LECTURE NOTES

ON

MANUFACTURING TECHNOLGY

2018 – 2019

II B. Tech I Semester (JNTUA-R15)

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UNIT I

CASTING

1.1 Introduction to Casting:

The casting process which involves pouring of liquid metal into a mold cavity and allowing it to solidify to obtain the final casting. The flow of molten metal into the mold cavity depends on several factors like minimum section thickness of the part, presence of corners, non-uniform cross-section of the cast, and so on. The casting processes can be broadly classified into expendable mold casting and permanent mold casting processes.

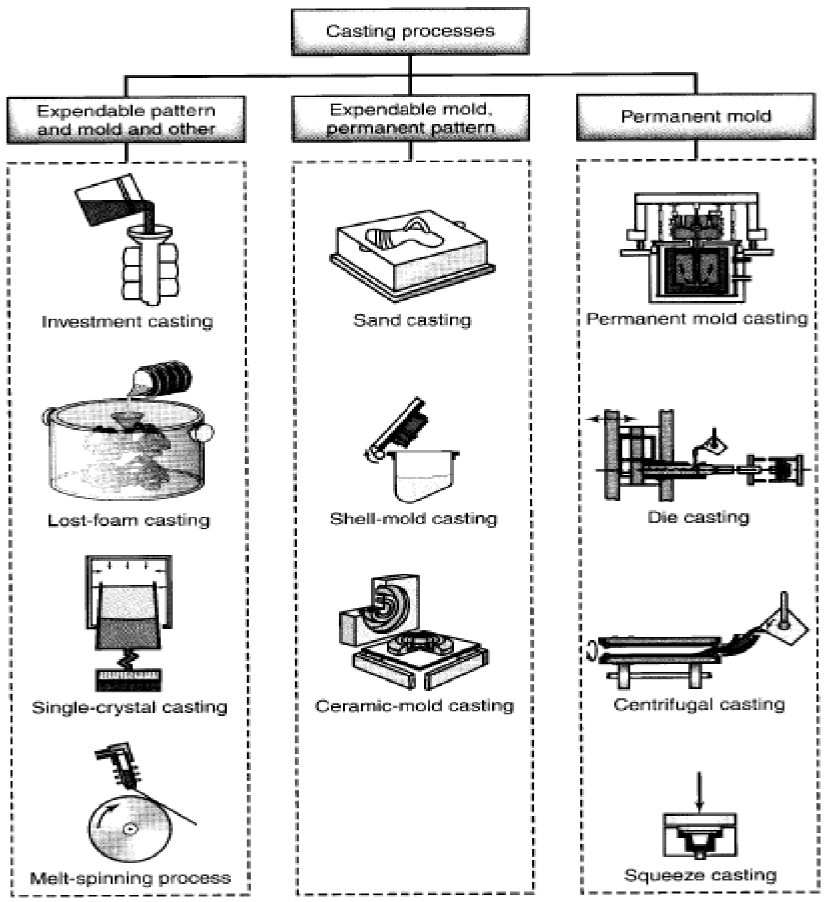


Figure: Various types of Casting Operations

1.2 Sand Casting

Sand casting is widely used for centuries because of the simplicity of the process. The sand casting process involves the following basic steps:

(a) place a wooden or metallic pattern in sand to create a mold,

(b) fit in the pattern and sand in a gating system,

(c) remove the pattern,

(d) fill the mold cavity with molten metal,

(e)allow the metal to cool, and

(f) Break the sand mold and remove the casting.

The sand casting process is usually economical for small batch size production. The quality of the sand casting depends on the quality and uniformity of green sand material that is used for making the mold.

1.2.1 Construction of sand casting:

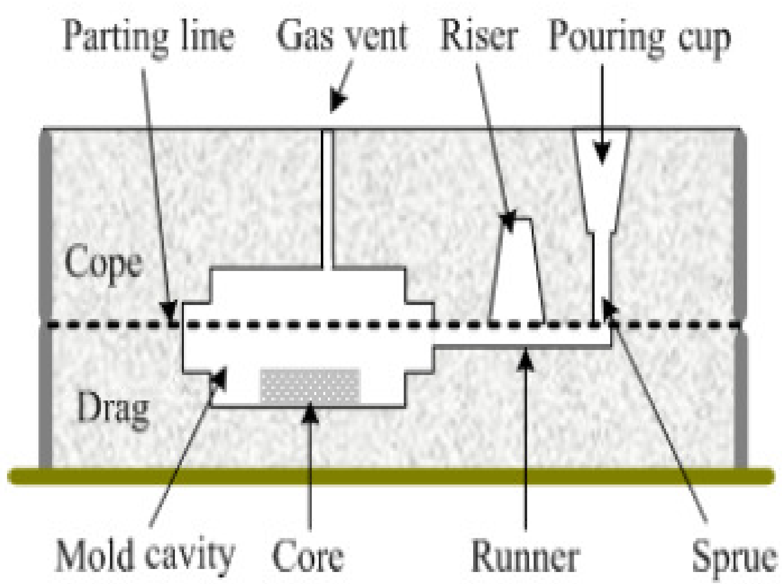


Figure: Construction of sand casting

The major features of molds in sand casting are as follows:

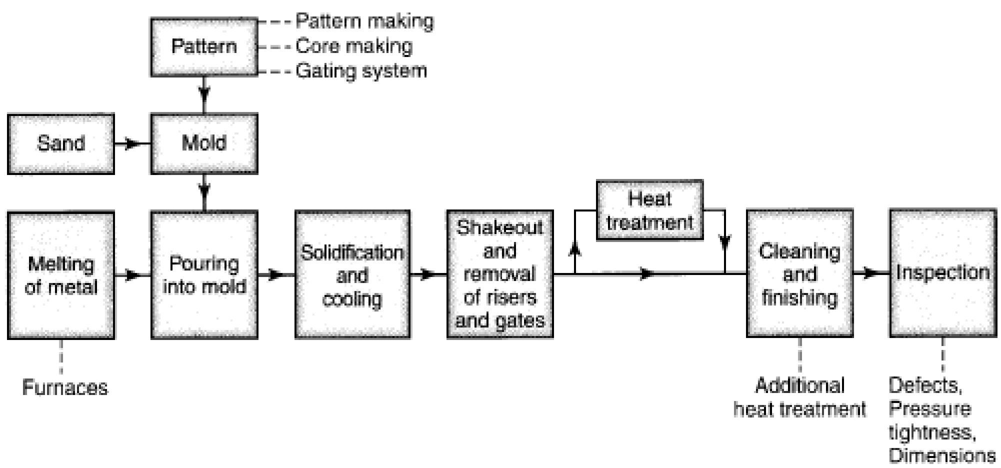
1. The **flask,** which supports the mold itself. Two-piece molds consist of a cope on top and a drag on the bottom; the seam between them is the parting line. When more than two pieces are used in a sand mold, the additional parts are called cheeks.
2. A **pouring basin** or pouring cup, into which the molten metal is poured.
3. A **sprue**, through which the molten metal flows downward.
4. The **runner system**, which has channels that carry the molten metal from the sprue to the mold cavity. Gates are the inlets into the mold cavity.
5. **Risers**, which supply additional molten metal to the casting as it shrinks during solidification.

6. **Cores**, which are inserts made from sand. They are placed in the mold to form hollow regions or otherwise define the interior surface of the casting. Cores also are used on the outside of the casting to form features such as lettering on the surface or deep external pockets.

7. **Vents**, which are placed in molds to carry off gases produced when the molten metal comes into contact with the sand in the mold and the core. Vents also exhaust air from the mold cavity as the molten metal flows into the mold.

1.2.2 Process of sand casting

The molten metal is poured through the pouring cup and it fills the mold cavity after passing through down sprue, runner and gate. The core refers to loose pieces which are placed inside the mold cavity to create internal holes or open section.



The riser serves as a reservoir of excess molten metal that facilitates additional filling of mold cavity to compensate for volumetric shrinkage during solidification. Sand castings process provides several advantages. It can be employed for all types of metal.

Advantages:

The tooling cost is low and can be used to cast very complex shapes.

Limitations:

However sand castings offer poor dimensional accuracy and surface finish.

Applications:

Engine blocks

1.3 Types of Sand Molds

Sand molds are characterized by the types of sand that comprise them and by the methods used to produce them.

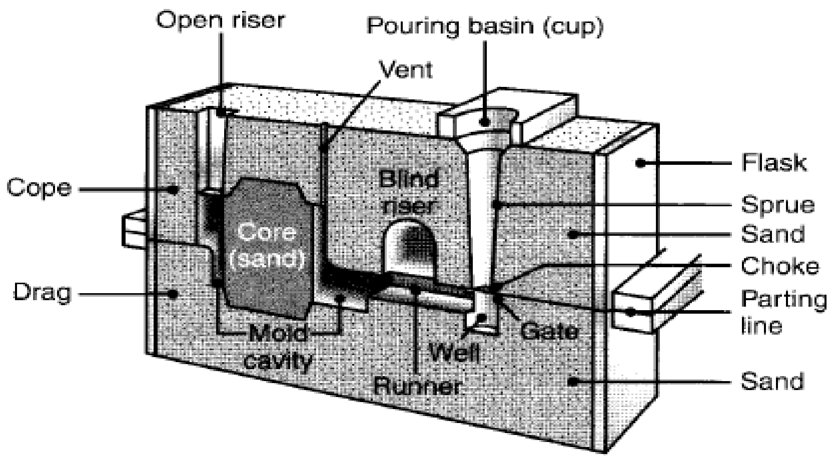


Figure Schematic Illustration of a sand mold

There are three basic types of sand molds

- green-sand,
- cold-box and
- No-bake molds

The most common mold material is green molding sand, which is a mixture of sand, clay, and water.

- The term "green" refers to the fact that the sand in the mold is moist or damp while the metal is being poured into it. Green-sand molding is the least expensive method of making molds, and the sand is recycled easily for subsequent reuse.
- In the skin-dried method, the mold surfaces are dried, either by storing the mold in air or by drying it with torches. Because of their higher strength, these molds generally are used for large castings.
- In the cold-box mold process, various organic and inorganic binders are blended into the sand to bond the grains chemically for greater strength. These molds are more dimensionally accurate than green-sand molds, but are more expensive.
- In the no-bake mold process, a synthetic liquid resin is mixed with the sand and the mixture hardens at room temperature. Because the bonding of the mold in this and in the cold-box process takes place without heat, they are called cold-setting processes.

Sand molds can be oven dried (baked) prior to pouring the molten metal; they are then stronger than green-sand molds and impart better dimensional accuracy and surface finish to the casting. However, this method has the drawbacks that

(a) Distortion of the mold is greater,

(b) The castings are more susceptible to hot tearing because of the lower collapsibility of the mold, and

(c) The production rate is lower because of the considerable drying time required.

1.4 Pattern

Patterns are used to mold the sand mixture into the shape of casting and may be made of wood, plastic, or metal.

1.4.1 Factors influencing the selection of patterns:

The following factors affect the choice of a pattern.

(i) Number of Castings to be produced.

(ii) Size and complexity of the shape and size of casting

(iii) Type of molding and castings method to be used.

(iv) Machining operation

(v) Characteristics of castings

1.4.2 Different types of patterns:

The common types of patterns are

1.4.2.1 Single piece pattern:

This is the simplest type of pattern, exactly like the desired casting. For making a mould, the pattern is accommodated either in cope or drag.

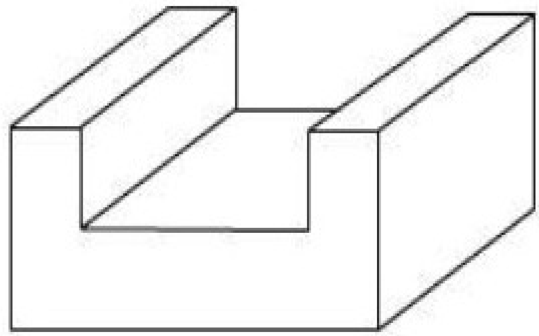


Figure: Single piece pattern

Applications:

Used for producing a few large castings, stuffing box of steam engine.

1.4.2.2 Split pattern:

These patterns are split along the parting plane (which may be flat or irregular surface) to facilitate the extraction of the pattern out of the mould before the pouring operation.

Applications:

For a more complex casting, the pattern may be split in more than two parts.

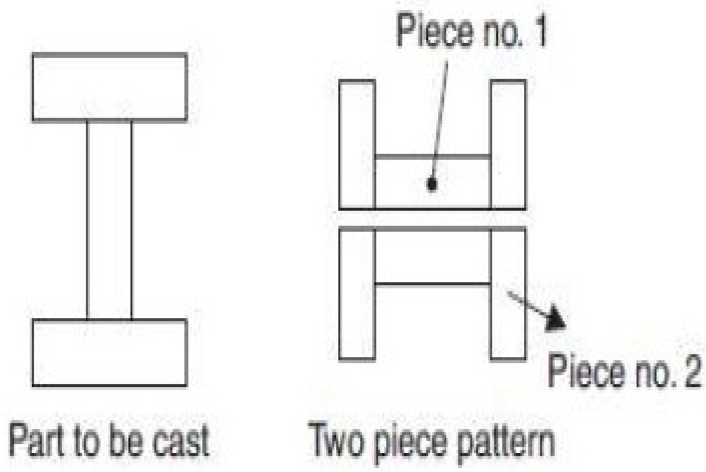


Figure: Spilt Pattern

1.4.2.3 Loose piece pattern:

When a one piece solid pattern has projections or back drafts which lie above or below the parting plane, it is impossible to with draw it from the mould. With such patterns, the projections are made with the help of loose pieces. One drawback of loose faces is that their shifting is possible during ramming.

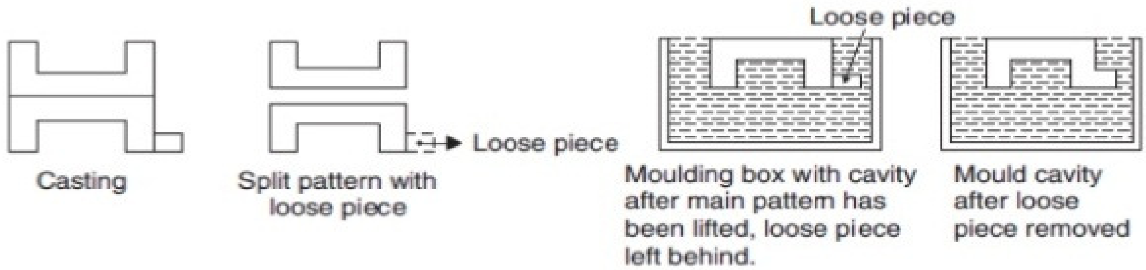


Figure: Loose piece pattern

1.4.2.4 Gated pattern:

A gated pattern is simply one or more loose patterns having attached gates and runners. Because of their higher cost, these patterns are used for producing small castings in mass production systems and on molding machines.

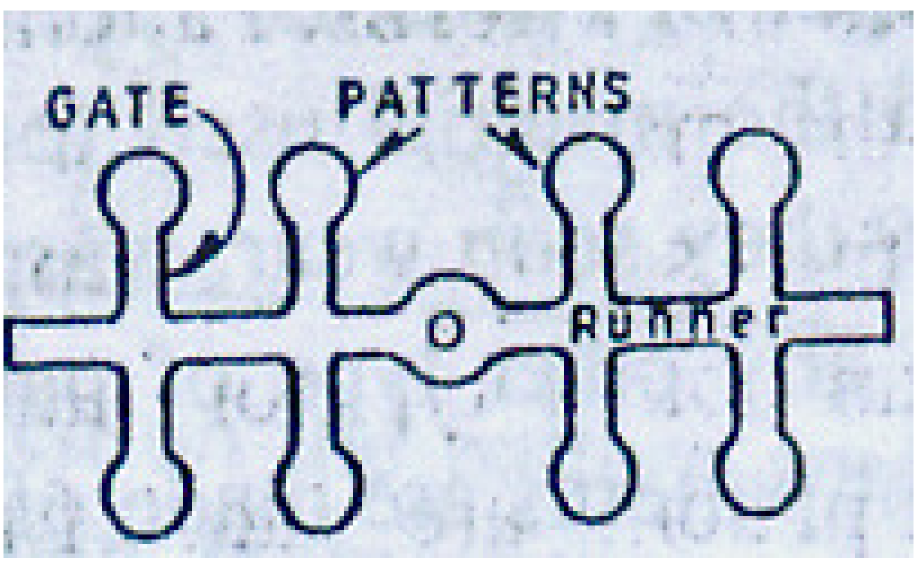


Figure: Gated pattern

1.4.2.5 Match plate pattern:

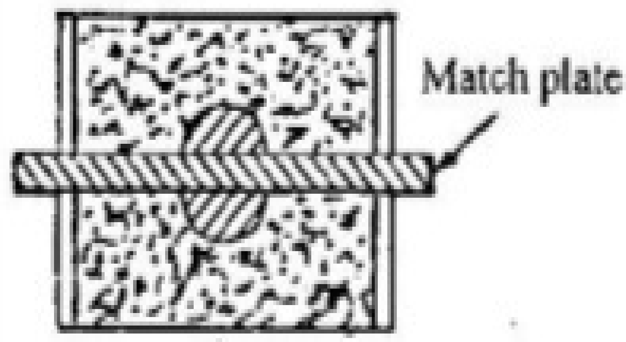


Figure: Match Plate pattern

A match plate pattern is a split pattern having the cope and drags portions mounted on opposite sides of a plate (usually metallic), called the "match plate" that conforms to the contour of the parting surface. The gates and runners are also mounted on the match plate, so that very little hand work is required. This results in higher productivity. This type of pattern is used for a large number of castings.

Applications:

Piston rings of I.C. engines are produced by this process.

1.4.2.6 Sweep pattern:

A sweep is a section or board (wooden) of proper contour that is rotated about one edge to shape mould cavities having shapes of rotational symmetry. This type of pattern is used when a casting of large size is to be produced in a short time.

Applications:

Large kettles of C.I. are made by sweep patterns.

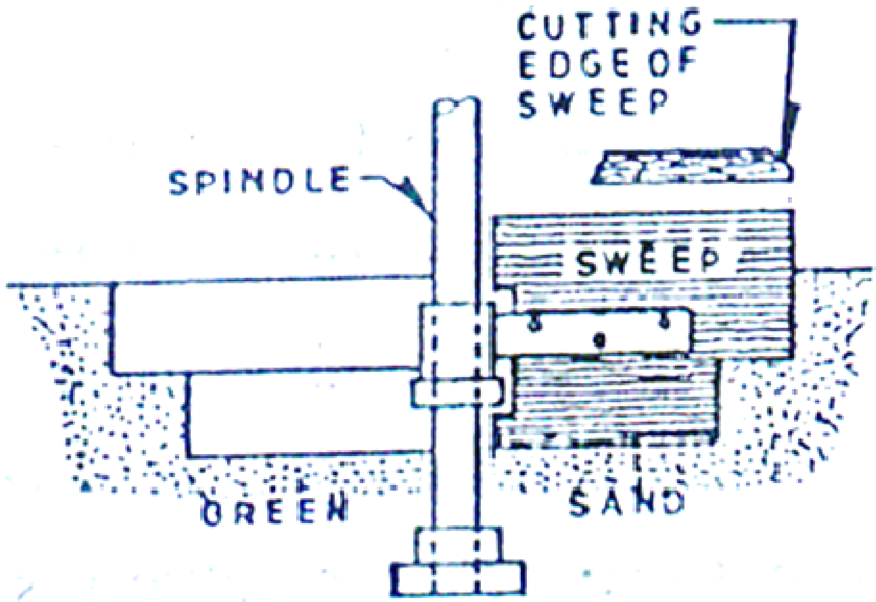


Figure: Sweep pattern

1.4.2.7 Cope and drag pattern:

A cope and drag pattern is a split pattern having the cope and drag portions each mounted on separate match plates.

Applications:

These patterns are used when in the production of large castings; the complete moulds are too heavy and unwieldy to be handled by a single worker.

1.4.2.8 Skeleton pattern:

For large castings having simple geometrical shapes, skeleton patterns are used. Just like sweep patterns, these are simple wooden frames that outline the shape of the part to be cast and are also used as guides by the molder in the hand shaping of the mould. This type of pattern is also used in pit or floor molding process.

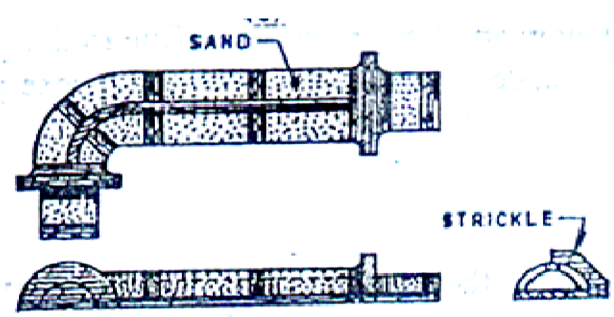


Figure: Skeleton pattern

1.4.2.9 Shell pattern:

The patterns are not made the exact size as the desired casting because such a pattern would produce undersize casting. When a pattern is prepared, certain allowances are given on the sizes specified in the drawing so that the finished and machined casting produced from the pattern will conform to the specified sizes.

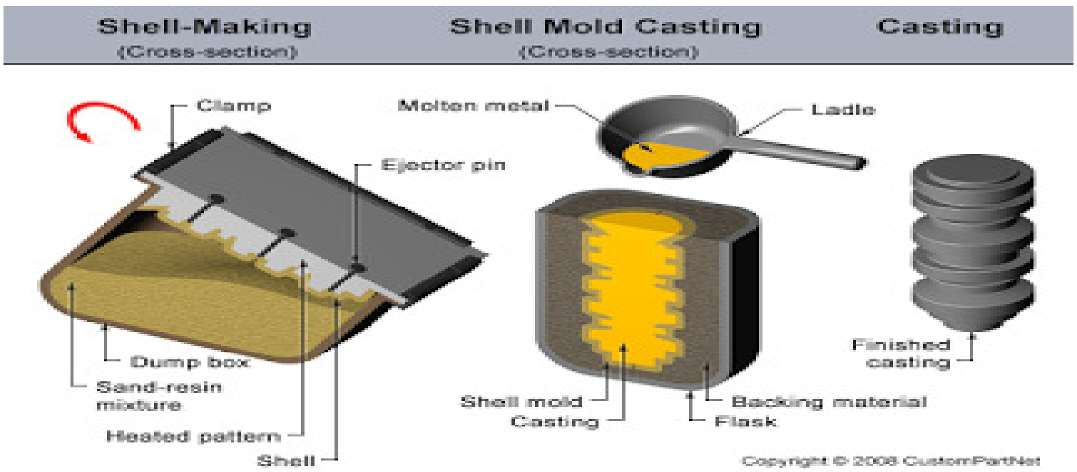


Figure: Shell pattern

1.5 Pattern Allowance

1.5.1 Allowance:

It is defined as the amount of something that is permitted, especially within a set of regulations or for a specified purpose. While designing pattern, the allowances commonly considered are discussed below.

1.5.2 Shrinkage Allowance:

Generally metals shrink in size during solidification and cooling in the mould. So casting becomes smaller than the pattern and the mould cavity.

Therefore, to compensate for this, mould and the pattern should be made larger than the casting by the amount of shrinkage. The amount of compensation for shrinkage is called the shrinkage allowance.

Generally shrinkage of casting varies not only with material but also with shape, thickness, casting temperature, mould temperature, and mould strength. Therefore, it is better to determine the amount of shrinkage according to the past record obtained from many experiences as below

Table: Typical shrinkage of important castings

Type of metal	Amount of shrinkage (%)	Type of metal	Amount of shrinkage (%)
Grey cast irons	0.55-1.00	Zinc	2.60
White cast irons	2.10	Brasses	1.30-1.55
Malleable cast irons	1.00	Bronzes	1.05-2.10
Steels	2.00	Aluminium	1.65
Manganese steel	2.60	Aluminium alloys	1.30-1.60
Magnesium	1.80	Tin	2.00

For mass-produced castings, a moulding die is sometimes made. In that case the master pattern must have allowances for the amount of shrinkage of the material of die and that of casting metal. This is called “double shrinkage allowance.”

1. **Problem**: In a Grey cast iron castings of dimension 80 mm are to be made in a metal mould made of aluminium alloy. The metal mould is to be made using a wooden pattern Determine the correct dimension of the wooden pattern considering the solidification contraction only. Here the wooden pattern must have a double shrinkage allowance for the shrinkage of metal mould (aluminium) and the casting (cast iron).

Solution:

Allowance for aluminium = (80 mm) x (1.20/100 mm/mm) = 0.96 mm

Allowance for cast iron = (80 mm) x (0.80/100 mm/mm) = 0.64 mm

Therefore, total shrinkage allowance = 0.96 + 0.64 = 1.60 mm

Hence, the dimension of the wooden pattern would be = 80 + 1.60 = 81.60 mm

1.5.3 Machining Allowance

In case the casting designed to be machined, they are cast over-sized in those dimensions shown in the finished working drawings. Where machining is done, the machined part is made extra thick which is called machining allowance.

Reasons for the need of machining allowance:

1. Castings get oxidised inside mould and during heat treatment. Scale thus formed requires to be removed.

2. For removing surface roughness, slag, dirt and other imperfections from the casting.

3.For obtaining exact dimensions on the casting

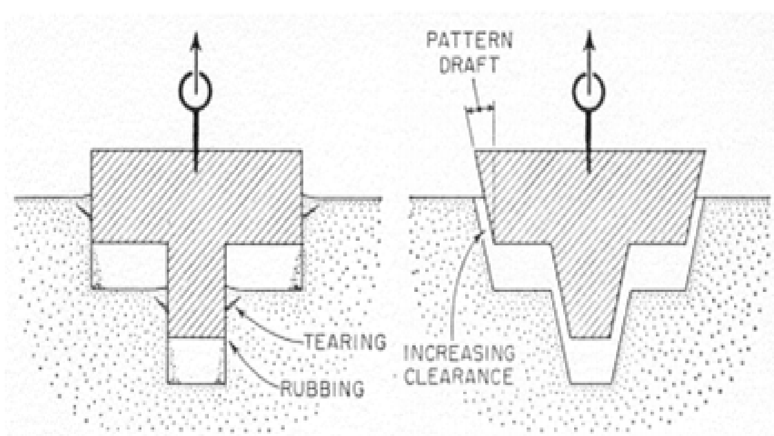
4. To achieve desired surface finish on the casting.

Table: Standards of General machining Allowance

Type of metal and alloys	*Machining allowance (mm)*
Cast irons	
(i) Large size castings (>1000 mm)	10.0
(ii) Medium size castings (<150 mm)	3.0
Cast steels	
(i) Large size castings (>1000 mm)	12.0
(ii) Medium size castings (<150 mm)	4.3
Non-ferrous materials	
(i) Large size castings (>1000 mm)	5.0
(ii) Medium size castings (<150 mm)	1.5

1.5.4 Draft Allowance or Taper Allowance

When a pattern is drawn from a mould, there is always a possibility of damaging the edges of the mould. Draft is taper made on the vertical faces of a pattern to make easier drawing of pattern out of the mould. The draft is expressed in millimetres per metre on a side or in degrees.



The amount of draft needed depends upon

(1) the shape of casting,

(2) depth of casting,

(3) moulding method, and

(4) moulding material.

Generally, the size of draft is 5 to 30 mm per metre, or average 20 mm per metre. But draft made sufficiently large, if permissible, will make moulding easier. For precision castings, a draft of about 3 to 6 mm per metre is required. The table below shows different taper allowances used for different moulding methods.

Table: Approximate taper allowances used in different moulding methods.

Height of pattern mm	Shell Moulding	Sand moulding		
		Metal	Wood	
		Machine drawn	Manual drawn	Machine drawn
Up to 20	0° 45'	1° 30'	3°	3°
20 to 50	0° 30'	1°	1° 30'	1° 30'
:	:	:	:	:
100 to 200	0° 20'	0° 30'	0° 45'	0° 45'

1.5.5. Rapping or Shaking Allowance

When the pattern is shaken for easy withdrawal, the mould cavity, hence the casting is slightly increased in size. In order to compensate for this increase, the pattern should be initially made slightly smaller. For small and medium sized castings, this allowance can be ignored. But for large sized and precision castings, however, shaking allowance is to be considered.

1.5.6. Distortion or Chamber Allowance

Sometimes castings, because of their size, shape and type of metal, tend to warp or distort during the cooling period depending on the cooling speed. This is due to the uneven shrinkage of different parts of the casting. Expecting the amount of warpage, a pattern may be made with allowance of warpage. It is called camber. For example, a U-shaped casting will be distorted during cooling with the legs diverging, instead of parallel. For compensating this warpage, the pattern is made with the legs converged but, as the casting cools, the legs straighten and remain parallel Warpage depends on the thickness and method of casting and it is actually determined by experience. Generally 2 to 3 mm is considered appropriate for 1 metre length.

(a) (b) (c)

Figure a] Casting without Camber b] Actual Casting C] Pattern with camber allowance

1.6 Molding sand properties

The properties that are generally required in molding materials are

1.6.1 Refractoriness

It is the ability of the molding material to resist the temperature of the liquid metal to be poured so that it does not get fused with the metal.

The refractoriness of the silica sand is highest.

1.6.2 Permeability

During pouring and subsequent solidification of a casting, a large amount of gases and steam is generated.

These gases are those that have been absorbed by the metal during melting, air absorbed from the atmosphere and the steam generated by the molding and core sand. If these gases are not allowed to escape from the mold, they would be entrapped inside the casting and cause casting defects.

To overcome this problem the molding material must be porous. Proper venting of the mold also helps in escaping the gases that are generated inside the mold cavity.

1.6.3 Green Strength

The molding sand that contains moisture is termed as green sand.The green sand particles must have the ability to cling to each other to impart sufficient strength to the mold.The green sand must have enough strength so that the constructed mold retains its shape.

1.6.4 Dry Strength

When the molten metal is poured in the mold, the sand around the mold cavity is quickly converted into dry sand as the moisture in the sand evaporates due to the heat of the molten metal.At this stage the molding sand must possess the sufficient strength to retain the exact shape of the mold cavity and at the same time it must be able to withstand the metallostatic pressure of the liquid material.

