base sand to prepare the green sand. Other base sands that are also used for making mold are zircon sand, Chromites sand, and olivine sand. Silica sand is cheapest among all types of base sand and it is available in abundance. The base sand plays an important role in controlling the surface roughness of the casting. The characteristics of the base sand such as size and its distribution affect the surface roughness of the casting and also affects the permeability i.e ability of the molding sand to escape out the gases from the mould cavity. Also, the base sand must be able to resist the temperature of the molten metal. In other words the fusion temperature of the molding sand should be higher.

#### **Binder**

Binders are of many types such as:

1. Clay binders,
2. Organic binders and
3. Inorganic binders

Clay binders are most commonly used binding agents mixed with the molding sands to provide the strength. The most popular clay types are: Kaolinite or fire clay ( $\text{Al}_2\text{O}_3\text{SiO}_2\text{H}_2\text{O}$ ) and Bentonite ( $\text{Al}_2\text{O}_3\text{SiO}_2\text{nH}_2\text{O}$ ). Amongst the two, the Bentonite can absorb more water which increases its bonding power.

### **Moisture**

The bonding action of clay activates in the presence of the required amount of moisture. Moisture in the form of water coats the surface of each flake of the clay. The moisture content in the clay should be in a controlled manner. Higher moisture will increase the plasticity and thus reduces the strength of the molding sand. Lower moisture content may result in less flowability of the molding sand resulting into poor packing of the molding aggregate around the pattern. A typical composition of molding sand is given in Table 7.1.1.

Molding Sand Constituent	Weight Percent
Silica sand	92
Clay (Sodium Bentonite)	8
Water	4

**Table 7.1.1 Typical Composition of Molding Sand**

### **Molding Material and its Properties**

The molding sand is used for making moulds and cores. Various types of molding sand are used in the metal casting industries. These sands include molding sand, backing sand, facing sand, parting sand, and core sand. These sands possess its own characteristics and properties. The most common type of molding sand properties are:

### **Refractoriness**

When liquid metal comes in contact with the sand mould, the sand may fuse. If the fusion temperature of the sand is low, it will fuse and lumps of the sand will be mixed with the metal. It is therefore required that the molding sand should have higher fusion point to avoid its fusion. The molding material must be able to withstand the temperature of the pouring liquid metal. This property of the sand is known as refractoriness. It is the ability of the molding material to resist

the temperature of the liquid metal to be poured so that it does not get fused with the metal. The refractoriness of the silica sand is highest (1700 degree centigrade).

### **Permeability**

When liquid metal is poured into the mould cavity, a large amount of gases are generated. These gases are generated because of the reaction of molding material with the liquid metal. The steam in the mold is generated because of the presence of moisture content. In addition, the liquid metal absorbs some gases from the atmosphere and on solidification of metal in the mould , these gases are also released. If these gases, due to reaction, due to moisture, and due to atmospheric gases, could not escape from the mould, it may be entrapped inside the casting and can cause various defects in the casting. Hence the mould must be able to escape these gases or it should be porous. The property of the molding sand which helps to escape the gases, is known as permeability. Higher the permeability of the molding sand better it is. Proper venting of the molding aggregate may also help in escaping the gases which are generated inside the molding aggregate.

### **Green Strength or Cohesiveness**

The molding sand constituents must be able to stick together. This property is known as green strength or cohesiveness. Higher the property better will be the strength of the molding aggregate. The higher strength is required in the molding aggregate to retain its shape as the molding aggregate is subject to metallostatic pressure.

### **Adhesiveness**

The molding aggregate should have the property of getting cling with the surface of the molding boxes. Otherwise, it will become difficult to transport the molding boxes from one place to the other.

### **Dry Strength**

As the hot liquid metal is poured into the mold, the moisture in the mold gets evaporated because of the heat of the liquid metal. The moisture is the source of activating the clay and thus helping

it to achieve the strength. After pouring, the sand becomes the dry strength as it loses the moisture. the dry stand should retain the strength till the first layer, that is the skin of the metal solidifies around the cavity at the same time it must be able to withstand the metallostatic pressure of the liquid material. This strength of the molding sand is called as dry strength.

### **Collapsibility**

When metal starts solidifying in the mould, it contracts. The molding sand should not hinder the contraction of the metal, otherwise the cracks in the casting may arise. To avoid the hindrance to the solidifying metal, the molding sand should posses high collapsibility properties.

Besides these specific properties the molding material should be cheap, reusable and should have good thermal conductivity.

## **COURSE: METAL CASTING**

### **Module No. 7: TESTING OF SAND**

#### **Lecture No-2**

#### **Clay, Moisture and Floability determination in green sands**

##### **Clay Determination of Green Sand**

The percentage of clay in a green sand sample can be determined by using Rapid Sand Washer (Type N) equipment manufactured by RIDSDALE-DIETERT. The equipment separates the clay particles from the sand grains in a sand by means of rapid agitation. The clay grade is held in suspension, removed by means of a siphon, and is determined by loss in weight. The Photograph of Rapid Sand Washer (Type N) is shown in Fig. 7.2.1.



**Fig. 7.2.1 The Photograph of Rapid Sand Washer (Type N)**

(Courtesy: Ridsdale & Co Ltd. ENGLAND)

##### **Testing Procedure**

1. Take a representative sample of moist sand weighing approximately 50 g.
2. Dry the sample, weigh accurately and place in the wash beaker.
3. Add 475 ml distilled water at room temperature and 25 ml of 1.5% w/v tetrasodium pyrophosphate solution (now recommended by the AFS as a deflocculant instead of

sodium hydroxide, which has a tendency to cause gelling problems preventing sand grains from settling properly).

4. Place the stirrer unit in the wash beaker.
5. Set the agitation period to 5 minutes
6. When the 5 minute period has elapsed and the motor stops. Remove the stirrer unit from the beaker, wash any sand grains which may adhere to the vertical baffles or agitator back into the beaker with distilled water. Fill the beaker with distilled water to the top line in such a manner that the contents are well stirred. Remove the beaker from the stand.
7. Set the settling time at 10 minutes.
8. When the first 10 minute settling period has elapsed, fill the siphon tube with water, and siphon clay/water suspension out of the beaker.
9. Fill the beaker to the top line with distilled water, stirring the sediment on the bottom and allow to settle for a second 10 minute period.
10. Siphon off the suspension when the 10 minute settling time has elapsed. Refill to the top line, allow to settle for 5 minutes and siphon off the suspension.
11. Repeat the process of 5 minute standing and siphoning until the water is clear at the end of a 5 minute settling period.
12. Siphon off the clear water and decant as much of the remaining water as possible without losing any sand grains.
13. Place the beaker in an oven at 105 °C – 110 °C and dry the sand grains. Transfer the sand grains from the beaker to a suitable balance.
14. Weigh and subtract the weight obtained from the original weight of dry sand. Divide this weight by the original weight of dry sand, multiply by 100 and express as percentage AFS clay.

### **Moisture Determination of Green Sand**

The percentage of moisture in a green sand sample can be determined by using Moisture Teller. A weighed representative sample of the moist material is placed in a special pan with fine gauze base and hot air at a thermostatically controlled temperature is blown through it for a pre-determined time to remove the moisture. When all the moisture has been removed the sample

pan and contents are rapidly cooled and re-weighed. The loss in weight is read directly as percentage moisture on the dial. The Photograph of Moisture Teller is shown in Fig. 7.2.2



**Fig. 7.2.2 The Photograph of Moisture Teller**

(Courtesy: Ridsdale & Co Ltd. ENGLAND)

### **Green Sand Sample Preparation**

For the determination of compression, tensile, transverse, shear and splitting strength of green sand, a sample of 50 mm  $\Phi$  x 50 mm need to be prepared. The sample of green sand can be prepared by compacting a predetermined weight of sand in a tube, or a core box of the required shape. This is achieved by dropping a known weight a fixed distance, and using the energy produced to compact the sand. The Photograph of sand Rammer to prepare the required sample is shown in Fig. 7.2.3. The green sand is filled in the tube and placed under the rammer and rammed with three drops of the sliding weight. Remove the sample from the tube. For

permeability and shatter index, sample need not to be removed from the tube after ramming three times.



**Fig. 7.2.3 The Photograph of Sand Rammer**

(Courtesy: Ridsdale & Co Ltd. ENGLAND)

### **Flowability Determination of Green Sand**

The flowability determination of green sand can be done by attaching a dial gauge, as shown in Fig. 7.2.4, on the sand rammer. This gauge measures the ability of a sand to flow and fill up mould interstices when subjected to ramming.

### **Testing Procedure**

1. Prepare a metric standard 50 mm diameter test specimen of moulding sand with three drops of the rammer weight.
2. Ram with a fourth drop of the weight and set the Indicator into position so that the ball point of the stem comes in contact with the plunger of the rammer. Set the bezel of the Indicator to read zero.

3. Ram a fifth time and record the reading on the Indicator as percentage Flowability. If the plunger does not descend any further, this indicates that the sand has “flowed” as far as possible with the initial four rams, hence the flowability is 100%.



**Fig. 7.2.4 The Photograph of dial Gauge fixed on Sand Rammer for flowability Measurement**

(Courtesy: Ridsdale & Co Ltd. ENGLAND)

## **COURSE: METAL CASTING**

### **Module No. 7: TESTING OF SAND**

#### **Lecture No-3**

#### **Compactability, Shatter index, Compression strength and Permeability in Green sands**

#### **Determination of Compactability of Green Sand**

The compactability test is carried out in conjunction with a metric Sand Rammer. This test measures the decrease in height of a riddled mass of sand, 120 mm high, under the influence of a standard compacting force. By this means the degree of temper of a sand can be measured and the water requirements determined. The Photograph of Comapactability Tester is shown in Fig. 7.3.1

#### **Testing Procedure**

1. Position a specimen tube and pedestal cup on the tube filler beneath the funnel outlet.
2. Pass the sand to be tested through the screen until the specimen tube is filled.
3. Strickle the sand level with the top of the tube.
4. Remove the specimen tube and pedestal cup and place in position on the sand rammer.
5. Lower the plunger gently onto the sand and ram with three blows.
6. Read percentage compactability as indicated by the position of the top of the plunger shaft on the scale.



**Fig. 7.3.1 Photograph of sand Funnel and Compactor Scale fitted on Sand Rammer**

(Courtesy: Ridsdale & Co Ltd. ENGLAND)

### Determination of Shatter Index of Green Sand

A Standard 50 mm diameter x 50 mm height specimen of moulding sand is allowed to free fall from a height of 1.83 metres onto a steel anvil of a Shatter Index tester, shown in Fig. 7.3.2. Weigh the sand in the receiver and calculate the weight of sand remaining on the sieve, by subtracting this weight from the total weight of the specimen.

$$\text{Shatter Index} = \frac{\text{Wt. of sand remaining on } 13.2 \text{ mm mesh sieve}}{\text{Total wt. of (sand) specimen}} \times 100$$

Total wt. of (sand) specimen



**Fig. 7.3.2 Photograph of the Shatter Index tester**

(Courtesy: Ridsdale & Co Ltd. ENGLAND)

**Determination of Compression Strength of Green Sand**

The Compression strength of the green sand specimen of size 50 mm diameter x 50 mm height can be found by using Green Compression Strength Machine shown in Fig. 7.3.3. The machine is designed to determine compression strength of prepared specimens of green sands and unbaked core sands by applying a progressively increasing spring load to the specimen until it collapses. The compression strength can be noted down directly from the dial of the machine.



**Fig. 7.3.3 The Photograph of Green Compression Strength Machine**

(Courtesy: Ridsdale & Co Ltd. ENGLAND)

### **Determination of Permeability of Green Sand**

Permeability is defined by the AFS as that physical property of moulded sand which allows gas to pass through it. It is determined by measuring the rate of flow of air through the metric standard rammed specimen under a standard pressure.

The general formula for the calculation of permeability may be expressed as follows :-

$$P = \frac{v \times h}{p \times a \times t}$$

Where

P = Permeability number

v = Volume of air in ml passing through the specimen

h = Height of test specimen in cm.

p = Pressure of air in cm of water.

a = Area of cross-section of specimen in  $\text{cm}^2$ .

T = Time in minutes.

Since the standard method requires that 2000 ml of air should be forced through a specimen 50 mm (5.0 cm) and 50 mm diameter (19.63 cm<sup>2</sup> area), by substituting these values for v, h, and a, and measuring the time in seconds, the formula becomes :-

$$P = \frac{30557}{pxt \text{ (in seconds)}}$$

the permeability of the moulding sand can be determined by using the above formula. The parameter that need to be determined from the permeability meter are pressure and time in seconds. The photograph of permeability meter is shown in Fig. 7.3.4.



**Fig. 7.3.4 The Photograph of Permeability Meter**

(Courtesy: Ridsdale & Co Ltd. ENGLAND)

**Note:** Various other sand tests can also be conducted. these tests include permeability determination, surface area determination, Tensile strength etc. For more details one can see the testing equipment catalogue and procedure provided by Ridsdale & Co Ltd. ENGLAND at their website.

## **COURSE: METAL CASTING**

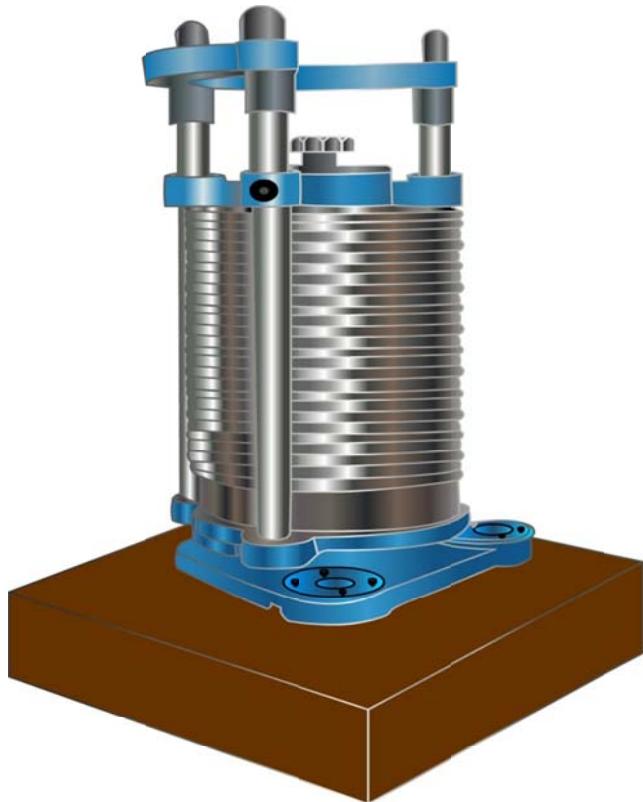
### **Module No. 7: TESTING OF SAND**

#### **Lecture No-4**

#### **Size and AFS number determination in sand testing**

#### **Determination of Size and Distribution of Base Sand**

The base sand is the left out aggregate after removal of clay and moisture from the sand aggregate. To determine the size and distribution of the base sand, sieve analysis is performed. The sieve analysis is carried out in a sieve shaker shown in figure 7.4.1. The sieve shaker consist of a nested column of sieves with wire mesh. A pan is being placed underneath the last sieve. A sample of weighted sand is put on the top the top sieve of the stack of sieves as per BS410:1986 standard. the sieve shaker is operated for 15 minutes. After this operation the sand is collected from each sieve and weighted. the percentage of sand accumulated on each sieve is then calculated and multiplied by the factor as given in the example shown in the table 7.4.1



**Fig: 7.4.1 Sieve Shaker**

Sieve Number	Sand Retained	% Retained	Multiplying factor	MF * % retained
12	0.8	1.6	5	8
20	0.24	0.48	10	4.8
30	0.1	0.2	20	4
50	1.6	3.2	40	128
70	12.8	25.6	50	1280
100	15.4	30.8	70	2156
140	10.8	21.6	100	2160
200	2.8	5.6	140	784
270	0.5	1	200	200
Pan	0.1	0.2	300	60
Total	45.14	90.28		6784.8
Clay	4.86	9.72		
Total	50.00 gm	100		

**Table 7.4.1 Determination of AFS Number**

The grain fineness number (AFS number) can be calculated by dividing the sum of the last column of the table 5 by 100. The AFS number of the base sand, calculation shown in the table 7.4.1 is 67.84

Average grain size of the base sand =  $25.4 / (2 * \text{AFS number})$

Average grain size =  $25.4 / 67.84 = 0.374 \text{ mm}$

The shape or the coefficient of angularity can be ascertained by using RIDSDALE-DIETERT Sand Specific Surface Tester, shown in Figure 7.4.2.



**Fig. 7.4.2 The Photograph of Sand Specific Surface Tester**

(Courtesy: Ridsdale & Co Ltd. ENGLAND)

## **Module No. 9 : ADVANCED METAL CASTING PROCESSES**

### **Lecture No-1**

#### **Evaporative Pattern Casting process (EPC)**

The Evaporative Pattern Casting Process is also known by several other names such as Full Mold Process, Lost Foam Process etc.

H.F. Shroyer patented the foam patterns for metal casting on April 15, 1958. In this patent, expanded polystyrene (EPS) block was used by him to machine the pattern and during pouring, it was supported by bonded sand. This process is called as full mold process. In the full mold process, the pattern is usually machined from an EPS block and is used to make large one-of-a kind castings primarily. Originally this process was also known as ‘lost foam process’.

