Basic Manufacturing Processes

MODULE-I&II

CASTING PROCESSES

Manufacturing can be defined as the process of converting raw materials (and information such as specifications) into a usable form of products. The process of manufacturing mainly encompases

(a) Product design

(b) Raw material selection, and

(c) Sequence of operations (processes) through which the product will be manufactured.

In general, the term '**process**' can be defined as a change in the properties of an object, including geometry, hardness, state, information content and so on. Depending on the main purpose of the process, it is either a material process, an energy process or an information process. In the present text it is mainly concerned with material process which produces geometrical changes or changes in the material property or both and known as **basic processes**.

A manufacturing process is the activity (or a set of activities) of transforming a given material into a product of different form and sizes and with or without changing the physical and mechanical properties of the material of the product. A manufacturing process normally consists of a series of basic processes, which constitute the structure of the material flow. A classification scheme of the basic manufacturing processes is shown in Fig. 1.1.

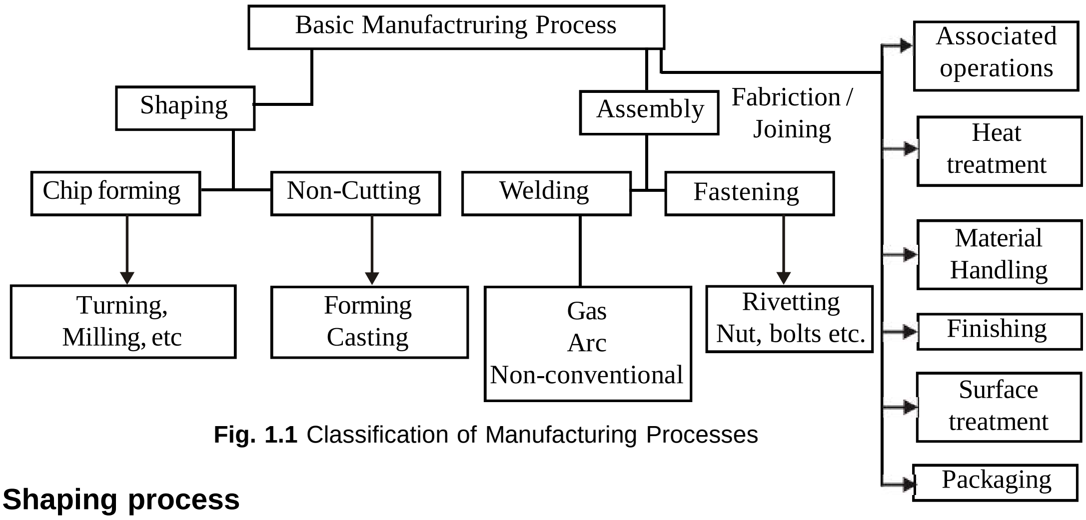


Fig. 1.1 Classification of Manufacturing Processes

Shaping process

These processes give desired shape and size to the raw material (s) to obtain the finished product through material removal process or non-material removal process.

The material removal process (machining process) removes excess material from the base material by a tool to get desired shape. Eg. Turning, Milling etc. The non-material removal process involves shaping of a material by putting it in a cavity either in a liquid state or a solid state to get the desired shape. Eg. Forming (extrusion, deep drawing etc.) and casting.

Assembly / Fabrication / Joining

These involve joining pieces either permanently or temporarily to perform necessary function. Joing can be made by applying both temperature and pressure on the materials to be joined or by fastering by using nuts and bolts. Eg. Welding (Gas, Arc and non-conventional), Rivetting, etc.

Associated operations

The associated operations such as heat treatment, finishing or super finishing operations, surface treatment etc. help in improving the material property of the final product.

1.1 FOUNDRY PROCESS / CASTING

The art of foundry (From latin 'fundere' means 'melting & pouring') is very primitive to civilization as it has been is use since 3000 B.C, when bronze arrowheads were cast in open-faced clay moulds.

Metal casting (or simply casting) it based on the property of liquid to take up the shape of the vessel which contains it. The process of metal casting involves pouring of molten metal into a mould, which is a cavity formed in some moulding material such as sand. The mould cavity exactly resembles in shape and size with the product to be made. After pouring, the molten metal is allowed to freeze there, taking up the shape of the mould cavity and the product is thus cast, is called a **casting**. A sand mould is shown in Fig. 1.2.

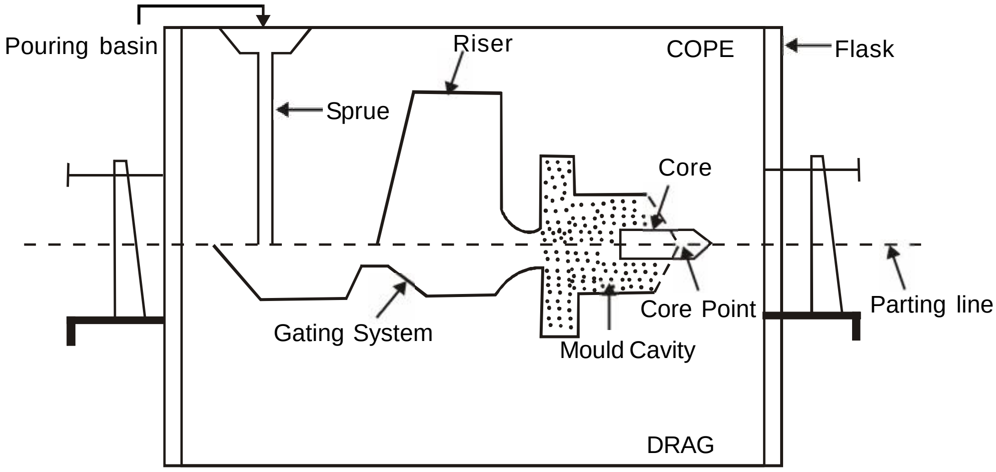


Fig. 1.2 Corss section of a two-part sand mould.

Flask A moulding flask is one which holds the sand mould intact. Depending on the position of the flask in the mould structure, it is referred to as drag, cope and cheek. It is generally made up of wood for temporary use or of metal for long term use.

Drag Lower moulding flask.

Cope Upper moulding flask.

Cheek Intermediate moulding flask used in three piece moulding.

Parting line This is the dividing line between the two moulding flasks that makes up the sand mould.

Core It is used for making hollow cavities in castings.

Pouring basin A small funnel shaped cavity at the top of the mould into which the molten metal is poured.

Sprue The passage through which the molten metal from the pouring basin reaches the mould cavity.

Runner The passage ways in the parting plane through which molten metal flow is requlated before they reach the mould cavity.

Gate The actual entry point through which molten metal enters mould cavity.

Chaplet Chaplets are used to support cores inside the mould cavity to take care of its own weight and overcome the metallostatic forces.

Chill Chills are metallic objects which are placed in the moulds to increase the rate of cooling of castings to provide uniform or desired cooling rate.

Riser It is the reservoir of molten metal provided in the casting so that hot metal can flow back into the mould cavity when there is a reduction in volume of metal due to solidification.

Core print An impression in the form of a recess is made in the mould with the help of a projection suitably placed on the pattern, for supporting the cores in the mould cavity. This projection is known as a core print.

1.1.1 Steps in casting

The whole process of producing casting may be classified in to five steps as follows :

(*i*) **Pattern making** The pattern is an exact fascimile or replica of the article to be cast. The patterns are designed and prepared as per the drawing.

(*ii*) **Moulding and core making** The moulds are prepared in either sand or similar materials with the help of patterns so that a cavity of the designed shape is produced. To obtain hollow portions, cores are prepared separately in core boxes. The moulds and cores are then baked to impart strength and finally assembled for pouring. Moulding can be done either manually or by machines depending on the output required. Provision of gates and risers are also made for flow of molten metal.

(*iii*) **Melting & casting** Correct composition of molten metal is melted in a suitable surface and poured into the moulds. The moulds are then allowed to cooldown for the metal to solidify. The castings are finally extracted by breaking the moulds.

(*iv*) **Fettling** The castings as obtained after solidification carry unwanted projections. Also sand particles tend to adhere to the surface of castings. The castings are therefore sent to fettling section when the projections are cut off and surface cleaned for further work. The casting may also need heat treatment depending on the specific properties required.

(*v*) **Testing & Inspection** Finally, before the casting is despatched from foundry, it is tested and inspected to ensure that it is flawless and confirms to the specifications desired.

1.1.2 Advantages and disadvantages of Metal Casting

Advantages

(A) Design advantages

(*i*) **Size :** There is no restriction on size. Items from a few grams to many tons can be produced by casting. In fact, casting is the only process for producing massive objects in one single piece. Eg. watch cases (few grams), rolling mill housing (around 50 tons).

(*ii*) **Complexity :** The most complex curved surfaces and complicated shapes which are difficult or rather impossible to manufacture by other processes, can usually be cast.

(*iii*) **Weight saving :** Large saving in weight is achieved as the metal can be placed exactly where it is required.

(*iv*) **production of prototypes :** The casting process is ideal for making models and prototypes required for creation of new designs.

(*v*) **Wide range of properties :** Special properties like corrosion resistance, heat resistance, damping capacity, high strength, electrical and thermal conductivity etc. are possible by alloying the base metal and proper heat treatment.

(B) Metallurgical advantages

(*i*) **Fibrous structure :** In cast metals, the inclusions are more or less randomly distributed during the solidification process. Thus the cast alloys usually do not exhibit any fibering or directionality of properties.

(*ii*) **Grain size :** Most non-ferrous alloys retain the grain size attained during freezing. Subsequent heat treatment can improve the grain size.

(*iii*) **Density :** The density of cast alloy is usually identical to that of the wrought alloys of the same chemical composition and heat treatment, when both are fully sound.

(C) Others

(*i*) **Low cost**

(*ii*) **Dimensional accuracy :** Tolerance as close as ± 0.1 mm can be achieved depending on the cast metal, the casting process and the shape and size of the casting. The surface finish can also be controlled and may vary from 5μ to 50μ.

(*iii*) **Versatility in production :** Suitable for small quantity job shop production as welll as large volume mass production by employing at automatic machines.

Disadvantages

(*i*) High energy consuming process.

(*ii*) Labour intensive as compared to other processes.

(*iii*) Needs large space and handling systems.

(*iv*) Time requirement for producing castings is quite long.

(*v*) Unfavorable working condition due to heat, dust fumes, heaps of scraps and slag etc. at different stages. Also there is high environmental pollution.

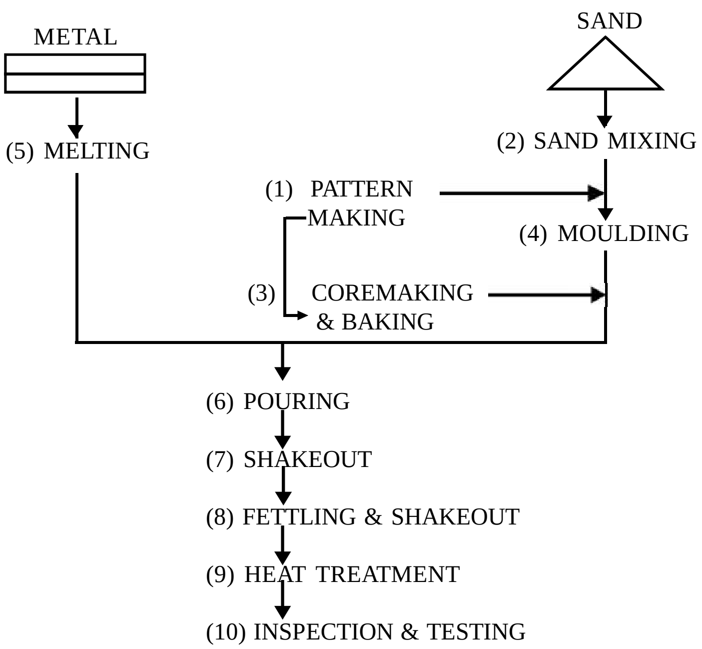
1.1.3 Applications of Casting (Metal : Ferrous and Non ferrous)

- Cylinder blocks
- Cylinder liners
- M/C Tool beds
- Pistons
- Piston rings
- Mill rolls

- Wheels
- Housing
- Water supply pipes
- Bells
- Jet engine blades
- Turbine blades

1.1.4 Sections of a Foundry

The sections of a foundry are as follows :



1.2 PATTERN

- Pattern may be defined as a model or replica of the object to be cast.
- Only variation according to dimension between casting and pattern are the various allowances.
- Sand is packed around the pattern and after its removal mould cavity is formed in which molten metal is poured to form final cast product.

1.2.1 Difference between Pattern and Casting

- Main difference between pattern and casting is their dimensions *i.e.*, a pattern is slightly larger in size than the casting because it carries shrinkage allowance (1 – 2 mm per 100 mm), draft allowance (1° and 3°) for tenal and internal surfaces and machining allowance.
- Pattern carries core prints.
- Pattern can be in two or three pieces but casting is a single piece object.
- Material required for both are different.

1.2.2 Functions of Pattern

- Produces mould cavity in sand.
- Its casting has a core pattern contains coreprints.
- It defines parting line and parting surfaces in the mould.
- Properly made patterns provide finished and smooth surface to casting and reduce defects.
- Properly constructed patterns reduce the overall cost of process.

1.2.3 Types of Pattern

- Single piece/ one piece pattern (solid pattern)
- Split/ Two piece pattern
- Loose piece pattern
- Match plate pattern
- Cope and Drag pattern
- Sweep pattern
- Gated pattern
- Skeleton pattern
- Follow board pattern

1.2.3.1 Single Piece Pattern

- Simplest pattern and inexpensive
- Made out of one piece and does not contain loose pieces or joints.
- Large size single castings are manufactured.
- Moulding operations are manual and so much time is required.
- Generally small numbers of castings are produced.
- Material used are wood or metal (depend on quantity of production)

- Stuffing box of steam engine.
- It is shown in Fig. 1.3.

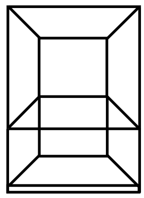


Fig. 1.3 Single piece pattern.

1.2.3.2 Split Pattern

- Castings of complicated shape can not be prepared in single piece because of some difficulties like withdrawing the pattern from the mould, etc.
- Upper part kept on cope and lower part in drag of mould.
- Alignment is maintained by using dowel pins. (*i.e.*, parting line for both pattern and mould are same)
- Taps, water stopcocks.
- It is shown in Fig. 1.4.

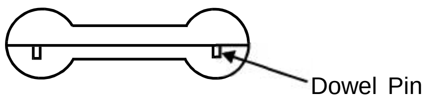


Fig. 1.4 Split Pattern

1.2.3.3 Loose Piece Pattern

- **Why Loose Pieces ?**

  Some patterns can not be removed after putting them in moulding sand. So for removing them, they are made of loose pieces.
- Loose pieces are attached to the main body by lower pins.
- Main body drawn out first and then loose pieces.
- Moulding needs more time.
- Provides errors.
- It is shown in Fig.1.5.

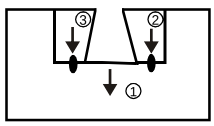


Fig. 1.5 Loose piece pattern

1.2.3.4 Match Plate Pattern

- It has a match plate on both side of which number of split patterns are fastened.
- Pattern of different size and shape can be fitted to a match plate.
- Match plate is clamped with drag by locator holes.
- Runner and gates are attached to the pattern assembly.
- After ramming the whole assembly is removed.

- Cope and drag fitted together-forms mould.
- Material - Aluminium normally used because of light weight and cheap in cost.
- Small castings are made in large scale.
- Piston rings and IC engines.
- It is shown in Fig. 1.6.

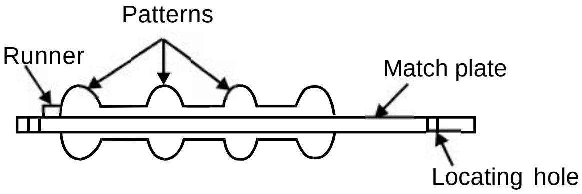


Fig. 1.6 Match plate pattern

1.2.3.5 Cope and Drag Pattern

- One kind of split pattern.
- Difference is that in this gating and risering system attached to both the halves using separate metal/wooden plate.
- Both the cope and drag parts of the final mould can be produced separately and assembled finally.
- Used for heavy castings inconvenient to handle.
- It is shown in Fig. 1.7.

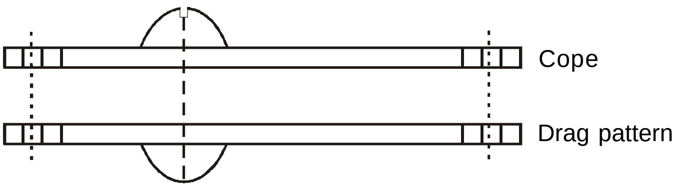


Fig. 1.7 Cope and Drag

1.2.3.6 Sweep Pattern

- It is illustrated in Fig. 1.8.

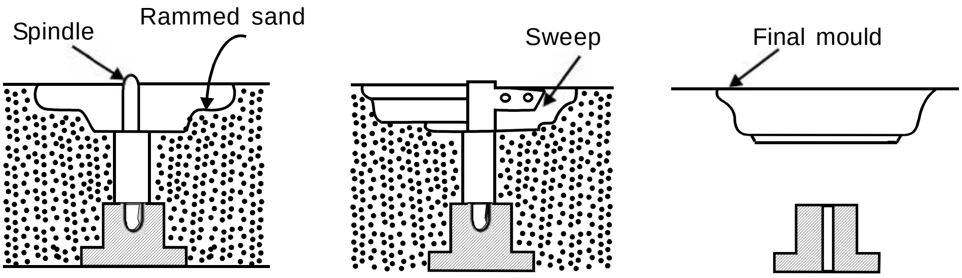


Fig.1.8 Sweep Pattern

- It is a form made on a wooden board which sweeps the shape of the casting around the post/spindle.
- It eliminates need of 3D pattern.
- Used for producing large castings of circular section and symmetrical shapes.
- Large bells etc.

1.2.3.7 Gated Pattern

- It is shown in Fig 1.9.
- Improvement of simple pattern
- Gating and runner system is a part of pattern.
- Productivity increases by eliminating preparation of gating system manually.
- For producing small size castings for mass production.

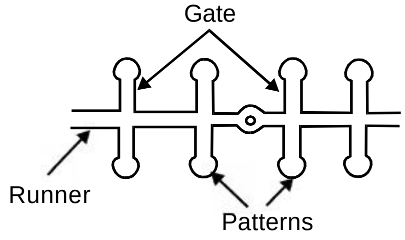


Fig. 1.9 Gated pattern

1.2.3.8 Skeleton Pattern

- It is shown in Fig. 1.10.
- This pattern is the skeleton of desired shape.
- Skeleton is made from wooden strips.
- Strickle board is used after ramming to remove extra sand.
- If object is symmetrical, then two halves can be moulded by using same pattern and finally moulds assembled before pouring.
- Large castings in small numbers.
- Turbine blades, water pipes, chutes, L - bends, etc.

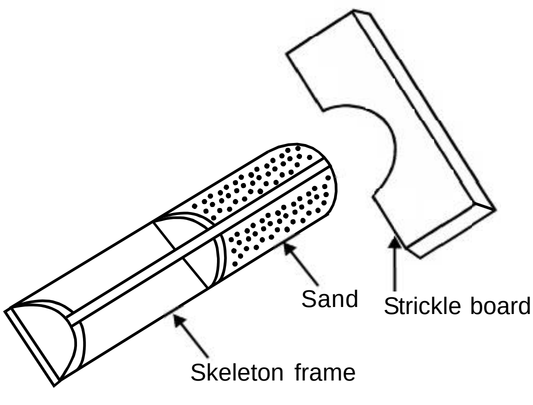


Fig. 1.10 Skeleton Pattern

1.2.3.9 Follow Board Pattern

- It is shown in Fig 1.11.
- Follow board is a wooden board.
- Supports pattern which is very thin and fragile. With this support, the drag is rammed, then follow board is withdrawn.
- The rammed drag is inverted, cope is mounted in it and rammed. At this time pattern remains over the inverted drag and gets support from rammed sand and the drag under it.
- Finally, pattern is removed and cope and drag assembled.
- Follow board forms natural parting line in the mould.

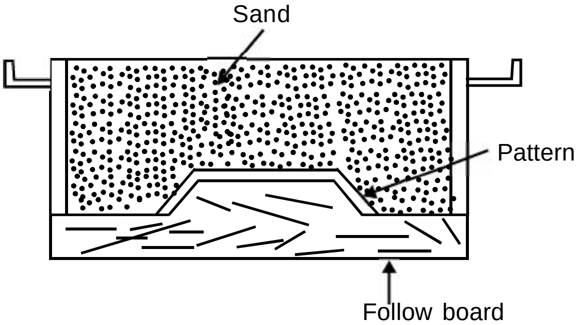


Fig. 1.11 Follow Board Pattern

1.2.4 Pattern Materials

Selection of pattern material depends on the following factors.

- Number of castings to be produced
- Required dimensional accuracy and surface finish.
- Process used like, sand, investment, shell, etc.
  - Moulding, hand/machine.
  - Shape, complexity and size of casting

Materials used are

(1) Wood (2) Metal (3) Plastic (4) Plaster and (5) Wax

1. Wood

Types

- White pine
- Mahogany
- Teak
- Deodar, etc.

Advantages

- Inexpensive
- Easy availability
- Light in weight
- Easy to machine
- Easy to join for obtaining complex shapes

Limitations

- Shrinkage and swelling
- Poor wear resistance
- Easily absorb moisture and result in change of shape and size.
- Weak compared to metal patterns.

Applications

Used where large size patterns produced for small number of castings.

2. Metal

These are cast from wooden patterns or machined.

Types

(*i*) *Al* and *Al* alloys
(*ii*) Steel
(*iii*) CI
(*iv*) Brass (Cu - Zn)

Advantages

- Stronger and accurate than wooden pattern.
- More life than wood.
- Greater resistance to abrasion
- Greater wear resistance
- Surface finish obtained is good.
- Stable in different environments.

Limitations

- More expensive as compared to wooden.
- Heavier than wooden (Ferrous pattern).
- Get rusted easily (Ferrous Patterns).
- Can't be easily repaired (Al) or machined.

Applications

Generally used where large number of castings are to be produced.

Aluminium and Al alloys

Advantages

- Best pattern material
- Good resistance to corrosion, swelling
- Good machinability, wear resistance and strength.
- Do not rust
- Pattern cost moderate

Limitations

- Do not withstand to rough handling
- Poor repairability

Applications

For any step patterns :

Cast-iron

Advantages

- Less expensive
- Durability is high
- Resistance against abrasive action of sand.
- Easily machined

Limitations

- More weight
- It is hard and brittle, so it can be broken easily
- Gets rusted in presence of moisture.

Steel

Advantages

- Good machinability
- High wear resistance
- High strength
- Good repairability

Limitations

- High weight
- Poor resistance to rust and corrosion.

3. Plastic

Advantages

- Durable
- Smooth cast surface
- Moisture resistant
- No markable change in shape and size during use.
- High abrasion resistance
- Good resistance against chemicals

Limitations

- Fragile and so may need metal reinforcements.
- Not satisfactory under shock (m/c moulding / jolting)

4. Wax

Advanatges

- Very good surface finish
- High accuracy in cast product.

Applications

Investment casting process

1.2.5 Pattern Allowances

Pattern is always larger in size than that of final casting. Because, certain allowances are provided due to metallurgical (shrinkage) and mechanical (machining draft, shake and distortion) reasons.

The various allowances in pattern are

(i) Shrinkage/Contraction
(ii) Machining/Finish
(iii) Draft / Taper
(iv) Distortion / Camper
(v) Shake / Rapping

1.2.5.1 Shrinkage Allowance

- Practically all metals shrink except bismuth.
- There are two types of shrinkage such as (*i*) liquid and (*ii*) solid.
- Liquid shrinkage is the reduction in volume from liquid to solid stage at solidus temperature.
- Risers are provided in mould to compensate this.
- Solid shrinkage is the reduction in volume when metal looses temperature in solid state.
- Shrinkage allowance is provided to compensate this.
- Difference metals shrink at different rates.
- For this, patternmaker is provided with a special rule.
- This rule has two scales on each side.
- The graduation is oversized proportionately eg. on one size scale, 1mm for each 100 mm.
- This contraction is still a guideline because actual contraction depends on several factors such as

  (*i*) composition of metal and impurity present (*ii*) moulding method

  (*iii*) pouring temperature (*iv*) complexity of design

1.2.5.2 Machining Allowance

- Finish and accuracy is normally less in sand casting. So machining is sometimes required to improve these parameters.
- Scales generated on ferrous materials are to be removed. So extra material is provided which is removed by either machining or cleaning

Machining allowance depends on

– metal to be cast

– type of moulding

– accuracy required

– surface complexity

Machining allowance may vary from 2 to 20 mm. Another classical way to reduce it is to keep the casting in drag flask totally so that dimensional variation and other defects due to parting plane are reduced to minimum.

1.2.5.3 Draft Allowance

At the time of removal of pattern from sand mould, the vertical faces of the pattern are continuously in contact with the sand. So there is chance of damage of mould cavity. To reduce this, vertical surfaces are tapered from parting line. It is called draft allowance.

- It is given to all surfaces perpendicular to parting line.
- It is given for easy removal of pattern without damaging mould cavity.
- Amount of taper depends on
  - shape and size of pattern vertically
  - moulding method
  - moulding materials
- It is provided on both external and internal surfaces.

  External $\rightarrow$ 10 to 25 mm/m

  Internal $\rightarrow$ 40 to 65 mm/m

1.2.5.4 Shake Allowance

- A pattern is rapped by striking with a wooden piece. It is done so that the pattern is loosened a little in mold for easy removal. This activity increases the size of mould cavity a little which results in larger size casting. For this reason a negative allowance is provided in pattern. This is called shake allowance.
- It is generally given in big castings and neglected in small ones.

1.2.5.5 Distortion Allowance

Just after solidification, casting is very weak and may distort. This tendency is more, for weaker sections such as U, V sections *i.e.*, which has thin, long sections connected to thick sections. For this reason some extra material is provided.

1.3 MOULDING MATERIALS

- Moulding material may be defined as the material out of which mould is made.
- It should be such that the mould cavity retains its shape until molten metal solidifies.
- Casting can be done in

  (*i*) Permanent mould – ferrous metal and alloys (steel, Gray CI).

  (*ii*) Temporary mould – refractory sand and resin.

  (*iii*) Wax, plaster of paris, carbon, ceramics, etc.
- Permanent mould normally used for casting low melting point metals.
- Permanent moulds are costly also.
- Refractory moulding used for casting high melting point materials and bigger in size.
- Most of the foundry output comes from temporary moulds.

Refractory Sands

Normally used refractory sands are

(*i*) Silica sand (*ii*) Magnesite (*iii*) Zircon (*iv*) Dolomite

(*v*) Olivine (*vi*) Sillimanite (*vii*) Graphite / Carbon

1.3.1 Sand Moulding

Generally two types

- Green sand mould
- Dry sand mould

1.3.1.1 Green Sand Mould

- – Green sand may be defined as sand which is in damp (wet) condition and contains moisture.
- – Clay binder is added to it.
- – In green sand mould, molten metal is poured while it is in wet/undried condition.
- – A green sand mould has low strength and low permeability.
- – Difficult shapes can be produced.
- – Castings do not crack because there is less resistance to soild shrinkage.
- – Suitable for small and medium size casting.

1.3.1.2 Dry Sand Mould

- – It is shown in Fig. 1.12.
- – Binders are added which harden when heated.

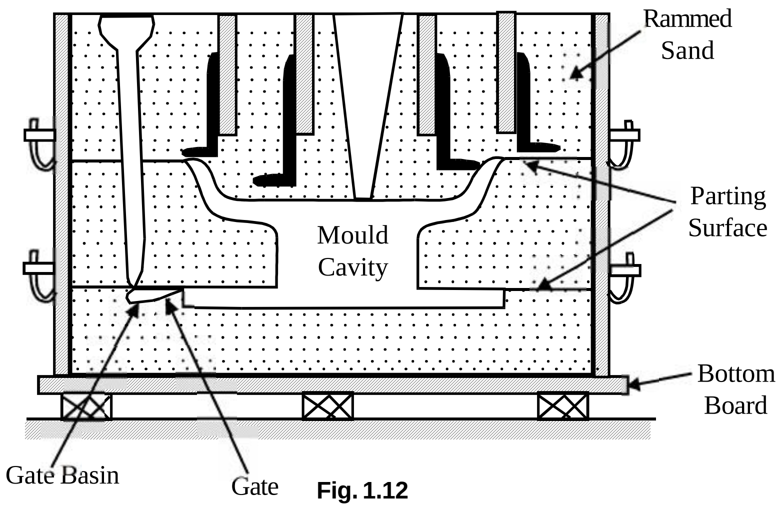


Fig. 1.12

- Mould is prepared in green (wet) condition and then heated in oven for drying (300° to 650°F) before pouring.
- It has more strength than green sand mould.
- More expensive.
- Mould gas generation is less than green sand mould.
- Smoother surface on casting because fine sand is used.
- Higher permeability than green mould.
- Preferred for large size casting.

1.3.2 Metal Moulding/ Dies

- These are also called permanent moulds.
- Generally made of grey cast iron/steel.
- Metal mould is made of two parts to facilitate removal of casting.
- Mould is manufactured by casting and then machining of the cavity.
- Generally used for casting nonferrous metals and alloys. (A1, Mg, Pb etc.)
- **Ex :** Aluminium alloy pistons (I.C. Engine) are cast in metal moulds.
- Metal moulds are used in the following type of castings.
  (*i*) Permanent mould casting
  (*ii*) Pressure die casting
  (*iii*) Centrifugal casting
- Surface produced by metal mould have
  (*i*) fine grain structure
  (*ii*) high dimensional accuracy
  (*iii*) very good surface finish
- Preferred for mass production of casting.

1.3.3 Investment Moulding

Process to be followed for investment moulding are as follows :

- Use a master pattern to make metallic die cavity.
- Pour molten wax in the die and get wax pattern.
- Protecting of wax pattern is done by repeatedly dipping it in slurry of a fine refractory material.
- Pour the investment moulding mixture around the protected wax pattern.
- Allow investment to harden.
- Invert the mould and heat it in the furnace (200° – 300°F).

- It results in

  (*i*) hardening of investment of mould

  (*ii*) melting and removal of wax (can be reused)
- Investment mould is heated from 1000°F to 1800°F.
- Molten metal can be poured into it.

1.3.4 Shell Moulding

- In this process, mould and cores are prepared of thin shells using a mixture of fine sand and thermosetting resin, sand (100 – 150 mesh).
- This mixture is poured on a heated metal pattern.
- Some amount of mixture adhere to the pattern.
- The resin cures and gets bonded with each other and forms a shell like structure around the pattern.
- The portion of the shell touching the metal pattern gets the shape and size of the pattern and is one half of the mould.
- In the same manner the other half is also prepared.
- Two halves are placed together which constitute the mould assembly.
- The assembly is placed in a flask and backup material placed around it
- Now molten metal can be poured in.
- It is shown in Fig. 1.13.

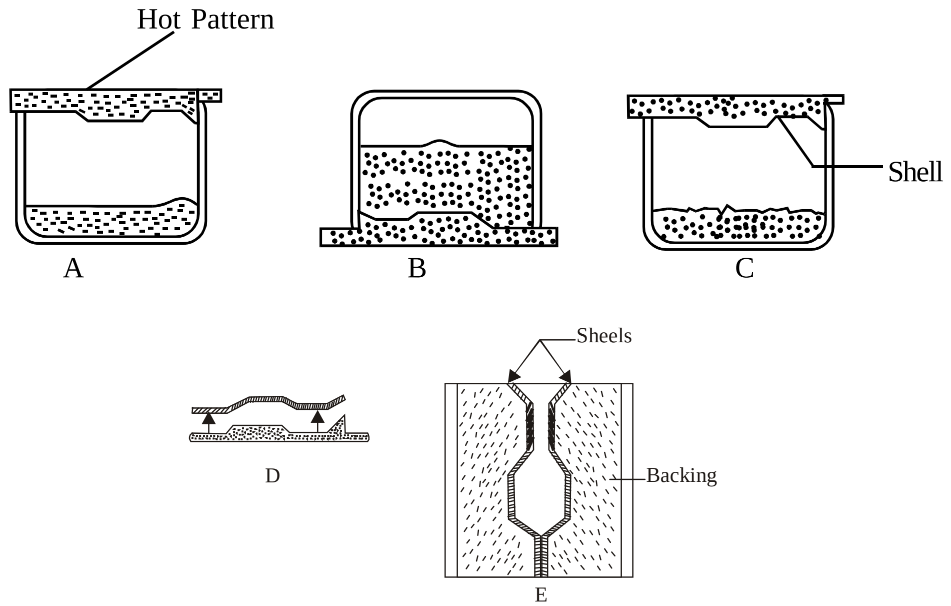


Fig. 1.13 Shell Moulding Process

1.4 COMPOSITION OF MOULDING SAND

Sand is the principal moulding material. It is used in foundry for all types of castings. Some important properties of it are

(*i*) refractoriness – withstand high temperature of molten metal and does not fuse.

(*ii*) chemical resistivity – doesnot chemically react with molten metal.

(*iii*) high permeability – allows gases and air to escape from the mould after pouring.

Composition

The principal ingredients of moulding sand are

(*i*) silica sand grains

(*ii*) clay (binder)

(*iii*) moisture (activate clay and provide plasticity)

1.4.1 Silica Sand

- It possesses major portion of moulding sand (upto 96%)
- The rest are other oxides as alumina, sodium oxide ($Na_2O + K_2O$) and magnesium oxide ($MgO + CaO$)
- These should be kept about 2%
- Main source of silica sand is river sand.
- Silica sand grains provide refractoriness, chemical resistivity and permeability to sand.
- It is specified according to its shape and size.
- Fine sand provides more intimate contact and less permeability .
- According to shape, these can be round, subangular, angular and very angular.

1.4.2 Zircon Sand

- Its chemical name is zirconium silicate ($Zr\ Si\ O_4$)
- Composition : – ZrO_2 – 66.25%, SiO_2 – 30.96%, Al_2O_3 – 1.92%
  Fe_2O_3 – 0.74% and other oxides in less quantity.
- It is very expensive.
- Available in Kerala (India) and Australia.
- Fusion point is 2400°C
- Important properties are high thermal conductivity and high density, etc.
- Less binder required (3%).
- Used for precision steel casting, precision investment.

1.4.3 Binders

- Binder may be defined as the material which is responsible for the cohesion between the moulding sand grains in both green and dry condition.
- Binders are less refractory than moulding sand.
- These provide strength to moulding sand to retain its shape in mould cavity.
- Increase in binder content reduces permeability and increases green compression strength to some extent.
- Clay is the generally used binder for its low cost and wider utility.
- The most popular clay types are

  (*i*) Kaolinite / Fire clay (Al_2O_3 $2SiO_2$ $2H_2O$)

  (*ii*) Bentonite (Al_2O_3 $4SiO_2$ H_2O_n H_2O)

  (*iii*) Water

Kaolinite

- Melting point 1750 – 1787°C.
- Absorbs less water than bentonite and so less shrinkage.
- It is the residue of weathered granite and basalt.
- Composition : Kaolinite (60%) + Illite (30%) + Quartz (10%)
- Softening point (3000 – 3100°F)

Bentonite

- Melting point 1250° – 1300°C
- Absorbs more water and so more bonding power.
- Two types

  (*i*) soidum bentonite/western bentonite(high dry and low green strength)

  (*ii*) calcium bentonite/southern bentonite (high green and low dry strength).
- The clay chosen should give required strength considering the metal to be cast and thickness of casting.
- Normally river sand contains large amount of clay and can be directly used.

Water

- Water is used to activate clay for plasticity and strength.
- Quantity of water is very important because a part of water helps bonding (absorbed) and another part improves plasticity (free water).
- If added in more quantity will decrease strength and formability.
- Normally 2 – 8% is added.
- Required water content varies with type of clay.

1.4.4 Additives

- The basic constituents of moulding sand mixture are sand, binder and water.
- The materials other than these, which are added to moulding sand mixtures are called additives.
- These are added in very small quantities.
- Additives are used to
  - increase the existing properties.
  - develop now properties.
- Cereal binders increase strength when added upto 2%
- Pitch used upto 3% increases hot strength
- Saw dust upto 2% increases permeability
- Other materials like sea coal improves surface appearance of cast iron.

1.4.5 Binders - Clay

Binders

Binders are added to a base sand to bond the sand particles together (i.e. it is the glue that holds the mold together.

Clay

Clays are generally used binding agents mixed to the molding sands to sustain strength . There are two types of clay commonly used: bentonite and kaolinite or fine clay

1.4.6 Binder for CO_2 Sand

- Sodium silicate is used as binder (water glass – SiO_2 Na_2O)
- Mould is prepared with a mixture of sodium silicate and sand and then treated with CO_2 for 2 – 3 minutes.
- CO_2 forms a weak acid which hydrolyses the sodium silicate which results in amorphous silica which makes bond.
- When CO_2 is supplied, hydrated sodium carbonate (Na_2CO_3 + H_2O) is formed.

$$\underset{\text{Sodium Silicate}}{Na_2SiO_3} + CO_2 \longrightarrow Na_2CO_3 + \underset{\text{Silica gel}}{SiO_2}$$

  This gel type component increases the viscosity of the binder till it becomes solid.
- Amount of binder required for grain size of 55 is 3% and for grain size 85 it is 4.5% (by weight).

1.4.7 Binder for Shell Moulding

- Thermosetting resin is used as binder.
- Sand is mixed with the binders and applied against a heated metallic pattern.
- Dry and fine sand completely free from clay is used.
- Grain size of sand depends on surface finish required.
- Too fine sand will require more amount of binder which will make it costly.
- The thermosetting resin binder gets hardened irreversibly by heat.
- Phenol phormaldehyde is widely used binder.
- Normal curing temperature is about 150°C and time required is 50 – 60 sec.

1.4.8 Binder for Core Sand

- Clay binder used in moulding sand are not sufficient for providing enough strength.
- Cores are surrounding molten metal on all sides. So it experiences much more severe thermal and mechanical conditions.
- Core sand should be of higher strength than moulding sand.
- If normal binders which are organic in nature are used for core making then it will become collapsible during cooling of casting.
- Some commercially available core binders are
  (*i*) Linseed oil
  (*ii*) core oil
  (*iii*) resins
  (*iv*) dextrin
  (*v*) molasses
  (*vi*) cereals
  (*vii*) sulphite - liquor
  (*viii*) protein
- The action of thermoplastic binders as rosin and pitch depend on the amount of heat which liquifies and disperses the binder in the sand.
- Rosin a is a form of resin which is obtained by distillation and extraction of pine wood.
- Generally used resin binders are phenol, urea and furan.
- Generally used core oils are vegetable oil (linseed oil and corn oil)

Required properties of a core binder are

– holding sand grains together.
– providing strength to cores.
– makes cores erosion and breaking resistant.
– provide sufficient collapsibility.

1.5 PROPERTIES OF MOULDING SAND

Important properties of moulding sand are :

(*i*) Refractoriness

(*ii*) Green strength

(*iii*) Dry strength

(*iv*) Hot strength

(*v*) Permeability/porosity

Refractoriness

It may be defined as the ability of the moulding material to sustain the high temperatures of the molten metal so that it does not cause fusion.

Green strength

The moulding sand which contains moisture is called green sand. The strength of the green sand which should be sufficient enough to maintain the shape of the mould is called green strength.

Dry strength

The moulding sand which does not contain any moisture is called dry sand. The strength of the dry sand (by hot metal effect) which should retain the shape of the mould cavities is called dry strength.

Hot strength

After all, the moisture is eliminated and the metal in the mould is in liquid state, the temperature of the sand becomes very high. The strength of the sand which is required to hold the shape of the mould cavity in that condition is called hot strength.

Permeability / Porosity

During solidification, large amount of gases come out from the mould. These are the gases which are absorbed by the metal in the furnace, from atmosphere or gases involved by the moulding and core sand. If these gases are not allowed to escape, these will be trapped inside the casting and cause defects. For this reasons, the moulding sand should be sufficiently porous so that the gases are allowed to escape out. The gas evolution capability of the moulding sand is called permeability/ porosity.

Collapsibility

Besides all the above properties, the moulding sand should have collapsibility so that during contraction of the solidified casting, it does not provide any resistance which may result in cracks in casting. Moulding sand should be reusable and having good thermal conductivity so that heat from casting is quickly transferred to the sand.

1.6 SAND TESTING

Various kind of tests are done on moulding sand. They are :

- Moisture content test
- Clay content test
- Grain fineness test
- Permeability test
- Strength tests
  - (*a*) Green and Dry compression
  - (*b*) Green tensile
  - (*c*) Green and Dry shear
  - (*d*) Transverse (bending)

1.6.1 Moisture Content Test

- Amount of water contained in moulding sand controls the properties of moulding sand.
- If moisture content is low strength will not be developed.
- If moisture content is high, permeability reduces. Moisture content can be determined by the following methods.

Using direct reading moisture teller

- The reaction is produced by providing calcium carbide

$$CaC_2 + 2H_2O = Ca(OH)_2 + C_2H_2$$

- Calcium carbide reacts with the moisture of moulding sand and produces acetylene gas.
- The pressure of C_2H_2 gives a direct reading of the water content of the pressure gauge.

Using infrared heating

The following steps are followed in this process.

(*i*) Fixed weight of 20 to 50 gms of prepared sand is placed in pan and is heated by infrared heater bulb for 2 – 3 minutes.

(*ii*) The moisture present evaporates.

(*iii*) Moulding sand is taken out of the pan and reweighted.

(*iv*) The percentage of moisture can be calculated from the difference in weights of original moist and final dry sand samples.

(*v*) The apparatus is shown in Fig. 1.14.