1.6.5 Hot Strength

As soon as the moisture is eliminated, the sand would reach at a high temperature when the metal in the mold is still in liquid state. The strength of the sand that is required to hold the shape of the cavity is called hot strength.

1.6.6 Collapsibility

The molding sand should also have collapsibility so that during the contraction of the solidified casting it does not provide any resistance, which may result in cracks in the castings. Besides these specific properties the molding material should be cheap, reusable and should have good thermal conductivity.

1.7 Moulding Sand Testing:

1.7.1 Determination of Moisture Content

Direct Weight Method:

Procedure:

Weigh accurately about 100 g cf sample of sand in a tared covered porcelain dish. Dry it in a uniformly heated oven between 105 and 11O'C for about one hour.

Cool to room temperature and weigh.

Repeat the process of drying and cooling till constant weight is attained.

Calculate the percentage moisture by the following formula:

Moisture, percent = (A/B) x 100

Where,

A = loss of weight of the sand sample in g on heating, and

B = weight in g of the sand sample taken.

Make the determination on three separate samples and take the average of three test results as the moisture content of the sand.

Calcium Carbide Method

Apparatus - Speedy moisture tester.

Procedure

- Weigh accurately about 6 g of sample of sand and place it in the cap of the instrument.
- Take a measure of calcium carbide and place in the shaker.
- Place the cap and the shaker in the horizontal position, adjust stirrup, fasten cap to shaker with set screw on stirrup and finally shake the contents. Read moisture content on dial gauge keeping the apparatus in a horizontal position. Make determinations on three separate samples and take the average of three results as the moisture content of the sand mixture.

1.7.2 Determination of Clay Content

Sodium Hydroxide Solution - Dissolve 30 g of sodium hydroxide in distilled water and dilute to a total volume of one litre.

Procedure

Take a 50-g representative sand sample. Spread it over a large area in thin layer and dry it for one hour at 105' to 110°C so that all moisture is expelled.

- Weigh the dried sample and place it in an electric rapid agitator equipped with vertical baffles or a rotating sand washer.
- Add 475 ml of distilled water (@H 7.0 deionized or demineralized water) &d 25 ml of sodium hydroxide solution at room temperature.
- Stir for five minutes. (If a rotating washer is used, place the cover on the jar, and the jar in a machine making about 60 rev/ min in such a manner as to allow the jar to be opened at each revolution.
- Operate the machine for one hour. Then remove the jar from the machine, unseal the cover and wash the adhering sand into the jar
- Wash sand from the stirrer into the jar and fill the jar with distilled water to a height of 150 mm above the bottom of the jar and in such a manner that the contents are well stirred.
- Allow to settle for 10 minutes and then syphon off the water to a depth of exactly 125 mm below the level to which it had been filled, leaving a minimum depth of 25 mm of water in the bottom of the jar.

- Add distilled water, again filling the jar to the 150 mm height, stirring the sediment at the bottom. After settling for the second time for 10 minutes, again siphon off 125 mm of the water.
- Add water again filling to 150 mm height, stirring the sediment at the bottom. After settling exactly for 5 minutes, siphon off 125 mm of the water. Repeat the process of five minutes stand.
- And siphoning until the water is clear to a depth of 125 mm at the end of five-minute period.
- By this method, the m&&al which fails t6 settle at a rate of 25 mm per minute is removed. This is standard clay grade matter and includes all grains of 20 microns or 'less in diameter.
- Dry and weigh the remaining grains. The difference between the weight of the dried grains and that of the original 50-g sample represents clay content.
- NOT= - Certain varieties of sand may rewire longer agitation to liberate properly the clay from the sand grains.
- Incomplete clay removal may be checked microscopically.
- Calculate clay content DND sand portion by the following

  Formulae

$$\text{Clay content, percent} = \{(W_1 - W_2)/W_1\} * 100$$

$$\text{Sand Portion, percent} = (W_2/W_1) * 100$$

Where,

W_1= weight in g of the dried sand sample taken for the test, and

W_2 = weight in g of the dried sand portion (free from clay).

1.7.3 Determination of Permeability

Permeability is defined as that physical property of the moulded mass of sand mixture which allows gas to pass through it. It is numerically equal to the volume of air in millilitres that will pass per minute under a pressure of 1 gf/ ems through a specimen of 1 ems in cross-sectional area and 1 cm high. Base permeability is the permeability of packed dry sand grains containing no clay or other bonding substance.

Apparatus

- Standard permeability meter
- Stop-watch

- Standard sand rammer

Procedure

Wash the sample for its clay content in accordance to dry the sand grains thoroughly at 105" to 110%. Place a base permeability screen, with sides of the cup upward, in the bottom of the standard specimen container. Place sufficient quantity of dried sand in the specimen container to produce the standard sand test specimen. Place the second base permeability screen, with sides of the cup downward, on top of the sand in the specimen container. Place the specimen container with the specimen in the mercury seal of the permeability apparatus. Find out the time required for exactly 2 000 ml of air to pass through the specimen. After the pressure has become steady read the pressure on the pressure indicator and record in gf/cm^2

Calculate the base permeability number (P) of the sand from the following formula:

$$P = (v \times h) / (p \times a \times t)$$

Where

V = volume of air in ml passed through the specimen

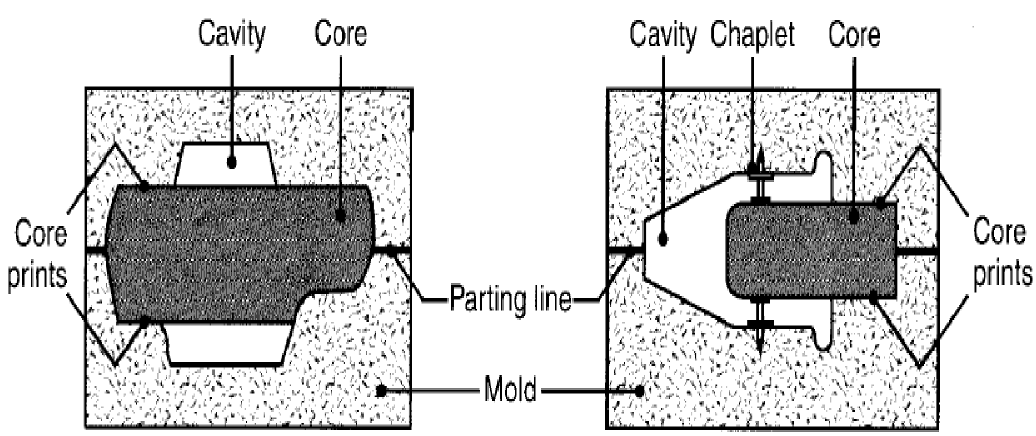
h = height of the test specimen in cm

p = pressure of the air in gf/cm2

a = Cross sectional area of the test specimen

t = time in min

1.8 Cores



For castings with internal cavities or passages, such as those found in an automotive engine block or a valve body, cores are utilized.

Cores are placed in the mold cavity to form the interior surfaces of the casting and are removed from the finished part during shakeout and further processing.

- Like mold, cores must possess strength, permeability, the ability to withstand heat, and collapsibility; hence, cores are made of sand aggregates.
- The core is anchored by core prints, which are recesses added to the pattern to locate and support the core and to provide vents for the escape of gases.
- A common problem with cores is that (for some casting requirements, as in the case where a recess is required) they may lack sufficient structural support in the cavity.
- To keep the core from shifting, metal supports (chaplets) may be used to anchor the core in place.
- Cores generally are made in a manner similar to that used in sand mold making; the majority are made with shell, no-bake, or cold-box processes.
- Cores are shaped in core boxes, which are used in much the same way that patterns are used to form sand molds.

UNIT II

SPECIAL CASTING PROCESS

2.1 Shell Moulding

It is widely used in producing high-precision molding cores. In this process, a mounted pattern made of a ferrous metal or aluminium is (a) heated to a range of 175° to 37O°C, (b) coated with a parting agent (such as silicone), and (c) clamped to a box or chamber.

The box contains fine sand, mixed with 2.5 to 4% of a thermosetting resin binder (such as phenol-formaldehyde) that coats the sand particles. Either the box is rotated upside down or the sand mixture is blown over the pattern, allowing it to form a coating.

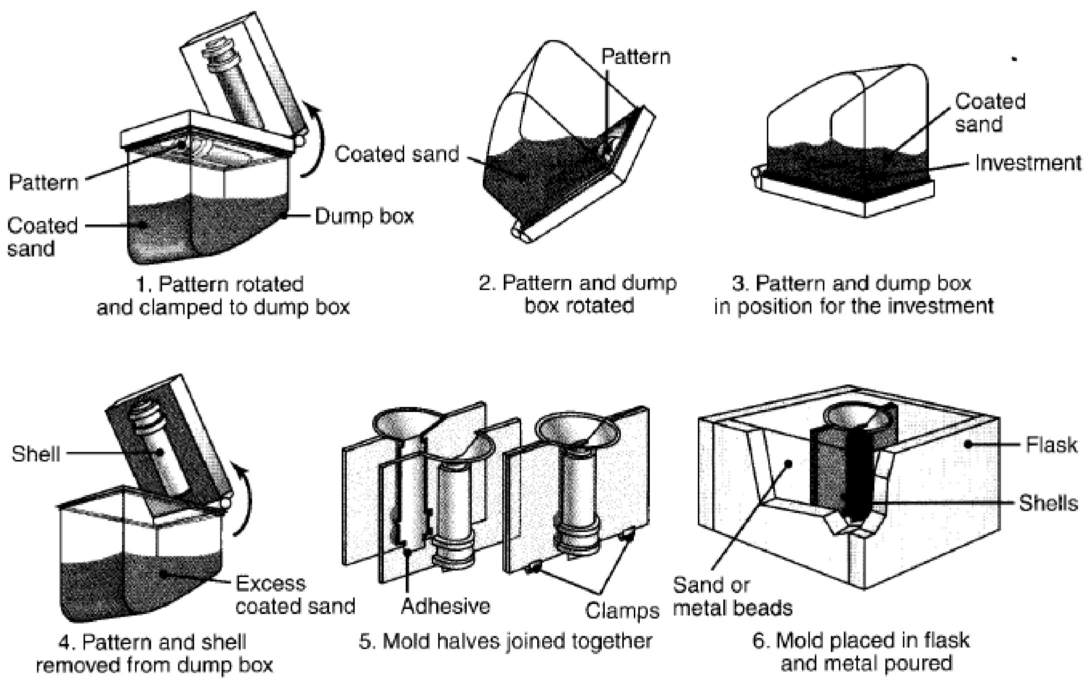


Figure: Sequence of Shell molding Operation

- The assembly is then placed in an oven for a short period of time to complete the curing of the resin. In most shell-molding machines, the oven consists of a metal box with gas-fired burners that swing over the shell mold to cure it.
- The shell hardens around the pattern and is removed from the pattern using built-in ejector pins. Two half-shells are made in this manner and are bonded or clamped together to form a mold.

- The thickness of the shell can be determined accurately by controlling the time that the pattern is in contact With the mold. In this way, the shell can be formed with the required strength and rigidity to hold the Weight of the molten liquid.
- The shells are light and thin-usually 5 to 10 mm-and consequently, their thermal characteristics are different from those for thicker molds. Shell sand has a much lower permeability than the sand used for green-sand molding, because a sand of much smaller grain size is used for shell molding.

Advantages:

- It can produce many types of castings with close dimensional tolerances
- Good surface finish at low cost.
- The high quality of the finished casting can reduce cleaning, machining, and other finishing costs significantly.
- Complex shapes can be produced with less labour, and the process can be automated fairly easily.

Disadvantages:

- The decomposition of the shell-sand binder also produces a high volume of gas.
- Consequently, unless the molds are vented properly, trapped air and gas can cause serious problems in the shell molding of ferrous castings.

Applications:

Shell-molding applications include small mechanical parts requiring high precision, such as gear housings, cylinder heads, and connecting rods.

2.2 Investment Casting

The investment-casting process, also called the lost-wax process, was first used during the period from 4000 to 3000 B.C.

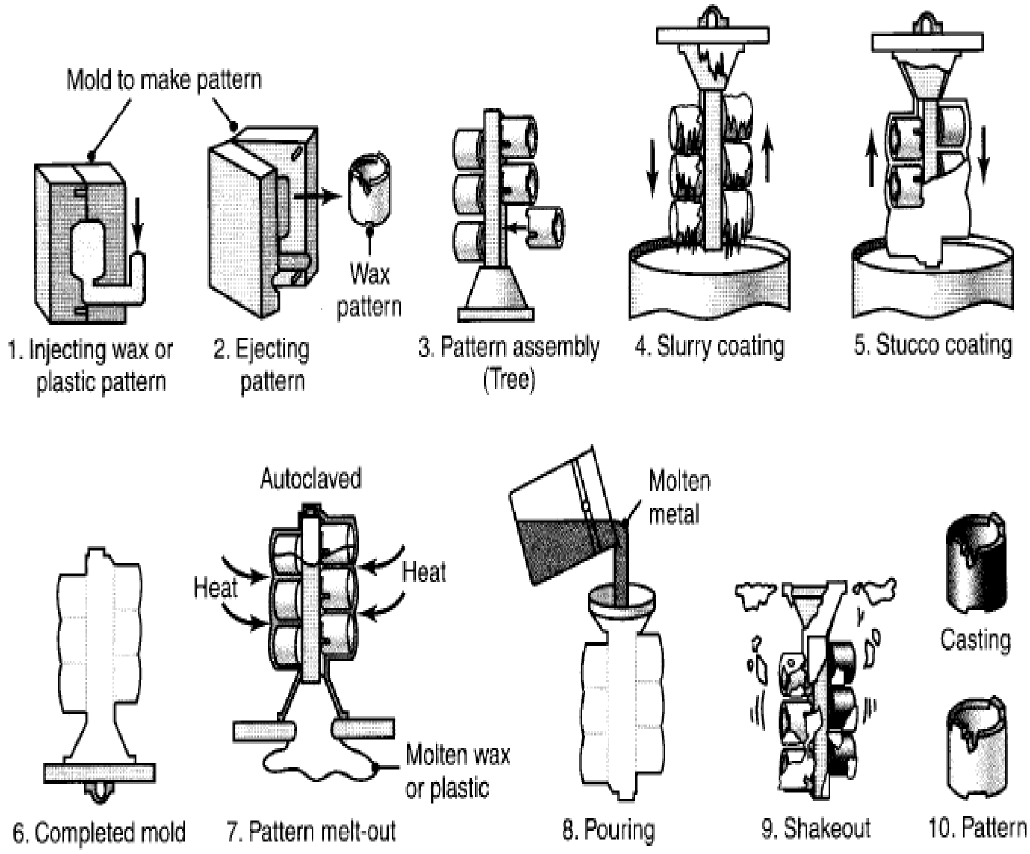


Figure: Schematic Diagram of Investment Casting

- The sequence involved in investment casting is shown in Figure. The pattern is made of wax, or of a plastic such as polystyrene, by molding or rapid prototyping techniques.
- The pattern is then dipped into a slurry of refractory material such as very fine silica and binders, including water, ethyl silicate, and acids.
- After this initial coating has dried, the pattern is coated repeatedly to increase its thickness for better strength.
- Note that the initial coating can use smaller particles to develop a better surface finish in the casting; subsequent layers use larger particles and are intended to build coating thickness quickly.
- The term investment derives from the fact that the pattern is invested (surrounded) with the refractory material.

- Wax patterns require careful handling because they are not strong enough to withstand the forces encountered during mold making; however, unlike plastic patterns, wax can be recovered and reused.
- The one-piece mold is dried in air and heated to a temperature of 90° to 175 °C. It is held in an inverted position for a few hours to melt out the wax.
- The mold is then fired to 650° to 105 0°C for about four hours (depending on the metal to be cast) to drive off the water of crystallization (chemically combined water) and to burn off any residual wax.
- After the metal has been poured and has solidified, the mold is broken up and the casting is removed. A number of patterns can be joined to make one mold, called a tree, significantly increasing the production rate.
- For small parts, the tree can be inserted into a permeable flask and filled with a liquid slurry investment. The investment then is placed into a chamber and evacuated (to remove the air bubbles in it) until the mold solidifies.
- The flask usually is placed in a vacuum-casting machine, so that molten metal is drawn into the permeable mold and onto the part, producing fine detail.
- The process is capable of producing intricate shapes, with parts weighing from 1 g to 35 kg, from a wide variety of ferrous and nonferrous metals and alloys.

Advantages:

- It is suitable for casting high-melting-point alloys with good surface finish and close dimensional tolerances
- Recent advances include the casting of titanium aircraft-engine and structural airframe components with wall thicknesses on the order of 1.5 mm, thus competing with previously used sheet-metal structures.

Disadvantages:

The mold materials and labour involved make the lost-wax process costly.

Applications:

Typical parts made are components for office equipment, as well as mechanical components such as gears, cams, valves, and ratchets. Parts up to 1.5 m in diameter and weighing as much as 1140 kg have been cast successfully by this process

2.3 Ceramic-shell Investment Casting

- The ceramic-mould casting process (also called cope-and-drag investment casting) is similar to the plaster-mold process, except that it uses refractory mold materials suitable for high-temperature applications.
- Parts weighing as much as 700 kg have been cast by this process.
- The slurry is a mixture of fine-grained zircon ($ZrSiO_4$), aluminium oxide, and fused silica, which are mixed with bonding agents and poured over the pattern which has been placed in a flask.

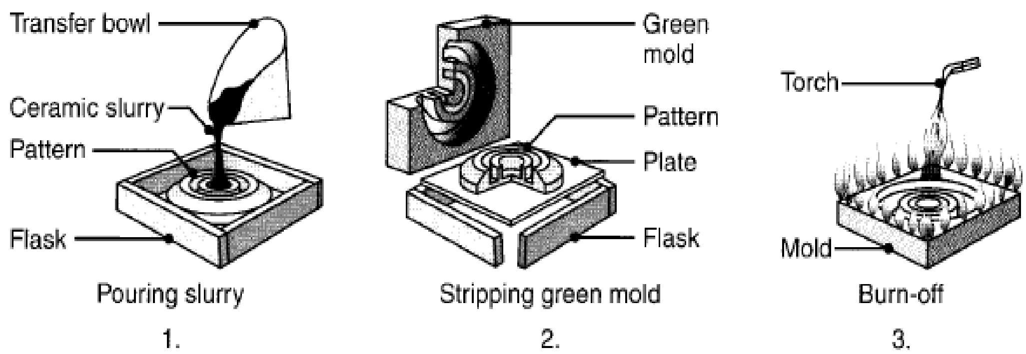


Figure Sequence of Ceramic Investment Casting

- The pattern may be made of wood or metal. After setting, the molds (ceramic facings) are removed, dried, ignited to burn off volatile matter, and baked.
- The molds are clamped firmly and used as all-ceramic molds. In the Shaw process, the ceramic facings are backed by fireclay (which resists high temperatures) to give strength to the mold.
- The facings then are assembled into a complete mold, ready to be poured.
- The high-temperature resistance of the refractory molding materials allows these molds to be used for casting ferrous and other high-temperature alloys, stainless steels, and tool steels.

Advantages:

The castings have good dimensional accuracy and surface finish over a wide range of sizes and intricate shapes.

Disadvantages:

It is an expensive

Applications:

Typical parts made are impellers, cutters for machining operations, dies for metalworking, and molds for making plastic and rubber Components.

2.4 Pressure Die Casting

In the die-casting process, molten metal is forced into the die cavity at pressures ranging from 0.7 to 700 MPa.

There are two basic types of die-casting machines:

- Hot-chamber and
- Cold-chamber machines.

2.4.1 Hot Chamber pressure die casting:

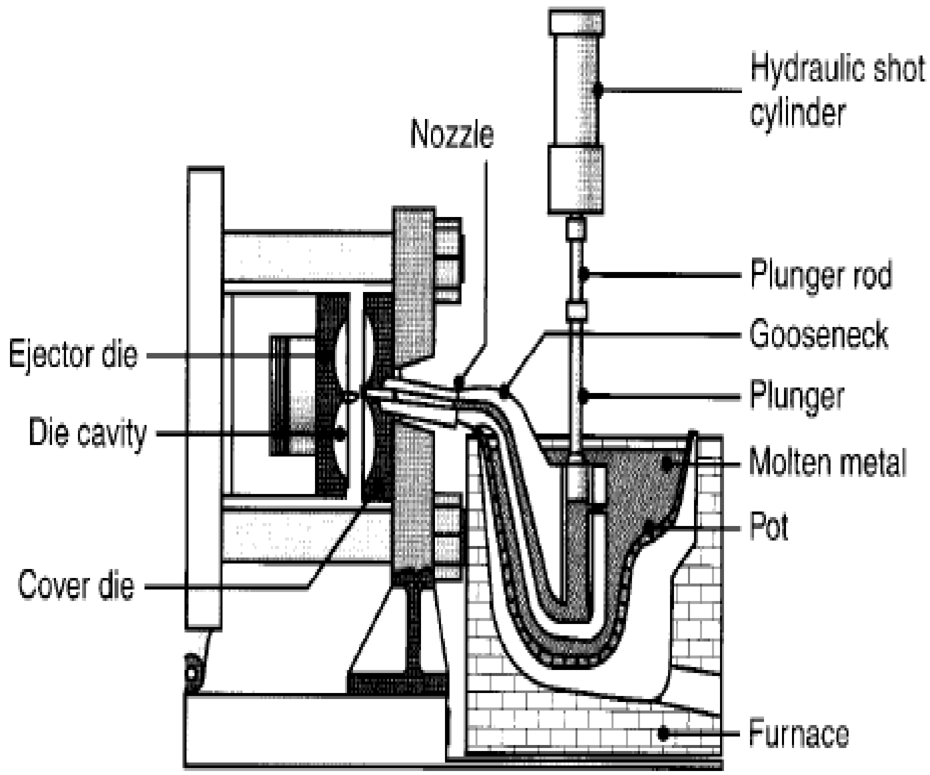


Figure: Schematic diagram of hot chamber pressure die casting

- The hot-chamber process involves the use of a piston, which forces a certain volume of metal into the die cavity through a gooseneck and nozzle.
- Pressures range up to 35 MPa, with an average of about 15 MPa. The metal is held under pressure until it solidifies in the die.

- To improve die life and to aid in rapid metal cooling (thereby reducing cycle time) dies usually are cooled by circulating water or oil through various passageways in the die block.
- Low-melting-point alloys (such as zinc, magnesium, tin, and lead) commonly are cast using this process.
- Cycle times usually range from 200 to 300 shots (individual injections) per hour for zinc, although very small components, such as zipper teeth, can be cast at rates of 18,000 shots per hour.

2.4.2 Cold Chamber Pressure die casting process:

In the cold-chamber process, molten metal is poured into the injection cylinder (shot chamber). The chamber is not heated-hence the term cold chamber. The metal is forced into the die cavity at pressures usually ranging from 20 to 70 MPa, although they may be as high as 150 MPa.

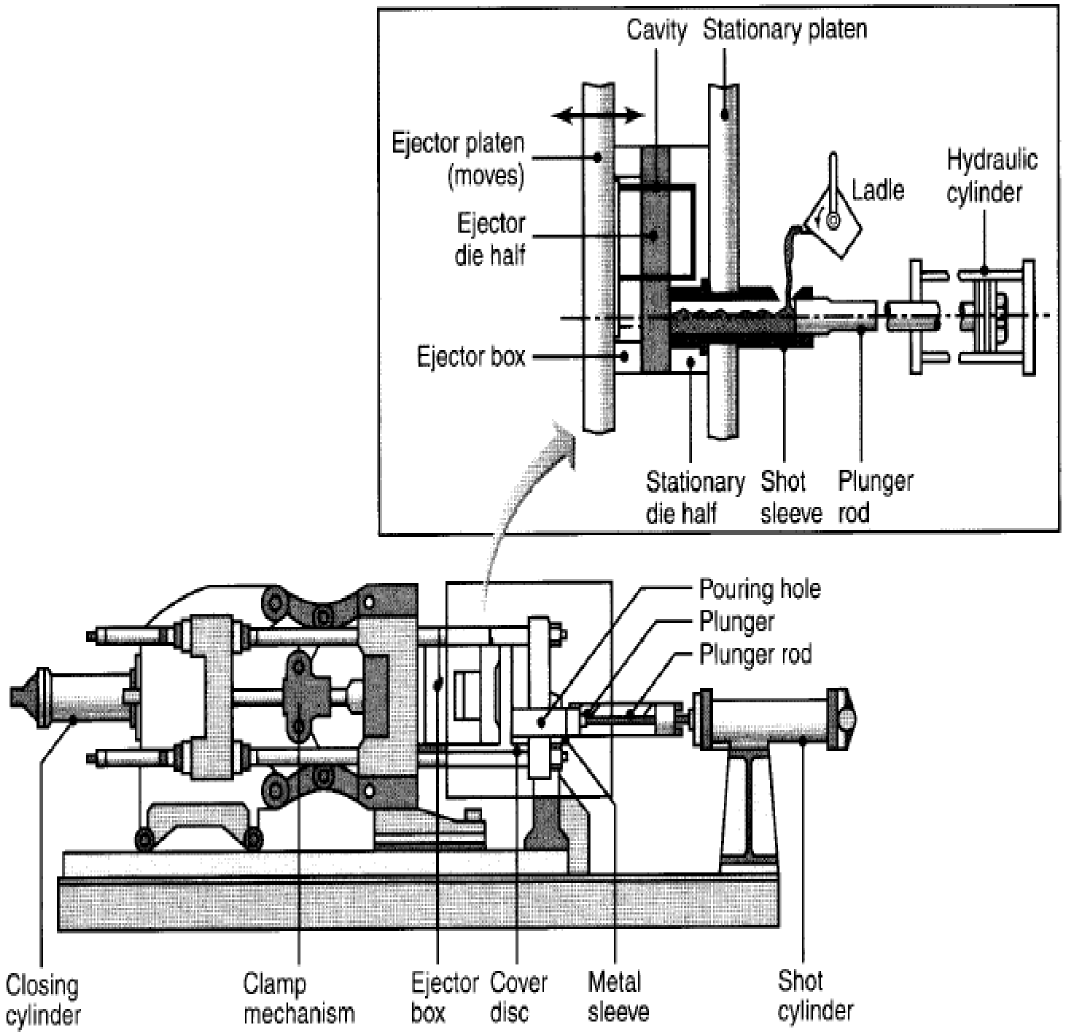


Figure: Schematic Illustration of Cold Chamfer die casting

- The machines may be horizontal (as in the figure)-or vertical, in which case the shot chamber is vertical.
- High-melting-point alloys of aluminium, magnesium, and copper normally are cast using this method, although other metals (including ferrous metals) also can be cast.
- Molten-metal temperatures start at about 600°C for aluminium and some magnesium alloys, and increase considerably for copper based and iron-based alloys.

Advantages:

Labour costs are generally low, because the process is semi- or fully automated. Die casting is economical for large production runs.

Disadvantages:

The weight of most castings ranges from less than 90 g to about 25 kg. Equipment costs, particularly the cost of dies, are high

Applications:

Typical parts made by die casting are housings, business-machine and appliance components, hand-tool components, and toys.

2.5 Centrifugal Casting

As its name implies, the centrifugal-casting process utilizes inertial forces (caused by rotation) to distribute the molten metal into the mold cavities-a method that was first suggested in the early 1800s.

There are three types of centrifugal casting

- True centrifugal casting,
- semi-centrifugal casting and
- Centrifuging.

2.5.1 True Centrifugal Casting

Process:

- Molten metal is poured into a rotating mold. The axis of rotation is usually horizontal, but can be vertical for short work pieces.
- Molds are made of steel, iron, or graphite and may be coated with a refractory lining to increase mold life.
- The mold surfaces can be shaped so that pipes with various external designs can be cast.

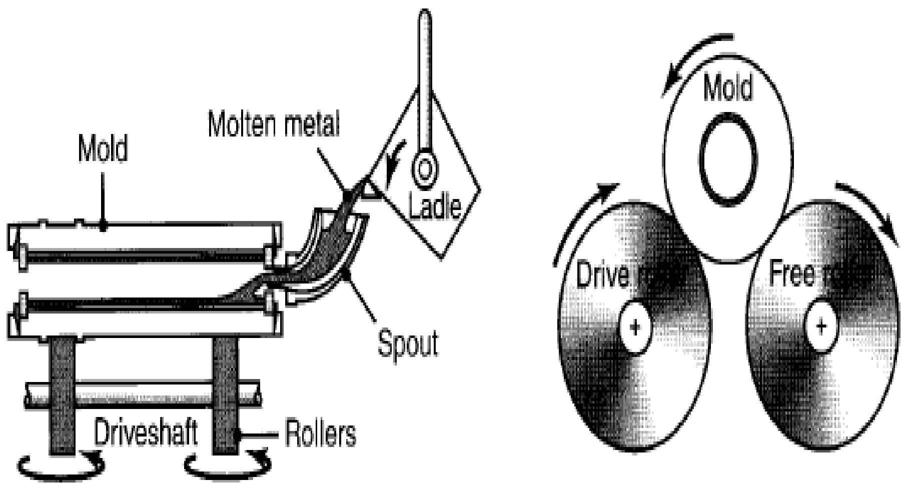


Figure: Schematic diagram of centrifugal casting

- The inner surface of the casting remains cylindrical, because the molten metal is distributed uniformly by the centrifugal forces.
- However, because of density differences, lighter elements (such as dross, impurities, and pieces of the refractory lining) tend to collect on the inner surface of the casting.
- Consequently, the properties of the casting can vary throughout its thickness. Cylindrical parts ranging from 13 mm to 3 m in diameter and 16 m long can be cast centrifugally with wall thicknesses ranging from 6 to 125 mm.
- The pressure generated by the centrifugal force is high (as much as 150 g); such high pressure is necessary for casting thick-walled parts.
- Castings with good quality, dimensional accuracy, and external surface detail are produced by this process.

Applications:

In true centrifugal casting, hollow cylindrical parts (such as pipes, gun barrels, bushings, engine-cylinder liners, bearing rings with or without flanges, and street lampposts) are produced by the technique.

2.5.2 Semi centrifugal Casting.

An example of semi centrifugal casting is shown in Figure. This method is used to cast parts with rotational symmetry, such as a wheel with spokes.