M.C. Flemming in 1964, used unbounded sand with the process. This is known today as lost foam casting (LFC). With LFC, the foam pattern is molded from polystyrene beads. LFC is differentiated from full mold with the use of unbounded sand (LFC) as opposed to bonded sand (full mold process).

The Evaporative pattern casting process (EPC) process is a binder less process and no physical bonding is required to bind the sand aggregates. Foam casting techniques have been known by a variety of generic and proprietary names such as lost foam casting, evaporative pattern casting, cavity less casting, full mold casting and evaporative foam casting. In this method, expanded polystyrene is used to prepare the complete pattern including the gates and risers. This pattern is further embedded in a sand of no bake type. The molten metal is poured through the sprue, while the pattern is still inside the mold. The heat of the molten metal is sufficient enough to gasify the pattern and the pattern progressively gets displaced by it.

Using unbounded sand and expandable polystyrene pattern, the EPC process is a very economical method in producing complex, close-tolerance castings. The expandable polystyrene can be molded into numerous complex and rigid shapes and it is basically a thermoplastic material. In the EPC process, expandable polystyrene patterns are attached to an expandable polystyrene gating system and a refractory coating is applied to the entire assembly. Once the coating gets dried, the entire foam pattern assembly is kept on loose dry sand in a vented flask. The flask is vibrated and additional sand is added to it until the pattern assembly gets completely embedded in sand. Molten metal is then poured into the sprue which further vaporizes the foam polystyrene and reproduces perfectly the used pattern to get the required casting.

In this process, a pattern used refers to an expandable polystyrene or foamed polystyrene part which gets vaporized by the molten metal. For every casting process, a new pattern is required.

### **Advantages of EPC Process**

- In the EPC process, no cores are required making it the most advantageous.
- No requirement for binders or other additives, as it is a binder less process
- Complete sand reclamation is possible using very simple and inexpensive techniques
- Sand shake out is easy as the sand is unbounded
- Since the pattern used in EPC process is one piece, hence no parting line and since cores are eliminated, hence no core prints. Also, no mismatch, core shift because of the mentioned reasons
- Improved casting quality. Close tolerances are possible
- The EPC is an environmentally favorable process
- As it is a binder less process, the efforts on cleaning the molded sand are virtually nil. Therefore, the EPC process is viewed as a value-added process rather than a substitute for sand casting.

### **Disadvantages / Limitations of EPC Process**

- Since every casting requires a new pattern, it is a costly process
- There is a limitations on the minimum section thickness of the pattern
- Quality of the casting fully depends upon the quality of the pattern
- As the sand is unbounded, during pouring, due of the difference in the evaporation rates of the pattern material and the flow rate of the metal, the sand falls down in the generated cavity generated, thereby leading to a defective casting.

### **Application of EPC Process**

- It is used for making automotive components (cylinder heads, engine blocks, inlet manifolds, heat exchanger ,crank shaft)
- It is used in marine, aerospace and construction industries

## **Module No. 9 : ADVANCED METAL CASTING PROCESSES**

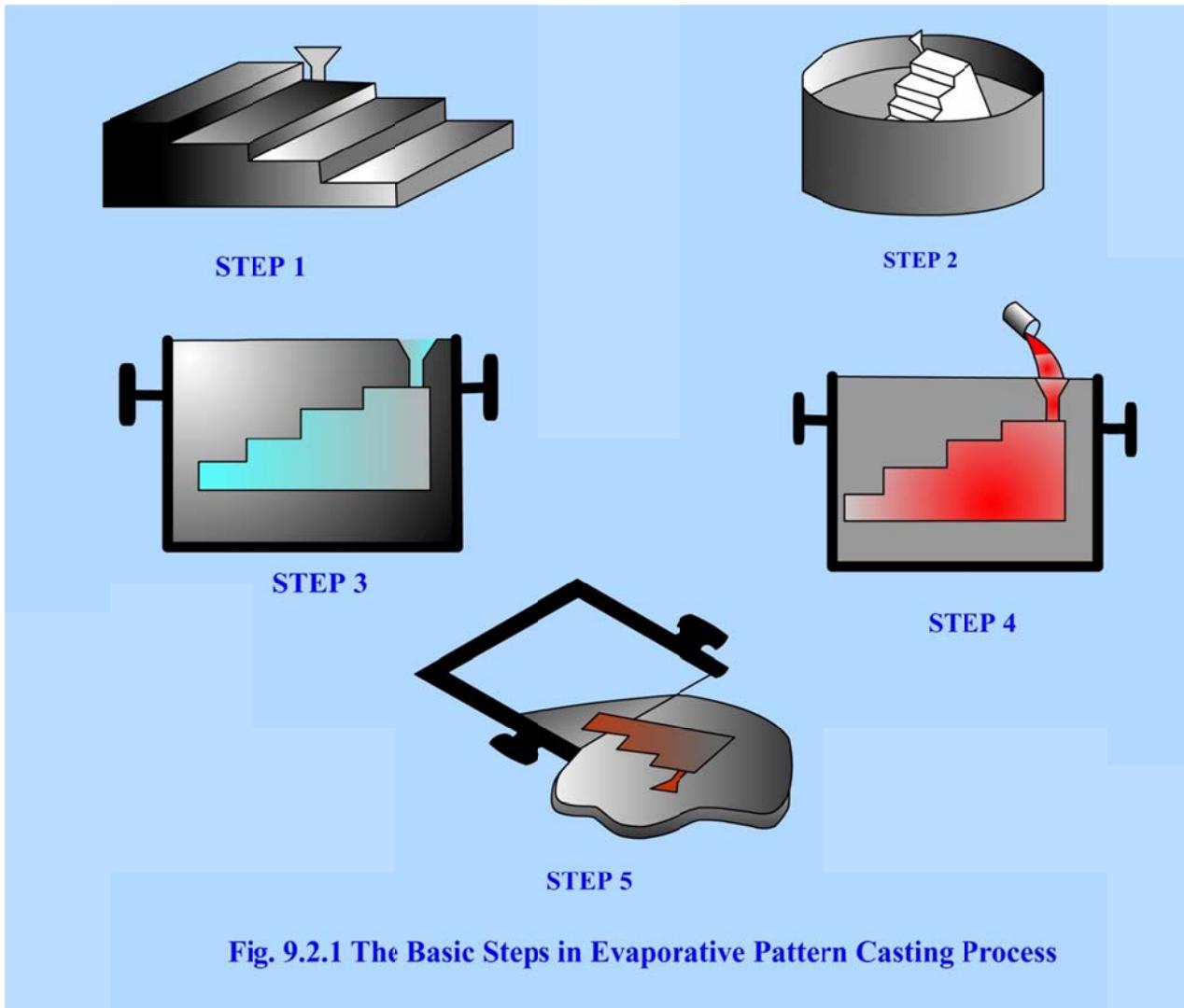
### **Lecture No-2**

#### **Processing Steps, Requirements and Variables in EPC**

##### **Process Description**

(Click here [Fig. 9.2.1](#))

1. The process of EPC starts with the pre-expansion of polystyrene beads. Once these pre-expanded beads get stabilized, pattern sections are formed by blowing them into a mold. A cycle of steam is used to fully expand and make the beads fuse in the mold itself.
2. Clusters are formed through assembly of the pattern sections using glue. The gating systems are also similarly glued and attached.
3. Ceramic coating is used to cover the foam cluster. The coating acts as a barrier preventing the penetration and sand erosion during pouring.
4. Once the coating gets dried, the cluster is placed in a flask along with backing of the bonded sand. Any suitable sand can be used as long as it resists the temperature of the molten metal being poured. Silica sand, zircon sand, olivine sand and chromites can be used as molding sand. The EPC process has high degree of sand re-clamation hence we can use zircon or chromite sands, which are otherwise considered expensive. The strength of mold can be determined through the frictional resistance between the sand grains. The mould strength with angular grains is higher although higher bulk density is provided by the rounded grains.
5. Inorder to ensure uniform and proper compaction, a vibrating table is used in the mold compaction. After completing this process, the cluster is packed in a flask and the mould is set ready for getting poured.



**Fig. 9.2.1 The Basic Steps in Evaporative Pattern Casting Process**

### Pattern

The patterns used in EPC process are made of Expendable Polystyrene (EPS). Pattern fabrication starts with the pre-expansion of polystyrene beads. They are blown into die cavity to form pattern sections. When the beads are in the die, a steam cycle causes them to fully expand and fuse together. A photograph of a simple pattern made by polystyrene beads is shown in Fig. 9.2.2

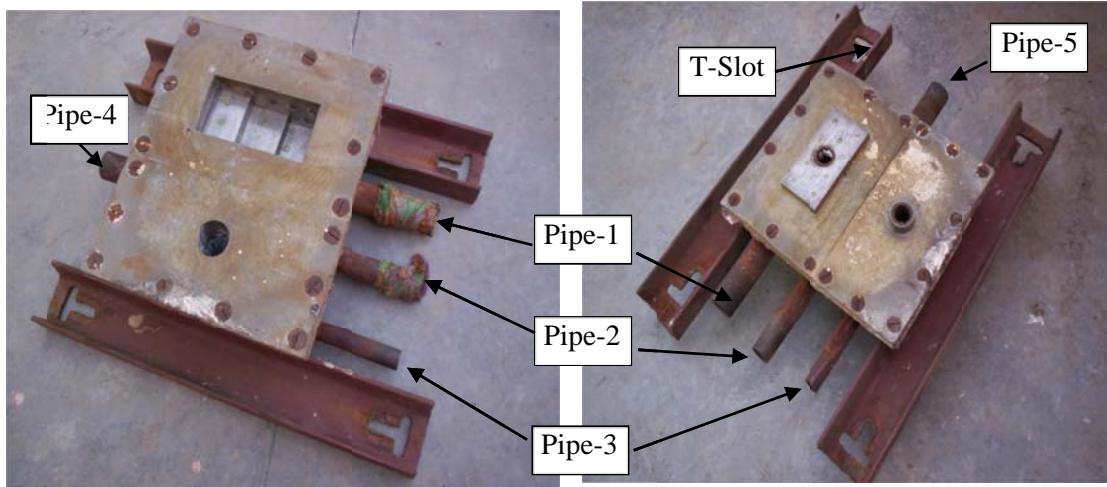


**Fig. 9.2.2 A Polystyrene Pattern**

### **Polystyrene Pattern Die**

For the fabrication of stepped pattern, die and sprue, a cavity as per the pattern dimensions was prepared. Aluminum was used as the die material. The complete die is fabricated in two parts, called male and female. Three inlet pipes (nos. 1, 2 and 3) and one outlet pipe (no. 4) are attached with male and female parts, as shown in Fig. 9.2.3.

([Click here](#) **Fig. 9.2.3**). The function of all three inlet pipes is same in male and female parts. The two outermost pipes (nos. 1 and 3) are used to supply the water as cooling agent in the die and the middle pipe (no. 2) is used to supply the steam into the cavity through pin holes to soften and expand the beads. Pipe 4 is used to draw water and steam from the die. Polystyrene beads are fed into the die cavity through a pipe which is connected at the top of the male part. At the four corner of the die, T slots are fabricated to hold both male and female parts of the die in the press.



**Fig. 9.2.3 Photographs of Expandable Polystyrene Pattern Die**

### **Pattern Density and Bead Size**

Density and bead size play important role in evaporative pattern casting process. In order to minimize the amount of gases evolved during vaporization of the pattern, patterns with low density are used. This ensures that the gases escape out through the coatings, sand, and vent into the atmosphere. If the gas forms faster than it can vent, a defective casting will be formed. Gas formation is a function of pouring temperature of the metal and the pattern density. If the pattern density is increased then at a constant pouring temperature, more gas is formed. If the pattern density is held constant and the pouring temperature is increased, more gas will be formed since the polystyrene molecules get broken down into many more basic molecules at the higher temperatures. The gases formed should pass through the coating on the pattern surface. The pattern density generally varies between 1 and 1.5 pcf which further depends on the geometry and metal that is being poured. Small beads are required for obtaining relatively non-beady, smooth surfaces on the molded patterns.

### **Requirement of Refractory Coating Material**

As the coatings are an inherent part of the casting process and also give a good quality surface to the casting, some specific demands, as mentioned below are desired for the refractory coatings in the application of evaporative pattern castings process :

- Highly permeable coating is preferred for rougher sand while medium and low permeable coating is used for finer sand.
- Quick drying preferred.
- Coating should get easily stuck to the pattern, and there should be possibility of controlling and adjusting coating layer thickness.
- Appropriate strength, resistance to abrasion, resistance to cracks during storage, resistance to bending and deformation during mould making.
- In cases where rough sands are used for molding at high temperatures, thicker refractory coating layers are required.

In cases where rough sands are used for molding at high temperatures, thicker refractory coating layers are desired.

### **Coating material**

The refractory coating plays an intimate role in the EPC process. Its function is to provide a refractory protection and seal any penetration of metals. It should also provide smooth surfaces and act as a membrane between the polystyrene pattern and the sand mass which is not-bounded. As the sand mass is not-bounded, it should be firmly held in place, till the polystyrene foam pattern gets decomposed under the effect of the molten metal stream which is entering. This is achieved by allowing the permeability of the refractory coating to restrict the free flow of decomposition gases and liquids through the coating into the unbounded sand mass. This causes a back pressure against the entering molten metal stream resulting in a pressure force that holds the unbounded sand in place. The gases that are escaping into the sand mass and its control is done through appropriate selection of the coating material along with the required permeability characteristics.

In order to obtain a variety of properties imperative to the casting process such as thermal insulation, abrasion resistance and liquid absorption, the coating is engineered.

There are several types of refractory coatings available to be used on evaporative pattern. The requirements from the refractory coatings have been enumerated above. Some of the coating materials are zircon sand, kaolin and talc. The coating generally recommended in

case of cast iron is iron powder, as it prevents the metal penetration. Siliminite, quartz, and aluminum silicate can be used as filler materials to make the coating cost effective.

### EPC Process Variables

To identify the process variables which can have a major effect on the quality of Evaporative Pattern Casting (EPC) process, an Ishikawa Cause and Effect diagram is drawn and shown in Fig. 9.2.4.

The EPC process variables can be grouped in the following categories:

- Variables based on Molding sand: Type of sand, shape of the sand grains, grain size and size distribution.
- Variables based on pattern: Density and size of pattern beads
- Variables based on pattern coating: Slurry material-base, filler, additives, and coating thickness
- Variables based on vibration : Amplitude of vibration, time of vibration and frequency of vibration
- Variables based on pouring : Pouring time and temperature

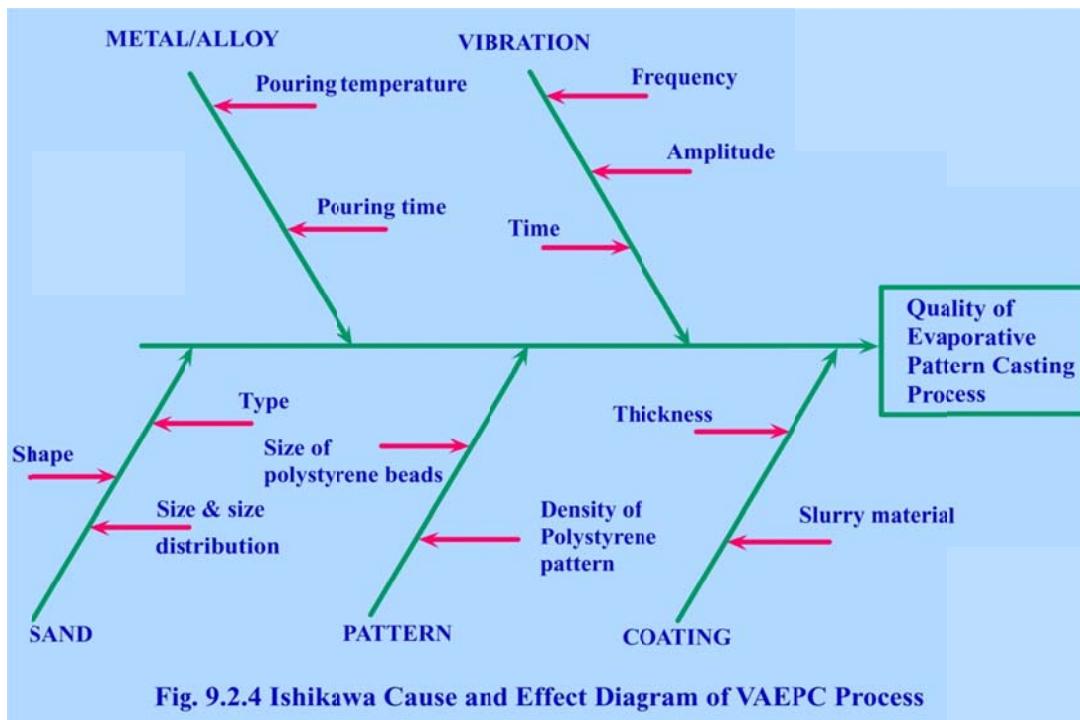


Fig. 9.2.4 Ishikawa Cause and Effect Diagram of VAEPC Process

## **Module-9: ADVANCED METAL CASTING PROCESSES:**

### **Lecture No-3**

#### **Hybrid EPC (Vacuum assisted Evaporative Pattern Casting Process)**

One of the limitations of EPC process is that the sand, which is free flowing, falls on the unfilled casting before the final solidification. This happens because the rate of evaporation of polystyrene pattern is higher than the metal flow rate. Pattern vaporizes ahead of the flowing stream of the metal because of the radiant heat generated from the hot metal. As a result, the sand falls in the cavity and in turn produces a defective casting.

