20

Casting and Welding

Chapter Objectives

In this chapter, you will learn about:

- Introduction to casting processes
- Pattern and mould making
- Properties of moulding sand
- Sand testing
- Special casting methods
- Casting defects and remedies
- Introduction to welding and allied processes
- Oxyacetylene welding and equipments
- Unconventional welding methods
- Welding defects

20.1 INTRODUCTION TO CASTING PROCESSES

Casting is an ancient manufacturing process. It had been used during 4,000–5,300 B.C. for manufacturing of copper arrowheads. In the field of casting, a number of modern technologies have been developed such as die casting, permanent mould casting, vacuum casting, continuous casting, electromagnetic casting, etc., but sand casting is one of the oldest casting technologies and has wider applications in the field of manufacturing technology. The use of casting parts is increasing continuously due to ease of manufacturing of complicated parts. Some metals can be shaped by casting only because of the specific metallurgical and mechanical properties. Casting is most suited for intricate shapes and for parts with internal cavities, such as engine blocks, cylinder heads, pump housing, crankshaft, machine tool beds and frames, etc.

The casting process can be defined as a primary shaping process in which a molten metal is poured into a mould cavity and allowed to solidify for pre-determined time so as to take the shape of the mould, after complete solidification, it is taken out from the mould. The product of casting is also known as casting and the place where casting work is done is known as 'foundry shop'.

20.2 CLASSIFICATION OF CASTING PROCESS

Casting process can be classified on the basis of expandable mould and multiple-use mould as shown in Figure 20.1. Expandable mould is destroyed after solidification of the casting. But, multiple-use mould can be used to make many castings. Expandable mould is used for very complicated casting

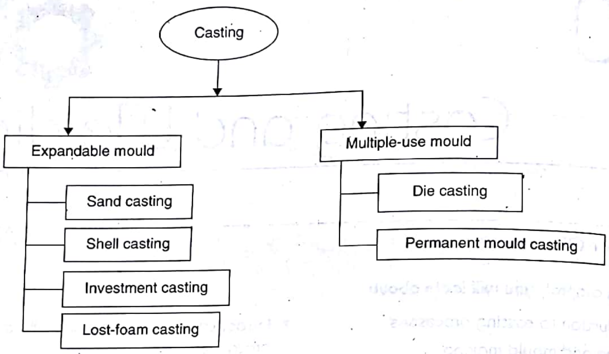


Figure 20.1 Classification of Casting Process

design. In this process, production rate is lower than the multiple-use mould. A multiple-use mould is used for simple casting and it has high production rate.

20.3 SAND CASTING

A model of mould used in sand casting is shown in Figure 20.2. Moulding material that is packed around the pattern to provide the mould cavity is green sand. The various parts of mould can be defined as follows:

Flask: It is a rigid box which opens at top and bottom that holds the complete mould. Flask may be divided into three parts—the upper, middle, and lower; these three parts are known as cope, cheek, and drag, respectively.

Core: A sand or metal shape that is inserted into the mould to create internal hole or recess.

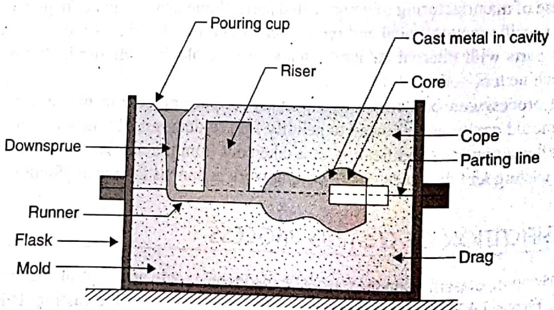


Figure 20.2 A Model of Mould Used in Sand Casting

Mould Cavity: It is a cavity of casting shape in the mould connected to runner and riser. It is used to pour the molten metal in which metal solidifies and gets the shape of cavity.

Riser: An additional opening in the mould that provides additional metal to compensate for shrinkage and also helps to remove gas or vapour formed during pouring the molten metal into the cavity.

Gating System: It is a network of channels that deliver the molten metal to the mould cavity.

Pouring Cup/Basin: It is located at the top surface of the mould and connected to upper part of downsprue. It prevents the splitting of molten metal.

Downsprue: It is vertical portion of the gating system. It facilitates the streamline flow of molten metal.

Runners: It is horizontal channels which connects the downsprue and gates.

Gate: It controls the amount of flow of molten metal at the entrance of cavity.

Parting Line: It is dividing line of cope and drag.

20.3.1 Steps in Sand Casting

Sand is the most suitable material for expandable mould. It has sufficient properties of moulding materials such as refractoriness, permeability, flowability, adhesiveness, cohesiveness, etc. Sand casting is the most versatile and common form of casting. In this method, a mould of sand with binding materials and water is prepared in which molten metal is poured and allowed to solidify. The entire casting process can be represented as a chain as shown in Figure 20.3.

A green sand mould is prepared with the help of pattern. The green sand is mixture of green sand, binders, and water. The pattern is made of wood plastics, metal, wax, etc. The selection of pattern materials is based on the type of casting process.

After pattern/mould making, metal is melted in the cupola or in other suitable furnace. The molten metal is poured into the mould cavity. The solidification process allows the product to gain the desired properties and strength. The shrinkage in casting is controlled by the riser and proper design of the mould. After solidification, casting is removed from the mould and sent to cleaning, finishing, and inspection. Finally, the casting defects are rectified.