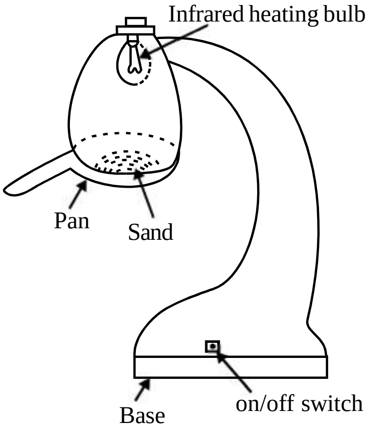


Fig.1.14 Moisture determining apparatus

1.6.2 Clay Content Test

Clay is a bonding agent for sand particles. The clay content of a moulding sand can be determined as follows :

- Take a small quantity of moulding sand and dry it throughly
- Take out 50 gms of dry moulding sand and put in a wash bottle.
- Add 475 cc of distilled water and 25 cc of 3% NaOH solution.
- Using a rapid sand stirrer, stirr the mixture for 10 minutes.
- Fill the wash bottle with water upto indicated mark.
- Allow 10 minutes for settling of sand, then takeout water from the bottle.
- Clay comes out with water in dissolved condition.
- Again add water to the sand and stir it, let the sand to settle down and take water out.
- Follow the above step till water over the settled sand is clean.
- So all the clay has been removed out of sand.
- Dry the sand.
- Calculate the clay content by measuring the difference in weights between initial and final sand sample.

1.6.3 Grain Fineness Test

This test determines

(*i*) Grain size

(*ii*) distribution

(*iii*) grain fineness

- The apparatus in shown in Fig. 1.15.

- It has a number of standard sieves mounted one above the other on a power driven shaker.
- The shaker vibrates the sieves and sand poured on top sieve gets screened and collected on different sieves depending upon the various sizes of grains present in moulding sand.
- There are generally eleven number of standard sieves mounted one above other and under the bottom most sieve pan is placed.

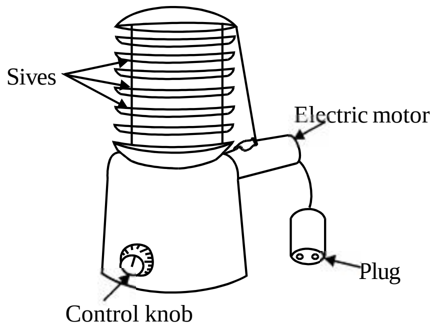


Fig. 1.15 Grain Finesess Tester

- The top sieve is the coarsest and bottom most sieve is the finest, in between sieves are placed in order.
- A sample of dry sand without clay is placed in upper sieve.
- Sand is vibrated for a definite period of time.
- The amount of sand obtained in each sieve is weighted and percentage distribution is calculated.
- For calculating grain finess number, each percentage is multiplied by a factor.
- The resulting products are added and divided by total percentage of sand grain retained.

$$\text{GFN} = \frac{\text{Sum of products}}{\text{Total sum of the percentages of sand retained on pan and each sieve}}$$

$$= \frac{\sum M_i f_i}{\sum f_i}$$

where, M_i = Multiplying factor of the i^{th} sieve.

f_i = Amount of sand retained on each sieve.

1.6.4 Permeability Test

Permeability may be defined as the property of moulding sand which allows stream and other gas generated in the mould during the pouring of molten metal to escape out.

It depends on

(*i*) grain size
(*ii*) grain shape
(*iii*) binder type and amount
(*iv*) degree of ramming
(*v*) water of content of moulding sand

- First, a specimen of standard size is prepared by Specimen Rammer.
- Permeability of sand specimen is determined by passing given volume of air through the sand.
- Permeability tester consists of
  - (*i*) an inverted bell jar, which floats in water.
  - (*ii*) specimen tube to hold the sand specimen.
  - (*iii*) manometer to read the air pressure.
- The apparatus is shown in Fig. 1.16.

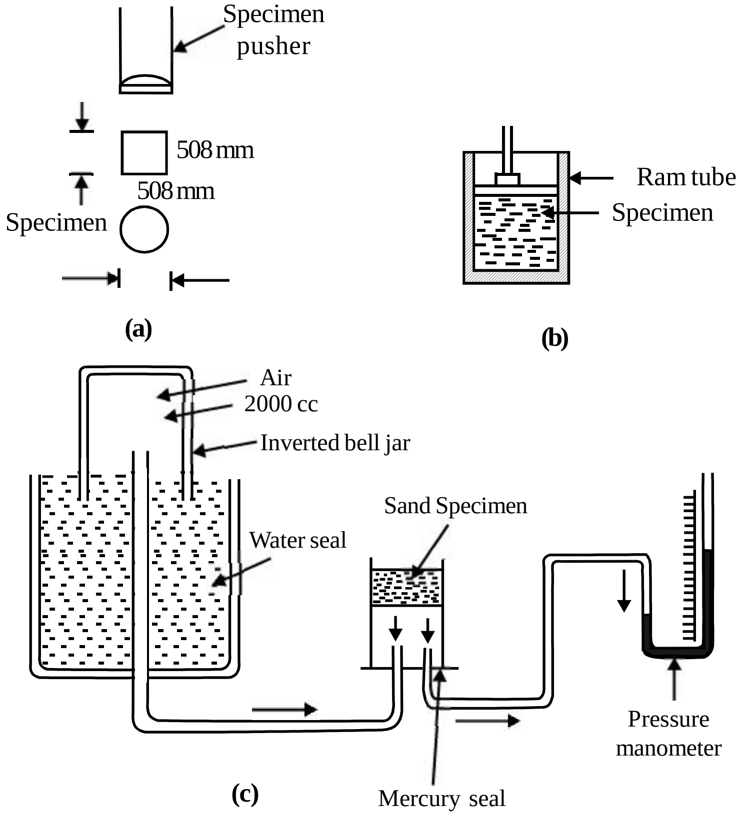


Fig. 1.16 Permeability Tester

Process

(*i*) 2000 cc of air held in inverted bell jar is forced to pass through sand specimen.

(*ii*) At some point the airflow stabilizes *i.e.*, amount of air entering the specimen = amount of air escaped through the specimen to atmosphere.

(*iii*) By this, a stable reading is obtained in manometer.

(*iv*) Using stopwatch, time required for the total 2000 cc of air to pass through the sand specimen is also recorded.

(*v*) Now permeability number can be calculated as follows :

$$\text{Permeability Number} = \frac{\text{V.H.}}{\text{A.P.T}}$$

where V = volume of air passed through specimen = 2000cc

H = height of the specimen

A = area of the specimen

T = time taken by 2000 CC air to pass through sand specimen (in minutes)

P = air pressure recorded by manometer (gm/cm^2).

1.6.5 Strength Test

- Strength test are done in order to control sand strength properly.
- Strength of a moulding sand can be determined by

(*i*) Compression

(*ii*) Tensile

(*iii*) Shear

and (*iv*) Transverse test

- Among all these compression test is most commonly used.
- All the tests can be done on sand specimen tester by using different attachments.
- The strength testing equipment is shown in Fig. 1.17.

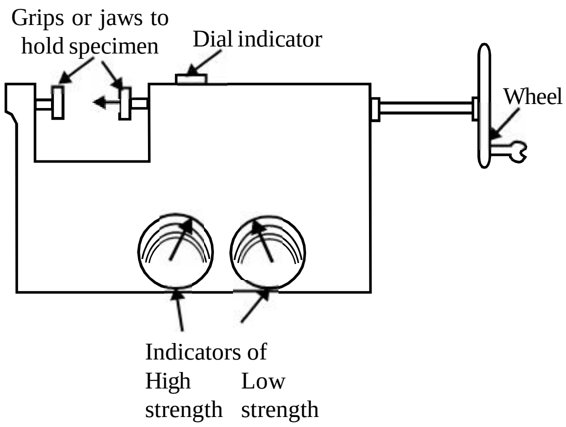


Fig. 1.17 Strength Testing Equipment

Process

(*i*) The specimen is held between the grips.

(*ii*) Hand wheel is rotated, it builds hydraulic (oil) pressure on specimen.

(*iii*) Dial indicator measures the deformation occurs.

(*iv*) There are two manometer indicators. One is for low strength sand and other is for high strength core sand.

(*v*) Each indicator has three scales. First for reading compressive strength, second for tensile (traverse) and third for shear strength.

(*vi*) The shape of specimen and the grips are shown in Fig 1.18.

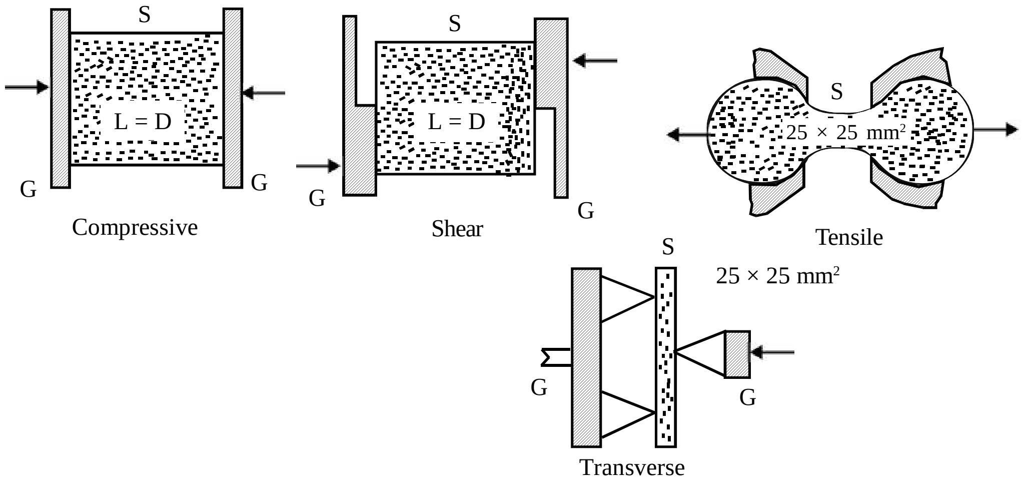


Fig. 1.18 Shapes of specimen and grips for strength tensing:
G → Grip, S → Specimen

1.7 MELTING FURNACE

- Furnace is used to melt the metal.
- Foundry furnace remelts the metal to be cast.
- A foundry furnace does not convert ore into usable metal as blast furnace.
- A furnace generally forms a high temperature zone surrounded by refractory bricks which can withstand the heat and minimize heat lose by insulating it from the outside environment.
- The metal is placed in this high temperature zone.

1.7.1 Remelting Furnaces for Casting

Metals are generally obtained from blast furnace, steel making furnace or other non-ferrous smelting furnaces.

These metals can not be cast directly into desired shapes of components basically due to following two reasons.

1. These metals are not always in a sufficiently refined state.
2. Practically it is difficult to pour huge quantity of molten metal into mould.

For the above reasons metals obtained from smelting furnaces are first cast into same regular shapes as ingots. These are then remelted in foundries for casting required components.

Various types of remelting furnaces are used for this purpose. They are as follows :

(*i*) Cupola Furnace

(*ii*) Electric Furnace

- (a) Resistance furnace
- (b) Induction furnace
  - – Core less type/ High frequency induction furnace
  - – Core type/Low frequency induction furnace
- (c) Arc furnace
  - – Direct arc furnace
  - – Indirect arc furnace/Rocking furnace

1.7.2 Selection of Remelting Furnace

Selection of remelting furnace depends on following factors.

(*i*) Initial cost of furnace.

(*ii*) Fuel cost

(*iii*) Metal/alloy to be melted.

(*iv*) Melting / pouring temperature.

(*v*) Quantity of metal to be melted.

(*vi*) Cost of melting per unit weight.

(*vii*) Flexibility of unit *i.e.*, whether can be used for melting other metal or not.

(*viii*) Speed of melting

(*ix*) Cost of operation

(*x*) Degree of cleanliness/pollution.

1.7.3 Cupola Furnace

A cupola furnace is generally used for melting and refining pig iron alongwith scrap for producing cast iron (Fig. 1.19).

Features/Advantages of Cupola

- simple operation
- continuous production
- economy of working
- increased output
- low melting cost
- easy tempeature control
- less fuel expensive and easily available

For producing white cast iron (below 2.71% carbon) duplex process is used.

Description of Cupola

Shell

- It is vertical and cylindrical in shape
- Made of sheet thickness 6 – 12 mm inside of which is lined with acid refractory bricks and clay consisting of silicon acid ($SiSO_2$) and Alumina (Al_2O_3).
- Diameter of cupola varies from 1 – 2 meters and height is 3 – 5 times diameter.

Foundation

- The shell is mounted on a brickwork foundation or cast iron columns.
- The bottom of the shell consists of a drop bottom door for cleaning purposes at the end of melting.

Tuyers

- Air for combustion of fuel is delivered through the tuyers.
- These are provided at height of between 0.6 to 1.2 m above the working bottom.

Wind Belt

- Air supplied by blower is delivered to the tuyers from wind belt/jacket.
- It is a jacket like structure which is a steel plate duct mounted on outside of shell.

Blower

A high pressure fan/ blower is used to supply air to the wind belt through a blast pipe.

Slag Hole

- It is used for removing the slag.
- It is placed at a level at about 250 mm below the centre of the tuyers.

Tapping Hole

- It is used for pouring out molten metal.
- It is located opposite and just below the slag hole.

Charging Hole

– It is used for feeding charge to the furnace.
– Charge is a mixture of metal, coke and flux.
– Normally situated 3 to 6 meters above the tuyers.

Chimney / Stack

– The shell normally continues for 4.5 m to 6 m above the charging hole to chimney.

Zones of Cupola

The entire cupola can be divided into the following sections.

Crucible Zone

It is between top of the sand bed and bottom of the tuyers.

Combustion / Oxidizing Zone

– It starts from top of the tuyer to 150 to 300 mm above it.
– Heat is generated in this zone due to the following reaction.

$$C + O_2 \rightarrow CO_2 + \text{ Heat}$$

$$Si + O_2 \rightarrow SiO_2 + \text{ Heat}$$

$$2\,Mn + O_2 \rightarrow 2\,MnO + \text{Heat}$$

$$Fe + O \rightarrow FeO + \text{ Heat}$$

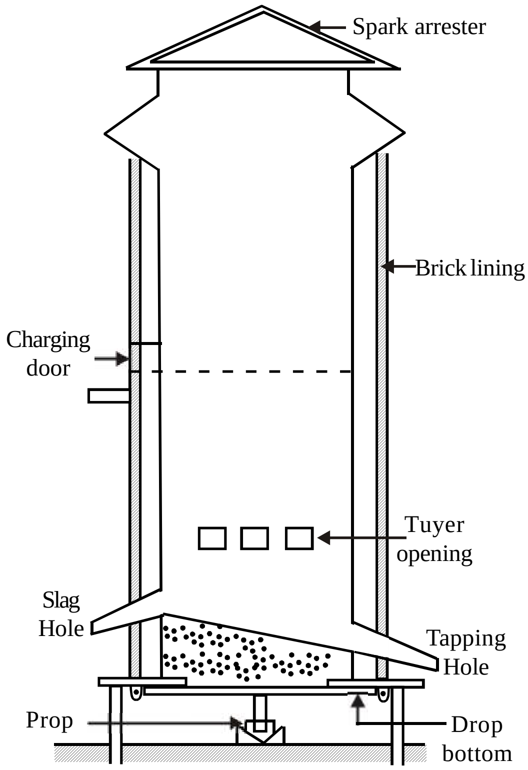


Fig. 1.19 Cross section of a Cupola

Reducing Zone

– It starts from the top of the combustion zone upto the top of cokebed.
– CO_2 is reduced in these zone.

Melting Zone

– It starts from top of the coke bed and ranges upto a height of 900 mm.
– Temperature is highest in this zone (1600°C).

Preheating / Charging Zone

- It starts from top of the melting zone and ranges upto the charging door.
- Charging materials when fed gets preheated here.

Stack Zone

- It starts from the charging zone upto top of cupola.
- Gases generated are carried out in this zone.

Operation of Cupola

Preparation of Cupola

- Clean the slag and repair damaged lining using mixture of fire clay and silica sand.
- Bottom doors are raised up and bottom sand poured.
- The surface of the sand is sloped from all directions towards the tap hole and rammed.
- Slag hole is also formed to remove slag.

Firing the Cupola

- Wood is ignited on sand bottom.
- Then coke is added to a level slightly above the tuyers.
- Air blast is turned on at a slower rate.
- After having red spots on the fuel bed, extra coke is poured upto required height.

Charging the Cupola

- Cupola starts burning properly.
- Then alternate layers of pig iron, coke and flux (limestone) are fed from charging door till cupola is full.
- Flux does two functions (*i*) prevent oxidation (*ii*) remove impurities (Flux is normally 2 – 3% of metal charge by weight)

Soaking of Iron

- After charging these get slowly heated up.
- Air blast is kept closed for 45 minutes.
- This causes iron to soak.

Opening of Air Blast

- Air blast is opened after near about 45 minutes.
- Tap hole is kept closed to gather sufficient amount of molten metal.
- The rate of charging should be equal to the rate of melting in order to keep the furnace full for continuous operation.

1.7.4 Resistance Furnace

- This furnace works on the principle of resistance heating effect of current (Fig. 1.20).
- It states that when a current carrying conductor carries current (I) having resistance (R) for time (*t*) then the heat produced will be I^2 Rt.
- Resistance heating of a single electrode provides required heat for melting
- Normally **silicon carbide** is melted in this kind of furnace.

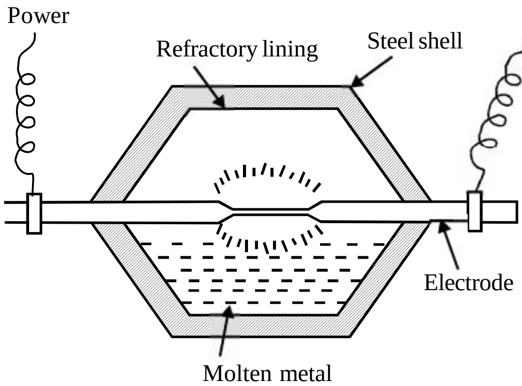


Fig. 1.20 Resistance heating furnace.

- The electrode has reduced diameter at its center.
- It offers greatest resistance to current flow as $R \propto \frac{1}{A}$.
- High heat is generated which is used for melting.
- The operation is noiseless and costly due to high cost of electricity.

1.7.5 Induction Furnace

1.7.5.1 Coreless type / High frequency Induction Furnace

- A high frequency induction furnace has a refractory crucible placed inside a water cooled copper coil.
- This crucible is kept in required position by ramming dry refractory sand around it.
- It can be of two types depending on the method of molten metal extraction. They are
  (*i*) tilting type (Fig. 1.21).
  (*ii*) lift coil type (Fig. 1.22).

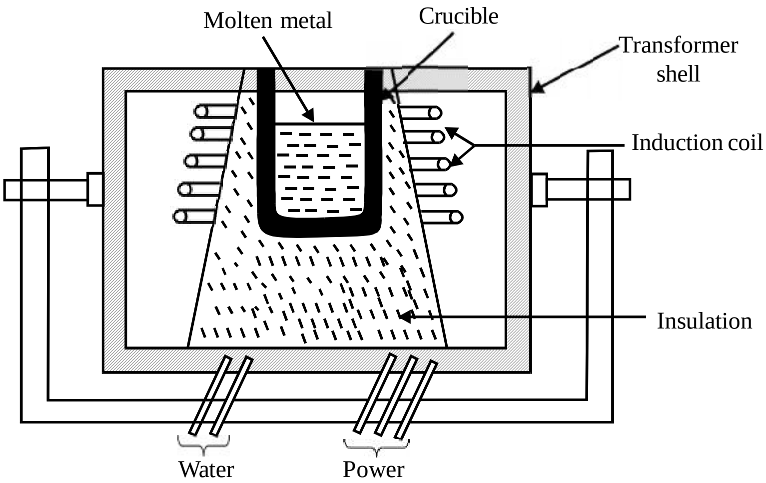


Fig. 1.21 Induction Furnace : tilting type

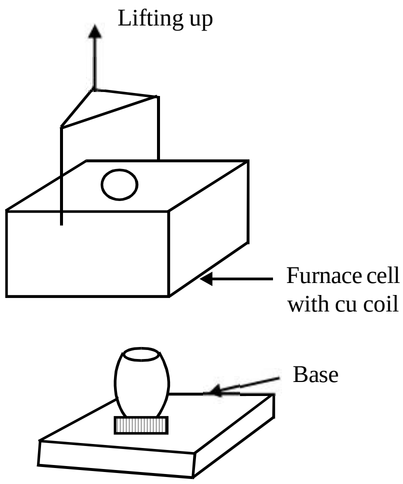


Fig. 1.22 Induction Furnace : lift coil type.

Operating Principle

- Steel pieces (scrap) normally used as charge is fed into the furnace.
- High frequency current is supplied to the coils. So the coil acts as primary of transformer and the charge acts as secondary.
- Due to electromagnetic induction alternating current is induced in secondary (charge).
- These offer resistance to secondary current due to which heat is generated.

- Due to conduction, this heat created on skin of charge propagates and melts the charge.
- A magnetic field is associated with the secondary current which provides a stirring action in the molten which results in.
  - speed up of melting process
  - mixing of metal charge uniformly
- This type of furnace takes very little time for melting.
- Pouring is done by any of the method aforesaid.
- It is used /preferred where different metals/alloys are to be melted in small amount.

Advantages

- Can melt small quantity (*i.e.,* 1.5 kg to 12 tons) of various types of methods or alloys quickly.
- Magnetic stirring produces uniform melt.
- Construction is simpler than core type induction furnace.
- No warm up time required.
- Great control over energy input and furnace atmosphere.

Limitations

- Initial cost is high
- There should be no error in charge in terms of composition because there is practically very less available for analysis.
- Thermal efficiency is less (upto 60%) than core type due to energy loss in motor generator set or spark gap convertor.

Applications

Used for melting general, special, alloy and high quality steels in small quantity.

1.7.5.2 Core type / Low Frequency Induction Furnace

- It is shown in Fig. 1.23.
- It works as an ordinary transformer.
- The primary coil has many turns which is wound on a laminated steel core, but the secondary has only one turn which is a channel of molten metal.
- The furnace uses an A.C. supply of 60 cycles per second (Hz).
- Secondary current (high current and low voltage) produced in molten metal around core generates heat due to electrical resistance to flow of secondary current.
- This channel of molten metal is connected to the main metal container which holds metal charge. So the metal in the channel gets heated, it circulates through the metal in the container and melting process goes on.

- Metal is poured into ladle when it reaches the required pouring temperature

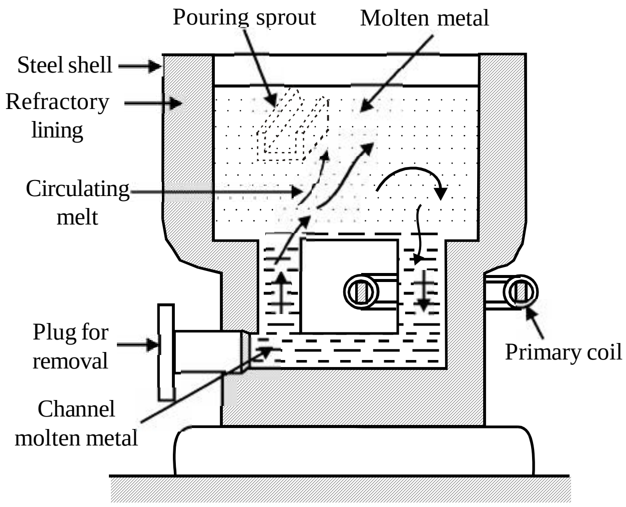


Fig. 1.23 Core type induction furnace

Advantages

- It is the most efficient induction furnace.
- Thermal efficiency is about 80%
- Rapid and clean melting.
- Uniform molten metal due to magnetic stirring.
- Accurate control of temperature and composition.
- Economical operation.

Limitations

- Furnace can not be started with solid metal charge. The channels have to be filled with molten metal produced by any other furnace.
- If by mistake metal in channel gets soildifield, can be remitted by heat created in secondary coil.
- Normally used to melt only one type of metal/alloy continuously because by this the liquid metal in channel will always be available.

Applications

- Generally used for melting non-ferrous metal and alloys continuously for a longtime.
- Generally used as a holding furnace for permanent mould and die casting because of ability to control temperature easily.
- Normally capacity is upto 5 tons.

1.7.6 Arc Furnace

1.7.6.1 Direct Arc Furnace

- The interior of the furnace is preheated before placing metal charge in the furnace.
- Preheating is done by alternatively striking and breaking the arc between the vertical electrodes and the used electrode pieces kept on the hearth.

After preheating is done, the electrode pieces placed on the hearth are removed.

- Few spare roofs should be available at all times because of their shorter life time.
- Charging may be done from charging door which is also used for removing slag or from furnace roof which is lifted for charging.
- Transformer rating – 800 kVA to 40000 kVA
- A 50 ton direct arc furnace require current of 2500 amps and voltage of 250 volts.
- Electrode guides placed on roof are water cooled to dissipate damaging heat.
- For removing slags before pouring molten metal, the furnace is tilted backward to pour off slag from charging door.
- The furnace is tilted forward for pouring molten metal into ladle.
- After each heat, hearth, side walls and roof are repaired using suitable refractory material.

1.7.6.2 Indirect Arc Furnace

- It has capacity from few kgs to 2 tons.
- Generally used for less capacity than direct arc type.
- In this type electric arc is produced between two graphite electrodes. So charge is not a part of arc.
- It is called rocking furnace because, it rocks back and forth during melting. So the metal comes in contact with the heated refractory lining for melting.
- Charge melts due to
  - heat from arc,
  - heat from hot refractory walls,

    due to conduction when furnace rocks and molten metal rolls over it.
- Indirect arc furnace is used for melting
  - cast-iron
  - steel
  - copper and its alloys
- Gets lower temperature and has lower efficiency than arc type.

Construction

- An indirect arc furnace has a barrel type shell made out of steel plates having refractory lining inside.
- There are three openings, two for two graphite electrodes and third one is for charging metal charge into furnace.
- Pouring tap is built up with charging door.
- These rollers are driven by rocking unit to rock the furnace back and forth for melting.

Working of Rocking Unit

- During rocking of furnace, the liquid metal flows over the heated refractory lining and absorbs heat.
- It also results in proper mixing of molten metal.
- Rocking
  - increases speed of melting.
  - stress the molten metal.
  - avoids overheating of refractory lining, thus its life time increased.
- The angle of rocking furnace is adjusted in such a manner that liquid metal level remains below the pouring tap.

Process of Operation

- Pig iron is charged first.
- Scrap is poured over pig iron.
- When electric power is supplied, graphite electrodes are brought nearer to each other till the current jumps and electric arc is produced between them.
- The heat is generated due to arc which melts charge. After some metal has been melted, rocking unit is activated.
- Rocking helps in better exchange of heat between refractory lining, molten metal and solid metal.

Advantages

- Metal charge is not a part of electrical circuit.
- Low cost scrap metal can be used.
- Operation and control are simple.

1.8 SOLIDIFICATION OF CASTING

- Solidifications of casting and its control for obtaining sound casting is the most important problem for foundry men.
- Soundness of casting may be defined as the degree of true metallic continuity.

- Casting is called sound if the volumetric shrinkage (due to change from molten metal to solid) is compensated by liquid metal provided by risers.
- The mechanism of solidification has to be understood properly to prevent defects due to shrinkage of metal.
- Solidification starts as soon as the molten metal is poured in the mould.
- Process of solidification affects
  (*i*) grain size, shape and orientation
  (*ii*) distribution of alloying element
  (*iii*) crystal structure and its imperfections.
- Volumetric shrinkage/contraction occurs in three stages. So contraction is of three types.
  (*i*) Liquid contraction/shrinkage – It occurs when the metal is in liquid state (pouring temperature to starting of solidification).
  (*ii*) Solidification contraction / shrinkage – It occurs when molten metal changes from liquid to solid, (when metal losses its latent heat).
  (*iii*) Solid contraction / shrinkage – It occurs when metal is solid.
  – Occurs after solidification
  – Does not affect shrinkage defect.
- Solidification occurs due to nucleation of very small grains called crystals.
- Grain growth occurs when solidification continues.
- The solidification may be (*i*) directional or (*ii*) discrete which is dependent upon nucleation and grain growth.

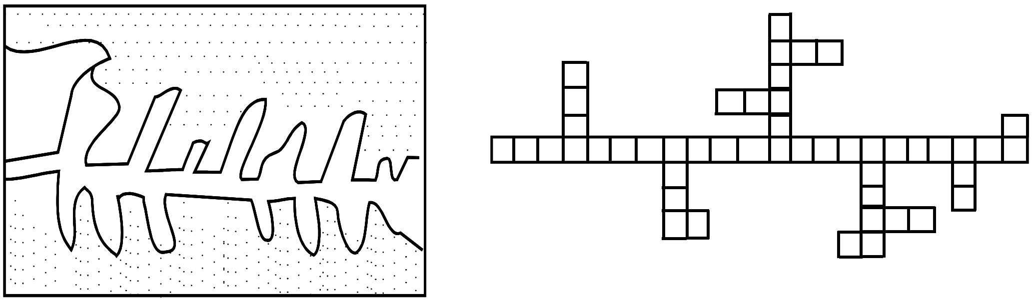
1.8.1 Nucleation

- It is the starting point of phase transformation.
- In this tiny new phase called nuclei grow in the molten metal. This nuclei grow into solid by further deposition of atoms.
- Nucleation is of two types. They are :
  (*i*) Homogeneous nucleation occurs in homogeneous materials as pure metals.
  (*ii*) Heterogeneous nucleation - occurs at surfaces, imperfections.

1.8.2 Grain Growth

- It occurs after nucleation
- It determines the final crystallographic structure of solid.
- Grain growth may be defined as increase of nucleus in size.
- Nuclei grow by addition of atoms.
- Total free energy is reduced due to grain growth.

- Metal in molten condition has high energy.
- Energy is lost as the molten metal cools to form crystals.
- Heat loss is more rapid near mould walls than any other place. So nuclei are formed here first.
- If no nuclei is in impurity form, then it becomes difficult to start crystallization.
- In this condition, the melt undercools and nuclei/seed crystal forms.
- The growth of crystal occurs in dendritic manner.
- Dendrites grow by forming small arms on original branches of individual dendrites. Slow cooling produces long dendrites and fast cooling produces short dendrites.
- Dendrites result in grains. So slow cooling produces large grain structure and fast cooling produces small grain structure.
- When solidification proceeds, more and more arms grow on existing dendrite and more and more dendrites form till the whole melt is crystallized.



(a) Dendritic growth (b) Unit cell and dendutic growh

Fig. 1.24

- Dendrites grow until they come in contact the neighboring dendrites and produce grain boundaries. After sometimes dendrite arms become thick and produce solid crystal or grain and there remains no indication of dendritic growth.

1.8.3 Chvorinov's Rule

It is observed that, when mould wall is plain and flat, the thickness of the skin formed is proportional to the square root of time.

So $t \propto \sqrt{T}$

where t = skin thickness and T = time after pouring the metal in mould.

or $t = k\sqrt{T}$

where k = constant whose value depends on mould material and its thermal conductivity.

Total time taken for solidification of casting can be expressed by Chvorinov's rule which is proportional to the square of the ratio of volume and surface area.

or $$\text{Solidification time} \propto \left(\frac{\text{Volume}}{\text{Area}}\right)^2$$

or $$t \propto \left(\frac{\text{V}}{\text{A}}\right)^2$$

or $$t = \text{k}_s \left(\frac{\text{V}}{\text{A}}\right)^2$$

where t = solidification time, k_s = solidification constant, (V/A) = shape factor.

This rule helps in determining the solidification time of casting. However, it is not very accurate, since it does not take into account the solidification contraction or shrinkage. This method is generally used for calculating proper riser size for short frezing-range alloys such as steel and pure metals.

1.8.4 Types of Solidification

- Progressive and
- Directional

1.8.4.1 Progressive Solidification

It may be defined as the growth of practically solid and partially liquid zone from the outside to the interior of the casting.

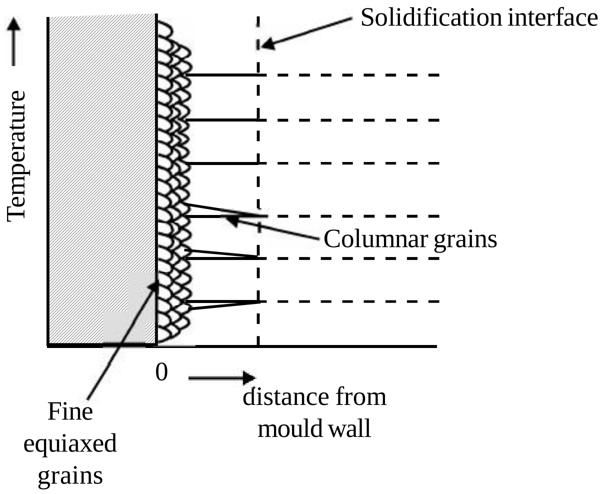


Fig. 1.25 Solidfication from a flat mould wall.

1.8.4.2 Directional Solidification

- When the gating system design is utilized to control this progressive solidification is such a way that no portion of the casting is isolated from liquid metal feeding channels during complete solidification cycle, it is called as **directional solidification**.
- It may be defined as solidification which is forced to occur in a particular direction.
- Directional solidification in castings starts and progress from the thinnest section towards the heaviest section.
- Effective directional solidification starts from those parts of the feeder heads (riser system). It proceeds through casting to the feeder heads. Feeder heads are designed to solidify last so that liquid metal can be supplied throughout freezing process.

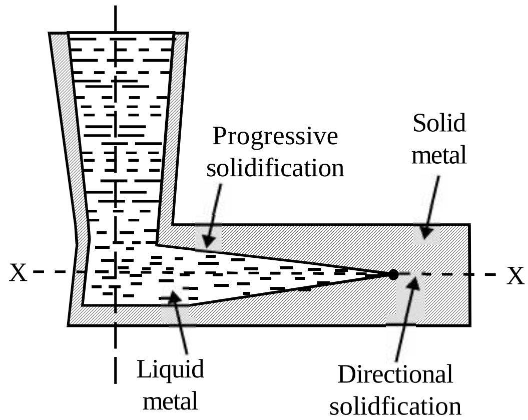


Fig. 1.26 Progressive and Directional solidfication

1.8.5 Gating System

Grating system consists of all the elements which are connected to the flow of molten metal from the ladle to the mould cavity. **Aim** of the design of gating system should be the production of defect free casting.

Elements of gating system are

(*i*) pouring basin
(*ii*) sprue
(*iii*) sprue base well
(*iv*) runner
(*v*) runner extension
(*vi*) ingate
(*vii*) riser

1.8.6 Design Considerations

- Cavity (mould) should be filled in smallest possible time.
- Metal should flow smoothly into mould without turbulence.
- Unwanted material as slag, dross etc. should not be allowed to enter.
- Metal should enter cavity in such a way that contamination by atmospheric air is prevented.

- Flow of metal should not erode gating system components or mould cavity.
- Sufficient molten metal should reach mould cavity.
- Gating system should be economical to prepare and easy to break.
- Casting yield should be maximized.

1.8.7 Riser

- During solidification most of the foundry metals and alloys shrink in volume.
- Voids (blank spaces) are created due to shrinkage if extra material is not fed in.
- So a reservoir of molten metal is to be provided which will supply molten metal to the casting when needed. This reservoir is called riser.

Considerations in Riser Design

(*i*) Metal in the riser should solidify last.

(*ii*) Riser volume should be sufficient to compensate the shrinkage in casting. So, the risers can be made sufficiently large. But it would increase process cost because it has to be cut off from the riser as scrap.

Classification

(*i*) Top risers – open to atmosphere (last effective and convenient to make)

(*ii*) Blind risers – completely in mould (more effective and more convenient to make)

(*iii*) Internal risers – enclosed on all sides by casting (most effective and must convenient to make)

- **Function of a riser** – feeding the casting during solidification so that no shrinkage cavities are formed.
- It depends on
  - metal poured and
  - complexity of casting
- Normally due to shrinkage the volume of material is reduced when cooled from liquid to solid.
- Grey cast iron some times shows negative shrinkage. It occurs due to higher carbon and silicon content. Graphitization occurs which increases volume. Risers may not be critical here

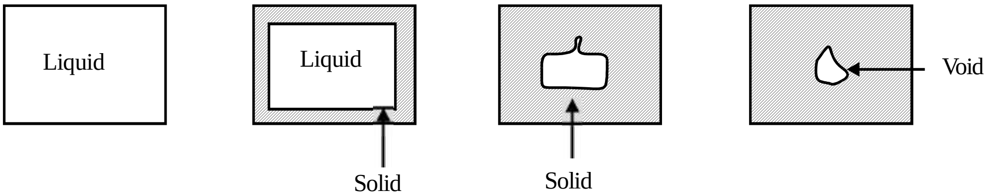


Fig. 1.27

Riser Design (Caine's Method)

Generally, risers are considered as cyclindrical shape

Freezing Ratio $(X) = \dfrac{SA_{casting}/V_{casting}}{SA_{riser}/V_{riser}}$

where SA = Surface Area

V = Volume of casting

Empirical Freezing Ratio $X = \dfrac{a}{Y-b} - c$

where $Y = \dfrac{\text{Riser volume}}{\text{Casting volume}}$ and

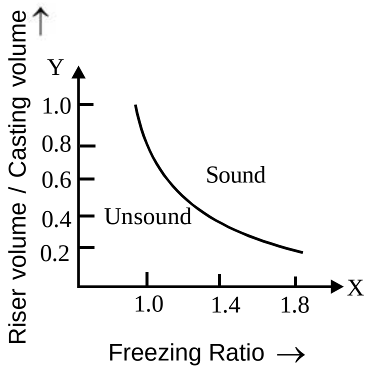


Fig. 1.28

a, b, c are constants (value of different materials)

For steel, a = 0.10, b = 0.3, c = 1.00

(*i*) Assuming certain value of riser diameter *X* can be found out.

(*ii*) Then by using graph, the value of *X* and *Y* can be plotted if the assumed diameter meets the above soundness curve then it is accepted [Fig. 1.28].

(*iii*) For example, value of *X* is 1.4 and *Y* is 0.4 for a particular diameter of riser then the point will be in soundness zone. So the riser is of required size. If it is in unsound zone then the suitable size is to be selected by hit and trial method.

NRL (Naval Research Laboratory Method) /Shape Factor Method

- Shape factor method is used for rough measurement of riser.
- This method is a simplification of Caine's method.
- It uses shape factor which replaces the freezing ratio.
- Shape factor $= \dfrac{\text{Length} + \text{Width}}{\text{Thickness}}$
- From the graph shown in Fig 1.29, the volume ratio can be obtained for sound casting considering shape factor.
- From the given data volume of the casting can be calculated. After Knowing the volume ratio, the riser volume can be calculated.

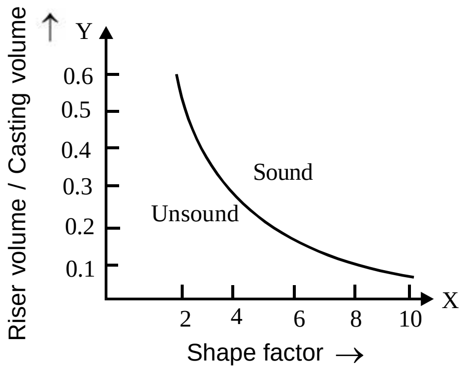


Fig. 1.29

1.8.8 Design of Runner

- It is generally located in the parting plane which connects sprue with ingates.
- It is normally trapezoidal in cross section
- Normally for ferrous materials runners are cut in cope and ingates in the drag.
- It is done to trap slag and dross which are lighter in the upper part of runners.
- For effective trapping of slag the runners should flow full.

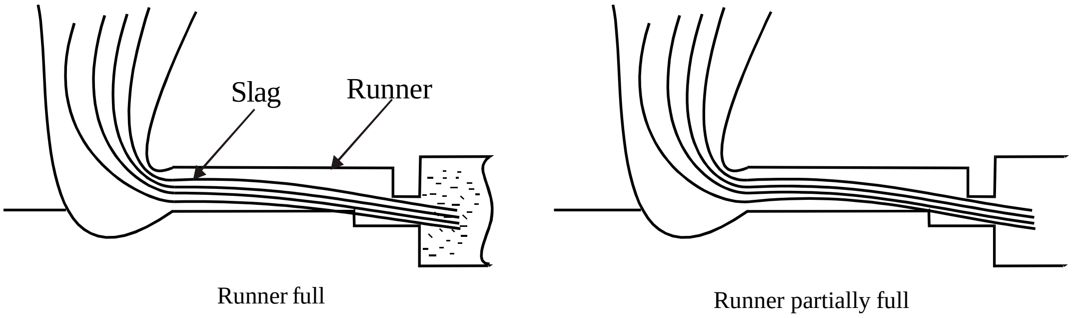


Fig. 1.30

- In order to get a fully filled casting the cross section area of runner must be larger than cross section area of gate.
- For minimum or less metal velocity in runner, area should be high

$$\frac{d_1}{d_2} = 1.3, \ \frac{d_2}{d_3} = 1.15 \qquad \text{(Fig. 1.31)}$$

- For this reason, generally runner to gate area ratio of 1.15 : 1 to 1.5:1 is used as a compromise.

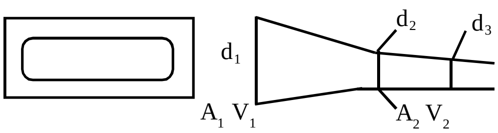


Fig. 1.31 Fluid flow across varying cross section

- The design obeys equation of continuity for fluid flow *i.e.*, $A_1V_1 = A_2V_2 = A_3V_3 =$ constant.
- The shape of the runner cross section gradully varies from round, trapezoidal, elliptical wide and flat to narrow and thick.
- A thick runner will solidify slower than thinner one.
- A flat runner looses heat faster before it enters gate.
- Normally maintained width to depth ratio is 1.6 : 1 to 1.8 : 1.