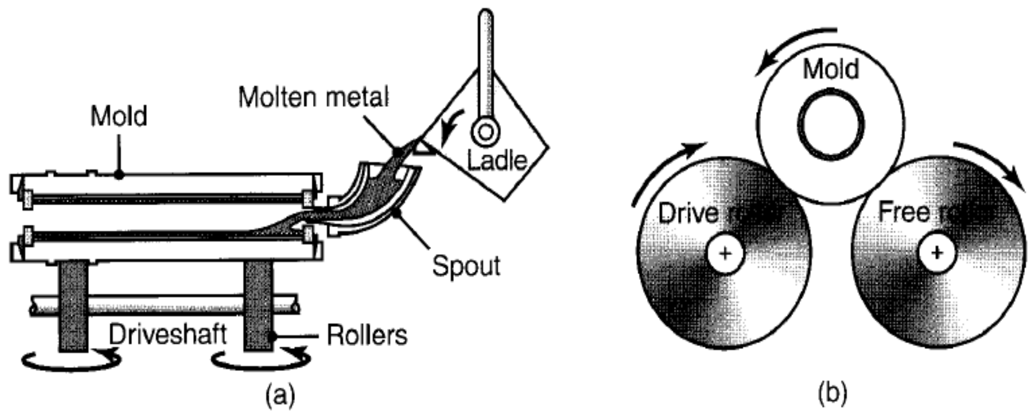


Figure Schematic Diagram of Semi Centrifugal Casting

2.5.3 Centrifuging

In centrifuging (also called centrifuge casting), mold cavities of any shape are placed at a certain distance from the axis of rotation. The molten metal is poured from the centre and is forced into the mold by centrifugal forces. The properties of the castings can vary by distance from the axis of rotation, as in true centrifugal casting.

CO_2 Casting

Introduction:

CO_2 Casting is a kind of sand casting process.

- In this process the sand molding mixture is hardened by blowing gas over the mold. This process is favoured by hobby metal casters because a lot of cost cutting can be done.
- In addition, one can be sure of getting dimensionally accurate castings with fine surface finish. But, this process is not economical than green sand casting process.
- The Mold for CO_2 Casting is made of a mixture of sand and liquid silicate binder which is hardened by passing Co_2 gas over the mold.
- The equipment of the molding process include Co_2 cylinder, regulator, and hoses and hand held applicator gun or nozzle. Carbon di oxide molding deliver great accuracy in production.
- Any existing pattern can be used for the molding purpose which can be placed in the mold before the mold is hardened. This method helps in producing strong mold and cores that can be used for high end applications.

- If the process is carefully executed then casting can be as precise as produced by the shell casting method.
- Carbon di oxide casting is favoured both by the commercial foundry men and hobbyist for a number of reasons. In commercial operations, foundry men can assure customers of affordable castings which require less machining.
- The molding process which can be fully automated is generally used for casting process that require speed, high production runs and flexibility. In home foundries this is one of the simplest process that improves the casting quality.

Applications:

Co_2 casting process is ideal where speed and flexibility is the prime requirement. Molds and cores of a varied sizes and shapes can be moulded by this process.

Advantages:

This process has many advantages in comparison to other forms of castings some of them are as follows:

- Compared to other casting methods cores and molds are strong
- Reduces fuel cost since gas is used instead of to other costly heating generating elements
- Reduces large requirement for number of mold boxes and core dryers
- Provides great dimensional tolerance and accuracy in production
- Moisture is completely eliminated from the molding sand
- This process can be fully automated.

2.6 Defects in Casting Processes

A brief explanation of some of the significant defects and their possible remedial measures are indicated in the text to follow.

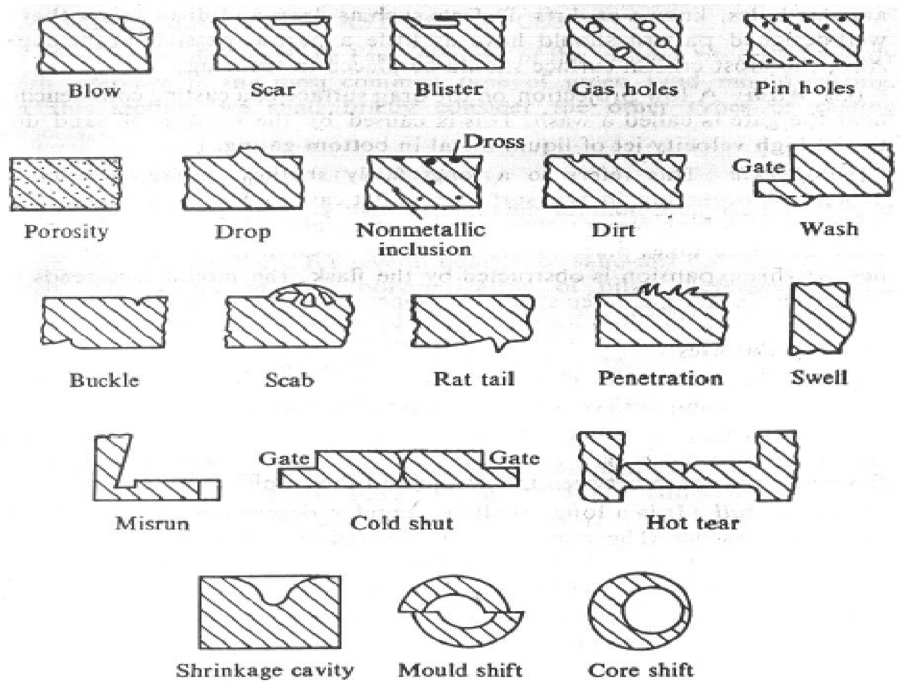


Figure : Defects in casting

Shrinkage

Causes:

- Shrinkage of molten metal as it solidifies is an important issue in casting. It can reduce the 5-10% volume of the cast.
- Gray cast iron expands upon solidification due to phase changes.
- Need to design part and mold to take this amount into consideration.
- The thickness of the boss or pad should be less than the thickness of the section of the boss adjoins and the transition should be gradual.
- The radius for good shrinkage control should be from one half to one third of the section thickness.

Remedies:

Shrinkage defect can be reduced by decreasing the number of walls and increasing the draft angle.

Porosity

Causes:

- Porosity is a phenomenon that occurs in materials, especially castings, as they change state from liquid to solid during the manufacturing process.
- Casting porosity has the form of surface and core imperfections which either effects the surface finish or as a leak path for gases and liquids.
- The poring temperature should be maintained properly to reduce porosity.

Remedies:

Adequate fluxing of metal and controlling the amount of gas-producing materials in the molding and core making sand mixes can help in minimizing this defect.

Hot tear:

- Hot tears are internal or external ragged discontinuities or crack on the casting surface, caused by rapid contraction occurring immediately after the metal solidified.
- They may be produced when the casting is poorly designed and abrupt sectional changes take place; no proper fillets and corner radii are provided, and chills are inappropriately placed.
- Hot tear may be caused when the mold and core have poor collapsibility or when the mold is too hard causing the casting to undergo severe strain during cooling. Incorrect pouring temperature and improper placement of gates and risers can also create hot tears.

Remedies:

Method to prevent hot tears may entail improving the casting design, achieving directional solidification and even rate of cooling all over, selecting proper mold and poured materials to suit the cast metal, and controlling the mold hardness in relation to other ingredients of sand.

Scar

It is usually found on the flat casting surface. It is a shallow blow.

Blowhole

Blowholes are smooth round holes that are clearly perceptible on the surface of the casting.

Remedies:

To prevent blowholes, moisture content in sand must be well adjusted, sand of proper grain size should be used, ramming should not be too hard and venting should be adequate.

Blister

This is a scar covered by the thin layers of the metal.

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 is known as dirts.

Wash

It is a low projection on the drag surface of a casting commencing near the gate. It is caused by the erosion of sand due to high velocity liquid metal.

Buckle

It refers to a long fairly shallow broad depression at the surface of a casting of a high temperature metal. Due to very high temperature of the molten metal, expansion of the thin layered of the sand at the mold face takes place. As this expansion is obstructed by the flux, the mold tends to bulge out forming a V shape.

Rat tail

It is a long shallow angular depression found in a thin casting. The cause is similar to buckle.

Shift

A shift results in a mismatch of the sections of a casting usually as a parting line. Misalignment is common cause of shift.

Remedies:

This defect can be prevented by ensuring proper alignment of the pattern for die parts, molding boxes, and checking of pattern flux locating pins before use.

Warped casting

Warping is an undesirable deformation in a casting which occurs during or after solidification.

- Large and flat sections are particularly prone to wrap edge.
- Wrap edge may also be due to insufficient gating system that may not allow rapid pouring of metal or due to low green strength of the sand mold or inadequate / inappropriate draft allowance in the pattern / mold cavity.

Metal Penetration and Rough Surfaces

This defect appears as an uneven and rough external surface of the casting. It may be caused when the sand has too high permeability, large grain size, and low strength. Soft ramming may also cause metal penetration.

Fin

- A thin projection of metal, not intended as a part of casting, is called a fin.
- Fins occur at the parting of the mold or core sections. Molds and cores in correctly assembled will cause the fin.
- High metal pressures due to too large downsprue, insufficient weighing of the molds or improper clamping of flasks may again produce the fin defect.

Cold Shut and Mis-Run

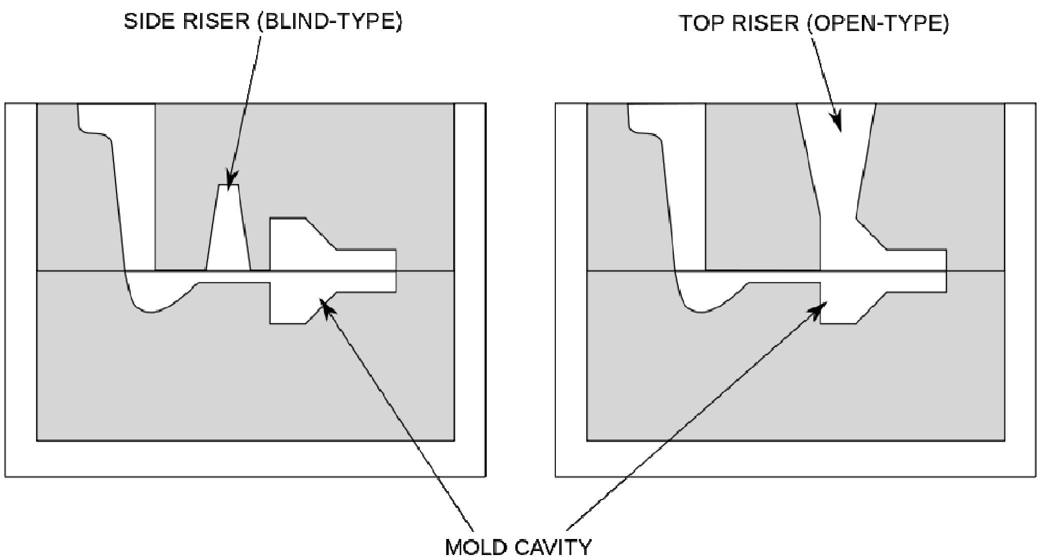
- A cold shut is a defect in which a discontinuity is formed due to the imperfect fusion of two streams of metal in the mold cavity.
- The reasons for cold shut or mis-run may be too thin sections and wall thickness, improper gating system, damaged patterns, slow and intermittent pouring , poor fluidity of metal caused by low pouring temperature, improper alloy composition, etc.

2.7 RISERS:

A riser, also known as a feeder, is a reservoir built into a metal casting mould to prevent cavities due to shrinkage. Most metals are less dense as a liquid than as a solid so castings shrink upon cooling, which can leave a void at the last point to solidify. Risers prevent this by providing molten metal to the casting as it solidifies, so that the cavity forms in the riser and not the casting. Risers are not effective on materials that have a large freezing range, because directional solidification is not possible. They are also not needed for casting processes that utilized pressure to fill the mould cavity. A feeder operated by a treadle is called an under feeder. The activity of planning of how a casting will be gated and risered is called foundry methoding or foundry engineering.

2.7.1 TYPES OF RISERS:

A riser is categorized based on three criteria: where it is located, whether it is open to the atmosphere, and how it is filled. If the riser is located on the casting then it is known as a top riser, but if it is located next to the casting it is known as a side riser. Top risers are advantageous because they take up less space in the flask than a side riser, plus they have a shorter feeding distance. If the riser is open to the atmosphere it is known as an open riser, but if the risers is completely contained in the mold it is known as a blind riser. An open riser is usually bigger than a blind because the open riser loses more heat to mold through the top of the riser. Finally, if the riser receives material from the gating system and fills before the mold cavity it is known as a live riser or hot riser. If the riser fills with material that has already flowed through the mold cavity it is known as a dead riser or cold riser. Live risers are usually smaller than dead risers. Top risers are almost always dead risers and risers in the gating system are almost always live risers.



The connection of the riser to the moulding cavity can be an issue for side risers. On one hand the connection should be as small as possible to make separation as easy as possible, but, on the other, the connection must be big enough for it to not solidify before the riser. The connection is usually made short to take advantage of the heat of both the riser and the moulding cavity, which will keep it hot throughout the process.

There are risering aids that can be implemented to slow the cooling of a riser or decrease its size. One is using an insulating sleeve and top around the riser. Another is placing a heater around only the riser.

2.7.2 Functions of Risers

- Provide extra metal to compensate for the volumetric shrinkage

  Allow mold gases to escape

- Provide extra metal pressure on the solidifying mold to reproduce mold details more exact

2.7.3 Design Requirements of Risers

Riser size: For a sound casting riser must be last to freeze. The ratio of (volume / surface area)^2 of the riser must be greater than that of the casting. However, when this condition does not meet the metal in the riser can be kept in liquid state by heating it externally or using exothermic materials in the risers.

Riser placement: the spacing of risers in the casting must be considered by effectively calculating the feeding distance of the risers.

Riser shape: cylindrical risers are recommended for most of the castings as spherical risers, although considers as best, are difficult to cast. To increase volume/surface area ratio the bottom of the riser can be shaped as hemisphere.

2.7.4 CASTING DESIGN CONSIDERATIONS

- All casting operations share the characteristics of phase change and thermal shrinkage during the casting cycle
- But each process will have its own design considerations
- Sand casting will require mold erosion and sand inclusions in the casting
- Die casting will not have this concern
- Defects frequently are random and difficult to reproduce

2.7.5 2 Types of design issues in casting:

- Geometric features and tolerances incorporated into the part Mould features that are needed to produce the desired casting

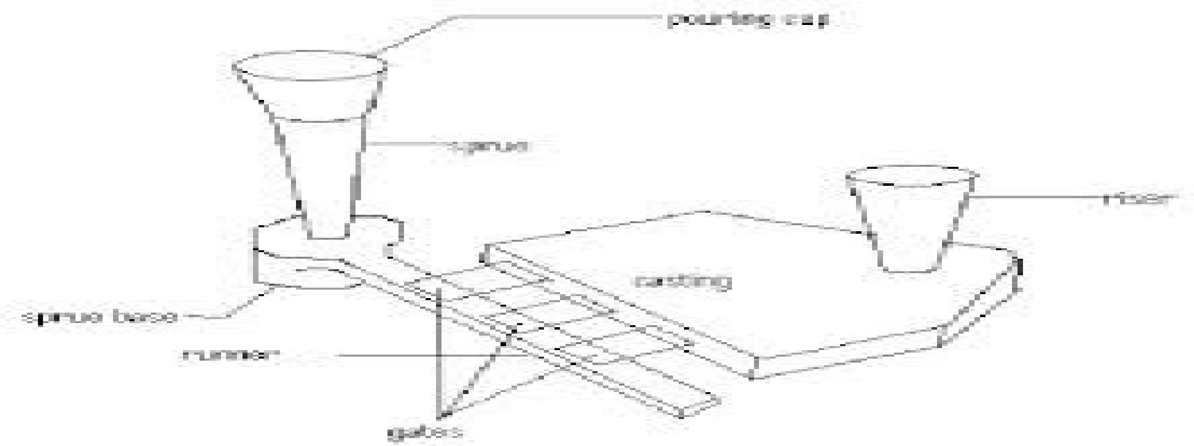
2.7.6 Gating System

The term gating system refers to all passageways through which the molten metal passes to enter the mould cavity.

The gating system is composed of

- Pouring basin
- Sprue

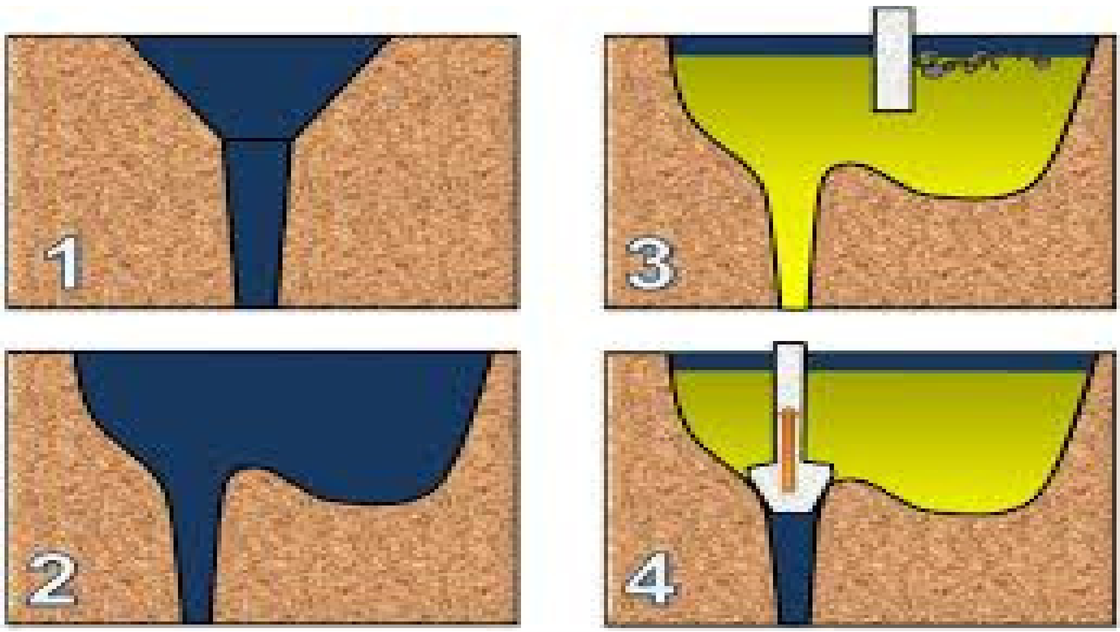
- Runner
- Gates
- Risers



Components of Gating System

- Any gating system designed should aim at providing a defect free casting. This can be achieved by considering following requirements.
  - ✓ A gating system should avoid sudden or right angle changes in direction.
  - ✓ A gating system should fill the mould cavity before freezing.
  - ✓ The metal should flow smoothly into the mould without any turbulence. A turbulence metal flow tends to form dross in the mould.
  - ✓ Unwanted materials such as slag, dross and other mould materials should not be allowed to enter the mould cavity.
  - ✓ The metal entry into the mould cavity should be properly controlled in such a way that aspiration of the atmospheric air is prevented.
  - ✓ A proper thermal gradient should be maintained so that the casting is cooled without any shrinkage cavities or distortions.
  - ✓ Metal flow should be maintained in such a way that no gating or mould erosion takes place.
  - ✓ The gating system should ensure that enough molten metal reaches the mould cavity.
  - ✓ It should be economical and easy to implement and remove after casting solidification.
- For proper functioning of the gating system, the following factors need to be controlled.
  - ✓ Type of pouring equipment, such as ladles, pouring basin etc.

- ✓ Temperature/ Fluidity of molten metal.
- ✓ Rate of liquid metal pouring.
- ✓ Type and size of sprue.
- ✓ Type and size of runner.
- ✓ Size, number and location of gates connecting runner and casting.
- ✓ Position of mould during pouring and solidification.



POURING BASINS

- A pouring basin makes it easier for the ladle or crucible operator to direct the flow of metal from crucible to sprue.
- Helps maintaining the required rate of liquid metal flow.
- Reduces turbulence at the sprue entrance.
- Helps separating dross, slag etc., from metal before it enters the sprue.

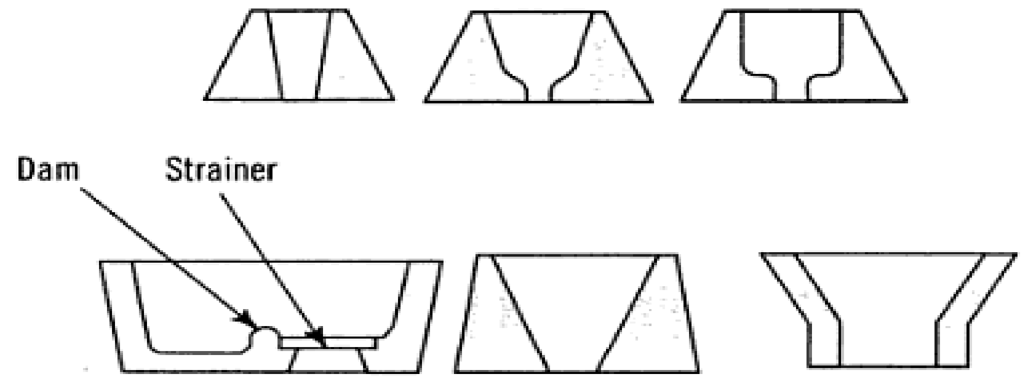


Fig. 5.2 *Typical shapes of pouring basins*

- If the pouring basins are made large,
  - ✓ Dross and slag formation will tend to float on the surface of the metal and may be stopped from entering the sprue and hence the mould.
  - ✓ They may be filled quickly without overflowing and may act as a reservoir of liquid metal to compensate metal shrinkage or contraction.

SPRUE:

- A sprue feeds metal to runner which in turn reaches the casting through gates.
- A sprue is tapered with its bigger end at top to receive the liquid metal. The smaller end is connected to runner.

GATES AND RISERS:

Gates and risers are part of the system to provide molten metal to the part you're casting. This page will provide a starting point for you, it is certainly not the definitive collection on the subject. There are whole books devoted to this subject. On my LINKS page there are some book titles for those who may want more information. That being said, it is possible to make good castings without following, or even knowing these rules. When I first started casting I just cut my gates and runners with an old kitchen spoon so that they looked right to me. If you remember to gate to the largest part of your casting and round all the corners in the system you will likely have good luck with your castings, particularly simple ones. If you have a casting that is giving you problems with shrinkage defects, misruns, etc. you may want to have a look at the information below to see if you can try any of it to help solve the problem. If your pattern is on a match plate, once you find a gating system that works well you can build that onto the match plate as well so it is molded at the same time as your mold cavity.

First some definitions will make it easier to understand this page.

Choke

A restriction in the gating system that limits the flow rate of the molten metal.

Cope

The top part of the mold.

Drag

The lower part of the mold.

Gate

A short passageway that connects the runner to the mold.

Match Plate

A type of pattern that is used for making a run of the same part, it is possible to make it so that it includes the gates, runners and sprue bases.

Pouring Basin

An enlarged portion at the top of the sprue.

Riser

A vertical passageway which provides a source of hot metal to prevent shrinkage in the casting.

Runner

The passageway the metal flows through to get to the gates from the sprue.

Runner Extension

A short extension of the runner which goes beyond the last gate

Sprue

A vertical passageway through which the molten metal gets to the runner.

The goals for the gating system are;

- To minimize turbulence to avoid trapping gases and breaking up the sand mold.
- To get enough metal into the mold cavity before the metal starts to solidify.
- To avoid shrinkage.

Sprue design

The design of the pouring basin and sprue can affect turbulence. For best results you want to design your pouring basin and sprue so that you can keep the sprue full of molten metal throughout your pour. A sprue tapered to a smaller size at its bottom will create a choke which will help keep the sprue full of molten metal. If you don't use a tapered sprue you can put a choke in when you are making the runners, you will want to have the choke as close to the bottom of the sprue as possible. The choke will also increase the speed of the molten metal, which is undesirable. To address this problem you can create an enlarged area at the bottom of the sprue, called a sprue base. This decreases the speed of the molten metal. There are two basic types of sprue bases, enlargement and well.

The general rules of thumb for enlargement bases are;

- Diameter is roughly 2.5 times the width of the runner.
- Depth is equal to the depth of the runner.

The general rules of thumb for well bases are;

- Depth of a well base is twice that of the runners.
- Cross sectional area of the base is 5 times the cross sectional area of the sprue exit (a 1/2 sq. in. sprue exit would mean you need a base with an area of 2.5 sq. in. which would be a 1.5 inch diameter).
- The bottom of the sprue base should be flat, not rounded like a bowl. If it's it will cause turbulence in the metal.

Runner Design

One of the most important things to remember in your runners and gates is to avoid sharp corners. Any changes in direction or cross sectional area should make use of rounded corners. Also make sure the runners and gates are well rammed and smooth. This will help avoid sand erosion and turbulence.

To ensure that the metal is not flowing too fast in the runners the rule of thumb is that the cross sectional area of the runners should be greater than the area of the choke. The walls of the runners should be as smooth as possible to avoid causing turbulence. The runners should be filled with metal before the gates are, one way to ensure this happens is to put the runners in the drag and the gates in the cope. If you need to have a choke in the runner to restrict flow it should be at least 6" from the first gate.

The cross sectional area of the runners should decrease as the gates come off them to keep the the same gating ratio. A good gating ration for aluminum is 1:4:4. The 1 is for the cross sectional area of the choke. The first 4 is the **total** cross sectional area of the runners (measured after the choke but before the first gate) and the final 4 is **total** cross sectional area of the gates. For example, say you have a tapered sprue with an exit area of 0.5 sq. in., two runners with 2 gates off of each runner. The total runner area should be 2 sq. in so each runner would be 1 sq. in. The total gate area should be 2 sq. in., there are 4 gates so each gate would have an area of 0.5 sq. in. The gate calculation only works this way if there are an equal number of gates on each runner. If that is not the case divide the area of the runner by the number of gates on that runner to get the area of each gate.

The area of the runners should be reduced just after a gate by an amount equal to the area of that gate. This will insure that each gate in the system will have the same flow of metal, even if it's farther from the sprue. The first bit of metal poured is most likely to be contaminated by air and sand entrapment. To prevent this metal from going into the mold cavity you use a runner extension. That first bit of metal will flow to the end of this dead end and be trapped there, where it can't harm the piece you're trying to cast.The runner extension will have the same area as that of the last gate on that runner.

Risers

Risers are important to ensure a flow of molten metal to the part being cast as it's starting to solidify. Without a riser heavier parts of the casting will have shrinkage defects, either on the surface or internally. As molten metal solidifies it shrinks. If it does not have a source of more molten metal to feed it as it shrinks you will get defects in your casting. A risers purpose is to provide that extra molten metal. Basically a riser is a vertical portion of the gating system, similar to a straight sprue, that stores the molten metal until it is needed by the casting. This means the metal in the riser must stay liquid longer than the metal in the part being cast.

A riser may be required for every hot spot in your cast part. In other words the part of the casting that solidifies last, usually an are with a larger volume of metal. The risers can either be attached to the top or the side of a part. They may also be blind risers. A blind riser is completely contained in the mold, not exposed to the air. Since it's not open to the air this type of riser cools slower and thus will stay liquid longer. It's important that no matter where it's located the gate that connects the riser to the casting is not too small and as short as possible or else the gate will solidify too soon and prevent the metal in the riser from reaching the casting, try and keep the length to 1/2 the diameter of the riser.

Risers may be upstream from the casting in the runner/gate system. In this case the metal must flow through the riser prior to reaching the casting and after the pour is completed the metal in the riser will be hotter than the metal in the casting. They may also be placed downstream, after the casting. This means the metal flows through the casting to get to the riser so the metal in the riser will be cooler than the metal in the casting. This could cause the metal in the casting to feed the riser as it cools, definitely not desired.

Moulding Flasks (casting):

A **flask** is a type of tooling used to contain a mold in metal casting. A flask has only sides, and no top or bottom, and forms a frame around the mold, which is typically made of molding sand. The shape of a flask may be square, rectangular, round or any convenient shape. A flask can be any size so long as it is larger than the pattern being used to make the sand mold. Flasks are commonly made of steel, aluminum or even wood. A simple flask has two parts, the cope and the drag, and more elaborate flasks may have three or even four parts.

Flask Design

1. Flasks are often designed with bars which extend span two opposite sides. The bars act as reinforcement to the molding sand which is relatively weak in tensile strength. The bars help support the sand through the molding and pouring operation.

2. Flasks are designed with an alignment or registration feature so that the two flasks can be aligned to one another to insure a casting can be more dimensionally accurate.
3. Flasks will usually have handles or trunnions designed into their construction which assist in handling the flasks with cranes or other lifting machinery.
4. Some flasks are used to form a mold and they are removed before pouring the casting so another mold can be made. Other flasks are designed to contain the mold through the pouring operation, and then the casting is shaken out of the mold. The flasks are then used again and again.

2.3 Melting Furnace:

2.3.1 Cupola furnace

Cupola furnaces are tall, cylindrical furnaces used to melt iron and ferrous alloys in foundry operations. Alternating layers of metal and ferrous alloys, coke, and limestone are fed into the furnace from the top.

A schematic diagram of a cupola is shown in Figure. This diagram of a cupola illustrates the furnace's cylindrical shaft lined with refractory and the alternating layers of coke and metal scrap. The molten metal flows out of a spout at the bottom of the cupola.

2.3.1.1 Construction of Cupola Furnace

The cupola consists of a vertical cylindrical steel sheet and lined inside with acid refractory bricks.

The lining is generally thicker in the lower portion of the cupola as the temperature are higher than in upper portion.