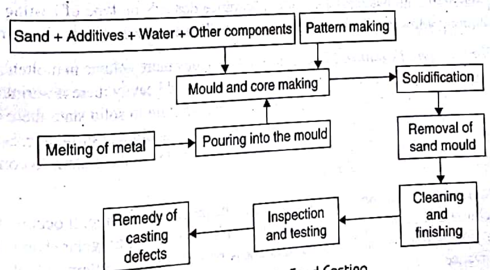


Figure 20.3 Steps in Sand Casting

20.3.2 Pattern Making

Pattern is a replica of the product, which is to be manufactured through casting. It is used to make a mould cavity of required shape and size. Various types of pattern materials such as wood, aluminium, steel, plastic, and cast iron are used in sand casting. The selection of pattern materials is based on their properties, for example, machinability, wear resistance, strength, weight, repairability, resistance to corrosion, and swelling.

Pattern Allowances

The surface finish of the casting product may not be as good as required, therefore, extra dimensions in the pattern are provided. The extra dimensions or extra materials provided for the pattern are known as allowances. The following allowances are provided for pattern making:

- Draft allowance/Taper allowance.
- Machining allowance.
- Shrinkage allowance.
- Distortion allowance.
- Shaking allowance/Rapping allowance.

Draft Allowance: To exit out the pattern from the mould easily, the surfaces of the pattern are made taper. The larger dimension side of the pattern is at the parting line. The taper provided may be 1°– 3°. When small jerk is given to pattern to exit out from the mould, air enters into the small clearance created due to the jerk and breaks the contact between pattern and mould surfaces. The inner side surface of the pattern is provided more taper angle because during solidification metal shrink towards the core. The amount of draft allowance depends on the material used for mould making shape, size of the pattern, etc.

Shaking/Rapping Allowance: To remove the pattern from the mould, pattern is rapped with the help of draw spike so that they can be detached from the mould. But due to rapping, the cavity in the mould gets enlarged. Therefore, the pattern is made smaller than the casting, which is known as shaking allowance. This is negative allowance.

Machining Allowance: The dimensional accuracy and surface finish of the casting (especially sand casting) is poor. Therefore, machining is required for good surface finish and dimensional accuracy; to compensate the removal of unwanted materials, extra materials are provided to the pattern, which is known as machining allowance. Machining allowance depends on type of casting process, for example, machining allowance in die casting is very small in comparison to sand casting.

Shrinkage/Contraction Allowance: Most of the metals occupy more volume in molten state in comparison to solid state. When molten metal is poured into a mould cavity there is shrinkage in metal during solidification. When metal is transferred from molten state to solid state there is shrinkage and from hot solid state to room temperature solid state, there is additional shrinkage. So the volume of pattern is larger than the casting. The extra dimension provided to the pattern to compensate the shrinkage is known as shrinkage allowance.

Distortion Allowance: Distortion in casting occurs in the process of cooling. It occurs due to differential solidification and setup of thermal stress. It applies to casting of irregular shape. To eliminate this defect, an opposite allowance of equal amount is provided in the pattern, which is known as distortion allowance.

20.3.3 Types of Pattern

- Solid pattern or Single piece pattern.
- Split pattern.
- Loose piece pattern.
- Gated pattern.
- Match plate pattern.
- Sweep pattern.
- Skeleton pattern.
- Cope and drag pattern.
- Segmental pattern.
- Follow board pattern.

Solid Pattern/Single Piece Pattern: A single piece pattern is used for a simple casting. In this pattern, no joint or partition is used. It can be moulded in a single moulding box as shown in Figure 20.4.

Split Pattern: If design of the pattern is not simple, it is difficult to withdraw as a single piece from mould. The pattern is made into two pieces or into a split form and joined together by dowels, which is shown in Figure 20.5.

Loose Pieces Pattern: Some single piece patterns are made to have loose pieces in order to enable their easy withdrawal from the mould. These pieces form an integral part of the pattern during moulding (Figure 20.6). After the mould is complete, the pattern is withdrawn leaving the pieces in the sand, which are later withdrawn separately through the cavity formed by the pattern.

Gated Pattern: In a mass production, where many castings are required, gated pattern may be used. Such patterns are made of metal to give them strength and to eliminate any warping tendency. The connecting parts between the patterns form the gates or runners for the passage of molten metal into the mould cavity, are the integrated parts of this pattern (Figure 20.7).

Match Plate Pattern: Match plates provide a substantial mounting for patterns and are widely used with machine moulding. In the figure, a match plate is shown upon which patterns are mounted for two

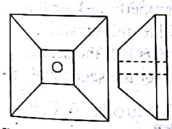


Figure 20.4 Single Piece Pattern

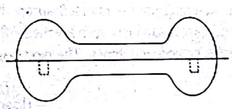


Figure 20.5 Split Pattern

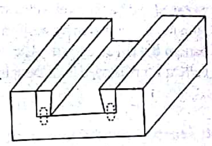


Figure 20.6 Loose Piece Pattern

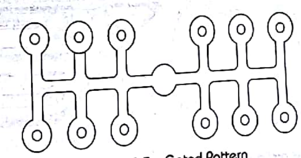


Figure 20.7 Gated Pattern

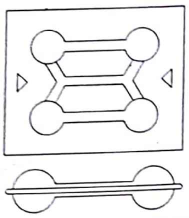


Figure 20.8 Match Plate Pattern

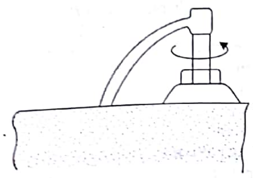


Figure 20.9 Sweep Pattern

small dumb bells. It consists of a flat metal or wooden plate to which the patterns and gates are permanently fastened. On either end of the plate, there are holes to fit into a standard flask (Figure 20.8).