1.8.9 Feeding Distance

- Feeding distance may be defined as the distance a riser can feed the metal in a casting.
- It is affected mainly by casting thickness.
- For plate type casting feeding distance normally maintained is 4.5 times the thickness (T) of casting.
- For bar type casting it is 2 – 2.5 times of thickness, generally $6\sqrt{T}$ is followed.
- Feeding distance can be improved by reducing the diameter of riser at the neck.
- It is measured from the edge of the riser.
- It can also be improved by providing chill in the mould.

1.8.10 Centre Line Feeding Resistance

- It may be defined as the resistance against feeding an alloy in a mould cavity due to uneven freezing rate.
- It comes as a whole number(%) which is called centre line freezing resistance. It is abbreviated as CFR.

$$\text{CFR} = \frac{\text{Time interval between start and end of freezing of centre line}}{\text{Total solidification time}} \times 100\%$$

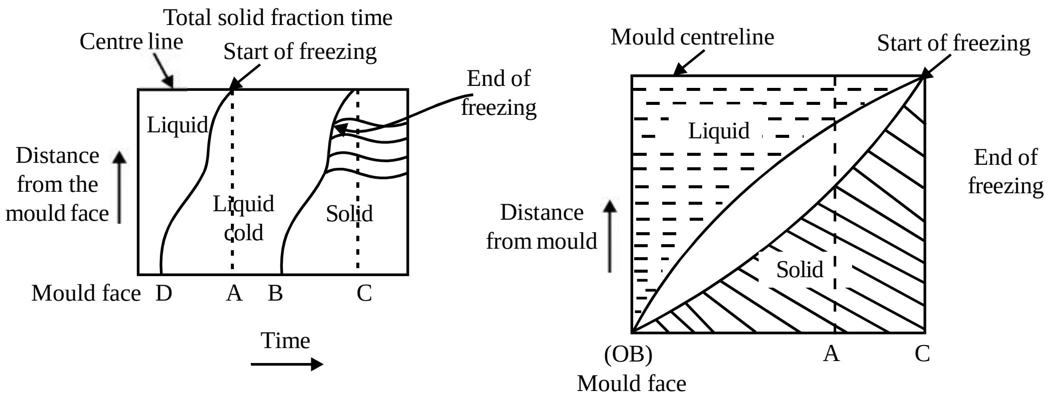


Fig 1.32 Freezing diagram for chilled mould

1.8.11 Chill

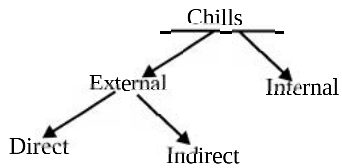
- Chill may be defined as a metallic object inserted in mould in order to speed up the solidification of a particular portion of the casting.
- A chill can be considered as a large heat sink.

- A chill
  - promotes solidification (progressive and directional)
  - avoids shrinkage cavities
- It is used where it is impossible to provide riser for a part which is heavy. This may be due to
  - complex shape of casting
  - unaccessible location of heavy sections of castings.
- Chills can equalize/increase the gap between the coding rate of thin sections as compared to thick sections.
- Chills promote solidification/increase the rate of cooling. This helps heavy sections to draw molten metal through the thin sections while they are still liquid.
- It also helps a section which is far from riser to solidify first to produce sound casting. Thus it promotes directional solidification.
- Metallic chills have the capacity of increasing the solidification rate as high as 14 times than sand moulds of same condition.
- For this reason, chills are used to obstruct the formation of graphite *i.e.*, carbon remains in combined form and cast the iron as white (C.I.) and hard.

Disadvantages

Due to high rate of cooling (when chill provided) may produce hard spot at the contact area which may require machining to bring it to shape.

Classification



The size, shape and position of a chill must be considered carefully. Because
- too rapid cooling of casting may produce cracks in it.
- too slow cooling of casting may not produce required chilling effect.

External Chills

- It is rammed in mould sand walls.
- It is a good way of controlling cooling rates in critical regions of casting.
- Direct external chill is in level with mould cavity wall and thus comes in direct contact with the liquid metal.
- Indirect external chill is placed behind the mould cavity wall and is fully buried in sand. It does not come in direct contact with the liquid metal.

- Sometimes indirect chill is placed at an angle to casting surface. So its chilling effect decreases as the chill tapers away from casting. This effect can be used to promote directional solidification in a casting (member) of uniform thickness.
- Direct chills are more effective than indirect chills.
- Normally made up of steel, cast iron and copper. Copper imparts highest effect of chilling because it is having highest conductivity.
- For ferrous casting chills are made out of iron and steel. For non-ferrous castings iron, steel, copper and block graphite are used.
- They can be reused.
- It should make sufficient contact (direct/indirect) but should be large enough so that it should not fuse with casting.
- Helps to eliminate porosity (micro and micro) at the portions of casting which is difficult to fed by riser.
- Direct chills should be clean, dry and free from rust. Sand blasting may be done.
- Direct chills should be preheated and dried before pouring molten metal in mould to avoid **blow holes** due to moisture present on chill.

Internal Chill

- Internal chills fuse into and become part of the casting. So these are made of the same metal which is to be cast.
- It is rarely used because structural homogeneity is less due to improper fusion which results in poor casting quality.
- Normally used in the area where it is used is to be removed after solidification. For example, bosses to be drilled/bored.
- These penetrate upto the position in mould cavity where external chills can not reach.
- One end of these remain hanging in mould cavity and the other end is supported in sand.
- Normally not used in nonferrous because it is difficult to fuse properly.
- It should be
  - clean (free from rust scale, grease etc.
  - fuse properly and thoroughly with casting.
- Chemical composition compatible with metals to be cast.
- Must not change mechanical or metallurgical properties of casting.
- Should not remain more than one hour in green sand mould before-pouring otherwise it may collect moisture.

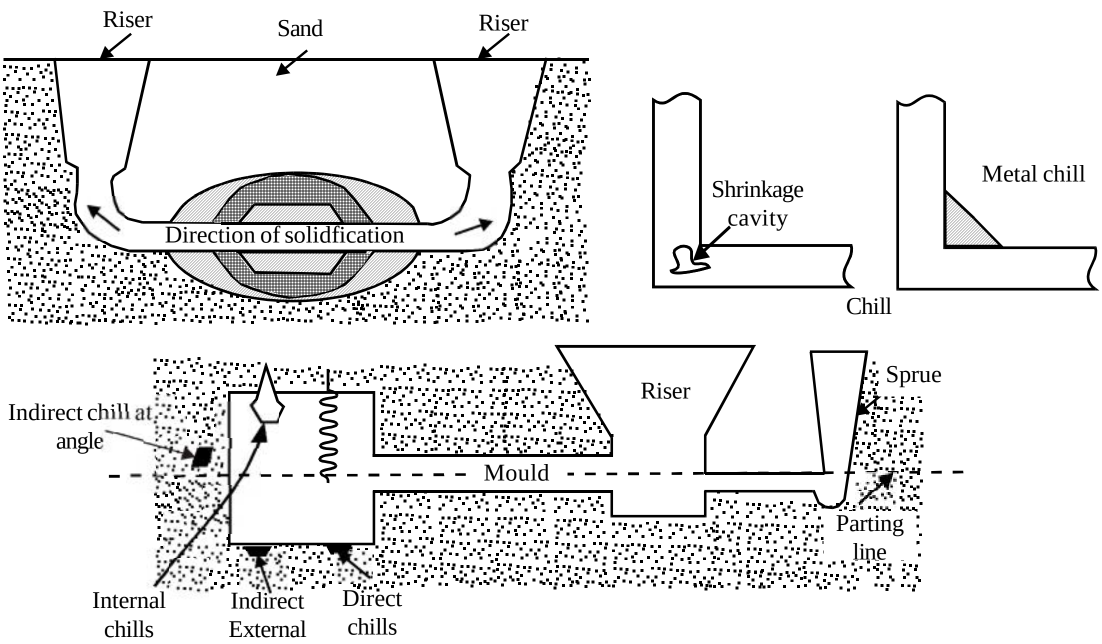


Fig. 1.33 Placing of external and internal chills.

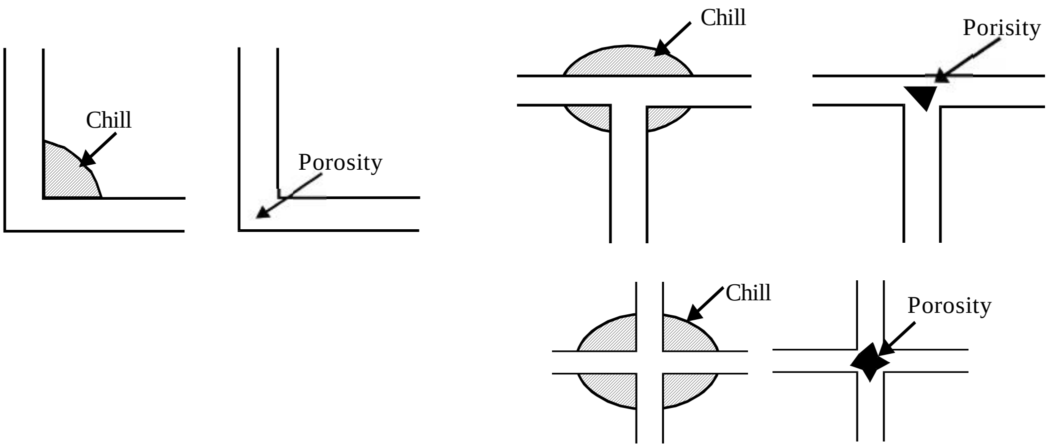


Fig. 1.34 Use of chills to prevent formation of porosity at casting junctions

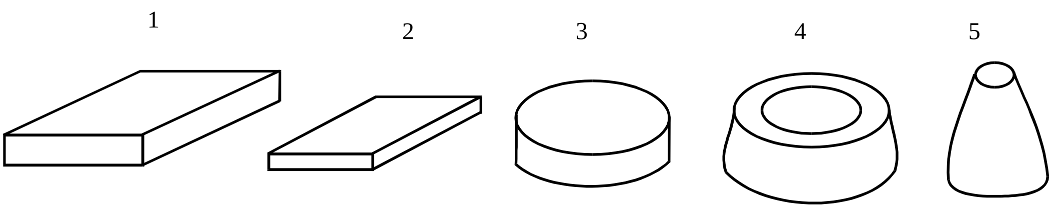


Fig. 1.35 External Chills

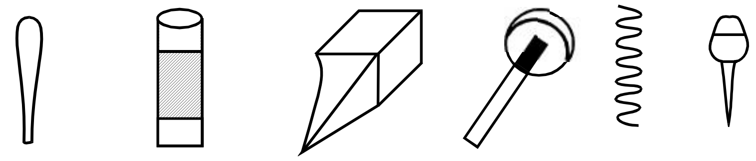


Fig. 1.36 Internal Chills

1.8.12 Chaplet

- Chaplet may be defined as the metallic support which is normally kept inside the mould cavity to support placement of cores.
- A chaplet is made of the same composition as that of the pouring metal.
- The molten metal provides sufficient heat to completely melt them first and then fuses with the casting during solidification.
- If the core is shifted from its position in the mould the cavity gets displaced and produces defective casting.
- Core must be firmly supported in the core seat to prevent its vertical movement due to buoyant forces experienced by the core due to poured molten metal.
- Chaplet may be described as metal shapes positioned/placed between mould and core surfaces.

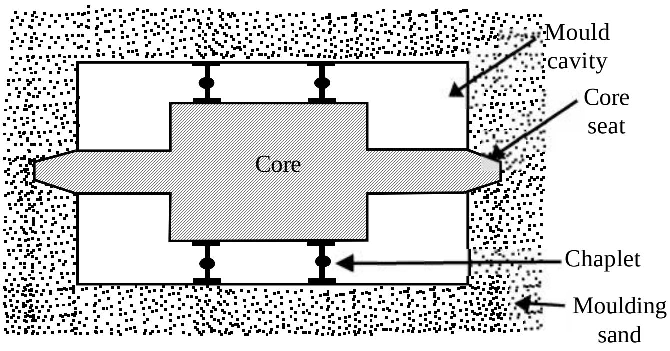


Fig. 1.37 Core supported between chaplets

- Chaplet is required to fuse with the parent metal after pouring but practically it is very difficult to achieve and normally forms a weak joint in the casting.
- The other commonly observed problem in chaplets is the condensation of moisture which results in blowholes.
- Generally the chaplets are thoroughly cleaned to extract dirt, and grease before placing them in mould.

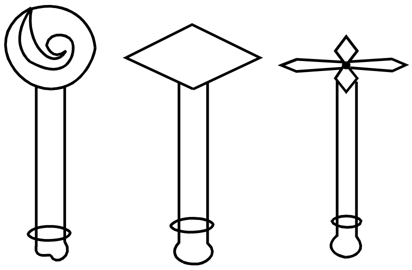
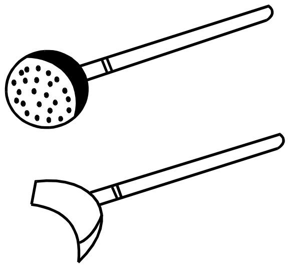


Fig. 1.38 Radiator chaplets



1.39 Steam chaplet

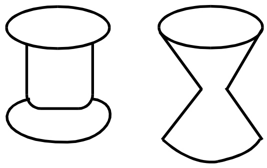


Fig. 1.40 Cast chaplet

1.9 SPECIAL TREATMENT OF METALS (MELTS)

- Before pouring, molten metals are given certain treatments to purify them or to alter the metallographic structure of the castings
- The important melt treatments are

(*a*) Refining

– Oxidation.

– Deoxidation.

– Degassing.

– Desulphurization.

(*b*) Inoculation

– Grain and constituent refinement.
– Refinement and eutectic modification.

1.10 GASES IN METALS

- Most of the problems for producing sound metal castings are due to lack of control of dissolved gases or reaction gas in the casting during the period of solidification.
- Gases are absorbed in molten metals due to the following sources.
  (*i*) Furnace charge
  (*ii*) Furnace refractories
  (*iii*) Furnace atmosphere
- Precautions to be taken to avoid gas absorption in melt are
  (*i*) Using bigger pieces possible as metal charge because they are less susceptible to contamination.
  (*ii*) Restrict the use of contaminated scrap as metal charge.
  (*iii*) Using preheated charge specially in case of continuous melting process.

(*iv*) Melt the metal first and handle it with little agitation. Metal handling includes skimming slags or protective atmospheres.

(*v*) Alloys, fluxes to be added and all other items as laddles or furnace tools coming in contact with molten metal should be perfectly dry.

(*vii*) Gas solubility decreases with temperature. So molten metal should be at minimum possible temperature. Overheating of melt should be avoided.

1.11 DEGASSIFICATION

Degassification is the process of removing the gases from the melt. If it is impossible to prevent the absorption of gases completely, the melt is a solution to obtain sound casting.

Effect of dissolved gas can be reduced by removing or isolating one or more of the components of gas.

Principle

Most degassing treatment are based on the equilibrium between molten metal and gas atmosphere.

If a gas is completely removed from the atmosphere around the molten metal, then the gas dissolved in molten metal tends to escape out.

$$V = k\sqrt{P},$$

V = volume of molecular gas
P = pressure of gas around and above liquid metal
k = constant

Techniques

(*i*) Vacuum Degassing
- static bath treatment
- induction degassing
- fractional degassing
- stream droplet degassing

(*ii*) Gas scavenging including solid degasser and jet degassing.

Vacuum Degassing

In this method melting and pouring of metal is done in vacuum. This method of degassing is very effective and also very costly.

Static Bath Treatement

- Metal is melted in air.
- Before pouring it is placed within a chamber which can be sealed and evacuated.
- In the second type, the laddle is sealed with a cover and molten metal degassed.

- After vacuum degassing pouring is done in atmosphere.
- Rate of degassing depends on
  - surface area of liquid metal.
  - mass of liquid metal.
  - extent of agitation and stirring which accelerate transport of dissolved gas to nearest atmosphere.
  - No circulation of melt is provided.
  - Dagassing occurs by natural convection only, thus it is a slow process.

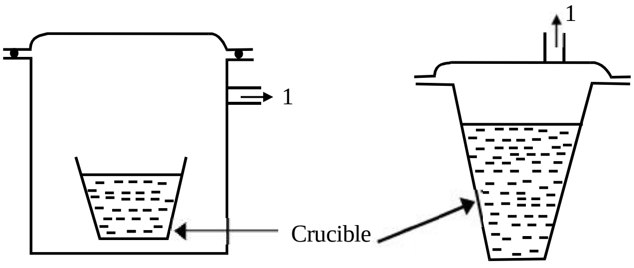


Fig. 1.41 Static Bath Vacuum Degassing

Induction Degassing

- In this method the laddle containing molten metal is placed in a chamber which can be sealed and evacuated.
- An induction stirring coil surrounds the laddle. It helps the gasses to evolve from the melt and the gas is drawn away by vacuum pump.
- Advantages
  (*i*) circulation of melt
  (*ii*) induction heating
- More efficient than static bath degassing

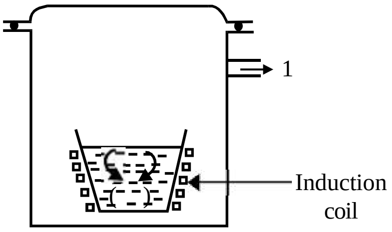


Fig. 1.42 Induction Degassing

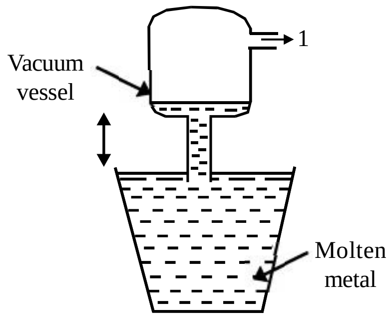


Fig. 1.43 Fractional Degassing

Fractional Degassing

- In this degassing method a separate vacuum vessel is utilized.
- The molten metal in the laddle is degassed by lowering and raising of the vessel alternately into the laddle.
- It occurs due to the raising of molten metal in the vacuum vessel.

Stream Droplet Degassing

- In this method the molten metal from the laddle is tapped into another preheated laddle placed in an evacuated chamber.
- This falling stream of molten metal is exposed to vacuum and thus degassing occurs.
- It is a very rapid method of dissolved gas extraction from molten metal (melt).

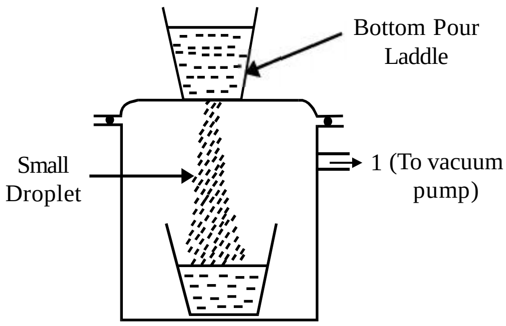


Fig. 1.44 Vacuum degassing

Gas Scavenging

- It is the most effective technique of gas extraction from melt.
- Inert gas is used for this purpose.
- Inert gas is bubbled through the melt using graphite tube.
- Pressure of dissolved gas within inert gas bubble is zero/negligible than in melt. So the dissolved gas migrate to the bubble. Then collected there and flushed out from melt.

Some allays and scavenging gases

Copper base ———— N_2

Aluminium base ———— N_2, Cl_2, Ar

Magnesium base ———— Cl_2, Ar

Nickel base ———— O_2

Solid Degassing

- In this method, inert gases are generated within the melt by decomposition of unstable compounds as C_2Cl_6 (hexachloro - ethane).
- C_2Cl_6 is a solid degasser.
- Tablets of hexachloroethance are plunged and held beneath the melt surface.
- They decompose and flushing is accomplished.

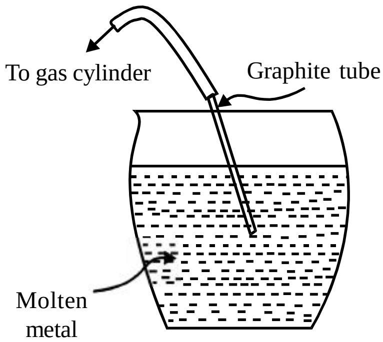


Fig. 1.45 Inert Gas Scavenging

- Calcium carbonate is used as solid degasser to generate CO_2 in copper base alloys.

Jet Degassing

- It is one of the methods of gas scavenging.
- In this process inert gas jet is impinged on surface of molten metal. For example argon jet is used to reduce hydrogen content in steel.
- In steel preparation, carbon monoxide from carbon boil (FeO + C = CO + Fe) acts as scavenging gas and removes hydrogen from melt.

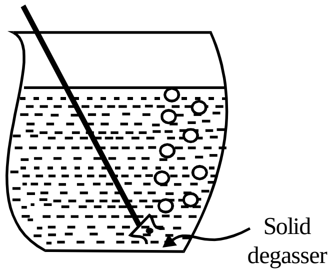


Fig. 1.46 Solid Degassing

1.12 INOCULATION OF METALS

Inoculation may be defined as addition of inoculant to molten metal in order to modify structure of metal after solidification and properties of cast metal or alloy. Action of inoculants is not just only simple alloying effect. Nucleation is an integral effect of inoculation. It is partially caused by addition of nuclei to the melt. A nucleus is a particle of matter which acts as centre to start graphitizations/crystallization.

It is applied late in melting operation/process. Some commonly applied inoculation treatments are :

(*i*) Grain and constituent refinement

Alloys	**Typical inoculants**
Steel ————	Al, Ti
Aluminium base ————	Ti, B, Nb, Zr
Magnesium base ————	C, Zr
Mg – Al ————	C

(*ii*) Refinement and eutectic modification

Alloys	**Typical inoculants**
Al - Si ————	Na
Cast iron (inoculation) ———	Si, C
Cast iron (S.G. iron structure –	Mg, Ce

Effects of Inoculation

- Aluminium in controlled amount is added in steel to produce fine grain size and special distribution of inclusions. This improves mechanical (especially impact) properties and response of metal to heat treatment.

- Titanium (0.2%) or boron (0.02%) are added at final stage of casting of light alloys (*Al*) reduce the cast grain size from 0.1 inch (2.5 mm) in dia to as small as 0.005 (0.125 mm) in dia.
- When iron and nickel are added in small percentages to aluminium bronze, it prevents the formation of a coarse crystalline structure.
- Carbon is added in small amounts to molten Mg - Al alloys for grain refinement.
- Zirconium is added in small amount to magnesium alloys (without any aluminium) for grain refinement.
- Eutectic structure of Al-Si alloys is modified by adding sodium in small quantity or treating with sodium salts. Sodium treatment ensures fine dispersion of Si and higher physical properties.
- Inoculation of molten cast iron
  - modifies structure or graphite formation
  - change in graphite type obtained by inoculation of molten iron.
  - improves mechanical and physical properties
  - reduces inherent section sensitivity of grey cast iron
  - makes material tougher, more predictable and less susceptible to changes in chemical composition.
  - In graphitization inoculation of grey cast iron, inoculant favours graphite formation. prevents (undercoding) chilling and avoids formation of white iron in thin sections.
- Common graphitizers are ferrosilicon, nickel silicon, Ca–Mn – Si and Si – Mn – Zr.
- Quantity of graphitizer (inoculant) should be such that it can add 0.5 – 1.0% silicon to the molten iron.
- Graphitizers produce more effect when added to the molten metal in laddle than when included in the furnace metal charge.
- If normal grey iron is inoculated with silicon at the time of pouring, the austenite – graphite eutectic grain size and graphite flake distribution can be controlled.
- In another treatment, when magnesium or cerium is added in the molten iron, the result is the spheroidal graphite structure and a ductile iron.
- Near about 0.04% residual magnesium changes graphite, flakes into spheroids with huge improvement in mechanical properties of the resulting iron.

1.13 SPECIAL CASTING TECHNIQUE

- Sand mould casting process gives satisfactory results at lowest cost.
- All metals can be cast in sand moulds.
- In sand mould technique no casting size limitation is present. But sand moulds are single purpose because they are completely destroyed during removal from moulding

box. This drawback generated permanent mould method by which considerable labour cost in moulding can be saved. So permanent moulding is a special casting method.

- There are some other limitations associated with conventional casting technique which gave rise to special casting processes.
- Special casting technique can not be employed in all foundries because of its high initial cost. But where conventional sand casting does not produce good result, it is used there e.g. turbine blades for jet engines.

1.14 ADVANTAGES OF SPECIAL CASTING OVER SAND CASTING

– Higher dimensional accuracy.
– Higher metallurgical quality.
– Lower production cost (in some cases).
– Ability to cast extremely thin sections.
– High production rate.
– Better as cast finish, so low labour and finishing cost afterwards.
– Minimum need for further machining of castings.
– Casting can have denser and finer grain structure.
– Castings are slightly more stronger and ductile than sand mould casting.

1.15 TECHNIQUE : SPECIAL CASTING PROCESSES

Classification

(1) Metal Mould Casting

(*i*) Gravity/permanent mould casting.

Die casting
- Hot chamber process
- Cold chamber process

(*ii*) Slush casting.
(*iii*) Pressed/Corthias casting.

(2) Non metallic mould casting

(*i*) Centrifugal casting
- True centrifugal casting
- Semi centrifugal casting
- Centrifuge casting

(*ii*) Carbon -dioxide moulding.

(*iii*) Investment mould casting / lost-wax process.

(*iv*) Shell moulding.

(*v*) Plaster moulding.

(*vi*) Mercast process.

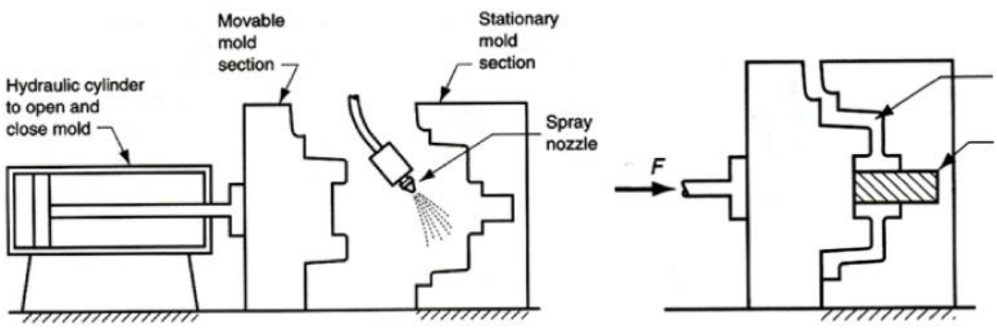
(3) Continuous Casting

(*i*) Reciprocating moulds. (*ii*) Draw casting.

(*iii*) Stationary moulds. (*iv*) Direct sheet casting.

1.16 DIE CASTING

- Die casting (pressure die casting) may be defined as a permanent mould casting in which pressure forces the molten metal into the mould cavity.
- The mould used is much more expensive than sand mould which is called a die.
- A complex machine is used to produce castings at a very high rate.
- If the molten metal is forced into a metallic die under gravity head as done is sand cavity, the process is known as **Gravity Die Casting** or **Permanent Mould Casting**.
- The mould is normally called a metallic die with two halves. One half is fixed (stationary cover) and the other is (ejector) movable.
- Commonly used die materials are medium carbon, low alloys, hot steels.
- The die carries all details required on the casting.
- Molten metal pressure is generally obtained by compressed air or hydraulically.
- The pressure varies from 70 to 5000 kg/cm^2 and is maintained when the casting solidifies.
- High velocity is associated with high pressure (externally applied) with which the liquid metal is injected into the die.
- All these conditions provide unique capacity for the production of complex components at relatively low cost.



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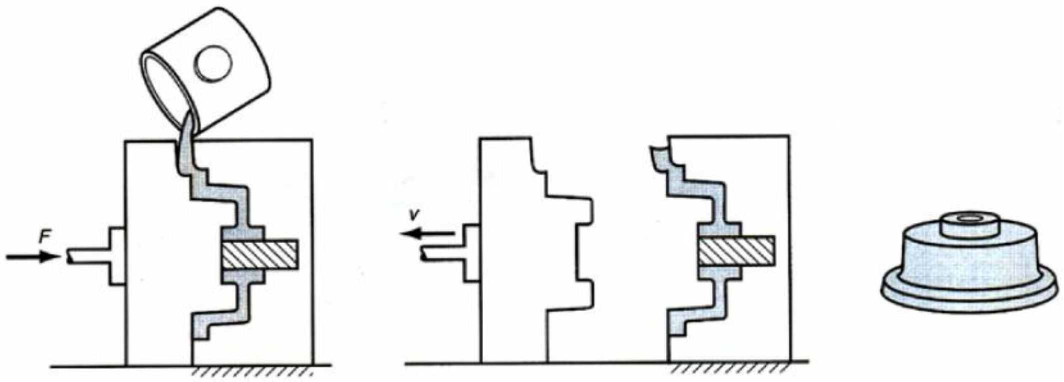


(c) (d) (e)

Fig. 1.47 Die Casting Process

The primary requirements for producing a good die casting

(*i*) A casting machine smoothly operating and properly designed to hold and operate a die under pressure.

(*ii*) Properly designed and constructed die.

(*iii*) Suitable casting alloy.

Die Casting Machines

Functions

(*i*) Holding two die halves firmly together

(*ii*) Closing the die

(*iii*) Injecting molten metal into die

(*iv*) Opening the die

(*v*) Ejecting the casting out of the die.

Parts

(*i*) Frame

(*ii*) Sources of molten metal and metal transfer

(*iii*) Die-casting dies

(*iv*) Metal injection mechanism

Frame

- Die casting machine frames are generally four-bar presses.
- Solid or one-piece frame has gained wide acceptance for small machines.
- The machine frame uses a stationary platen and a movable platen to which die halves are attached and they open and close in correct alignment.
- The frame should be sufficiently strong because the weight of an assembled die may exceed several tons.

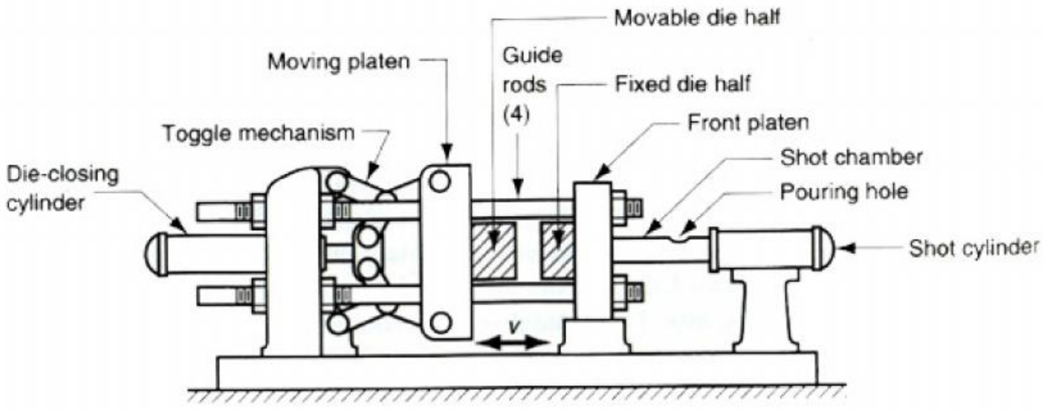


Fig. 1.48 Die Casting Machine

Sources of molten metal and molten metal transfer

- Generally each die casting machine has a holding furnace for feeding the metal.
- Holding furnace is provided with automatic temperature controls.
- Metal charge is melted in a separate foundary furnace (*i.e.*, pot, crucible, reverberatory, electric, etc) and is then transferred to holding furnaces.
- Normally, magnesium is melted and held in fabricated steel crucibles, aluminium alloys in graphite crucibles and zinc alloys in cast iron crucibles.
- Gas fired furnaces are commonly used for melting almost all die casting alloys. Oil fired furnaces are also used.
- Electric resistance furnaces are generally not preferred, but low frequency induction furnaces are gaining demand.
- Molten metal can be transferred from holding furnaces to die casting machines with the help of hand-ladles or automatically if the casting weights more than 7 kg or even when producing smaller castings, at high production rates.

Automatic molten metal transfer from holding furnace to the casting machine may work with the following mechanisms.

(*i*) a holding furnace and die casting furnace is connected through a refractory tube. Air or nitrogen at low pressure when introduced in the enclosed furnace exerts pressure on the molten metal which via refractory tube flows into the injection cylinder of the die casting machine.

(*ii*) Non-metallic or refractory pumps can be placed in the holding furnace for molten metal transfer.

(*iii*) A monorail is mounted between die casting machine and holding furnace. A valved bottom inlet crucible riding on the monorail is lowered into the holding furnace for taking metal and is than moved along the monorail to the casting machine where it discharges molten metal into the injection cylinder.

Die Casting Dies

- A die may be defined as a type of permanent mould made of two halves for facilitating easy removal of casting.
- One die half is stationary called fixed / cover die and the other is movable called ejector die which moves to open or close the complete die.
- The two halves are aligned properly using dowel pins.
- Molten metal is forced under pressure into closed die to produce casting.
- When the casting is solidified, the movable die half containing the casting is pulled to open and the ejector pins advance beyond the movable die to detach the casting from the die.

Die Material

There are three modes of die failure related to die material.

(*i*) Thermal fatigue

(*ii*) Mechanical erosion

(*iii*) Chemical attack

The following is the composition of different die casting die steels

Type			**Composition %**					
	C	**Cr**	**Mo**	**w**	**V**	**Co**	**Ni**	**Use**
Hot work								
tool steel								
H11	0.35	5.0	1.50		0.5			Zn casting dies
H12	0.35	5.0	1.50	1.5	0.4			
H13	0.35	5.0	1.50		1.0		–––––	]All casting dies
H19	0.40	4.25		4.25	2.0	4.25		
H20	0.35	2.00		9.0		————		Brass and Bronze casting dies
H21	0.35	3.50		9.0		————		
Mould steel	0.30	1.70	0.4					
Maraging steel								
250 grade			5.0			8.0	18.0	Cu alloy casting dies
300 grade			5.0			9.0	18.0	
Refractory w								Cu alloy casting dies brass
Refractory M_o								

Metal Injection Mechanism

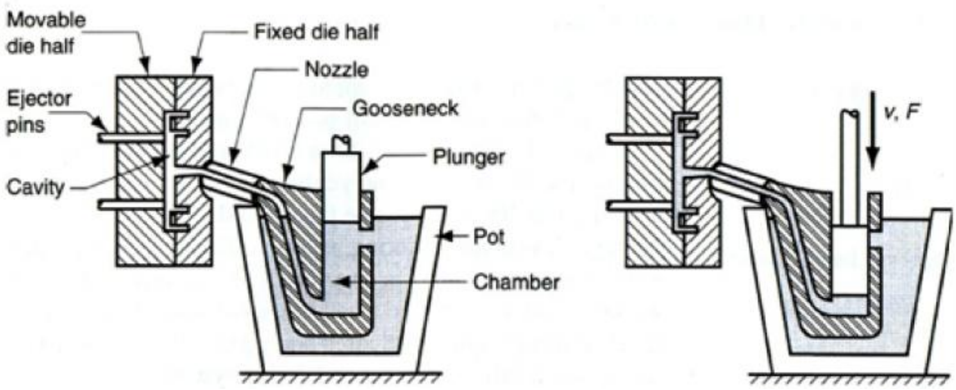
There are two general types of molten metal injection mechanisms for die casting machines.

(*i*) Hot chamber → Goose neck / air injection type
→ Submerged plunger type

(*ii*) Cold chamber

Hot Chamber Process

- Hot chamber die casting machine / process is the oldest die casting process.
- Depending on size a hot chamber die casting machine can produce about 60 or more number of castings having weight upto 20 kg each per hour. It can produce several hundred castings per hour for castings weighing few grams.
- The distinguishing feature is that in hot chamber machine the melting unit is an integral part of the process.
- The molten metal pocesses normal amount of superheat. So less pressure is required to force the liquid metal into the die.
- A gooseneck is used for pumping the liquid metal into the die cavity.
- The gooseneck is submerged in the holding furnace containing the moltel metal.
- Goosneck is made of grey, alloy or ductile iron or cast steel.
- Plunger used is hydraulically operated and is made of alloy cast iron.
- Plunger moves up in the gooseneck to open the entry port to facilitat entry of liquid metal in gooseneck.
- Then the plunger goes down to produce required pressure for forcing metal into die cavity.
- A nozzle is provided at the end of the gooseneck which is in close contact with the sprue located in the cover die.



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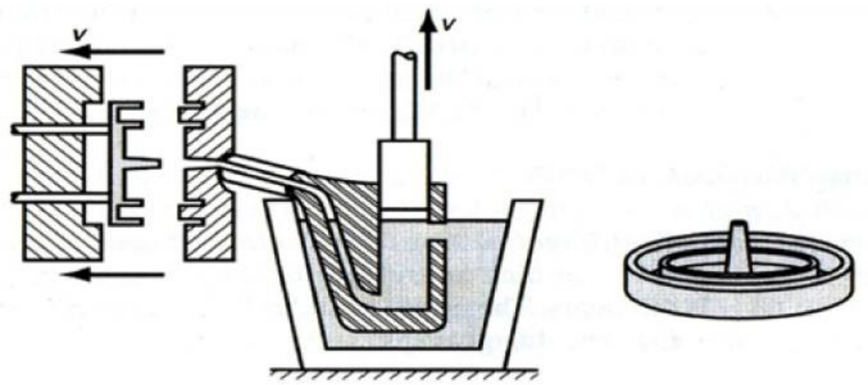


(c)

Fig. 1.49 Hot Chamber Process

Operation

(*i*) Close and lock the two halves of the die. The plunger at this time is located at highest position is gooseneck (*i.e.*, it is filled)

(*ii*) Plunger moves down and forces molten metal in the gooseneck to be injected into the die cavity under pressure.

(*iii*) This pressure is to be maintained till solidification.

(*iv*) The die is opened and if any core is present is taken out.

(*v*) The plunger is moved back to return the unused liquid metal in the gooseneck.

(*vi*) The casting is ejected with assembly of sprue, runners and gates.

(*vii*) The above cycle is repeated.

- The weight of most castings is from 90 gms to 25 kgs.
- Die casting machines are normally rated by the magnitude of clamping force.
- In another method shot weight capacity is specified for the injection system.

Advantages

(*i*) It is a simple machine as per its construction and operation.

(*ii*) Except plunger there is no moving parts.

Disadvantage

Production rate is low.

Application

Castings of low melting point metals eg., zinc, tin, lead.

Cold Chamber Process

- The hot chamber process is used for most of the low melting point alloys such as zinc, lead and tin. But for materials such as aluminium and brass having higher melting point makes it difficult to cast them by hot chamber process. The reasons is as follows :

– gooseneck of hot chamber machine is continuously in contact with molten metal.
– liquid aluminium would attack the gooseneck material.

- So molten metal is poured with a laddle into the shot chamber for every shot. It reduces the contact time between the liquid metal and the shot chamber.
- The cold chamber die casting machine consists of a pressure chamber or cold chamber of cylindrical shape fitted with a ram or piston which is normally operated by hydraulic pressure.
- Strong, high grade, heat resistant alloys steels are used for making the working parts of the machine as well as the dies. It is due to the high temperature and pressure associated with the process.

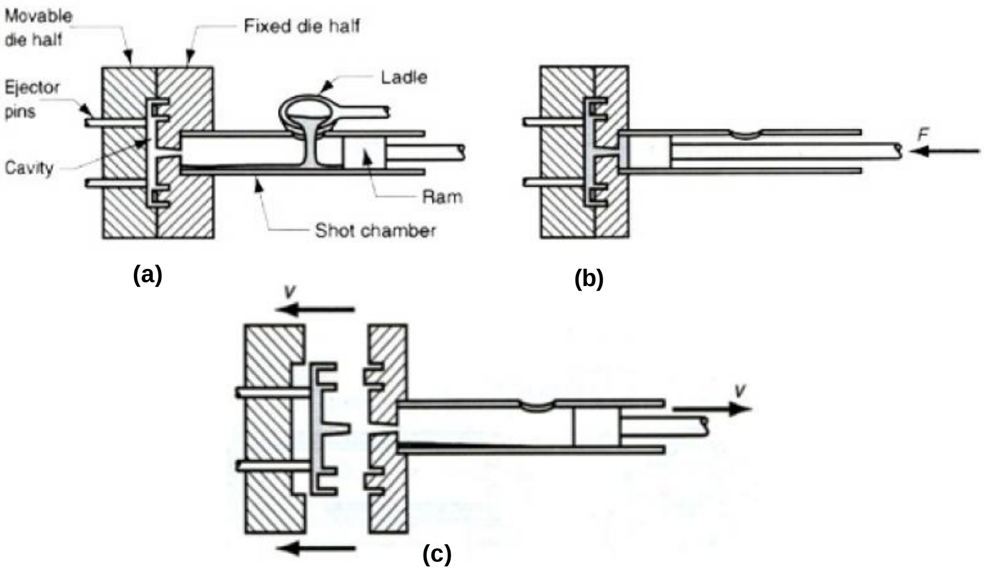


Fig. 1.50 Cold Chamber Process

Operation

- The operation starts with the spraying of die lubricants throughout the die cavity and closing of the die.
- Molten metal is ladled into the shot chamber of the machine either manually by a hand ladle or by means of an autoladle.
- An autoladle is a robotic device which automatically scoops / unloads molten aluminium from the holding furnace and pours into the die at the exact time/moment in the casting cycle.
- The volume of metal and pouring temperature is precisely controlled by using an auto ladle, so that required cast quality can be obtained.
- Ram/plunger forces the metal into die cavity and maintains the pressure till it solidifies.
- Pressure required to force metal into the die is of the order of 200 to 2000 kg/cm^2. So high squeezing action is exerted on the metal while it solidifies.

- After solidification die is opened and casting ejected.
- At the same time plunger/ram returns to its original position which completes the operation.

Advantages

(*i*) Castings are of greater density and more dimensional accuracy.

(*ii*) Separation of melting unit (*i.e.*, furnace and pot etc.) from the working parts of die casting machine increases its life and efficiency.

Limitations

(*i*) Longer cycle time needed compared to hot chamber process.

(*ii*) Metal is ladled into machine from furnace, so it may lose superheat and sometimes may cause defects such as cold shuts.