This problem has been overcome by combining the process sequence of EPC and vacuum sealed molding process.

#### **Vacuum Assisted Evaporative Pattern Casting Process (VAEPC)**

The concept of hybrid casting process is introduced with an aim to achieve better performance of the advanced casting processes. The reason for developing hybrid-casting processes is to make use of combined or mutually enhanced advantages and to avoid or reduce some adverse effects (if any) of the constituent processes when they are individually applied. The Evaporative pattern casting process (EPC) is a binder less process wherein physical bonding is required to bind the sand aggregates. The process however, does not guarantee a sound casting every time as it becomes difficult to control the rate of pouring so as to match with the rate of polystyrene burning. To overcome this effect, EPC process is combined with the Vacuum Sealed Molding process (V-process). In the V-process, the physical bonding is achieved by using pressure or vacuum in the molds. The vacuum system when used with EPC process helps in withdrawing the decomposed gases and it also helps in providing rigidity to the sand mould.

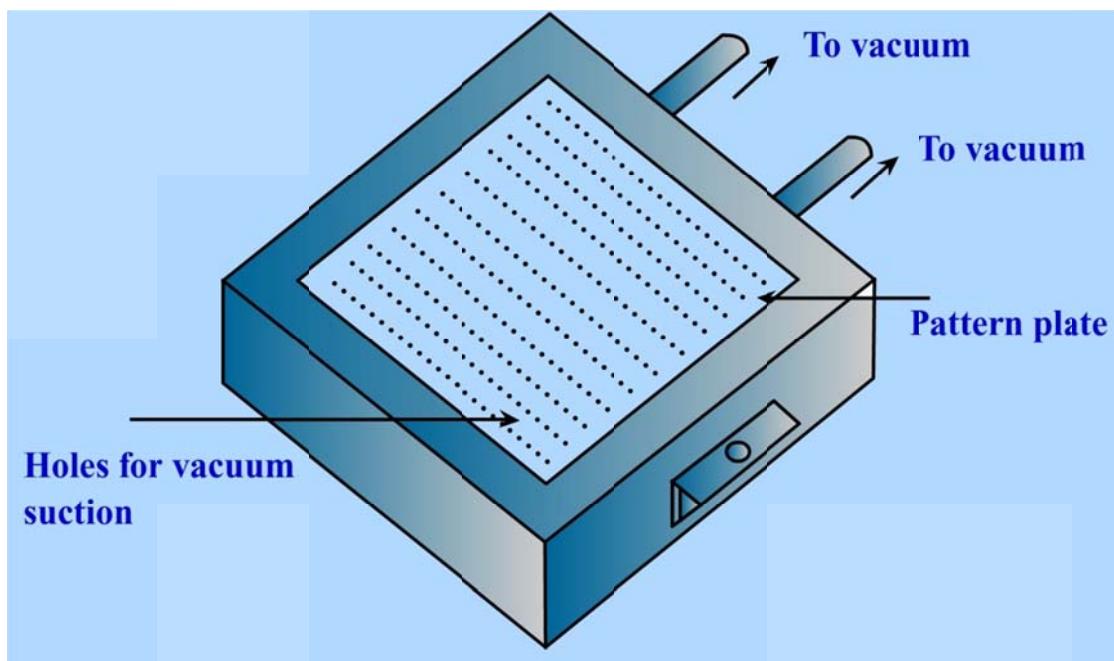
#### **Additional (other than EPC process) requirements for Vacuum Assisted Evaporative Pattern Casting Process (VAEPC)**

In VAEPC process, there is a need to have a special pattern and molding box. The details of these special pattern and molding boxes are given in the lectures related to Vacuum

sealed molding process (V-Process). Similarly as in the V-Process, there is a need to have an arrangement for vacuum generating system to apply vacuum in the pattern and molding boxes, VAEPC process also uses such an arrangement. The details of the vacuum system are also given in the lectures related to V-Process.

### The Pattern Box

The pattern box is shown in Fig. 9.3.1. The pattern plate is placed on the straight top open surface of the pattern box and perfect matching between the mating surfaces is achieved. In order to ascertain the perfect matching, the pattern plate is provided with four support blocks at the four corners in the pattern box. Additional support at the centre has been provided to prevent warping of the pattern plate when subjected to vacuum pressure. The pattern box is fixed to the vibrating table. A pattern plate, having small holes at equidistant places can be used.

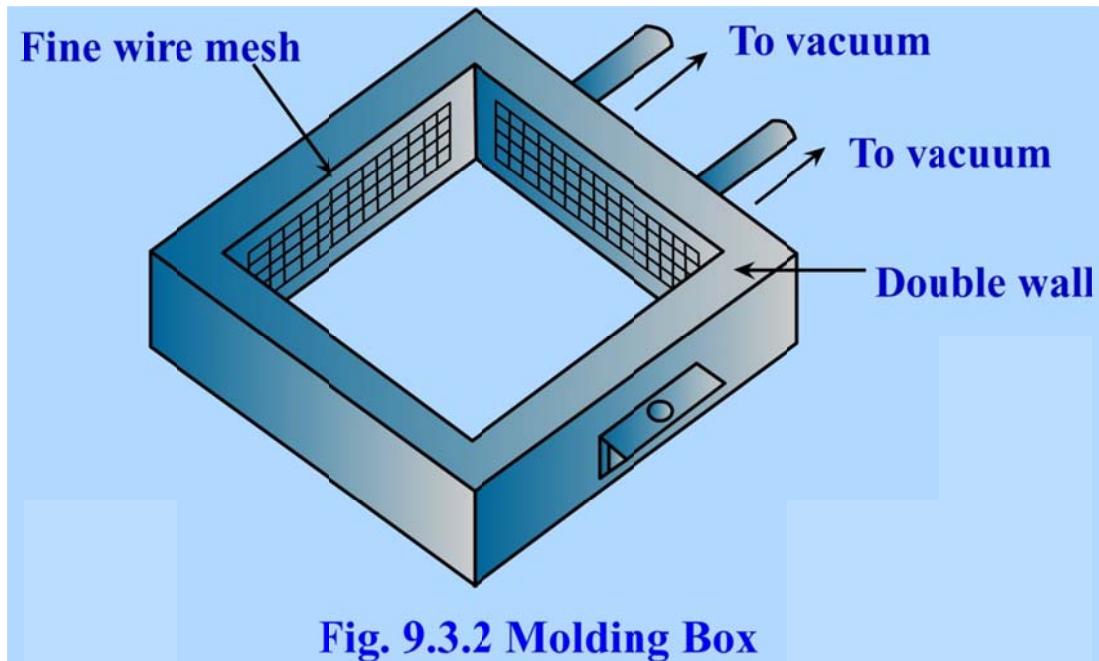


**Pattern Fig.9.3.1 Pattern plate**

### Molding Box

In the design of molding box, the major consideration is to have a uniform distribution of vacuum throughout the body of sand to form the mould. The design of molding box for VAEPC process is more complicated than conventional sand molding process. The box has to be made with annular wall on all the four sides. Inside walls are provided with

windows. These windows are covered with very fine mesh and backed by a metal strip having small holes for supporting the fine mesh. This mesh prevents very fine sand particles from being sucked up from the sand voids in the box and into the vacuum pump. Two pipes are connected with outside wall of the box. One pipe sucks the vacuum from the box and another pipe releases the vacuum to the atmosphere. The moulding box is shown in Fig. 9.3.2.



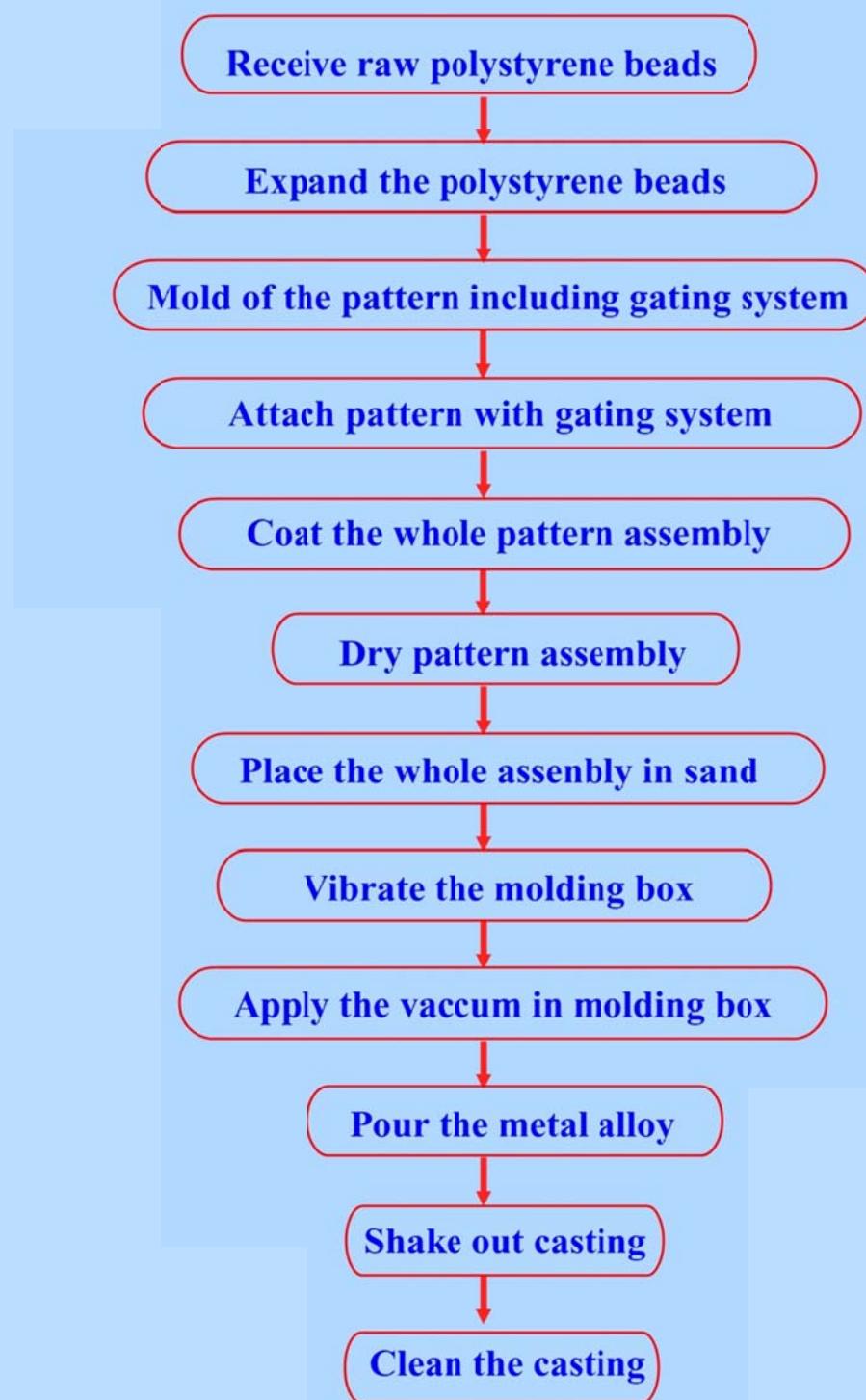
**Fig. 9.3.2 Molding Box**

### VAEPC: Process Description

The process sequence of VAEPC is shown in Fig. 9.3.3. ([Click here Fig. 9.3.3](#))

1. The VAEPC procedure initiates with the pre-expansion of beads, usually polystyrene (same as the first step of EPC). After the pre-expanded beads are stabilized, they are blown into a mold to form pattern sections. In the mold, the steam cycle helps in fusing the beads together by full expansion. (This step is the same the first step of EPC)
2. The different sections of pattern are joined by gluing together and assembled. The gating system too is glued and attached in a similar fashion. (This step is same as the first step of EPC)

3. A ceramic coating covers the foam cluster and it forms a barrier such that penetration of molten metal or erosion of sand during pouring does not take place. (This step is the same as the first step of EPC)
4. Once the coating is dried, the cluster is placed into a flask containing bonded sand as the backing material. In this process, any sand which has enough refractory strength to resist the molten metal temperature can be used. Silica sand, olivine sand, zircon sand and chromites can be used as molding sands. As in the EPC process, the sand loss is less and much of it is recovered, even the expensive sands such as zircon or chromites can be used. The frictional resistance between the sand grains determines the strength of the mold. The mould strength with angular grains is higher, although higher bulk density is provided by the rounded grains. (This step is the same the first step of EPC)
5. The pattern, coated with a suitable refractory wash, is further embedded with dry, unbounded sand. It is next vibrated to produce a rigid mold.
6. Two plastic films are used to encapsulate the mold inbetween and vacuum is applied in the sand mold. The vacuum gives rigidity to the mold and greater hardness is thereby achieved. After this process, the cluster is packed and vacuum is continued thereby making the mold ready for pouring.
7. After pouring the molten metal occupies precisely the shape and size of the pattern and duplicates all of its features. Hence the surface finish and dimensional accuracy of the pattern is very important as it has a direct relation to the casting quality being produced.
8. Once the casting is removed from the mold by shake out method, very little fettling is required, as the process doesn't require mold joint lines and even the cores are entirely eliminated.

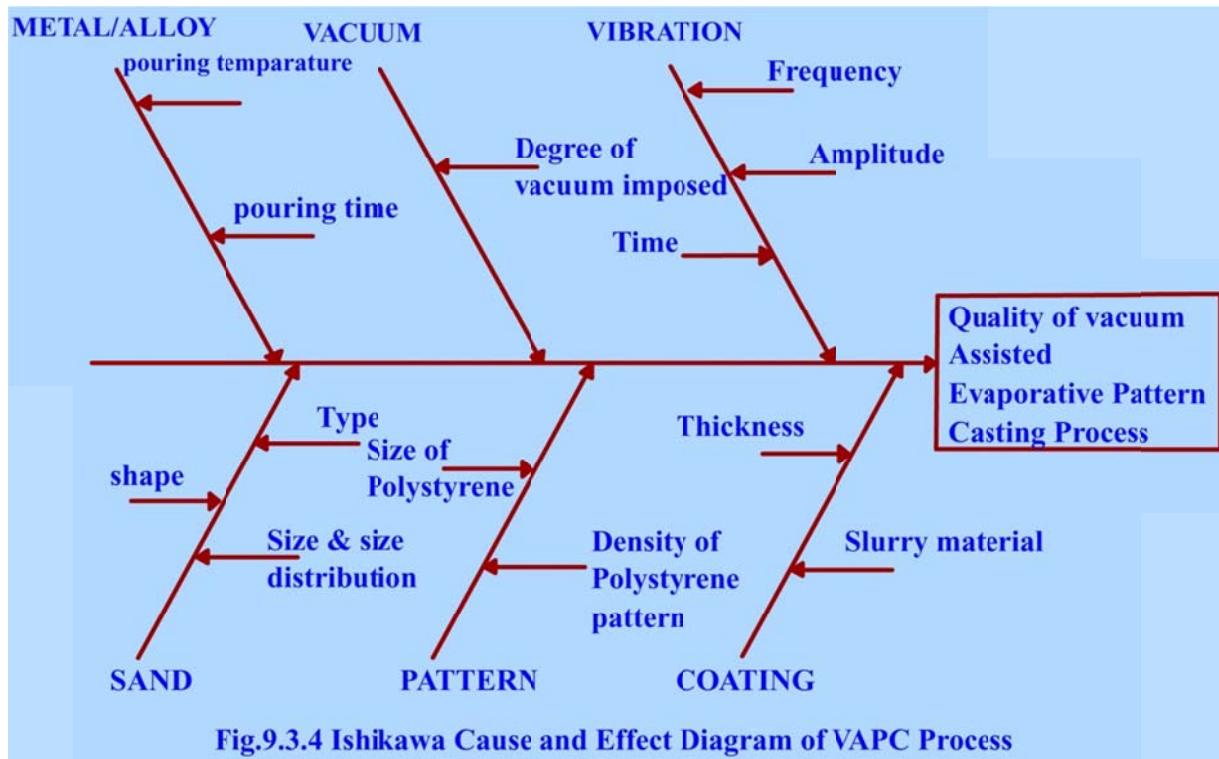


**Fig.9.3.3 Process Sequence of VAEPC**

## Process Parameters of VAEPC

To identify the important process variables affecting the quality of Vacuum Assisted Evaporative Pattern Casting (VAEPC) process, an Ishikawa Cause and Effect diagram is constructed and is shown in Fig. 9.3.4. ([Click here Fig. 9.3.4](#)). The process variables of the VAEPC process can be grouped in the following categories:

- Variables based on molding sand: Sand type, shape of the sand grains, grain size and size distribution.
- Variables based on pattern: Density and size of pattern beads
- Variables based on coating of patterns : material used for the slurry and coating thickness
- Variables based on vibration: Amplitude of vibration, frequency and time.
- Variables based on vacuum : Degree of vacuum imposed
- Variables based on material being poured: Pouring time and temperature



## **Module-9: ADVANCED METAL CASTING PROCESSES:**

### **Lecture No-4**

#### **Vacuum Sealed Molding Process (VSMP)**

The Vacuum sealed molding (V process) makes use of dry sand, plastic film and a negative vacuum pressure as a means for binding. The process was developed in 1971 in Japan. Due to its unique capability in producing smooth and accurate castings, the process gained further importance. The basic difference that exists between the V-process and other sand molding processes is the different method by which sand is bound to form the mold cavity. In vacuum used in the V-process is of the order of 250 – 450 mm Hg. This pressure is used to bind the dry and free flowing sand particles which is encapsulated in between two plastic films. This process makes use of vacuum assisted by the plastic film to form a mold cavity over the pattern. Unbounded dry sand is used as a backing material and vibrations are used to compact it. After pouring the molten metal into the mold, the plastic film melts and gets sucked inside the sand voids due to imposed vacuum. It further gets condensed and forms a shell-like layer. The vacuum is required to be maintained till the metal is solidified. Then it is released, allowing the sand to drop away, thereby leaving behind the casting with a smooth surface. The process does not require shaking out methods and equipment to remove the casting out and the sand can be reused after cooling without any treatments.