There is a charging door through which coke, pig iron, steel scrap and flux is charged

- The blast is blown through the tuyeres
- These tuyeres are arranged in one or more row around the periphery of cupola
- Hot gases which ascends from the bottom (combustion zone) preheats the iron in the preheating zone
- Cupolas are provided with a drop bottom door through which debris, consisting of coke, slag etc. can be discharged at the end of the melt

- A slag hole is provided to remove the slag from the melt
- Through the tap hole molten metal is poured into the ladle
- At the top conical cap called the spark arrest is provided to prevent the spark emerging to outside

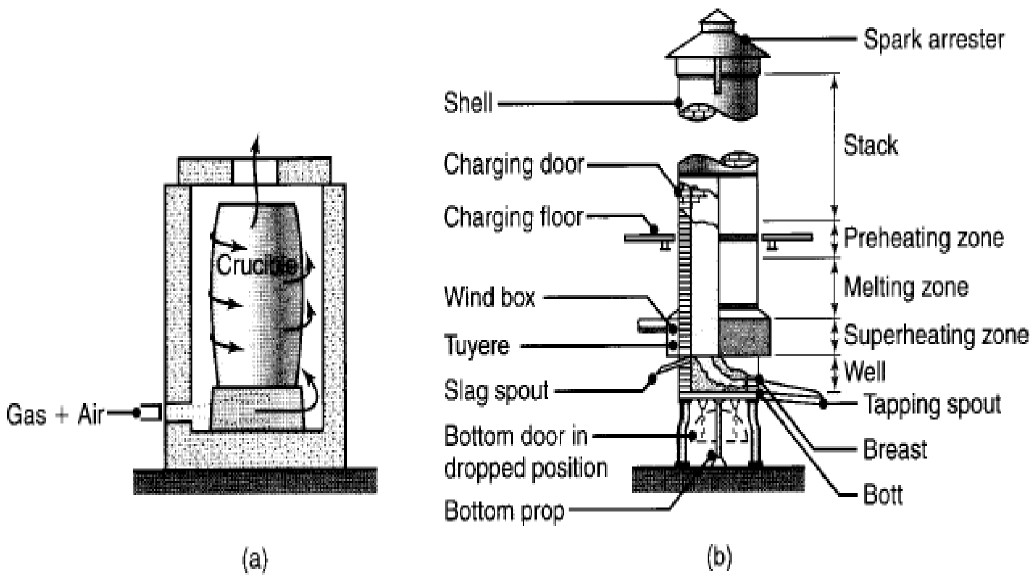


Figure: (a) Crucible Furnace (b) Schematic of a Cupola

2.3.1.2 Operation of Cupola

- The cupola is charged with wood at the bottom.
- On the top of the wood a bed of coke is built.
- Alternating layers of metal and ferrous alloys, coke, and limestone are fed into the furnace from the top.
- The purpose of adding flux is to eliminate the impurities and to protect the metal from oxidation.
- Air blast is opened for the complete combustion of coke.
- When sufficient metal has been melted that slag hole is first opened to remove the slag.
- Tap hole is then opened to collect the metal in the ladle.

2.3.2 Blast furnace

Blast furnace iron making is an example in which both unit processes that is reduction of iron oxide and smelting to separate liquid pig iron from slag is done simultaneously in a single reactor. Height of the blast furnace is around 25 to 30m. It must be mentioned that blast furnace is a very efficient reactor both in terms of heat and mass exchange between solids and gases.

2.3.2.1 Blast furnace operation

In the blast furnace burden (consists of iron ore sinter/pellets +coke +limestone/lime) at 298K is charged from top. During its descent, there occurs heat and mass exchange with the hot gases which are moving up. Hot gases comprise of CO,CO_2 and N_2. Thus blast furnace is a counter- current heat and mass exchange reactor.In approximately 75% of the total height of the blast furnace (i.e. from top to bottom of stack), reduction of iron oxide to Fe and decomposition of limestone occur. Burden permeability is very important for the smooth operation. The following figure shows that the input charging of metals

Sketch of a blast furnace showing inputs of charge materials and outputs of the product. The directions of descending of burden and ascending of gases are also shown (Burden is a mixture of iron ore + coke + limestone) Blast furnace cannot work without coke. Since coke is not a natural resource, coke making is an integral part of blast furnace iron making. In view of the importance of coke, let me discuss coke making.

Functions of coke

- Source of thermal energy
- Source of chemical energy
- Coke maintains permeability of the burden
- Strength reactivity, chemical composition etc. are the important properties Coke consumption varies from 500-550 kg/ton of hot metal. Modern blast furnaces with pulverized coal injection work with 300-350 kg/ton of hot metal.

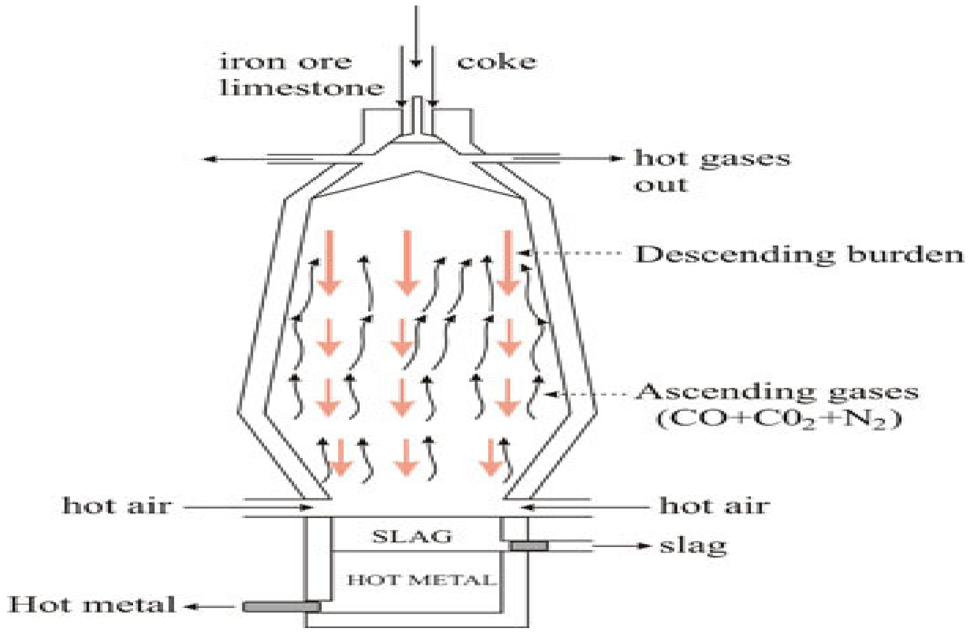


Figure: Schematic Illustration of Blast Furnace

UNIT III

WELDING & CUTTING OF METALS

3.1 WELDING

- Welding is a materials joining process which produces coalescence of materials by heating them to suitable temperatures with or without the application of pressure or by the application of pressure alone, and with or without the use of filler material.
- Welding is used for making permanent joints.
- It is used in the manufacture of automobile bodies, aircraft frames, railway wagons, machine frames, structural works, tanks, furniture, boilers, general repair work and ship building.

3.2 BASIC TYPES OF WELDING PROCESSES

Plastic Welding or Pressure Welding

- The piece of metal to be joined are heated to a plastic state and forced together by external pressure (Ex) Resistance welding
- Fusion Welding or Non-Pressure Welding
- The material at the joint is heated to a molten state and allowed to solidify (Ex) Gas welding, Arc welding

3.3 Classification of welding processes:

(i) Arc welding
- Carbon arc
- Metal arc
- Metal inert gas
- Tungsten inert gas
- Plasma arc
- Submerged arc
- Electro-slag

(ii) Gas Welding
- Oxy-acetylene
- Air-acetylene
- Oxy-hydrogen

(iii) Resistance Welding
- Butt
- Spot
- Seam
- Projection
- Percussion

(iv)ThermoChemical Welding
- Thermit Welding
- Atomic Hydrogen Welding

(v) Solid State Welding
- Friction
- Ultrasonic
- Diffusion
- Explosive

(vi) Radiant Energy Welding
- Electron-beam
- Laser

(vii) Related Process
- Oxy-acetylene cutting
- Arc cutting
- Hard facing
- Brazing
- Soldering

3.4 Fusion Welding Process

Fusion welding is a joining process that uses fusion of the base metal to make the weld. The three major types of fusion welding processes are as follows:

1. **Gas welding**:
Oxyacetylene welding (OAW)

2. **Arc welding**:
Shielded metal arc welding (SMAW)
Gas–tungsten arc welding (GTAW)
Plasma arc welding (PAW)
Gas–metal arc welding (GMAW)
Flux-cored arc welding (FCAW)
Submerged arc welding (SAW)
Electroslag welding (ESW)

3. **High-energy beam welding**:
Electron beam welding (EBW)
Laser beam welding (LBW)

3.5 Design of Welded Joint

The details of a joint, which includes both the geometry and the required dimensions, are called the joint design. Just what type of joint design is best suited for a particular job depends on many factors. Although welded joints are designed primarily to meet strength and safety requirements, there are other factors that must be considered. A few of these factors areas follows: Whether the load will be in tension or compression and whether bending, fatigue, or impact stresses will be applied

- How a load will be applied; that is, whether the load will be steady, sudden, or variable
- The direction of the load as applied to the joint
- The cost of preparing the joint

Another consideration that must be made is the ratio of the strength of the joint compared to the strength of the base metal. This ratio is called joint efficiency. An efficient joint is one that is just as strong as the base metal. Normally, the joint design is determined by a designer or engineer and is included in the project plans and specifications. Even so, understanding the joint design for a weld enables you to produce better welds. Earlier in this chapter, we discussed the five basic types of welded joints—butt, corner, tee, lap, and edge. While there are many variations, every joint you weld will be one of these basic types. Now, we will consider some of the variations of the welded joint designs and the efficiency of the joints.

3.5.1 BUTT JOINTS

The square butt joint is used primarily for metals that are 3/16 inch or less in thickness. The joint is reasonably strong, but its use is not recommended when the metals are subject to fatigue or impact loads. Preparation of the joint is simple, since it only requires matching the edges of the plates together; however, as with any other joint, it is important that it is fitted together correctly for the entire length of the joint. It is also important that you allow enough root opening for the joint. Figure 3-23 shows an example of this type of joint.

When you are welding metals greater than 3/16 inch in thickness, it is often necessary to use a grooved butt joint. The purpose of grooving is to give the joint the required strength. When you are using a grooved joint, it is important that the groove angle is sufficient to allow the electrode into the joint; otherwise, the weld will lack penetration and may crack. However, you also should avoid excess beveling because this wastes both weld metal and time. Depending on the thickness of the base metal, the joint is either single-grooved (grooved on one side only) or double-grooved (grooved on both sides). As a welder, you primarily use the single-V and double-V grooved joints.

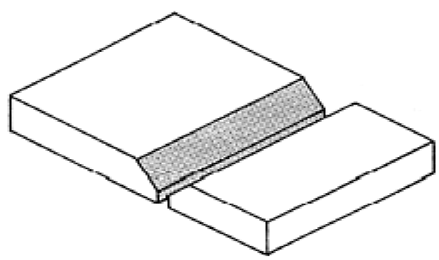


Figure 3.1—Butt joints.

The single-V butt joint (fig. 3-23, view B) is for use on plates 1/4 inch through 3/4 inch in thickness. Each member should be beveled so the included angle for the joint is approximately 60 degrees for plate and 75 degrees for pipe. Preparation of the joint requires a special beveling machine (or cutting torch), which makes it more costly than a square butt joint. It also requires more filler material than the square joint; how-ever, the joint is stronger than the square butt joint. But, as with the square joint, it is not recommended when subjected to bending at the root of the weld.

The double-V butt joint (fig. 3-23, view C) is an excellent joint for all load conditions. Its primary use is on metals thicker than 3/4 inch but can be used on thinner plate where strength is critical. Compared to the single-V joint, preparation time is greater, but you use less filler metal because of the narrower included angle. Because of the heat produced by welding, you should alternate weld deposits, welding first on one side and then on the other side. This practice produces a more symmetrical weld and minimizes

Remember, to produce good quality welds using the groove joint, you should ensure the fit-up is consistent for the entire length of the joint, use the correct groove angle, use the correct root opening, and use the correct root face for the joint. When you follow these principles, you produce better welds every time. Other standard grooved butt joint designs include the bevel groove, J-groove, and U-groove, as shown in figure 3-24.

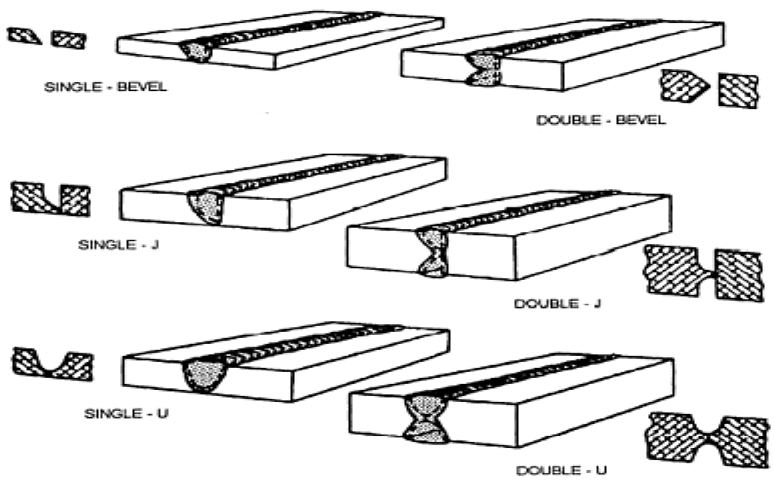


Figure 3-2.—Additiona1 types of groove welds.

3.5.2 CORNER JOINTS

The flush corner joint (fig. 3-25, view A) is designed primarily for welding sheet metal that is 12 gauge or thinner. It is restricted to lighter materials, because deep penetration is sometimes difficult and the design can support only moderate loads. The half-open corner joint (fig. 3-25, view B) is used for welding materials heavier than 12 gauge. Penetration is better than in the flush corner joint, but its use is only recommended for moderate loads. The full-open corner joint (fig. 3-25, view C) produces a strong joint, especially when welded on both sides. It is useful for welding plates of all thicknesses.

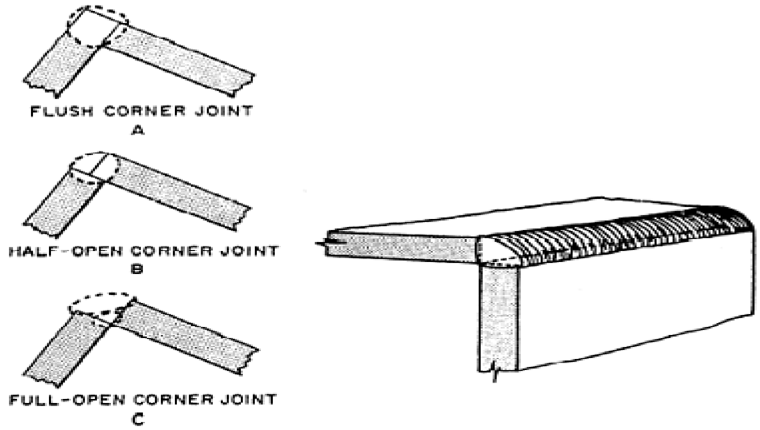


Figure 3-25.—Corner joints.

3.5.3 TEE JOINTS

The square tee joint (fig. 3-26, view A) requires a fillet weld that can be made on one or both sides. It can be used for light or fairly thick materials. For maximum strength, considerable weld metal should be placed on each side of the vertical plate. The single-bevel tee joint (fig. 3-26, view B) can withstand more severe loadings than the square tee joint, because of better distribution of stresses. It is generally used on plates of 1/2 inch or less in thickness and where welding can only be done from one side.

The double-bevel tee joint (fig. 3-26, view C) is for use where heavy loads are applied and the welding can be done on both sides of the vertical plate.

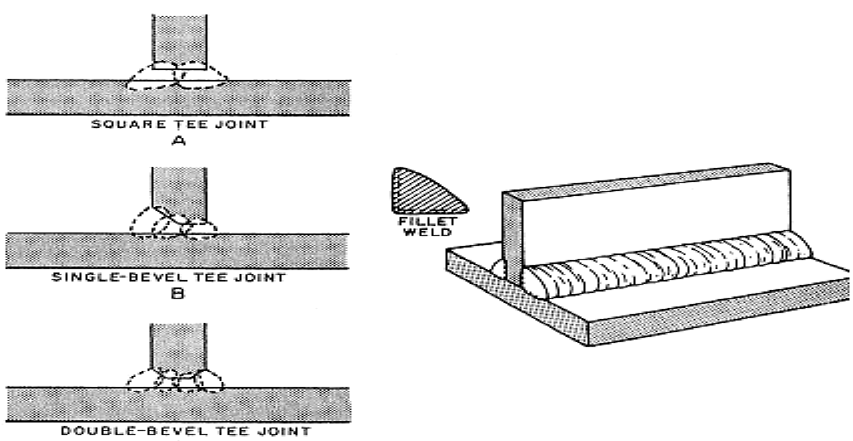


Figure 3-26.—T ee joints.

3.5.4 LAP JOINTS

The single-fillet lap joint (fig. 3-27, view A) is easy to weld, since the filler metal is simply deposited along the seam. The strength of the weld depends on the size of the fillet. Metal up to 1/2 inch in thickness and not subject to heavy loads can be welded using this joint. When the joint will be subjected to heavy loads, you should use the double-fillet lap joint (fig. 3-27, view B). When welded properly, the strength of this joint is very close to the strength of the base metal.

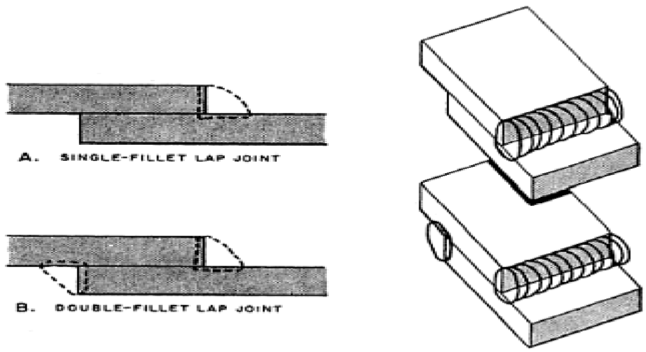


Figure 3-27.—Lap joints,

3.5.5 EDGE JOINTS

The flanged edge joint (fig. 3-28, view A) is suitable for plate 1/4 inch or less in thickness and can only sustain light loads. Edge preparation for this joint may be done, as shown in either views B or C.

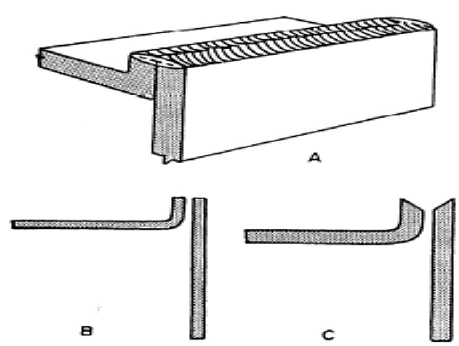


Figure 3-28.—Flanged edge Joints.

3.6 Welding Positions

All welding is done in one of four positions:

1. Flat
2. Horizontal
3. Vertical
4. Overhead

Fillet or groove welds can be made in all of these positions. Figure 3-29 shows the various positions used in plate welding. The American Welding Society (AWS) identifies these positions by a number/letter designation; for instance, the 1G position refers to a groove weld that is to be made in the flat position. Here the 1 is used to indicate the flat position and the G indicates a groove weld. For a fillet weld made in the flat position, the number/letter designation is 1F (F for fillet). These number/letter designations refer to test positions. These are positions a welder would be required to use during a welding qualification test. As a welder, there is a good possibility that someday you will be required to certify or perform a welding qualification test; therefore, it is important that you have a good understanding and can apply the techniques for welding in each of the test positions.

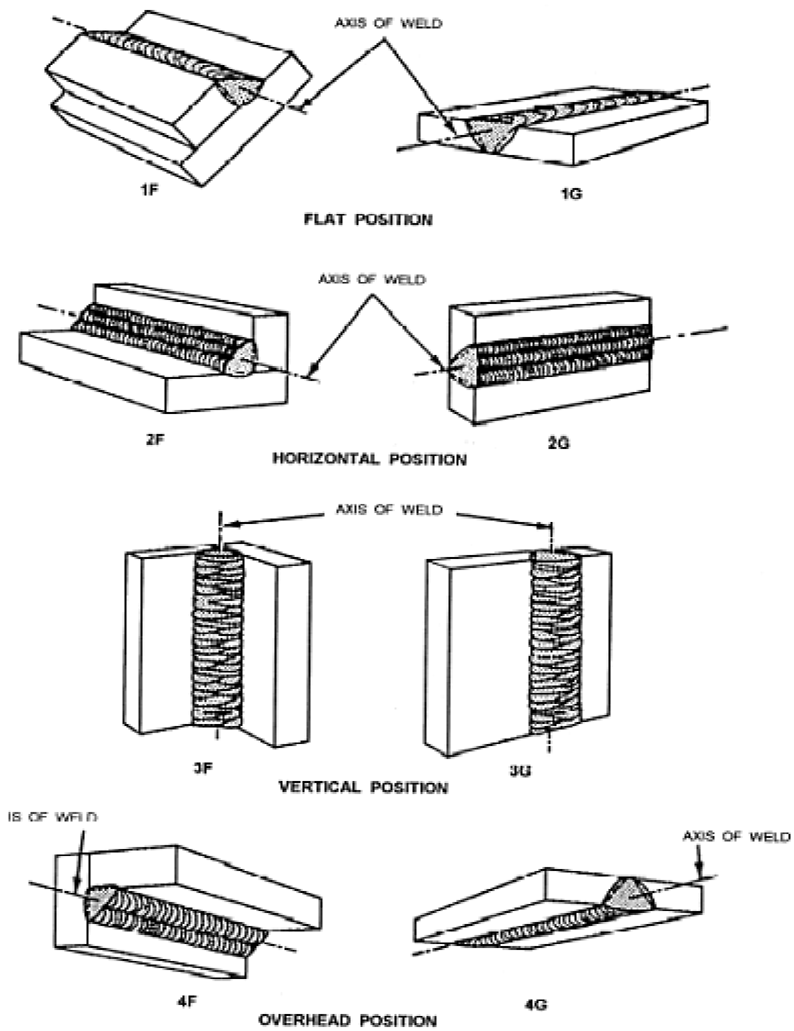


Figure 3-9.—Welding positions—plate.

Because of gravity, the position in which you are welding affects the flow of molten filler metal. Use the flat position, if at all possible, because gravity draws the molten metal downward into the joint making the welding faster and easier. Horizontal welding is a little more difficult, because the molten metal tends to sag or flow downhill onto the lower plate. Vertical welding is done in a vertical line, usually from bottom to top; however, on thin material downhill or down hand welding may be easier. The overhead position is the most difficult position. Because the weld metal flows downward, this position requires considerable practice on your part to produce good quality welds. Although the terms flat, horizontal, vertical, and overhead sufficiently describe the positions for plate welding, they do not adequately describe pipe welding positions. In pipe welding, there are four basic test positions used (fig. 3-30). Notice that the position refers to the position of the pipe, not the position of welding.

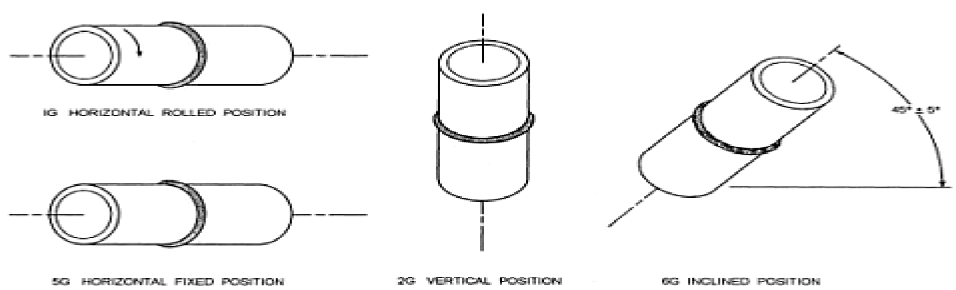


Figure 3-30.—Welding position-pipe.

Test position 1G is made with the pipe in the horizontal position. In this position, the pipe is rolled so that the welding is done in the flat position with the pipe rotating under the arc. This position is the most advantageous of all the pipe welding positions. When you are welding in the 2G position, the pipe is placed in the vertical position so the welding can be done in the horizontal position. The 5G position is similar to the 1G position in that the axis of the pipe is horizontal. But, when you are using the 5G position, the pipe is not turned or rolled during the welding operation; therefore, the welding is more difficult in this position. When you are using the 6G position for pipe welding, the axis of the pipe is at a 45-degree angle with the horizontal and the pipe is not rolled. Since the pipe is not rolled, welding has to be done in all the positions— flat, vertical, horizontal, and overhead. If you can weld pipe in this position, you can handle all the other welding positions.

3.7 Expansion and Contraction

When a piece of metal is heated, the metal expands. Upon cooling, the metal contracts and tries to resume its original shape. The effects of this expansion and contraction are shown in figure 3-31. View A shows a bar that is not restricted in any way. When the bar is heated, it is free to expand in all directions. If the bar is allowed to cool without restraint, it contracts to its original dimensions.

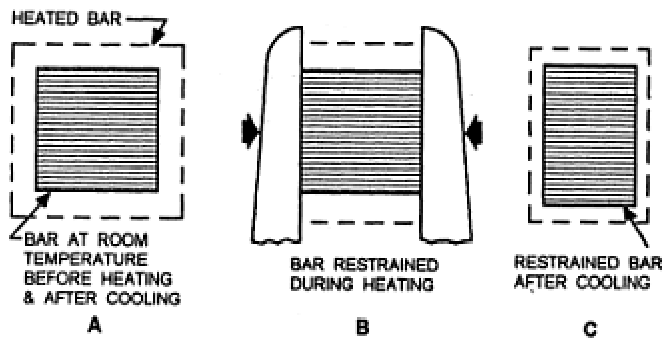


Figure 3-31.—Effects of expansion and contraction.

When the bar is clamped in a vise (view B) and heated, expansion is limited to the unrestricted sides of the bar. As the bar begins to cool, it still contracts uniformly in all directions. As a result, the bar is now deformed. It has become narrower and thicker, as shown in view C.These same expansion and contraction forces act on the weld metal and base metal of a welded joint; how-ever, when two pieces of metal are welded together, expansion and contraction may not be uniform throughout all parts of the metal. This is due to the difference in the temperature from the actual weld joint out to the edges of the joint. This difference in temperature leads to internal stresses, distortion, and war page. Figure 3-32 shows some of the most common difficulties that you are likely to encounter.

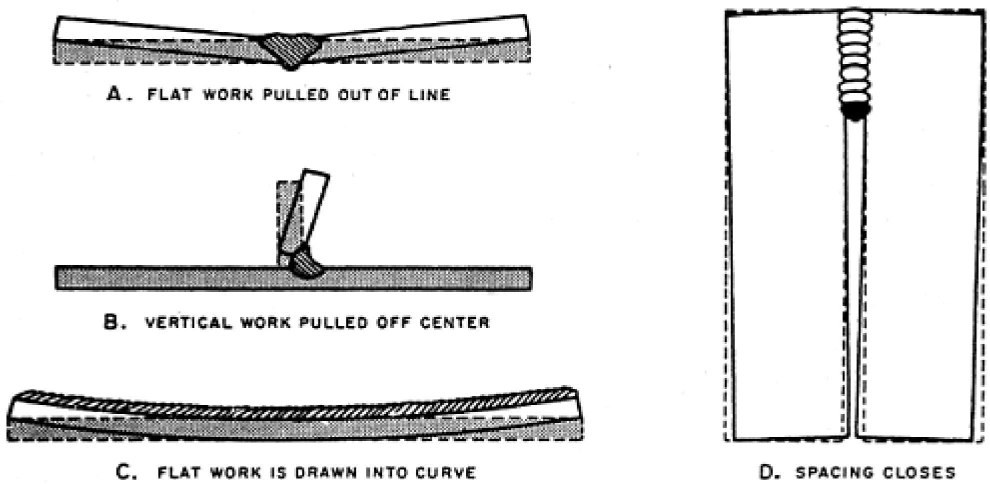


Figure 3-32.—Distortion caused by welding.

When you are welding a single-V butt joint (fig.3-32, view A), the highest temperature is at the surface of the molten puddle. The temperature decreases as you move toward the root of the weld and away from the weld. Because of the high temperature of the molten metal, this is where expansion and contraction are greatest. When the weld begins to cool, the surface of the weld joint contracts (or shrinks) the most, thus causing war page or distortion. View B shows how the same principles apply to a tee joint. Views C and D show the distortions caused by welding a bead on one side of a plate and welding two plates together without proper tack welds.

All metals, when exposed to heat buildup during welding, expand in the direction of least resistance. Conversely, when the metal cools, it contracts by the same amount; therefore, if you want to prevent or reduce the distortion of the weldment, you have to use some method to overcome the effects of heating and cooling.

3.8 Gas welding:

- Gas welding is a welding process that melts and joins metals by heating them with a flame caused by the reaction between a fuel gas and oxygen.
- Sound weld is obtained by selecting proper size of flame, filler material and method of moving torch
- The temperature generated during the process is 3300^0c

- When the metal is fused, oxygen from the atmosphere and the torch combines with molten metal and forms oxides, results defective weld
- Fluxes are added to the welded metal to remove oxides
- Common fluxes used are made of sodium, potassium. Lithium and borax.
- Flux can be applied as paste, powder, liquid, solid coating or gas.

