7. Special Casting Processes

Shell molding, Precision investment casting, Die casting, Centrifugal casting, Continuous casting.

Classification of casting Processes

Casting processes can be classified into following FOUR categories:

1. Conventional Molding Processes
   a) Green Sand Molding
   b) Dry Sand Molding
   c) Flask less Molding

2. Chemical Sand Molding Processes
   a) Shell Molding
   b) Sodium Silicate Molding
   c) No-Bake Molding

3. Permanent Mold Processes
   a) Gravity Die casting
   b) Low and High Pressure Die Casting

4. Special Casting Processes
   a) Lost Wax
   b) Ceramics Shell Molding
   c) Evaporative Pattern Casting
   d) Vacuum Sealed Molding
   e) Centrifugal Casting

a) Green Sand Molding

- Green sand molding is the most diversified molding method used in metal casting operations.
- The process utilizes a mold made of compressed or compacted moist sand.
- The term "green" denotes the presence of moisture in the molding sand.
- The mold material consists of silica sand mixed with a suitable bonding agent (usually clay) and moisture.
Advantages:

- Most metals can be cast by this method.
- Pattern costs and material costs are relatively low.
- No Limitation with respect to size of casting and type of metal or alloy used.

Disadvantages:

- Surface Finish of the castings obtained by this process is not good and machining is often required to achieve the finished product.

b) Dry Sand Molding

When it is desired that the gas forming materials are lowered in the molds, air-dried molds are sometimes preferred to green sand molds. Two types of drying of molds are often required.

1. Skin drying and
2. Complete mold drying.

- In skin drying a firm mold face is produced. Shakeout of the mold is almost as good as that obtained with green sand molding.
- The most common method of drying the refractory mold coating uses hot air, gas or oil flame
- Skin drying of the mold can be accomplished with the aid of torches, directed at the mold surface.

Sand Mold Making Procedure

The procedure for making mold of a cast iron wheel is shown in figure 7 (a), (b), (c).

- The first step in making mold is to place the pattern on the molding board.
- The drag is placed on the board (Figure 7 (a)).
- Dry facing sand is sprinkled over the board and pattern to provide a non sticky layer.
- Molding sand is then riddled in to cover the pattern with the fingers; then the drag is completely filled.
- The sand is then firmly packed in the drag by means of hand rammers. The ramming must be proper i.e. it must neither be too hard or soft.
- After the ramming is over, the excess sand is leveled off with a straight bar known as a strike rod.
- With the help of vent rod, vent holes are made in the drag to the full depth of the flask as well as to the pattern to facilitate the removal of gases during pouring and solidification.
• The finished drag flask is now rolled over to the bottom board exposing the pattern.

• Cope half of the pattern is then placed over the drag pattern with the help of locating pins. The cope flask on the drag is located aligning again with the help of pins (Figure 7(b)).

• The dry parting sand is sprinkled all over the drag and on the pattern.

• A sprue pin for making the sprue passage is located at a small distance from the pattern. Also, riser pin, if required, is placed at an appropriate place.

• The operation of filling, ramming and venting of the cope proceed in the same manner as performed in the drag.

• The sprue and riser pins are removed first and a pouring basin is scooped out at the top to pour the liquid metal.

• Then pattern from the cope and drag is removed and facing sand in the form of paste is applied all over the mold cavity and runners which would give the finished casting a good surface finish.

The mold is now assembled. The mold now is ready for pouring (Figure 7(c))
c) Shell Molding Process

- It is a process in which, the sand mixed with a thermosetting resin is allowed to come in contact with a heated pattern plate (200 °C), this causes a skin (Shell) of about 3.5 mm of sand/plastic mixture to adhere to the pattern.
- Then the shell is removed from the pattern.
- The cope and drag shells are kept in a flask with necessary backup material and the molten metal is poured into the mold.
- This process can produce complex parts with good surface finish 1.25 µm to 3.75 µm, and dimensional tolerance of 0.5%.
- A good surface finish and good size tolerance reduce the need for machining.
- The process overall is quite cost effective due to reduced machining and cleanup costs.
- The materials that can be used with this process are cast iron, and aluminum and copper alloys.

Molding Sand in Shell Molding Process:

The molding sand is a mixture of fine grained quartz sand and powdered bakelite. There are two methods of coating the sand grains with bakelite. First method is Cold coating method and another one is the hot method of coating.