Sweep Pattern: Sweeps can be used for preparing moulds of large symmetrical castings of circular cross-section. The sweeping equipment consists of a base, suitably placed in the sand mass, a vertical spindle, and a wooden template, called sweep. The sweep may have different shapes of casting desired. The sweep is rotated about the spindle to form the cavity (Figure 20.9). Then the sweep and spindle are removed. The filling sand patches the hole of spindle. Cores are fitted as required.

Skeleton Pattern: Skeleton pattern requires large amount of wooden work. It is used for large size casting. A pattern consists of a wooden frame and strips, called skeleton pattern. It is filled with loam sand and rammed properly, and surplus sand is removed. Both halves of the pattern are symmetrical as shown in Figure 20.10.

Cope and Drag Pattern: Cope and drag pattern is used for heavy casting which is difficult to handle in a single piece. This pattern is made in two parts in cope and drag and finally assembled together to form a complete mould cavity (Figure 20.11).

Segmental Pattern: Segmental pattern is used for large ring-shaped casting (Figure 20.12). A vertical central spindle is firmly fixed near the centre of a drag flask. The bottom of the mould is then rammed and swept level with a sweep. Now, with the segmental pattern is properly fastened to the spindle and in a starting position, moulding sand is rammed up on the inside and outside of the pattern but not at the ends. After the surplus sand has been levelled off from its top, the segmental pattern is unfastened from the spindle, rapped, and drawn. The next position for the segmental pattern will be adjoining its last position with sufficient overlap to ensure continuity. The process is continued until a complete ring-shaped mould cavity has been made. The mould may be closed with a cope or with cover cores. Sweeps and segmental patterns are widely used for making large gears, wheels, and sheaves. Cores made in one core box may be set together on a level surface to form spokes and inside surfaces of the rim and the hub. A large cast gear can be moulded with a segmental pattern having only three or four teeth.

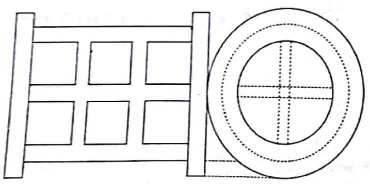


Figure 20.10 Skeleton Pattern

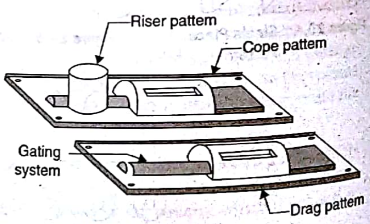


Figure 20.11 Cope and Drag Pattern

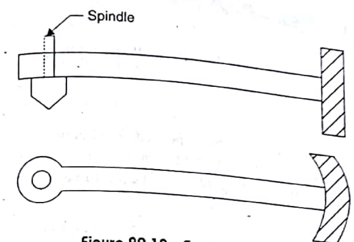


Figure 20.12 Segmental Pattern

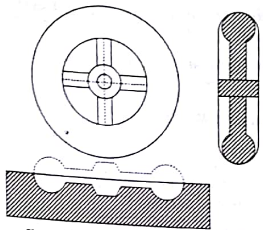


Figure 20.13 Follow Board Pattern

Follow Board Pattern: Follow board is a wooden board, which is used to support a thin section pattern. The pattern may have a cavity shape or projection shape. Due to thin section during ramming there is chance of breaking of pattern, therefore a support of same shape follow board is required which is shown in Figure 20.13.

Colour Codes Used in Pattern

Following colour codes are used on pattern for various purposes as given below:

- **Red:** Surface is to be machined.
- **Black:** Surface is to be left unmachined.
- **Yellow:** Core print is to be used.
- **Black strips or Yellow base:** Stop offs.
- **Clear or no colour:** Parting surface.

20.3.4 Mould Making

Mould making is a process of creating a replica of casting with the help of patterns and moulding sand. The cavity, produced in sand body, facilitates the molten metal to solidify and to take the shape of the cavity. Various types of moulding sands used in a foundry are classified as follows:

Green Sand: Green sand is a mixture of silica sand, clay, and water. Normally percentages of water and silica in green sand are 6% and 18%, respectively.

Dry Sand: Dry sand initially has high moisture content but the moisture has been evaporated from it by drying its mould in an oven.

Parting Sand: Parting sand is used on the parting plane to prevent the sticking of cope and drag part.

Baking Sand: This is already used sand in casting. Before reuse, it is riddled to remove all foreign materials and used to fill the moulding flask after facing sand has been rammed around the pattern.

Facing Sand: This is fresh prepared and tempered foundry sand and it is used all around the pattern and remainder may be green sand.

Types of Moulds

Mould is a cavity of heat resistant materials into which a molten metal is poured. Sand is most suitable for mould material due to heat receptivity, permeability, and low cost but metal moulds are also used for small non-ferrous and precision casting. The various types of moulds used in casting can be classified as follows:

Green Sand Mould: Green sand is a mixture of silica sand, clay, and water. The percentages of clay and water in the mixture vary from 10% to 12% and 3% to 6%, respectively. It is known as green sand due to wetness.

Skin-dried Moulds: In this mould, the cavity surface up to a depth of ½ inch is dried and hard. Generally, two methods are employed to prepare a skin dried sand mould. In the first method for preparing the skin-dried mould, the sand around the pattern to a depth of ½ inch is mixed with a binder so that when it is dried it will leave a hard surface on the mould. In the second method, the entire internal surface of the mould is coated by spray or wash with linseed oil, molasses water, gelatinized starch, etc., which harden on heating.