3.8.1 GAS WELDING EQUIPMENT

1. Gas Cylinders (With Oxygen Pressure as 125 kg/cm2 & Acetylene Pressure as 16 kg/cm2)
2. Regulators
3. Pressure Gauges
4. Hoses
5. Welding torch
6. Check valve
7. Non return valve

3.9 ARC WELDING:

- Arc welding, developed in the mid-1800's, the heat required is obtained from electrical energy.
- The process involves either a consumable or a nonconsumable electrode.
- An AC or a DC power supply produces an arc between the tip of the electrode and the workpiece to be welded.
- The arc generates temperatures of about 30,000°C, which are much higher than those developed in oxyfuel-gas welding.
- Arc welding is the most common method of welding metals.
- Electricity travels from electrode to base metal to ground

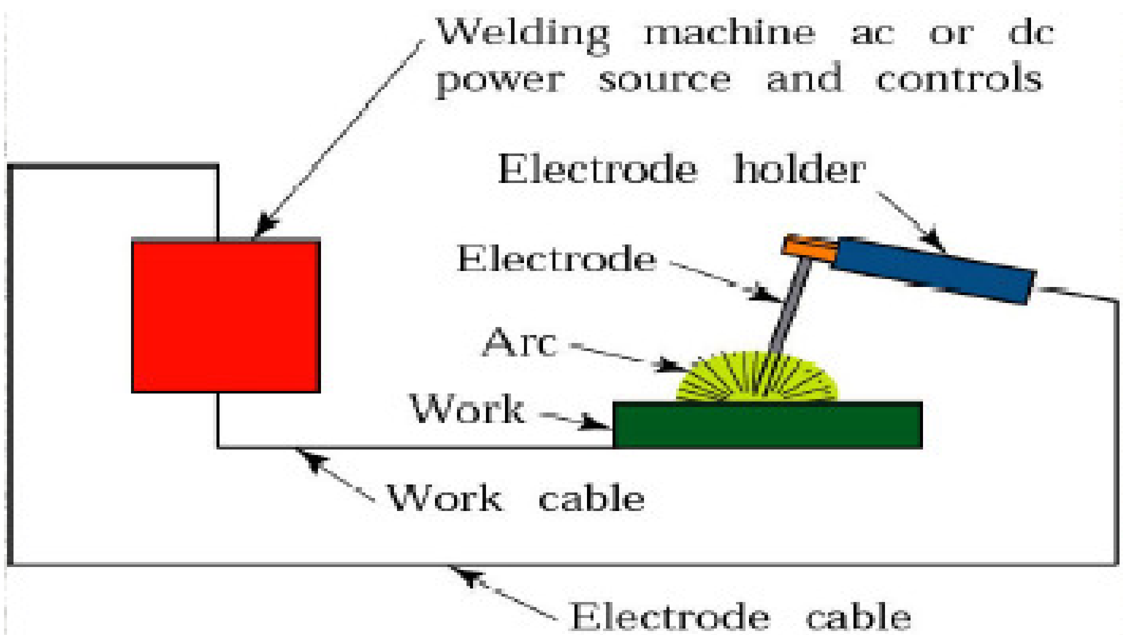
3.9.1 Manual Metal Arc Welding (Shielded Metal Arc Welding)

Definition and General Description

- SHIELDED METAL ARC welding (SMAW or MMAW) is an arc welding process in which coalescence of metals is produced by heat from an electric arc that is maintained between the tip of a covered electrode and the surface of the base metal in the joint being welded.

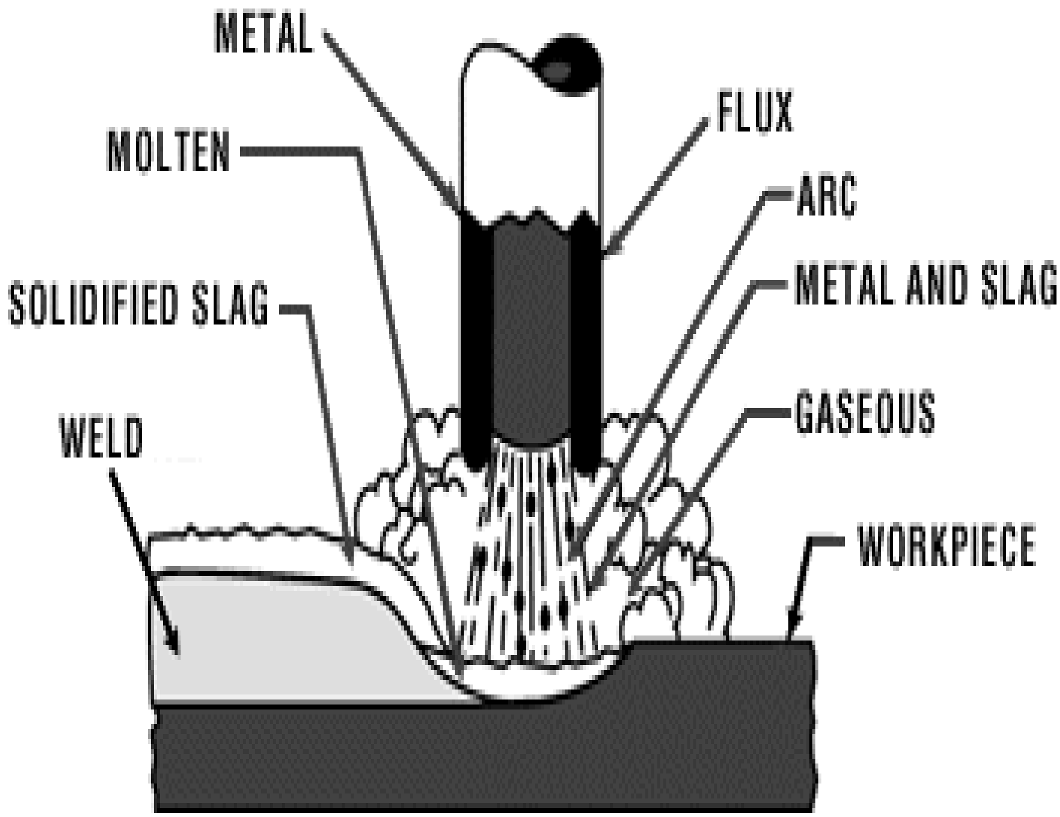
- The core of the covered electrode consists of either a solid metal rod of drawn or cast material or one fabricated by encasing metal powders in a metallic sheath.
- The core rod conducts the electric current to the arc and provides filler metal for the joint.
- The primary functions of the electrode covering are to provide arc stability and to shield the molten metal from the atmosphere with gases created as the coating decomposes from the heat of the arc.
- The shielding employed, along with other ingredients in the covering and the core wire, largely controls the mechanical properties, chemical composition, and metallurgical structure of the weld metal, as well as the arc characteristics of the electrode.
- The composition of the electrode covering varies according to the type of electrode.

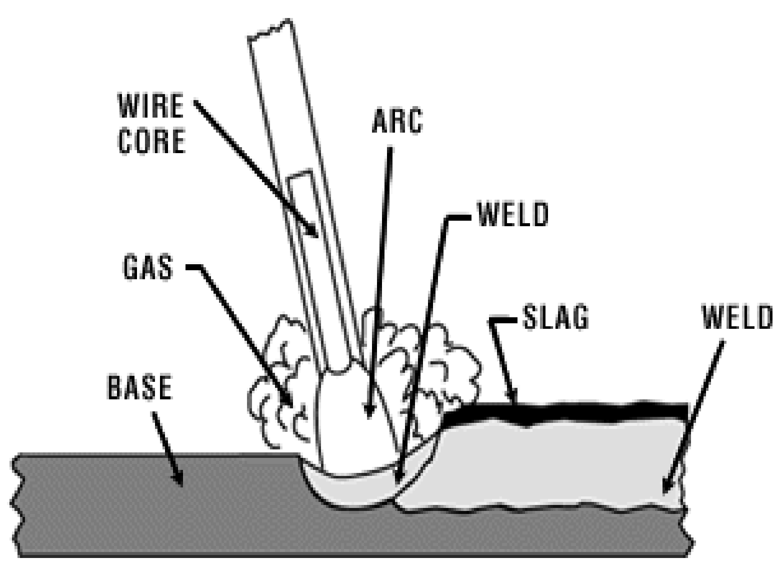
<u>Principles of Operation</u>



- The electrode and the work are part of an electric circuit illustrated in Figure.
- This circuit begins with the electric power source and includes the welding cables, an electrode holder, a workpiece connection, the workpiece (weldment), and an arc welding electrode.
- One of the two cables from the power source is attached to the work.
- The other is attached to the electrode holder.

- To strike the electric arc, the electrode is brought into contact with the workpiece by a very light touch with the electrode to the base metal then is pulled back slightly.
- This initiates the arc and thus the melting of the workpiece and the consumable electrode, and causes droplets of the electrode to be passed from the electrode to the weld pool.
- The intense heat of the arc melts the tip of the electrode and the surface of the work close to the arc.





ELECTRODE

- As the electrode melts, the flux covering disintegrates, giving off shielding gases that protect the weld area from atmospheric gases.
- In addition, the flux provides molten slag which covers the filler metal as it travels.
- Once part of the weld pool, the slag floats to the surface and protects the weld from contamination as it solidifies.
- In this manner, filler metal is deposited· as the electrode is progressively consumed.
- The arc is moved over the work at an appropriate arc length and travel speed, melting and fusing a portion of the base metal and continuously adding filler metal.

Advantages of MMAW:

- Heat input to the workpiece can be easily controlled by changing the arc length.
- Workpiece distortion is negligible.
- Process is simple and good welding skill can be acquired in short time.
- Total welding cost is less as compared to other welding processes.
- The equipment is relatively simple, inexpensive, and portable.
- The filler metal, and the means of protecting it and the weld metal from harmful oxidation during welding, are provided by the covered electrode.
- Auxiliary gas shielding or granular flux is not required.
- The process is less sensitive to wind and draft than gas shielded arc welding processes.
- It can be used in areas of limited access.
- The process is suitable for most of the commonly used metals and alloys.

Disadvantages of MMAW:

- In the absence of proper electrode geometry and in confined spaces arc blow results which gives poor welds with blow holes and porosity.
- Need high energy causing danger
- Not convenient for disassembly.
- Defects are hard to detect at joints.
- A separate filler metal is needed, which (when used) slows down the welding speed.
- Low melting metals, such as lead, tin, and zinc, and their alloys, are not welded with SMAW because the intense heat of the arc is too high for them.

- SMAW is not suitable for reactive metals such as titanium, zirconium, tantalum, and columbium because the shielding provided is inadequate to prevent oxygen contamination of the weld.

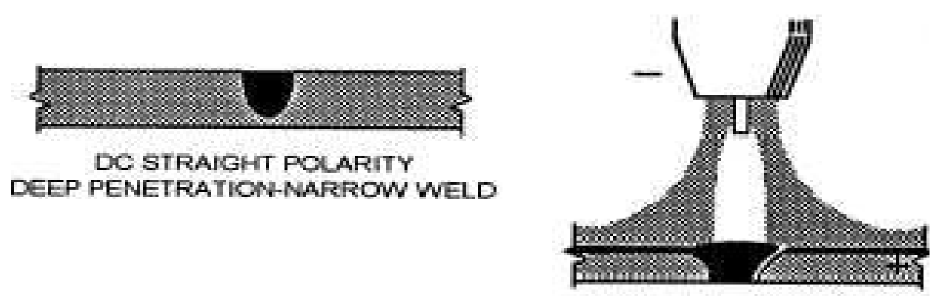
Applications of MMAW:

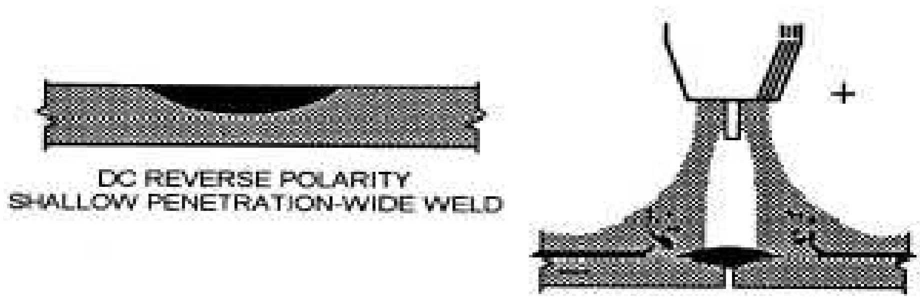
SMAW electrodes are available to weld carbon and low alloy steels, stainless steels, cast irons, copper, and nickel and their alloys, and for some aluminium applications.

Comparison of A.C. and D.C. arc welding:

Sl. No.	Alternating Current (from Transformer)	Direct Current (from Generator)
1	More efficiency	Less efficiency
2	Power consumption less	Power consumption more
3	Cost of equipment is less	Cost of equipment is more
4	Higher voltage – hence not safe	Low voltage – safer operation
5	Not suitable for welding non-ferrous metals	suitable for both ferrous non-ferrous metals
6	Not preferred for welding thin sections	preferred for welding thin sections
7	Any terminal can be connected to the work or electrode	Positive terminal connected to the work Negative terminal connected to the electrode

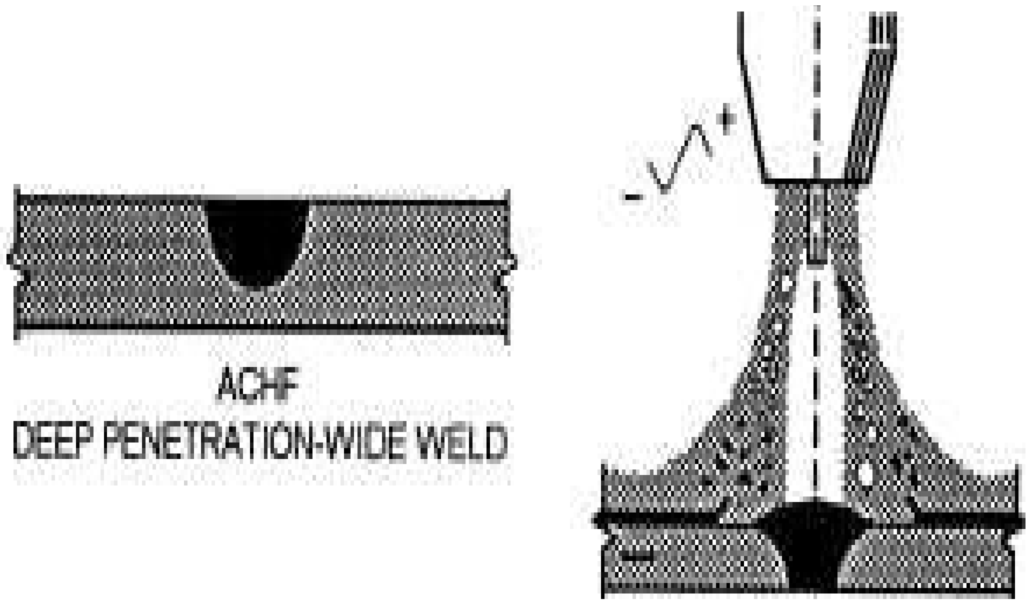
DIRECT CURRENT:





- Direct-current welding circuit may be either straight or reverse polarity.
- When the machine is set on straight polarity, the electrons flow from the electrode to the plate, concentrating most of the heat on the work.
- With reverse polarity, the flow of electrons is from the plate to the electrode, thus causing a greater concentration of heat at the electrode.
- Because of this intense heat, the electrode tends to melt off; therefore, direct-current reverse polarity (DCRP) requires a larger diameter electrode than direct-current straight polarity (DCSP)

ALTERNATING CURRENT:



- AC welding is actually a combination of DCSP and DCRP.
- AC welding machines were developed with a high-frequency current flow unit to prevent this rectification.
- The high frequency current pierces the oxide film and forms a path for the welding current to follow.
- Notice that ACHF offers both the advantages of DCRP and DCSP.
- ACHF is excellent for welding aluminium.

3.10 Welding Electrode Classification:

3.10.1 Mild Steel Coated Electrodes

E7018-X

E - Indicates that this is an electrode

70 - Indicates how strong this electrode is when welded. Measured in thousands of pounds per square inch.

1 - Indicates in what **welding positions** it can be used.

8 - Indicates the coating, penetration, and current type used. (See **Classification Table** below)

X - Indicates that there are more requirements. (See **Additional Requirements** below)

3.10.2 Welding Positions:

- 1 Flat, Horizontal, Vertical (up), Overhead
- 2 Flat, Horizontal
- 4 Flat, Horizontal, Overhead, Vertical (down)
- Flat Position - usually groove welds, fillet welds only if welded like a "V"
- Horizontal - Fillet welds, welds on walls (travel is from side to side).
- Vertical - welds on walls (travel is either up or down).
- Overhead - weld that needs to be done upside down.

CLASSIFICATION TABLE:

Class Electrode Coating Penetration Current Type

- Exxx0 Cellulose, Sodium Deep DCEP
- Exxx1 Cellulose, Potassium Deep AC, DCEP
- Exxx2 Rutile, Sodium, Medium AC, DCEN
- Exxx3 Rutile, Potassium, Light AC, DCEP, DCEN
- Exxx4 Rutile, Iron Powder, Medium AC, DCEP, DCEN
- Exxx5 Low Hydrogen, Sodium Medium DCEP
- Exxx6 Low Hydrogen, Potassium Medium AC, DCEP

Additional Requirement:

- 1 Increased toughness (impact strength)
- M Meets most military requirements - greater toughness, lower moisture content as received after exposure, diffusible hydrogen limits for weld metal.
- H4 Indicates the maximum diffusible hydrogen limit measured in g per 100 grams. Example: H4 = 4g per 100 grams

3.10.3 Rutile Electrodes – In this type, about 35% in weight of the coating is titanium dioxide (TiO_2) facilitates arc ignition, makes it possible to work with a soft arc and reduces spatter.

3.10.4 Basic (Low Hydrogen - Lime Coated) Electrodes - The coating of this type of electrode consist of calcium fluoride plus calcium and other alkaline carbonates. This type of electrodes is preferred when welding medium and thick steel plates that require high strength, high welding quality and high crack resistance. Basic electrodes are mainly used in the heavy machinery and equipment's industries, such as ship building.

3.10.5 Cellulosic Electrodes:

- The coating of these electrodes contains organic materials that turn into gases in the arc. About 30% of the coating weight is cellulose.
- These organic compounds in the coating decompose in the arc to from carbon monoxide, carbon dioxide and hydrogen, which increase the arc tension and thus, the welding arc becomes stronger and harder.
- The main features of cellulosic electrodes are Deep penetrating welding in every position & Weld metal with good mechanical properties

3.11 FLUXES:

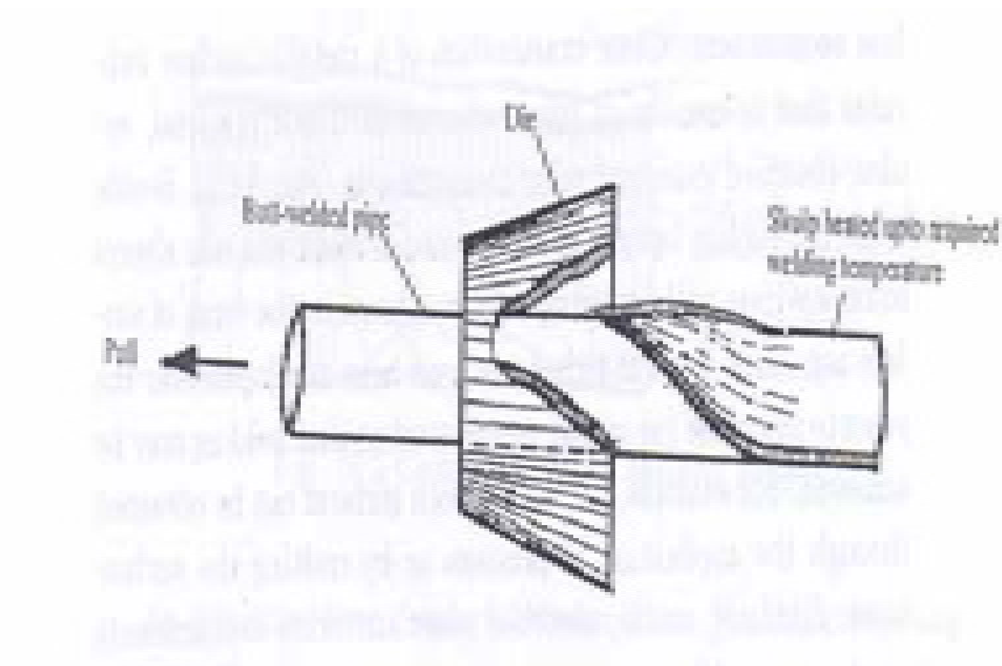
According to their main constituents, fluxes are termed

- Manganese silicate (MS) types, containing mainly MnO and SiO ;
- Calcium silicate (CS) types containing mainly CaO, MgO and SiO;
- Aluminate rutile (AR) types, containing mainly Al_2O_3 and TiO_2, aluminate basic types (AB), containing mainly Al_2O_3+CaO+MgO, and fluoride basic (FB) types, containing mainly CaO, MgO and CaF_2.

3.12 FORGE WELDING:

1. Forge welding is the oldest method of welding in the category of solid state welding.
2. Surfaces to be joined are heated till they are red hot and then forced together by hammering.
3. It is a crude method of welding and quality depends upon the skill of the welder.
4. A modern version of this type of welding is manufacture of butt welded pipes.

5. In this process, the skulp heated up to the required welding temperature is pulled through die which forces the two edges of the heated skulp to contact under pressure and get welded.

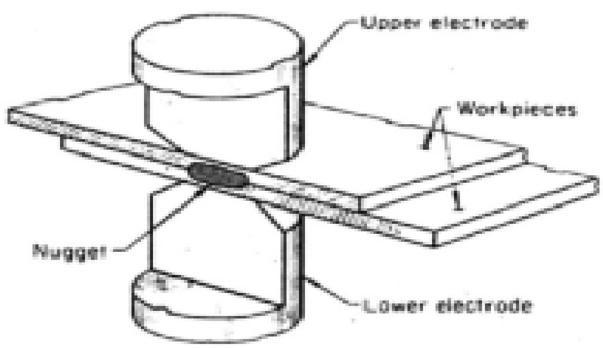


3.13 RESISTANCE WELDING:

Resistance welding is a welding technology widely used in manufacturing industry for joining metal sheets and components. The weld is made by conducting a strong current through the metal combination to heat up and finally melt the metals at localized point(s) predetermined by the design of the electrodes and/or the work pieces to be welded. A force is always applied before, during and after the application of current to confine the contact area at the weld interfaces and, in some applications, to forge the work pieces. Depending on the shape of the work pieces and the form of the electrodes, resistance welding processes can be classified into several variants as described below:

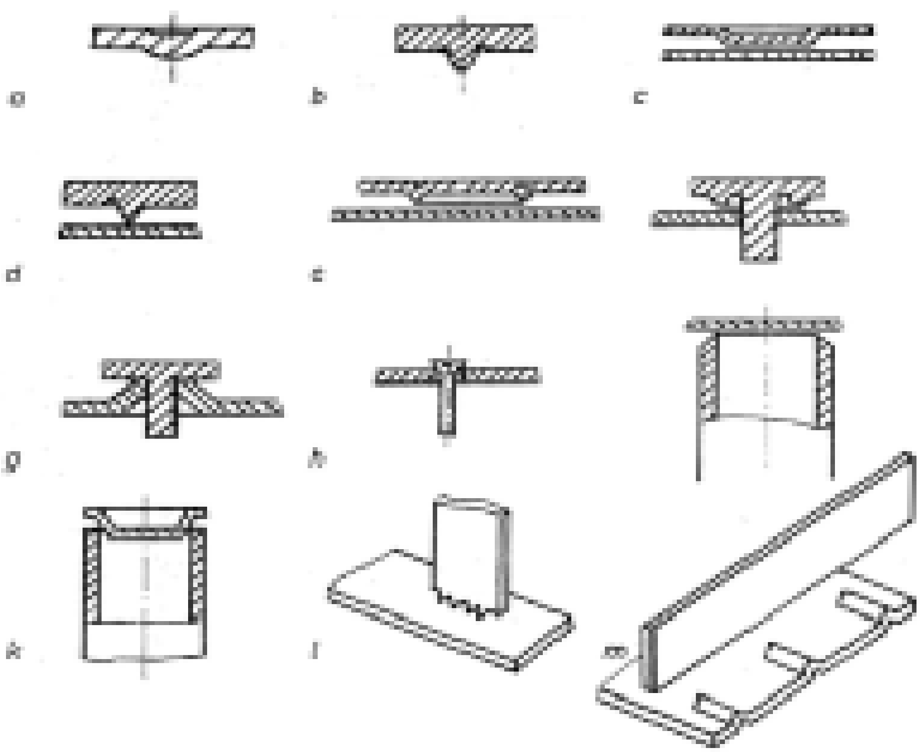
3.13.1 Resistance Spot Welding

Spot welding is a resistance welding process for joining metal sheets by directly applying opposing forces with electrodes with pointed tips. The current and the heat generation are localized by the form of the electrodes. The weld nugget size is usually defined by the electrode tip contact area.



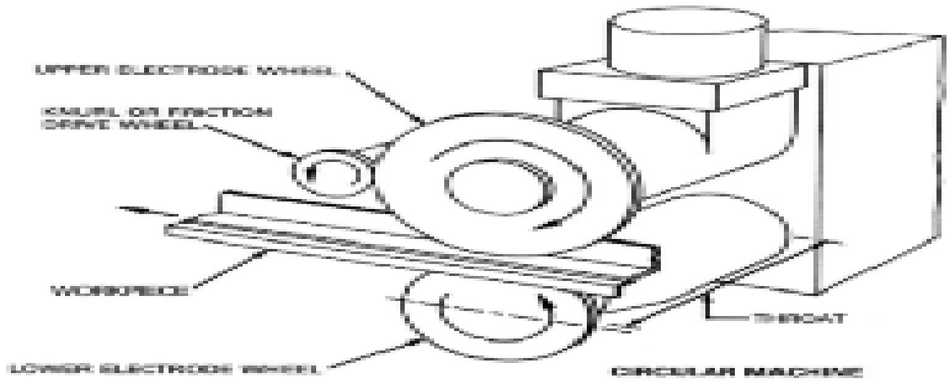
Spot welding is the predominant joining process in automotive industry for assembling the automobile bodies and large components. It is also widely used for manufacturing of furniture and domestic equipment etc.

3.13.2 Resistance Projection Welding



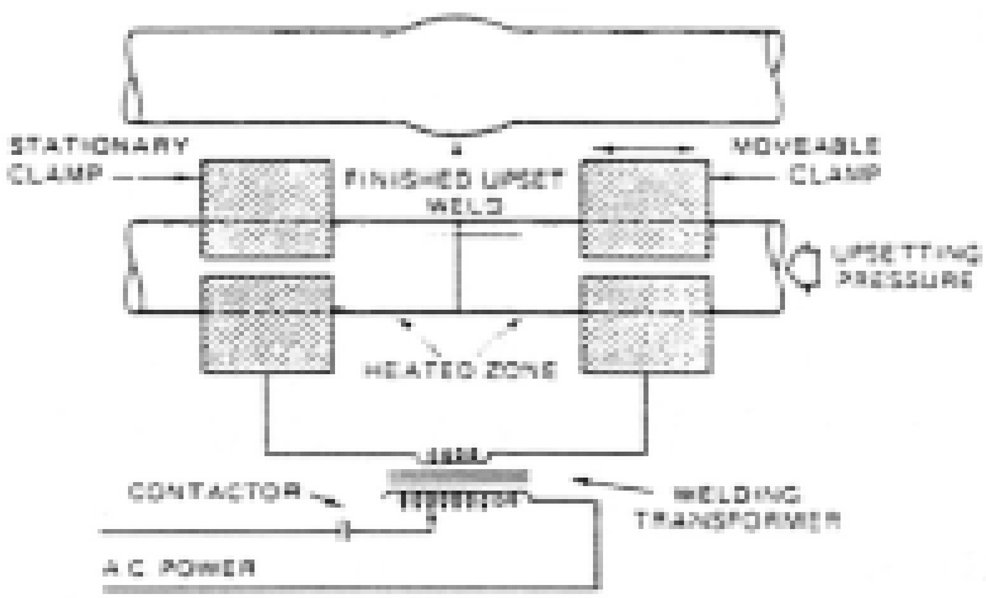
Projection welding is a resistance welding process for joining metal components or sheets with embossments by directly applying opposing forces with electrodes specially designed to fit the shapes of the work pieces. The current and the heat generation are localized by the shape of the work pieces either with their natural shape or with specially designed projection. Large deformation or collapse will occur in the projection part of the work pieces implying high process/machine dynamics. Projection welding is widely used in electrical, electronics, automotive and construction industries, and manufacturing of sensors, valves and pumps etc.

3.13.3 Resistance Seam Welding



Seam welding is a resistance welding process for joining metal sheets in continuous, often leak tight, seam joints by directly applying opposing forces with electrodes consisting of rotary wheels. The current and the heat generation are localized by the peripheral shapes of the electrode wheels. Seam welding is mostly applied in manufacturing of containers, radiators and heat exchangers etc.

3.13.4 Resistance Butt Welding



Butt welding is a resistance welding process for joining thick metal plates or bars at the ends by directly applying opposing forces with electrodes clamping the work pieces. A forging operation is applied after the work pieces are heated up. Often no melt occurs, thus a solid state weld can be obtained. Butt welding is applied in manufacturing of wheel rims, wire joints and railway track joints etc.

Single-Sided (One-Sided) Resistance Welding is a special resistance welding process where the weld is made with only one electrode accessing from one side to the weld zone with or without a backing plate from the other side. Low weld force is usually used, which limits the single-sided (one-sided) spot welding to joining of relatively thin sheets. It may be useful for welding components with limitation of electrode access from both sides.

Resistance Weld Bonding is a combined joining process with adhesive bonding and resistance welding. The adhesive is applied to the faying surfaces of sheets to be welded, and subsequently resistance spot weld is made through the sheets before curing of the adhesive. The joint can have good strength from the spot welding and good stiffness from the adhesive bonding.

Cross Wire Welding is a resistance welding process for joining bars or wires in cross joints by directly applying opposing forces with usually flat electrodes. The current and the heat generation are localized at the contact points of the crossed bars or wires. Cross wire welding is widely used in construction and electrical industry as well as for manufacturing of metal wire nets and shopping trolleys etc.

Indirect Welding is a special resistance welding process where a single weld is made with one electrode directly connecting to the weld zone, while the other electrode is offset at a distance, but still conducts the current along the workpiece.

Series Welding is a special resistance welding process where two welds are made at the same time with two electrodes offset at a distance but still conducting the current along the workpieces between the two welds.

Micro Resistance Welding refers to the resistance welding processes for joining micro or miniaturized components, which in principle can be any of the above mentioned process variants but in a micro scale.

Parallel Gap Welding is a special micro resistance welding process for joining thin foils or thin wires. The two electrodes are configured in parallel, having a gap between them in which insulation material is inserted. The weld is made with the two parallel electrodes accessing the work pieces from the same side.