In the method of cold coating, quartz sand is poured into the mixer and then the solution of powdered bakelite in acetone and ethyl aldehyde are added. The typical mixture is 92% quartz sand, 5% bakelite, 3% ethyl aldehyde. During mixing of the ingredients, the resin envelops the sand grains and
the solvent evaporates, leaving a thin film that uniformly coats the surface of sand grains, thereby imparting fluidity to the sand mixtures.

In the method of hot coating, the mixture is heated to 150-180°C prior to loading the sand. In the course of sand mixing, the soluble phenol formaldehyde resin is added. The mixer is allowed to cool up to 80 – 90°C. This method gives better properties to the mixtures than cold method.

d) Sodium Silicate Molding Process

In this process, the refractory material is coated with a sodium silicate-based binder. For molds, the sand mixture can be compacted manually, jolted or squeezed around the pattern in the flask. After compaction, CO₂ gas is passed through the core or mold. The CO₂ chemically reacts with the sodium silicate to cure, or harden, the binder. This cured binder then holds the refractory in place around the pattern. After curing, the pattern is withdrawn from the mold.

The sodium silicate process is one of the most environmentally acceptable of the chemical processes available. The major disadvantage of the process is that the binder is very hygroscopic and readily absorbs water, which causes a porosity in the castings. Also, because the binder creates such a hard, rigid mold wall, shakeout and collapsibility characteristics can slow down production. Some of the advantages of the process are:

- A hard, rigid core and mold are typical of the process, which gives the casting good dimensional tolerances;
- good casting surface finishes are readily obtainable;

e) Permanent Mold Process

- In all the above processes, a mold need to be prepared for each of the casting produced. For large-scale production, making a mold, for every casting to be produced, may be difficult and expensive.
- Therefore, a permanent mold, called the die may be made from which a large number of castings can be produced; the molds are usually made of cast iron or steel, although graphite, copper and aluminum have been used as mold materials.
- The process in which we use a die to make the castings is called permanent mold casting or gravity die casting, since the metal enters the mold under gravity.
- Some time in die-casting we inject the molten metal with a high pressure. When we apply pressure in injecting the metal it is called pressure die casting process.
Advantages:
- Permanent Molding produces a sound dense casting with superior mechanical properties.
- The castings produced are quite uniform in shape, have a higher degree of dimensional accuracy than castings produced in sand.
- The permanent mold process is also capable of producing a consistent quality of finish on castings.

Disadvantages:
- The cost of tooling is usually higher than for sand castings.
- The process is generally limited to the production of small castings of simple exterior design, although complex castings such as aluminum engine blocks and heads are now commonplace.

f) Centrifugal Casting

- In this process, the mold is rotated rapidly about its central axis as the metal is poured into it.
- Because of the centrifugal force, a continuous pressure will be acting on the metal as it solidifies.
- The slag, oxides and other inclusions being lighter, get separated from the metal and segregate towards the center.
- This process is normally used for the making of hollow pipes, tubes, hollow bushes, etc., which are axi-symmetric with a concentric hole.
- Since the metal is always pushed outward because of the centrifugal force, no core needs to be used for making the concentric hole.
- The mold can be rotated about a vertical, horizontal or an inclined axis or about its horizontal and vertical axes simultaneously.
- The length and outside diameter are fixed by the mold cavity dimensions while the inside diameter is determined by the amount of molten metal poured into the mold.

![Figure 9 Vertical Centrifugal Casting](image1)

![Figure 10 Horizontal Centrifugal Casting](image2)
Advantages:
- Formation of hollow interiors in cylinders without cores
- Less material required for gate
- Fine grained structure at the outer surface of the casting free of gas and shrinkage cavities and porosity

Disadvantages:
- More segregation of alloy component during pouring under the forces of rotation
- Contamination of internal surface of castings with non-metallic inclusions
- Inaccurate internal diameter

g) Investment Casting Process
- The root of the investment casting process, the cire perdue or “lost wax” method dates back to at least the fourth millennium B.C.
- The artists and sculptors of ancient Egypt and Mesopotamia used the rudiments of the investment casting process to create intricately detailed jewelry, pectorals and idols.
- The investment casting process also called lost wax process begins with the production of wax replicas or patterns of the desired shape of the castings.
- A pattern is needed for every casting to be produced.
- The patterns are prepared by injecting wax or polystyrene in a metal dies.
- A number of patterns are attached to a central wax sprue to form a assembly.
- The mold is prepared by surrounding the pattern with refractory slurry that can set at room temperature.
- The mold is then heated so that pattern melts and flows out, leaving a clean cavity behind.
- The mould is further hardened by heating and the molten metal is poured while it is still hot.
- When the casting is solidified, the mold is broken and the casting taken out.