Dry Sand Moulds: Dry sand mould is made from coarse moulding sand with binding material. It is a mixture of green sand, cereal flour, and coal tar. The prepared mould is backed in an oven at 110–260°C for several hours for hardening. This type of mould is generally used for large steel castings. They give better surface finish and also reduce the incidence of the casting defects such as gas holes, blowholes, or porosity. However, due to the greater strength of these moulds, tearing may occur in hot-short materials.

Loam Sand Moulds: Loam sand moulds are used for large work like pit moulding. The mould is first built with bricks or iron parts. These parts are then plastered over with a thick loam mortar, the shape of the mould being obtained with sweeps or skeleton pattern. The mould is then allowed to dry thoroughly so that it can resist the wear due to heavy rush of molten metal.

Core Sand Moulds: Core sand moulds are made from core sand in subparts and assembled together. They are made in subparts due to difficulty in handling during baking.

Metal Moulds: Metal moulds are used in die casting of low melting temperature alloys. It may be used for ferrous and non-ferrous casting but it is more suitable for non-ferrous casting. Castings have smooth surface finish, accurate size, and better mechanical properties and are produced with faster rate of production. Thus, machining works are eliminated.

Special Moulds

CO_2 Moulds: This is also a sand moulding in which water glass (Na_2OxSiO_2, sodium silicate) is used as binder. After mould is prepared, CO_2 is made to flow through the mould and mould gets hardened. The chemical reaction for the process is

$$Na_2OxSiO_2 + nH_2O + CO_2 \rightarrow Na_2CO_3 + xSiO_2 n\,(H_2O) \text{ stiff gel.}$$

This is a one of the method of quick mould hardening.

Resin-bonded Sand Moulds: In these moulds, green sand mixture is mixed with thermosetting resins such as linseed oil. The resin is oxidized during baking and mould gets hardened due to polymerization.

Shell moulds: These moulds are prepared by heating a mixture of sand and resin over the surface of a metallic pattern. This enables the production of a thin and rigid layer of uniform thickness which, when separated from the pattern surface, forms one part of the shell. Two such parts are joined to form a complete shell mould.

20.3.5 Properties of Mouldings Sands

Refractoriness: Refractoriness is a property of moulding sand due to which it can withstand high temperature of molten metal without fusing and burning.

Permeability: Permeability is ability of moulding sand to escape vapour and gases formed during pouring the molten metal into the mould cavity. Due to lack of permeability there may be casting defects like blowhole, porosity, and pinholes.

Flowability or Plasticity: Flowability is that property of moulding sand due to which it flows uniformly into the moulding box during ramming.

Adhesiveness: Adhesiveness is the adhering ability of the sand particles to other materials due to which the heavy sand mass is successfully held in a moulding flask without any danger of its falling down.

Cohesiveness: This is a property of sand particles due to which it binds together firmly so that it can easily be withdrawn from moulding box without damage to the mould surfaces and edges.

Collapsibility: It is property of the moulding sand due to which mould collapses automatically after solidification of the casting to allow free contraction of the metal.

Binders Used in Moulding Sand

Various types of binders used in moulding sand are given as below:

- **Clays:** Fire clay $2SiO_2 \cdot Al_2O_3 \cdot 2H_2O$.
- **Southern bentonite:** $Al_{1.67} Mg_{0.33} Ca_{0.35}, O_3 \cdot 4SiO_2 \cdot 2H_2O$.
- **Western bentonite:** $Al_{1.67} Mg_{0.33} Na_{0.33}, O_3 4SiO_2 \cdot H_2O$.
- **Secondary mica clays:** $K_2O \cdot 6SiO_2 \cdot 3Al_2O_3 \cdot 2H_2O$.
- **Oils:** (Hardened by baking.) Vegetable oil (linseed oil), marine animal (whale oil), and minera[l] oil (used as diluting oil).
- **Synthetic resins (thermosetting plastic):** Urea formaldehyde, phenol formaldehyde.
- **Cereal binders made from corn:** Gelatinized starch (made by wet milling contains starch an[d] gluten), gelatinized corn flour (made by dry milling), and dextrin (made from starch, a wat[er] soluble sugar).
- **Wood products binder:** Natural resin (e.g., rosin, thermoplastic), sulphite binders (contain li[g]nin, produced in paper-pulp process), water soluble gums, resins, and organic chemicals.
- **Protein binders (contains nitrogen):** Glue, casein.

- **Other binders:** Portland cement, pitch (coal tar products), molasses, cements, sodium silicate (water glass, CO_2).
- **Additives** used in moulding sands are coal dust, sea coal, cereals or corn flour, silica flour, wood flour, pitch, dextrin and molasses, and fuel oil.

20.3.6 Hand Tools Used in Moulding (Figure 20.14)

Bellows: This is used to blow out loose sand from the cavities and surface of the mould.

Slick: Slick is used for repairing moulds. It is a small double-ended tool having a flat on one end and a spoon on the other. It is also available in various shapes.

Lifters: Lifters are used for smoothing and cleaning out depressions in the mould. They are made of thin sections of steel of various widths and lengths with one end bent at right angle.

Rammer: A hand rammer is used to pack the sand in the mould. One edge of the rammer, called the peen end, is wedge shaped, and the other end, called butt end, is flat. Pneumatic rammers are used in large moulds, saving considerable time.

Draw Spike: The draw spike is a pointed tool at one end and loop at other end. It is driven into a wooden pattern and withdraws the pattern from the mould.

Riddle: A riddle is a standard mesh screen used to remove foreign particles from the sand.

Swab: A swab is a small brush having long hemp fibres and is used for moistening the sand around the edge before the pattern is removed.