#### **Advantages**

- Very good surface finish with good dimensional accuracy.
- Patterns have a long life.
- Reproducibility is good and consistent.
- Draft is not required, thereby reducing material and cost
- Low Cleaning / Finishing Cost

#### **Applications**

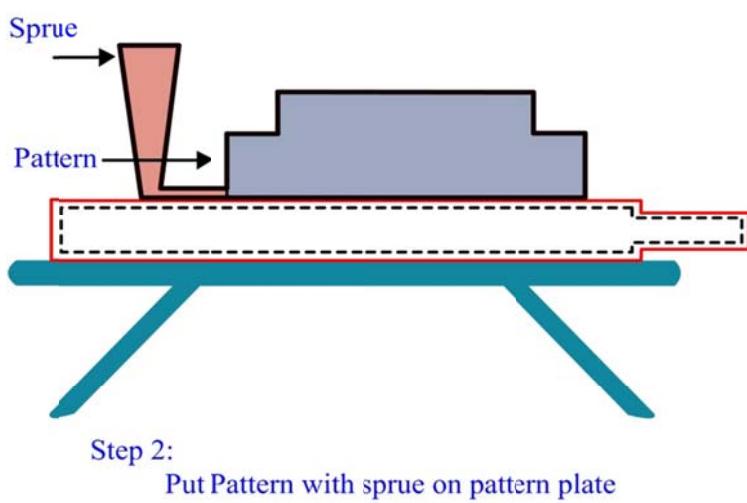
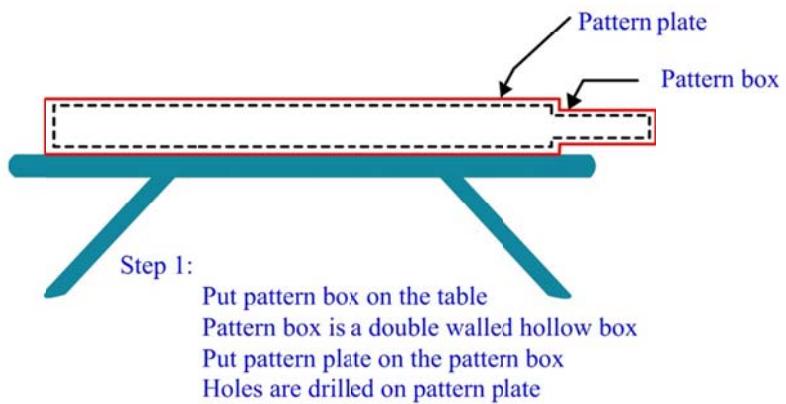
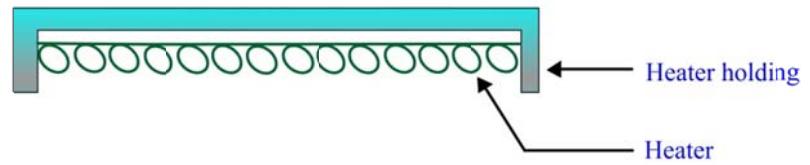
The size of the product is no limitation in the V-Process. However, as found in literatures, the application of V-process castings are in the range of up to 8 tons for ingots. Some other applications, wherein V-process was used as a preferred casting method are:

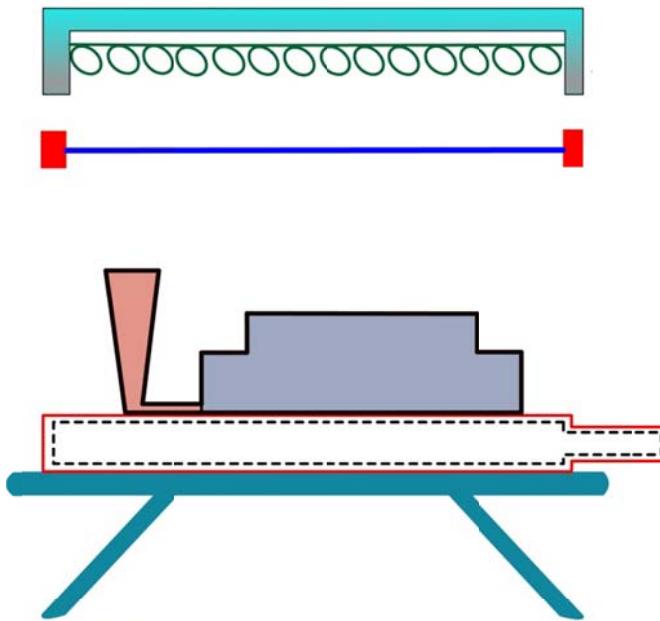
- Medical devices
- Computers
- Instrumentations
- Electronic Enclosures

**Sequence of Producing V-Process Molds ( As shown in fig.9.4.1 below)**

1. The Pattern is set on the pattern plate of pattern box. The pattern and the pattern plates have numerous small holes, which help the plastic film to adhere closely on the pattern when vacuum is applied.
2. In-order to soften the plastic film, a suitable heater is used.
3. The pattern is draped by a softened plastic film. The suction of vacuum takes place through the vents and the plastic film adheres very close to the pattern.
4. The mold box is set on the film coated pattern
5. The mold box is compacted by filling it with dry sand and providing slow vibrations.
6. The mold is further leveled and a plastic film is covered on the top of the box. The suction created due to vacuum helps in stiffening the mold.
7. Releasing the vacuum on the pattern box, helps in stripping off the mold easily.
8. Cope and Drag are both assembled and the metal is poured. Vacuum is maintained during pouring.
9. The vacuum is further released, once the mold boxes get cooled, this allows sand to freely flow back, thereby leaving a clean casting behind.

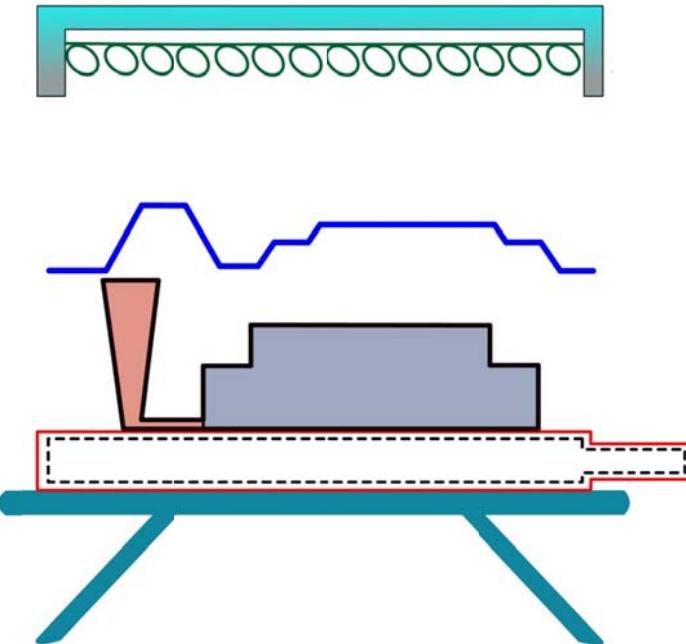
The sequence of producing the casting made by vacuum sealed molding process is shown in following figures.





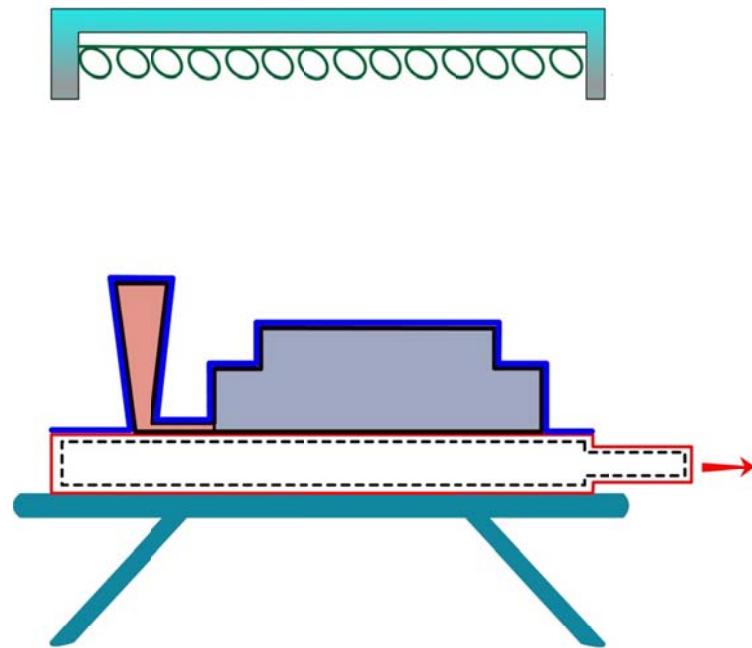
Step 3 (a):

Switch on the heater, heat film and put it over pattern plate  
Apply vacuum to pattern box.



Step 3 (b):

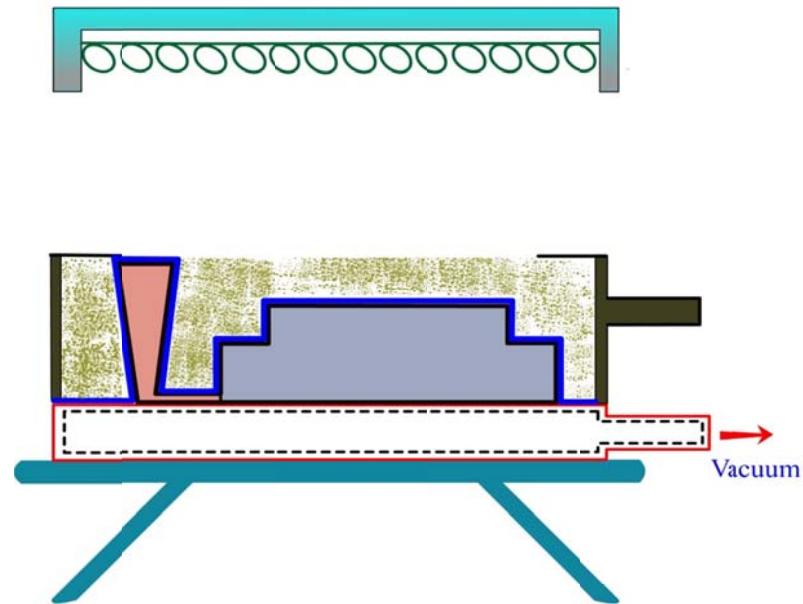
Switch on the heater, heat film and put it over pattern plate  
Apply vacuum to pattern box.



Step 3:

Switch on the heater, heat film and put it over pattern plate  
Apply vacuum to pattern box.

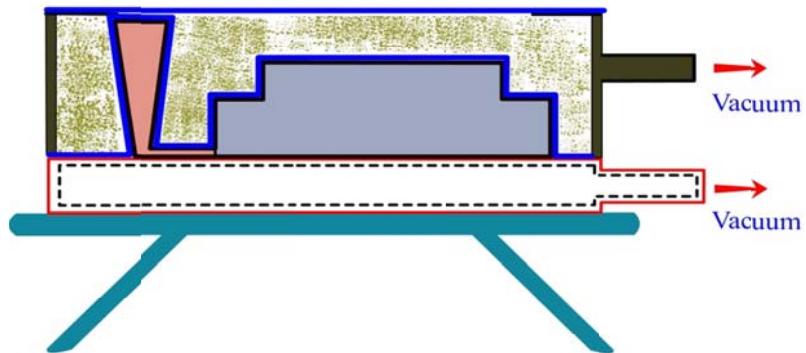
[To see animation \(Click here\)](#)



Step 4:

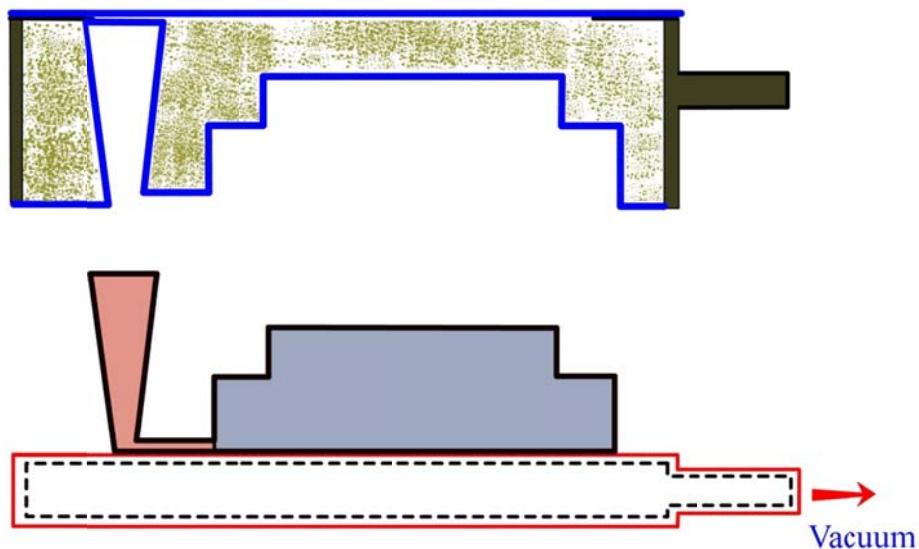
Now put cope on pattern plate fill it with sand ans shake it

[To see animation \(Click here\)](#)



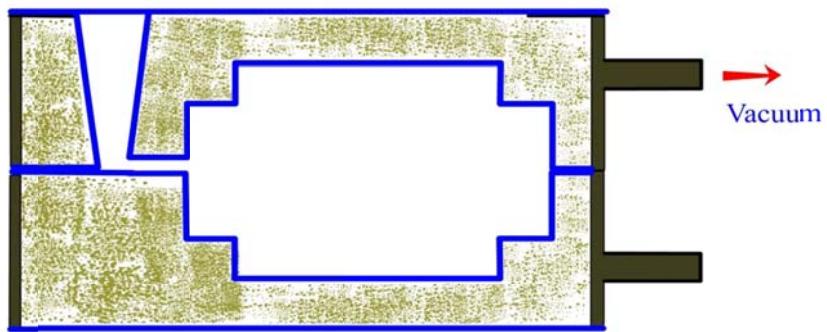
Step 5:  
Heat film and put it over cope and apply vacuum

[To see animation \(Click here\)](#)



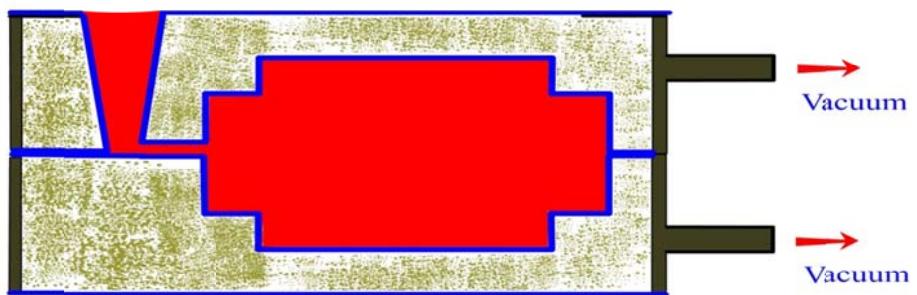
Step 6:  
Release the vacuum of pattern plate and remove cope  
with sand carefully from pattern plate.