The basic steps of the investment casting process are (Figure 11):
1. Production of heat-disposable wax, plastic, or polystyrene patterns
2. Assembly of these patterns onto a gating system
3. “Investing,” or covering the pattern assembly with refractory slurry
4. Melting the pattern assembly to remove the pattern material
5. Firing the mold to remove the last traces of the pattern material
6. Pouring
Figure 11: The Basic Steps of the Investment Casting Process
Defects in Casting: Causes and remedies, cleaning and inspection of casting-fettling operations,

Non-destructive testing: X-ray radiography, Dye-penetrant test, ultrasonic test, magnetic particle inspection.

Classification of casting defects:

It always difficult to classify casting defects because of the wide range of contributory cause and the nature of defects. However, casting defects can be broadly classified under the following headings.

a) Based on nature of defects:

i) Surface defects: are visible on the surface of castings such as incorrect shape and size, misrun, laps, flashes, metal penetration, rat tail, poor surface finish, etc.

ii) Internal defects: are present in the interior of castings and are revealed by non-destructive testing alone. Examples are pin holes, blow hole, slag inclusion, etc.

iii) Incorrect chemical composition which may also result in the formation of undesirable microstructure.

iv) Un-satisfactory mechanical properties.

b) Based on contributing causes or origins

i) Defects caused by pattern and molding box equipment such as incorrect dimension, poor surface finish, flash, mismatch etc.

ii) Defects due to improper mold and core and core making. These include blowholes, drops, scabs, pinholes, hot tear etc.

iii) Defects caused by improper gating and risering, resulting in cold shut, mistune, sand inclusion, hot tear, shrinkage cavity etc.

Casting Defects: (Figure 8.1)

The following are the major defects, which are likely to occur in sand castings

1. Gas defects
2. Shrinkage cavities
3. Molding material defects
4. Pouring metal defects
5. Mold shift / Core shift

1. Gas Defects:

- A condition existing in a casting caused by the trapping of gas in the molten metal or by mold gases evolved during the pouring of the casting.

- The defects in this category can be classified into
a) Blowholes and

b) Pinhole porosity

✓ Blowholes are spherical or elongated cavities present in the casting on the surface or inside the casting.

✓ Pinhole porosity occurs due to the dissolution of hydrogen gas, which gets entrapped during heating of molten metal.

Causes:

- The lower gas-passing tendency of the mold, which may be due to lower venting, lower permeability of the mold or improper design of the casting.

- The lower permeability is caused by finer grain size of the sand, high percentage of clay in mold mixture, and excessive moisture present in the mold.
  
  i) Metal contains gas
  
  ii) Mold is too hot
  
  iii) Poor mold burnout

2. Shrinkage Cavities:

- These are caused by liquid shrinkage occurring during the solidification of the casting.

- To compensate for this, proper feeding of liquid metal is required.

- For this reason risers are placed at the appropriate places in the mold.

- Sprues may be too thin, too long or not attached in the proper location, causing shrinkage cavities.

- It is recommended to use thick sprues to avoid shrinkage cavities.

3. Molding Material Defects:

The defects in this category are

  i) Cuts and washes
  
  ii) Metal penetration
  
  iii) Fusion, and
  
  iv) Swell
  
  v) Drop
  
  vi) Expansion scabs

i) Cut and washes:
• These appear as rough spots and areas of excess metal, and are caused by erosion of molding sand by the flowing metal.

• This is caused by the molding sand not having enough strength and the molten metal flowing at high velocity.

• The former can be taken care of by the proper choice of molding sand and the latter can be overcome by the proper design of the gating system.

ii) **Metal penetration:**

• When molten metal enters into the gaps between sand grains, the result is a rough casting surface.

• This occurs because the sand is coarse or no mold wash was applied on the surface of the mold.

• The coarser the sand grains more the metal penetration.

iii) **Fusion:**

• This is caused by the fusion of the sand grains with the molten metal, giving a brittle, glassy appearance on the casting surface.