3.14 PLASMA (AIR AND WATER) WELDING:

Plasma arc welding (PAW) is an arc welding process similar to gas tungsten arc welding (GTAW). The electric arc is formed between an electrode (which is usually but not always made of sintered tungsten) and the workpiece. The key difference from GTAW is that in PAW, by positioning the electrode within the body of the torch, the plasma arc can be separated from the shielding gas envelope. The plasma is then forced through a fine-bore copper nozzle which constricts the arc and the plasma exits the orifice at high velocities (approaching the speed of sound) and a temperature approaching 28,000 °C (50,000 °F) or higher. Arc plasma is the temporary state of a gas. The gas gets ionized after passage of electric current through it and it becomes a conductor of electricity. In ionized state atoms break into electrons (−) and ions (+) and the system contains a mixture of ions, electrons and highly excited atoms. The degree of ionization may be between 1% and greater than 100% i.e.; double and triple degrees of ionization. Such states exist as more number of electrons are pulled from their orbits.

The energy of the plasma jet and thus the temperature is dependent upon the electrical power employed to create arc plasma. A typical value of temperature obtained in a plasma jet torch may be of the order of 28000 °C(50000 °F) against about 5500 °C (10000 °F) in ordinary electric welding arc. Actually all welding arcs are (partially ionized) plasmas, but the one in plasma arc welding is a constricted arc plasma.

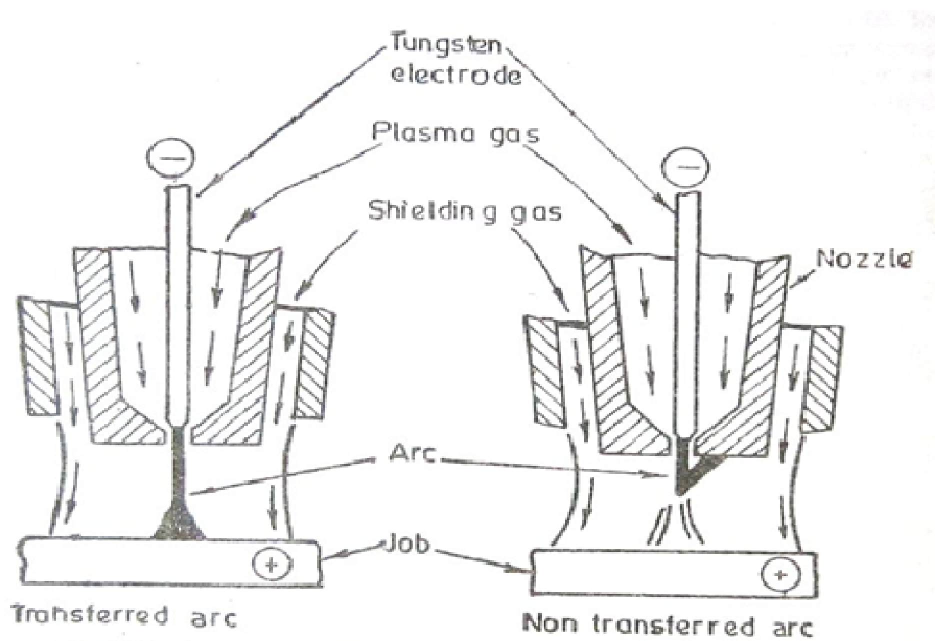


Fig. 4·26. Concept of transferred and non-transferred arc processes.

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 intensely and thus improves arc stability, arc shape and heat transfer characteristics. Plasma arc welding process can be divided into two basic types:

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 work piece and the work piece does not form a part of the electrical circuit. Just as an arc flame (as in atomic hydrogen welding), it can be moved from one place to another and can be better controlled. The non transferred plasma arc possesses comparatively less energy density as compared to a transferred arc plasma and it is employed for welding and in applications involving ceramics or metal plating (spraying). High density metal coatings can be produced by this process. A non-transferred arc is initiated by using a high frequency unit in the circuit.

Transferred arc process

The arc is formed between the electrode(-) and the work piece(+). In other words, arc is transferred from the electrode to the work piece. A transferred arc possesses high energy density and plasma jet velocity. For this reason it is employed to cut and melt metals. Besides carbon steels this process can cut stainless steel and nonferrous metals also where oxyacetylene torch does not succeed. Transferred arc can also be used for welding at high arc travel speeds. For initiating a transferred arc, a current limiting resistor is put in the circuit, which permits a flow of about 50 amps, between the nozzle and electrode and a pilot arc is established between the electrode and the nozzle. As the pilot arc touches the job main current starts flowing between electrode and job, thus igniting the transferred arc. The pilot arc initiating unit gets disconnected and pilot arc extinguishes as soon as the arc between the electrode and the job is started. The temperature of a constricted plasma arc may be of the order of 8000 - 25000^0C.

Equipment

The equipment needed in plasma arc welding along with their functions are as follows:

Power Supply

A direct current power source (generator or rectifier) having drooping characteristics and open circuit voltage of 70 volts or above is suitable for plasma arc welding. Rectifiers are generally preferred over DC generators. Working with helium as an inert gas needs open circuit voltage above 70 volts. This higher voltage can be obtained by series operation of two power sources; or the arc can be initiated with argon at normal open circuit voltage and then helium can be switched on.

Typical welding parameters for plasma arc welding are as follows:

Current 50 to 350 amps, voltage 27 to 31 volts, gas flow rates 2 to 40 liters/minute (lower range for orifice gas and higher range for outer shielding gas), DCSP is normally employed except for the welding of aluminium in which cases water cooled copper anode and DCSP are preferred.

High frequency generator and current limiting resistors

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

Plasma Torch

It is either transferred arc or non transferred arc typed. It is hand operated or mechanized. At present, almost all applications require automated system. The torch is water cooled to increase the life of the nozzle and the electrode. The size and the type of nozzle tip are selected depending upon the metal to be welded, weld shapes and desired penetration height.

Shielding gases

Two inert gases or gas mixtures are employed. The orifice gas at lower pressure and flow rate forms the plasma arc. The pressure of the orifice gas is intentionally kept low to avoid weld metal turbulence, but this low pressure is not able to provide proper shielding of the weld pool. To have suitable shielding protection same or another inert gas is sent through the outer shielding ring of the torch at comparatively higher flow rates. Most of the materials can be welded with argon, helium, argon+hydrogen and argon+helium, as inert gases or gas mixtures. Argon is very commonly used. Helium is preferred where a broad heat input pattern and flatter cover pass is desired. A mixture of argon and hydrogen supplies heat energy higher than when only argon is used and thus permits higher arc alloys and stainless steels.

For cutting purposes a mixture of argon and hydrogen (10-30%) or that of nitrogen may be used. Hydrogen, because of its dissociation into atomic form and thereafter recombination generates temperatures above those attained by using argon or helium alone.

Voltage control

Voltage control is required in contour welding. In normal key hole welding a variation in arc length up to 1.5 mm does not affect weld bead penetration or bead shape to any significant extent and thus a voltage control is not considered essential.

Current and gas decay control

It is necessary to close the key hole properly while terminating the weld in the structure.

Fixture

It is required to avoid atmospheric contamination of the molten metal under bead.

Process Description

Technique of work piece cleaning and filler metal addition is similar to that in TIG welding. Filler metal is added at the leading edge of the weld pool. Filler metal is not required in making root pass weld.

Type of Joints:

For welding work piece up to 25 mm thick, joints like square butt, J or V are employed. Plasma welding is used to make both key hole and non-key hole types of welds.

Making a non-key hole weld:

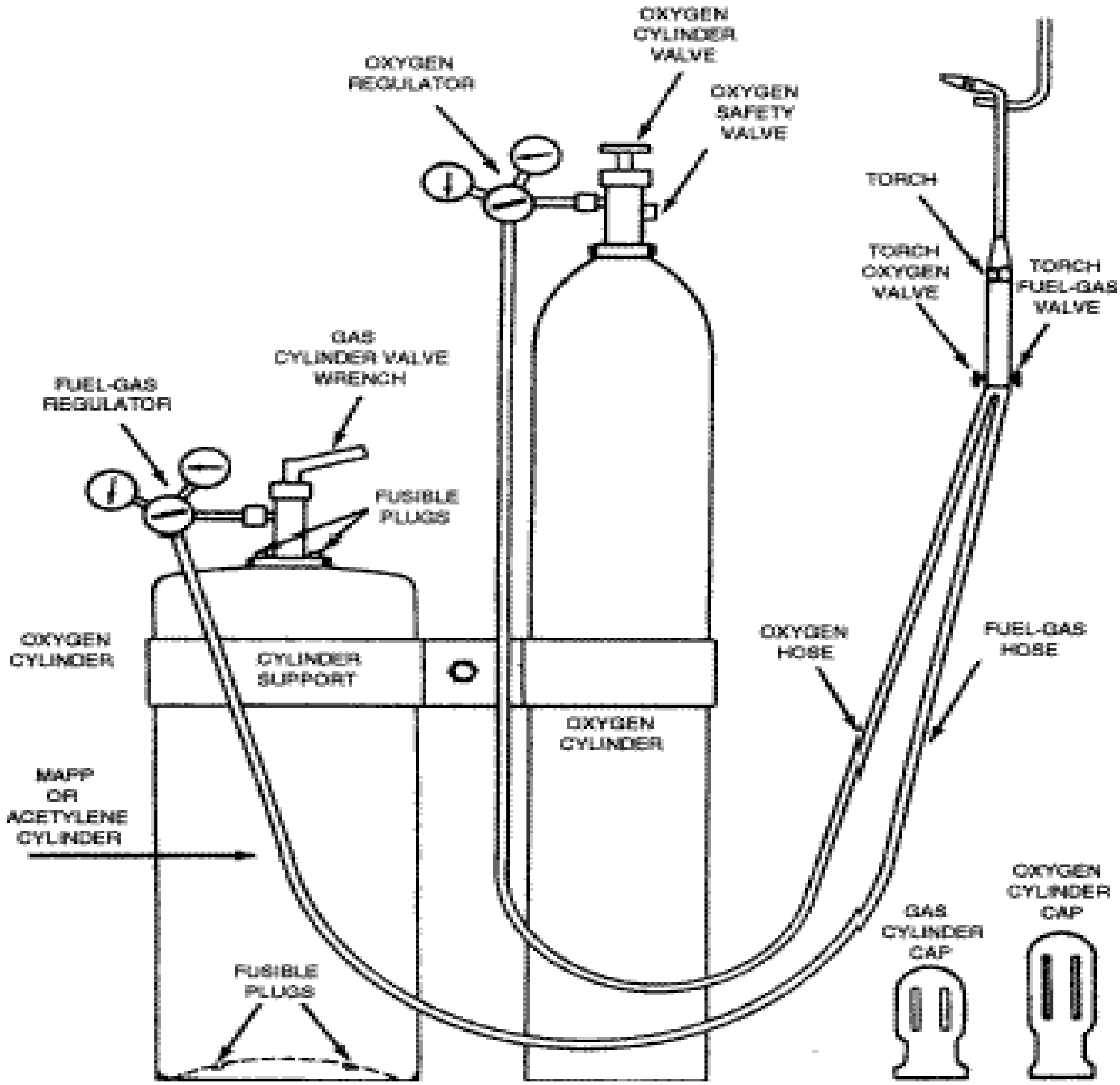
The process can make non key hole welds on work pieces having thickness 2.4 mm and under.

Making a keyhole welds:

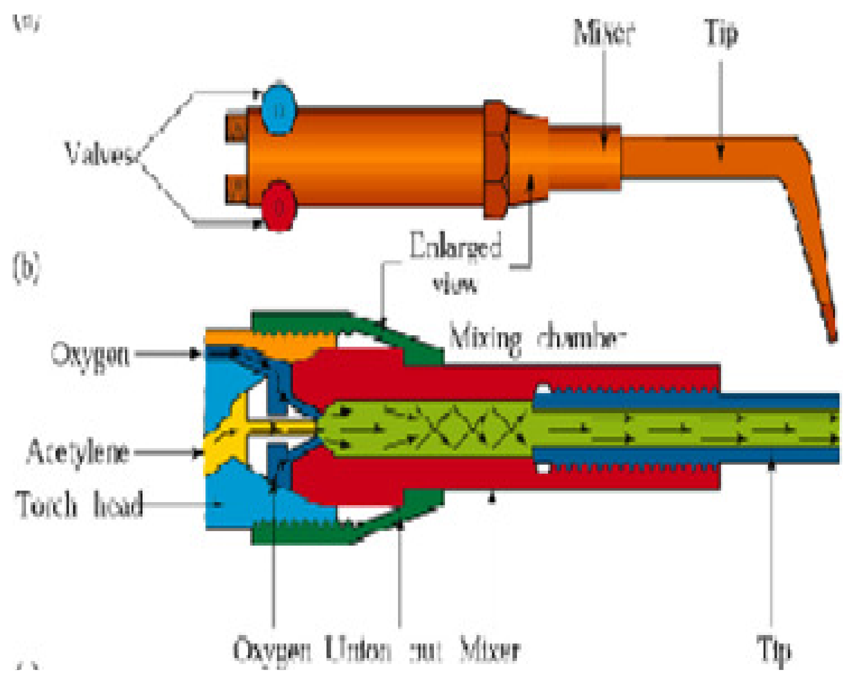
An outstanding characteristics of plasma arc welding, owing to exceptional penetrating power of plasma jet, is its ability to produce keyhole welds in work piece having thickness from 2.5 mm to 25 mm. A keyhole effect is achieved through right selection of current, nozzle orifice diameter and travel speed, which create a forceful plasma jet to penetrate completely through the work piece. Plasma jet in no case should expel the molten metal from the joint. The major advantages of keyhole technique are the ability to penetrate rapidly through relatively thick root sections and to produce a uniform under bead without mechanical backing. Also, the ratio of the depth of penetration to the width of the weld is much higher, resulting narrower weld and heat-affected zone. As the weld progresses, base metal ahead the keyhole melts, flow around the same solidifies and forms the weld bead. Key holing aids deep penetration at faster speeds and produces high quality bead. While welding thicker pieces, in laying others than root run, and using filler metal, the force of plasma jet is reduced by suitably controlling the amount of orifice gas.

3.15 Cutting Of Metals

3.15.1 Oxy-Acetylene welding:



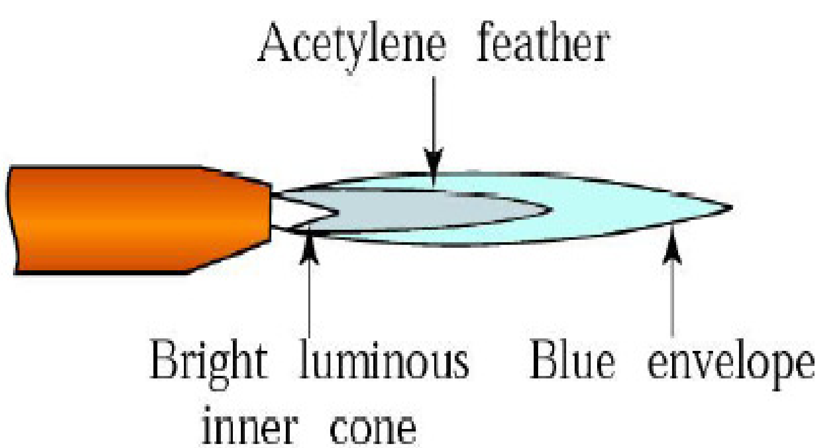
Torch Used in Oxyacetylene Welding:



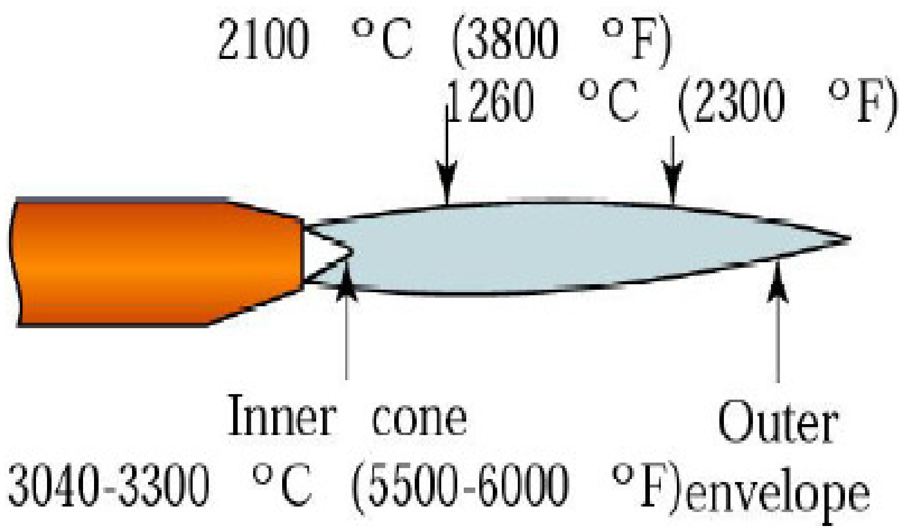
3.15.2 Types of Flames in Oxy-Acetylene Welding:

(i) Carburizing flame

- Oxygen is turned on, flame immediately changes into a long white inner area (Feather) surrounded by a transparent blue envelope is called Carburizing flame (3000□ C)
- A reducing flame does not completely, consume the available carbon; therefore, its burning temperature is lower and the left over carbon is forced into the molten metal.
- A carburizing flame contains more acetylene. A carburizing flame is used in the welding of lead and for carburizing (surface hardening) purposes.



(ii) Neutral flame



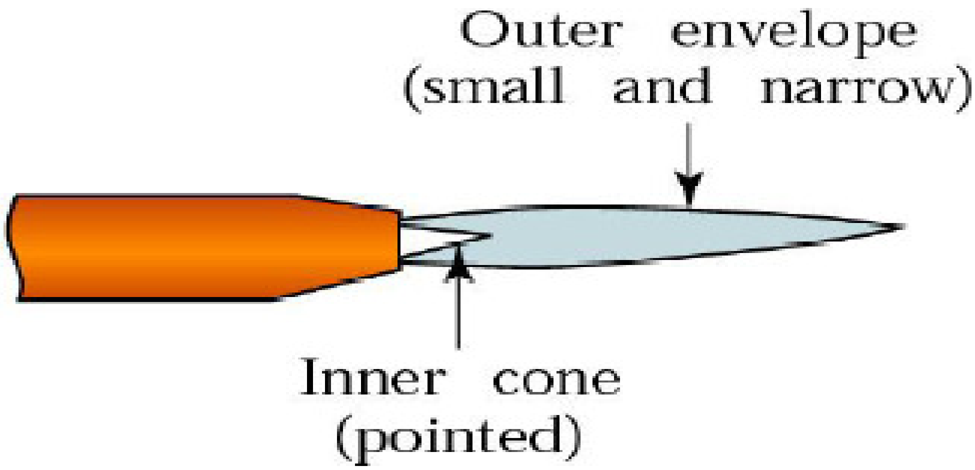
- Addition of little more oxygen give a bright whitish cone surrounded by the transparent blue envelope is called Neutral flame (3200□ C).
- A neutral flame is named so because it effects no chemical change in the molten metal and therefore will not oxidize or carburize the metal.
- The neutral flame is commonly used for the welding of:

  (1) Mild steel (2) Stainless steel (3) Cast Iron (4) Copper (5) Aluminium

(iii) Oxidizing flame

- If more oxygen is added, the cone becomes darker and more pointed, while the envelope becomes shorter and more fierce is called Oxidizing flame
- Has the highest temperature about 3400□ C
- The high temperature of an oxidizing flame (O_2: C_2H_2 = 1.5: 1) would be an advantage if it were not for the fact that the excess oxygen, especially at high temperatures, tends to combine with many metals to form hard, brittle, low strength oxides.
- Moreover, an excess of oxygen causes the weld bead and the surrounding area to have a scummy or dirty appearance
- For these reasons, an oxidizing flame is of limited use in welding. It is not used in the welding of steel

- Used for welding brass and brazing operation.



3.15.3 Oxy-Acetylene Gas Cutting

- Ferrous metal is heated in to red hot condition and a jet of pure oxygen is projected onto the surface, which rapidly oxidizes
- Oxides having lower melting point than the metal, melt and are blown away by the force of the jet, to make a cut
- Fast and efficient method of cutting steel to a high degree of accuracy
- Torch is different from welding
- Cutting torch has preheated orifice and one central orifice for oxygen jet
- PIERCING and GOUGING are two important operations
- Piercing, used to cut a hole at the center of the plate or away from the edge of the plate
- Gouging, to cut a groove into the steel surface

Advantages of Oxy-Acetylene welding

- The main advantage of the oxyacetylene welding process is that the equipment is simple, portable, and inexpensive. Therefore, it is convenient for maintenance and repair applications.

Limitations Oxy-Acetylene welding

- However, due to its limited power density, the welding speed is very low and the total heat input per unit length of the weld is rather high, resulting in large heat-affected zones and severe distortion.
- The oxyacetylene welding process is not recommended for welding reactive metal such as titanium and zirconium because of its limited protection power.

3.15.4 FERROUS METALS

- Mild Steel – Carbon content of 0.1 to 0.3% and Iron content of 99.7 – 99.9%. Used for engineering purposes and in general, none specialised metal products.
- Carbon steel – Carbon content of 0.6 to 1.4% and Iron content of 98.6 to 99.4 %. Used to make cutting tools such as drill bits.
- Stainless Steel – Made up of Iron, nickel and chromium. Resists staining and corrosion and is therefore used for the likes of cutlery and surgical instrumentation. See our info graphic

celebrating 100 years of stainless steel usage in buildings or the different types of stainless steel.

- Cast Iron – carbon 2 – 6% and Iron at 94 to 98%. Very strong but brittle. Used to manufacture items such as engine blocks and manhole covers.
- Wrought Iron – Composed of almost 100% iron. Used to make items such as ornamental gates and fencing. Has fallen out of use somewhat.

3.15.5 NON FERROUS METALS

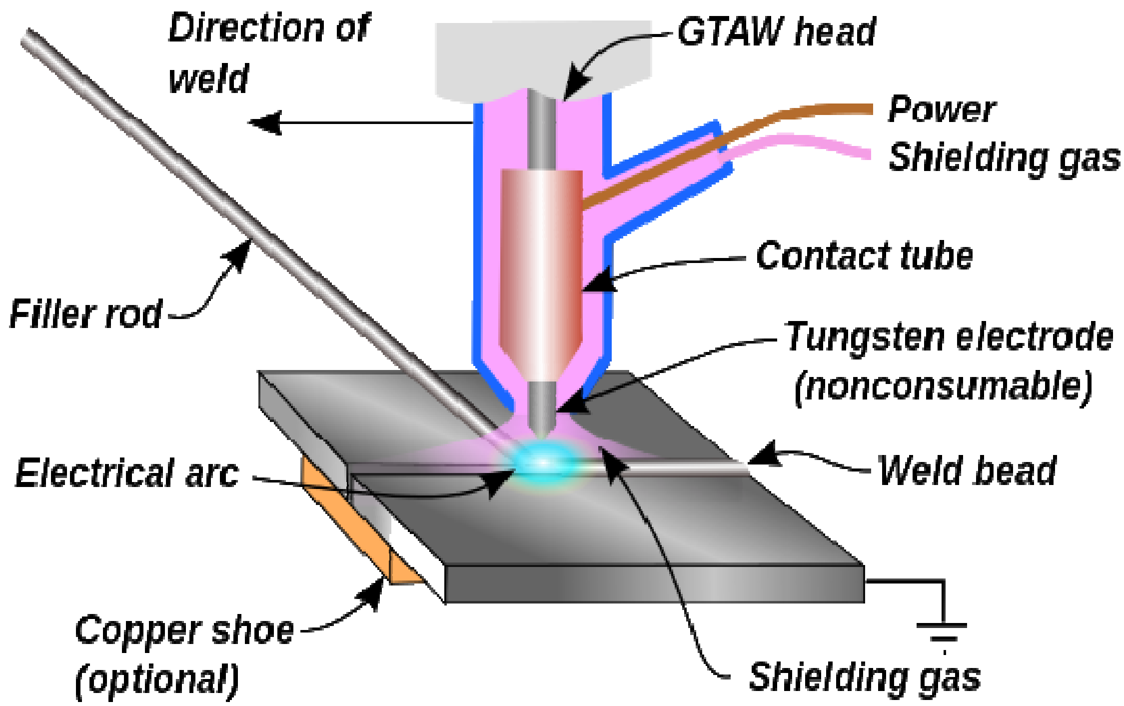
- Aluminium – An alloy of aluminium, copper and manganese. Very lightweight and easily worked. Used in aircraft manufacture, window frames and some kitchen ware.
- Copper – Copper is a natural occurring substance. The fact that it conducts heat and electricity means that it is used for wiring, tubing and pipe work.
- Brass – A combination of copper and zinc, usually in the proportions of 65% to 35% respectively. Is used for ornamental purposes and within electrical fittings.
- Silver – Mainly a natural substance, but mixing with copper creates sterling silver. Used for decorative impact in jewellery and ornaments, and also to solder different metals together.
- Lead – Lead is a naturally occurring substance. It is heavy and very soft and is often used in roofing, in batteries and to make pipes.

UNIT IV

4. Tungsten inert gas (TIG) welding

4.1 Gas tungsten arc welding (**GTAW**), also known as **tungsten inert gas** (**TIG**) **welding**, is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmospheric contamination by an inert shielding gas (argon or helium), and a filler metal is normally used, though some welds, known as autogenous welds, do not require it. A constant-current welding power supply produces electrical energy, which is conducted across the arc through a column of highly ionized gas and metal vapours known as a plasma.

GTAW is most commonly used to weld thin sections of stainless steel and non-ferrous metals such as aluminium, magnesium, and copper alloys. The process grants the operator greater control over the weld than competing processes such as shielded metal arc welding and gas metal arc welding, allowing for stronger, higher quality welds. However, GTAW is comparatively more complex and difficult to master, and furthermore, it is significantly slower than most other welding techniques. A related process, plasma arc welding, uses a slightly different welding torch to create a more focused welding arc and as a result is often automated.



Operation:

Manual gas tungsten arc welding is a relatively difficult welding method, due to the coordination required by the welder. Similar to torch welding, GTAW normally requires two hands, since most applications require that the welder manually feed a filler metal into the weld area with one hand while manipulating the welding torch in the other. Maintaining a short arc length, while preventing contact between the electrode and the work piece, is also important.

To strike the welding arc, a high frequency generator (similar to a Tesla coil) provides an electric spark. This spark is a conductive path for the welding current through the shielding gas and allows the arc to be initiated while the electrode and the work piece are separated, typically about 1.5–3 mm (0.06–0.12 in) apart.

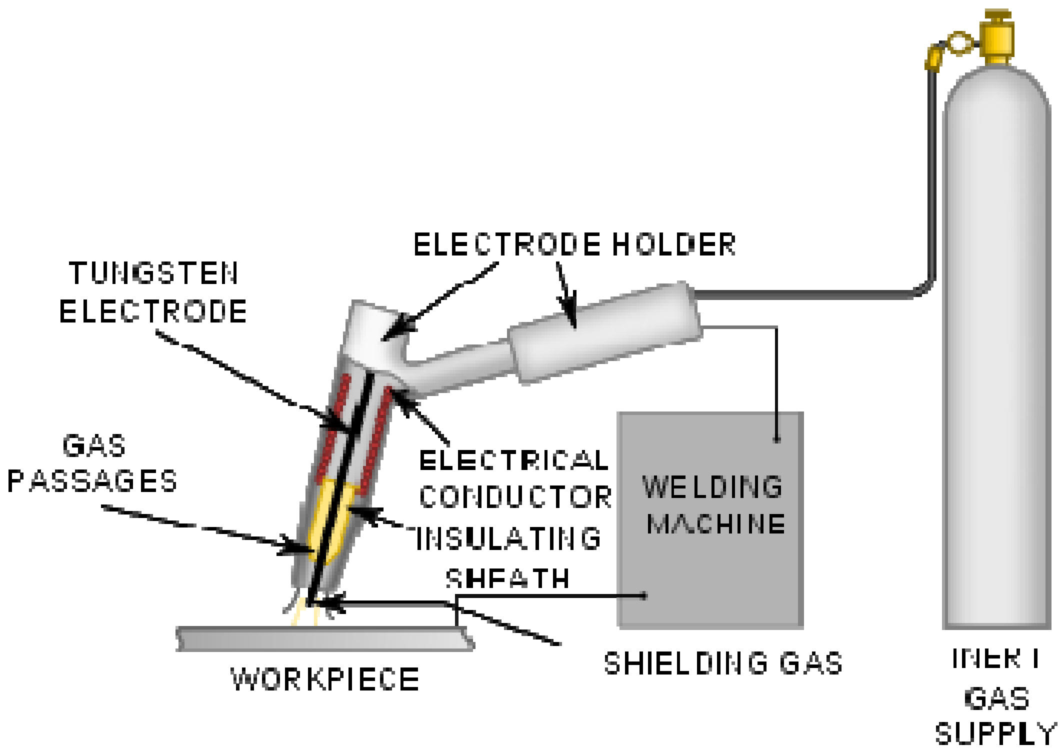
Once the arc is struck, the welder moves the torch in a small circle to create a welding pool, the size of which depends on the size of the electrode and the amount of current. While maintaining a constant separation between the electrode and the work piece, the operator then moves the torch back slightly and tilts it backward about 10–15 degrees from vertical. Filler metal is added manually to the front end of the weld pool as it is needed.

Welders often develop a technique of rapidly alternating between moving the torch forward (to advance the weld pool) and adding filler metal. The filler rod is withdrawn from the weld pool each time the electrode advances, but it is always kept inside the gas shield to prevent oxidation of its surface and contamination of the weld. Filler rods composed of metals with a low melting temperature, such as aluminum, require that the operator maintain some distance from the arc while staying inside the gas shield. If held too close to the arc, the filler rod can melt before it makes contact with the weld puddle. As the weld nears completion, the arc current is often gradually reduced to allow the weld crater to solidify and prevent the formation of crater cracks at the end of the weld.