(*iii*) Dies have to be made stronger because of high pressures involved.

Application

Cold chamber die casting machine are widely used for producing castings of aluminium, brass and magnesium.

Feature Difference between Hot and Cold Chamber Process

(*i*) Melting unit is not an integral part of cold chamber die casting m/c. Molten metal is brought and poured into die casting machine using ladles.

(*ii*) In cold chamber die casting machine molten metal is poured at a lower temperature than in hot chamber die casting machine.

(*iii*) For the above reason pressure is more (200 to 2000 kg/cm^2) in case of cold chamber process than in hot chamber process.

(*iv*) High pressure tries to increase fluidity of molten metal which has relatively low temperature in cold chamber process.

(*v*) Molten metal having low temperature and high injection pressure produces castings of dense structure, sustained dimensional accuracy and free from blowholes.

(*vi*) Die castings of cold chamber process has less thermal stress because of lower temperature of molten metal. But die must be stronger to bear high pressures.

Die Casting : Advantages, Disadvantages and applications

Advantages

- Large quantities of identical parts can be produced rapidly and economically.
- Very little machining is required on the parts produced.
- Complex castings can be prepared.
- Parts having thin and complex shape can be cast accurately and easily.

- Very high production rate can be achieved. (eg., 200 pieces per hr)
- Due to metallic dies, surface finish of the order of 1 micron can be obtained.
- Die cast surfaces can be directly electroplated without ant further processing.
- Closer dimensional tolerance ± 0.08 mm can be obtained.
- Die has a long life which is of the order of 300000 pieces for zinc alloys and 150000 pieces for aluminium alloys.
- Die castings give better mechanical properties compared to sand castings. It is due to fine grained skin formed during solidification.
- Inserts can be readily cast in place.
- Holes upto minimum of 1.5 mm dia can be easily cored during casting.
- Die castings prove very economical when used for large scale production.
- Die castings requires less floor area than other casting techniques.
- Soundness of die cast products are more.

Disadvantages

- The cost of equipment and die is high.
- Maximum size of casting is limited
- A limited range of non ferrous alloys can be die cast.
- Maintenance requires special skill
- Entrapment of air present in die cavity in casting creates a problem (porosity defect).
- Economy in production is possible only in case a large quantity is to be produced. Generally, holds good upto 20000 castings.

Applications

- Transmission housings
- Valve bodies
- Carburettors
- Motors
- Hand tools
- Toys
- Crank cases
- Handle bar housings
- Head temperature bezzels
- Magnetos
- Zip fasteners
- Other decorative item in automobiles

1.17 CENTRIFUGAL CASTING

- The principle of contrifugal casting was originally established by A.G. Eckhardt in 1809.
- It was used after 1920 for manufacturing C.I. pipes.
- The main feature of centrifugal casting is the introduction of liquid metal into a rotating mould.
- Centrifugal force plays a major role in shaping and feeding of casting.
- The centrifugal force is utilized in two ways :
  (*i*) The centrifugal force is utilized to distribute liquid metal over the outer surfaces of a mould. Hollow cylinders and other annular shapes are formed in this way.
  (*ii*) The centrifugal force tries to fly the poured metal and freezing metal outward, away from axis of rotation. This creates high pressure on the metal or casting while it is freezing. So it produces casting of high metallurgical quality.
- The slag, oxides and other inclusions are lighter. So they get separated from the metal and seggregate toward the centre.
- For developing a solid casting, the axis of rotation is shifted at the end of the casting. So the process is useful to produce dense casting whether hollow or soild.
- Centrifugal action seggregates the less dense non metallic inclusions and slag particles near the centre of rotation which are removed by machining later.
- Cylindrical pipes and parts are most suitable to cast.
- The castings are produced with promoted directional solidification because the cold metal is thrown to outerside of casting and hotter metal nearer the axis of rotation which also acts as feeder during solidification of metal.

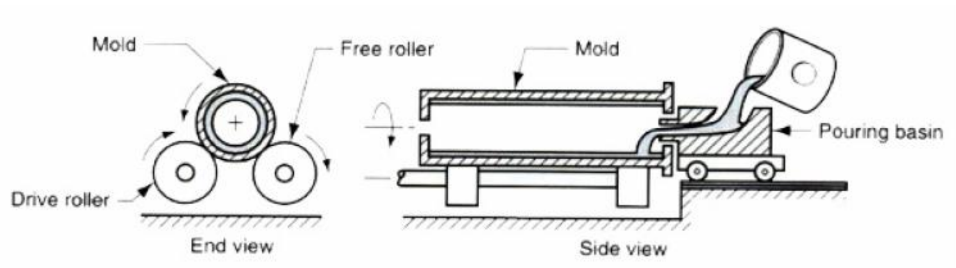


Fig. 1.51 Centrifugal Casting

Methods

There are three main types of centrifugal casting processes.

(*i*) True centrifugal casting
(*ii*) Semi centrifugal casting
(*iii*) Centrifuging

1.17.1 True Centrifugal Casting

- This process is used for making castings of hollow cylindrical parts e.g. pipes, gun barrels and lamp posts, hollow bushes, etc which are axisymmetric with a concentric hole.
- The molten metal is poured in a rotating mould.
- The axis of rotation is usually horizontal but can be vertical for short workpieces.
- The moulds are made of steel, iron, graphite and may be coated with a refractory lining to increase mould life.
- Mould surfaces can be shaped so that pipes with various outer shapes, including square, polygonal, can be cast.
- The inner surface of the casting remains cylindrical because the molten metal is uniformly distributed by centrifugal forces.
- No core is required for making concentric hole because of the outward centrifugal force.

  Process of Centrifugal Casting of Cast Iron Pipe in Sand Mould

  (*i*) The moulding flask is properly rammed with sand to conform to the outer contour of the pipe to be made.

  (*ii*) End details as spigot ends or flanged ends are obtained by using dry sand cores located in the ends.

  (*iii*) Then the flask is dynamically balanced to reduce occurance of unwanted vibrations during casting.

  (*iv*) The finished flask is mounted between rollers.

  (*v*) Mould is rotated slowely.

  (*vi*) Molten metal in required quantity is poured into the mould through the movable pouring basin.

  (*vii*) Amount of molten metal determines the thickness of pipe to be cast.

  (*viii*) After pouring, mould is rotated at operational speed till solidification to form required thickness.

  (*ix*) Mould is replaced by new mould machine and the process is repeated.

- In true centrifugal casting the casting solidifies from outside towards the axis of rotation. So it provides / creates conditions which set up directional solidification to produce castings free from shrinkage.
- True centrifugal castings may be produced in metal or sand lined moulds. It largely depends on the quantity to be produced.
- A water jacket is provided around the mould for cooling it.
- The casting machine is mounted on wheels with the pouring laddle which has a long spout extending till the other end of the pipe to be made.

Advantages

(*i*) Relatively higher impurities within the liquid such as sand, slag, oxides and gas float more quickly towards the centre of rotation. At this point it can be easily machined to produce a clean metal casting.

(*ii*) Dense and fine grained metal castings are produced by this technique.

(*iii*) Proper directional solidification obtained except for castings with greater wall thickness.

(*iv*) There is no need of central core.

(*v*) No gating system is required. This raises the casting yield as high as 100% in certain cases.

(*vi*) This process can be used for mass production.

Disadvantages

(*i*) These are limited upto/for certain shapes (axisymmetric)

(*ii*) Equipment cost is high. So only for large scale production is profitable.

(*iii*) Skilled workers are required for operation and maintenance.

Applications

(*i*) Bearings for electric motors and industrial machinery.

(*ii*) Cast iron pipes, alloy steel pipes and tubings.

(*iii*) Liners for I.C. engines.

(*iv*) Rings, short or long pots and other annular components.

1.17.2 Semi Centrifugal Casting

- It is also known as **profited centrifugal casting**.
- Gear blanks, wheels are produced.
- This process is used for jobs which are more complicated than those possible in true centrifugal casting but are axisymmetric in nature.
- The central hole is not necessary but if present/required is to be produced by using a core (out of sand)
- Moulds may be made of sand or metal.
- The axis of rotation is always vertical.
- Metal enters the mould through central pouring basin.
- The rotating speed in this process is not as high as true centrifugal casting.
- Directional solidification can be obtained by proper gating of casting and using proper chills.
- For producing more than one castings at a time, a number of moulds are stacked together one over the other fed by a common central sprue.

Advantages

(*i*) This process ensures purity and density at the extreme point of casting as cast wheel or pulley.

(*ii*) Poor structure forms at the centre of the casting, it can be readily machined.

1.17.3 Centrifuging / Pressure Casting

- Centrifuging method is used to obtain higher metal pressures
- Bearing caps, small brackets during solidification, when casting shapes are not axisymmetrical.
- This process is suitable for small jobs of any shape.
- A number of small jobs are joined together by radial runners with central sprue on a revolving table.
- The jobs are uniformly placed on the table around periphery so that their masses are properly balanced.
- The casting is possible only in vertical direction.
- The casting shape has no special limitations in this process and an almost unlimited variety of smaller shapes can be cast.
- When castings in multiple layers one above the other are produced in one mould, the method is called **Stack moulding**. It is used for producing valve bodies, valve bonnets, plugs, yokes, pillow blocks and a wide variety of industrial castings.

1.17.4 Advantages of Centrifugal Casting

- Obtain castings of better quality
- Castings produced more economically.
- Parts which are unsuitable to produce by other methods can be cast satisfactorily.
- High rate of production can be achieved.
- Cleaning and fitting costs are reduced considerably.This produces dense casting which obtains physical properties compared to that of forging.
- In some metals this process improves tensile strength because of resultant increase in homogeneity and density.
- There is no flow lines in centrifugal castings as obtained in case of conventional gear castings, low lines parallel to the lines of force and grain structure runs perpendicular to the gear tooth line of force.
- Castings having thin sections or fine outside surface details can be easily produced.
- Percentage of rejection is very low.
- Directional solidification can be achieved easily
- Easy to inspect, because defects if any will occur on the surface and not inside the castings.

1.18 CONTINUOUS CASTING

- It is also known as strand casting.
- This method is used to directly cast slabs, billets, blooms without going through rolling process.
- It is a fast and economical process.

Process

- The molten metal in the laddle is cleaned and equialised in temperature by blowing nitrogen gas through it for 5 to 10 mins.
- The metal is then poured in a refractory lined intermediate pouring vessel which is called **tundish**. Here impurities are skimmed off.
- A tundish may hold as much as three tonnes of metal.
- The molten metal travels through water cooled copper moulds and begins to solidify when it travels downward along a path supported by pinch rollers.
- Before the process of casting is started, a solid starter or dummy bar is inserted into the bottom of the mould.
- The molten metal is poured and solidified on the starter bar.
- The bar is withdrawn at the same rate as that of pouring of metal.
- The cooling rate is such that the metal developes a solidified skin/shell to support it during its downward travel, normally at the rate of 25 mm/s.
- The shell thickness at the exit of the mould is about 12 – 18 mm.
- Further intensive cooling is provided by water sprays as the metal moves downward.
- Moulds are normally coated with graphite or similar solid lubricants to reduce friction and adhesion at the mould metal interface.
- The moulds are vibrated to reduce friction and sticking further.
- The continuously cast bars are cut into desired length by shearing or torch cutting.
- It can also be directly fed into a rolling mill for further reductions in thickness and for shape rolling of products such as channels and I- beams.
- Contineously cast metals have more uniform compositions and properties than metal obtained by ingot casting.

1.19 CASTING DEFECTS

Any unwanted deviation from the desired requirements in a cast product results in a defect. Some defects inthe cast products are tolerable while others can be rectified by additional processes like welding etc. Thefollowing are the major defects which are likely to occur in sand castings:

(a) Gas defects
(b) Shrinkage cavities
(c) Moulding material defects
(d) Pouring metal defects
(e) Metallurgical defects

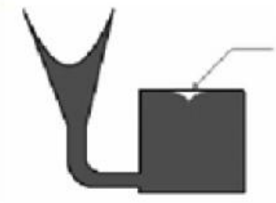
Gas Defects

These defects are due to lower gas passing tendency of the mould which is caused by less venting, lower permeability of the mould and improper design of the casting. The lower permeability of the mould is due to use of finer size grains of sand, higher percentage of clay & moisture and excessive ramming of the mould. The various gas defects are;

- **Blow holes and Open blows**: These are spherical, flattened or elongated cavities present inside the casting or on the surface. When present inside the casting it is called blow hole while it is termed as open blow if it appears on the surface of the casting. These defects are caused by the entrapped of steam due to moisture left in the mould and the core. These are predominant in green sand mould and to get rid of these proper venting is required.
- **Scar**: A shallow blow, usually found on a flat casting surface, is referred to as a scar.
- **Blister**: This is a scar covered by the thin layers of a metal.
- **Air inclusions**: The main reasons for this defect are the higher pouring temperatures which increase the amount of gas absorbed in molten metal; poor gating design such as straight sprue in unpressurised gating; abrupt bends and other turbulence causing practices in the gating, which increase the air aspiration and finally the low permeability of the mould. The remedies would be to choose the appropriate pouring temperature and improve gating practices by reducing the turbulence.
- **Pin hole porosity**: The high pouring temperature which increases the gas pick up is the main reason for this defect. The hydrogen gas which is picked up by the molten metal either in the furnace from the unburnt fuel or by the dissociation of water inside the mould cavity may escape the solidifying metal leaving behind very small diameter and long pin holes showing the path of escape.

Shrinkage Cavities

These are caused by the liquid shrinkage occurring during the solidification of the casting. An improper riser and gating system may give this type of defects which has a shape of a funnel.

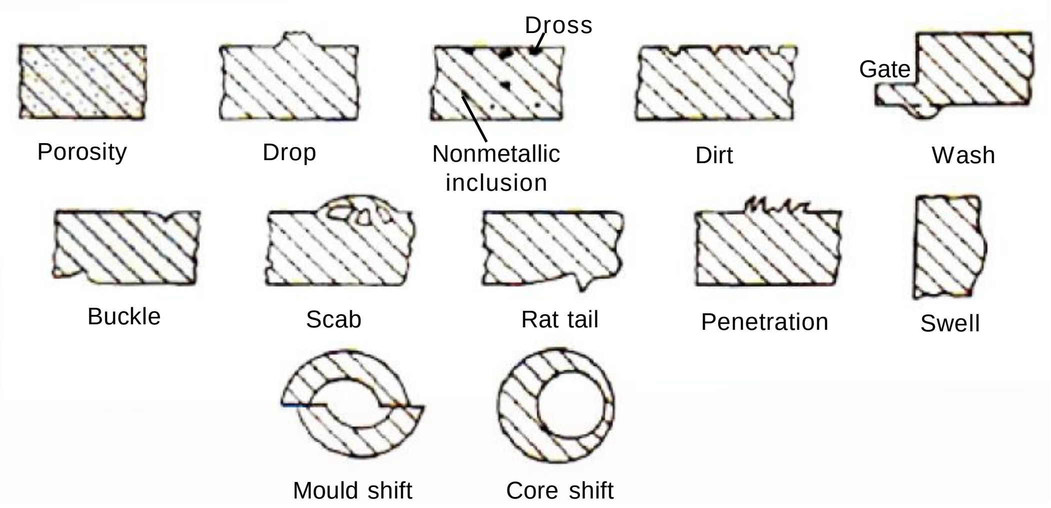


Moulding Material Defects

These defects are originated due to some specific characteristics of the moulding materials such as insufficient strength, improper ramming etc. The various defects under this category are

- **Cuts and Washes**: Theses appear as rough spots and areas of excess metal and are caused by the erosion of the moulding sand by the flowing molten metal. This may be due to insufficient strength of mould material or the high velocity of the molten metal. The proper choice of moulding sand and appropriate moulding method together with proper design of gating system can eliminate these defects.
- **Metal Penetration**: When molten metal enters the gaps between the sand grains, the result would be a rough casting surface. This can also be caused by higher pouring temperature. Choosing appropriate grain sizes, together with proper mould wash should be able to eliminate this defect.
- **Fusion**: This is caused by the fusion of sand grains with molten metal, giving a brittle, glassy appearance on the casting surface. The main reasons for this defect are the lower refractoriness of the clay used in moulding sand and very high pouring temperature. The choice of an appropriate type and amount of Bentonite would cure this defect.
- **Run out**: This occurs when the molten metal leaks out of the mould due to faulty mould making or defective moulding flask.
- **Buckles**: This refers to a long, fairly shallow, broad, v-shaped depression occurring in the surface of a flat casting. The expansion of thin layer of sand at the mould face when obstructed by the flask, the mould face tends to bulge out, forming the v-shape. A proper amount of volatile additives in the sand-mix is therefore essential to make room for this expansion and to avoid the buckles.
- **Rat tail**: It is a long shallow angular depression normally found in a thin casting. The reason for its formation is the same as that of buckles. Here, instead of the expanding sand up heaving, the compressed layer fails by one layer, gliding over the other.
- **Scab**: This refers to the rough thin layer of a metal, protruding above the casting surface, on top of a thin layer of sand. A scab results when the upheaved sand is separated from the mould surface and the liquid metal flows into the space between the mould and the displaced sand.
- **Swell**: Under the influence of metallostatic forces, the mould wall may move back causing a swell in the dimensions of the casting. The main cause of this defect is improper ramming of the mould.

- **Drop**: An irregularly shaped projection on the cope surface of a casting is called a drop. This is caused by dropping of sand from the cope or other overhanging projections into the mould. An adequate strength of the sand and the use of gaggers can help in avoiding the drops.
- **Dross**: Lighter impurities appearing on the top of a casting are called dross. It can be taken care of at the pouring stage by using items such as a strainer and skim bob.
- **Dirt**: Sometimes sand particles dropping out of the cope get embedded on the top surface of a casting. When removed, these leave small, angular holes, known as dirts.
- **Mould and Core shift**: A misalignment between two halves of a mould or of a core may give rise to a defective casting.



Pouring Metal Defects

The defects occur due to due to lower fluidity of the molten metal, small thickness of the casting, large surface area to volume ratio of the casting, high heat transfer rate of the mould material and back pressure of the gases entrapped in the mould cavity due to inadequate venting. The likely defects under this category are;

- **Misrun**: The liquid metal due to insufficient superheat, start freezing before reaching the farthest point of the mould cavity. This defect is called Misrun.
- **Cold shut**: For a casting with gates at its two sides, the misrun may show up at the centre of the casting due to non fusion of two streams of metal resulting in a discontinuity or weak spot in casting.
- **Slag inclusions**: Slag caused due to flux added during the melting process, if not removed before tapping may enter the mould cavity causing weak casting and damaged surface.

Metallurgical Defects

The defects under this category are hot tears and hard spots.

- **Hot tears**: Since metal has low strength at higher temperatures, any unwanted cooling stress may cause the rupture of the casting. The better design of casting avoids this defect.
- **Hard spots**: These are caused by the chilling of the casting causing subsequent machining difficult. This can be avoided by controlling properly the rate of coling.

MODULE-III

Welding Processes

2.1 INTRODUCTION

Welding is the process of joining two similar or dissimilar metallic components with the application of heat, with or without the application of pressure and filler material. Heat may be obtained by chemical reaction, electric arc, electrical resistance, frictional heat, sound and light energy.

When a welding process takes place without addition of filler metal by melting the edges together to join similar metals is called **autogenous welding**, for example, cold and hot pressure welding and electric resistance welding etc. hen the welding process makes the use of filter metal but the same composition as the parent metal is known as **homogeneous welding,** for example, welding of plain low-C steel with a low-C welding rod and welding of 70- 0 brass with a 70-30 brass welding rod etc. In case of **heterogeneous welding process** the filler metal is introduced, the melting point of which is below that of the metals to be welded, for example, brazing and soldering processes.

The autogenous welding is especially applicable to iron, steel and lead, while the heterogeneous welding is indispensable for zinc, brass, aluminium, or, in general, for those metals which oxidise or volatilise at a temperature near that of the point of fusion.

2.2 ADVANTAGES, DISADVANTAGES AND APPLICATIONS OF WELDING

Advantages

- Welding can join large number of both similar and dissimilar metals/alloys.
- A good weld is as strong as the base metal.
- Portable welding equipment are available.
- Welding permits considerable freedom in design.
- Low manufacturing cost and reduced labour content of production.
- Welding results in a good saving of material and maximum homogeneity.

Disadvantages

- Welding results in residual stresses and distortion of the workpieces.
- Welding heat produces metallurgical changes.
- Welding produces harmful radiations, fumes and spatter.
- Jigs and fixtures are generally required to hold and position the parts to be welded.
- Skilled worker is needed for this process.

Applications

- Welding is widely used in fabrication of pressure vessels, bridges, building structures, aircraft and space crafts, railway coaches and general applications.
- It is also being used in shipbuilding, automobile, electrical, electronic and defence industries.
- Welding is vastly being used for construction of transport tankers for transporting oil, milk and fabrication of welded tubes and pipes, chains, LPG cylinders and other items.
- Steel furniture, gates, doors and door frames, body and other parts of a number of items such as refrigerators, washing machines, microwave ovens etc are fabricated by welding.

2.3 CLASSIFICATION OF WELDING PROCESSES

The welding processes may be classified as follows :

I. Fusion Welding

1. Gas welding
2. Electric arc welding

   (*i*) Shielded metal arc welding (*ii*) Carbon arc welding

   (*iii*) Gas metal arc welding (*iv*) Gas tungsten arc welding

(*v*) Submerged arc welding (*vi*) Plasma arc welding
vii) Electroslag welding (*vii*) Electrogas welding

II. Resistance Welding

(*i*) Spot welding (*ii*) Seam welding (*iii*) Projection welding
(*iv*) Resistance butt welding (*v*) Resistance flash welding (*vi*) Percussion welding

III. Solid State Welding

(*i*) Cold welding (*ii*) Diffusion welding (*iii*) Ultrasonic welding
(*iv*) Explosive welding (*v*) Friction welding (*vi*) Forge welding

IV. Thermochemical Welding

(*i*) Thermit welding (*ii*) Atomic hydrogen welding

V. Radiant Energy Welding

(*i*) Laser beam welding (*ii*) Electron beam welding

VI. Allied Processes

(*i*) Soldering (*ii*) Brazing

2.4 GAS WELDING

Gas welding is a method of fusion welding in which a flame produced by combustion of gases to heat and melt the parent metal and filter rod of a joint. A filler metal may be added to the flowing molten metal to fill up the cavity made during the end preparation. Many different combinations of gasses can be used to obtain heating flame, but the most commonly used combinations are;

Oxygen and Acetylene (Oxy-Acetylene welding)
Oxygen and Hydrogen (Oxy-hydrogen welding)
Air and Acetylene (Air-Acetylene welding)

2.4.1 Oxy - Acetylene Welding

Oxy-acetylene welding derives heat from the combustion of fuel gas acetylene in combination with oxygen. Acetylene mixed with oxygen when burnt under a controlled environment produces large amount of heat giving higher temperature rise. This burning also produces carbon dioxide which helps in preventing oxidation of metals being welded. The chemical reaction involved in burning of acetylene is

$$2C_2H_2 + 50_2 = 4CO_2 + 2H_20 + \text{Heat}$$

Oxy- Acetylene gas welding is accomplished by the melting the edges or surfaces to be joined by gas flame and allowing the molten metal to flow together, thus forming a solid continuous joint.

This process is particularly suitable for joining metal sheets and plates having thickness of 2 to 50 mm.

Principle of Gas Welding

The principle of oxy-Acetylence welding as shown in [Fig. 2.1]. The flame is obtained by ignition of oxygen and acetylene gases, mixed in a blow pipe fitted with a nozzle of suitable diameter. This flame is applied to the edges of the joint and to a wire filler of appropriate metal, to melt them for forming the joint. When acetylene is burned in an atmosphere of oxygen, an intensely hot flame with a temperature of about 3000°C is produced. As the melting point of steel is approximately 1300°C, the metal fuse rapidly at the point of application of the flame.

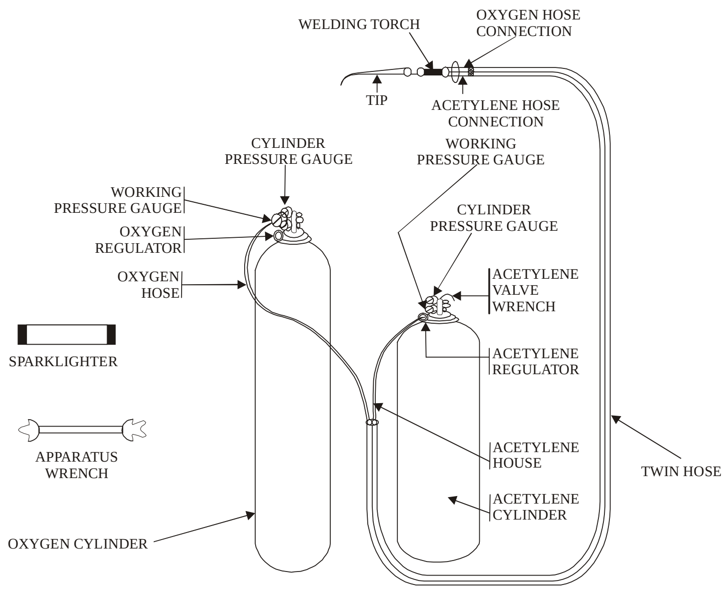


Fig. 2.1 Oxy-Acetylene Gas welding

Welding Techniques

Depending upon the ways in which welding rod and the welding torch can be used, there are two usual techniques used in gas welding;

(*i*) Leftward or Forward welding

(*ii*) Rightward or Backward welding

(*i*) Leftward or Forward or Forehand Technique

- In leftward welding, the welder starts welding at the right hand end of the joint and proceeds towards the left as shown in Fig. 2.2. The welding flame is directed away from the finished weld *i.e.,* towards the unwelded part of the joint.
- The blowpipe or welding torch is kept at an angle of 60° to 70° to the surface of the work so that the flame plays ahead of it. The filler rod is held at an angle of 30° to 40° ahead of the flame and progressively fed into it.
- The base metal gets preheated which facilitates proper fusion. This technique is usually used on relatively thin metals *i.e.,* thickness less than 5 mm.
- The tip of the rod causes weld contamination, when the weld is recommenced. Necessary actions may be taken to prevent it.

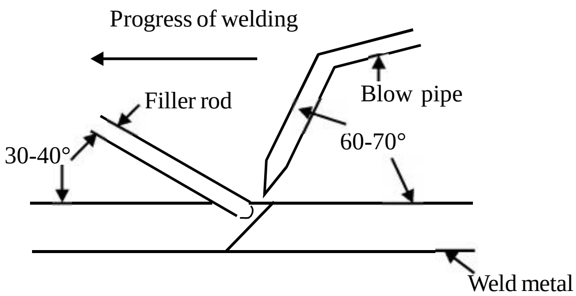


Fig. 2.2 Left ward welding

(*ii*) Rightward or Backward or Backhand Technique

- Welding begins at the left hand end of the joint and proceeds towards the right, hence it is known as **rightward technique** as shown in Fig. 2.3.
- The torch flame in rightward technique is directed toward the completed weld and the filler rod remains between the flame and the completed weld section. The weld is thus annealed which relieves the residual stress.
- Smaller total volume of deposited metal reduces shrinkage and distortion and because of less consumption of filler rod, the cost of welding is less.

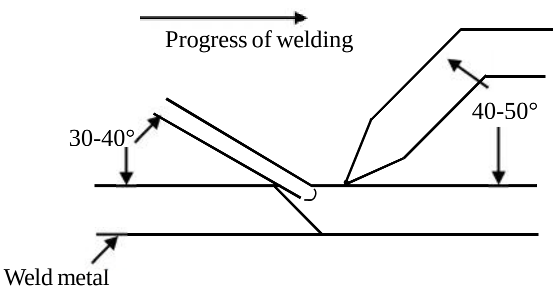


Fig. 2.3 Right ward welding

Types of Flames

Three types of flames are obtained from oxygen and acetylene mixture.

(*i*) Neutral flame

(*ii*) Carburising flame

(*iii*) Oxidising flame

Neutral Flame

When the ratio of oxygen and acetylene is equal, a neutral flame is obtained. This type of flame has a maximum temperature of about 3100°C, is white in colour and has sharply defined central cone with a reddish purple envelope as shown in Fig. 2.4. It does not react chemically with the parent metal and protect it from oxidations and carburisation. The neutral flame is used to weld mild steel, stainless steel, cast iron, copper, and aluminium etc.

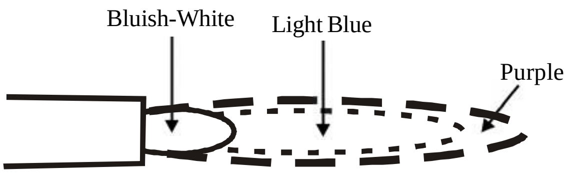


Fig. 2.4 Neutral Flame

Carburising Flame

An excess of acetylene creates a carburshing flame (Fig. 2.5). It consists of the following three zones.

– Luminious zone.
– Feather or intermediate cone of white colour.
– Outer envelope.

It is also called as reducing flame and has a maximum temperature of 2900°C. The carbursing flame is used to weld monel metal, high carbon steel and alloy steel.

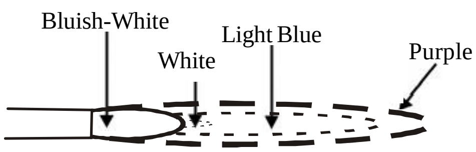


Fig. 2.5 Reducing flame

Oxidising Flame

It occurs when the oxygen content is more than that of acetylene in the gas mixture. It is characterised by a purple-white inner cone with purple envelope (Fig. 2.6). The maximum temperature obtained is 3300^{0}C. It is used to weld nonferrous metals and alloys such as copper, brass, bronze and zinc alloys etc.This flame is harmful for steels, because it oxidizes the steels.

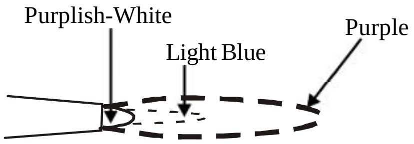


Fig. 2.6 Oxidizing Flame

2.4.2 Gas Welding Equipment

For gas welding following equipments are used.

1. Gas cylinders
2. Pressure regulators
3. Pressure gauges
4. Welding torch
5. Hoses and the Hose fitting
6. Safety device etc.

Gas Cylinders

Oxygen Cylinders

Oxygen cylinders are painted black and the valve outlets are screwed right handed. The usual size of oxygen cylinders are 3400, 5200 and 6800 lt . For safety purposes oxygen cylinders are fitted at a pressure 12500 to 14000 kN/m^2.

Acetylene Cylinder

An acetylene cylinder is painted maroon and the valves are screwed left handed. The usual size of acetylene cylinders are 2800 and 5600 lt. The cylinder is usually fitted to pressure of 1600 to 2100 kN/m^2.

Pressure Regulators

The cylinders are provided with pressure regulators to control the working pressure of oxygen and acetylene to the welding torch. Value of supply pressure depends upon inside diameter of outlet nozzle, supply flow rate of gas.

Pressure Gauges

Pressure gauge measures the pressure with respect to the atmospheric pressure. Two pressure gauges are mounted on each of the cylinders. One for knowing pressure of gas inside the cylinder which is the measure of gas content inside the cylinder. Second gauge is used to know the supply pressure of the gas to below pipe. Former gauge is called cylinder pressure gauge and later one is called outlet pressure gauge.

Welding torch or blow pipe

It is used for moving oxygen and acetylene in the required volume and igniting it at the mouth of its tip.

There are two types of welding torches available.

(*i*) High pressure (or equal pressure) type.

(*ii*) Low pressure (Injector) type

High pressure blow pipes or torches are used with (dissolved) acetylene stored in cylinders at a pressure of 8 bar. Low pressure blow pipes are used with acetylene obtained from an acetylene generator at a pressure of 200 mm head of water (approximately 0.02 bar).

Hose and Hose Fittings

– Hose pipes are used to carry gases from their respective cylinders to blow pipe. These are made up of rubber and fabric; painted black or green for oxygen and red or maroon for acetylene.
– For welding purposes, the hoses should be strong, non porous, flexible and not subject to kinking.
– Special fittings are used for connecting hoses to equipment .

Safety Devices

– Gloves made of leather, canvas and asbestos are worn to protect hands from any injury.
– Goggles fitted with coloured glasses are used to protect the eyes from harmful ultraviolet rays and heat.

2.4.3 Advantages, Disadvantages and Applications of Gas Welding

Advantages

– It is probably the most versatile process. It can be applied to a wide variety of manufacturing and maintenance situations.
– Since the sources of heat and the filler metal are separate, the welder has control over the filler metal deposition rates.
– The equipment is versatile, low cost, self sufficient and usually portable. Besides gas welding, the equipment can be used for preheating, post heating, braze welding and can be readily converted to oxygen cutting.
– The cost and maintenance of the welding equipment is low when compared to that of some other welding processes.

Disadvantages

- Heavy sections cannot be joined economically
- Refractory metals (e.g. tungsten, molybdenum etc) and reactive metals (e.g. titanium and zirconium) cannot be gas welded.
- More safety problems associated with handling and storing of gases.
- As compared to arc welding, it takes considerably longer time for the metal to heat up.
- Heat affected zone is wider.

Applications

- For joining thin materials.
- For joining materials in whose case excessively high temperatures or rapid heating and cooling of the job would produce unwanted or harmful changes in the metal.
- In automotive and air craft industries.
- For joining most ferrous and non ferrous metals. e.g., carbon steels, alloy steels, cast iron, aluminium, magnesium, nickel, copper and its alloy etc.
- In sheet metal fabrication plants.

2.4.4 Gas Cutting

Oxy fuel gas cutting is a process by which metal (ferrous) to be cut is heated up by means of flame and then oxygen gas is impinged on this red heat metal so as to form the metal oxide and then remove the metal from there. Metal upto thickness as high as 2 m can be cut by this method.

Principle of Operation

- Iron and steel when heated to a temperature between 800 to 1000°C get oxidised (burn). When a high pressure (300 kPa) oxygen jet is directed against a metal, it burns the metal and blows it away causing the cut (kerf).

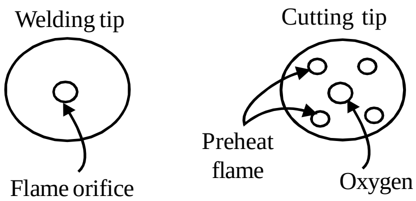


Fig. 2.7 Oxy-Acetylene torch tips

- The oxy-acetylene gas cutting outfit is similar to that of oxy-acetylene welding except for the torch tip. Here, the torch tip has provision for preheating the plate as well as providing the oxygen jet. Thus the tip has a central hole for oxygen jet with surrounding holes for preheating flames as shown in Fig. 2.7. The cutting tip should be properly chosen for intended application. The size normally depends on the thickness of the plate as it determines the amount of preheating as well as the oxygen jet flow required for cutting.
- Gas cutting would be useful only for those materials which readily get oxidised and the oxides have lower melting points than the metals. Thus it is most widely used for ferrous materials. But it cannot be used for materials such as aluminium, bronze, stainless steel and like metals since they resist oxidation.

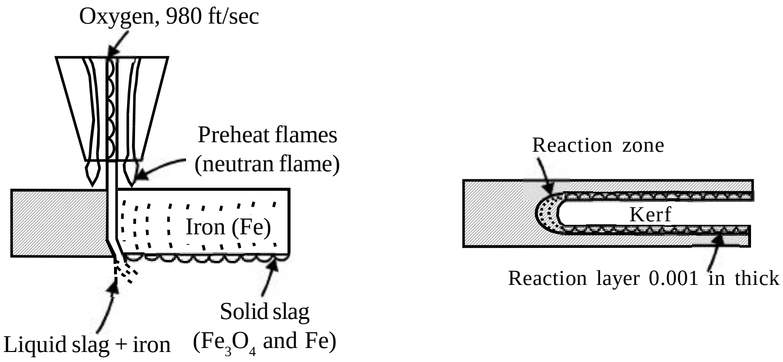


Fig. 2.8 Oxy-Acetylene cutting

2.5 ARC WELDING

Electric arc welding is one of the fusion welding processes in which coalescence (joining) of the metal is achieved by the heat from an electric arc between an electrode and workpiece. An arc is a sustained electric discharge through the ionised gas column called **plasma** between the two electrodes.

Principle of Arc Welding

In electric arc welding, when electrode is brought into contact with the work and is then quickly separated by a short distance (approximately 1.5 to 3 mm.) such that the current continues to flow through a path of ionized particles, an electric arc is formed. The arc is sustained due to continuous presence of a thermally ionized column of gas. The circuit operates at low voltage and high current, therefore arc is established in the gap due to thermoionic emission from electrode (Cathode) to workpiece (Anode). This arc produces a temperature of the order of 5500°C or higher. In this way a pool of molten metal consisting of workpiece metal and filler metal is formed in the welding zone as shown in Fig. 2.9.

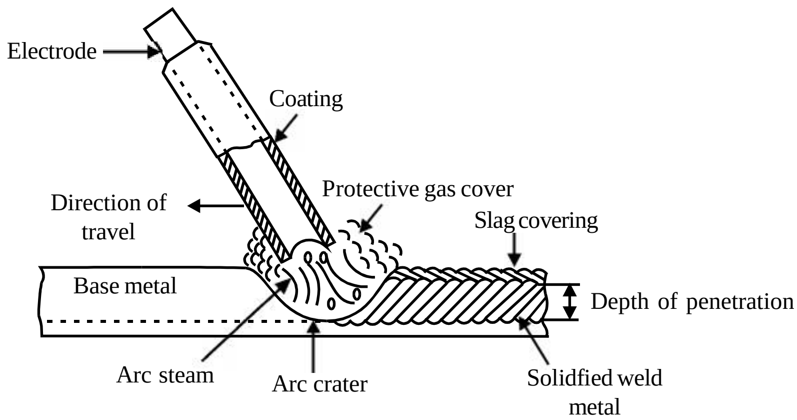


Fig. 2.9 Principle of Arc Welding

Arc Welding Equipment

The equipments used in Arc welding are as follows. (Fig. 2.10).

Power Source

Both alternative current (AC) and direct current (DC) are used for welding. AC machines are recommended for ferrous metal and DC machines are recommended for other metals. The main component of welding machine is the transformer which converts the supply to low voltage and high current. Normally, the power requirement for AC welding is 80 to 110 volt s and 50 to 80 amperes and in case of DC welding the power required is 8 to 25 volts and 50 amperes.

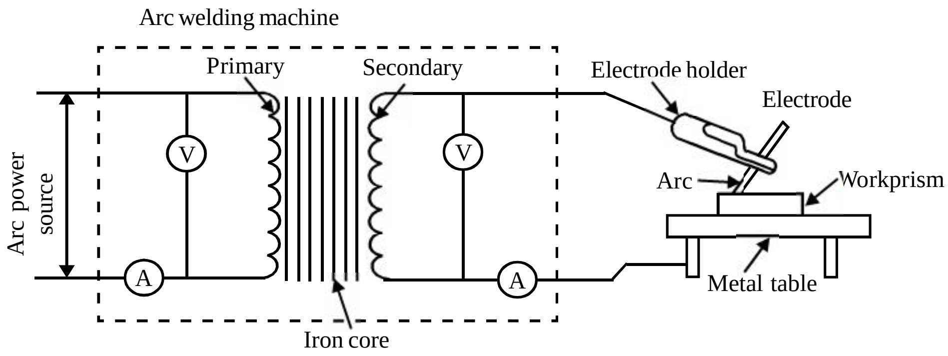


Fig. 2.10 Arc welding set up

Comparison Between A.C and D.C Arc Welding

Aspects	AC Welding	DC Welding
Power consumption	Low	High
Arc stability	Unstable	Stable
Cost	Less	More
Weight	Light	Heavy
Efficiency	High	Low
Operation	Noiseless	Noisy
Suitability	Non ferrous metals cannot be joined.	Suitable for both ferrous and non ferrous metals.
Electrode used	Only coated.	Bare electrodes are also used.
Welding of thin sections	Not preferred	Prefferred.
Miscellaneous	Work can act as cathode while electrode acts as anode and vice versa.	Electrode is always negative and the work is positive.

Welding Electrodes

The electrodes (welding rods) can be consumable type or non-consumable type. In consumable type, the electrode in the form of thin small rods or sticks (bare or coated with flux) or coil of bare round wire is fed continuously during welding which forms a part of the weld metal pool after melting. The electrodes are of the same composition as the metal to be welded.

Coated Consumable Electrodes are the most popular arc welding electrodes (Fig. 2.11). No additional filler metal and flux are required with them. In general these electrodes have core of mild steel with a coating of flux material over them. The coating develops a reducing atmosphere and prevents oxidation, forms separable slag from metal impurities, provides necessary alloying elements to the weld pool. One of the major concerns with the coated electrodes is the moisture pick up by the coating. This moisture, dissociate into oxygen and hydrogen with the hydrogen being absorbed by the liquid metal and subsequently released during solidification, causing porosity. Therefore, they should be kept in a dry place.

Bare electrodes are simple rods made of filler metal with no coating over them. In case of bare electrode flux is required additionally. Examples of arc welding processes using consumable electrode include: carbon arc welding, shielded metal arc welding, submerged arc welding etc.

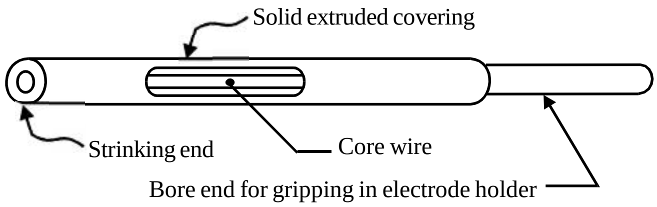


Fig. 2.11 Parts of an electrode

In non-consumable type, the electrode used is not consumed and does not form a part of the weld deposit. Typically, a non-consumable carbon or tungsten electrode is used which, as one pole of the arc, generates high heat for welding. Their depletion rate is very slow. Metal and flux are supplied additionally. The typical examples are: gas tungsten arc welding, plasma arc welding etc.