• The main reason for this is that the clay or the sand particles are of lower refractoriness or that the pouring temperature is too high.

iv) **Swell:**

• Under the influence of metallostatic forces, the mold wall may move back causing a swell in the dimension of the casting.

• A proper ramming of the mold will correct this defect.

v) **Drop:**

• This occurs when some portion of the mold usually from cope surface breaks off and falls into the mold cavity. Remedy is to ram the sand properly.

vi) **Expansion scabs:**

• These are due to expansion property of sand, that is when molten metal is poured, the sand will expand due to high temperature.

• If this expansion is prevented due to mold condition, it will develop minute cracks and molten metal may enter these cracks resulting in a poor surface condition in casting.

• This may be due to hard ramming of mold, high clay content, low thermal stability of sand resulting in expansion and low hot deformation of the mold.

• The remedy is to reduce clay content, less ramming and use of additives which reduce thermal expansion but increase hot deformation of sand.
b) Inclusions:
- Particles of slag, refractory materials, sand or deoxidation products are trapped in the casting during pouring solidification.
- The provision of choke in the gating system and the pouring basin at the top of the mold can prevent this defect.

4. Pouring Metal Defects:
The likely defects in this category are
i) Mis-runs and
ii) Cold shuts.

i) Mis-run:
- A mis-run is caused when the metal is unable to fill the mold cavity completely and thus leaves unfilled cavities.
- A mis-run results when the metal is too cold to flow to the extremities of the mold cavity before freezing.
- Long, thin sections are subject to this defect and should be avoided in casting design.

ii) Cold shut:
- A cold shut is caused when two streams while meeting in the mold cavity, do not fuse together properly thus forming a discontinuity in the casting.
- When the molten metal is poured into the mold cavity through more-than-one gate, multiple liquid fronts will have to flow together and become one solid.
- If the flowing metal fronts are too cool, they may not flow together, but will leave a seam in the part.
- Such a seam is called a cold shut, and can be prevented by assuring sufficient superheat in the poured metal and thick enough walls in the casting design.

Causes:
- The mis-run and cold shut defects are caused either by a lower fluidity of the mold or when the section thickness of the casting is very small.
- Fluidity can be improved by changing the composition of the metal and by increasing the pouring temperature of the metal.
5. Mold Shift / Core shift:

- The mold shift defect occurs when cope and drag or molding boxes have not been properly aligned.
- Core surfaces sometimes shift due to the metallo-static pressure. The remedy is to provide adequate support to the core by using chaplets.

![Diagram of Casting Defects]

Fettling and cleaning of casting:

- After solidification of the casting, it is separated from the molding using knock out vibrators.
- Due to this vibration, the cores also get loosened and hence they can be easily separated from the casting.

1. Core removal and surface cleaning:

a) Manual cleaning methods:

- After the casting has solidified, a good lot of sand will be sticking to its surface and this is more in steel castings compared to non-ferrous castings.
- In small foundries cleaning can be accomplished with wire brushes, which is tedious and time consuming and hence mechanical equipments are generally used.

b) Mechanical methods:
i) Tumbling:

- The components to be cleaned are placed inside a barrel along with hardened steel rods.
- The barrel is then rotated about its central axis for a sufficient length of time, so that the surfaces are cleaned by peening action as castings rub against the steel rods.

ii) Compressed air impact cleaning:

- Here, a stream of suitable abrasive particles along with compressed air is directed at high velocities against the surfaces to be cleaned.
- This is done in tightly closed chambers and due to the impact, the surfaces of the castings will be cleaned.

iii) Mechanical impact cleaning (shot blasting):

- The abrasive particles are thrown against surfaces to be cleaned by centrifugal force.
- Due to the impact, the surfaces of the castings are cleaned.

iv) Hydroblasting:

- In this method, a high velocity stream containing about 15% sand and 85% water is directed against the surfaces to be cleaned.
- Water at a pressure of about 140 atmospheres is supplied to a nozzle so that stream velocities of upto 6000 m/min are obtained, due to this the minimum weight of the casting cleaned this way should be at least 120 kg, the jet angled at 45°.
- Used sand may be reclaimed.