Gate Cutter: This is u-shaped thin metal strip, which is used to cut a gate for metal feeding into the cavity.

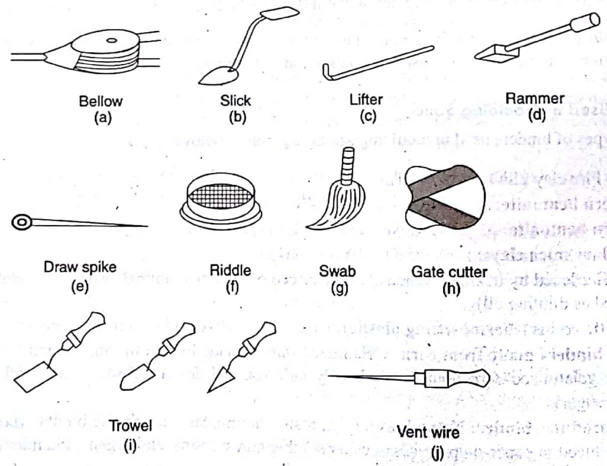


Figure 20.14 Hand Tools for Sand Moulding

Trowel: It is available in various shapes and is used for finishing and repairing mould cavities as well as for smoothing over the pasting surface of the mould.

Vent Wire: This is a sharp pointed wire used to punch holes through the sand after ramming for escape of the vapour and gases produced on pouring the molten metal.

Cope and Drag: Cope is upper part of moulding box. Drag is lower part of moulding box. The middle part of the moulding box is known as chick if three parts of moulding box are used.

20.3.7 Moulding Procedure

At first, pattern is placed on moulding board, which fits the flask being used. The lower moulding box is placed on the board with the pin down as shown in Figure 20.15 (a). Moulding sand, which has previously been tempered, is filled over the pattern. The sand should be pressed around the pattern with the fingers and then the box is filled completely. The sand is then firmly packed in drag part of the box by means of a hand rammer. For ramming the sand near the wall of the flask, the peen end rammer should be used first, additional sand being placed into the drag as the sand is settled down. The inside area of the drag is then rammed with the butt end of the rammer. The ramming should be optimum. If the mould is not sufficiently rammed, there will be chance of breaking of the mould during handling. On the other hand, it will not permit the vapour and gas to escape from the mould if it is rammed too hard.

When ramming has been completed, the surplus sand is levelled off with the help of strike off bar. In order to ensure the escape of the gases, few small vent holes are made through the mould with the help of vent wire. The completed lower half of mould, i.e., the drag is then rolled over and pattern

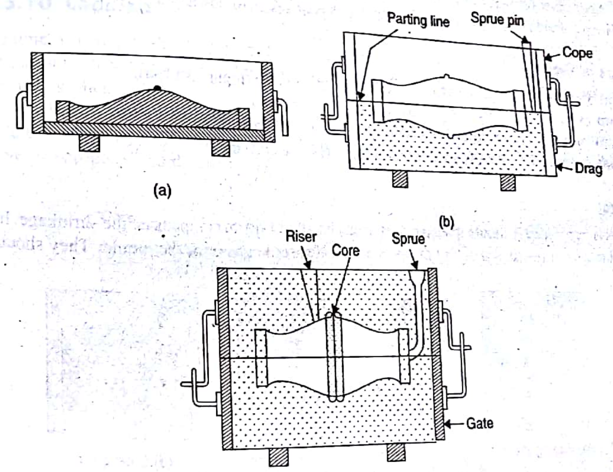


Figure 20.15 Steps in Mould Making

is exposed. The upper surface of the mould is first smoothed over with a trowel and is then covered with a fine coating of dry parting sand to prevent the sticking of the sands in the cope.

The cope is now placed on the drag as shown in Figure 20.15 (b), the pins on either side holding it in proper position. A sprue pin and riser is placed at right position. The rest of the operations such as filling, ramming, and venting of the cope are repeated in the same manner as before.

Riser and sprue pin is removed. The cope half of the flask is lifted off and set to one side. Before the pattern is withdrawn, the sand around the edge of the pattern should be moistened with a swab so that the edges of the mould will hold firmly together when the pattern is withdrawn.

To loosen the pattern, a draw spike is driven into it and rapped lightly in all directions. The pattern can then be withdrawn by lifting up the draw spike. Before mould is closed again, a small passage, i.e., gate must be cut from the mould at the bottom of the sprue opening. Now mould is closed for pouring the molten metal.

20.3.8 Gating System

A network of passage of molten metal from pouring basin to mould cavity is known as gating system. It consists of pouring basin, downsprue, skim bob, runner, gate, riser, etc. A good gating system should have the following properties:

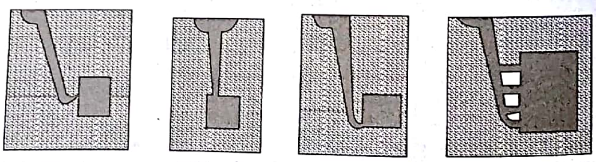
- Metal should enter the mould cavity with low turbulence.
- Erosion of passageway should be avoided.
- There should be provision of directional solidification of metal. The solidification should progress from mould surfaces to the hottest metal so that there is always hot metal available to compensate for shrinkage.
- Slag or other foreign particles should be prevented from entering the mould cavity using skim bob.
- There should not be aspiration problem due to poor design of downsprue.

Types of Gates

- **Parting line gate:** Metal enters the cavity at parting plane (Figure 20.16a).
- **Top gate:** Metal enters at top of the cavity (Figure 20.16b).
- **Bottom gate:** Metal enters from bottom of the cavity (Figure 20.16c).
- **Side gate:** metal enters from side of the cavity (Figure 20.16d).