[To see animation \(Click here\)](#)



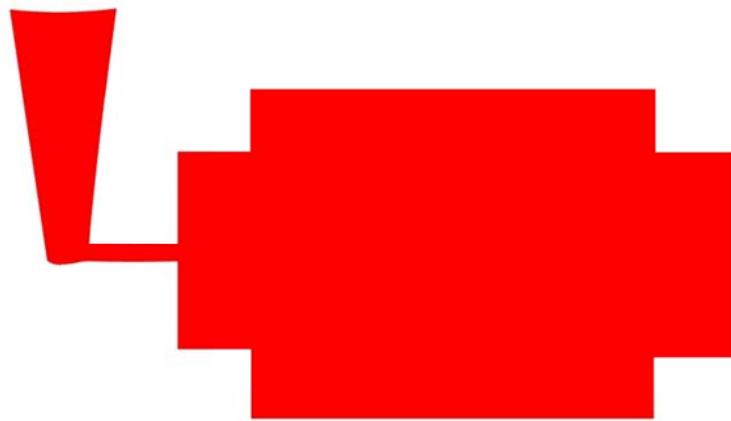
Step 7:  
Prepare drag simillarly

[To see animation \(Click here\)](#)



Step 8:  
Pour molten metal in cavity and release vacuum  
form cope and drag

[To see animation \(Click here\)](#)



It is the final casting

**Fig.9.4.1: Different steps in vacuum sealed molding process**

## **Module-9: ADVANCED METAL CASTING PROCESSES:**

### **Lecture No-5**

#### **Step-up and Process Parameters in V-Process**

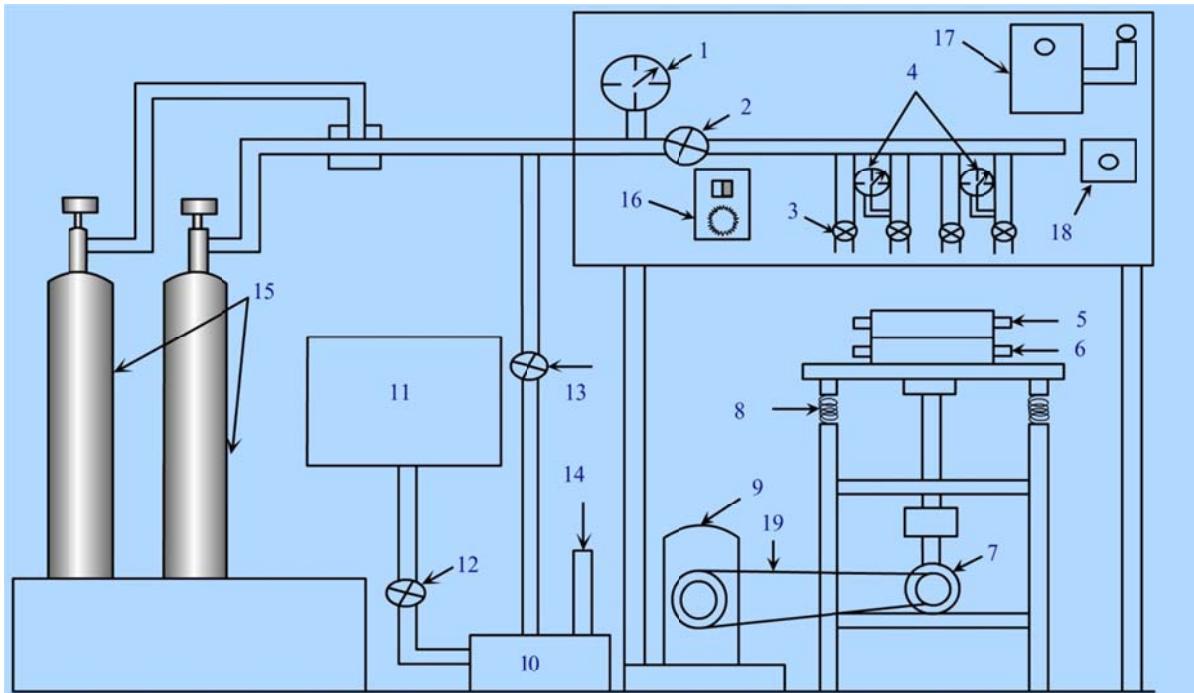
##### **The V-Process set-up:**

These details are not available in literature. However, at IIT Roorkee the set up, to produce the V-Process mold, was developed. A photograph of the set up is shown in Fig. 9.5.1. The schematic diagram of the V-process experimental set up is shown in Fig. 9.5.2. The whole set up is divided into the following parts:

- Molding System: (a) Pattern box, (b) Molding box, (c) Pattern
- Vacuum System
- Vibrating System: (a) Vibration table, (b) Vibrator, (c) Motor
- Plastic Film Holding and Heating System



**Fig.9.5.1 Photograph of Experimental Set-up in Vacuum Sealed Molding**



1. Vacuum gauge in main line, 2. Main control valve, 3. Control valves in sub line for cope and drag,
4. Vacuum gauge in sub-line, 5. Molding box, 6. Pattern plate, 7. Vibrator, 8. Spring, 9. Motor,
10. Vacuum pump, 11. Water tanks, 12. Water out let valve, 13. Inlet control valve of vacuum pump,
14. Outlet control valve of vacuum pump, 15. Surge tank, 16. speed controller box,
17. Main starting switch, 18. Vacuum pump control switch, 19. V-belt

**Fig.9.5.2 Schematic diagram of V process experimental set-up**

### Molding System

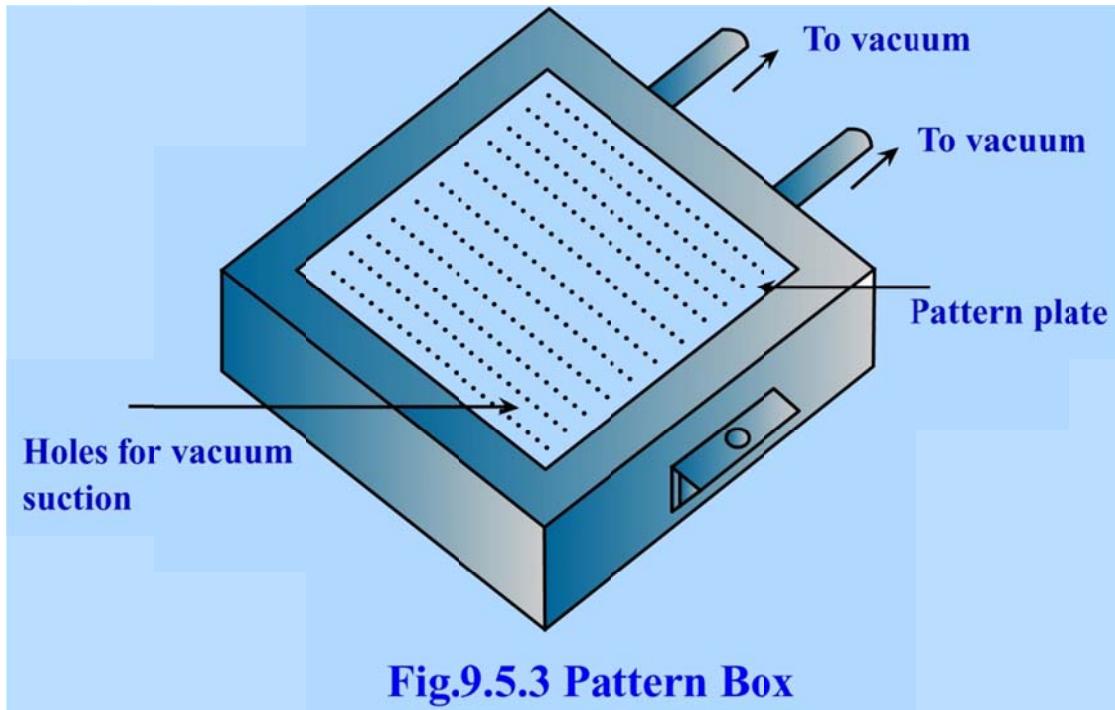
The molding system comprises of the equipment needed to prepare the mould. This includes the pattern box, molding box and pattern.

#### Pattern box

The pattern box is shown in Fig. 9.5.3. The pattern plate is placed on the straight top open surface of the pattern box, and perfect matching between the mating surfaces is achieved. In order to ascertain the perfect matching, the pattern plate, having equidistant holes, is provided with four support blocks at the four corners in the pattern box. Additional support at the centre has been provided to prevent warping of pattern plate when subjected to vacuum pressure. The pattern box is fixed to the vibrating table.

## Molding box

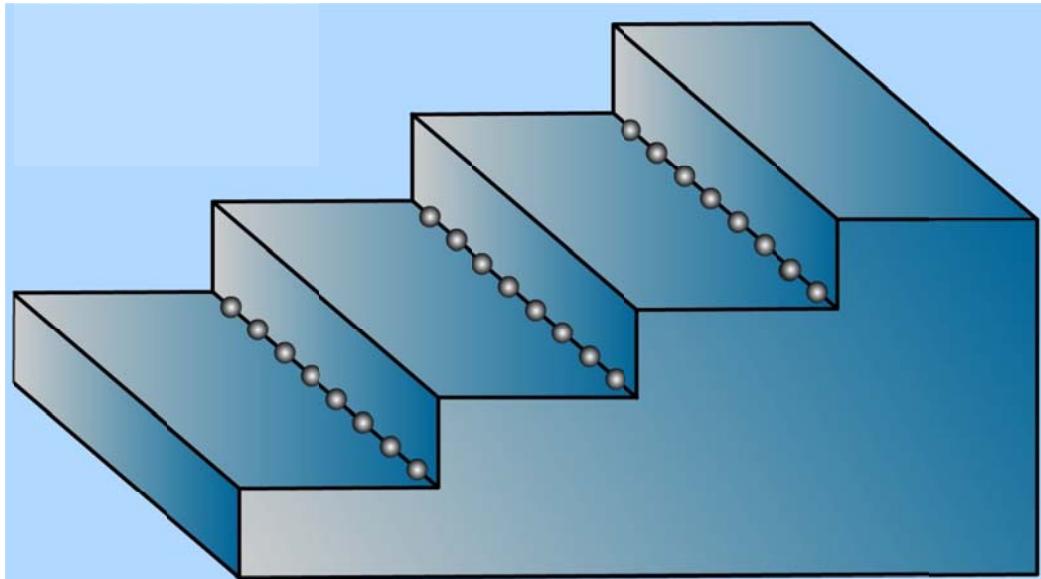
In the design of molding box, shown in Fig. 9.5.4, the major consideration is to have a uniform distribution of vacuum throughout the body of sand to form the mould. The design of molding box for V-process is more complicated than conventional sand molding process. The box has to be made with annular wall on all the four sides. Inside walls are provided with windows. These windows are covered with very fine mesh and backed by a thin metallic strip having small holes for supporting the fine mesh. This mesh prevents very fine sand particles from being sucked up from the sand voids in the box into the vacuum pump. Two metallic pipes are connected with outside wall of the box. One pipe is used to suck the vacuum from the box and another pipe to release the vacuum to the atmosphere.



## Pattern

The patterns used in V-process are similar to the pattern used in other conventional sand casting processes. Numerous small holes are created on the vertical edges of the pattern, used in V-Process, so that plastic film is correctly adhered to the vertical surface of the

pattern, thus creating the right cavity in the mold. A simple three stepped pattern, having small holes at the vertical edges, is shown in Fig. 9.5.5.



**Fig.9.5.5 Four Stepped Pattern**

### **Vacuum System**

Vacuum is applied to the molding box containing sand to ruggedize the mould as well as to withdraw the decomposed gases. It remains constant and active during pouring of molten metal till solidification.

### **Vibrating System**

Vibration system is used to compact the sand. Vibration system must have a provision for varying vibration amplitude and frequency. The vibration system consists of vibrating table, vibrator and digital varied-drive motor.

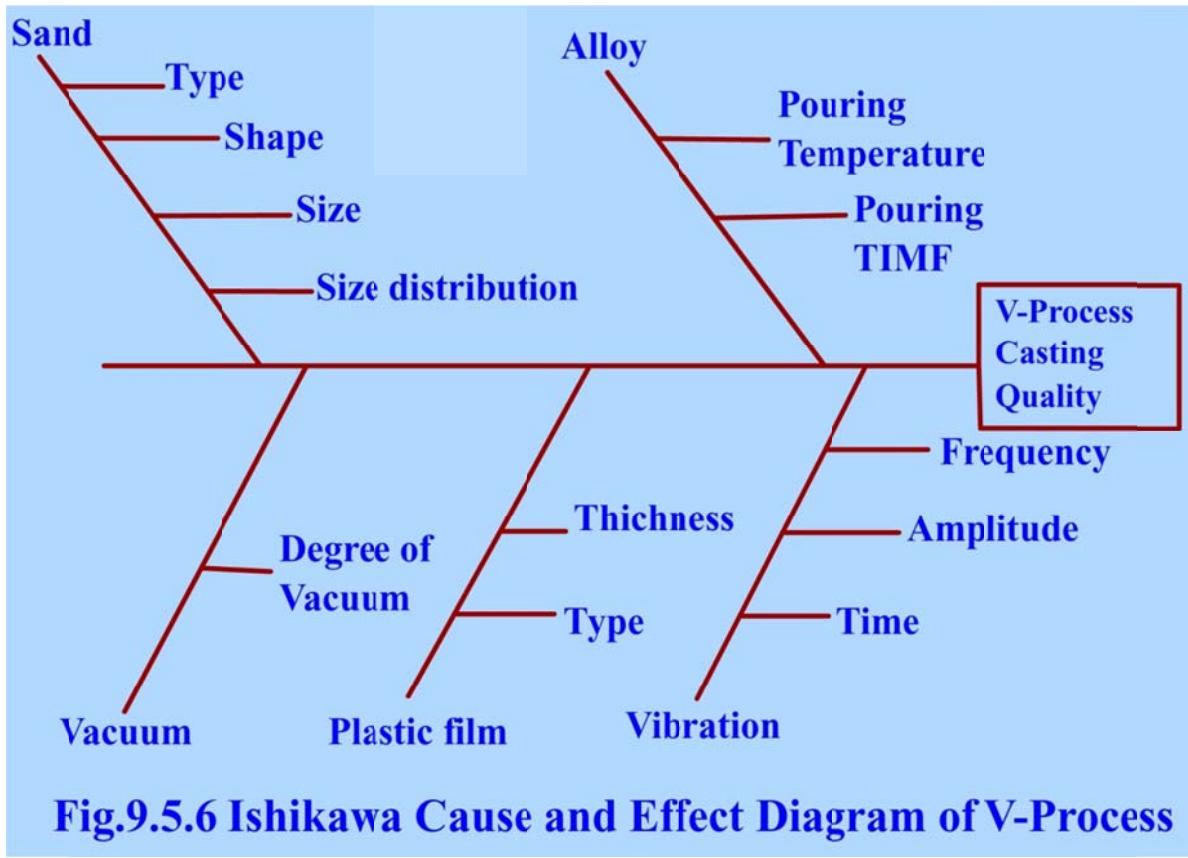
### **Plastic Film Holding and Heating System**

To prepare a mould, two plastic polyethylene / Ethylene vinyl Alcohol films are used. The purpose of using two plastic films (one on top and other for bottom of the molding box) is to seal the box. The film is heated up to plastic deformation so that it adheres tightly to the pattern and the top / bottom surface of the mold. Also, heating system is needed to soften the plastic film.

## Process Parameters of V-Process

To identify the major process parameters which affect the qualities in a V-process, an Ishikawa cause and effect diagram is constructed and is shown in Fig. 9.5.6. It depicts that the following process parameters considerably affect the quality of castings produced by V-process.

- Variables based on molding sand: - shape, type, size and size distribution.
- Variables based on plastic film - type and thickness.
- Variables based on vibration - amplitude, frequency and time of vibration.
- Variables based on vacuum - degree of vacuum imposed.
- Pouring material based variables – pouring time and temperature.



**Fig.9.5.6 Ishikawa Cause and Effect Diagram of V-Process**

## **V-Process Outcome Specifications**

- Tolerances:                          One side of parting line  $\pm .010"$  up to 1".  
    Over 1" add  $\pm .002"/in.$
  
- Surface Finish:                        125 – 150 RMS
- Surface Finish: Cored Area    150 – 250 RMS
- Draft Requirement:                    Nil
- Minimum Section Thickness: 2.5 mm

## **Module-9: ADVANCED METAL CASTING PROCESSES:**

### **Lecture No-6**

#### **Investment Casting Process**

The investment casting process which is commonly referred to as the “lost wax method”, originated in and around the fourth millennium B.C. It is evidenced through the architectural works found in the form of idols, pectorals and jewelry in remains of the ancient Egypt and Mesopotamia. The investment casting process initiates with the production of wax replicas or patterns of the required shape of castings. Each and every casting requires a pattern to be produced. Wax or polystyrene is made used as the injecting material. The assembly of large number of patterns are made and attached to a wax sprue centrally. Metallic dies are used to prepare the patterns. The pattern is immersed in refractory slurry which completely surrounds it and gets set at room temperature forming the mold. The mold is further heated, so that the pattern melts and flows out, leaving the required cavity behind. After heating, the mold gets further hardened and molten metal is poured while it is still hot. After the casting gets solidified, the mold is broken and it is taken out.