Applications

While the aerospace industry is one of the primary users of gas tungsten arc welding, the process is used in a number of other areas. Many industries use GTAW for welding thin work pieces, especially nonferrous metals. It is used extensively in the manufacture of space vehicles, and is also frequently employed to weld small-diameter, thin-wall tubing such as those used in the bicycle industry. In addition, GTAW is often used to make root or first-pass welds for piping of various sizes. In maintenance and repair work, the process is commonly used to repair tools and dies, especially components made of aluminium and magnesium. Because the weld metal is not transferred directly across the electric arc like most open arc welding processes, a vast assortment of welding filler metal is available to the welding engineer. In fact, no other welding process permits the welding of so many alloys in so many product configurations. Filler metal alloys, such as elemental aluminium and chromium, can be lost through the electric arc from volatilization. This loss does not occur with the GTAW process. Because the resulting welds have the same chemical integrity as the original base metal or match the base metals more closely, GTAW welds are highly resistant to corrosion and cracking over long time periods, making GTAW the welding procedure of choice for critical operations like sealing spent nuclear fuel canisters before burial.

Shielding gas



GTAW system setup

As with other welding processes such as gas metal arc welding, shielding gases are necessary in GTAW to protect the welding area from atmospheric gases such as nitrogen and oxygen, which can cause fusion defects, porosity, and weld metal embrittlement if they come in contact with the electrode, the arc, or the welding metal. The gas also transfers heat from the tungsten electrode to the metal, and it helps start and maintain a stable arc.

The selection of a shielding gas depends on several factors, including the type of material being welded, joint design, and desired final weld appearance. Argon is the most commonly used shielding gas for GTAW, since it helps prevent defects due to a varying arc length. When used with alternating current, argon shielding results in high weld quality and good appearance. Another common shielding gas, helium, is most often used to increase the weld penetration in a joint, to increase the welding speed, and to weld metals with high heat conductivity, such as copper and aluminium. A significant disadvantage is the difficulty of striking an arc with helium gas, and the decreased weld quality associated with a varying arc length.

Argon-helium mixtures are also frequently utilized in GTAW, since they can increase control of the heat input while maintaining the benefits of using argon. Normally, the mixtures are made with primarily helium (often about 75% or higher) and a balance of argon. These mixtures increase the speed and quality of the AC welding of aluminium, and also make it easier to strike an arc. Another shielding gas mixture, argon-hydrogen, is used in the mechanized welding of light gauge stainless steel, but because hydrogen can cause porosity, its uses are limited. Similarly, nitrogen can sometimes be added to argon to help stabilize the austenite in austenitic stainless steels and increase penetration when welding copper. Due to porosity problems in ferritic steels and limited benefits, however, it is not a popular shielding gas additive.

Materials:

Gas tungsten arc welding is most commonly used to weld stainless steel and nonferrous materials, such as aluminium and magnesium, but it can be applied to nearly all metals, with a notable exception being zinc and its alloys. Its applications involving carbon steels are limited not because of process restrictions, but because of the existence of more economical steel welding techniques, such as gas metal arc welding and shielded metal arc welding. Furthermore, GTAW can be performed in a variety of other-than-flat positions, depending on the skill of the welder and the materials being welded.

4.2 GAS METAL ARC WELDING

Gas metal arc welding (**GMAW**), sometimes referred to by its subtypes **metal inert gas** (**MIG**) **welding** or **metal active gas** (**MAG**) **welding**, is a welding process in which an electric arc forms between a consumable wire electrode and the workpiece metal(s), which heats the workpiece metal(s), causing them to melt, and join.

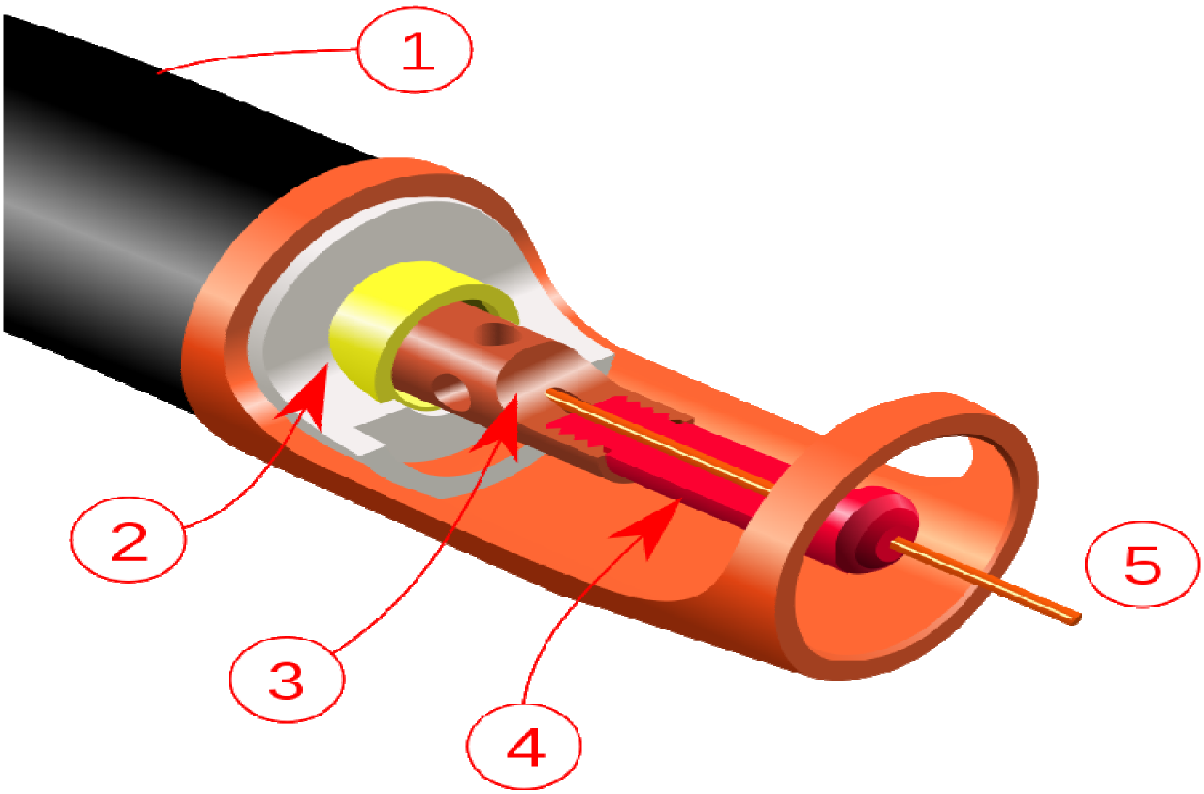
Along with the wire electrode, a shielding gas feeds through the welding gun, which shields the process from contaminants in the air. The process can be semi-automatic or automatic. A constant voltage, direct current power source is most commonly used with GMAW, but constant current systems, as well as alternating current, can be used. There are four primary methods of metal transfer in GMAW, called globular, short-circuiting, spray, and pulsed-spray, each of which has distinct properties and corresponding advantages and limitations.

Originally developed for welding aluminum and other non-ferrous materials in the 1940s, GMAW was soon applied to steels because it provided faster welding time compared to other welding processes. The cost of inert gas limited its use in steels until several years later, when the use of semi-inert gases such as carbon dioxide became common. Further developments during the 1950s and 1960s gave the process more versatility and as a result, it became a highly used industrial process. Today, GMAW is the most common industrial welding process, preferred for its versatility, speed and the relative ease of adapting the process to robotic automation. Unlike welding processes that do not employ a shielding gas, such as shielded metal arc welding, it is rarely used outdoors or in other areas of air volatility. A related process, flux cored arc welding, often does not use a shielding gas, but instead employs an electrode wire that is hollow and filled with flux.

Equipment

To perform gas metal arc welding, the basic necessary equipment is a welding gun, a wire feed unit, a welding power supply, a welding electrode wire, and a shielding gas supply.

Welding gun and wire feed unit



(1) Torch handle,

(2) Molded phenolic dielectric (shown in white) and threaded metal nut insert (yellow),

(3) Shielding gas diffuser,

(4) Contact tip,

(5) Nozzle output face

The typical GMAW welding gun has a number of key parts—a control switch, a contact tip, a power cable, a gas nozzle, an electrode conduit and liner, and a gas hose. The control switch, or trigger, when pressed by the operator, initiates the wire feed, electric power, and the shielding gas flow, causing an electric arc to be struck. The contact tip, normally made of copper and sometimes chemically treated to reduce spatter, is connected to the welding power source through the power cable and transmits the electrical energy to the electrode while directing it to the weld area. It must be firmly secured and properly sized, since it must allow the electrode to pass while maintaining electrical contact. On the way to the contact tip, the wire is protected and guided by the electrode conduit and liner, which help prevent buckling and maintain an uninterrupted wire feed. The gas nozzle directs the shielding gas evenly into the welding zone. Inconsistent flow may not adequately protect the weld area. Larger nozzles provide greater shielding gas flow, which is useful for high current welding operations that develop a larger molten weld pool. A gas hose from the tanks of shielding gas supplies the gas to the nozzle. Sometimes, a water hose is also built into the welding gun, cooling the gun in high heat operations.

The wire feed unit supplies the electrode to the work, driving it through the conduit and on to the contact tip. Most models provide the wire at a constant feed rate, but more advanced machines can vary the feed rate in response to the arc length and voltage. Some wire feeders can reach feed rates as high as 30.5 m/min (1200 in/min), but feed rates for semiautomatic GMAW typically range from 2 to 10 m/min (75 – 400 in/min).

Tool style

The most common electrode holder is a semiautomatic air-cooled holder. Compressed air circulates through it to maintain moderate temperatures. It is used with lower current levels for welding lap or butt joints. The second most common type of electrode holder is semiautomatic water-cooled, where the only difference is that water takes the place of air. It uses higher current levels for welding T or corner joints. The third typical holder type is a water cooled automatic electrode holder—which is typically used with automated equipment.

Power supply

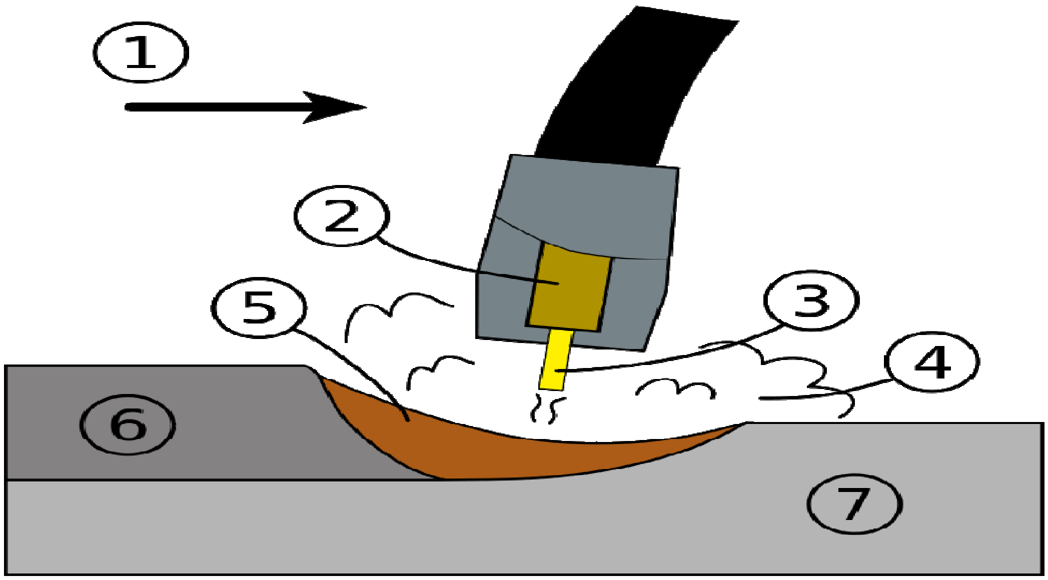
Most applications of gas metal arc welding use a constant voltage power supply. As a result, any change in arc length (which is directly related to voltage) results in a large change in heat input and current. A shorter arc length causes a much greater heat input, which makes the wire electrode melt more quickly and thereby restore the original arc length. This helps operators keep the arc length consistent even when manually welding with hand-held welding guns. To achieve a similar effect, sometimes a constant current power source is used in combination with an arc voltage-controlled wire feed unit. In this case, a change in arc length makes the wire feed rate adjust to maintain a relatively constant arc length. In rare circumstances, a constant current power source and a constant wire feed rate unit might be coupled, especially for the welding of metals with high thermal conductivities, such as aluminium. This grants the operator additional control over the heat input into the weld, but requires significant skill to perform successfully.

Alternating current is rarely used with GMAW; instead, direct current is employed and the electrode is generally positively charged. Since the anode tends to have a greater heat concentration, this results in faster melting of the feed wire, which increases weld penetration and welding speed. The polarity can be reversed only when special emissive-coated electrode wires are used, but since these are not popular, a negatively charged electrode is rarely employed.

Electrode

Electrode selection is based primarily on the composition of the metal being welded, the process variation being used, joint design and the material surface conditions. Electrode selection greatly influences the mechanical properties of the weld and is a key factor of weld quality. In general the finished weld metal should have mechanical properties similar to those of the base material with no defects such as discontinuities, entrained contaminants or porosity within the weld. To achieve these goals a wide variety of electrodes exist. All commercially available electrodes contain deoxidizing metals such as silicon, manganese, titanium and aluminium in small percentages to help prevent oxygen porosity. Some contain denaturising metals such as titanium and zirconium to avoid nitrogen porosity. Depending on the process variation and base material being welded the diameters of the electrodes used in GMAW typically range from 0.7 to 2.4 mm (0.028 – 0.095 in) but can be as large as 4 mm (0.16 in). The smallest electrodes, generally up to 1.14 mm (0.045 in) are associated with the short-circuiting metal transfer process, while the most common spray-transfer process mode electrodes are usually at least 0.9 mm (0.035 in).

Operation



GMAW weld area.

(1) Direction of travel,

(2) Contact tube,

(3) Electrode,

(4) Shielding gas,

(5) Molten weld metal,

(6) Solidified weld metal,

(7) Work piece.

For most of its applications gas metal arc welding is a fairly simple welding process to learn requiring no more than a week or two to master basic welding technique. Even when welding is performed by well-trained operators weld quality can fluctuate since it depends on a number of external factors. All GMAW is dangerous, though perhaps less so than some other welding methods, such as shielded metal arc welding.

Technique

The basic technique for GMAW is quite simple, since the electrode is fed automatically through the torch (head of tip). By contrast, in gas tungsten arc welding, the welder must handle a welding torch in one hand and a separate filler wire in the other, and in shielded metal arc welding, the operator must frequently chip off slag and change welding electrodes. GMAW requires only that the operator guide the welding gun with proper position and orientation along the area being welded. Keeping a consistent contact tip-to-work distance (the *stick out* distance) is important, because a long stick out distance can cause the electrode to overheat and also wastes shielding gas. Stick out distance varies for different GMAW weld processes and applications. The orientation of the gun is also important—it should be held so as to bisect the angle between the work pieces; that is, at 45 degrees for a fillet weld and 90 degrees for welding a flat surface. The travel angle, or lead angle, is the angle of the torch with respect to the direction of travel, and it should generally remain approximately vertical. However, the desirable angle changes somewhat depending on the type of shielding gas used—with pure inert gases, the bottom of the torch is often slightly in front of the upper section, while the opposite is true when the welding atmosphere is carbon dioxide.

4.3 Friction welding

Friction welding (FRW) is a solid-state welding process that generates heat through mechanical friction between work pieces in relative motion to one another, with the addition of a lateral force called "upset" to plastically displace and fuse the materials. Technically, because no melt occurs, friction welding is not actually a welding process in the traditional sense, but a forging technique. However, due to the similarities between these techniques and traditional welding, the term has become common. Friction welding is used with metals and thermoplastics in a wide variety of aviation and automotive applications.

Benefits

The combination of fast joining times (on the order of a few seconds), and direct heat input at the weld interface, yields relatively small heat-affected zones. Friction welding techniques are generally melt-free, which avoids grain growth in engineered materials, such as high-strength heat-treated steels. Another advantage is that the motion tends to "clean" the surface between the materials being welded, which means they can be joined with less preparation. During the welding process, depending on the method being used, small pieces of the plastic or metal will be forced out of the working mass (flash). It is believed that the flash carries away debris and dirt

Another advantage of friction welding is that it allows dissimilar materials to be joined. This is particularly useful in aerospace, where it is used to join lightweight aluminium stock to high-strength steels. Normally the wide difference in melting points of the two materials would make it impossible to weld using traditional techniques, and would require some sort of mechanical connection. Friction welding provides a "full strength" bond with no additional weight. Other common uses for these sorts of bi-metal joins is in the nuclear industry, where copper-steel joints are common in the reactor cooling systems; and in the transport of cryogenic fluids, where friction welding has been used to join aluminium alloys to stainless steels and high-nickel-alloy materials for cryogenic-fluid piping and containment vessels.

Friction welding is also used with thermoplastics, which act in a fashion analogous to metals under heat and pressure. The heat and pressure used on these materials is much lower than metals, but the technique can be used to join metals to plastics with the metal interface being machined. For instance, the technique can be used to join eyeglass frames to the pins in their hinges. The lower energies and pressures used allows for a wider variety of techniques to be used.

METAL TECHNIQUES

Spin welding

Spin welding systems consist of two chucks for holding the materials to be welded, one of which is fixed and the other rotating. Before welding one of the work pieces is attached to the rotating chuck along with a flywheel of a given weight. The piece is then spun up to a high rate of rotation to store the required energy in the flywheel.

Once spinning at the proper speed, the motor is removed and the pieces forced together under pressure. The force is kept on the pieces after the spinning stops to allow the weld to "set".

This technique is also known as inertia welding, rotational (or rotary friction) welding or inertial friction welding.

In Inertia Friction Welding the drive motor is disengaged, and the work pieces are forced together by a friction welding force. The kinetic energy stored in the rotating flywheel is dissipated as heat at the weld interface as the flywheel speed decreases.

Linear friction welding

Linear friction welding (*LFW*) is similar to spin welding except that the moving chuck oscillates laterally instead of spinning. The speeds are much lower in general, which requires the pieces to be kept under pressure at all times. This also requires the parts to have a high shear strength. Linear friction welding requires more complex machinery than spin welding, but has the advantage that parts of any shape can be joined, as opposed to parts with a circular meeting point. Another advantage is that in most instances quality of joint is better than that obtained using rotating technique.

Friction surfacing

Friction surfacing is a process derived from friction welding where a coating material is applied to a substrate. A rod composed of the coating material (called a mechtrode) is rotated under pressure, generating a plasticised layer in the rod at the interface with the substrate. By moving a substrate across the face of the rotating rod a plasticised layer is deposited between 0.2–2.5 millimetres (0.0079–0.0984 in) thick depending on Electrode diameter and coating material.

Thermoplastic techniques

Linear vibration welding

In *linear vibration welding* the materials are placed in contact and put under pressure. An external vibration force is then applied to slip the pieces relative to each other, perpendicular to the pressure being applied. The parts are vibrated through a relatively small displacement known as the amplitude, typically between 1.0 and 1.8 mm, for a frequency of vibration of 200 Hz (high frequency), or 2–4 mm at 100 Hz (low frequency), in the plane of the joint. This technique is widely used in the automotive industry, among others. A minor modification is *angular friction welding*, which vibrates the materials by torquing them through a small angle.

Orbital friction welding

Orbital friction welding is similar to spin welding, but uses a more complex machine to produce an orbital motion in which the moving part rotates in a small circle, much smaller than the size of the joint as a whole.

Seizure resistance

Friction welding may unintentionally occur at sliding surfaces like bearings. This happens in particular if the lubricating oil film between sliding surfaces becomes thinner than the surface roughness, which may be the case for low speed, low temperature, oil starvation, excessive clearance, low viscosity of the oil, high roughness of the surfaces.

4.4 Induction welding

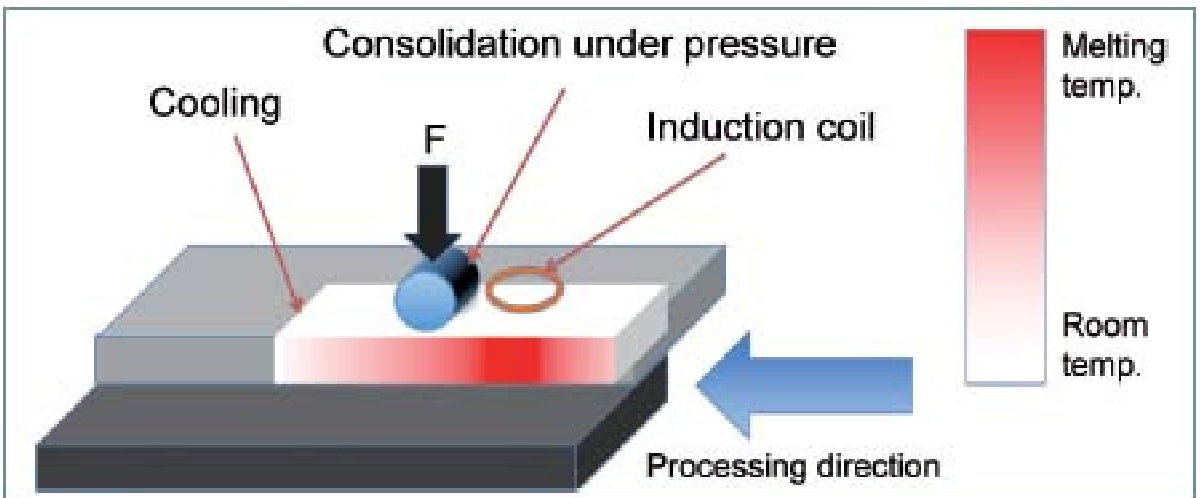


Fig. 2: Process conduct for 2D induction welding (schematic/qualitative).

Induction welding is a form of welding that uses electromagnetic induction to heat the work piece. The welding apparatus contains an induction coil that is energised with a radio-frequency electric current. This generates a high-frequency electromagnetic field that acts on either an electrically conductive or a ferromagnetic work piece. In an electrically conductive work piece, the main heating effect is resistive heating, which is due to induced currents called eddy currents. In a ferromagnetic work piece, the heating is caused mainly by hysteresis, as the electromagnetic field repeatedly distorts the magnetic domains of the ferromagnetic material. In practice, most materials undergo a combination of these two effects.

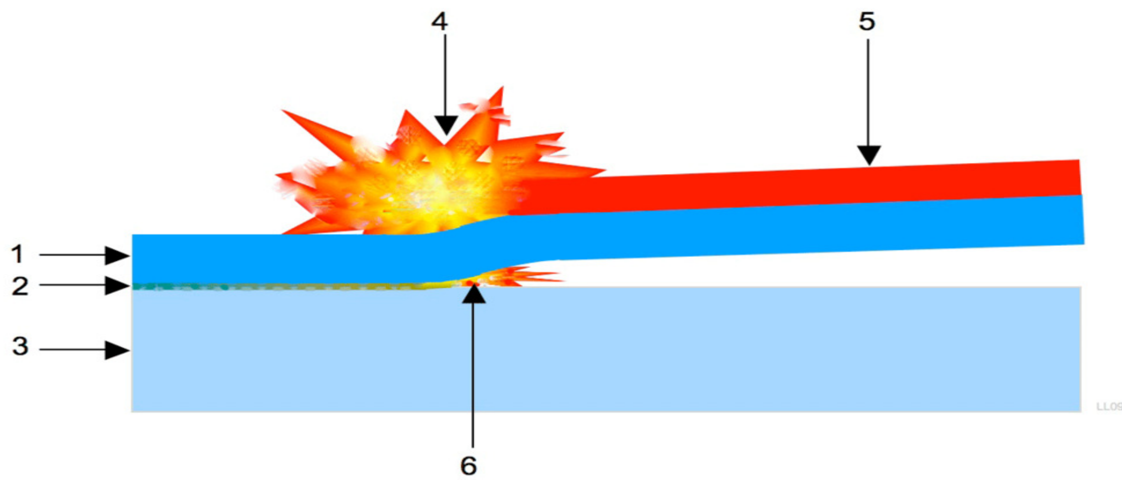
Nonmagnetic materials and electrical insulators such as plastics can be induction-welded by implanting them with metallic or ferromagnetic compounds, called subsectors, that absorb the electromagnetic energy from the induction coil, become hot, and lose their heat to the surrounding material by thermal conduction. Plastic can also be induction welded by embedding the plastic with electrically conductive fibers like metals or carbon fiber. Induced eddy currents resistively heat the embedded fibers which lose their heat to the surrounding plastic by conduction. Induction welding of carbon fiber reinforced plastics is commonly used in the aerospace industry.

Induction welding is used for long production runs and is a highly automated process, usually used for welding the seams of pipes. It can be a very fast process, as a lot of power can be transferred to a localised area, so the faying surfaces melt very quickly and can be pressed together to form a continuous rolling weld.

The depth that the currents, and therefore heating, penetrates from the surface is inversely proportional to the square root of the frequency. The temperature of the metals being welded and their composition will also affect the penetration depth. This process is very similar to resistance welding, except that in the case of resistance welding the current is delivered using contacts to the work piece instead of using induction.

4.5 Explosion welding

Explosion welding (**EXW**) is a solid state (solid-phase) process where welding is accomplished by accelerating one of the components at extremely high velocity through the use of chemical explosives. This process is most commonly utilized to clad carbon steel plate with a thin layer of corrosion resistant material (e.g., stainless steel, nickel alloy, titanium, or zirconium). Due to the nature of this process, producible geometries are very limited. They must be simple. Typical geometries produced include plates, tubing and tube sheets.



Explosion welding

1 Flyer (cladding).

2 Resolidified zone (needs to be minimised for welding of dissimilar materials).

3 Target (substrate).

4 Explosion.

5 Explosive powders.

6 Plasma jet.

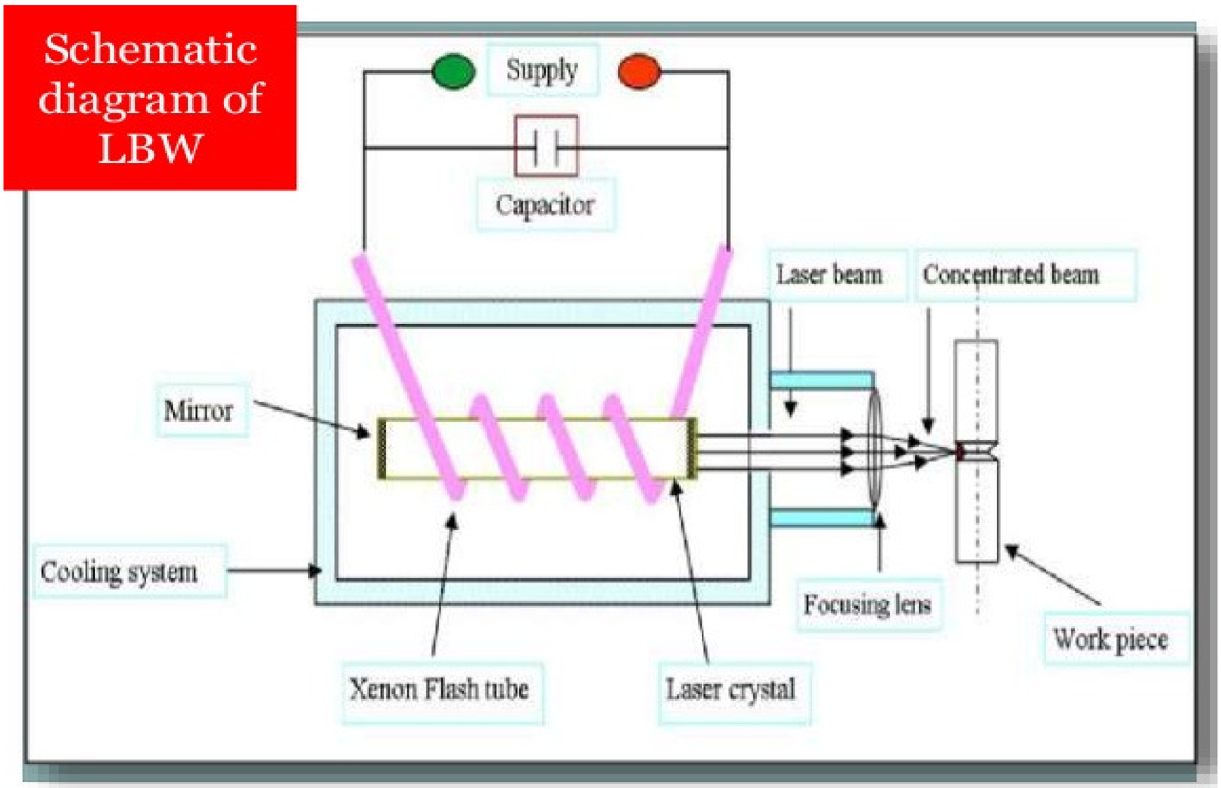
Advantages and disadvantages

Explosion welding can produce a bond between two metals that cannot necessarily be welded by conventional means. The process does not melt either metal, instead it plasticizes the surfaces of both metals, causing them to come into intimate contact sufficient to create a weld. This is a similar principle to other non-fusion welding techniques, such as friction welding. Large areas can be bonded extremely quickly and the weld itself is very clean, due to the fact that the surface material of both metals is violently expelled during the reaction.

A disadvantage of this method is that extensive knowledge of explosives is needed before the procedure may be attempted safely. Regulations for the use of high explosives may require special licensing.

4.6 Laser beam welding

Laser beam welding (LBW) is a welding technique used to join multiple pieces of metal through the use of a laser. The beam provides a concentrated heat source, allowing for narrow, deep welds and high welding rates. The process is frequently used in high volume applications, such as in the automotive industry. It is based on keyhole or Penetration mode welding.



Operation

Like electron beam welding (EBW), laser beam welding has high power density (on the order of 1 MW/cm^2) resulting in small heat-affected zones and high heating and cooling rates. The spot size of the laser can vary between 0.2 mm and 13 mm, though only smaller sizes are used for welding. The depth of penetration is proportional to the amount of power supplied, but is also dependent on the location of the focal point: penetration is maximized when the focal point is slightly below the surface of the work piece

A continuous or pulsed laser beam may be used depending upon the application. Millisecond-long pulses are used to weld thin materials such as razor blades while continuous laser systems are employed for deep welds.