The factors that affect the selection of electrodes are: (a) availability of current, (b) composition of base metal, (c) thickness of base metal, (d) welding position-flat, horizontal vertical etc. and (e) amount of penetration required in welding.

Coding of Electrode

An electrode is specified by six digits with a prefix letter 'M' which indicates that it is suitable for metal arc welding, according to ISI coding system. The meanings of the codes are as given below.

First Digit (1 to 8)	: Stands for particular type of coating on the electrode.
Second Digit (1 to 6)	: Indicates welding position.
Third Digit (0 to 7)	: Representing a particular current condition.
Fourth Digit (1 to 8)	: Indicates minimum tensile strength of the wledment.
Fifth Digit (1 to 5)	: Indicates the percentage elongation of deposited weldment.
Sixth Digit (1 to 5)	: Signifies the minimum impact strength of the weldment.

Electrode Holder

Electrode holder holds the electrode with its jaws. Jaws of holder are made of metal with high conductivity and heat resistant. Electrode holder needs proper insulation as electric current flows in to the welding zone through it. In the cases, when the jaws are subjected to very high temperature, provision for cooling is made.

Work Table

The parts to be welded are placed on the work table. It is connected with the power source to give a particular polarity to the workpiece. Electric circuit forms when electrode is brought in contact of workpiece through work table and electrode holder.

Connecting Cables

The connecting cable is used to connect electrode holder with the power source. It should be flexible enough to facilitate easy movement of electrode, properly insulated and capable of carrying high current.

Welding Shield

Welding shields are used for the protection of eyes of the welder (operator). Further, electric arc welding generates ultraviolet radiations which may cause permanent damage to eyes. Therefore, welding shield used in arc welding should be opaque to ultraviolet radiations. Other safety devices such as goggle, gloves, and apron are also used in arc welding.

Chipping Hammer

Chipping hammer and wire brush are used in arc welding to clean the joint.

Filler Metal

Filler metals are used in case of non-consumable electrode to improve properties of the weldment. The filler metal may be bare or coated. A coating of flux material is provided on the filler metal in coated type. No coating of flux is there in a bare type filler metal. It is supplied additionally as per the requirement. Filler metal composition should be same as that of the material to be welded. Sometimes, additional alloying elements are added to improve mechanical properties of weldment.

Flux Material

Flux is used in arc welding to prevent weak joint due to oxidation of the weld. Flux can be supplied through coating of electrode or coating on filler metal or separately. Sometimes spray of inert gas is used to prevent oxidation and no flux is required in such cases. Ingredients used to produce reducing atmosphere are cellulose, dalomine, wood flour, starch. Iron powder provides higher deposition rate. The common ingredients act as flux which help in slag formation are asbestos, mica, silica, fluorspar, stealite, titanium dioxide, iron oxide, metal carbonates, etc. Manganese oxide and potassium silicate and titanate are the alloying elements and stabilizers.

2.5.1 Shielded Metal Arc Welding (SMAW)

Shielded metal arc welding (SMAW) (or manual metal-arc welding or stick welding or simply manual arc welding is the most commonly used for fabrication and maintenance jobs. Arc is generated between consumable coated metal electrode and the work piece (Fig. 2.9). The heat generated due to the arc is about 5000^{0}C. Under this intense heat a small part of the base metal melts. At the same time, the end of metal electrodes also melts, yielding tiny drops or globules of molten metal, which pass through the arc and reach the weld metal pool. The coalescence with the molten part of the base metal occurs after cooling. Burning of flux coating on the electrode helps in creating a protective gas shield and the molten flux forms a slag that protects the weld bead from oxidation. This slag is later chipped off to get the clean weld.

Arc Initiation

Arc initiation refers to starting an arc between the electrode and the workpiece. It can be obtained by the following two methods.

(*i*) Touch start. In this method the electrode is first touched with the workpiece for a very short time and immediately withdrawn. The short-circuit due to touch causes rise in current and thus the temperature at the point of contact. This causes local melting and vapourisation of the eletrode tip and workpiece material besides emission of electrons from the cathode. These electrons collide with the atoms and molecules of air present in the gap between electrode and the workpiece breaking them into free electrons, thus creating a ionised gas column. Under these circumstances, a small amount of electron emission is enough to initiate an arc.

(*ii*) High voltage discharge. The arc is initiated by using a high frequency unit which superimposes a high frequency voltage in the welding circuit. This produces an electric field of very high strength. The high frequency, high voltage oscillators supply a pulse of high voltage to initiate an arc. In this method the contamination of electrode is eliminated.

Arc Crater

Because of the penetration of electric arc into the parent metal, small depression will be formed in the parent metal around which molten metal is piled up, known as the arc crater. Its depth depends on the thickness of the parent metal. The arc penetration is judged by observing this crater depth.

Arc Length

The distance through the centre of the arc from the tip of the electrode to the bottom of the arc crater is termed as arc length. It should be 2 to 4 mm. Arc length should be proper and constant during welding to obtain good results.

Arc Stability

A stable arc is uniform and steady which resluts in good weld bead and defect-free weld nugget. For stable arc, the welding plant should be such that a little variation in arc length should not extinguish the arc. Also, addition of proper arc stabilizing elements in the flux coating can help making the arc stable.

Polarity

Polarity means the type of potential (positive or negative) given to the workpiece or electrode. The positive and negative terminals are fixed in direct current (DC) power source, whereas in case of alternating current (AC) power source, positive and negative terminals are not fixed i.e. the terminal which is positive during one half of a cycle become negative in another half. So polarity principle is applicable only to direct current power source. Polarities are of following two types:

(*i*) Straight Polarity. In straight polarity, electrode is having negative terminal while workpiece is connected to the positive terminal of the direct current power source.

(*ii*) Reverse Polarity. In reverse polarity, electrode is connected to positive terminal whereas workpiece is connected to the negative terminal of the direct current power source.

Direct Current Straight Polarity (DCSP)

- About 67% of heat is generated at the workpiece (+ terminal) while rest of total heat is generated at the electrode (- terminal). Hence, bare and medium coated electrodes are used.
- Deep penetration.
- Mostly used for welding thicker sections.

Direct Current Reverse Polarity (DCRP)

- About 67% of heat is generated at the electrode (+ terminal) while rest of total heat is generated at the workpiece (- terminal). Hence, heavily coated electrodes are used to prevent overheating and melting of the electrodes.
- Shallow penetration.
- Mostly used for welding thin sections.

Arc Blow

Arc blow occurs in DC welding. It is a phenomenon of wandering of arc. When current flows in any conductor, a magnetic field is formed around the conductor in the direction right angle to the current. Since in DC arc welding, there is current through the electrode, workpiece and ground clamps, so magnetic field exists around each of these components. This magnetic field tends to bend the arc from its intended path and is called arc blow. Magnetic field concentration is always more at the ends so chances of arc blow are also more at the beginning and at the end of the weld. Since in DC welding the polarities are fixed, therefore the induced magnetic fields are constant only in one direction. But in AC welding polarity is not fixed (direction of current flows changes alternatively), therefore, there is no arc blow. Arc blow, if not controlled, may result in porosity and other defects in the weld atmospheric gases may be pulled into the arc. Arc blow may be corrected by;

- Placing ground connections as far as possible from the joints to be welded.
- Using AC instead of DC, if possible.
- Selecting proper arc length, current and welding speed.
- Welding towards a heavy stack weld or an already existing weld.
- Wrapping the ground cable around the workpiece such that the current following in it, sets up a magnetic field in opposite direction counteracting the arc blow.

Advantages

- The arc welding equipment is simple, less costly, and portable.
- Welding can be carried out in any position with highest weld qualities.
- Wide varieties of electrodes are available to weld various metals.

Disadvantages

- The length of each electrode is limited and when new electrode is used, proper cleaning is required reducing the the welding speed.
- Welding control is difficult as compared to MIG welding.
- Flux covering, if absorbs moisture, causes the porosity defect.
- Chances of slag entrapment are more due to flux coating.

Applications

- It is used as a fabrication process as well as for regular maintenance and repair jobs.
- It is used in ship buildings, long pipe lines, buildings and bridge construction, tanks, boilers, automotive and aircraft industries etc.

2.5.2 Carbon Arc Welding(CAW)

Carbon Arc Welding (CAW) is a welding process, in which heat is generated by an electric arc struck between a non-consumable carbon (baked carbon or graphite) electrode and the work piece. If required, filler rod may be used. Shields (neutral gas, flux) may be used for weld pool protection depending on the type of welded metal.

Principle of Operation

In carbon arc welding, DC power supply with straight polarity is used. The carbon electrode is connected to negative terminal and work piece is connected to positive terminal. The arc heats and melts the work pieces edges, forming a joint. The welding is done with a long arc to protect the molten metal from the atmosphere. Carbon monoxide gas produced during welding, surrounds the molten metal and protects it.

Modification of carbon arc welding is twin carbon electrode arc welding, utilizing arc struck between two carbon electrodes. In this method, work piece is not a part of welding electric circuit. Therefore, the welding torch may be moved from one work piece to other without extinguishing the arc.

Advantages

- Low cost of equipment and welding operation.
- Low skill level required and the process can be easily automated.
- Low distortion of work piece.

Disadvantages

- Unstable quality of the weld (porosity).
- Carbon of electrode contaminates weld material with carbides.
- Carbon electrodes erode after longer use.

Applications

- Used to weld both ferrous and non ferrous metals such as sheets of steel, copper alloys, brass and aluminium etc.
- Repairing of castings, pre-heating and post-heating of weldments.
- Most suitable for butt welding of thinner metal (upto 2mm) as workpiece distortions are negligible.

2.5.3 Tungsten Inert Gas (TIG) Welding

Tungsten inert gas (TIG) welding or gas tungsten arc welding (GATW) is an arc welding process in which heat is produced from an electric arc established between a tungsten (non-consumable) electrode and the job. The electrodes contain 2% of thoria (thoriumoxide) or 0.15 to 0.40% of Zirconia (zirconium oxide) mixed with the core tungsten which gives better electron emission, easy start of arc, cool running, better arc stability and restart of arc at low current. Filler metal if required is fed separately. The method is well suited for welding thickness upto 6mm.

The welding is carried out in an inert atmosphere using shielding gas (argon, helium, nitrogen etc.) to avoid atmospheric contamination of the molten weld pool. Argon is normally preferred over helium because it requires a lower arc voltage, easier arc starting and provides a smooth arc action. It is also economical and heaviest. Helium can withstand the higher arc voltage, therefore it is used where higher heat input is required. Both DC and AC power source can be used.

Principle of Operation

The non-consumable tungsten electrode mounted in a special electrode holder. The holder is designed in such a way that it facilitates flow of inert gas around the electrode and around the arc as shown in Fig. 2.12. Welding operation is carried out by striking an arc between the workpiece and tungsten electrode in an atmosphere of inert gas. The arc is initiated either by touching the electrode with a scrap metal tungsten piece or using a high frequency unit. After the arc is initiated, it is allowed to impinge on the job and a molten weld pool is created. The welding torch and the filler metal are generally kept inclined at angles of 70^0-80^0 and 10^0-20^0 respectively, with the flat workpiece. Filler metal, if required is added by dipping the filler rod in the weld pool.

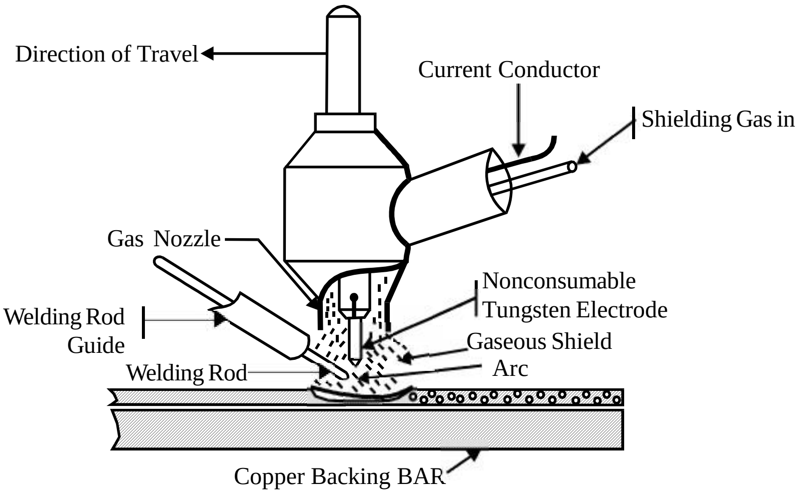


Fig. 2.12 TIG Welding (GTAM Welding)

Polarities

- DCSP (Direct Current Straight Polarity): Tungsten electrode (-ve), work (+ve). Used for welding mild steel, stainless steel, copper and titanium.
- DCRP (Direct Current Reverse Polarity): Tungsten electrode (+ve), work (-ve). Used for welding aluminum and heavily oxidized aluminum castings.
- ACHF (Alternating Current High Frequency): It is used for Al and Mg. High frequency also helps in oxide cleaning actions.

Joint Design

TIG welding is applicable to the following types of joints.

(*i*) Butt, Lap, Corner, Edge and T joint are all used in TIG welding.

(*ii*) A square groove butt joint is used for smaller thickness. A single V groove butt joint is required for base metal thickness between 4.8 and 9.6 mm.

(*iii*) A corner joint is used for fabricating box like structure.

Advantages of TIG Welding

(*i*) This process can weld in all positions and produces smooth and sound welds with less spatter.

(*ii*) TIG welding is very much suitable for high quality welding of thin materials (as thin as 0.125 mm).

(*iii*) No flux is used, hence there is no danger of flux entrapment when welding refrigerator and air conditioner components.

(*iv*) Because of clear visibility of the arc and the job, the operator can exercise a better control on the welding process.

(*v*) It is very good process for welding nonferrous metals (aluminium etc) and stainless steel.

(*vi*) Dissimilar metals such as mild steel to stainless steel, brass to copper etc. can be welded to each other.

(*vii*) Smaller heat affected zone (HAZ).

Disadvantages

(*i*) Under similar applications, TIG welding is a slower process as compared to MIG welding, since it requires a separate filler rod.

(*ii*) Tungsten if it transfers to molten weld pool can contaminate the same. Tungsten inclusion is hard and brittle.

(*iii*) Filler rod end if it by chance comes out of the inert gas shield can cause weld metal contanination.

(*iv*) Equipment costs are higher than that for shielded metal arc welding.

Applications

(*i*) Welding aluminium, magnesium, copper, nickel and their alloys and hard surfacing alloys like zirconium, titanium etc.

(*ii*) Welding of expansion bellows, transistor cases, instrument diaphragms and can seal joints.

(*iii*) Welding sheet metal and thinner sections.

(*iv*) Precision welding in atomic energy, aircraft, chemical and instrument industries.

(*v*) Rocket motor chamber fabrications in lounch vehicles.

2.5.4 Metal Inert-Gas (MIG) Welding

This welding process is also called Gas Metal Arc Welding (GMAW). It is an arc welding process wherein coalescence is produced by heating the job with an electric arc established between a continuously fed metal electrode and the job. No flux is used but the arc and molten metal are shielded by an inert gas, which may be argon, helium, carbon dioxide or a gas mixture.

Principle of Operation

The inert-gas consumable electrode process, or the MIG process is a refinement of the TIG process. However, in this process, the tangsten electrode is replaced with a consumable electrode. The consumable electrode is in the form of a wire reel, which is fed at a constant rate, through the feed rollers. The welding torch is connected to the gas supply cylinder, which provides the necessary inert gas as shown in Fig. 2.13. The electrode and the workpieces are connected to the welding power supply. The power supplied are generally of the constant voltage type. The current from the welding machine is changed by changing the rate of feeding of the electrode wire. Normally DC arc welding machines are used for GMAW with electrode positive (DCRP).

The DCRP increases the metal deposition rate and also provides a stable arc and smooth electrode metal transfer. During welding, torch remains about 10 ± 2 mm away from the job and arc length is kept in between 1.5 to 4 mm. Arc length is maintained constant by using the principles of self adjusted arc or self controlled arc in semi-automatic and automatic welding sets.

Self adjusted Arc

The electrode is fed from a coil through the grooved rollers run by a constant speed motor. If arc length decreases, voltage decreases and arc current increases. The increased current melts electrode at a faster rate resulting in increase of arc length and thus becomes normal. The reverse will occur if arc length increases above the set value. For self adjusting arc, a welding power source with flat characteristics is preferred over another having drooping characteristics because for same change in arc length, there is a larger change in arc current.

Self Controlled Arc

The electrode is fed from a coil through the rollers run by a variable speed electric motor whose speed increases or decreases as the arc voltage increases or decreases. It the arc length decreases, arc voltage will decrease, which in turn reduces the speed of electric motor and electrode feed-rate. This will increase and bring the arc length to the normal set value. Reverse will occur if the arc length increases. For self controlled arcs, a welding power source with drooping characteristics is preferred over another having flat characteristics because with the same change in arc length, there is a greater change in arc voltage, which in turn increases or decreases the speed of electrode feed motor.

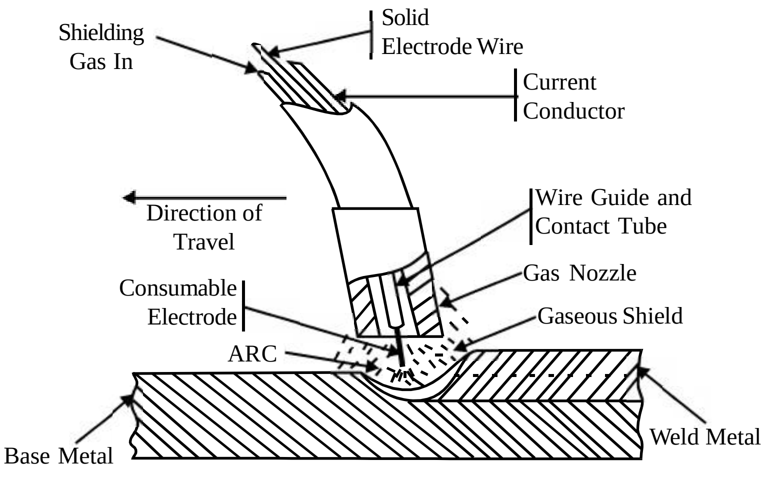


Fig. 2.13 Metal Inert Gas (MIG) or GMAW welding process

Advantages

- It can produce joints with deep penetration.
- Both thick and thin workpieces can be welded effectively.
- Large metal deposition rates are achieved by MIG welding process.
- Because of continuously fed electrode, MIG welding process is much faster as compared to TIG welding.
- The process can be easily automated.
- No flux is used. MIG welding produces smooth, neat, clean and spatter free welded surfaces which require no further cleaning. This helps reducing total welding cost.
- Higher arc travel speeds associated with MIG welding reduces distortion considerably.
- Operator with lesser degree of skill is required.

Disadvantages

- The process is slightly more complex as compared to TIG welding because a number of variables are required to be controlled effectively to achieve good results.
- Welding equipment is more complex, more costly and less portable.
- Since air drafts may disperse the shielding gas, MIG welding may not work well in outdoor welding applications.
- Weld metal cooling rates are higher than with the process that deposit slag over the weld metal.
- The metallurgical and mechanical properties of the joint may be affected due to high cooling rate.

Applications

- The process can be used for the welding of carbon, silicon and low alloy steels, stainless steels, heat resisting alloys, Aluminium, copper, magnesium and their alloys etc.
- For welding tool steels and dies.
- For the manufacture of refrigerator parts.
- MIG welding has been used successfully in industries like aircraft, automobile, pressure vessel and slip building.

Comparison between TIG and MIG Welding

TIG Welding	MIG Welding
1. Permanent non-consumable tungsten electrode is used in this process.	1. Consumable metallic electrode is used in this process.
2. Filler metal may or may not be used in TIG welding.	2. Filler metal in the form of wire is used in MIG welding.
3. Penetration is not so much deeper as compared to MIG.	3. Deeper penetration can be obtained as compared to TIG.
4. Both AC and DC power source can be used.	4. DC power source with reverse polarity is generally used.
5. Metal thickness which can be welded is limited to about 6 mm.	5. Suitable for thickness more than 6 mm. Thickness can go upto 40 mm.
6. Electrode feed not required in case of TIG welding.	6. Electrode need to be fed at a constant speed from a wire reel.
7. Welding speed is slow.	7. Welding is faster
8. TIG welding torch is water cooled.	8. No cooling is necessary.
9. Additional fixtures required to hold the work piece.	9. No fixturing required. process can be easily automated.
10. Requires skilled operator.	10. Less skilled operator can perform.

2.5.5 Plasma Arc Welding (PAW)

Plasm arc welding is an arc welding process wherein coalescence is produced by the heat obtained from a constricted arc set up between a tungsten/alloy tungsten electrode and the water-cooled (constricted) nozzle (non-transferred arc) or between a tungsten/alloy tungsten electrode and the job (transferred arc). The process employs two inert gases, one forms the arc plasma, and the second shields the arc plasma. Filler metal may or may not be added. Pressure, normally is not employed.

Principle of Operation

Plasma arc welding is a constricted arc process. The arc is constricted with the help of a water cooled small diameter, nozzle which squeezes the arc, increases its pressure, temperature and heat intensively and thus improves arc stability, arc shape and heat transfer characteristics.

There are two types of plasma arc welding processes as shown in Fig. 2.14.

(*i*) Non-Transferred Arc Process : The arc is formed between the electrode (–) and the water cooled constricting nozzle (+). Arc plasma comes out of the nozzle as a flame. The arc is independent of the workpiece and the workpiece does not form a part of the electrical circuit. The non-transferred arc plasma develops less energy density as compared to a transferred arc plasma. It is employed for welding and other applications involving ceramics or metal plating.

(*ii*) Transferred Arc Process : The arc is formed between the electrode (–) and the workpiece (+). A transferred arc develops high energy density and plasma jet velocity.

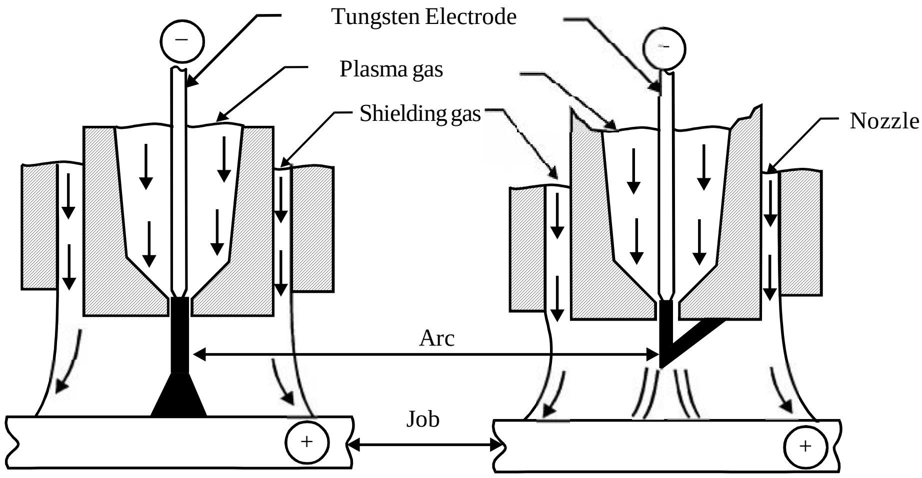


Fig. 2.14 Transferred and non transferred arc in plasma Arc welding

Equipment

The plasma arc welding system consists of the following equipments (Refer. Fig. 2.15).

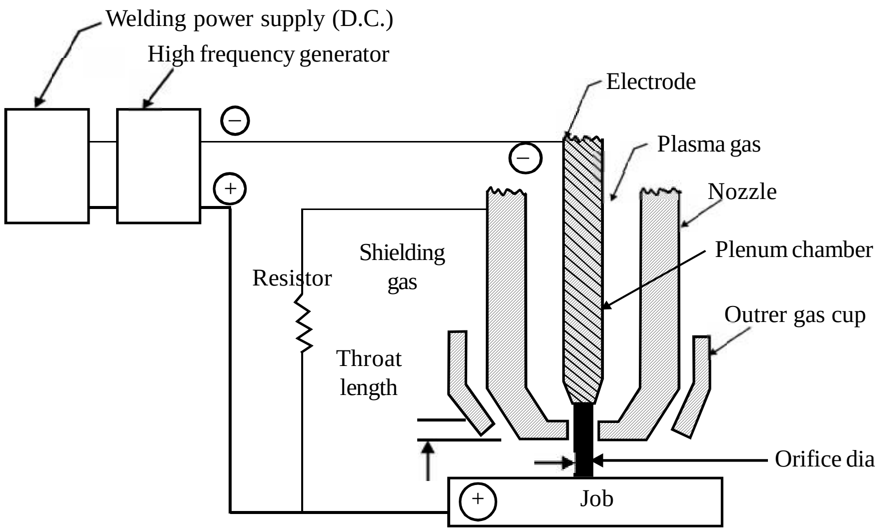


Fig. 2.15 Plasma Arc welding system

(*i*) **Power Supply :** A direct current power source (generator or rectifier) having dropping characteristics and open circuit voltage of 70 volts or above is suitable for plasma arc welding.

(*ii*) High frequency generator and current limiting resistors arc used for arc ignition. Arc starting system may be separate or built in the system.

(*iii*) **Plasma torch :** It is either transferred arc or non-transferred arc type. It is hand operated or mechanised.

(*iv*) **Shielding gas :** Two inert gases or gas mixtures are used. The orifice gas at lower pressure and flow rates forms the arc plasma. Most of the materials can be welded with argon, helium, argon + hydrogen and argon + helium with inert gases or gas mixtures.

(*v*) **Current and gas decay control :** It is necessary to close the keyhole properly while terminating the weld in the structure.

(*vi*) **Fixture :** It is required to avoid atmospheric contamination of the molten metal under bead.

Advantages

The plasma arc welding has following merits :

(*i*) Stability of arc.

(*ii*) Excellent weld quality.

(*iii*) Uniform penetration.

(*iv*) Simplified fixtures.

(*v*) It is possible to produce fully penetrated keyhole welds on pieces upto and about 6 mm thick with square butt joint.

(*vi*) Rewelding of the root of the joint saved.

Disadvantages

(*i*) The process is limited to metal thickness of 25 mm and lower for butt welds.

(*ii*) Inert gas consumption is high.

(*iii*) More chances of electrical hazards are associated with this process.

(*iv*) Welder need ear plugs because of unpleasant distrubing and damaging noise.

Applications

(*i*) Welding cryogenic, aerospace and high temperature corrosion resistant alloys.

(*ii*) Welding of stainless steel tubes (thickness 2.6 to 6.3 mm).

(*iii*) Welding titanium plates upto 8 mm thickness.

(*iv*) Plasma torch can be applied to spraying, welding and cutting of difficult to cut metals alloys.

(*v*) The base metal welded by plasma welding are; Carbon and low alloy steels, Stainless steels, Copper alloys, Nickel and cobalt alloys, Titanium alloys, Aluminium alloys etc.

2.5.6 Submerged Arc Welding (SAW)

In submerged arc welding process arc is generated between bare or copper coated metal electrode (or electrodes) and the workpiece. The arc, electrode end and the molten metal pool remain invisible being submerged under a granular material (flux). The continuously fed bare metal electrode melts and acts as filler rod (Fig. 2.16). It is possible to use large welding electrodes (12 mm), more than one electrode and very high current (4000 A) so that very high metal deposition rates of the order of 20 kg/hr or more can be achieved. Very high welding speeds (5 m/min) and welding plates of thickness high as 75 mm in butt joint in a single pass are possible.

Principle of Operation

The arc is struck either by touching the electrode with the job or placing steel wool between electrode and job or by using a high frequency unit. The flux placed over the job, when cold, is non-conductor of electricity. Initially, the flux is insulator but once it melts by the heat due to the arc, it becomes highly conductive. Hence, the current flow is maintained between the electrode and the job through the molten flux. No pressure is applied. The upper portion of the flux remains solid and can be reused.

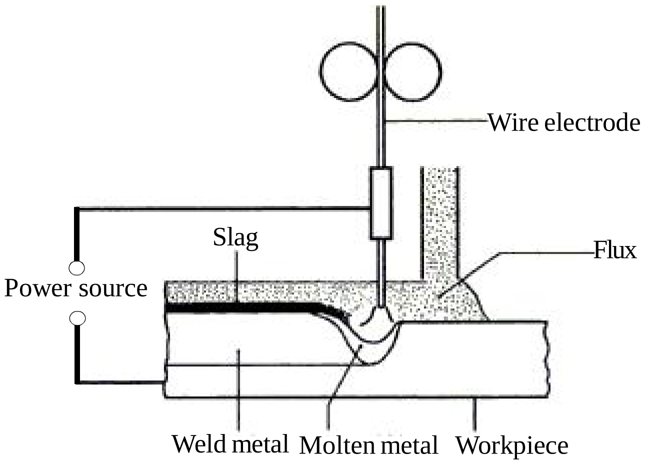


Fig. 2.16 Submerged arc welding

Advantages

- No usual sparks, spatter or smoke. Operator, thus, can work without safety equipment.
- Due to deep penetrations and high deposition rates, fewer passes are required for longer and thicker jobs.
- No edge preparation is required.
- The process is faster and causes less distortion.
- Very neat appearance and smooth weld shapes can be obtained.
- It is often used in automotive mode.

Disadvantages

- Jigs, fixtures and other accessories are required to ensure proper positioning, as the arc and the end of the electrode remains completely hidden under the flux.
- Flux consumption is high and needs regular flux replacement.
- It is not economical for smaller welds and for thin pieces. Also CI, Al alloys, Mg alloys cannot be welded by this process.
- It is limited to welding in flat position only.
- Welding equipment is costly as it is highly automated.

Applications

- Welding of bridge girders, railroads, structural shapes, pressure vessels, pipes and structure of railway coaches and locomotives.
- Ship buildings, automotive industries, nuclear power industries etc.
- Effective for long stretches of weld and most suitable for mass production of steel sections. Welding metals like mild steel, low alloy steels etc.

2.5.7 Electroslag Welding (ESW)

Electroslag welding (ESW) is similar to submerged arc welding but in vertical position. The joint is produced by casting the filler metal between workpieces in a single pass. Welding of very large and long plates can be done by this method. The welding heat is produced by the molten slag, which melts the filler metal and the surfaces of the workpiece to be welded.

Principle of Operation

Electroslag welding is initiated by starting an arc between the electrode and the work. This arc heats the flux and melts it to form the slag. The arc is then extinguished and the slag (conductive) is kept in molten state by the heat produced due to its resistance to the flow of electric current between the electrode and the workpiece (Fig. 2.17). The temperature of this molten slag pool is approximately 1650^0 C at the surface and 1950°C inside, under the surface which is sufficient to weld thick sections in a single

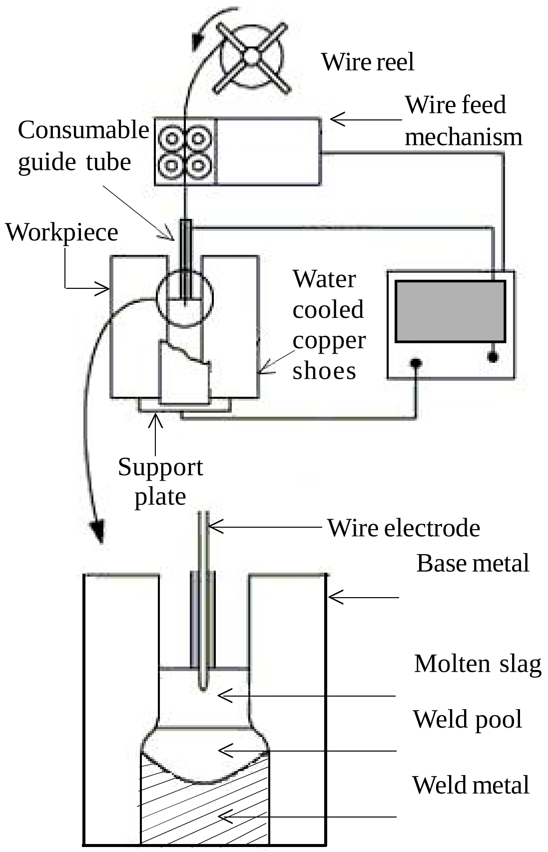


Fig. 2.17 Electroslag Welding

pass. Several electrodes are used for longer welds so that the heat is more uniformly spread. Water-cooled shoe or copper dam plate fastened to the sides of the workpiece prevents the molten metal from running off. These plates also assist the solidification process by transferring heat and move up as the weld progresses. Generally, combination of oxides of silicon, manganese, titanium, calcium, magnesium and fluorspar are used as flux in this process. It also shields the molten metal and clears the impurities from the molten metal.

Advantages

- Thicker and longer plates can be welded economically in a single pass.
- Extremely high deposition rates can be achieved (10-20 kg/hr electrode).
- Flux consumption as compared to submerged arc welding is low.
- No spattering and arc flashing occurs.
- Welding speed about 1.5 m/hr is possible.

Disadvantages

- For joints below 60 mm electroslag welding is less economical submerged arc welding
- Cylindrical welds are difficult to be closed.

Applications

- Fabrication of high pressure vessels, frames of heavy mechanical and hydraulic presses.
- Rolling mill frames, ship hulls, locomotive frames, etc.

2.5.8 Electrogas Welding (ESW)

Electrogas welding is an arc welding process which uses an arc between a continuous filler metal electrode and the weld pool, employing vertical position welding with suitable backing to confine the molten weld metal. No pressure is applied and shielding gas may or may not be used. A groove (square or V) joint is positioned so that the axis or length of the weld remains vertical. Repositioning of the joint is not possible once welding starts. The welding is completed in one pass. It is a machine welding process.

Principle of Operation

The consumable electrode, either solid or flux cored, is fed downward into a cavity formed by the base metals to be welded and the retaining shoes (Fig. 2.18). An arc is initiated between the electrode and the sump (starting tab). Heat from the arc melts the continuously fed electrode and the groove faces. Melted filler metal and base metal collect in a pool beneath the arc and solidify to form the weld. The electrode can be flux-cored to provide the weld with protection from atmospheric contamination, or a shielding gas—generally carbon dioxide—can be used with a solid wire electrode. The electrode may be oscillated horizontally through the joint for uniform distribution of heat and weld metal. As the cavity fills, one or both shoes may move upward. Although the weld travel is vertical, the weld metal is actually deposited in the flat position at the bottom of the cavity. EGW uses a constant voltage, direct current welding power supply, and the electrode has positive polarity. The welding current can range from 100 A to 800 A, and the voltage can range between 30 V and 50 V.

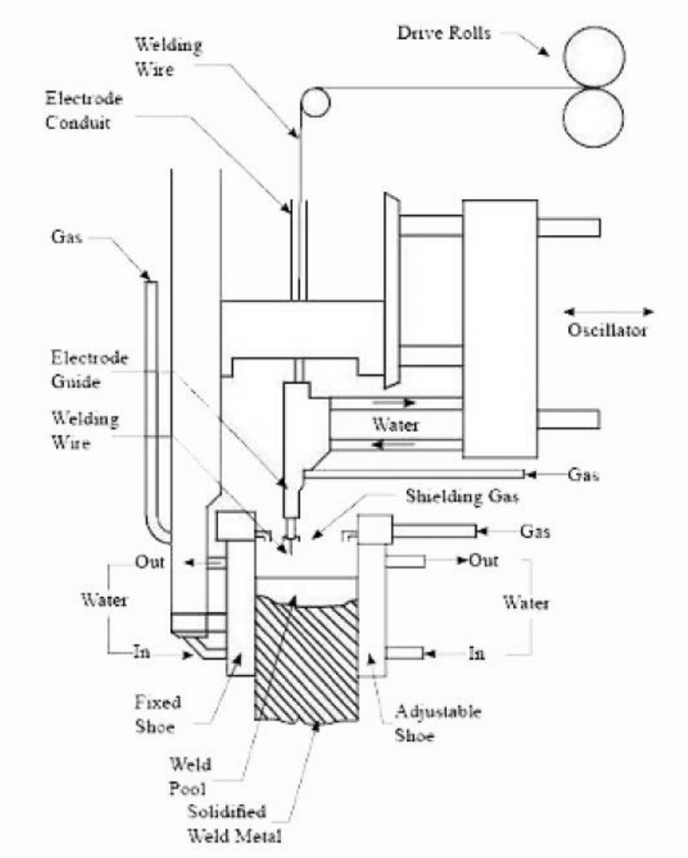


Fig. 2.18 Electrogas Welding

Advantages

- Suitable for welding of thick steels in vertical position.
- Time and cost is saved in the avoidance of joint preparation, preheating and inter-pass temperature control, and inter-pass cleaning.
- There is little or no angular distortion of the base metal.
- The welding action is quiet, with little spatter.

Disadvantages

- EGW, if interrupted during welding, can leave major discontinuities in the joint that are difficult to access and repair.

- The large grain size caused due to high heat input, and subsequent slow cooling, reduces toughness.
- Requires protection of the joint from wind over 8 kmph.
- Requires addition safety measures as the process is often performed at great heights.

Applications

- Making square-groove welds for butt and t-joints, especially in the shipbuilding industry and in the construction of storage tanks.
- Electrogas welding can be applied to most steels, including low and medium carbon steels, low alloy high strength steels, and some stainless steels.
- Quenched and tempered steels may also be welded by the process with proper heat input.

2.6 RESISTANCE WELDING

Resistance welding is a group of welding processes where in coalescence is produced by the heat obtained from resistance of the work to the flow of electric current in a circuit of which the work is a part and by the applications of pressure. No filter metal is needed in this process.

Principle of Operation

Successful operation of a resistance welding process depends upon correct application and proper control of the following factors.

(*i*) The generation of heat at the place where a weld is to be made.

(*ii*) The application of pressure at the place where a weld joint is to be formed.

Heat (H)

The heat H, for electric resistance welding is generated by passing a large electrical current (of the order of 3000 to 100,000 Amps with a voltage between 1 and 25 volts) through two pieces of metal that are touching each other.

$$H = I^2RT \qquad (2.1)$$

where H is the heat generated in joule.

I is the current in root mean square ampere.

R is the resistance in Ohm.

T is the time (from fraction of a second to few seconds) of current flow through the pieces to be welded.

Current (I)

With other parameters kept constant, the temperature in resistance welding is regulated by controlling the magnitude and timing of the welding current. The current is obtained from a step down transformer. Generally, three types of current supply are used in resistance welding.

(*i*) AC systems
(*ii*) DC systems
(*iii*) Stored energy current systems

Resistance (R)

The total resistance of the system between the electrodes consists of

(*i*) The resistance of the workpiece R_1.
(*ii*) The contact resistance between the electrodes and the work, R_2.
(*iii*) The resistance between the surfaces of the two metal pieces to be welded together, R_3.

Time (T)

Four definite segments or periods of timing are set up on a resistance spot welding machine during one welding cycle.

(*i*) Squeeze time
(*ii*) Weld time
(*iii*) Hold time
(*iv*) Off time.

Squeeze time

It is the time between the initial application of the electrode pressure on the work and the initial application of current to make the weld. During this period the upper electrode comes in contact with the workpiece and develops full electrode force. At the end of the squeeze time, the welding current is applied.

Weld time

During this period the welding current is through the circuit *i.e.*, it enters from one electrode, passes through the workpieces and goes out from the second electrode.

Hold time

It is the time during which force acts at the point of welding after the last impulse of welding current ceases.

Off time

It is the interval from the end of the hold time to the beginning of the squeeze time for the next (resistance) welding cycle.

Pressure or Electrode Force

Electrode force is the force applied to the workpieces by the electrodes during the welding cycle. Pressure exerted on the workpieces by the welding electrodes does the following.

- It brings the various interfaces into intimate contact and thus affects the contact resistance between the two workpieces.
- It ensures the completion of the electrical circuit between the electrode and through the work.
- It permits the weld to be made at lower temperature.
- It provides a forging action and thus reduces weld porosity.

Advantages

- Faster rate of production.
- A high degree of reliability and reproducibility can be achieved.
- It is possible to weld both similar and dissimilar metals.
- No filler rod and flux are required.
- The operation required little skill and can be easily mechanised and automated.
- Heating of workpiece is confined to very small part which results in less distortion.
- Very economical process.

Disadvantages

- The initial cost of equipment is high.
- Certain resistance welding processes are limited only to lap joints.
- Bigger job thicknesses cannot be welded.
- Skilled persons are needed for the maintenance of equipment and its control.
- In some materials, special surface pernetration is required.

Applications

Resistance welding is used for

- Joining sheets, bars, rods and tubes
- Making tubes and metal furniture
- Welding aircraft and automobile parts
- Making wire fabric, grids, grills mash weld, containers etc.

2.6.1 Resistance Spot Welding

Spot welding is a resistance welding process in which overlapping sheets are joined by local fussion at one or more spots by the heat generated due to resistance to the flow of electric current through workpieces. The work pieces are held together under force by two electrodes, one above and the other below the two overlapping sheets.

Principle of Operation

Refer to Fig. 2.19, the resistance offered to current as it passes through the metal raises the temperature of the metal between the electrode to welding heat. The current is cut-off and mechanical pressure is then applied by the electrodes to forge the welds. Finally the electrodes open.

- When sheets of unequal thickness are joined, the current and pressure setting for the thinner sheets are used.
- Currents usually range from 3000A to 40,000A, depending on the materials being welded and their thickness.
- Modern equipment for spot welding is computer controlled for optimum timing of current and pressure, and the spot welding guns are manipulated by programmable robots.