The basic steps of the investment casting process are shown in figure-9.6.1 and discussed as below:

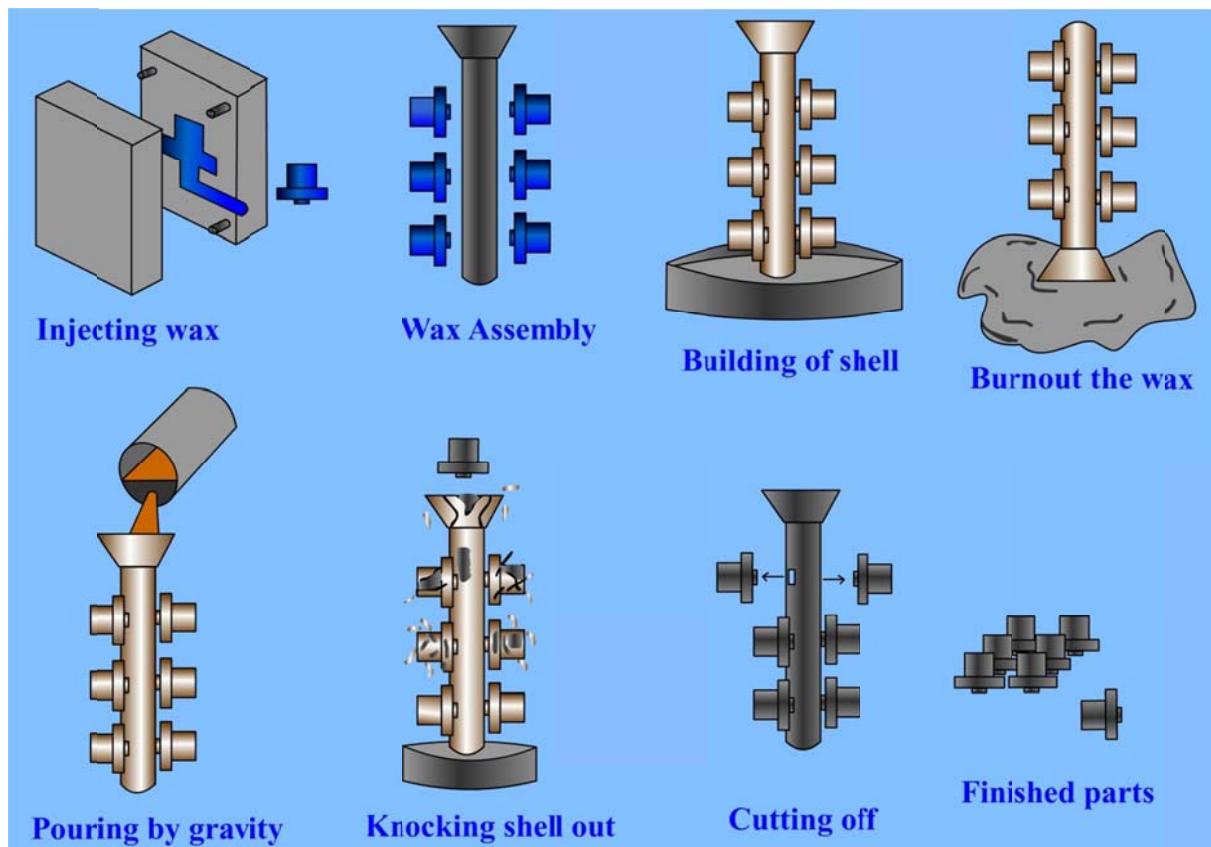
1. Preparing the heat-disposable wax, plastic or polystyrene patterns in a die.
2. Assembly of the prepared patterns onto a gating system
3. “Investing,” (covering) the pattern assembly with a refractory slurry which builds the shell.
4. Melting the pattern assembly (burning out the wax) by firing, for removing the traces of the pattern material
5. The metal in molten state is poured into the formed mold.
6. Once the metal solidifies, the shell is removed (knocked out).
7. Fettling (cutting off) of the pouring basin and gates followed by finishing operations to get the desired dimensional tolerances and finish.

## Advantages

- Closed dimensional tolerances and intricate geometries are easily obtained.
- A single process gives good surface finish.
- Alloys with higher melting points can also be cast.

## Limitations

- Expensive process since it uses the wax, which increases the cost.
- The cross section of molds being thin, the process is limited by size and mass of casting.
- The quality of the pattern determines the quality of the casting.
- Removal of the wax from the mold again adds up time and cost.



**Fig. 9.6.1: The Basic Steps of the Investment Casting Process**

## **Module-9: ADVANCED METAL CASTING PROCESSES:**

### **Lecture No-7**

#### **Ceramic Shell Investment Casting Process**

Ceramic Shell Investment Casting (CSIC) is one of the near net shape casting technologies. The process is based on expendable wax patterns for producing joint-less moulds that are required for near net shape castings.

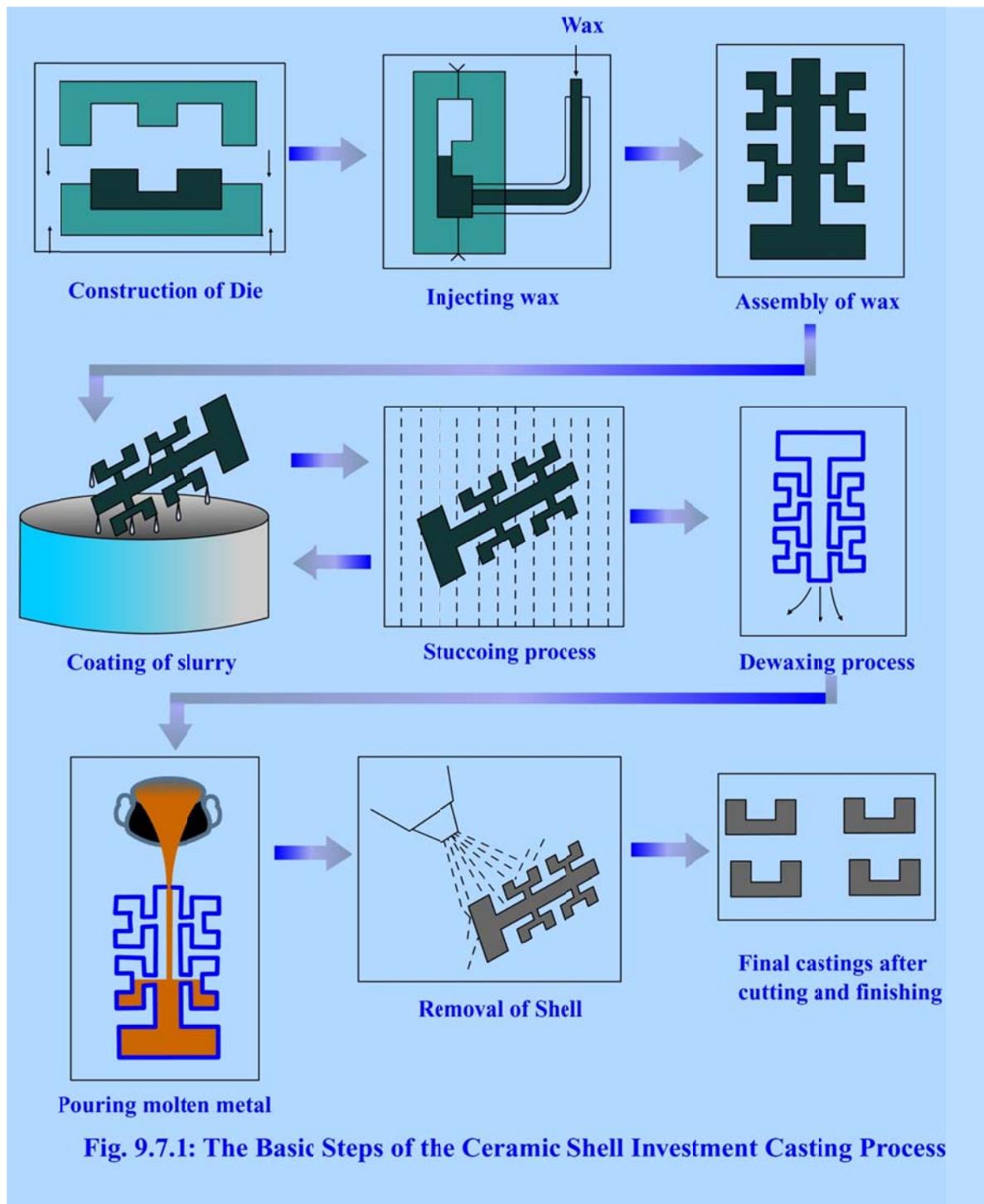
Before we start the discussion on the ceramic shell investment casting process, it is desirable to understand in brief, the process sequence and details of investment casting process, already discussed in the earlier lecture.

The main difference between investment casting and ceramic shell investment casting is that, in the former process, before dewaxing the wax pattern, it is immersed in a refractory aggregate. Whereas, in the ceramic shell investment casting, a ceramic shell gets built around the tree assembly through repeated dipping of the pattern into slurry (refractory material such as zircon with binder). After getting the required thickness of cross section, the tree assembly is de-waxed. The shell obtained is further immersed in a refractory coating and the metal is poured into it.

In this process, a wax pattern/assembly is first dipped into a ceramic slurry bath for its primary coating. Thereafter, the pattern is withdrawn from the slurry and is manipulated to drain of the excess slurry to produce a uniform coating layer. The wet layer further stuccoed through sprinkling the relatively coarse ceramic particles on it or by immersing it into such fluidized bed of particles. The ceramic coating is built by successive dipping and stuccoing process. This procedure is further repeated till the shell thickness as desired is obtained. Upon completion, the entire assembly is placed into an autoclave or flash fire furnace at a high temperature. In-order to burnout out any residual wax, the shell is heated to about 982°C which helps to develop a bonding of high-temperature in shell. Such molds are stored for future use wherein they are preheated for removing the moisture content from it and then, molten metal can be poured into it.

## Sequence of Producing Ceramic Shell Investment Casting

The process sequence of Ceramic shell investment casting is given below and some of steps are shown in Fig. 9.7.1.



### **Steps:**

1. Manufacturing of the master pattern of wax through the master dies.
2. Preparation of wax blend and injecting it into the die.
3. Manufacture of wax pattern and assembly of wax pattern
4. Investment of wax with slurry (coating the slurry)
5. Drying of shell thickness (stuccoing)
6. De-waxing of raw moulds followed by heating and baking of the shells
7. Pouring of moulds with molten metal
8. Once the metal is solidified, the shells are removed.
9. Cutting off the gates / risers (fettling) followed by finishing operations.

### **Advantages**

- Complex shapes that are difficult to produce by other casting methods are very easily possible to be produced by this method.
- Thin cross sections and intricacies can be made by this process.
- Finish machining is considerably reduced or eliminated on the castings made by this process, making it economical in cost.
- The process has no metallurgical limitations.
- This process produces castings with excellent surface finish.

### **Disadvantages**

- Expensive process due to the cost of ceramics and pattern (wax cost).
- As the shells are delicate, the process is limited by the size and mass obtained.
- Making intricate and high quality pattern increases the process costs.

### **Applications**

- Aircraft: Turbine blades; carburetor and fuel-pump parts; cams; jet nozzles; special alloy valves.

- Chemical Industries: Impellers; pipe fittings; evaporators; mixers.
- Tool and Die: Milling cutters; lathe bits; forming dies; stamping dies; permanent molds etc.
- General and Industrial applications: cloth cutters, sewing machine parts; welding torches; cutter, spray nozzles; metal pumps; etc.

## **Module-9: ADVANCED METAL CASTING PROCESSES:**

### **Lecture No-8**

#### **Wax: Its types and wax pattern preparations**

##### **Types of Wax**

##### **Preparation of Wax Blend Pattern**

The pattern material selection is most important point in the ceramic shell investment casting (CSIC) process. The patterns are prepared through injecting wax into the die. The patterns thus made should be fracture-resistant and distortion free such that part accuracy is maintained.

The key demand for tighter tolerances from CSIC process is to calculate and control the shrinkage of pattern material inorder to improve the accuracy of products. The shrinkage characteristics of waxes and its influence on the final dimensions of casting are of great fundamental importance in getting high-quality castings; minimizing product cost and scrap.

Numerous factors can affect the degree to which contraction in dimension can occur while taking into account the wax pattern accuracies obtained through such patterns from the die.

##### **Types of Waxes and Wax Blend Composition**

Four types of waxes (bees wax, paraffin wax, carnauba wax and montana wax,) with different melting temperatures ( $58.2^{\circ}\text{C}$  to  $83.8^{\circ}\text{C}$ ) can be used to make the pattern suitable for use in investment and ceramic shell investment castings. The physical properties of the various waxes are given in the table 9.8.1 below:

The form of each of the above wax is solid at room temperatures. The recommend blend / mix of waxes for the best dimensional and surface properties of the pattern are in the following ratio (weight ratio): Paraffin: Bees: Montana: Carnauba: 10: 6: 3: 1

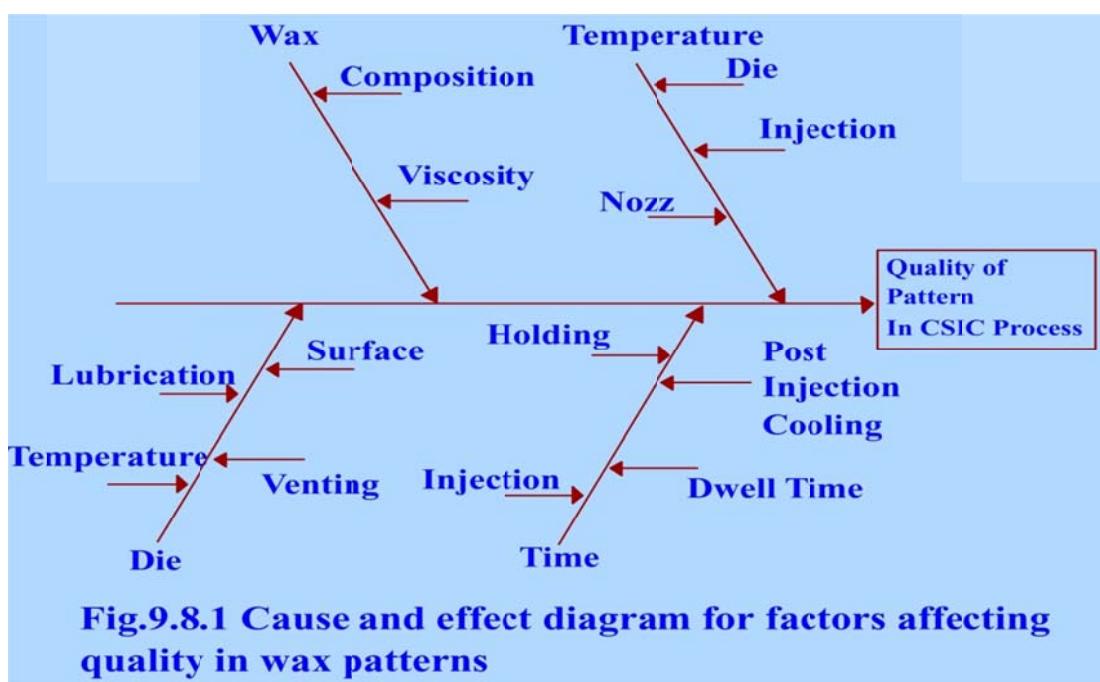
**Table 9.8.1 Wax properties**

<b>Wax</b>	<b>Color</b>	<b>Melting Point (Degree Centigrade)</b>	<b>Density (gm/cc)</b>
Bees Wax	White	58.2	0.97
Paraffin Wax	White	58.5	0.94
Carnauba Wax	Black	81.9	0.99
Montana Wax	Brown	83.8	1.02

### Process Parameters affecting the Quality of Wax Pattern

In-order to identify the process parameters which affect the quality of wax patterns an Ishikawa cause and effect diagram is constructed, as shown in Fig. 9.8.1. It indicates that the following process parameters have an effect on the quality of the wax patterns (dimensional accuracy and surface roughness) made from the dies.

- Wax composition, wax temperature in the injection machine and temperature of the wax injection. (nozzle temperature)
- Die temperature, die lubrication, die venting, die surface
- Sprue design, injection pressure and wax flow rate
- Holding time, injection time, dwell time and post-injection cooling



## Pattern Die

A typical three step pattern used for making the mould by CSIC Process is shown in Fig. 9.8.2. A die made of aluminum is shown in the photograph in fig. 9.8.3. It can be prepared for the production of wax patterns in CSIC process. The photograph of the wax pattern which inturn will be removed from the die, is shown in Fig. 9.8.4.