Risers

Risers are provided in mould to feed molten metal into the cavity to compensate the shrinkage. In the initial stages of pouring, it allows the air, steam, and gases to go out of the mould. They should be large in section, so as to remain molten as long as possible and should be located near heavy sections that will be subject to heavy shrinkage and are last to freeze.



(a) Parting line gate (b) Top gate (c) Bottom gate (d) Side gate

Figure 20.16 Types of Gating Systems

Risers used in casting may be either open type or blind type. The open riser is open to atmosphere. The blind risers are dome shaped either on the top or side of a casting. It is surrounded by the moulding sand from all sides. A vent may be provided at its top. This riser may be located in either the cope or the drag. It derives its feeding force from the force of gravity on the liquid metal in it. Blind risers provide molten metal more hot in comparison to open risers.

20.3.9 Chills

Chills are used to improve the directional solidification with faster heat conduction by metallic chills; solidification is initiated and accelerated at desired locations. The thinner section of a casting solidifies earlier in comparison to thicker section, which results in distortion, internal stress set up, crack etc. Chills increase the solidification rate in thicker section and equal the solidification rate in thinner section. There are of two types of chills: internal and external chills.

Internal Chills: They are located within the mould cavity and form a part of the casting. They are usually in the form of thin wires and are hung in the mould by inserting their one end into the sand.

External Chills: They are embedded in the mould such that they are flush with the mould walls and form a part of it. Their exposed surface is given the desired shape so that it confirms to the shape of mould wall and hence of the casting.

Chills are metallic objects of high heat capacity and high thermal conductivity which are placed in the mould/mould cavity to increase the cooling rate of castings or to promote directional solidification. These are cleaned of scale/oxide to avoid any reaction with hot metal.

20.3.10 Chaplets

Sometime, it is impossible to use core print to support the core. In this case, a metallic support is used which is known as chaplet. Chaplet is made of same material as the material of casting. It gets fused with molten metal.

Chaplets are placed in a mould between the mould face and the core as shown in Figure 20.17. It should be in such a position that its head is large enough to provide large bearing surface and stem thin to fuse properly into the molten metal.

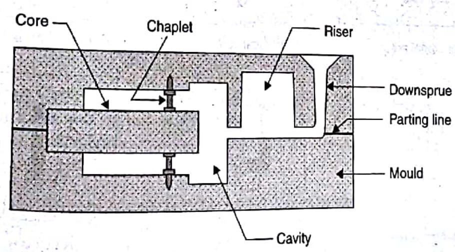


Figure 20.17 Use of Chaplets In a Sand Mould

20.3.11 Cores

Core is a sand body specially prepared in a core box and it is used to form a cavity/hole/recess or projection in a casting for different purposes. As core is surrounded by liquid metal from all the sides, it has to have better characteristics than the moulds. Better raw sand and binder are used for the purpose. The main characteristics of core are highly permeable, highly refractory, hard, and high collapsible. Various types of cores are shown in Figure 20.18.

Horizontal Core: Horizontal core is used to provide a hole in the casting from one end to other end and lies axially horizontal. Both the ends of core are supported in the mould. Generally, it is located at parting line but its location depends on shape. In the case of uniform core, it is located at parting line.

Vertical Core: This is similar to horizontal core but lies axially vertical. It is supported by core prints in drag and cope. It is slightly tapered and its major part lies in drag.

Balanced Core: This is just like a cantilever. Its one end is supported in mould and the other end is free. It is used to produce a blind hole in a casting.

Hanging Core: Hanging core is supported only at the tope in the cope and there is no support at the bottom. The whole portion of the core lies in the cavity in the drag of the mould. It is also known as cover core since it acts as a cover for the cavity.

Drop Core: A drop core is required when hole is not in line with the parting surface but must be formed at lower level. Its one side remains flush with the inner surface of the mould and back is provided with enough taper for its location.

Kiss Core: Kiss core is held vertically in the mould. It is not supported by the core print. It is held vertically due to pressure of the cope and drag part of the mould.

Core Print: Core print is a sand body, which is used to give support to the core.

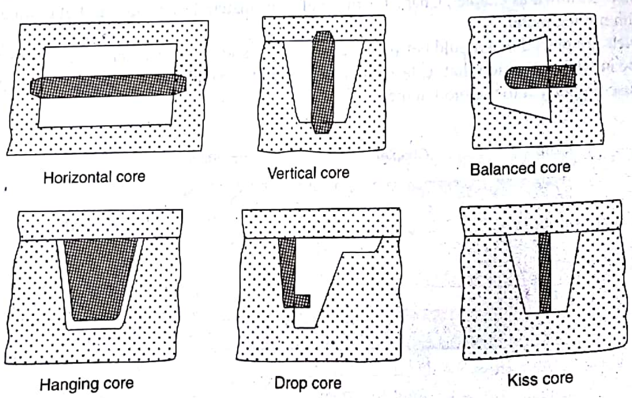


Figure 20.18 Types of Cores

20.3.12 Sand Testing

Following sand testing are used in foundry.

Moisture Content Test: To find the moisture content in sand, moisture teller equipment is used. It consists of cast iron pan and an infrared heater bulb fitted in a shade. Twenty grams of sand is taken in a pan and it is exposed in infrared heater for 2–3 min. Difference in weight is found (i.e., weight before drying and weight after drying), which shows the amount of moisture.