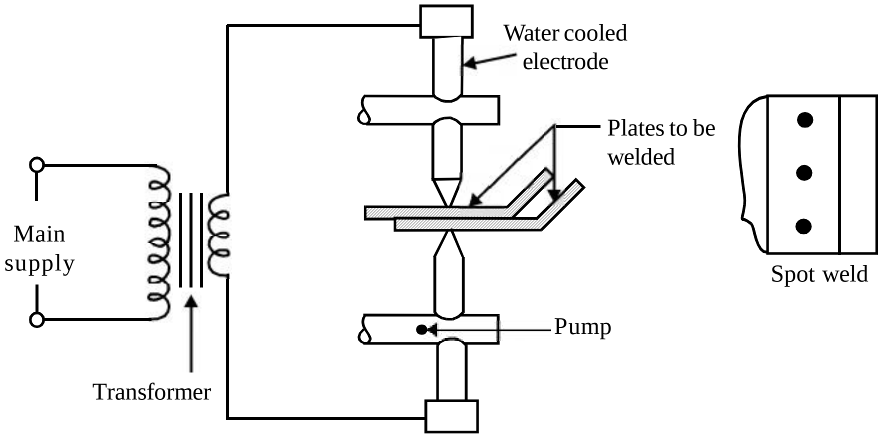


Fig. 2.19 Spot Welding

Applications

- Spot welding is used for fabricating sheet metal products which forms a cheap and satisfactory substitute for riveting.
- Low carbon steel, high speed steel, stainless steels, brass, Al, Cu, nickel, nickel alloys etc. can be joined by this method.
- Steel household furniture and containers are joined by this method.

Advantages

- High production rate.
- Very economical process.
- High skill not required.
- Most suitable for welding sheet metals.
- No edge preparation is needed.

- Dissimilar metals can be welded.
- Small heat affected area.

Limitations

- Suitable for thin sheets only.
- High equipment cost.

2.6.2 Resistance Seam Welding

Seam welding is a resistance welding process where in coalescence at the laying surfaces is produced by the heat obtained from resistance to electric current through the work parts held together under pressure by electrodes. The resulting weld is a series of overlapping resistance seam welds made progressively along a joint by rotating the circular electrodes.

Principle of Operation

Seam welding is analogous to spot welding with the difference the electrodes are in the form of rollers and the work moves in direction perpendicular to roller axis as shown in Fig. 2.20.

- The current is interrupted 300 to 1500 times a minute to give a series of overlapping spot welds. The welding is usually done under water to keep the heating of the welding rollers and the work to a minimum and thus to give lower roller maintenance and less distortion of the work.
- Welding current range from 2000A to 5000A while the force applied to the rollers may be as high as 5 kN to 6 kN.
- The typical welding speed is 1.5 m/min for thin sheet.

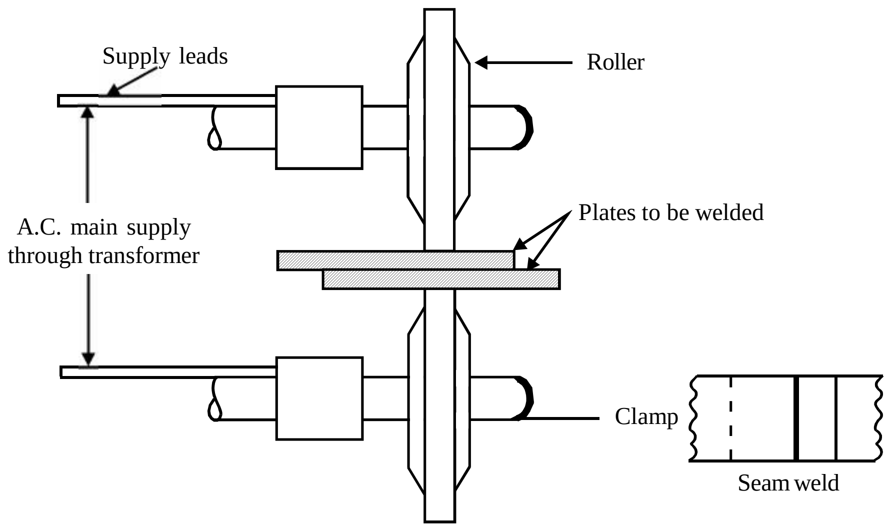


Fig. 2.20 Seam Welding

Advantages of Seam Welding

- It can produce gas tight or liquid tight joints
- Overlap is less than for spot or projection welds.
- A single seam weld or severall parallel seams may be produced simultaneously.

Disadvantages of Seam Welding

- Welding can be only along a straight or uniformly curved line.
- It is difficult to weld thickness greater than 3 mm.
- High cost of equipment as compared to spot welding.

Applications

It is applicable on many types of pressure tanks, for oil switches, transformers, refrigerators, evaporators and condensers air craft tanks, paint and varnish contaniners etc.

2.6.3 Resistance Projection Welding

Projection welding is a resistance welding process wherein coalescnce is produced by the heat obtained from resistance to electric current flow through the work parts held together under pressure by electrodes. The resulting welds are localized at predetermined points by projections and intersections (Fig. 2.21).

Principle of Operation

Projection welding is similar to spot welding except that

(*i*) The electrides, instead of being tip as in spot welding, are flat and relatively large in surface area. Electrodes are cooled as in spot welding.

(*ii*) Since a number of welds are made at each operation, both the electrical power and mechanical pressure must be correspondingly greater, as compared to a spot welder.

The success of projection welding depends on the surface penetration of the work-pieces to be welded. Projections (of the order of 0.8 mm), small deformations that will touch the surface of the material to be welded are formed on the weld area by embossing, stamping, casting or machining. These projections serve to concentrate the welding heat at these areas and facilitate fusion without the necessity of employing a large current.

Advantages of Projection Welding

- A number of welds can be made simultaneously.
- Projection welds can be made in metals that are too thick to be joined by spot welding.
- Projection welding electrodes process longer life than spot welding ones because of less wear and maintenance resulting from fusion and overheating.

- Projection welding locates the welds at certain desired points.
- A better heat balance can be obtained in difficult to weld combinations of compositions and thickness.
- Projection welding lowers the amount of current and pressure needed to form a good bond between two surfaces. This reduces the chances of shrinkage and distortion around the weld zone.
- Scale, rust, oil and work metal coatings interfere less with projection welding than with spot welding.

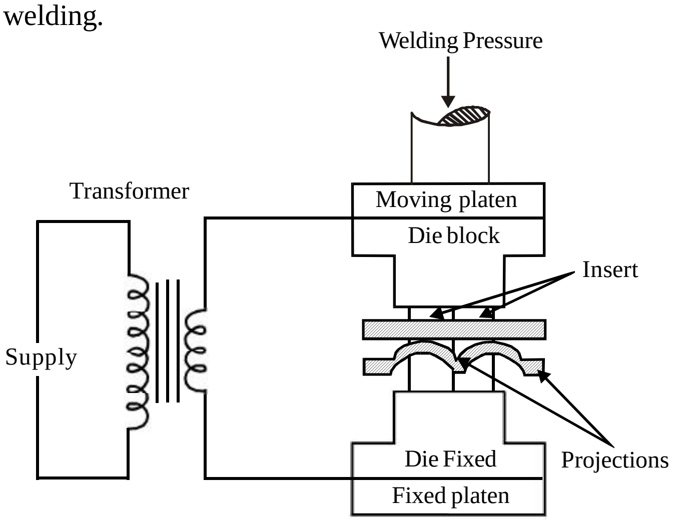


Fig. 2.21 Projection Welding

Disadvantages

- The projection welding is limited to combinations of metal thickness and composition which can be embossed.
- For proper welding, all projections must be of the same height.
- Metals that are not strong enough to support projections cannot be projection welded satisfactorily.

Applications

- Small fasteners, nuts etc. can be welded to larger components.
- It is used for welding of refrigerator condensers, joining of wires etc.
- Welding of stainless steel parts, titanium alloys, monel alloys etc.

2.6.4 Resistance Butt Welding

This is also called upset butt welding or simply upset welding. In this welding, the two pieces to be joined are held tightly together and current is applied, so that the heat is generated over the entire area of abutting surfaces. Pressure is applied throughout the heating period. The coalescence is produced simultaneously over the entire area.

Principle of Operation

One of the workpiece to be joined is clamped in stationary clamping block and the other is clamped in movable clamp (Fig. 2.22). The two workpieces are brought together by pressure forming a butt and a current of high magnitude is then passed through these workpieces. Heat is generated because of resistance to the flow of electric current. When desired welding temperature is reached, pressure is increased for proper joining. The welding current is cut off after the weld is obtained. The welding pressure is released when the welded joint reaches normal temperature.

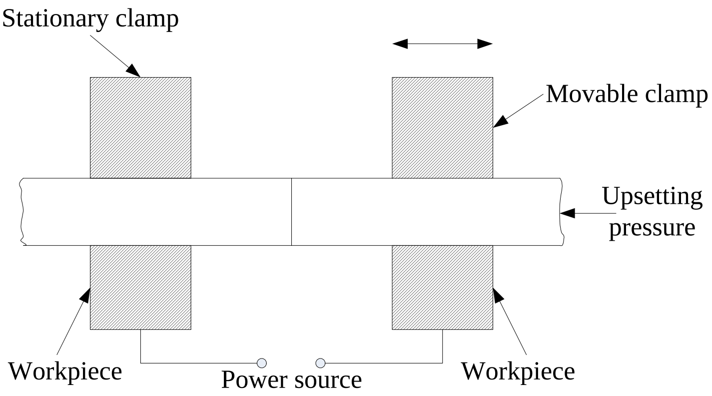


Fig. 2.22 Resistance Butt Welding

Applications

- Wires, bars, strips and tubes are butt welded.
- Joining small strips of ferrous and non-ferrous metals and longitudinal butt joints in tubes and pipes.
- Metals welded include copper alloys, low carbon steels, stainless steels, Al and Ni alloys.

2.6.5 Flash Butt Welding

Flash butt welding has largely replaced resistance butt welding. It is similar to upset butt welding except that the heat required for melting is obtained by means of an arc rather than the simple resistance heating.

Principle of Operation

In this welding, the workpieces are clamped in the stationary and movable block with a small gap (Fig. 2.23). When the current is turned on, it jumps through the gap causing a flash. This flashing produces the welding heat. When sufficient heat is produced, more pressure is applied to join the workpieces. The welding current is cut off and workpieces are unclamped after joining is over.

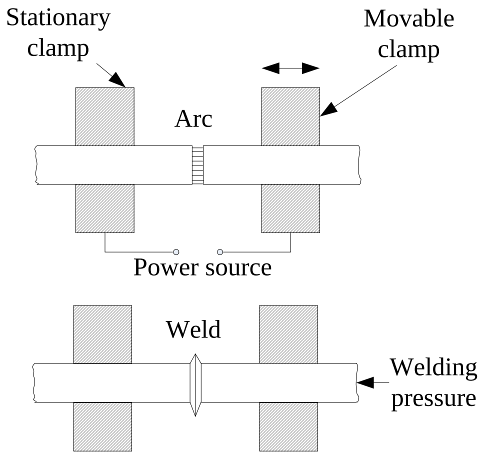


Fig. 2.23 Flash butt welding

Advantages

- Flash butt welding offers strength factor upto 100% and consumes less welding current than upset butt welding process.
- The process is cheap, faster and no weld surface preparation is required.

Disadvantages

- Concentricity and straightness of workpieces during welding is difficult to maintain.
- There is possibility of fire and health hazards due to the flash.

Applications

- It is used for the welding of bars, rods and tubes. Metals welded include: low carbon steels, low alloy steels, stainless steels, tool steel, Al alloys, copper, magnesium and Ni alloys.
- It is also used for the welding of saw blades into continuous loops, taps and reamers to alloy steel shanks.
- The process is used in automobile industry, aircraft industry, refrigerators and farm implements.

Differences between Resistance Butt welding and Flash Butt welding

- No flashing takes place in resistance butt welding.
- The movable platen in flash butt welding keeps on moving constantly towards the stationary platen which is not so in case of resistance butt welding.
- Less current is consumed in flash welding but the application time is more.
- Application of heat precedes pressure application in flash welding whereas in resistance butt welding constant pressure is applied during heating.

2.6.6 Percussion Welding

Percussion welding (PEW) is a resistance welding process wherein coalescence is produced simultaneously over the entire area of abutting surfaces by heat obtained from an arc produced by a rapid discharge of electrical energy, with pressure percussively (rapidly) applied during or immediately following the electrical discharge.

Principle of Operation

The cleaned workpieces are clamped into the welding machine and light force is applied to bring the ends of the two workpieces near (Fig. 2.24). The arc between the faces of workpieces is struck either by ionizing the gap or by bringing the workpieces into light contact to establish a flow of current and then retracting those. At this stage, welding force is applied. It extinguishes the arc and holds the parts together to form the weld after cooling.

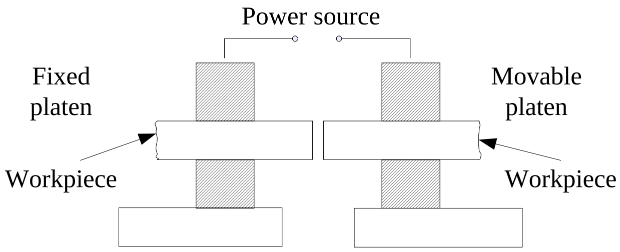


Fig. 2.24 Percussion welding

Advantages

- Because of the extreme brevity of the arc, fusion is confined to the surface of the parts being welded and there is almost complete absence of flash or upset.
- Heat treated or cold worked metals can be welded without annealing or destroying the heat treatment.

Disadvantages

- The process is limited to butt welded joints only.
- Since control of the path of an arc is difficult, the joint used is limited to about 1.5 to 3 sq. cm.

Applications

- Mostly used for aluminium and its alloys.
- Copper alloys, low carbon steel, stainless steel and copper to molybdenum are also weld by this method.

2.7 SOLID STATE WELDING

A solid state welding process produces coalscence at temperatures below the melting point of the base metal being joined. The welding is carried out without the addition of a filler metal but with the application of pressure. At least one of the metal to be joined should be highly ductile and should not exhibit extreme work hardening.

2.7.1 Cold Welding

Cold or contact welding is a solid-state welding process in which joining takes place without fusion or heating at the interface of the two parts to be welded. A layer of metal oxide exists on the metal surface. During cold working a part of the oxide is removed. When two such partly cleaned surfaces are pressed together, the remaining thin oxide film forms spot fragments. The metal behind the oxide film undergo plastic deformation under pressure and metal to metal contact occurs. Due to plastic deformation metals fuse in to one another. The ductility of the metal produces a true fusion condition.

Principle of Operation

The parts to be welded are first cleaned and clamped in a die with some initial extension. A forging force is then applied to complete welding (Fig. 2.25).

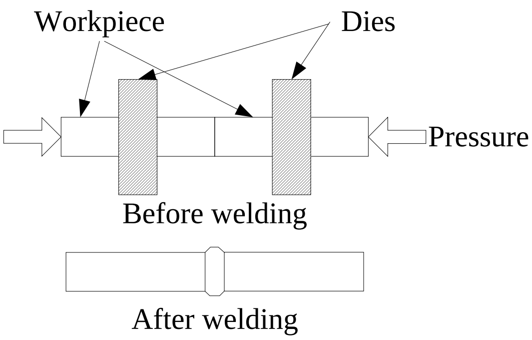


Fig. 2.25 Cold welding

Advantages

- Total absence of applied heating.
- Dissimilar metals can be joined.

Disadvantages

- Needs a lot of surface preparation.
- At least one of the metals is required to be ductile without excessive work hardening.

Applications

- Used to weld aluminium, copper and its alloys, aluminium to copper, nickel to iron etc.
- Cold welded butt joints are used in the manufacturing of aluminum, copper, gold, silver, and platinum wire.
- Successive reels of wire are joined for continuous drawing to a smaller diameter by cold welding.
- Cladding and joining many similar and dissimilar metals.
- Joining metals in explosive areas

2.7.2 Diffusion Welding

Diffusion welding is a solid state welding process, in which pressure applied to two workpieces with carefully cleaned surfaces and at an elevated temperature below the melting point of the metals. Bonding of the materials is a result of mutual diffusion of their interface atoms. The process does not involve macroscopic deformation, or relative motion of the work pieces. No appreciable deformations of the workpieces occur.

Principle of Operation

The process needs metal to metal contact. A large pressure (350 to 700 kg/cm^2) is applied to the workpieces which breaks the surface oxide layer establishing metal to metal contact (Fig. 2.26). For achieving the diffusion and grain growth to complete the weld, temperature up to 1100^0 is used. Due to metal contact, the atoms are within the attractive force field of each other and hence a high strength joint is established. In order to keep the bonded surfaces clean from oxides and other air contaminations, the process is often conducted in vacuum.

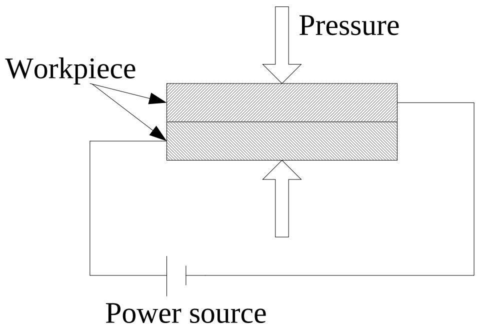


Fig. 2.26 Diffusion welding

Advantages

- Dissimilar materials may be welded (Metals, Ceramics, Graphite, glass).
- Welds of high quality are obtained without pores, inclusions, chemical segregation and distortion.
- No limitation of workpiece thickness.

Disadvantages

- Time consuming process with low productivity requiring thorough surface preparation.
- The mating surfaces must be precisely fitted to each other.
- Relatively high initial investments in equipment.

Applications

- Finds applications in fabrication of the reactor components in atomic energy industry, rocket engines, helicopter rotor hub, missiles, bombers and space shuttle.
- Used for joining titanium alloys, zirconium alloys and nickel based alloys.
- Used for joining composite materials.

2.7.3 Ultrasonic Welding (USW)

Ultrasonic welding is a solid state welding process where in coalescence is produced between a wide range of similar and dissimilar combinations of metals by the local application of high frequency vibratory energy in very short cycle times without melting the materials being joined.

Principle of Operation

In ultrasonic welding a power supply converts low frequency electrical energy into frequency electrical pulses. These are, in turn, converted to mechanical vibrations by means of a transducer. A coupling system transmits and applies the high frequency mechanical vibrations to the weld interface clamping force. The clamping force produces a uniform, symmetrical stress that radiates into the material from the dimpling point. As the lateral welding force is applied, the stress distribution in the material shifts to one side of the clamp point. This represents one-half of a vibration cycle. During the second half of the vibration cycle, the lateral force reverses direction and the stress distribution within the workpiece shifts to the opposite side of the clamping point.

Welding Equipment

The ultrasonic welding equipment as shown in Fig. 2.27 consists of

(*i*) Power supply.

(*ii*) Transducer.

(*iii*) The coupling system.

(*iv*) The clamping system.

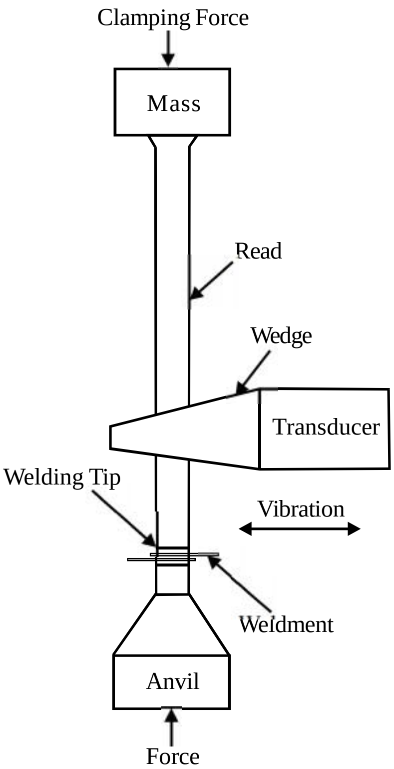


Fig. 2.27 Ultrasonic Welding

(*i*) Power Supply

The USM power supply is responsible for covering 50 or 60 Hz electrical signal to a much higher frequency signal. This is accomplished through the use of a frequency generator and amplifier. The frequency generators used for various welding applications are capable of operating at frequencies from 10 to 75 kHz.

(*ii*) Transducer

The role of the transducer is to convert the electrical energy from the power supply into mechanical energy that will perform the welding. There are two types of

(*iii*) The Coupling System

The coupling systems transmit the high frequency vibrations from the transducers to the workpiece. There are two methods for transmitting energy to the weld, the wedgereed system and the lateral drive system.

(*iv*) Clamping System

Clamping systems provide the force being applied through their welding tip or the workpiece itself as well as providing the static force necessary to held the workpiece together during the weld cycle.

Advantages

(*i*) Surface preparation is not critical.
(*ii*) No defects are produced from arc, gases and filler metals.
(*iii*) Dissimilar metals having vastly different melting points can be joined.
(*iv*) Minimum surface deformation results.
(*v*) Short welding cycle and low energy consumption.
(*vi*) Due to low temperature involvement, the characteristics of the materials are not attered and are continued through the weld zone.
(*vii*) Welding of glass is impossible by any other means.

Disadvantages

(*i*) This process is restricted to joining thin material sheet foil and wire. The maximum is about 3.0 mm for aluminium and 1 mm for harder metals.
(*ii*) Materials being welded tend to weld to the tip and anvil .
(*iii*) Due to fatigue welding, the life of equipment is short.
(*iv*) Hard materials will fatigue under the stresses necessary for welding.

Applications

The most common application for ultrasonic welding are :

(*i*) Joining electrical and electronic components.
(*ii*) Thermatic sealing of materials and devices
(*iii*) Welding aluminium wire and sheet.
(*iv*) Fabricating nuclear fuel elements.

2.7.4 Explosive Welding

Explosive welding is a solid state welding process where incoalescence is effected by high velocity movement produced by a controlled detonation.

Principle of Operation

In this process welding is achieved through very high contact of pressure developed by detonating a thin layer of explosive placed over one of the pieces to be joined as shown in Fig. 2.28. The detonation imparts high kinetic energy to the piece which on striking the other piece causes plastic deformation and squeezes the contaminated surface layers out of interface resulting a high quality welded joint.

Advantages

(*i*) Welds can be produced on heat-treated metals without affecting their microstructures.

(*ii*) Extremely large surface can be bounded.

(*iii*) High joint strength.

(*iv*) Wide range of thickness can be explosively clad together.

(*v*) The foils can be bounded to heavier plates.

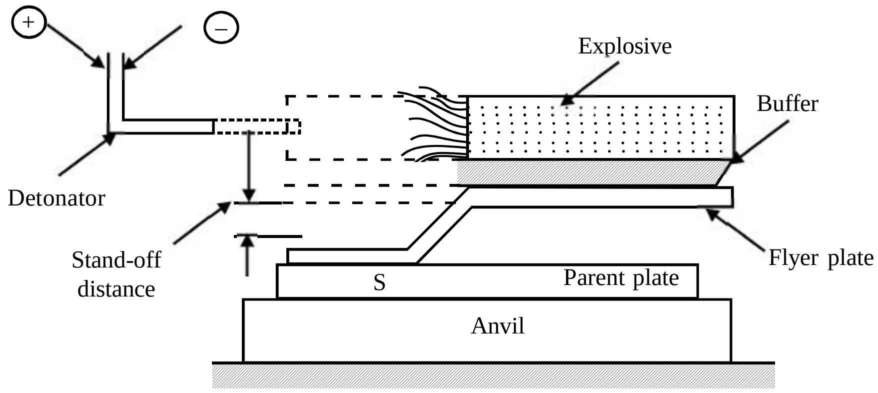


Fig. 2.28 Explosive welding

Disadvantages

(*i*) In industrial areas the use of explosives will be severely restricted by the noise and ground vibration caused by explosion.

(*ii*) Metals to be welded by this process must posses some ductility and some impact resistance.

(*iii*) Metal thickness greater than 62 mm of each alloy cannot be joined easily and require high explosive loads.

Applications

(*i*) A number of dissimilar metal combinations have been joined successfully with the help of explosive welding e.g. (a) aluminium to steel (b) tungsten to steel (c) aluminium to stainless steel etc.

(*ii*) It is used in die casting industry for nozzles, die-cast biscuits and other components.

(*iii*) Heat exchangers tube sheets and pressure vessels.

(*iv*) Pipes and tubes upto 1.5 m length have been clad with this process.

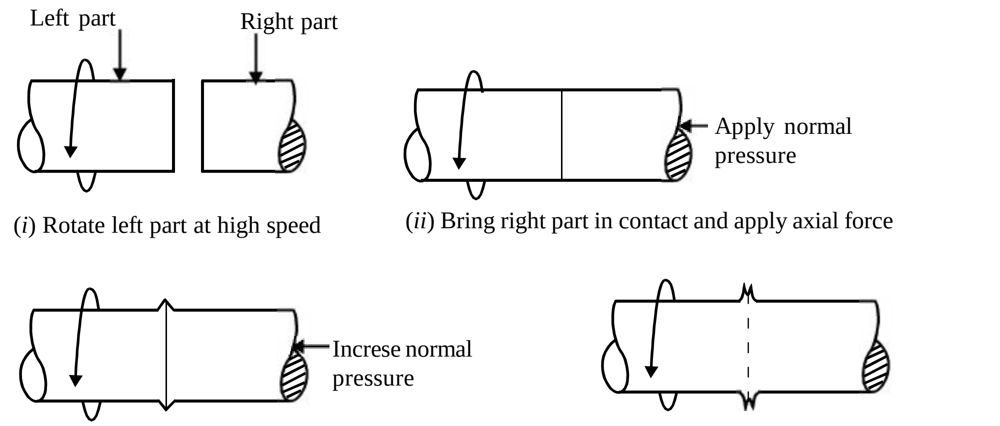
2.7.5 Friction Welding

Friction welding is a solid state welding process, in which two cylindrical parts are brought in contact by a friction pressure when one of them rotates. Friction between the parts results in heating their ends. Pressure is then applied to the pieces providing formation of the joint. This process is also known as "**inertia welding**".

The shape of the welded joint depends on the rotational speed and the axial force applied. These factors must be controlled to obtain a uniformly strong joint. The radially outward movement of the hot metal at the interface pushes oxides and other contaminants out of the interface. Filler metals, fluxes or shielding gases are not required and welds can be made with a minimum of joint preparation. This method is most suitable for circular parts *i.e.*, butt welding of round bars or tubes.

Principle of Operation

Coalscence is produced by the heat obtained from mechanically induced sliding motion between rubbing surfaces. the two components are held in axial alignment (Fig. 2.29). One component is held in the chuck spindle of the rotating machine and accelerated at desired speed. The other component is held stationery and moved forward to contact the rotating component. Pressure and rotation are maintained until high temperature is reached. High temperature takes the metal to plastic state. Braking is applied to stop rotation and axial force is increased to weld two components together.



(*i*) Rotate left part at high speed (*ii*) Bring right part in contact and apply axial force

(*iii*) Flash begins to form when axial force is increased (*iv*) Stop rotating left part when flash is formed

Fig. 2.29 Friction welding process

Advantages

(*i*) High quality welds.

(*ii*) Very little loss of material through exclusions.

(*iii*) Annealing of weld zone is not necessary.

(*iv*) The heating zone being very thin, therefore dissimilar metals easily joined.

Disadvantages

(*i*) The parts to be welded must be essentially round and must be able to withstand the high torque developed during welding.
(*ii*) The method is limited to smaller components.

Applications

(*i*) It is applicable for
(*ii*) H.S.S twist drills
(*iii*) Gas turbine shafts.
(*iv*) Refrigerator tubes of dissimilar metals
(*v*) Welding of sintered products.
(*vi*) String columns
(*vii*) Aero engine drive shafts and valves.

2.7.6 Forge Welding

Forge welding is the oldest method of welding in the category of solid state welding. Surfaces to be joined are heated till they are red hot and then forced together by hammering. Prior to forge welding, the parts are cleaned in order to prevent entrapment of oxides in the joint. It is a crude method of welding and quality depends upon the skill of the welder.

Principle of Operation

The process is carried out by heating the components to be joined to a plastic state in a blacksmith's forge with upsetting edges. The hot workpieces are withdrawn in appropriate time and joined by repeated hammer blows. Borax in combination with ammoniac is the most commonly used flux in forge welding of steel.

Advantages

- Good quality weld may be obtained;
- Parts of intricate shape may be welded;
- No filler material is required.

Disadvantages

- Welding is restricted to wrought iron and mild steel.
- High level of the operator's skill is required.
- Slow welding process.
- Weld may be contaminated by the coke used in heating furnace.

Applications

- Used in railroad shops and general repair shops.
- Making pipes from plates by rolling.
- Used for manufacturing metal art pieces and welded tubes.

2.8 THERMOCHEMICAL WELDING

2.8.1 Thermit Welding

Thermit welding is the method of uniting iron or steel parts by surrounding the joint with steel at sufficient high temperature to fuse the adjacent surface of the parts together.

In this process the coalescence is produced by heating with superheated liquid metal and slag resulting from chemical reaction between a metal oxide and aluminium with or without the application of pressure.

Principle of Operation

Thermit welding is based on casting and foundry practice and consists essentially of providing, by means of a chemical reaction, a volume of molten weld metal which is poured into the joint to be welded.

The chemical or thermit reaction takes place between a metal oxide and a metal reducing agent. The chemical affinity of aluminium for oxygen is the basis for the thermit process. Thermit reaction is an exothermic one.

A few typical thermit reactions are

(*i*) $3Fe_3O_4 + 8Al \cdots > 9Fe + 4Al_2O_3 \, (3088°C) \, 719.3$ kcal

(*ii*) $Fe_2O_3 + 2Al \cdots > 2Fe + Al_2O_2 \, (2960°C) \, 181.5$ kcal

(*iii*) $3Cuo + 2al \cdots > 3Cu + Al_2O_3 \, (4865°C) \, 275.3$ kcal

(*iv*) $Cr_2O_3 + 2Al \cdots > 2Cr + Al_2O_3 \, (3977°C) \, 546.5$ kcal

The working of thermit welding process is;

- Here a wax pattern of desired size and shape is prepared around the joint or region where the weld is to be affected as shown in Fig. 2.30.
- The wax pattern is then surrounded by sheet iron box and the space between box and pattern is filled and rammed with sand.
- After curring, pouring and heating gates and risers a flame is directed into the heating oven due to which the wax pattern metals and drains out, the heating is continued to raise the temperature of the parts to be welded.
- The thermit fixture (finely divided aluminimum iron oxide) is packed in the crucible of conical shape formed from a sheet-iron casting lined with heat resisting cement and is ignited with magnesium or torch yielding a highly superheated (3000°C) molten iron and a slag of aluminium oxide.
- The molten iron is then run into the mould which fuses with the parts to be welded and forms a thermit collar at the joint.

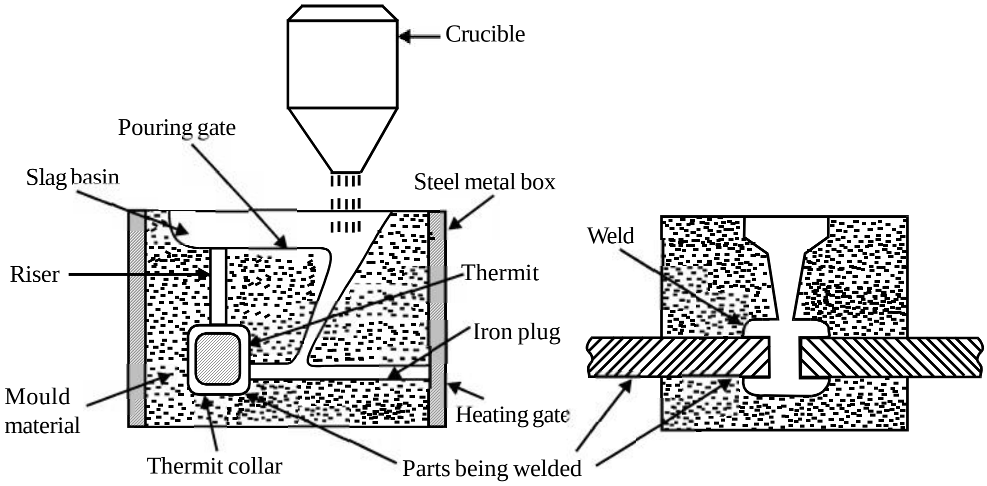


Fig. 2.30 Thermit Welding

Advantages

- The heat necessary for welding is obtained from a chemical reaction and thus no costly power supply is required.
- Can be used anywhere.
- Most suitable for welding of thick sections.
- Not a highly skilled operation.

Disadvantages

- Thermit welding is applicable only to ferrous metal parts of heavy sections *i.e.,* mill housings and heavy rail sections.
- High set-up and cycle time.
- The process is uneconomical if used to weld cheap metals or light parts.

Applications

Thermit welding is used chiefly in the repair or assembly of large components *i.e.,*

(*i*) For reparing fractured rails (railway tracks)

(*ii*) For butt welding pipes end to end

2.8.2 Atomic Hydrogen Welding (AHW)

Atomic hydrogen welding is a thermo-chemical welding process in which the work pieces are joined by the heat obtained on passing a stream of hydrogen through an electric arc struck between two tungsten electrodes. The arc supplies the energy for a chemical reaction to take place, thereafter heat is obtained for welding. Filler metal may or may not be used.

Principle of Operation

The equipment consists of a welding torch with two tungsten electrodes inclined and adjusted to maintain a stable arc (Fig. 2.31). Annular nozzles around the tungsten electrodes carry the hydrogen gas supplied from the gas cylinders. The work pieces are cleaned to remove dirt, oxides and other impurities to obtain a sound weld. Hydrogen gas supply and welding current are then switched ON. An arc is struck by bringing the tow tungsten electrodes in contact with each other and instantaneously separated by a small distance, such that the arc still remains between the two electrodes. As the jet of hydrogen gas passes through the electric arc, it disassociates into atomic hydrogen by absorbing large amounts of heat supplied by the electric arc.

H_2 = H + H - 422 KJ (Endothermic Reaction)

The heat thus absorbed can be released by recombination of the hydrogen atoms into hydrogen molecule (H_2). The recombination takes place as the atomic hydrogen touches the cold workpiece liberating a large amount of heat.

H + H = H_2 + 422 KJ (Exothermic reaction)

AC power source is suitable compared to DC, because equal amount of heat will be available at both the electrodes. A transformer with an open circuit voltage of 300 volts is required to strike and maintain the arc.

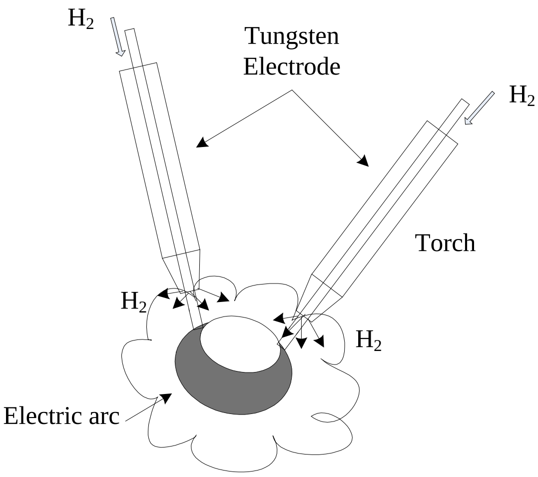


Fig. 2.31 Atomic hydrogen Welding

Advantages

- Less distortion as the can be concentrated at the joint.
- Welding is faster.
- Problems like striking the arc and maintaining the arc column are eliminated as the workpiece do not form a part of the electric circuit.
- Separate flux / shielding gas are not required. The hydrogen envelope itself prevents oxidation of the metal and the tungsten electrode. It also reduces the risk of nitrogen pick up.

Disadvantages

- Cost of welding is high.
- Welding is limited to flat positions only.

Applications

- Used for welding plain carbon steel, alloy steel, stainless steel, Al, Cu and Ni.
- Hard facing and surfacing of dies and tools and heat resisting alloys.

2.9 RADIANT ENERGY WELDING

2.9.1 Laser Beam Welding (LBW)

The laser (light amplification by stimulated emission of radiation) beam welding process is the fousing of a monochromatic light into extremely concentrated beams. It employs a carefully focused beam of light that concentrates tremendous amount of energy on a small area to produce fusion.

Equipment

The laser welding process comprises the following equipments as shown in Fig. 2.32.

(*i*) Electrical storage unit
(*ii*) Capacitor bank
(*iii*) Triggering device
(*iv*) Flash tube that is wrapped with a wire
(*v*) Lasing material
(*vi*) Focusing lens mechanism
(*vii*) Work table

Principle of Operation

- When capacitor bank is triggered energy is injected into the wire that surrounds the flash tube. This wire establishes the imbalances in the material inside the flash tube. Thick Xenon often is used in the material for the flash tube, producing high power levels for very short period of time. The flash tubes or lamps are designed for operation at a rate of thousands of flashes per second. By operating in the manner, the lamps become an efficient device for converting electrical energy into light energy, the process of pumping the laser. The laser is then activated. The beam is emitted through the coated end of the lasing material. It goes through a focusing device where it is pin-pointed on the work-piece. Fusion takes place and the weld is accomplished.
- Both the Nd : YAG (neodymium-doped yttrium aluminum garnet; $Nd{:}Y_3Al_5O_{12}$) and CO_2 lasers may be used for welding.

- Since Nd : YAG laser is pulsed, it is used for producing spot and seam welds.
- CO_2 laser can produce deeper weld at higher rates of speed than possible with Nd : YAG laser.

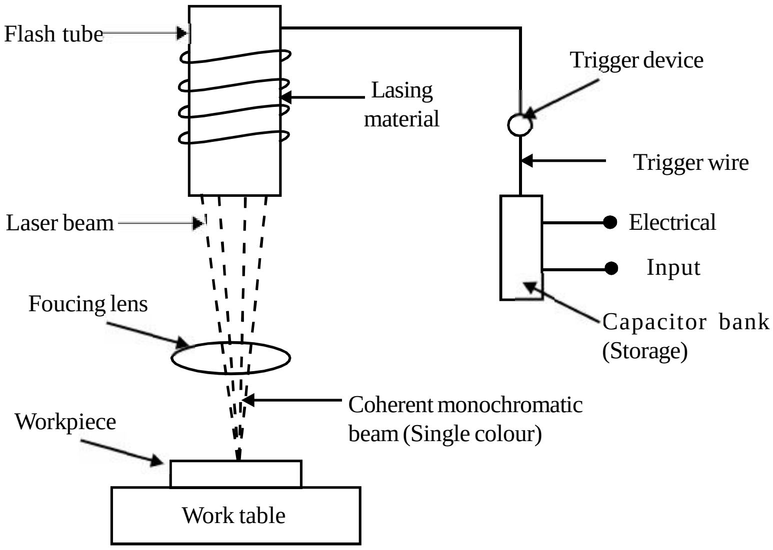


Fig. 2.32 Laser beam welding

Advantages

- Metals with relatively high electrical resistance and parts of considerably different sizes and mass can be welded.
- Welds can be made with a high degree of precision.
- Laser welding holds thermal distortion and shrinkage to a minimum.
- This process can be used to weld dissimilar metals with widely varying physical properties.
- Welds can be made in air or with shielding gas.
- Deeper penetration welding can be done even with dissimilar metals.

Disadvantages

- High energy losses
- Highly skilled operation
- Slow welding speed.
- Eye protection required
- Suitable for narrow and deep joints
- Weld joints made for lasers must be prepared and fixtures to close tolerances.
- Welds are normally limited to materials 0.3 mm thick or less.

Applications

- It is used for cutting and welding.
- It is used for welding of copper, nickel, titanium etc.

2.9.2 Electron Beam Welding (EBW)

Electron beam welding is a high energy density fusion welding process that utilizes a lightly focused, high velocity stream of electrons as the thermal source. The electron beam welding process allows fusion welds of great depth with a minimum width because the beam can be focussed and magnified. The depth of the weld bead can exceed the width of the weld bead by as much as 15 times.

Principle of Operation

The process joins separate pieces of base metal by fusing of molten metals. The melting is achieved by a concentrated bombardment of a dense stream of electrons which are accelerated at high velocities, sometimes as high as the speed of light. The entire process is mostly carried out inside a vacuum chamber. The chambers house not only the workpiece but also the cathode, the focusing device and the remainder of the gun, preventing contamination of the weldment and the electron beam gun itself (Fig. 2.33).

The operation is performed in vacuum to prevent the reduction of electron velocity. If a vacuum were not used, the electrons would strike the small particles in the atmosphere, reducing their velocity and decreasing their heading ability.

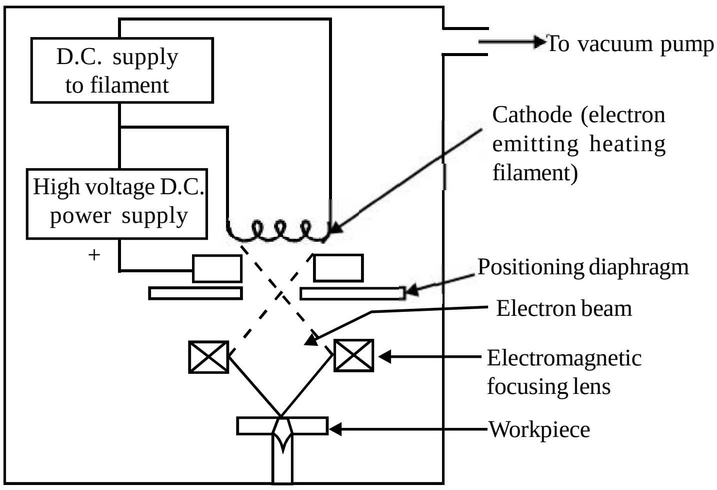


Fig. 2.33 Electron Beam welding

Advantages

(*i*) Low thermal input.
(*ii*) High purity, clean and sound welds.
(*iii*) Deep penetration.
(*iv*) Welds high conductivity metals.
(*v*) Energy conversion efficiency is high about 65%.

Disadvantages

(*i*) High joint preparation and tool costs.
(*ii*) Limited penetration and stand off distance.
(*iii*) X-ray shielding required.
(*iv*) Limitations of the vacuum chamber. Work size is limited by the size of the chamber.
(*v*) Expensive equipment.

Applications

Welding of automobile, airplane, aerospace, form and other types of equipment including ball bearing over 100 mm.

2.10 WELDABILITY

Weldability is defined as the capacity of a metal to be welded under the fabrication conditions imposed in a specific suitable designed structure and to perform satisfactorily in the intended service.