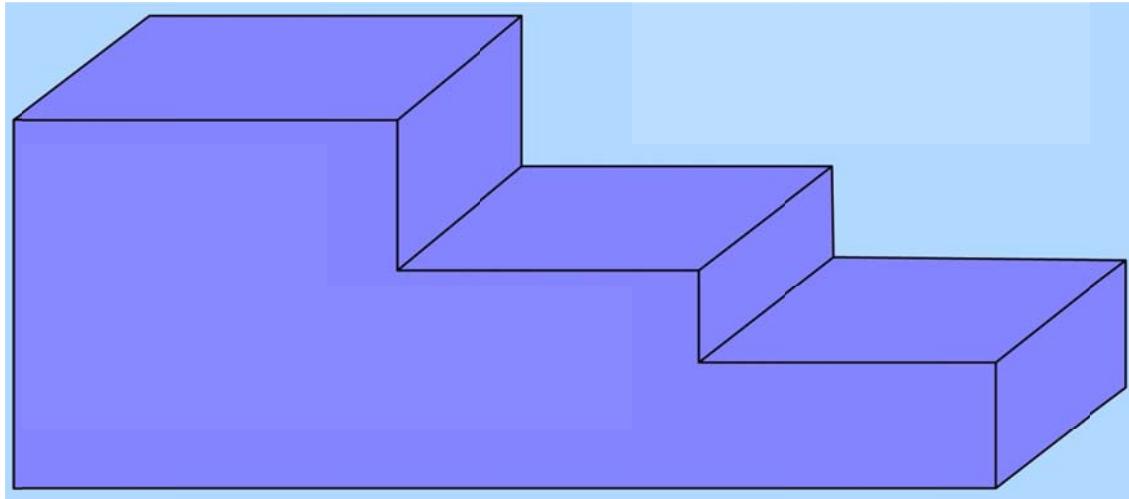
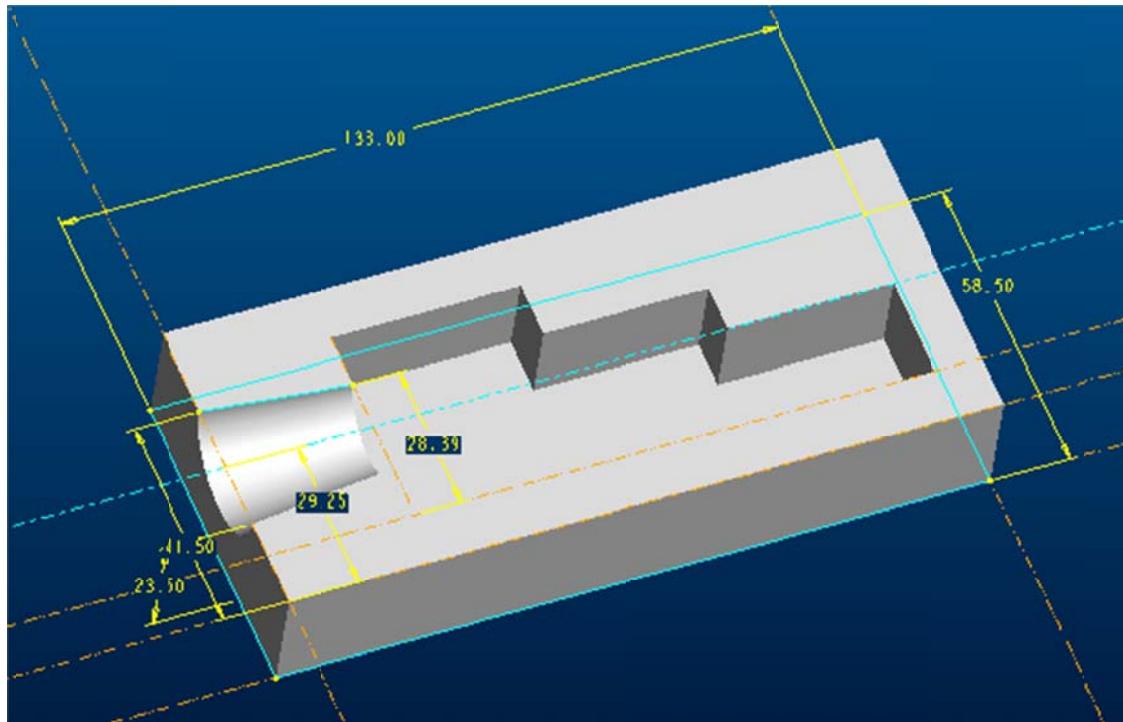
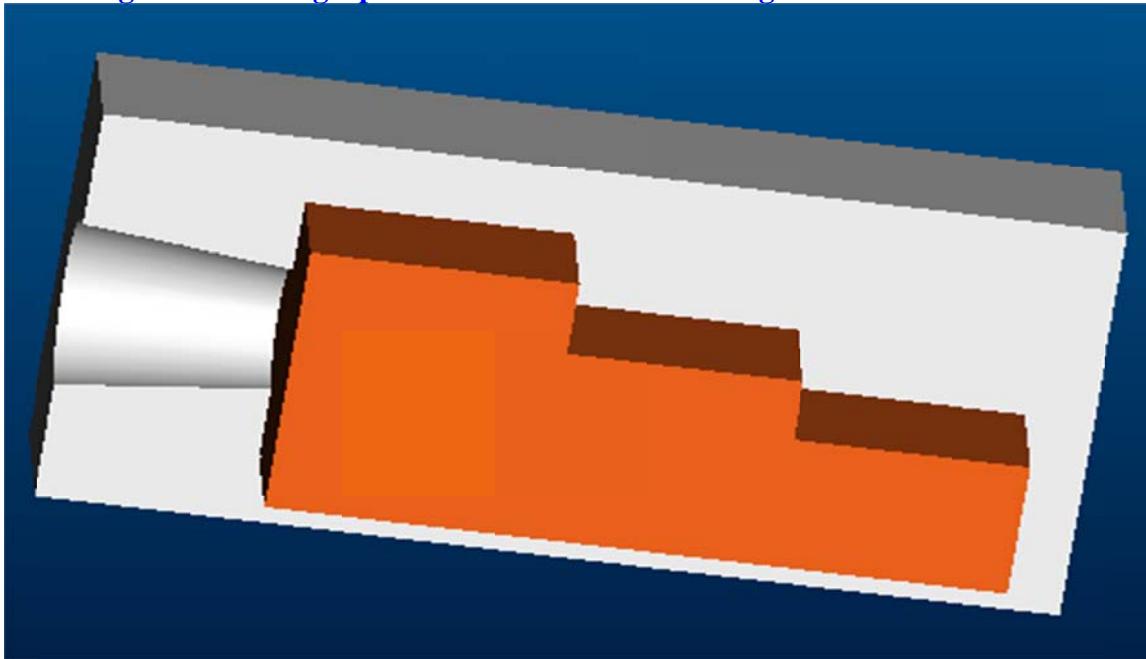


Fig. 9.8.2 The Pattern



**Fig. 9.8.3: Photograph of Die to be used in making the Wax Pattern**



**Fig. 9.8.4 Photograph of Wax Pattern to be removed from the die**

### **Wax Injection Machine**

A wax injector is a machine which makes use of an earlier conditioned wax and injects it into a die in-order to produce a wax pattern. Such an injection machine was designed and fabricated at I.I.T. Roorkee and is shown in Figure 9.8.5. The machine has three basic components:

- The heating unit,
- The injection unit and
- The die clamping system

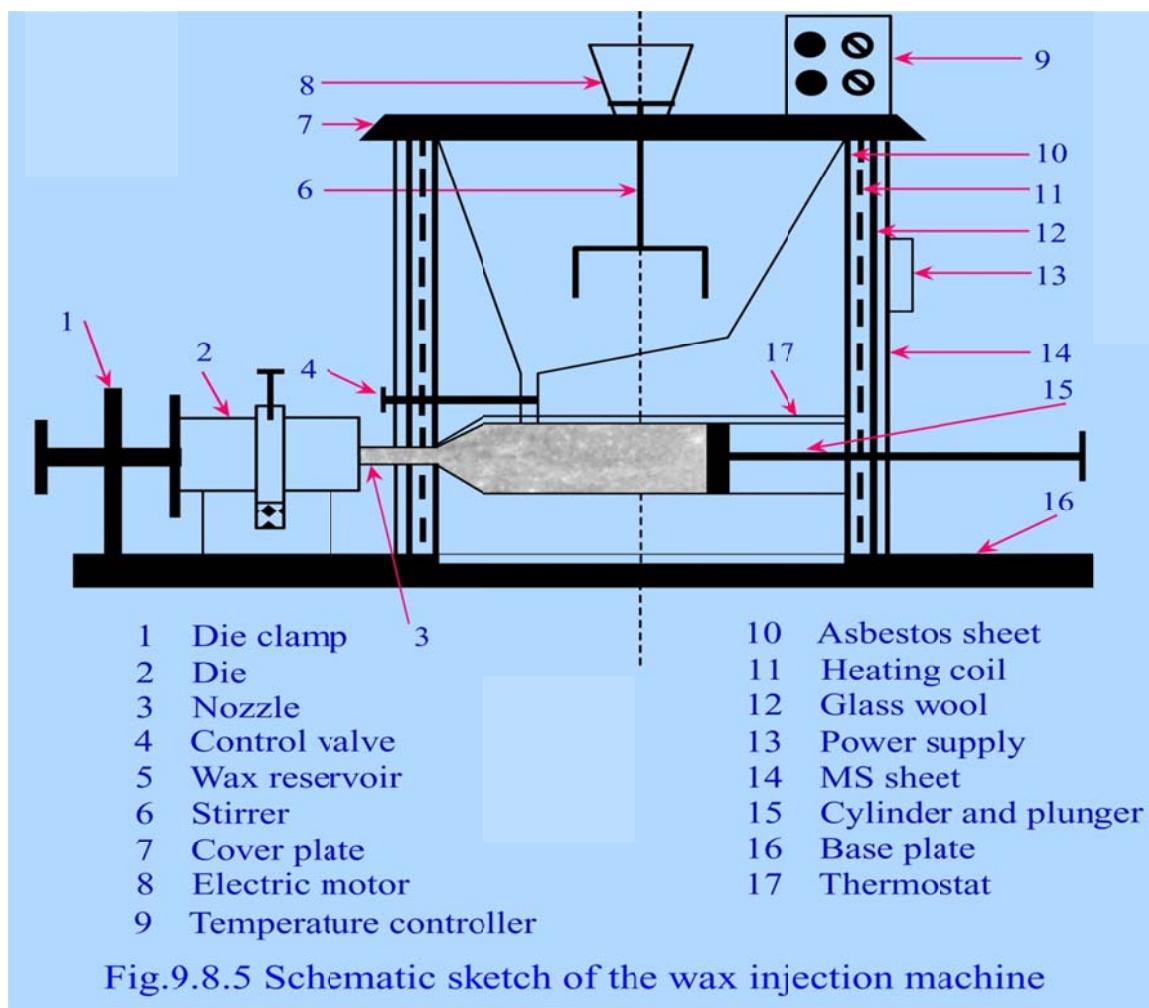
This machine performs the following essential functions:

- A Jacket provided for heating and melting of the wax occurs in an aluminum reservoir tank with provision for slow speed stirring
- Injecting of the liquid wax from the brass cylinder under pressure into a closed mold

- Maintaining the injected wax under pressure for a specified time to prevent the back flow of liquid wax and to compensate for decrease in the volume of melt while solidification

Through these basic three functions, the mechanical and thermal inputs of the injection equipment are coordinated in-line with the basic properties and behavior of the wax under process.

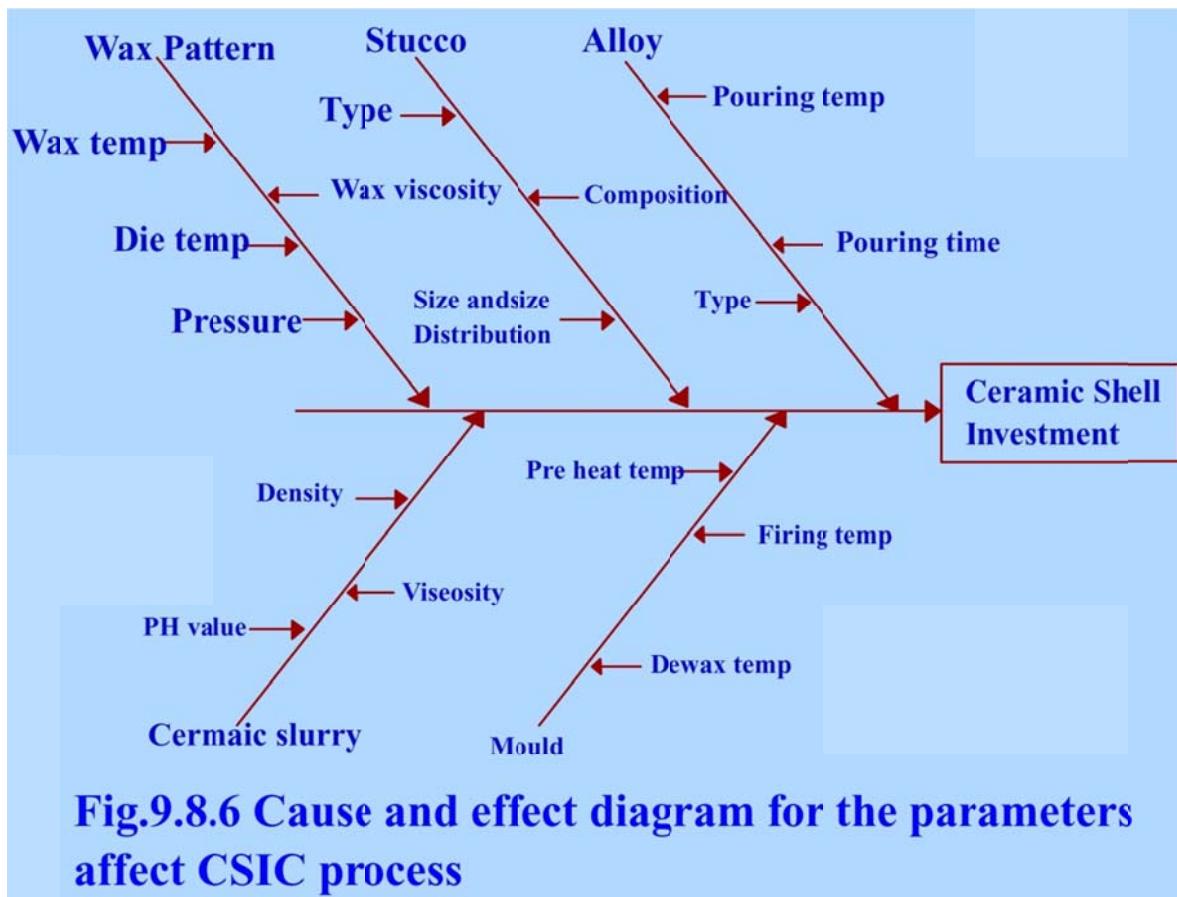
The injection process includes some other sub-processes such as feeding of the brass cylinder through an aluminum reservoir gravimetrically, use of a control valve and controlling temperature with thermostat during melting, conditioning and injection to ensure high pattern quality. A temperature control is made use for controlling the temperature during wax injection in the set-up.



## Parameters Affecting the Quality of Castings Produced by CSIC process

To identify the process parameters that affect the quality of the castings produced by CSIC process, Ishikawa cause and effect diagram is constructed, as shown in Fig. 9.8.6. The Ishikawa cause-effect diagram depicts that the following parameters can affect the quality of the casting (dimensional accuracy, surface roughness, mechanical and metallurgical properties) made by the CSIC process.

- Wax Pattern: Wax temperature, Die temperature, Pressure and Wax Viscosity
- Stucco: Type, Composition, Size and Size Distribution
- Alloy: Pouring temperature, Pouring time and Type of Alloy
- Ceramic Slurry: PH value, density, viscosity
- Mould: Firing temperature, Dewaxing temperature



## **Module-9: ADVANCED METAL CASTING PROCESSES:**

### **Lecture No-9**

#### **Shell Moulding: History and Features**

##### **History of Shell Moulding process:**

The process was invented in Germany by Dr. Croning, hence it has also been named as the Croning process. In this process the silica sand is mixed with phenolic resin along with a curing agent. The process has a major limitation which is in the form of separation of the sand and resin at the end. The process however has low strength, the curing rate is slow, dusty and the sand resin mixture tends to become heterogeneous. In-order to overcome these issues, Novolak phenolic resin dissolved in alcohol is used and the sand is warm coated with it.

By using this technique, better strengths were achieved with lower resin addition along with excellent curing characteristics with lesser dust problems. Over the years, various new coating techniques have been started and this has helped in improving the quality of the resin coated sands. The Shell process, in many ways is simple to operate than many other competitive processes. The versatility of the process enables it to be used for all types of metals both ferrous & nonferrous e.g. cast iron, s.g. iron, carbon steel, high alloys., stainless steel, manganese steel, aluminum & copper alloys.

The main application of shell process is in the mass production of near to net shape castings particularly in the small & medium range. Shell process has been widely accepted for producing the casting for automobile and hydraulic applications, wherein the accuracy and surface finish is the prime requirement.

##### **Advantages**

The shell process has several unique properties which makes it an important process in the foundries. These properties can be briefed as:

- **Excellent Surface Finish:** Shell sand process has the ability to produce castings with excellent surface finish and capacity to produce very fine detail.
- **Dimensional Accuracy:** The process has an ability to produce castings to tight dimensional tolerances. Due to this characteristic, machining allowance can be reduced which ultimately helps in reduction of the fettling and finishing costs. The shell process accommodates easily deep drawer patterns with less tapers than conventional production processes.
- **Hollow Cores:** With the shell sands hollow cores and thin profile moulds can be possible. This characteristic gives economics in sand usage & ease of handling. Hollow cores increase the permeability hence usage of very fine sands is also possible.
- **Sand to Metal Ratio:** This is a unique process that gives hollow cores and thin walled moulds, which results in substantial weight reduction and material savings. The normal sand to metal ratio is 1:1 which is much lower than other processes.
- **Ease of Handling:** The molds and cores made by shell molding have exceptional resistance to damage during storage and handling. They have a very high resistance to humidity and can be easily stored for long periods.
- **Resistant to Moisture Pickup:** The shell process has higher resistance to moisture and can be stored in humid conditions for months together. The resin used in shell molding process is very stable and moisture resistant.
- **Excellent Flow-Ability:** The dry coating on sand, gives better flowability and blowing ability compared to processes based on wet sand mixes. This property helps in producing intricate cores and moulds which can be blown to a greater density. e.g. cores for water jacket.
- **Less Inclusions & High Thermal Stability:** The shell sands are less prone to erosion by molten metal due to higher thermal stability of the phenolic resins. This unique characteristic helps in reducing defects like non-metallic burn-in and scabs etc.
- **Lesser Pattern Wear:** As most of the patterns are made from cast iron, very little or no-wear is observed which results in higher pattern life. This helps in producing large number of castings without much difficulty.

- **Longer Shelf Life:** When properly stored, the shell sands have an indefinite shelf life hence these sands can be stored and used as needed in the foundry.

### **Disadvantages**

- **High Cost of The Process:** Phenolic resins used for the shell process is very costly. The percentage of resin usage is also very high as compared to other processes. Hence this process requires very tight control of the shell thickness else the competitiveness of the process will be sacrificed.
- **High Tolling Cost:** The shell process is thermoset in nature thereby requiring higher curing temperatures. The patterns used are of cast iron with smooth surfaces which have very low expansion coefficient.
- **Cycle Time:** Comparatively cycle time required for shell process is more than either cold box or Co<sub>2</sub> processes.
- **Limited Casting Weight:** The shell molding process is best suited for use in small, intricate and light weight castings. The process can be effectively used for casting weights up to 80kg.