Clay Content Test: Clay content in sand is determined by washing the clay from a 50 g of sand in water and sodium hydroxide several times. After washing sand is dried and weighed. The decrease in weight is clay content in the sand.

Fineness Test: According to American Foundrymen's Society Sieve Analysis, the foundry sand for its grain size is tested with the help of sieve. The test is performed on 50 g clay-free, dried sand sample. The sample is placed on the top of a series of 11 sieves having the numbers as 6, 12, 20, 30, 40, 50, 70, 100, and the sieves are shaken. The amount of sands retained on each sieve and the bottom pan is weighed and its percentage in total sample is determined. To obtain the AFS fineness number, each percentage is multiplied by a factor, which is the size of the preceding sieve. The fineness number is obtained by adding all the resulting products and dividing the total by the percentage of sand retained in the sieve set and pan.

$$\text{AFS Grain Fineness Number} = \frac{\text{Sum of the products of weight of sand and sieve factors}}{\text{Total sum of the percentage retained on each sieve and pan}}$$

Permeability Test: Permeability is a measure of gas passes through the narrow voids between the sand grains. It is measured in terms of a number known as permeability number. Permeability number is defined as the volume of air in cubic centimetres that will pass per minute under a pressure of 10 g/cm² through a sand specimen, which is 1 cm² in cross-section and 1 cm deep.

$$\text{Permeability number,} \qquad p = \frac{VH}{PAT}$$

where V = Volume of air, H = Height of specimen, P = Air pressure, A = Cross-sectional area of sand specimen, T = Time in seconds)

$$p = \frac{3{,}007.2}{T\,(s)}$$

Compression Test: Compressive strength of moulding sand is found by this test. A compressive load of sufficient amount is applied on a cylindrical sample of 50 mm height and 50 mm in diameter so that it just starts to break. Sands of low moisture and excess moisture are said to have poor strength.

Hardness Test: Hardness test of sand mould or core is done on a hardness testing machine. It carries a hemispherical ball or tip at its bottom, which is penetrated into the mould surface. A spring-loaded shaft inside the hollow body of the instrument actuates the needle of the dial gauge fitted at the top. The dial of this gauge provides direct reading of the mould hardness.

20.4 SPECIAL CASTING METHODS

In addition to sand casting, there are several other casting processes that are mentioned below.

20.4.1 Gravity/Permanent Mould Casting

In this casting method, metallic moulds are used which can withstand the high temperatures of molten metal. The permanent mould is made into two parts; both parts are hinged at one end and clamped at other end. Mould is pre-heated before filling the molten metal. After solidification mould is opened and casting is removed. Again it is closed and used for another casting without pre-heating since the heat from previous cast is usually sufficient to maintain the mould temperature.

Advantages

- Fine grain structure is obtained which results in better mechanical properties.
- Casting has good surface finish and closer dimensional tolerance.
- Casting is free from embedded sand.
- This process is economic for large production.

Disadvantages

- This process is not suitable for small production due to high cost of die.
- This process is more suitable for casting of low melting point metal or alloys.
- Mould life is limited.
- A complicated shaped casting is difficult to produce by this process.

20.4.2 Slush Casting

This is a special type permanent mould casting in which hollow casting is prepared without core since solidification of molten metal starts from mould surface towards centre. The molten metal is kept inside the mould cavity for a pre-determined time for solidification of particular thickness and then the mould is turned down. The rest of the molten metal comes out from the mould. This is used for casting of ornaments, toys, hollow lamp stand, etc.

20.4.3 Pressed or Carthias Casting

This process was developed by Carthias in France and mainly used for ornamental products. A definite amount of metal is poured into an open ended mould, and a close-fitting core is forced into the cavity, causing the metal to be forced into the mould cavities with some pressure. The core is removed as soon as the metal sets, leaving a hollow thin-walled casting. The steps involved in Carthias casting is shown in Figure 20.19.

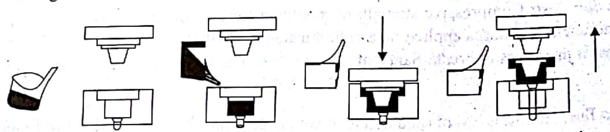


Figure 20.19 Steps in Carthias Casting

20.4.4 Die Casting

There are two types of high pressure die casting.

1. Hot-chamber die casting.
2. Cold-chamber die casting.

Hot-chamber Die Casting

A hot-chamber die casting machine is shown in Figure 20.20. This machine is used with alloys of low melting points because of the difficulties encountered such as increased corrosion of the machine parts at high temperatures. Since many metals have an affinity for iron, only those casting alloys are used that do not attack the immersed metal parts. Alloys of zinc, tin, and lead are particularly recommended for these machines.

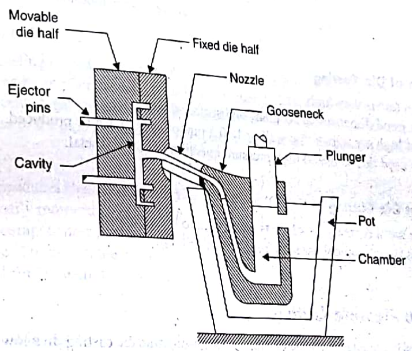


Figure 20.20 Hot-chamber Die Casting Machine

In the hot-chamber die casting method, the melting pot is included within the machine and the injection cylinder is immersed in the molten metal. The injection cylinder is actuated by either air or hydraulic pressure, which forces the metal into the die cavity. The metal is held under pressure until it solidifies. The improved die design and rapid cooling can reduce cycle time.