2. Removal of gates and risers:

Several methods are used depending upon the metal, casting size and other conditions. These are,

i) Breaking the gates from the casting
ii) Sawing with hand, disc or hacksaw
iii) Flame cutting with oxyacetylene torch
iv) Cutting with an abrasive cut – off wheel

3. Removal of fins, unwanted projections etc.:

This can be done using methods such as chipping, sawing, flame cutting, grinding etc.

4. Repair of castings:

- After the casting is made, sometimes very minute defects may be noticed in the casting which may not affect its usefulness.
- In such cases, these defects are filled up using weld metal etc.
Inspection of castings: can be carried out at various stages as follows –

i) Process inspection:
   - It is done to detect defects and to allow corrections to be made before the parts have been processed i.e., before it is too late.

ii) Visual inspection:
   - This is the simplest, fastest and most commonly employed method for finding many defects visually.
   - It is limited to the defects which can be observed on surfaces.

iii) Dimensional inspection:
   - First casting to be machined is to be dimensionally checked in the foundry by setting up on a surface plate with angle plate and measuring instruments such as micrometer, vernier height gauge, etc. to ensure that the pattern and core boxes used are correct.

iv) Pressure testing:
   - Castings to be used for containing or conveying liquids or gases have to be tested for leaks through their walls.
   - The castings with porosity may leak and leaks may be detected by submerging the complete casting under water for gas pressures or by virtual inspection for liquid pressures.

v) Destructive testing:
   - Destructive tests such as tensile, compression, impact, fatigue and creep may be performed on specimens machined out of the castings to assess the various properties.

vi) Non-destructive testing:
   - The basic feature of this test is that the parts are inspected for internal and surface defects without destroying the components. Different methods available
     a) Liquid penetrant test
     b) Magnetic particle inspection
     c) X-ray radiography
     d) Ultrasonic inspection
     e) Eddy current test
     f) Gamma ray radiography
Nondestructive testing:

Nondestructive testing (NDT), also called nondestructive examination (NDE) and nondestructive inspection (NDI), is testing that does not destroy the test object.

NDE is vital for constructing and maintaining all types of components and structures.

To detect different defects such as cracking and corrosion, there are different methods of testing available, such as X-ray (where cracks show up on the film) and ultrasound (where cracks show up as an echo blip on the screen).

While destructive testing usually provides a more reliable assessment of the state of the test object, destruction of the test object usually makes this type of test more costly to the test object's owner than nondestructive testing.

Destructive testing is also inappropriate in many circumstances, such as forensic investigation. That there is a tradeoff between the cost of the test and its reliability favors a strategy in which most test objects are inspected nondestructively; destructive testing is performed on a sampling of test objects that is drawn randomly for the purpose of characterizing the testing reliability of the nondestructive test.

The need for NDT:

- It is very difficult to weld or mold a solid object that has the risk of breaking in service, so testing at manufacture and during use is often essential.
- During the process of casting a metal object, for example, the metal may shrink as it cools, and crack or introduce voids inside the structure.
- Even the best welders (and welding machines) do not make 100% perfect welds. Some typical weld defects that need to be found and repaired are lack of fusion of the weld to the metal and porous bubbles inside the weld, both of which could cause a structure to break or a pipeline to rupture.

During their service lives, many industrial components need regular nondestructive tests to detect damage that may be difficult or expensive to find by everyday methods.

For example:

- aircraft skins need regular checking to detect cracks;
- underground pipelines are subject to corrosion and stress corrosion cracking;
- pipes in industrial plants may be subject to erosion and corrosion from the products they carry;
- concrete structures may be weakened if the inner reinforcing steel is corroded;
- pressure vessels may develop cracks in welds;
- the wire ropes in suspension bridges are subject to weather, vibration, and high loads, so testing for broken wires and other damage is important.
Dye penetrant inspection:

- **Dye penetrant inspection (DPI)**, also called **liquid penetrant inspection (LPI)**, is a widely applied and low-cost inspection method used to locate surface-breaking defects in all non-porous materials (metals, plastics, or ceramics).

- Penetrant may be applied to all non-ferrous materials, but for inspection of ferrous components magnetic-particle inspection is preferred for its subsurface detection capability.

- LPI is used to detect casting and forging defects, cracks, and leaks in new products, and fatigue cracks on in-service components.

**Principles:**

- DPI is based upon capillary action, where low surface tension fluid penetrates into clean and dry surface-breaking discontinuities.