Weldability can be known by determining a metal's behaviours under fusion and cooling, by crack and notch sensitivity or by comparision of the heating and cooling effects which takes place at the joint of the metal with the metal of known weldability.

2.10.1 Factors Affecting Weldability

Welding of a metal is affected by the following factors :

(*i*) Composition of metal
(*ii*) Thermal properties
(*iii*) Welding technique
(*iv*) Filler materials
(*v*) Flux material
(*vi*) Brittileness of metal
(*vii*) Strength of metal at high temperature
(*viii*) Stability at micro-constituents upto welding temperature.

2.11 PREPARATION OF WELDING

2.11.1 Types of Welding Joints

The type of joint is determined by the relative positions of the two pieces being joined. The following are the commonly used joints as shown in Fig. 2.34.

(*i*) Lap joint (*ii*) Butt joint (*iii*) Corner joint (*iv*) Edge joint (*v*) T-joint

(*i*) Lap Joint

The lap joint is obtained by overlapping the plates and then welding the edges of the plates. The lap joints may be signle traverse, double traverse and parallel lap joints. These joints are employed on plates having thickness less than 3 mm.

(*ii*) Butt Joint

The butt joint is obtained by placing the edge to edge as shown in Fig. 2.34. In this type of joints if the plate thickness is less than 5 mm, bevelling is not required. When the thickness of the plates ranges between 5 mm to 12.5 mm, the edge is required to be bevelled to V or U grove while the plates having thickness above 12.5 mm should have a V or U grove on both sides.

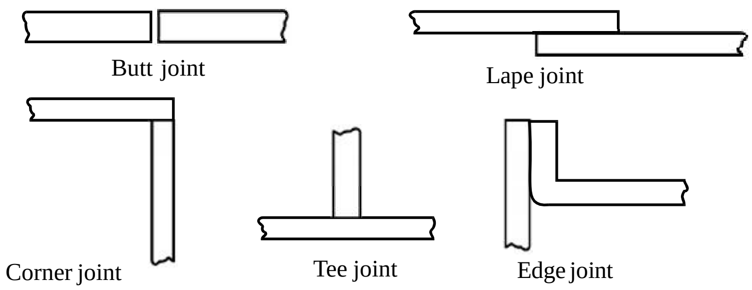


Fig. 2.34 Types of welded joints

(*iii*) Corner joint

A corner joint is obtained by joining the edges of two plates whose surfaces are at an angle of 90° to each other. In some cases corner joint can be welded, without any filler metal, by melting off the edges of the parent metal. This joint is used for both light and heavy gauge sheet metal.

(*iv*) Edge joint

- This joint is obtained by joining two parallel plates.
- It is economical for plates having thickness less than 6 mm.

(*v*) T-Joint

- It is obtained by joining two plates whose surfaces are approximately at right angles to each other.
- These joints are suitable upto 3 mm thickness.
- T-joint is widely used to weld stiffeners in air craft and other thin walled structures.

Welding Positions

The common welding positions are as shown in Fig. 2.35 are

- **Flat Position :** In this welding position, the welding is done from the upper side of joint and the welding material is normally applied in the downward direction as shown in Fig.2.35.
- **Horizontal Position:** In this welding position, the weld is deposited upon the side of a horizontal and against a vertical surface.
- **Vertical position :** In this position, the axis of the weld remains either vertical or at an inclination of less than 45° with the vertical plane.
- **Overhead position :** In this case, the welding is performed from the underside of the joint. The workpieces remain over the head of the welder.

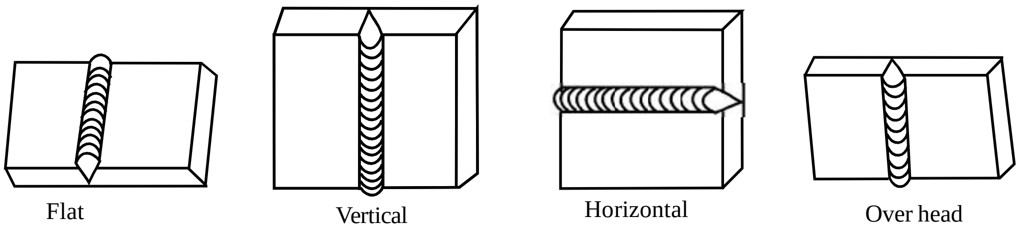


Fig. 2.35 Types of welded joints

2.11.2 Edge Preparation in Butt Welding

- In order to obtain sound welded joint, edge preparation is very essential. It consists of bevelling the edges. After that cleaning of faces is done [Fig. 2.36].
- The square or straight butt welded joints are used where thickness of the plate is from 3 to 5 mm. In this edges are kept 3 mm.
- The single V-butt welded joints are used when the thickness of the plates is between 8-16 mm. The angle of bevel is about 70 degree to 90 degree.
- The double V-butt welded joints are used when the thickness of the plates is more than 16 mm and where welding can be performed on both sides of the plate.
- The single and double U-butt welded joints are used when the thickness of the plates is more than 20 mm. Double U-butt welded joint can be performed on both sides of the plate.

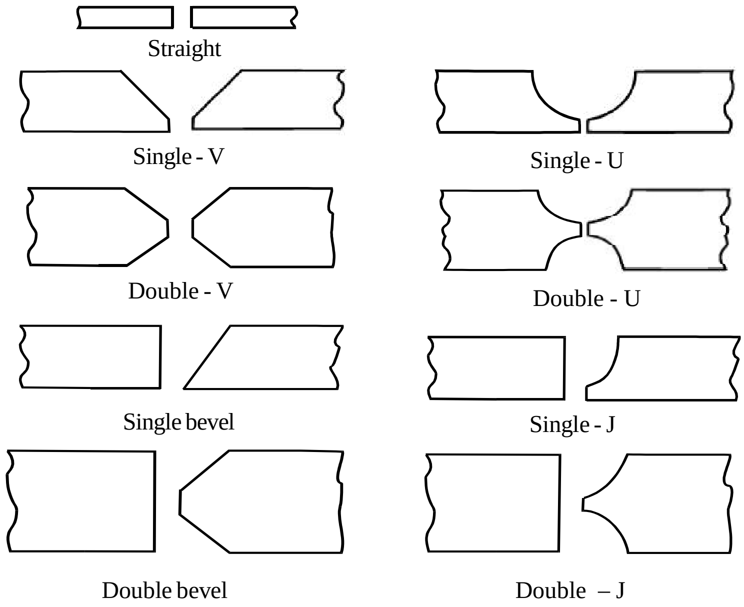


Fig. 2.36 Butt point edge preparation methods

2.12 SOLDERING AND BRAZING

2.12.1 Soldering

- Soldering is an operation of joining two or more parts together by molten metal whose liquidus temperature is below 450°C.
- It is a quick method of making joints in light articles made from steel, copper and brass and for wire joints such as occuring in electrical work.

Classification of Soldering Methods

Soldering methods are classified by the method of heat application. The heat should be applied in such a manner that the solder melts while the surface is heated to permit the molten solder to wet and flow over the surface.

The various soldering methods are

1. Soldering iron methods. 2. Torch method.
3. Dip and wave methods. 4. Induction method.
5. Resistance method. 6. Furnace and hot method.
7. Spray method. 8. Ultrasonic method.
9. Condensation method.

Types of Solder

There two types of solder basically used are :

(*i*) Soft solder, which is usually a lead-tin mixture.

(*ii*) Hard solders, which may be of following types.

- (*a*) Brass solders (copper-zinc alloy)
- (*b*) Silver solders (copper-silver alloy)
- (*c*) Copper solders
- (*d*) Nickel-silver solders.

Soldering Equipments

Soldering equipments include soldering iron and soldering gas stove/heater.

(*a*) Soldering iron : It is a tool used during a soldering operation to heat the solder and parts to be joined.

Soldering irons are of two main types :

(*i*) Those heated by either solid or gaseous fuel.

(*ii*) Those heated electrically.

(*b*) Soldering gas stove/ heater : The soldering gas stove/heater used for heating the soldering bit for accomplishment of soldering operation as shown in Fig. 2.37.

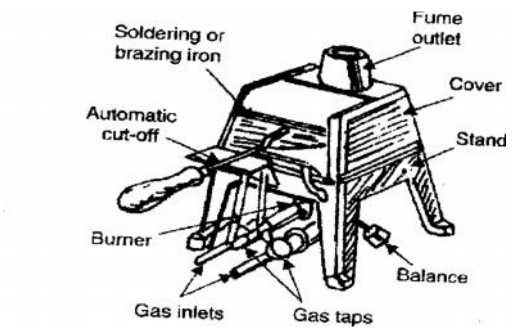


Fig. 2.37 Soldering gas stove

Soldering Procedure

The process of soldering is carried out by the following steps.

(*i*) The surface of the pieces to be joined must be thoroughly cleaned and made free from rust, grease, oil and dirt by scraping with dull knife or emery paper.

(*ii*) Then coat the surfaces with flux.

(*iii*) Take a blob of solder on the bit of the hot soldering iron and allow it run down hill filling the recess of the joints for light work. For heavy work the hot iron should be allowed to fill the longer length of the joint.

(*iv*) Wipe off excess of solder with a place of felt or cotton waste.

(*v*) Wash the joint thoroughly with warm water to remove the traces of acid flux.

Advantages of Soldering

The advantages of soldering are as follows :

(*i*) Simplicity and cheapness of the equipment.

(*ii*) The properties of base metal are not affected due to low temperature.

(*iii*) Good and effective sealing in fabrication as compared to other process like reveling spot welding etc.

(*iv*) Low cost.

Disadvantages of Soldering

(*i*) The soldered joints are not suitable for high temperature because of low melting.

(*ii*) The joint has poor mechanical strength.

Applications of Soldering

The soldering is applicable for

(*i*) Connection in wireless set, T.V. sets etc.

(*ii*) Wiring joints in electrical connections, battery and other terminals.

(*iii*) Drain water gutters and pipes.

(*iv*) Radiator brass tubes for motor car.

(*v*) It is sometimes used to repair utensils.

2.12.2 Brazing

Brazing is a soldering operation using brass as the joining medium. The brazing operation is simply a form of hard soldering using a copper zinc alloy *i.e.,* brass as the uniting medium (the term hard soldering is used because the welding alloy used in the joint is harder than solder, naturally the joint is much more stronger than soldering).

The brass used for making the joint in brazing is generally called "**Spelter**" and its composition depends upon the metal being brazed because it is essential that the spelter shall have a lower melting point than the material being joined.

Three brazing alloys are

1. Copper = 70%, Zinc = 30%, Melting point = 960°C
2. Copper = 60%, Zinc = 40%, Melting point = 910°C
3. Copper = 50%, Zinc = 50%, Melting point = 870°C

When brazing or hard soldering uses a brass mixture, the heating may be by means of

(*i*) Coal gas and heating blow pipe for very small work.

(*ii*) Coal gas and compressed air using the normal blow pipe.

(*iii*) Oxy-acetylene leve torch.

(*iv*) Oxy-hydrogen torch.

(*v*) Coal-gas and oxygen with a suitable torch.

(*vi*) Electrical resistance as on a spot.

Brazing Equipment

The brazing equipment mainly comprises as shown in Fig. 2.38 a blow pipe and brazing hearth. The heat for brazing is obtained by a blowpipe fed with coal gas and air at a slight pressure. When heating of the work is taking place it is advisable to make the most of the heat given out from the blow pipe flame. For this reason a small sheet metal hearth containing fire brick or coke should be used. If the work is placed upon a substance, heat is reflected back on it is undesirable and this conserves the heat during the operation.

Brazing Methods

The brazing methods are as follows :

1.	Torch brazing	2.	Furnace brazing
3.	Induction brazing	4.	Dip brazing
5.	Resistance brazing	6.	Laser brazing and electron beam brazing

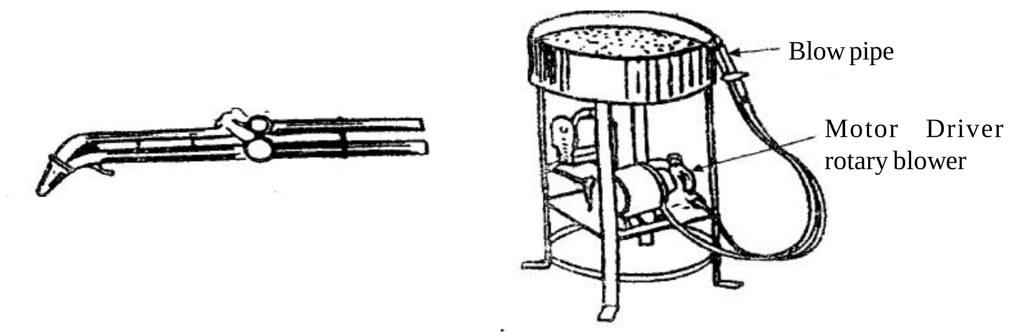


Fig. 2.38 Blow pipe and brazing hearth

Brazing Procedure

1. The surfaces to be joined are thoroughly cleaned.
2. Then a paste made of flux and spelter is kept in the joint, the joint is kept in position by suitable clamps or tongs.
3. The flame is directed over the joint held on a fire brick piece. The flux and spelter will soon melt and fill the recess between the joints. The liquid is spread uniformly over the joints either with a pointed wire piece or by moving the jet of flame circular over the joints.

4. When the joint is hot, common salt is put to soften the glossy hard flux that sets over the joint.
5. The work is removed from the clamp after it is cooled.

Advantages of Brazing

1. Cast and wrought metals can be joined.
2. Metallurgical properties of the base materials are not seriously disturbed.
3. Assemblies can be brazed in a stress free condition.
4. Dissimilar metals can be joined.
5. Non metals can be joined to metals, when the non metal is coated.
6. Materials of different thickness can be joined easily.
7. Complex assemblies can be brazed in several steps by using filler metals with progressively lower melting temperatures.
8. Litter or no finishing is required by the brazed joints.
9. Several operations can be mechanised.
10. Almost all the common engineering materials may be satisfactorily brazed or braze welded.

Limitations of Brazing

1. High degree of skill required
2. Limited size of parts
3. Machining of the joint edges forgetting the desired fit is costly.
4. Joint design is somewhat limited if strength is a factor.

Applications of Brazing

1. Parts of bicycle such as fames and rims.
2. Pipe joints subjected to vibrations.
3. Exhaust pipes in motor engines .
4. Band saws.
5. Tipped Tools.

2.13 WELDING DEFFECTS

Some of the defects found in the weld metals are :

1. Under cut
2. Incomplete fusion
3. Porosity
4. Slag inclusion
5. Hot cracking
6. Cold cracking
7. Lamellar tearing

Under Cut

This appears like a small notch in the weld interface. This is generally attributed to the improper welding technique or excessive welding current. This is mainly caused by the incorrect manipulation of the electrode while depositing the bead, mostly in horizontal and vertical welding.

Incomplete Fusion

Incomplete fusion will be seen as a discontinuity in the weld zone. The main cases for this defect are improper penetration of the joint, wrong design of the joint or in-correct welding technique including the wrong choice of the welding parameters. The main parameter is the welding current, if lower than required would not sufficiently heat all the faces of the joint to promote proper fusion.

Porosity

Porosity in welding is caused by the presence of gases which get entrapped during the solidification process. The main gases that cause porosity are hydrogen, oxygen, and nitrogen. Due to porosity the strength of joint may be reduced.

Slag Inclusion

- Slag is formed by the reaction with the fluxes and it is generally lighter. If this slag is mixed with weld bead that defect is called slag inclusion.
- Some of the factors that cause slag inclusion are as follows :
  - High viscosity of weld metal.
  - Rapid solidification.
  - Insufficient welding heat.
  - Inproper manipulation of the electrode.
  - Undercut on previous pass.
- Slag inclusion weakens the metal by providing discontinuities.

Hot Cracking

The weld metal cracks are called hot cracking because these appear as a result if stress and lack of ductility of the deposited metal at the high temperature. Low melting point compounds such as Fe that get deposited on the grain boundries during solidification are usually responsible for a low ductility and the appearance of the cracks.

Cold Cracking

These cracks are formed near the weld area and are due to excessive cooling rates and the absorbed hydrogen. Since these appear a long time after the welding as cold cracks. This is more danger in the low alloy and high carbon steel welds.

Lamellar Tearing

It is generally formed at the edge of the heat affected zone. It appears as a long and continuous visual separation line between the base metal and heat affected zone. This is caused by the presence of the elongated inclusions such as Mn, Fe, and S in the base metal.

2.14 DESTRUCTIVE AND NON DESTRUCTIVE TESTING OF CASINGS AND WELDING

2.14.1 Destructive Test

It is very essential to have careful examination of the component at each stage of manufacture. Thus, by inspection or quality control, the welding defects are located and preventive measures are devised to reduce or eliminate them.

The welded joints may be subjected to the following destructive tests :

Tensile Test

The tensile testing machine consists of a mechanism for exerting a pull on a test coupled to a device which measures the load or stress. The stressing mechanism may be hydraulic, consisting of a cyclinder with a piston carrying one of the test pieces or it may consist of a screw driven in an axial direction by the rotation of a nut or it may be a simple fulcrum and beam device.

The universal testing machine can be used for tensile testing. Tests for tensile strength, percentage of elongation, elastic limit, yield point, and reduction can be made. The test specimen size is an important aspect of tensile testing. The tensile strength of many metals is high e.g. mild steel has tensile strength of 62, 000 Psi.

Bending Test

Bending test can be accomplished with two types of tests, *i.e.*, the free bend test and the guided bend test. Bend tests of ductile metals are usually conducted on a qualitative basis with no attention paid to the initial stages of bending or the amount of force employed in bending Bending is continued for beyond the limit of elastic properties of metal and into the plastic zone. The failure of the weld bead in the free bend test means that the bead does not have strength that is equal to the base metal.

Impact Test

Impact testing determines the relative toughness of a material. Toughness is defined as the resistance of a metal to fracture after plastic deformation has begun. This plastic deformation is tested by the swing of a weighted pendulum as shown in the Fig. 2.39. Two major tests for determining impact toughness are the Iozd test and the Charpy test.

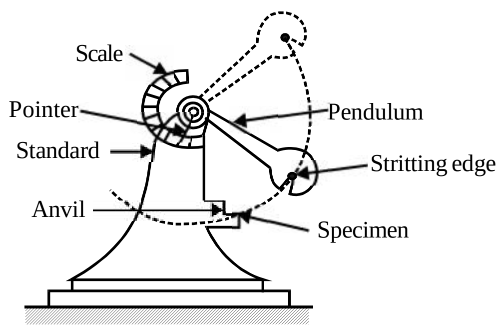


Fig. 2.39 Impact Testing Machine (Pendulum Type)

Hardness Test

Hardness is the ability of a metal to resist penetration, to resist abrasive wear or to resist the absorption of energy under impact loads.

The most common hardness tests are as follows :

1. Brinell Hardness test
2. Rockwell Harness test
3. Vickers Hardness test

Brinell Hardness Test

The Brinell hardness test uses a hardened steel ball 10 mm in diameter, which is forced under a pressure of 3000 kg for hard metals and 500 kg for soft metals, into a flat surface on the test specimen (Fig. 2.40). The ball is allowed to remain there for a minimum of 10 sec for iron and ferrous materials or for at least 30 sec for non ferrous metals. Then the hardened steel ball is removed, leaving a slight spherical impression. The diameter of this impression is then measured with a special microscope. The hardness of the specimen is defined as the quotient of the pressure divided by the area of the surface of the impression, which is assumed to be spherical. From this measurement, the Brinell hardness number is calculated.

$$\text{B.H.N (Brinell Hardness Number)} = \frac{P}{\frac{\pi D}{2}\left(D - \sqrt{D^2 - d^2}\right)}$$

where B = Brinell hardness number.

P = 300 or 500 kg load.

D = diameter of the impression.

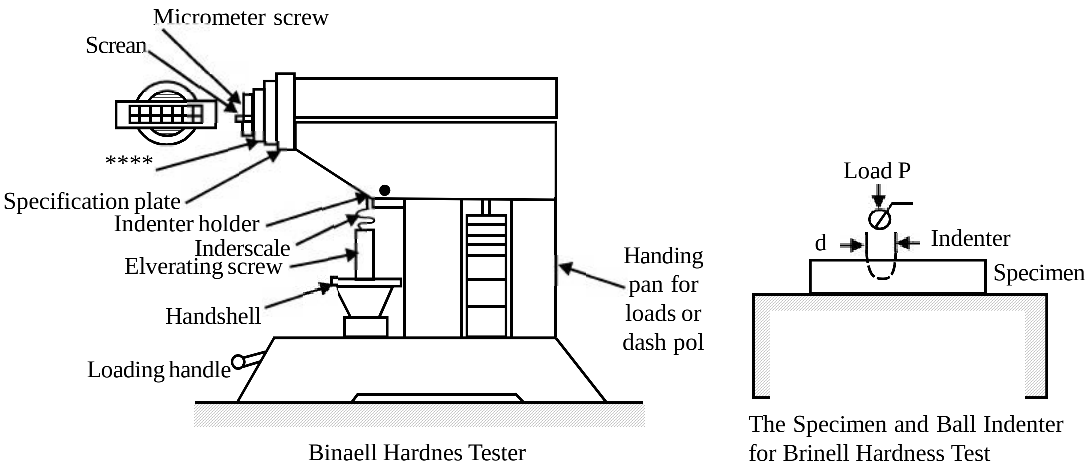


Fig. 2.40 Brnell hardness Tuster

Rockwell Hardness Test

Rockwell tester uses small penetrators and smaller loads than does the Brinell Tester (Fig. 2.41). In this two types of indenters *i.e.*, a Brinell Indenter in form of 120 degree diamond cone or steel balls of $\frac{1}{16}$ and $\frac{1}{8}$ inch diameter are used as shown in Fig. 2.41. Rockwell hardness is measured on an arbitrary in which hardness number is inversely proportional to the depth of penetration.

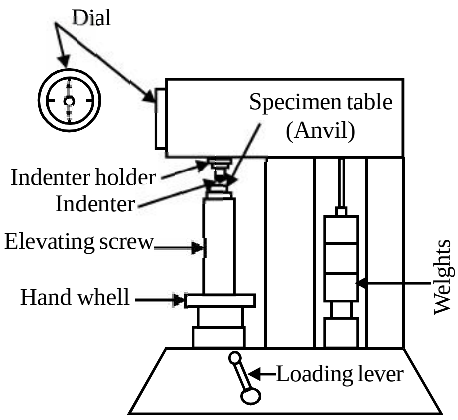


Fig. 2.41 Rockwell Hardness Tester

Vickers Hardness Test

Basically Vicker's hardness test is similar to Brinell hardness test. The difference between two test methods lies in use of indenter. The vicker indenter is a diamond pyramid with square base with included angle of 136° between two faces.

$$\text{Vicker Hardness Number (VHN)} = \frac{2p\sin(\theta/2)}{d^2} = \frac{1.854\,p}{d^2}$$

where P = Indenting load in kgf.

d = Average of two diagonals.

Q = The angle between opposite faces of diamond pyramid which is 136°.

2.14.2 Non-Destructive Test

Visual Inspection

This is suited when appearance is the criterion of checking the quality of weld. Templates are used to check the contour of the welds. It is also used to check cracks, inclusion, contour etc.for strength assessment.

Magnetic Particle Inspection

It is used to check surface flaws in materials which can be magnetised. The surface to be inspected is coated with a liquid solution containing very tiny coloured magnetic particles, and then subjected to magnetic field created by either passing a current through it or by placing a powerful magnet against it. Any lack of continuity at or near the surface on mangetisation creates a local north south magnetic poles and attracts the metallic particles in the solution. On removal of magnetic field, the flaws are detected by magnetic field, the flaws are detected by concentrations of magnetic particles since best results are obtained when magnetic field flux lines are perpendicular to the crack, the object is tested by magnetising twice, creating magnetic fields at 90° to check all flaws.

Liquid Penetrant Inspection

- This method detects surface flaws in all types of metals.
- Either a liquid dye penetrant or a fluroscent liquid is applied to the surface to be inspected and allowed to penetrate for some time.
- The liquid is then removed with a cleaner and surface is dried.
- In former case a developer is then sprayed on the surface which brings out the colour in the dye penetrant that has penetrated into the flaws. In latter case a backlight source is brought upto the surface so that where fluorescent liquid has penetrated will show up slowly.

Ultrasonic Inspection

- It can detect surface as well as internal flaws.
- Ultrasonic waves are passed from a transmitter receiver units through the metal for 1 – 3 micro-seconds and then the selected waves from back surface and flaw surfaces are received back and listened by the same unit. This action wave is repeated 0.5 to 5 million times per second. Each wave is individually represented on an oscilloscope which is callibrated to show the distance between searching unit and any flaw.
- The ultrasonic search unit is traversed in a zig- zag way to detect any flaws indicated by peaks on the oscilloscope screen.

X-ray Inspection

X-rays can pass through any material and reproduce their image, clearly showing any internal flaws, on film or on fluorescent screen or on a cathode ray tube. *X*-ray inspection equipment can be portable one also by utilizing radioactive isotope and then field weld can be tested in as installed condition. *X*-ray inspection equipment selection is dependent on the kind of material to be tested and its thickness geometry and access.

Eddy Current Inspection

In this method an a.c. coil is brought up close to the conductive metal to be tested so as to induce eddy currents in it. These eddy currents produce their own magnetic field which opposes the field of the a.c coil, increasing the impedance of a.c coil which can be measured and provides alarm to indicate presence of flaw in metal.

Testing Welds for Leakage by Testing Tanks/Vessels Hydraulically

In this method CO_2 is pressurised and a soap and water solution is put on the outside of each weld. leaks are indicated by the formation of bubbles. In another method, the vessel is pressurised and pressure gauges installed to indicate fall in pressure in about 24 hours to indicate the degree of tightness of vessels and leaks.

MODULE-IV

Metal Forming Processes

3.1 INTRODUCTION

In this chapter we will briefly review the plastic deformation of metals, hot working, cold working and different types of metal forming process. More importantly, by plastic deformation and machining process metals are formed into useful shapes such as tubes and sheets. A question now arises. What is plastic deformation ? Quite clearly, when the stress is applied on a material exceeds its elastic limit, it produces permanent deformation *i.e.,* non-recoverable called **plastic deformation** in the metal. However, deformation is the change in dimensions of metal under the action of applied forces. Infact, the main objective of deformation is to form various shapes without rupture. The examples of plastic deformation process are rolling, florging, drawing, extrusion etc.

The plastic deformation of a metal depends on

(*i*) Chemical composition of metal
(*ii*) Structure content
(*iii*) Grain size
(*iv*) Heating temperature
(*v*) Direction and magnitude of forces deforming the material.

3.2 VARIABLES IN METAL FORMING AND THEIR OPTIMIZATION

Basically, there are two types of variables in metal forming process such as dependent variable and independent variable.

The dependent variables include :

- Force or power requirements.
- Material properties of the product.
- Exit temperature.
- Surface finish.
- Dimensional precision.
- Nature of the material flow.

The independent variables include :

- Starting material.
- Starting geometry of workpiece.
- Tools and die geometry.
- Lubrication.
- Starting temperature.
- Speed of operation.
- Amount of deformation.

3.3 DEPENDANCE OF STRESS-STRAIN DIAGRAM ON STRAIN RATE AND TEMPERATURE

When an external load is applied on the material, the latter undergoes deformation either temporarily or permanently. In the case of temporary deformation, the material returns to its original condition on removal of the external load and the material is said to have undergone elastic deformation. In the second case, the material does not recover its original condition on the removal of the load and is said to have undergone plastic deformation. In either case, the applied load is measured in terms of the force per unit area called the Stress, (σ) . Thus,

$$\text{Engineering stress, } \sigma = \frac{\text{Force}}{\text{Original cross-sectional area}} = \frac{F}{A} \tag{3.1}$$

The units for engineering stress are Newtons per square meter (N/m^2)

or Pascals (Pa), where $1N/m^2 = 1$ Pa

However, in engineering applications megapascal (MPa) units are widely used.

The deformation of the material is measured in terms of strain, (*e*). Thus, the engineering strain is the ratio of change in dimension to the original dimension, and hence it is dimensionless.

$$\text{Engineering strain, } e = \frac{\Delta L}{L_0} = \frac{\text{Change in length}}{\text{Original length}} \tag{3.2}$$

In industrial practice, engineering strain is expressed in terms of percent strain or percent elongation, *i.e.*,

% engineering strain = engineering strain ×100% = % elongation.

From the above discussion, we learnt that the engineering strain is caused by the action of an external force on the surface of the material (*i.e.*, the stress). An interesting question now arises: How are stress and strain related? Before plunging into a discussion on their relation, it is essential to consider the types of stresses that a material is subjected to.

There are four types of stresses, namely,

(*i*) Tensile, (*ii*) Compressive, (*iii*) Shear and (*iv*) Bulk.

Under a tensile stress, when a load is applied on the material, its length increases while the length decreases in case of a compressive stress. Thus, it follows that strain is positive under tensile stress and negative under compressive stress. As pointed out earlier, strain may be reversible (*i.e*, elastic deformation) or permanent (*i.e*., plastic deformation). Shear stress is the force per unit area applied parallel to the surface area of the specimen. The deformation occurred in shear stress is measured in terms of the angle of shear called the shear strain. The shear stress (τ) and the shear strain (γ) are related as

$$\tau = G\gamma \tag{3.3}$$

where G is called the shear modulus. Bulk stress is the force per unit area applied on the material uniformly in all directions, so as to change the volume of the material without changing its shape. The ratio of the change in volume to the original volume gives the bulk strain. The bulk modulus is defined as the ratio of bulk stress to bulk strain.

$$\text{Bulk modulus} = \frac{\text{bulk stress}}{\text{bulk strain}}$$

$$= \frac{\text{change in pressure}}{\text{change in volume per unit volume}}$$

$$= \frac{-dP}{dV/V} = -\frac{V.dP}{dV} \tag{3.4}$$

The reciprocal of bulk modulus gives the compressibility, i.e, equals to

$$-dV/V.dP \tag{3.5}$$

The negative sign means that with increase of pressure volume decreases.

Strain rate is defined as :

Strain rate = V/h

where V = Deformation velocity and

h = Instantaneous height or length of the workpiece.

Stress - Strain Relation

When stress values are low, for most materials, the stress is proportional to the strain

i.e., stress $\propto$ strain

or $$\sigma = Ee \quad (3.6)$$

The relation (3.6) is called the Hooke's law and the proportionality constant, *E* is the modulus of elasticity, or Young's modulus, or the stiffness constant. The stiffness constant is a measure of the ability of the material that withstands the applied external load without much deformation.

The unit of *E* is N/m^2 or Pa. Normally *E* is given in units of Mega Pascal (MPa) or Giga Pascals (GPa). For most typical metals the magnitude of *E* ranges between 45 GPa for magnesium and 407 GPa, for tungsten.

Deformation in which stress and strain are proportional is called elastic deformation. A plot of stress (ordinate) versus strain (abscissae) gives rise to a linear relationship as shown in Fig. 3.1. The slope of the straight line gives the modulus of elasticity, or stiffness constant, E. The greater tha modulus the stiffer the material or the smaller the elastic strain. The modulus is an important characteristic for considering the mechanical behaviour of the material.

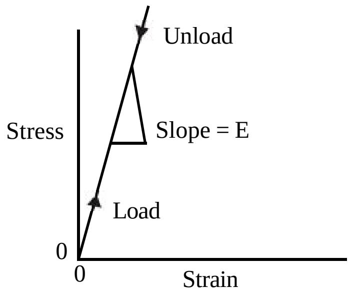


Fig. 3.1 Linear stress-strain curve

A material which obeys Hooke's law is said to be elastic such an elastic deformation is nonpermanent, which means that on release of the applied load, the material returns to its original condition. As shown in Fig. 4.1, application of the load corresponds to moving up in a straight line from the origin and upon release of the load, the line is traced back to the origin. Most materials are elastic at relatively low stresses.

There are some materials like gray cast iron, concrete and many polymers for which the stress -strain curve is non-linear (Fig. 3.2).
Such materials are said to be plastic. For low stresses, the material is elastic but beyond a certain stress value the material becomes plastic. In such cases, it is not possible to determine the value of E, and normally, either tangent or secant modulus is determined. Tangent modulus is obtained from the slope of the stress strain curve at some specified range of stress, while secant modulus is taken as the slope of a secant drawn from the origin to some given point of the curve.

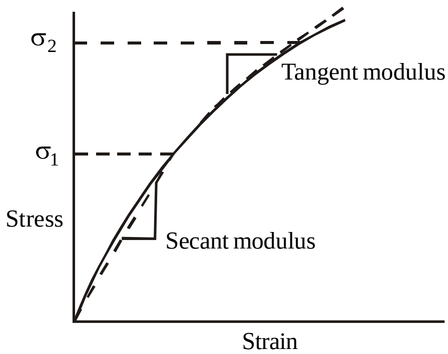


Fig. 3.2 Non-linear stress-strain curve

The stiffness constants of some materials are given below :

Material	E(GPa)	Material	E(GPa)
Diamond	786	Ni	207
Tungsten Carbide	620	Steel	207
Al_2O_3	345	Nylon	2.75
Cu	110	Vulcanized rubber	3.40
Al	69	Natural rubber	0.007 – 0.06

A comparison of the E values shows that the ceramic materials possess higher values of E than the metals and the polymer materials possess lower values of E, the stiffness constant.

Effect of Strain rate

– Flow stress of metal increases with strain rate.
– Temperature of work material increased with strain rate.
– Strain rate increases by improved lubrication of tool-metal interface.

3.4 COLD WORKING AND HOT WORKING OF METALS

3.4.1 Cold Working

Plastic deformation of metals below the recrystallization temperature is known as **cold working**. Generally the cold working is carried out at room temperature. Many cold working processes are used for mass production.

Advantages

The advantages of cold working in comparison with hot working are as follows :

– Better accuracy is obtained.
– Better surface finish is obtained.
– No heating is required.
– Better strength, fatigue and wear properties of materials.

Disadvantages

– Higher forces are required to initiate and complete the deformation.
– Heavier equipment is required.
– More powerful equipment is required.
– Undesirable residual stresses may be produced.

3.4.2 Hot Working

Hot working is defined as working of metals above their recrystallization temperatures. Here plastic deformation of metal carried out at temperature above the recrystallization temperature.

Advantages

- Less force is required for deformation.
- Less power equipment is needed.
- Grain size obtained is favourable which leads to better mechanical properties of metal.

Disadvantages

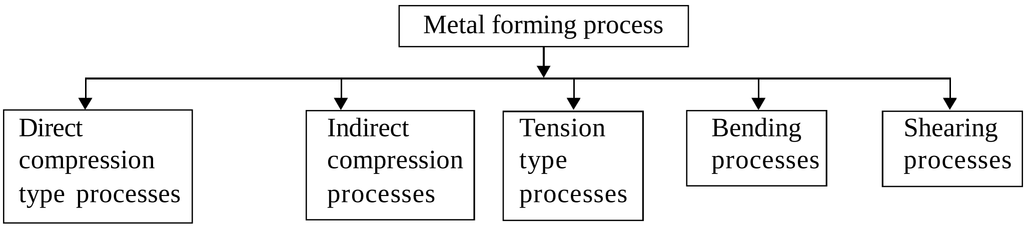
- Poor surface finish of material is obtained.
- Poor dimensional accuracy.
- Lower life of tooling and equipment

3.4.3 Comparison of Hot working and Cold working

Hot Working	Cold Working
■ Process is carried out at a temperature above the recrystallization temperature.	■ Process is carried out at a temperature below recrystalisation temperature.
■ Mechanical properties like elongation, reduction of area improved.	■ Elongation, reduction area and inpact value are decreased by cold working.
■ Microstructure shows refined grain structure.	■ Microstructure shows distorted grain structure.
■ Less stress is required for deformation	■ More stress is required for deformation.
■ Energy required for plastic deformation is less.	■ Energy required for plastic deformation is more.
■ Surface finish obtained is not so good due to oxidation at high temperature.	■ Surface finish obtained is good.
■ Material handling is difficult	■ Material handling is easy

3.5 CLASSIFICATION OF METAL FORMING PROCESS

Metal forming process are classified according to the type of forces applied to the workpiece. The classification of metal forming process are as follows :



Example Rolling.

Example Extrusion.

Example Stretch forming.

Direct Compression Process

In this process the force is applied to the workpiece surface. Here the metal flows at right angles to the compression direction. Rolling and forging are the examples of direct compression process (Fig. 4.3).

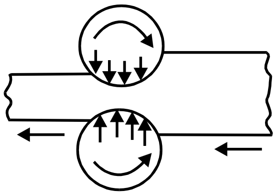


Fig. 4.3 Rolling

Indirect Compression Process

In this type of process the applied forces are tensile, but the indirect compressive forces are generated by the reaction of workpiece with the die. Extrusion is an example of indirect compression process as shown in Fig. 4.4.

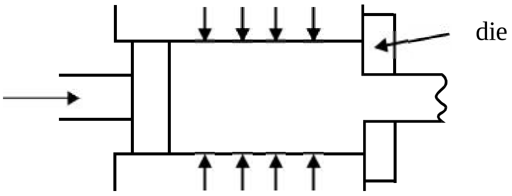


Fig. 4.4 Extrusion

Tension Type Forming Process

In this type of process the sheet metal is wrapped to the contour of a die applying of tensile force. Stretch forming is an example of tension type forming process as shown in Fig. 4.5.

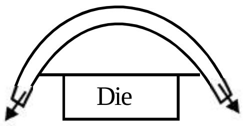


Fig. 4.5 Stretch forming

Bending Process

Bending is the process where bending moment is applied to the sheet. V–bending is one of the examples of bending process (Fig. 4.6).

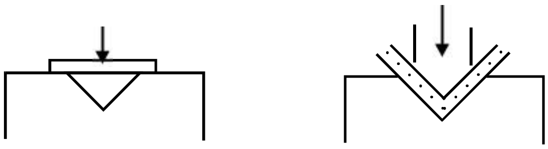


Fig. 4.6 V-bending

Shearing Process

Shearing is the process where shearing forces are applied to rupture the metal in the shear plane.

Extrusion

4.1 INTRODUCTION

In extrusion, a block of metal (billet) is forced to flow through an opening having a smaller cross sectional area than that of the original billet. The opening is provided by a die designed to give the desired shape to the product. More importantly, die geometry remains the same throughout the operation, extended products have a constant section.

Typical products made by extrusion are railings for sliding doors, tubing having various cross sections, structural and architectural shapes and door and window frames etc. Extruded products may be of sections like square, angle, T, I etc. More specifically, aluminimum alloys are mostly used in the production of extruded materials Rubber, lead, tin, copper, titanium, molybdenum, vanadium, steel, can also be extruded.

4.1.1 Advantages of Extrusion over other forming processes

- Higher reduction in a single pass is possible.
- Since it is a compression process, some brittle material can be extruded.
- The range of extruded items is very wide. Cross sectional shapes not possible by rolling, such as those with re-eutrant sections can also be extruded.
- Dimensional accuracy of extended parts is generally superior to that of rolled ones.
- Smaller parts in large quantities can be made.

- Now-a-days extrusion processes are mainly used to produce a large variety of shapes in long products such as bars, angles, sutings, circular and and non-circular tubes, tooth paste tubes etc.

4.2 TYPES OF EXTRUSION PROCESS

The different extrusion processes are as follows :

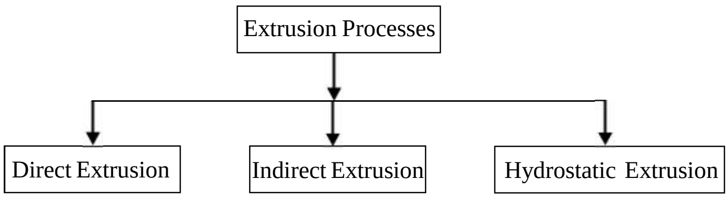


Fig. 4.1 Types of extrusion processes.

4.3 DIRECT EXTRUSION

The direct extrusion is shown in Fig. 4.2.

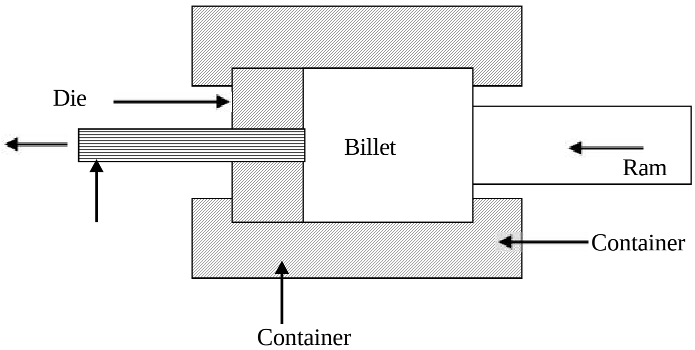


Fig. 4.2 Direct extrusion.

In direct extrusion, the product emerges from the die in the same direction as the direction of the application of pressure. The process starts with placing the billet in a cylinder. On the other end of the cylinder a die shape of extrude is fixed. The product flow out of the die. This process is used for manufacture of circular as well as non-circular bars and tubes, angle sections etc. Since the direction in which the material extruded is same as that of punch motion, hence the name **forward extrusion**. Relation between extrusion load and ram travel is shown in Fig. 4.3.

The extrusion force is calculated by the relation ;

$$F = A_0 K \, l_n \left(\frac{A_0}{A_f} \right),$$

where, A_0 = Area of the billet

A_f = Area of the extruded part

K = Extrusion Constant

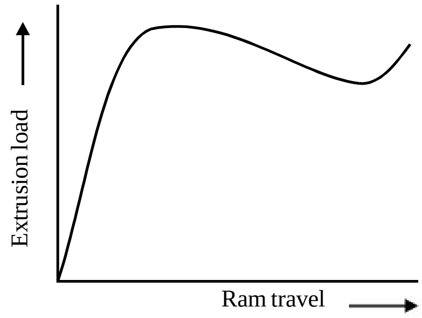


Fig. 4.3 Extrusion load Vs ram travel

Applications of Direct Extrusion

Extrude circular as well as non-circular solid sections and tubular sections.