## **Module-9: ADVANCED METAL CASTING PROCESSES:**

### **Lecture No -10**

#### **Process Parameters and Steps in Shell molding**

In this process the moulds and cores are prepared by mixing the dry free flowing sand with thermosetting resins and then heating the aggregate (mixture of fine sand (100-150 mesh) and thermosetting resins) against a heated metal plate. Due to the heat, the resin cures, which causes the sand grains to get bonded with each other and it forms a hard shell around the metallic pattern. The inside portion of the shell is the exact replica of the pattern against which the sand aggregate is placed before heating. The shape and dimension of the inside portion of the shell thus formed is exactly the same as that of the pattern. If the pattern is of two pieces then the other half of the shell is also prepared the same way. Two halves of the shells prepared are placed together after inserting the core, if any, to make the assembly of the mould. The assembly of the shell is then placed in a molding flask and backing material is placed all around the shell mould assembly to give its assembly the sufficient strength. Now the shell mould is fully ready for pouring the liquid metal.

#### **Sand**

The dry free flowing sand used in the shell mould must be completely free of clay content. The grain size of the sand used in shell molding is generally in the range of 100-150 mesh, as the shell casting process is recommended for castings that require good surface finish. However, depending on the requirement of surface finish of the final casting, the grain size of the sand can be ascertained. Also, if the grain size is very fine, it requires large amount of resins, making it expensive.

#### **Resin and Catalyst**

The resins most widely used, are the phenol formaldehyde resins, which are thermosetting in nature. Combined with sand, they give very high strength and resistance to heat. The resin initially has excess phenol and acts like a thermoplastic material. In

order to develop the thermosetting properties of the resin, the coating of the sand is done with resin and a catalyst (Hexa-methylene-tetramine, known as Hexa). The measure of resin is 4-6% of sand by weight, the catalysts 14-16% of sand by weight. The curing temperature of the resin along with the catalysts is around 150° C and the time required for complete curing is 50 – 65 seconds. The sand composition to be used in making various casting of different materials can be seen from the relevant standards.

The resins available are of water-bourn, flake, or the granular types. The specifications of liquid, flakes or powder resins can be obtained from IS 8246-1976, IS 11266-1985, and IS 10979-1981 respectively.

The resin sand mix aggregate can be prepared by the following three ways.

**Hot coating process:** in hot coating process the curing of resin takes place due to the combined effect of heat as well as chemical action of the resin with the catalyst. Once the curing is done, the cured sand is cooled at 40-50 degree centigrade to prevent the lumps and agglomerates and to improve the flow-ability.

**Warm coating process:** In this process, different resin formulation (liquid solvent solution) is used and curing takes place at around 80 degree centigrade. The process is simpler than hot coating but the quantity of resin consumed is larger.

**Cold coating process:** In this process, the sand is first mixed with catalysts, then the resin mixed with alcohol is added to the aggregate. The amount of resin requirement is highest in comparison to the amount required in hot and warm coating processes.

#### **Phenol-Formaldehyde Resins:**

In manufacturing the shell sand, phenol, formaldehyde resin is used as a binder. The form of resin may be liquid or flake type. Liquid resin is nothing but is a resin dissolved in alcohol. Liquid resin is used for manufacturing shell sand by either warm air process or by ignition process, whereas solid or flake resin is used for hot coating process. Most of Indian manufacturers of shell sand use liquid resin, because of the easiness of resins of

the process. The following properties of resins are generally checked as acceptance criteria.

### **Liquid Resins**

- Clarity
- Viscosity
- Specific Gravity
- Solid content
- PH value
- Coated sand properties at certain percentage of the resin.

### **Solid Resins**

- Softening point
- Flow rate
- Particle size

### **Hexa Catalyst**

The phenol formaldehyde resins are thermoplastic in nature and require a formaldehyde donor to cure at a certain temperature. Thus after blending of the resin and the catalyst, it becomes thermo-set in nature and thus the formation of shell molds and cores is accomplished. The catalyst used is a blend of hexa methylene tetra-amine and a lubricant. Lubrication helps in the flowability of shell sands. Hexa catalyst is available in the form of a fine powder.

### **Use of Additives**

Additives may be added to the sand aggregate to further enhance the surface finish of the casting or to improve the strength of the mould or to develop the resistance to thermal cracking and distortion. The recommended additives are coal dust, manganese dioxide, calcium carbonate, ammonium boro-fluoride, lignin and iron oxide. To improve the flowability of the sand and to permit easy removal of shell from the pattern plate, some

lubricants are added in the resin sand aggregate. The common lubricants used for such purpose is calcium or zinc stearate.

### **Steps in Preparing the Shell Mould:**

The steps to prepare the shell mould are shown in Figure 9.10.1.

1. A match plate metal pattern comprising the cope and drag is heated to the required temperature and fitted over the box containing the mixture of sand and thermosetting resin
2. Next this box is inverted such that, the sand-resin mixture falls on the hot pattern. This cures a layer of the mixture to a certain extent and forms a hard shell.
3. Once the desired thickness of shell is achieved, the box is rotated back to its original upside position. The excess sand then falls back into the box, thus forming a shell over the pattern. The obtained thickness depends on the temperature and the time of contact of sand-mixture.

The required shell thickness for casting depends on the temperature of the pouring metal and complexity of the final casting. It may range from 2-8 mms.

4. To complete the curing process, the sand shell along with the metal plate is heated in an oven for some calculated time.
5. The obtained shell mold from this process is removed from the pattern.
6. Now the two portions (cope and drag) of the shell mold are thereby assembled and some sand particles or metal shots are used in a box for support purpose to add stability to the shell and the pouring is done.
7. After it gets cooled the finished casting along with sprue is taken out and fettling is done.

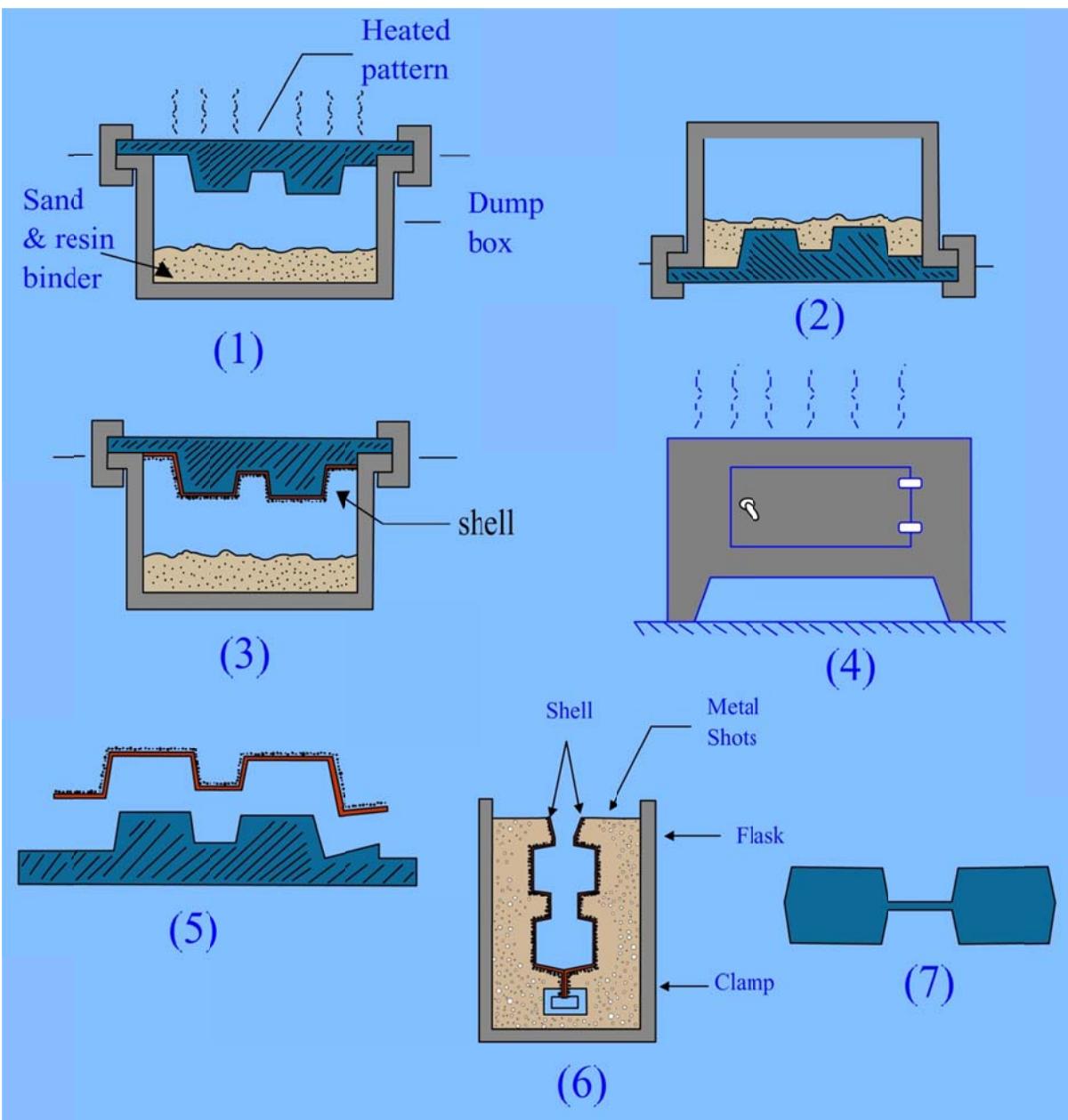


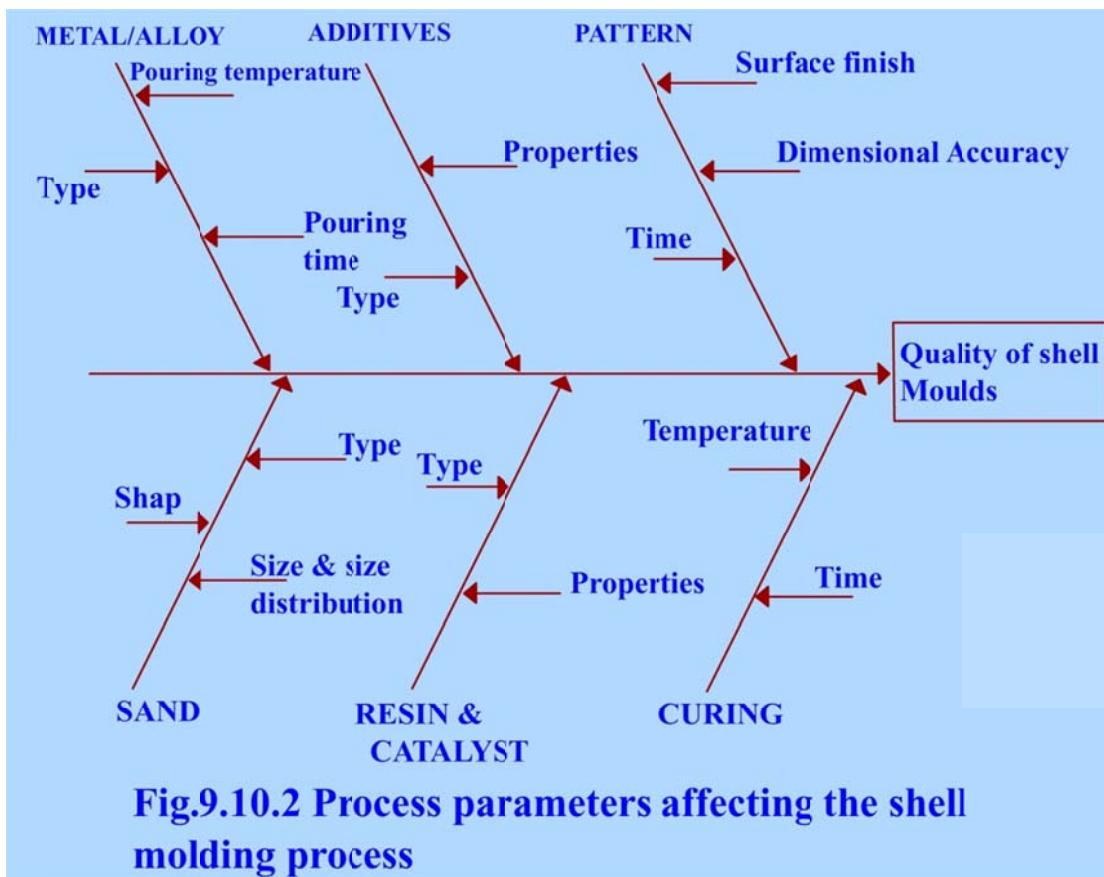
Fig. 9.10.1 Process Sequence of Shell Mould

#### Parameters affecting the quality of castings produced by Shell Mould Process

To identify the process parameters that affect the quality of the castings produced by shell molding process, Ishikawa cause-effect diagram has been constructed, as shown in Fig. 9.10.2. It is indicated through the Ishikawa cause-effect diagram that the following

process parameters can affect the casting quality (dimensional accuracy, surface roughness, mechanical and metallurgical properties) made by shell molding process.

- Pattern: Dimensional Accuracy, Surface finish and Draft requirement.
- Additive: Type, Function of additive, properties.
- Alloy: Pouring temperature, Pouring time and Type of Alloy.
- Sand: Type: Silica, Zircon, Size, Size distribution and grain shape.
- Resin and Catalyst: Type of resins, catalysts and costs.
- Curing: Temperature and time.



## **COURSE: METAL CASTING**

### **Module No. 13: CLEANING AND INSPECTION OF CASTINGS**

#### **Lecture No-1**

#### **Cleaning process, Measurements, Inspection and testing of castings**

##### **Cleaning of Castings**

After the solidification of the casting, the mould is knocked out and solidified casting is taken out of the moulding sand. At this juncture the cast product is attached with risers, and gates. many times the moulding sand also get adhered to the casting as some of the sand gets fused with the molten metal. The cleaning of castings refers to the removal of gates, risers and sand. Also, cleaning may involve machining or abrasive finishing of the cast product. The cleaning operations usually performed on a casting are given below:

1. Removal of gates, in-gates, riser, feeder etc.
2. Surface cleaning
3. Trimming
4. Finishing

##### **Removal of gates, in-gates, riser, feeder etc.**

There are various methods of removal of unwanted metallic parts from the solidified cast product. in case of brittle material, the gates, risers, and feeder can be removed by impact force. this is usually done in shakeout or knock out devices. Other processes that may be used to cut off the metallic parts include, band saws, grinding machine, shearing machine, cutting torches, etc.

##### **Surface cleaning**

As the temperature of molten metal is usually high, sand particles near the surface of the casting gets fused and adheres to the surface of the casting. the cleaning of the surfaces both interior and exterior thus becomes necessary. There exist several methods to remove the adhered sand from the castings. Some of the most common methods of removal of sand are tumbling, and sand or

metallic shot blasting. Tumbling is done in a barrel like machine called as tumbling mill which helps to remove the sand by rubbing action of the cast parts with each other. Whereas, in blasting, abrasive particles are thrown on the surface of the casting in a carrying medium. Air is the most common medium used in this process. Sometimes, metallic shots are thrown on the surface of the castings to remove the unwanted material. Blasting processes include air blasting, centrifugal blasting, hydro-blasting etc. Other methods to clean the cast surface include wire brushing, and buffing.

### **Trimming**

Trimming operations involves the removal of fins, gates and risers appendages, metallic chaplets, etc. These unwanted material is removed by using hammer and chisel called as chipping process, or by pneumatic chipping hammers or by the use of grinders.

### **Finishing**

The finishing at this stage refers to the final cleaning. The castings after the removal of gates, risers, fins, chaplets, adhered sand is washed and then depending upon the requirements of the end product final finish is provided by machining, polishing, buffing, chemical treatment etc.

### **Inspection of Castings**

Inspection of castings is done to ascertain various characteristics. Generally the inspection of castings is carried out to ascertain the required surface finish, dimensional accuracy, various mechanical and metallurgical properties and soundness. various tests used for inspection of castings are:

1. Measurement of the final dimensions
2. Measurement of Surface finish
3. Destructive testing
4. Non-destructive testing

### **Measurement of the final dimensions**

The casting dimension can be measured through various callipers or gauges. the final dimension obtained is compared with the design dimension and dimensional accuracy can be calculated.

### **Measurement of surface finish**

The surface finish of a casting can be measured by perthometer, roughness tester, and by using profilo-meter. Usually Root mean square values are measured.

### **Destructive testing**

As the name of the test suggests destructive, the casting sample is prepared after cutting the final casting. Such types of tests are required to measure mechanical and metallurgical properties of the product. Mechanical tests include tensile strength measurement, toughness measurement, and hardness measurement. Metallurgical tests include dendrite arms spacing, type of structure obtained, and shrinkage cavities.

### **Non-Destructive testing**

The various methods employed in this category of test are:

1. Visual inspection: is carried out to check the final appearance of the casting. major cracks, swells, tears etc may be detected by this method.
2. Radiographic inspection: radiography is used to identify and measure the internal defects in the casting. generally X-rays are used to identify the internal defects in castings.
3. Magnetic particle inspection: this test is not applicable to non-ferrous alloys. This test is conducted to determine and locate the structural discontinuity and subsurface defects in castings.
4. Pressure testing: It is employed to locate leaks in a casting or to check the overall strength of a casting in resistance to bursting under hydraulic pressure. It is carried out on tubes and pipes.
5. Fluorescent penetrate: the fluorescent penetrate is sued to locate the minutes pores and cracks in the final castings.