- Penetrant may be applied to the test component by dipping, spraying, or brushing.

- After adequate penetration time has been allowed, the excess penetrant is removed, a developer is applied.

- The developer helps to draw penetrant out of the flaw where a visible indication becomes visible to the inspector.

- Inspection is performed under ultraviolet or white light, depending upon the type of dye used - fluorescent or nonfluorescent (visible).

1. Section of material with a surface-breaking crack that is not visible to the naked eye.
2. Penetrant is applied to the surface.
3. Excess penetrant is removed.
4. Developer is applied, rendering the crack visible.

**Figure 8.2 Steps in dye penetrant inspection**

**Materials:**

- Penetrants are classified into sensitivity levels.

- Visible penetrants are typically red in color, and represent the lowest sensitivity.

- Fluorescent penetrants contain two or more dyes that fluoresce when excited by ultraviolet (UV-A) radiation (also known as black light).
Since fluorescent penetrant inspection is performed in a darkened environment, and the excited dyes emit brilliant yellow-green light that contrasts strongly against the dark background, this material is more sensitive to small defects.

When selecting a sensitivity level one must consider many factors, including

- the environment under which the test will be performed,
- the surface finish of the specimen, and
- the size of defects sought.

One must also assure that the test chemicals are compatible with the sample so that the examination will not cause permanent staining, or degradation.

This technique can be quite portable, because in its simplest form the inspection requires only 3 aerosol spray cans, some paper towels, and adequate visible light.

Stationary systems with dedicated application, wash, and development stations, are more costly and complicated, but result in better sensitivity and higher sample through-put.

**Inspection Steps:** Below are the main steps of Liquid Penetrant Inspection:

1. **Pre-cleaning:**
   - The test surface is cleaned to remove any dirt, paint, oil, grease or any loose scale that could either keep penetrant out of a defect, or cause irrelevant or false indications.
   - Cleaning methods may include solvents, alkaline cleaning steps, vapor degreasing, or media blasting.
   - The end goal of this step is a clean surface where any defects present are open to the surface, dry, and free of contamination.

2. **Application of Penetrant:**
   - The penetrant is then applied to the surface of the item being tested.
   - The penetrant is allowed time to soak into any flaws (generally 10 to 30 minutes).
   - The soak time mainly depends upon the material being testing and the size of flaws sought.
   - As expected, smaller flaws require a longer penetration time.
   - Due to their incompatible nature one must be careful not to apply visible red dye penetrant to a sample that may later be inspected with fluorescent penetrant.

3. **Excess Penetrant Removal:**
   - The excess penetrant is then removed from the surface.
   - Removal method is controlled by the type of penetrant used.
- Water-washable, solvent-removable, lipophilic post-emulsifiable, or hydrophilic post-emulsifiable are the common choices.

- Emulsifiers represent the highest sensitivity level, and chemically interact with the oily penetrant to make it removable with a water spray.

- When using solvent remover and lint-free cloth it is important to not spray the solvent on the test surface directly, because this can remove the penetrant from the flaws.

- This process must be performed under controlled conditions so that all penetrant on the surface is removed (background noise), but penetrant trapped in real defects remains in place.

4. Application of Developer:

- After excess penetrant has been removed a white developer is applied to the sample.

- Several developer types are available, including: non-aqueous wet developer, dry powder, water suspendible, and water soluble.

- Choice of developer is governed by penetrant compatibility (one can't use water-soluble or suspendible developer with water-washable penetrant), and by inspection conditions.

- When using non-aqueous wet developer (NAWD) or dry powder the sample must be dried prior to application, while soluble and suspendible developers are applied with the part still wet from the previous step.

- NAWD is commercially available in aerosol spray cans, and may employ acetone, isopropyl alcohol, or a propellant that is a combination of the two.

- Developer should form a thin, even coating on the surface.

- The developer draws penetrant from defects out onto the surface to form a visible indication, a process similar to the action of blotting paper.

- Any colored stains indicate the positions and types of defects on the surface under inspection.

5. Inspection:

- The inspector will use visible light with adequate intensity (100 foot-candles is typical) for visible dye penetrant.

- Ultraviolet (UV-A) radiation of adequate intensity (1,000 micro-watts per centimeter squared is common), along with low ambient light levels (less than 2 foot-candles) for fluorescent penetrant examinations.