4.4 INDIRECT EXTRUSION

Indirect extrusion is shown in Fig. 4.4.

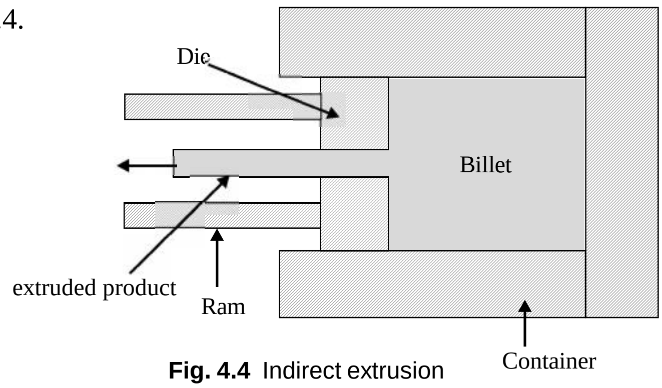


Fig. 4.4 Indirect extrusion

In indirect extrusion, the metal flows in the opposite direction of the ram. It is more efficient since it reduces friction losses considerably. The only limitation is that it is not extensively used because it restricts the length of the extended component. This process is also known as **backward extrusion** because during the ram travel, the die applies pressure on the billet and the deformed metal flows through the die opening in the direction opposite to the ram motion. The variation of extrusion pressure with ram travel is shown in Fig. 4.5.

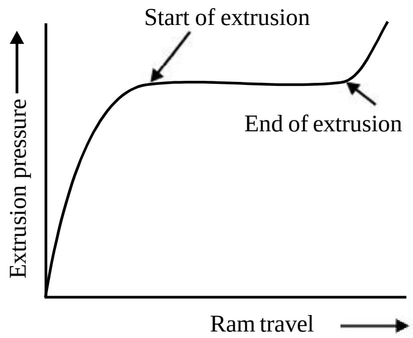


Fig. 4.5 Variation of extrusion pressure with ram travel.

4.5 IMPACT EXTRUSION

Basically, it is a cold extrusion process. The impact extrusion is shown in Fig. 4.6. This process is carried out at a high speed.

The blank (slug) is placed in the die as shown in Fig. 4.6. The plunger strikes the blank. The punch travel cause the material to heat up and then become plastic. Therefore, the material is extruded quickly through the space between the die and the punch as shown in Fig. 4.7.

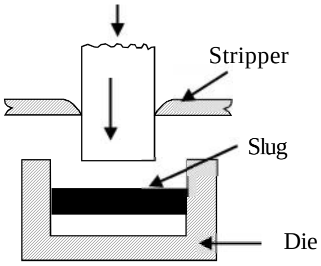


Fig. 4.6 Slug in die

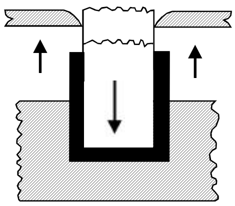


Fig. 4.7 Extrusion completed

Applications

Thin walled items such as tooth paste containers, radio shields, food containers, conderser boxes, thin-walled box cases for condensers and cigarette lighter cases are made by this process. Lead, tin, aluminium and copper can be extruded easily.

4.6 HYDROSTATIC EXTRUSION

In hydrostatic extrusion billet is filled with fluid and pressure is transmitted by a ram pushing the billet forward and compresses the billet circumferentially [Fig. 4.8].

Brittle material can also be extruded successfully by this method. Here the billet is smaller in diameter than that the chamber. There is no friction to overcome along the container walls. In this type of extrusion process the working loads are less and extrusion is also defect free.

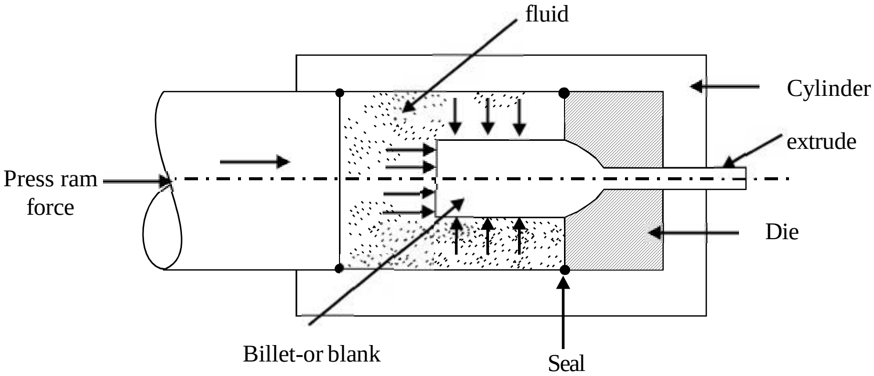


Fig. 4.8 Hydrostatic extrusion

Applications

The application of hydrostatic extrusion include extrusion of nuclear reactor fuel-rods and cladding of metals.

Due to the pressurised fluid, lubrication is very effective. Extruded parts possesess better surface finish and dimensional accuracy. However, the process is costly.

4.7 EXTRUSION OF TUBES

It is a form of direct extrusion. In this type of extrusion a mandrel is used to shape the inside of the tube After the billet is placed inside, the die containing the mandrel is pushed through the billet. The ram then advances, extrudes the metal through the die and around the mandrel as shown in Fig. 4.9.

The heated metal (billet) is placed into the cylinder as shown in Fig. 4.10.

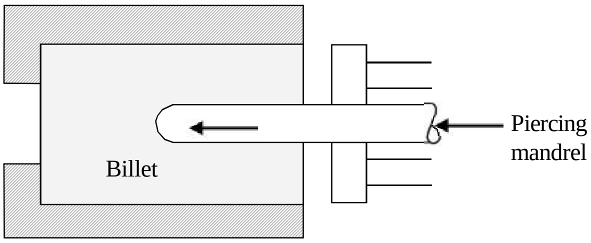


Fig. 4.9 Process piercing

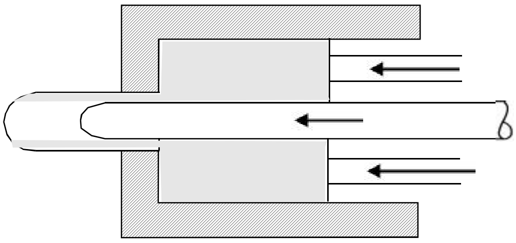


Fig. 4.10 Extrusion of tubes

Wire Drawing

5.1 WIRE DRAWING

Drawing operations involve pulling metal through a die by means of a tensile force applied to the exit side of the die. The plastic flow is caused by compression force, arising from the reaction of the metal with the die wire drawing is a bulk deformation process involving pulling the wire, tube or strip through a converging die. It is usually carried out a room temperapure, except for large deformation, which leads to considerable rise in temperature during drawing. The metal to be drawn, generally, has a circular symmetry.

Wire Drawing Process

In the wire drawing process, one end of the coil is reduced in cross section upto certain length and fed through the drawing die and gripped. By successive drawing operations through dies of reducing diameter, the diameter of the wire can be reduced further. Small diameter wires is wound round on a draw block. The rotation of the block pulls the wire through the die. The drawn wire is taken off and it may be fed to another die. Annealing before drawing permits large reduction (Fig. 5.1).

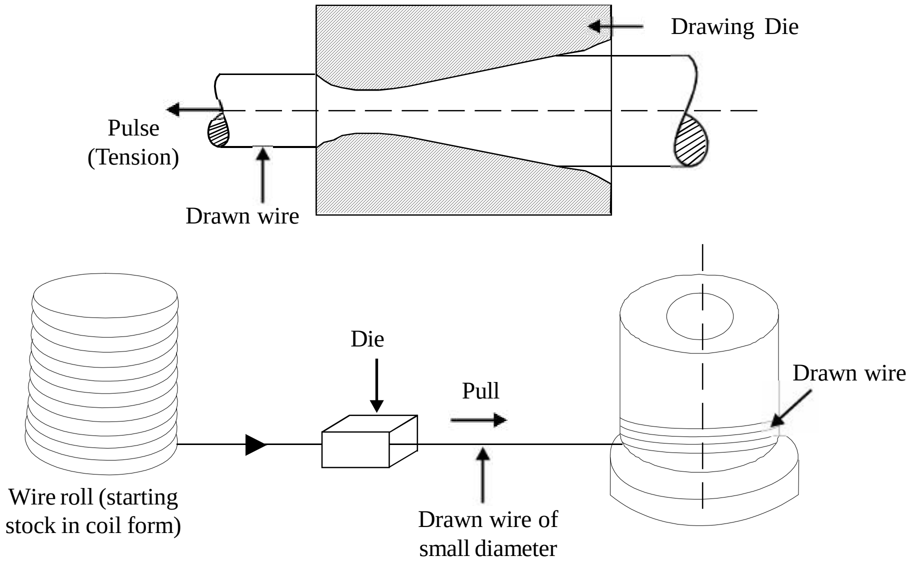


Fig. 5.1 Finish draw block.

Basically, wire is drawn through a single die or several dies. However, reduction in each pass through a die range from 15% to 40%. If greater reductions are required the wire may be drawn through several die.

In wire drawing, a difference is made according to the dimensions of the wire between :

coarse drawing : d = 16 to 4.2 mm

medium drawing : d = 4.2 to 1.6 mm

fine drawing : d = 1.6 to 0.7 mm

ultra-fine drawing : d < 0.7 mm.

5.2 METHODS OF WIRE DRAWING

Two processes are commonly used for wire drawing.They are as follows :

Single draft method

In single draft drawing method the operation is carried out by pulling of wire through the tapered die attached to a power operated reel.

Continuous drawing method

In continuous drawing method, the wire is drawn continuously. Several dies and draw blocks arranged in series are used in this method.

5.3 PROCESS VARIABLES IN WIRE DRAWING

The following are the process variables in wire drawing.

- Reduction in cross sectional area per pass.
- Die angle.
- Friction along the die-workpiece interfaces.
- Drawing speed.
- The temperature.
- The lubrication.

The die angle influences the drawing force and the quality of the drawn products.

Drawing force

The expression for drawing force is given by

$$F = \sigma_{avg} A_f \, ln\left(\frac{A_0}{A_f}\right)$$

where F = Drawing force.

σ_{avg} = Average true stress of the material.

A_0 = Initial area of cross section

A_f = Final area of cross section

The draft, d, is given by

$$d = D_o - D_f$$

where D_o and D_f are original and final diameters of the wire respectively.

5.4 OPTIMUM DIE SHAPE FOR EXTRUSION

The following points should be considered for die design in extrusion.

- Symmetry of entry side.
- More balanced die.
- No sharp corners should be provided.
- Section thickness should be kept uniform.
- Voids should be balanced.

Die materials for hot extrusion are generally hot work die steels.

Types of Extrusion dies

Generally two types of dies are generally used.They are as follows :

Conical die

Dies with conical entrance angles used in extrusion process are known as conical dies. As shown in Fig. 5.2 (a). They require good lubricants. Decrease in die angle results in increase of homogineity and lower extrusion pressure. But beyond a point the firciton in the die surfaces becomes too great. For most operations $45^o < \alpha < 60^o$.

Square die (Flat faced Die)

It is shown in Fig.5.2(b).Square dies produce dead-metal zones. This zone develop a die angle in the deformation zone due to integral shear.

A parallel land on the exit side of the die helps strengthen the die and allow for reworking of the flat face on the entrance side of the die without increasing the exit diameter. Square dies are used for extrusion of non-ferrous metals particularly alluminimum.

Other types of die generally used are

- Spider die
- Porthole die
- Bridge die

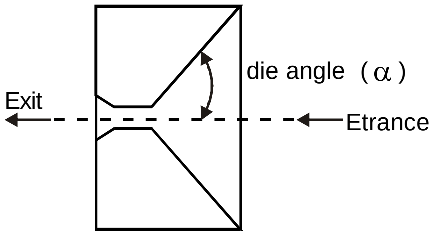


Fig. 5.2 (a) Conical die

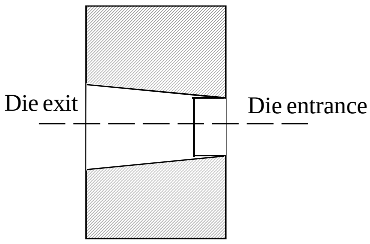


Fig. 5.2 (b) Square die

5.5 OPTIMUM DIE SHAPE FOR DRAWING

Generally the dies are made of tungsten carbide, ceramic, diamond or hard alloy. Tungsten carbide dies are used for drawing wires of small, medium and large size. Hard alloy dies are used for large diameter wires. However, diamond dies are used for drawing very fine wire. For improved wear resistance, steel dies having chromium plating and carbide dies coated with titanium nitride are used.

The cross section of a conical drawing die is shown in Fig. 5.3.

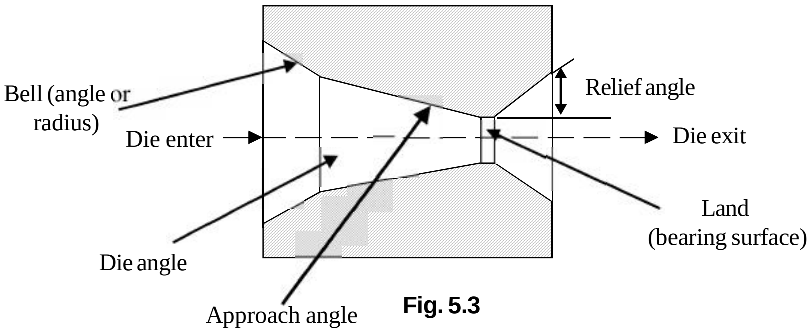


Fig. 5.3

The die angles usually range from 6° to 15°. The entrance of the die is known as **bell**. Bell is designed for entrance of the die and drawing the lubricant with it. The approach angle is responsible for the actual reduction in diameter of the wire. The cone angle of the conical region of the die is known as **die angle**. The value of the die angle should be optimum *i.e.*, the angle at which the process requires the minimum drawing force. The land is the cylindrical region in the die for producing frictional drag on the wire. Also, it provides the strength to the die. The relief angle allows the metal to enhance slightly.

Rolling

6.1 INTRODUCTION

Rolling is the primary metal forming process. In the rolling process, the piece of metal is passed through two rolls rotating in opposite directions at a uniform speed. The gap between the rolls is adjusted to confirm to the desired thickness of rolled section. However, rolling is the process of reducing thickness or changing the cross sectional area of workpiece by means of rolling mills. The metal is subjected to highly compressive force between the rolls for deformation. Moreover, it is generally used for forming metals into desired shapes. Rolling process basically depends upon the friction generated between the rolls and the piece of metal surface being rolled. The friction created helps in gripping the metal so that it can be easily pulled through the space between the rolls [Fig. 6.1].

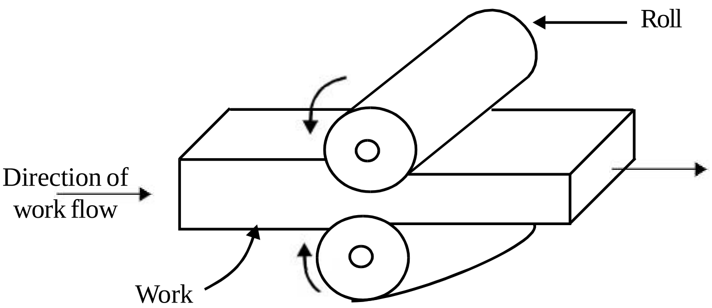


Fig. 6.1

6.2 TERMINOLOGY USED IN ROLLED PRODUCTS

Bloom

Width of bloom equals to its thickness. This is square cross section varying from billet : 150 mm × 150 mm to 400 mm × 400 mm.

Billet

Minimum cross sectional area is 40 mm × 40 mm and varies upto 150 mm × 150 mm.

Slab

It is a hot rolled ingot with cross section with width varying form 500 mm to 1800 mm and thickness varying from 50 to 300 mm.

Plate

Plate has a thickness greater than 6 mm.

Sheet

Thickness less than 6 mm and has a greater width.

Strip

Strip refers to rolled product with a width not more than 600 mm and thickness less than 6 mm.

6.3 PRESSURE AND FORCES IN ROLLING

The rolling process is shown in Fig. 6.2 Here a thickness h_0 enters the roll gap and is reduced to thickness h_f by a rotating rolls.

Let P = Normal force

F = Frictional force

μ = Coefficient of friction between the metal and the roll surfaces

We have $F = \mu P$

Let h_0 = Initial thickness

h_f = Final thickness

α = Angle of bite

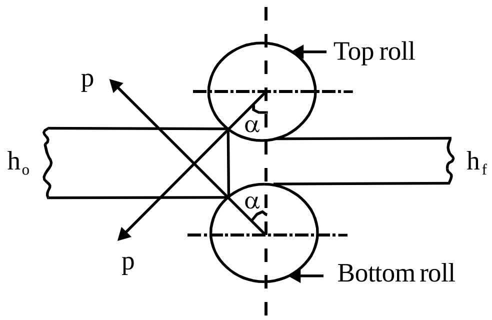


Fig. 6.2

Roll Force (F)

Roll force F is given by the formula

$$F = L \times w \times \sigma_{avg}$$

where F = Roll force.

$w =$ width of the strip.

$\sigma_{avg} =$ Average true stress of the strip in the roll gap.

The above equation is valid for frictionless condition. Also the arc of contact is generally very less compared to roll radius.

Draft

The difference between final thickness and initial thickness is known as draft and it is a function of coefficient of friction and roll radius. Therefore.

$$h_0 - h_f = \mu^2 R$$

Calculation of Roll-strip contact -length

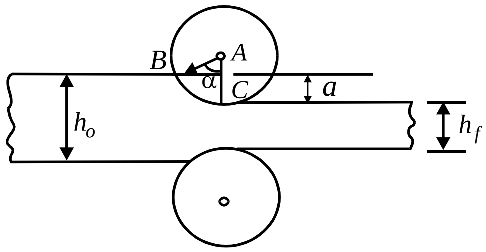


Fig. 5.3

$$BC = L$$

$$\angle CAB = \alpha$$

$$R^2 = L^2 + (R-a)^2$$

$$\Rightarrow \quad L^2 = R^2 - (R-a)^2$$

$$= R^2 - (R^2 + a^2 - 2Ra)$$

$$= R^2 - R^2 - a^2 + 2Ra$$

$$\Rightarrow \quad L^2 = R^2 - R^2 - a^2 + 2Ra$$

$$L^2 = 2Ra - a^2$$

(Since value of a is very less it can be neglected)

$$\Rightarrow \quad L = \sqrt{2Ra}$$

$$= \sqrt{R \times 2a} = \sqrt{R \times \Delta h}$$

$$\Rightarrow \quad L = \sqrt{R \times (h_0 - h_f)}$$

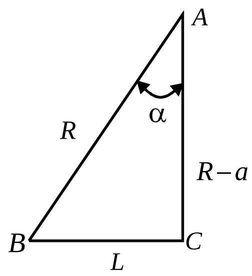


Fig. 5.4

Again $\quad \mu = \tan\alpha = \dfrac{L}{R-a} = \dfrac{\sqrt{R \times \Delta h}}{R - \dfrac{\Delta h}{2}} \qquad \left[\because \; 2a = \Delta h \;\; \Rightarrow \; a = \dfrac{\Delta h}{2}\right]$

Neglecting $\Delta h/2$ as very small,

$$\mu = \sqrt{\frac{\Delta h}{R}}$$

Therefore, for maximum reduction

$$\Delta h_{max} = \mu^2 R$$

Power developed in rolling process

The power developed in rolling process is given by

$$P = \frac{2\pi F\,LN}{60,000} kW$$

where, F is in Newtons, L in meter and N in rpm of the rolls.

6.4 TYPES OF ROLLING MILLS

Basically a rolling mill consists of rolls, bearings, a housing. Also it contains a drive applying power to the rolls and a drive applying power to the rolls and controlling their speed. However, the commonly used rolling mills are

(*i*) Two high rolling mill
(*ii*) Three high rolling mill
(*iii*) Four high rolling mill
(*iv*) Cluster rolling mill
(*v*) Planetary rolling mill
(vi) Continuous rolling mill

Two High Rolling Mill

Rolls are rotated only in one direction. They are made up of equal size. Here in between the two rolls the sheet or bar to be rolled is placed. Rolling process carried out in one direction only [Fig 6.5 (a)].

Three High Rolling Mill

There are three rolling mill in the three high roll mill. The top and bottom rolls are power driven where as the middle roll rotates only by friction. Moreover, these rolling mills are employed as blooming mills for billet rolling and finish rolling [Fig. 6.5 (b)].

Four High Rolling Mill

In this type of rolling mill there are four rolls. The small diameter roll is called working roll and where as two large diameter roll known as back up rolls. Back up rolls are provided with a larger radius to increase the rigidity. Four high mills are used to produce wide plates and hot rolled or cold rolled sheet as well as strip of uniform thickness [Fig. 6.5 (c)].

Cluster Rolling Mill

In cluster rolling mill, each of work rolls is supported by two backing rolls. The cluster mill is used for rolling thin sheet of high strength metals [Fig. 6.5 (d)].

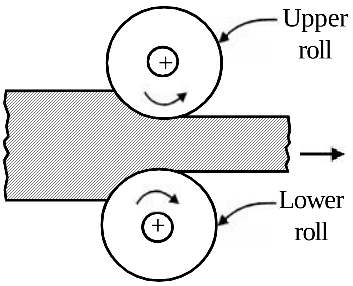
Planentary Rolling Mill

This type of mill consists of multiple rollers of small diameter. These multiple rollers are backed up by a larger roll. These are equispaced on its periphery. This type planetary rolling mill is used to reduce stable slabs to coiled hot rolled strips in a single pass [Fig. 6.5 (e)].

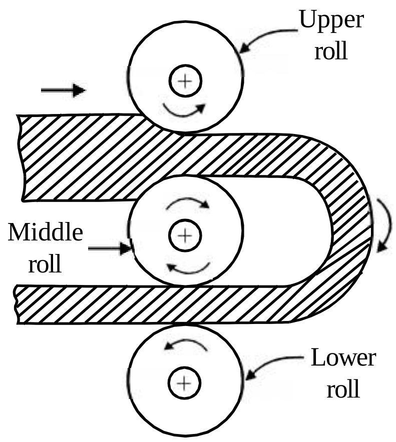
Continuous Rolling Mill

For high production continuous mill is commonly used. It consists of each set of roll known as stand. or rolling mill stand. Here the strip will be moving at different velocities at each stage in the mill[Fig. 6.5 (f)].

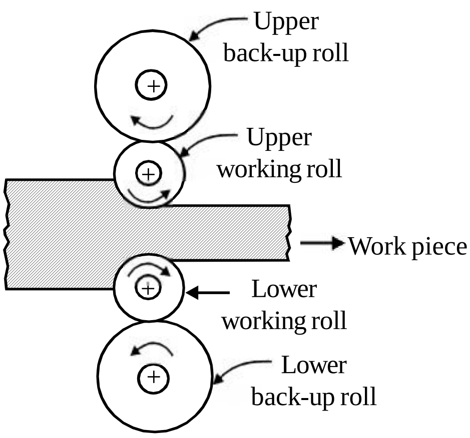
The function of the uncoiler and the wind up reel is to feed the stock to the rolls and coiling up the final product.



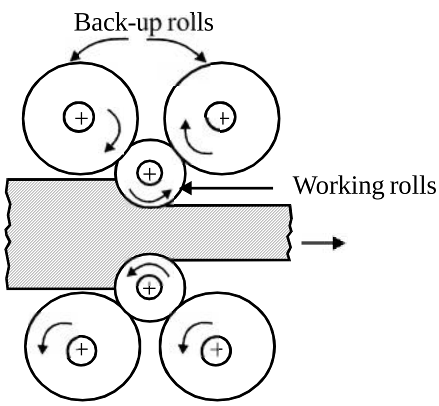
(a) Two-high roll mill



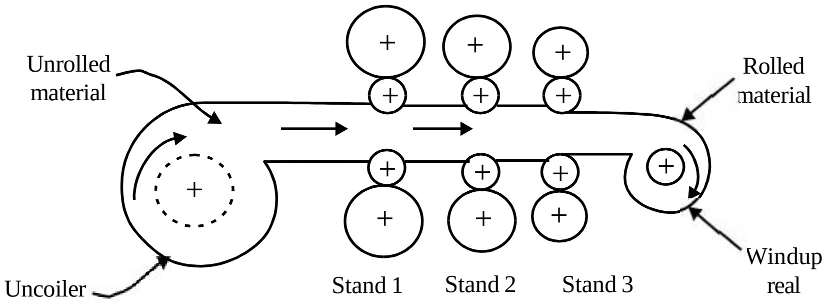
(b) Three high roll mill



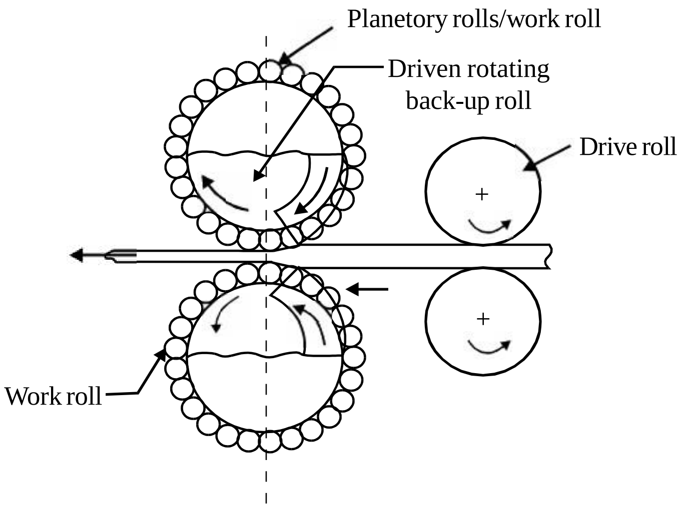
(c) Four-high roll mill



(d) Cluster rolling mill



(e) Cluster rolling mill



(f) Arrangement of rolls in a planetary rolling mill.

Fig. 6.5 Types of Rolling Mills

6.5 ROLLING DEFECTS

Mainly there are two categories of defects occur in the rolling process. They are as follows :

- Surface defects.
- Internal structure defects.

Surface defects

The surface defects are scale, rust, blow holes, scratches, pits etc. These defects generally takes place due to impurities and inclusions present in the original cast material and due to improer material preparation.

Internal structural defects

Wavy Edges

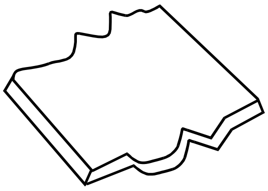


Fig. 6.6

The compressive strain at the edges and tensile strain at the centre leads to wavy edges as shown in Fig. 6.6. Due to result of roll bending the wavy edges occur.

Zipper Cracks

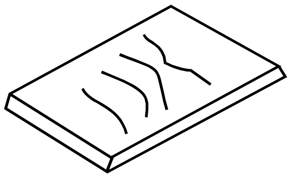


Fig. 6.7

When the strain distribution results in cracks in the centre of the sheet is known as zipper cracks [Fig. 6.7].

However, to compensate the chances of these defects camber is provided to the rolls.

Edge Cracks

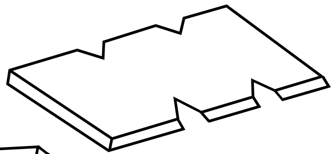


Fig. 6.8

When the edges of the sheet are strained in tension, the edge cracking occurs. Due to poor ductility material the edge cracks occurs [Fig. 6.8].

Centre Split

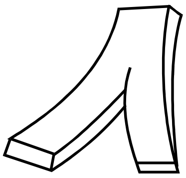


Fig. 6.9

The strain distribution leads to center split of the sheet as shown in Fig. 6.9.

Alligatorling

Complex phenomenon caused by non-uniform deformation and due to improper material structure.

Also there are other types of rolling defects are center wrinkling, residual stress, warping etc.

Sheet Metal Working

7.1 SHEET METAL WORKING

Sheet metal is one of the fundamental forms used in metal working process. Sheet metal parts are usually made by forming material in cold condition. Basically it is a chipless manufacturing process which is used for mass production.

Three factors govern the choice of a material for sheet metal working operations.

- Strength
- Wear resistance
- Corrosion resistance

Press working is carried out on work materials in the form of sheet. Thickness is not changed during this operation. The press working operations are highly benefical due to :

- High degree of accuracy
- High production rate
- Low cost of production

Most sheet metal forming operations are performed on a press. The press either shapes or cuts sheet metal by the tools attached to it and application of force.

Punch and Die

The fundamental tools used with a metal working press are punch and die. Generally the punch is the moving element.

Applications of Sheet Metal Working

Application of sheet metal working process includes washing machine, fans, roofing sheets, automobile components, aircraft bodies etc.

There are various methods of sheet metal working processes.They are :

- Shearing
- Bending
- Drawing
- Forming

Low carbon sheet is most commonly used material for press working.

7.2 BENDING PROCESS

Bending is a very common sheet metal forming operation process. Bending is the process by which a straight length is converted into a curved length. By this process sheet and plate can be converted into channel, drums, tanks etc.

In bending the metal flow is uniform along the beud axis with the inner surface subjected to compression and outer surface subjected to tension.

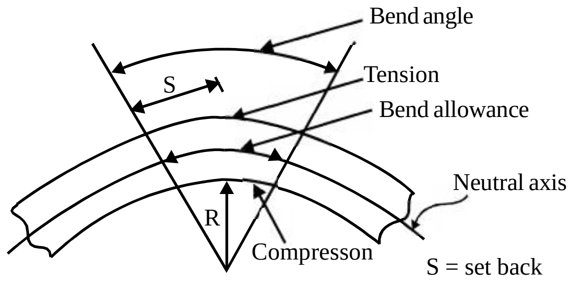


Fig. 7.1

During the bending process, the metal gets distorted plastically within the bend area. Metal towards inner bend surface suffers compression and metal which is towards outer surface is under tension.

Bend angle

This is the angle included between the two extreme positions of bend radius.

Bend allowance

The curved neutral plane of the bend area is called bend allowance.

The bend allowame is approximately given by the relation

$$L_b = a(R + kt)$$

where $L_b =$ Bend allowance (mm)

a = Bend angle (radian)

R = Bend radius (mm)

t = Thickness of sheet (mm) and

k = Constant

Basically, there are three types of bending process such as

- Edge bending
- V- bending
- U - bending

Edge bending : The material is bent at one edge with the help of a punch.

V-bending : The V-shaped punch is used for V-bending process.

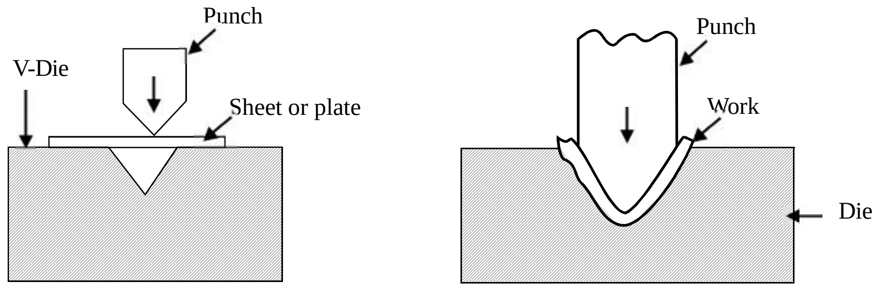


Fig. 7.2 V and U bending

U-Bending : U-bending uses a U-shaped punch

Bending Force : The force is given by

$$F_b = \frac{K.L.\sigma_m t^2}{W}$$

where F_b = Bending force in tonnes.

K= Die opening factor.

L = Length of work in cm.

σ_m = Ultimate tensile strength in tonnes/cm^2.

W = Width of die in cm.

Spring Back

Spring back is the phenomenon associated with bending process. After the applied force is withdrawn, the metal tries to resume its original position leading to decrease in bend angle. This is due to elastic stresses present in the bend area.

Factors Affecting Amount of Bending

- Properties of material.
- Bend length.
- Condition of cut edge.

7.3 FORMING PROCESS

In the forming process the part takes the shape of the punch or die.The commonly used forming dies are

- Solid form dies
- Pad type form dies
- Embossing dies
- Coining dies
- Bending dies

7.4 CLASSIFICATION OF FORMING PROCESS

The sheet metal forming processes can be classified into mainly two categories. They are :

- Shearing process
- Forming process

7.4.1 Shearing Process

Shearing is a cutting operation used to remove a blank of required diemnsions from a large sheet. Shearing process includes.

- Punching
- Blanking
- Perforating
- Parting
- Notching
- Lancing

Principle of Shearing

When a punch penetrates a sheet metal workpiece and enters in to the die, a section through the work piece provides a smooth cut area [Fig.7.3].

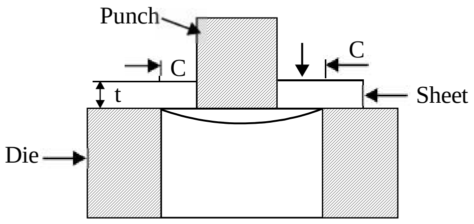


Fig. 7.3 Shearing

Punching

In punching, hole is the discarded product, the material punched out to form the hole being waste. *i.e.*, the cut out part is waste and left out piece is of importance [Fig.7.4].

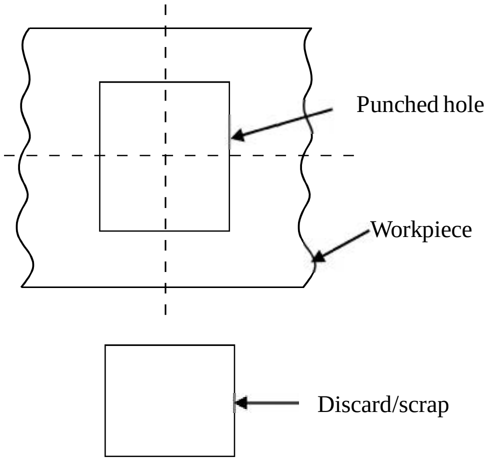


Fig. 7.4 Punching

Blanking

If the removed piece is the useful part and the rest is scrap, the operation is called blanking. The cut out part from the strip is the required component [Fig. 7.5].

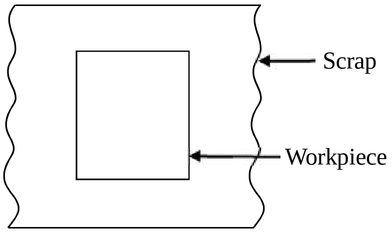


Fig. 7.5 Blanking

The main difference between the punching and blanking is that in punching the metal inside the part is removed and in blanking the metal around the part is removed.

Force in blanking : The maximum force (F_s) required during blanking is given by

$$F_s = \pi D t K_s \quad \text{(for round holes)}$$

$$F_s = t L K_s \quad \text{(for other contours)}$$

where t = Sheet thickness in mm.

L = Length of cut to be cut in mm.

K_s = Shearing resistance of sheet.

Perforating

Punching a number of uniformly spaced holes in a sheet is called perforating. The holes may be of any size and shape [Fig. 7.6].

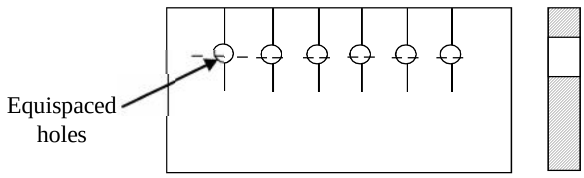


Fig. 7.6 Perforating

Parting

Shearing the sheet into two or more pieces is called parting. It is shown in Fig. 7.7.

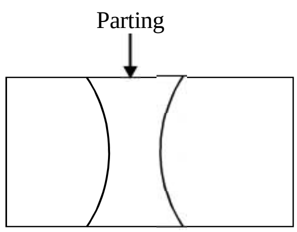


Fig. 7.7 Parting

Notching

Removing pieces from the edges is called notching. It is an operation in which a specified small amount of metal is cut from a blank [Fig. 7.8].

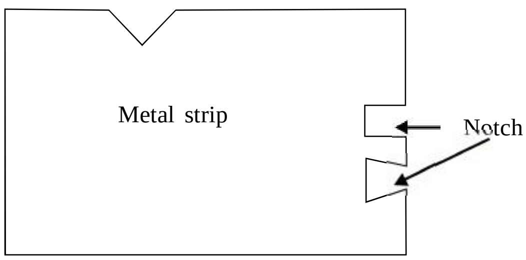


Fig. 7.8 Notching

7.4.2 Forming process

Forming processes are basically bending or stretching operations in which the thickness of the metal materials do not change. When multiple bends are made with a single die, it is called **forming**.

There are generally two principles on which forming process is based.

- Stretching or compressing the material beyond the elastic limit on the outside and inside of the bend.
- Stretching the material beyond the elastic limit without compression, or compressing the material beyond the elastic limit without stretching.

Examples

- Stretch forming
- Deep drawing

Stretch forming

Sheet metal is stretched to the yield point in tension and wrapped over and around the form block (die). In this process the spring back is completely eliminated because the forming is done by introducing uniform tensile stresses to exceed elastic limit of metal.

In stretch forming operation, bending takes place but simultaneously stretching of sheet occurs.

Advantages

Spring back is greatly reduced or completely eliminated as shown in Fig. 7.9.

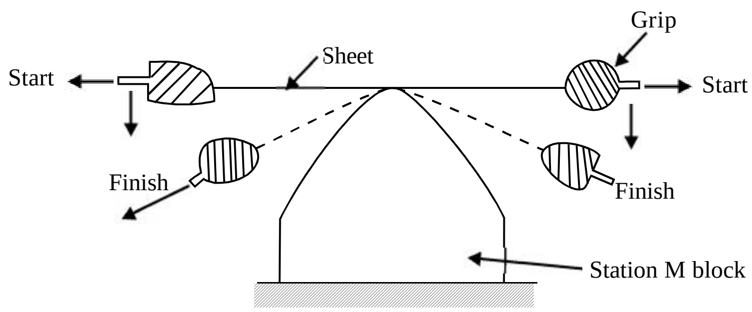


Fig. 7.9 Strech forming

7.5 DEEP DRAWING

Deep drawing is defined as the process for the making of cup shaped parts from flat sheet metal blanks. During this process, a punch forces the blank to flow through a die, producing a shape same as the die shape. The process involves forcing the sheet metal blank into a die cavity with a punch. However, in forming a cup, the metal goes completely into the die. If the depth of the formed cup exceeds the diameter it is called deep drawing.

Examples

- Bottle caps.
- Automobile panels.
- Bath tubs.

Shallow Drawing

Shallow drawing is used when the height of the cup formed is less than half of its diameter.

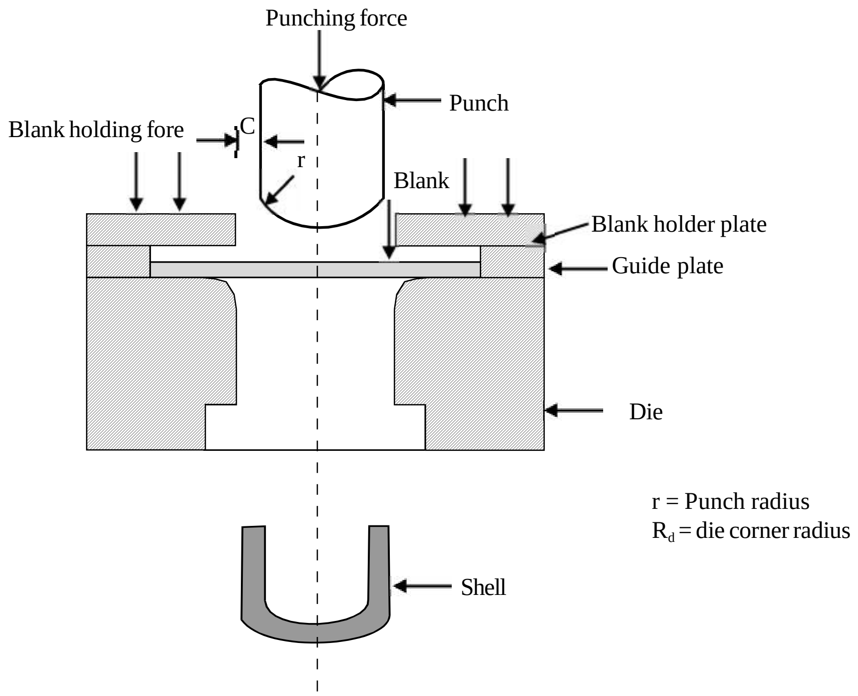


Fig. 7.10 Shallow drawing

Applications of deep drawing

- Kitchen wares.
- Boxes of various wares.
- Components of car bodies.
- Domestic gas cylinders.

Equipment for deep drawing

- A die with a central hole having a profile radius.
- A blank holding plate which keeps the sheet pressed flat on the die surface.
- A punch.

Variables in the deep drawing process

The variables in the deep drawing process are properties of the sheet metal, clearance between punch and die, punch radius, die corner radius, blank holding force, friction and lubrication.

Blank Size

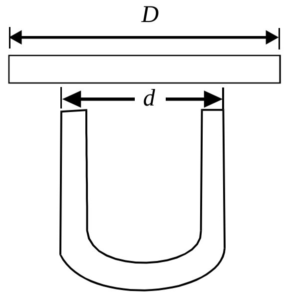


Fig. 7.11

Let D = Blank diameter in mm

r = Corner radius of punch in mm.

h = Height of the shell

d = Out side diameter of cup

$$D = \sqrt{d^2 + 4dh} \text{ for } \frac{d}{r} \text{ is 20 or more}$$

$$D = \sqrt{d^2 + 4dh - 0.5r} \text{ for } 15 \le \frac{d}{r} < 20$$

$$D = \sqrt{d^2 + 4dh - r} \text{ for } 10 < \frac{d}{r} < 15$$

Advantages of deep drawing

- High production rate.
- Moderate equipment and tooling cost.
- Good surface finish.

Limitations

- Limited to forming of thin sheets.
- Forming of shallow or deep parts of simple shapes only.
- Finishing required.