LBW is a versatile process, capable of welding carbon steels, HSLA steels, stainless steel, aluminium, and titanium. Due to high cooling rates, cracking is a concern when welding high-carbon steels. The weld quality is high, similar to that of electron beam welding. The speed of welding is proportional to the amount of power supplied but also depends on the type and thickness of the work pieces. The high power capability of gas lasers make them especially suitable for high volume applications. LBW is particularly dominant in the automotive industry.

Some of the advantages of LBW in comparison to EBW are as follows:

- the laser beam can be transmitted through air rather than requiring a vacuum
- the process is easily automated with robotic machinery
- x-rays are not generated
- LBW results in higher quality welds

A derivative of LBW, laser-hybrid welding, combines the laser of LBW with an arc welding method such as gas metal arc welding. This combination allows for greater positioning flexibility, since GMAW supplies molten metal to fill the joint, and due to the use of a laser, increases the welding speed over what is normally possible with GMAW. Weld quality tends to be higher as well, since the potential for undercutting is reduced.

Equipment

- The two types of lasers commonly used are solid-state lasers and gas lasers.
- The first type uses one of several solid media, including synthetic ruby (chromium in aluminum oxide), neodymium in glass and the most common type, neodymium in yttrium aluminum garnet
- Gas lasers use mixtures of gases such as helium, nitrogen, and carbon dioxide (CO_2 laser) as a medium.
- Regardless of type, however, when the medium is excited, it emits photons and forms the laser beam.

Solid state laser

Solid-state lasers operate at wavelengths on the order of 1 micrometer, much shorter than gas lasers, and as a result require that operators wear special eyewear or use special screens to prevent retina damage. lasers can operate in both pulsed and continuous mode, but the other types are limited to pulsed mode. The original and still popular solid-state design is a single crystal shaped as a rod approximately 20 mm in diameter and 200 mm long, and the ends are ground flat. This rod is surrounded by a flash tube containing xenon or krypton. When flashed, a pulse of light lasting about two milliseconds is emitted by the laser. Disk shaped crystals are growing in popularity in the industry, and flash lamps are giving way to diodes due to their high efficiency. Typical power output for ruby lasers is 10–20 W, while the laser outputs between 0.04–6,000 W. To deliver the laser beam to the weld area, fiber optics are usually employed.

Gas laser

Gas lasers use high-voltage, low-current power sources to supply the energy needed to excite the gas mixture used as a lasing medium. These lasers can operate in both continuous and pulsed mode, and the wavelength of the CO_2 gas laser beam is 10.6 µm, deep infrared, i.e. 'heat'. Fiber optic cable absorbs and is destroyed by this wavelength, so a rigid lens and mirror delivery system is used. Power outputs for gas lasers can be much higher than solid-state lasers, reaching 25 kW.

Fiber laser

In fiber lasers, the gain medium is the optical fiber itself. They are capable of power up to 50 kW and are increasingly being used for robotic industrial welding.

Laser beam delivery

Modern laser beam welding machines can be grouped into two types. In the traditional type, the laser output is moved to follow the seam. This is usually achieved with a robot. In many modern applications, remote laser beam welding is used. In this method, the laser beam is moved along the seam with the help of a laser scanner, so that the robotic arm does not need to follow the seam any more. The advantages of remote laser welding are the higher speed and the higher precision of the welding process.

4.7 Soldering

Soldering is a process in which two or more items (usually metal) are joined together by melting and putting a filler metal (solder) into the joint, the filler metal having a lower melting point than the adjoining metal. Soldering differs from welding in that soldering does not involve melting the work pieces. In brazing, the filler metal melts at a higher temperature, but the work piece metal does not melt. In the past, nearly all solders contained lead, but environmental and health concerns have increasingly dictated use of lead-free alloys for electronics and plumbing purposes.

Solders

Soldering filler materials are available in many different alloys for differing applications. In electronics assembly, the eutectic alloy of 63% tin and 37% lead (or 60/40, which is almost identical in melting point) has been the alloy of choice. Other alloys are used for plumbing, mechanical assembly, and other applications. Some examples of soft-solder are tin-lead for general purposes, tin-zinc for joining aluminium, lead-silver for strength at higher than room temperature, cadmium-silver for strength at high temperatures, zinc-aluminium for aluminium and corrosion resistance, and tin-silver and tin-bismuth for electronics.

A eutectic formulation has advantages when applied to soldering: the liquids and solidus temperatures are the same, so there is no plastic phase, and it has the lowest possible melting point. Having the lowest possible melting point minimizes heat stress on electronic components during soldering. And, having no plastic phase allows for quicker wetting as the solder heats up, and quicker setup as the solder cools. A non-eutectic formulation must remain still as the temperature drops through the liquidus and solidus temperatures. Any movement during the plastic phase may result in cracks, resulting in an unreliable joint.

Common solder formulations based on tin and lead are listed below. The fractions represent percentage of tin first, then lead, totalling 100%:

- 63/37: melts at 183 °C (361 °F) (eutectic: the only mixture that melts at a *point*, instead of over a range)
- 60/40: melts between 183–190 °C (361–374 °F)
- 50/50: melts between 183–215 °C (361–419 °F)

For environmental reasons (and the introduction of regulations such as the European RoHS (Restriction of Hazardous Substances Directive)), lead-free solders are becoming more widely used. They are also suggested anywhere young children may come into contact with (since young children are likely to place things into their mouths), or for outdoor use where rain and other precipitation may wash the lead into the groundwater. Unfortunately, most lead-free solders are not eutectic formulations, melting at around 250 °C (482 °F), making it more difficult to create reliable joints with them.

Other common solders include low-temperature formulations (often containing bismuth), which are often used to join previously-soldered assemblies without un-soldering earlier connections, and high-temperature formulations (usually containing silver) which are used for high-temperature operation or for first assembly of items which must not become unsoldered during subsequent operations. Alloying silver with other metals changes the melting point, adhesion and wetting characteristics, and tensile strength. Of all the brazing alloys, silver solders have the greatest strength and the broadest applications. Specialty alloys are available with properties such as higher strength, the ability to solder aluminum, better electrical conductivity, and higher corrosion resistance.

Flux

The purpose of flux is to facilitate the soldering process. One of the obstacles to a successful solder joint is an impurity at the site of the joint, for example, dirt, oil or oxidation. The impurities can be removed by mechanical cleaning or by chemical means, but the elevated temperatures required to melt the filler metal (the solder) encourages the work piece (and the solder) to re-oxidize. This effect is accelerated as the soldering temperatures increase and can completely prevent the solder from joining to the work piece. One of the earliest forms of flux was charcoal, which acts as a reducing agent and helps prevent oxidation during the soldering process. Some fluxes go beyond the simple prevention of oxidation and also provide some form of chemical cleaning (corrosion).

For many years, the most common type of flux used in electronics (soft soldering) was rosin-based, using the rosin from selected pine trees. It was ideal in that it was non-corrosive and non-conductive at normal temperatures but became mildly reactive (corrosive) at the elevated soldering temperatures. Plumbing and automotive applications, among others, typically use an acid-based (hydrochloric acid) flux which provides cleaning of the joint. These fluxes cannot be used in electronics because they are conductive and because they will eventually dissolve the small diameter wires. Many fluxes also act as a wetting agent in the soldering process, reducing the surface tension of the molten solder and causing it to flow and wet the work pieces more easily.

Fluxes for soft solder are currently available in three basic formulations:

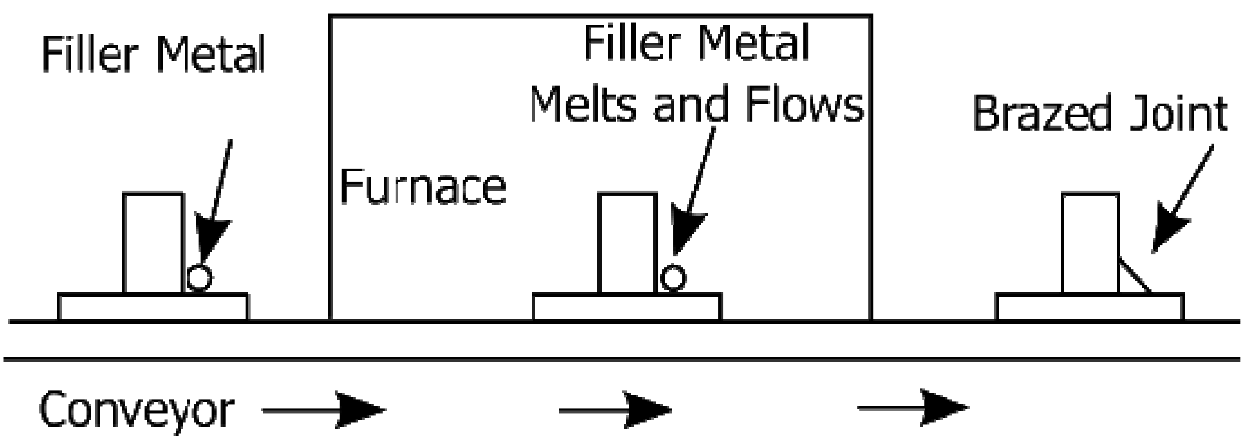
1. Water-soluble fluxes - higher activity fluxes designed to be removed with water after soldering (no VOCs required for removal).
2. No-clean fluxes - mild enough to not "require" removal due to their non-conductive and non-corrosive residue. These fluxes are called "no-clean" because the residue left after the solder operation is non-conductive and won't cause electrical shorts; nevertheless they leave a plainly visible white residue that resembles diluted bird-droppings. No-clean flux residue is acceptable on all 3 classes of PCBs as defined by IPC-610 provided it does not inhibit visual inspection, access to test points, or have a wet, tacky or excessive residue that may spread onto other areas. Connector mating surfaces must also be free of flux residue. Finger prints in no clean residue is a class 3 defect

3. Traditional rosin fluxes - available in non-activated (R), mildly activated (RMA) and activated (RA) formulations. RA and RMA fluxes contain rosin combined with an activating agent, typically an acid, which increases the wettability of metals to which it is applied by removing existing oxides. The residue resulting from the use of RA flux is corrosive and must be cleaned. RMA flux is formulated to result in a residue which is not significantly corrosive, with cleaning being preferred but optional.

Applications

1. Soldering is used in plumbing, electronics, and metalwork from flashing to jewellery.
2. Soldering provides reasonably permanent but reversible connections between copper pipes in plumbing systems as well as joints in sheet metal objects such as food cans, roof flashing, rain gutters and automobile radiators.
3. Jewellery components, machine tools and some refrigeration and plumbing components are often assembled and repaired by the higher temperature silver soldering process. Small mechanical parts are often soldered or brazed as well. Soldering is also used to join lead came and copper foil in stained glass work. It can also be used as a semi-permanent patch for a leak in a container or cooking vessel.

4.8 Brazing



Brazing is a metal-joining process in which two or more metal items are joined together by melting and flowing a filler metal into the joint, the filler metal having a lower melting point than the adjoining metal.

Brazing differs from welding in that it does not involve melting the work pieces and from soldering in using higher temperatures for a similar process, while also requiring much more closely fitted parts than when soldering. The filler metal flows into the gap between close-fitting parts by capillary action. The filler metal is brought slightly above its melting (liquidus) temperature while protected by a suitable atmosphere, usually a flux. It then flows over the base metal (known as wetting) and is then cooled to join the work pieces together.[1] It is similar to soldering, except the temperatures used to melt the filler metal are higher for brazing. A major advantage of brazing is the ability to join the same or different metals with considerable strength.

Fundamentals

High-quality brazed joints require that parts be closely fitted, and the base metals exceptionally clean and free of oxides. In most cases, joint clearances of 0.03 to 0.08 mm (0.0012 to 0.0031 in) are recommended for the best capillary action and joint strength. However, in some brazing operations it is not uncommon to have joint clearances around 0.6 mm (0.024 in). Cleanliness of the brazing surfaces is also important, as any contamination can cause poor wetting (flow). The two main methods for cleaning parts, prior to brazing, are chemical cleaning and abrasive or mechanical cleaning. In the case of mechanical cleaning, it is important to maintain the proper surface roughness as wetting on a rough surface occurs much more readily than on a smooth surface of the same geometry.

Another consideration that cannot be overlooked is the effect of temperature and time on the quality of brazed joints. As the temperature of the braze alloy is increased, the alloying and wetting action of the filler metal increases as well. In general, the brazing temperature selected must be above the melting point of the filler metal. However, several factors influence the joint designer's temperature selection. The best temperature is usually selected to:

- Be the lowest possible braze temperature
- Minimize any heat effects on the assembly
- Minimize filler metal/base metal interaction

- Maximize the life of any fixtures or jigs used

In some cases, a worker may select a higher temperature to accommodate other factors in the design (e.g., to allow use of a different filler metal, or to control metallurgical effects, or to sufficiently remove surface contamination). The effect of time on the brazed joint primarily affects the extent to which these effects are present. In general, however, most production processes are selected to minimize brazing time and associated costs. This is not always the case, however, since in some non-production settings, time and cost are secondary to other joint attributes (e.g., strength, appearance).

Flux

In the case of brazing operations not contained within an inert or reducing atmosphere environment (i.e. a vacuum furnace), flux is required to prevent oxides from forming while the metal is heated. The flux also serves the purpose of cleaning any contamination left on the brazing surfaces. Flux can be applied in any number of forms including flux paste, liquid, powder or pre-made brazing pastes that combine flux with filler metal powder. Flux can also be applied using brazing rods with a coating of flux, or a flux core. In either case, the flux flows into the joint when applied to the heated joint and is displaced by the molten filler metal entering the joint.

Excess flux should be removed when the cycle is completed because flux left in the joint can lead to corrosion, impede joint inspection, and prevent further surface finishing operations. Phosphorus-containing brazing alloys can be self-fluxing when joining copper to copper. Fluxes are generally selected based on their performance on particular base metals. To be effective, the flux must be chemically compatible with both the base metal and the filler metal being used. Self-fluxing phosphorus filler alloys produce brittle phosphates if used on iron or nickel. As a general rule, longer brazing cycles should use less active fluxes than short brazing operations.

Filler materials

A variety of alloys are used as filler metals for brazing depending on the intended use or application method. In general, braze alloys are made up of 3 or more metals to form an alloy with the desired properties. The filler metal for a particular application is chosen based on its ability to: wet the base metals, withstand the service conditions required, and melt at a lower temperature than the base metals or at a very specific temperature.

Braze alloy is generally available as rod, ribbon, powder, paste, cream, wire and performs (such as stamped washers). Depending on the application, the filler material can be pre-placed at the desired location or applied during the heating cycle. For manual brazing, wire and rod forms are generally used as they are the easiest to apply while heating. In the case of furnace brazing, alloy is usually placed beforehand since the process is usually highly automated. Some of the more common types of filler metals used are

- Aluminum-silicon
- Copper
- Copper-silver
- Copper-zinc (brass)
- Copper-tin (bronze)
- Gold-silver
- Nickel alloy
- Silver
- Amorphous brazing foil using nickel, iron, copper, silicon, boron, phosphorus, etc.

Atmosphere

As brazing work requires high temperatures, oxidation of the metal surface occurs in an oxygen-containing atmosphere. This may necessitate the use of an atmospheric environment other than air. The commonly used atmospheres are

- **Air**: Simple and economical. Many materials susceptible to oxidation and buildup of scale. Acid cleaning bath or mechanical cleaning can be used to remove the oxidation after work. Flux counteracts the oxidation, but may weaken the joint.
- **Combusted fuel gas** (low hydrogen, AWS type 1, "exothermic generated atmospheres"): 87% N_2, 11–12% CO_2, 5-1% CO, 5-1% H_2. For silver, copper-phosphorus and copper-zinc filler metals. For brazing copper and brass.
- **Combusted fuel gas** (decarburizing, AWS type 2, "endothermic generated atmospheres"): 70–71% N_2, 5–6% CO_2, 9–10% CO, 14–15% H_2. For copper, silver,

copper-phosphorus and copper-zinc filler metals. For brazing copper, brass, nickel alloys, Monel, medium carbon steels.

- **Combusted fuel gas** (dried, AWS type 3, "endothermic generated atmospheres"): 73–75% N_2, 10–11% CO, 15–16% H_2. For copper, silver, copper-phosphorus and copper-zinc filler metals. For brazing copper, brass, low-nickel alloys, Monel, medium and high carbon steels.
- **Combusted fuel gas** (dried, decarburizing, AWS type 4): 41–45% N_2, 17–19% CO, 38–40% H_2. For copper, silver, copper-phosphorus and copper-zinc filler metals. For brazing copper, brass, low-nickel alloys, medium and high carbon steels.
- **Ammonia** (AWS type 5, also called **forming gas**): Dissociated ammonia (75% hydrogen, 25% nitrogen) can be used for many types of brazing and annealing. Inexpensive. For copper, silver, nickel, copper-phosphorus and copper-zinc filler metals. For brazing copper, brass, nickel alloys, Monel, medium and high carbon steels and chromium alloys.
- **Nitrogen+hydrogen**, cryogenic or purified (AWS type 6A): 70–99% N_2, 1–30% H_2. For copper, silver, nickel, copper-phosphorus and copper-zinc filler metals.
- **Nitrogen+hydrogen+carbon monoxide**, cryogenic or purified (AWS type 6B): 70–99% N_2, 2–20% H_2, 1–10% CO. For copper, silver, nickel, copper-phosphorus and copper-zinc filler metals. For brazing copper, brass, low-nickel alloys, medium and high carbon steels.
- **Nitrogen**, cryogenic or purified (AWS type 6C): Non-oxidizing, economical. At high temperatures can react with some metals, e.g. certain steels, forming nitrides. For copper, silver, nickel, copper-phosphorus and copper-zinc filler metals. For brazing copper, brass, low-nickel alloys, Monel, medium and high carbon steels.
- **Hydrogen** (AWS type 7): Strong deoxidizer, highly thermally conductive. Can be used for copper brazing and annealing steel. May cause hydrogen embrittlement to some alloys. For copper, silver, nickel, copper-phosphorus and copper-zinc filler metals. For brazing copper, brass, nickel alloys, Monel, medium and high carbon steels and chromium alloys, cobalt alloys, tungsten alloys, and carbides.

- **Inorganic vapors** (various volatile fluorides, AWS type 8): Special purpose. Can be mixed with atmospheres AWS 1–5 to replace flux. Used for silver-brazing of brasses.
- **Noble gas** (usually argon, AWS type 9): Non-oxidizing, more expensive than nitrogen. Inert. Parts must be very clean, gas must be pure. For copper, silver, nickel, copper-phosphorus and copper-zinc filler metals. For brazing copper, brass, nickel alloys, Monel, medium and high carbon steels chromium alloys, titanium, zirconium, hafnium.
- **Noble gas+hydrogen** (AWS type 9A)
- **Vacuum**: Requires evacuating the work chamber. Expensive. Unsuitable (or requires special care) for metals with high vapor pressure, e.g. silver, zinc, phosphorus, cadmium, and manganese. Used for highest-quality joints, for e.g. aerospace applications.

Torch brazing

Torch brazing is by far the most common method of mechanized brazing in use. It is best used in small production volumes or in specialized operations, and in some countries, it accounts for a majority of the brazing taking place. There are three main categories of torch brazing in use: manual, machine, and automatic torch brazing.

Manual torch brazing is a procedure where the heat is applied using a gas flame placed on or near the joint being brazed. The torch can either be hand held or held in a fixed position depending on whether the operation is completely manual or has some level of automation. Manual brazing is most commonly used on small production volumes or in applications where the part size or configuration makes other brazing methods impossible. The main drawback is the high labour cost associated with the method as well as the operator skill required to obtain quality brazed joints. The use of flux or self-fluxing material is required to prevent oxidation. Torch brazing of copper can be done without the use of flux if it is brazed with a torch using oxygen and hydrogen gas, rather than oxygen and other flammable gases.

Machine torch brazing is commonly used where a repetitive braze operation is being carried out. This method is a mix of both automated and manual operations with an operator often placing brazes material, flux and jigging parts while the machine mechanism carries out the actual braze. The advantage of this method is that it reduces the high labour and skill requirement of manual brazing. The use of flux is also required for this method as there is no protective atmosphere, and it is best suited to small to medium production volumes.

Automatic torch brazing is a method that almost eliminates the need for manual labour in the brazing operation, except for loading and unloading of the machine. The main advantages of this method are: a high production rate, uniform braze quality, and reduced operating cost. The equipment used is essentially the same as that used for Machine torch brazing, with the main difference being that the machinery replaces the operator in the part preparation.

Furnace brazing

Furnace brazing is a semi-automatic process used widely in industrial brazing operations due to its adaptability to mass production and use of unskilled labor. There are many advantages of furnace brazing over other heating methods that make it ideal for mass production. One main advantage is the ease with which it can produce large numbers of small parts that are easily jigged or self-locating.[11] The process also offers the benefits of a controlled heat cycle (allowing use of parts that might distort under localized heating) and no need for post braze cleaning. Common atmospheres used include: inert, reducing or vacuum atmospheres all of which protect the part from oxidation. Some other advantages include: low unit cost when used in mass production, close temperature control, and the ability to braze multiple joints at once. Furnaces are typically heated using either electric, gas or oil depending on the type of furnace and application. However, some of the disadvantages of this method include: high capital equipment cost, more difficult design considerations and high power consumption

There are four main types of furnaces used in brazing operations: batch type; continuous; retort with controlled atmosphere; and vacuum.

A *batch* type furnace has relatively low initial equipment costs, and can heat each part load separately. It can turned on and off at will, which reduces operating expenses when it's not in use. These furnaces are suited to medium to large volume production, and offer a large degree of flexibility in type of parts that can be brazed. Either controlled atmospheres or flux can be used to control oxidation and cleanliness of parts.

Continuous type furnaces are best suited to a steady flow of similar-sized parts through the furnace. These furnaces are often conveyor fed, moving parts through the hot zone at a controlled speed. It is common to use either controlled atmosphere or pre-applied flux in continuous furnaces. In particular, these furnaces offer the benefit of very low manual labor requirements and so are best suited to large scale production operations.

Retort-type furnaces differ from other batch-type furnaces in that they make use of a sealed lining called a "retort". The retort is generally sealed with either a gasket or is welded shut and filled completely with the desired atmosphere and then heated externally by conventional heating elements. Due to the high temperatures involved, the retort is usually made of heat resistant alloys that resist oxidation. Retort furnaces are often either used in a batch or semi-continuous versions.

Vacuum furnaces is a relatively economical method of oxide prevention and is most often used to braze materials with very stable oxides (aluminum, titanium and zirconium) that cannot be brazed in atmosphere furnaces. Vacuum brazing is also used heavily with refractory materials and other exotic alloy combinations unsuited to atmosphere furnaces. Due to the absence of flux or a reducing atmosphere, the part cleanliness is critical when brazing in a vacuum. The three main types of vacuum furnace are: single-wall hot retort, double-walled hot retort, and cold-wall retort. Typical vacuum levels for brazing range from pressures of 1.3 to 0.13 pascals (10^{-2} to 10^{-3} Torr) to 0.00013 Pa (10^{-6} Torr) or lower. Vacuum furnaces are most commonly batch-type, and they are suited to medium and high production volumes.

Silver brazing

Silver brazing, sometimes known as a *silver soldering* or *hard soldering*, is brazing using a silver alloy based filler. These silver alloys consist of many different percentages of silver and other metals, such as copper, zinc and cadmium.

Brazing is widely used in the tool industry to fasten 'hard metal' (carbide, ceramics, cermet, and similar) tips to tools such as saw blades. "Pretinning" is often done: the braze alloy is melted onto the hard metal tip, which is placed next to the steel and remelted. Pretinning gets around the problem that hard metals are hard to wet.

Brazed hard metal joints are typically two to seven mils thick. The braze alloy joins the materials and compensates for the difference in their expansion rates. It also provides a cushion between the hard carbide tip and the hard steel, which softens impact and prevents tip loss and damage—much as a vehicle's suspension helps prevent damage to the tires and the vehicle. Finally, the braze alloy joins the other two materials to create a composite structure, much as layers of wood and glue create plywood. The standard for braze joint strength in many industries is a joint that is stronger than either base material, so that when under stress, one or other of the base materials fails before the joint.

One special silver brazing method is called *pin brazing* or *pin brazing*. It has been developed especially for connecting cables to railway track or for cathodic protection installations. The method uses a silver- and flux-containing brazing pin, which is melted in the eye of a cable lug. The equipment is normally powered from batteries.

Braze welding

Braze welding is the use of a bronze or brass filler rod coated with flux to join steel workpieces. The equipment needed for braze welding is basically identical to the equipment used in brazing. Since braze welding usually requires more heat than brazing, acetylene or methylacetylene-propadiene (MAP) gas fuel is commonly used. The name comes from the fact that no capillary action is used.

Braze welding has many advantages over fusion welding. It allows the joining of dissimilar metals, minimization of heat distortion, and can reduce the need for extensive pre-heating. Additionally, since the metals joined are not melted in the process, the components retain their original shape; edges and contours are not eroded or changed by the formation of a fillet. Another effect of braze welding is the elimination of stored-up stresses that are often present in fusion welding. This is extremely important in the repair of large castings. The disadvantages are the loss of strength when subjected to high temperatures and the inability to withstand high stresses.

Carbide, cermet and ceramic tips are plated and then joined to steel to make tipped band saws. The plating acts as a braze alloy.

Cast iron "welding"

The "welding" of cast iron is usually a brazing operation, with a filler rod made chiefly of nickel being used although true welding with cast iron rods is also available. Ductile cast iron pipe may be also "cadwelded," a process that connects joints by means of a small copper wire fused into the iron when previously ground down to the bare metal, parallel to the iron joints being formed as per hub pipe with neoprene gasket seals. The purpose behind this operation is to use electricity along the copper for keeping underground pipes warm in cold climates.

Vacuum brazing

Vacuum brazing is a material joining technique that offers significant advantages: extremely clean, superior, flux-free braze joints of high integrity and strength. The process can be expensive because it must be performed inside a vacuum chamber vessel. Temperature uniformity is maintained on the work piece when heating in a vacuum, greatly reducing residual stresses due to slow heating and cooling cycles. This, in turn, can significantly improve the thermal and mechanical properties of the material, thus providing unique heat treatment capabilities. One such capability is heat-treating or age-hardening the workpiece while performing a metal-joining process, all in a single furnace thermal cycle.

Vacuum brazing is often conducted in a furnace; this means that several joints can be made at once because the whole workpiece reaches the brazing temperature. The heat is transferred using radiation, as many other methods cannot be used in a vacuum.

Dip brazing

Dip brazing is especially suited for brazing aluminum because air is excluded, thus preventing the formation of oxides. The parts to be joined are fixtured and the brazing compound applied to the mating surfaces, typically in slurry form. Then the assemblies are dipped into a bath of molten salt (typically NaCl, KCl and other compounds), which functions as both heat transfer medium and flux.

4.9 Adhesive bonding

Adhesive bonding (also referred to as gluing or glue bonding) describes a wafer bonding technique with applying an intermediate layer to connect substrates of different materials. These produced connections can be soluble or insoluble. The commercially available adhesive can be organic or inorganic and is deposited on one or both substrate surfaces. Adhesives, especially the well-established SU-8, and benzo cyclobutene (BCB), are specialized for MEMS or electronic component production.

The procedure enables bonding temperatures from 1000 °C down to room temperature. The most important process parameters for achieving a high bonding strength are:

- adhesive material
- coating thickness
- bonding temperature
- processing time
- chamber pressure
- tool pressure

Adhesive bonding has the advantage of relatively low bonding temperature as well as the absence of electric voltage and current. Based on the fact that the wafers are not in direct contact, this procedure enables the use of different substrates, e.g. silicon, glass, metals and other semiconductor materials. A drawback is that small structures become wider during patterning which hampers the production of an accurate intermediate layer with tight dimension control. Further, the possibility of corrosion due to out-gassed products, thermal instability and penetration of moisture limits the reliability of the bonding process.

Procedural steps

The procedural steps for dry etch BCB are:

1. Cleaning
2. Supplying the adhesion promoter
3. Drying of the primer
4. BCB deposition

5. Photosensitive BCB
    1. Exposure and development
6. Dry etch BCB
    1. Pre-bake/soft-cure
    2. Patterning of the BCB layer by lithography and dry-etching
7. Bonding at specific temperature, ambient pressure for specific amount of time
8. Post-bake/hard-cure to form solid BCB monomer layer

The wafers can be cleaned using H_2O_2 + H_2SO_4 or oxygen plasma. The cleaned wafers are rinsed with DI water and dried at elevated temperature, e.g. 100 to 200 °C for 120 min.The adhesion promoter with a specific thickness is deposited, i.e. spin-coated or contact printed on the wafer to improve the bonding strength. Spray coating is preferable when the adhesive is deposited on free standing structures

Heat-affected zone

The heat-affected zone (HAZ) is the area of base material, either a metal or a thermoplastic, which is not melted and has had its microstructure and properties altered by welding or heat intensive cutting operations. The heat from the welding process and subsequent re-cooling causes this change from the weld interface to the termination of the sensitizing temperature in the base metal. The extent and magnitude of property change depends primarily on the base material, the weld filler metal, and the amount and concentration of heat input by the welding process.

The thermal diffusivity of the base material plays a large role—if the diffusivity is high, the material cooling rate is high and the HAZ is relatively small. Alternatively, a low diffusivity leads to slower cooling and a larger HAZ. The amount of heat input during the welding process also plays an important role as well, as processes like oxyfuel welding use high heat input and increase the size of the HAZ. Processes like laser beam welding and electron beam welding give a highly concentrated, limited amount of heat, resulting in a small HAZ.

4.10 Common Weld Defects – Causes and Cures

For any weld to be acceptable, it must meet three specific criteria:

1. The weld procedure must demonstrate that the weld metal will meet all the required mechanical and metallurgical properties of the design.
2. The specific design of the weld joint must meet the strength requirements to support the loads applied to the joint.
3. The production weld must meet the quality requirements and design sizes specified by the design engineer and the relevant construction codes.
4. The purpose of inspection is to verify compliance of the production welds with the requirements of the third element. Below are some of the common types of problems that inspectors find, with suggestions on how to eliminate and/or remediate the problem.