- Inspection of the test surface should take place after a 10 minute development time.

- This time delay allows the blotting action to occur.

- The inspector may observe the sample for indication formation when using visible dye, but this should not be done when using fluorescent penetrant.
Also of concern, if one waits too long after development the indications may "bleed out" such that interpretation is hindered.

6. Post Cleaning:

- The test surface is often cleaned after inspection and recording of defects (if found), especially if post-inspection coating processes are scheduled.

**Advantages:**

1. Special equipment is not necessary.
2. Easy to use.
3. Low cost both in material and labour.
4. Easily portable to any location.

**Disadvantages:**

1. Only surface cracks can be detected successfully

**Features:**

- The flaws are more visible, because:
  - The defect indication has a high visual contrast (e.g. red dye against a white developer background, or a bright fluorescent indication against a dark background).
  - The developer draws the penetrant out of the flaw over a wider area than the real flaw, so it looks wider.
- Limited training is required for the operator — although experience is quite valuable.
- Low testing costs.
- Proper cleaning is necessary to assure that surface contaminants have been removed and any defects present are clean and dry. Some cleaning methods have been shown to be detrimental to test sensitivity, so acid etching to remove metal smearing and re-open the defect may be necessary.
- Penetrant dyes stain cloth, skin and other porous surfaces brought into contact. One should verify compatibility on the test material, especially when considering the testing of plastic components.
- Further information on inspection steps may be found in industry standards (e.g. the American Welding Society, American Society for Testing and Materials, the British Standards Institute, and the Society for Automotive Engineers).
Magnetic-particle inspection:

- This method is the most satisfactory method for finding surface and slightly subsurface defects.
- It is quick and cheap to operate and it is very sensitive.
- It can be applied to only ferrous metals such as steel and cast iron.

Principle:

- It is seen that when a piece of metal is placed in a magnetic field and the lines of magnetic flux are intersected by a defect or discontinuity.
- Due to this there will be an abrupt change in the path of flux resulting in a local leakage.
- Such an effect can be detected with a magnetic particle, which are attracted to the region of discontinuity and gets piled up in the region.

Procedure:

The various steps are

1. Preparation of the specimen
2. Magnetization of the specimen
3. Application of magnetic particles
4. Inspecting the defect

1. Preparation of the specimen:

- The surface of the specimen should be cleaned thoroughly to remove rust, grease, oil, paint, etc. which hinder the movement of the magnetic particles.
- This can be done by using steel brushes, shot blasting or by using various solvents.

2. Magnetization:

- Two methods are available to induce magnetic lines of force in the test specimen, they are permanent magnet or an electromagnet.
- The magnetic lines of force induced will be same in both cases.
- But it is observed that the electromagnet is capable of producing a stronger magnetic force field than the permanent magnet.
- The type of magnetization depends on whether the defects are parallel to or perpendicular to the interface or sides of the test specimen.
- Longitudinal or parallel defects are indicated because the electrical current flow sets up magnetic flux lines $90^\circ$ to the current flow as shown in figure 8.3, following the left hand rule of current flow.
For a defect to be detected successfully, the magnetic lines of force must cross the defect in a perpendicular line.

On the other hand, if the defect is parallel to the lines of force, there is a possibility that the defect would not be noticeable.

In order to check the specimen fully, both longitudinal and perpendicular indications must be checked.

Figure 8.4 shows the two types of magnetization.
3. Application of magnetic particles:

- The magnetic particles are applied to the surface so that they are free to move over the entire test section.
- The particles must be as fine as possible, generally, pulverized iron oxide or carbonyl iron powders are widely used.
- The powder can be in the following forms:
  
  i) Powder suspended in liquid petroleum
  
  ii) Dry powder which is fully recoverable
  
  iii) Fluorescent powder which has to be viewed under ultra violet light
- The magnetic particle is applied all over the surface.

4. Inspecting the defect:

- Inspection is carried out in good light.
- Figure 8.4 shows magnetic flux lines in a part being inspected.
- If there are no flaws or defects, the magnetic particles align in a regular pattern showing uninterrupted flux lines.
- If a crack or void interrupts a magnetic field, the flux lines get distorted as shown by the path of magnetic particles in figure 8.4 (b).
- As the magnetic permeability of air is low in comparison with iron, the magnetic flux spreads around the void.
- Thus discontinuity is noticed or located distinctly because the magnetic particles collect and pile up at any discontinuity or cracks.

Advantages:

1. Magnetic particle inspection is fast, simple and inexpensive
2. Clear indications are visible on the surface
3. Very thin layer of paint etc. may not affect the process

Disadvantages:

1. The method is applicable to only ferromagnetic materials
2. Defects below the surface are not indicated satisfactorily
3. The direction of magnetic field affects the results
4. Good knowledge and experience is needed to interpret the results.
X - Ray radiography:

- X-rays are produced when high energy electrons collide with the nucleus of an atom.
- The x-ray equipment consists of a filament, which is similar to an incandescent light, which is placed near a highly charged cathode, causing the electrons to flow from the cathode which is attracted by the anode or target.
- The collision of the electrons with the target, produces x-rays of continuous nature.
- The pattern of the x-ray so produced depends on the shape of the target. Further, the intensity of x-rays produced is directly proportional to the number of electrons freed at the filament.
- A radiographic film is placed next to the part to be tested and x-rays are directed against the part.
- The x-rays will pass through the part to be tested and exposes the film.
- The absorption of x-rays is directly proportional to the density and thickness of the part. If the part has no defects, the x-rays will pass uniformly through the part (fig. 8.5b).
- However, if there are any defects such as porosity which leads to lesser density, the penetration of x-rays will be more through them which shows up as darker areas on the film.
- X-ray technique is effective in locating cracks, slag inclusions, porosity, blow holes, pin holes etc.
- X-rays can be used for inspection of castings and weldmets in all type of metals like steel, aluminum, magnesium - etc.
- However x-ray inspection is a slow and expensive NDT technique.
Ultrasonic testing:

**Principle of operation:**

- Ultrasonic testing is based on the piezoelectric effect, which converts electrical energy to mechanical energy thus generating ultrasonic waves.
- Ultrasonic waves are generated when a high frequency alternating current of about a million times per second is impressed across the faces of a piezoelectric material like quartz crystal.
- The crystal expands in the first half of the cycle and contracts when the electric field is reversed, thus producing mechanical vibrations.
- Ultrasonic waves with a frequency range of 200,000 to 24,000,000 Hz are suitable for testing purposes.
- These are similar to light waves, i.e., they can be reflected, focused or refracted.
- The important characteristics of the sound wave is that they can pass through a solid object with little absorption.

**Testing method:**

- It is essential to clean the surface of the casting and make the surface fairly smooth by machining or otherwise.
- This helps transmitting the ultrasonic wave effectively from the probe to the casting.
- Separate probes can be employed; one for transmitting and the other for receiving the waves. However, a single probe may also be employed both as a transmitter and as a receiver.
- During testing, ultrasonic transducers are placed on the surface of the article being tested.
- Generally, a couplant such as an oily, glycerin-based substance is used between the transducer and the surface of the material.
- This helps in removing the air between the transducer and the surface of the material and also provides a medium for the transfer of the sound vibrations.
On a commercial scale, three different types of test devices are available such as,

i) the pulse echo systems,

ii) the through transmission system and

iii) the resonance system.

Of the three, the pulse echo system (fig. 8.6) is the most widely used.

The transducer is placed on the test specimen with a layer of couplant between them.

The ultrasonic wave generated by the transducer is passed through the test specimen.

The same transducer is used to receive the waves also.

The signal is displayed on the cathode ray tube (CRT).

Ultrasonic waves are reflected not only from the boundary of the material being tested but also from any discontinuity or defect in their path.

First, when the waves pass through the top surface of the specimen being tested, there will be a pip on the CRT, which indicates the top boundary of the specimen.

Similarly another pip is noticed on the CRT corresponding to the other end or boundary of the specimen.

If the specimen has any flaw or defect in between, a pip B will be noticed corresponding to the reflected wave from the defect.
Thus using this method, the thickness of the specimen can be measured and at the same time the exact location of the defect within the material can be easily determined.

**Advantages**

i) This method is quite fast and reliable.

ii) It is more sensitive than radiography.

iii) By using higher frequency ultrasonic waves, greater sensitivity can be achieved.

**Disadvantages**

i) This method is more sensitive to surface roughness and as a result surface machining is a must.

ii) In intricate castings, the interpretation becomes difficult because the waves may also be reflected by sharp corners etc.