Cold-chamber Die Casting

Cold-chamber die casting is used for relatively high melting point non-ferrous alloys such as aluminium, magnesium, and brass which require higher pressure and temperature for melting. These metals are not melted in a self-contained pot as in hot-chamber die casting due to short life of pot (Figure 20.21). Therefore, the metal is melted in an auxiliary furnace and is ladled to the plunger cavity next to the dies. It is then forced into the dies under hydraulic pressure. The cold-chamber die casting machines operating by this method are built very strong and rigid to withstand the heavy pressure exerted on the metal as it is forced into the dies.

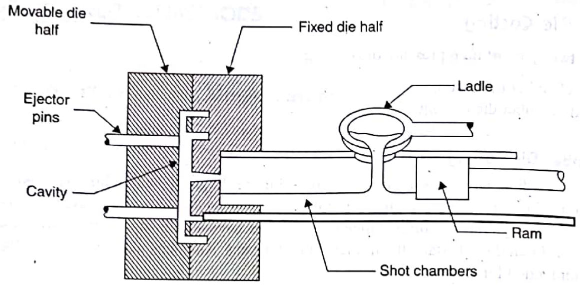


Figure 20.21 Cold-chamber Die Casting Machine

Advantages of Die Casting

- Production rate is very high.
- Parts have good dimensional accuracy and surface finish.
- Because of high pressure a thin wall up to 0.5 mm of casting can be produced.
- No riser is used due to use of high pressure injection of molten metal.

Limitations of Die Casting

- Die casting has a porosity problem as gases tend to be entrapped.
- The process is economical for large production run only.

20.4.5 Low Pressure Casting

This process lies between gravity die casting and high-pressure die casting. In a low-pressure casting process, the molten metal is forced upward by gas or air pressure into a graphite or metal mould. The mould is located just above the furnace. It may take half a minute to fill up the mould, so any entrapped gas has time to escape; the casting part cools from the top to down. The applied pressure continually feeds molten metal to compensate for shrinkage and the unused metal in the feed tube drops back into the crucible after the pressure is released. When the metal is completely solidified in the mould, the upper half of the mould is lifted up with the casting entrapped in it. An ejector pin drops the casting in a hopper.

Advantages

- High pressure die castings have a porosity problem that is non-existent in the low pressure system.
- The casting is dense, free from inclusions and oxidation, and of good dimensional accuracy.
- Mechanical properties of casting are improved as close control of temperature and pressure.
- Cost of the machine is less than that of high pressure die casting.
- Die life is longer than the high pressure die casting.

Limitations

- Wider tolerance is required.
- Casting modifications are tough.

20.4.6 Centrifugal Casting

In this casting process, centrifugal force is used to feed the molten metal into the mould cavity, i.e., mould is rotated at high speeds (300–3,000 rpm). This process is more suitable for symmetrical shaped casting but other types of casting can also be produced. The centrifugal casting can be classified as follows:

- True centrifugal casting.
- Semi-centrifugal casting.
- Centrifuging.

True Centrifugal Casting

True centrifugal casting is used for pipe, liners, and symmetrical hollow body. They are cast by rotating the mould about its axis horizontally or vertically (Figure 20.22). The metal is held against the wall of the mould by centrifugal force and no core is used to form a cylindrical cavity inside the casting. The wall thickness of the pipe produced is controlled by the amount of metal poured into the mould.

Advantages

- This process produces clean casting since all foreign matter collected on the surface of the central hole can be easily removed by machining.
- Dense metal component is produced due to centrifugal force.
- There is no need to use central core, riser, and runner.
- It can be used for large production.

Disadvantages

- Equipment cost is high.
- True centrifugal casting is limited to certain shapes only.

Semi-centrifugal Casting

Semi-centrifugal casting is used for the castings that are symmetrical about a central axis but complicated than true centrifugal castings. It is not necessary to have a central hole. A core will have to

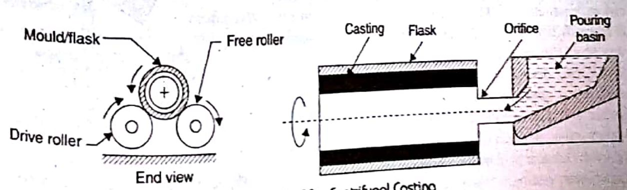


Figure 20.22 Centrifugal Casting

20.5 CASTING DEFECTS

Casting defects are unwanted feature or irregularities in casting which make it of poor quality. These defects occur due to several reasons such as poor design of casting, excess moisture in mould, improper ramming of moulding sand, misalignment of cope and drag, etc. The various types of casting defects are shown in Figure 20.27.

Shifts: Misalignment of flask, i.e., cope and drag and mismatching of core cause shifts. These can be prevented by proper alignments and placing of core.

Blow: Blow is small, round holes appearing at the surface of the casting covered with a thin layer of metal.

Scar: It is shallow blow, which is usually found on a flat casting surface.

Swell: Swell is an enlargement of the mould cavity due to metal pressure. It is caused due to defective ramming of the mould. To avoid swells, the sand should be rammed properly and evenly.

Blister: This is scar covered by a thin layer of a metal.

Drop: When the upper surface of the mould cracks, and pieces of sand fall into the molten metal, this defect occurs. This is caused by low strength and soft ramming of sand, in sufficient fluxing of molten metal and insufficient reinforcement of sand projections in the cope.

Scab: Liquid metal penetrates behind the surface of mould. Scabs can be identified as rough, irregular projection on the surface containing embedded sand. They are caused using too fine sand, sand having low permeability and high moisture content, and by uneven mould ramming or slow running of molten metal over the sand surface thereby producing intense local heating.

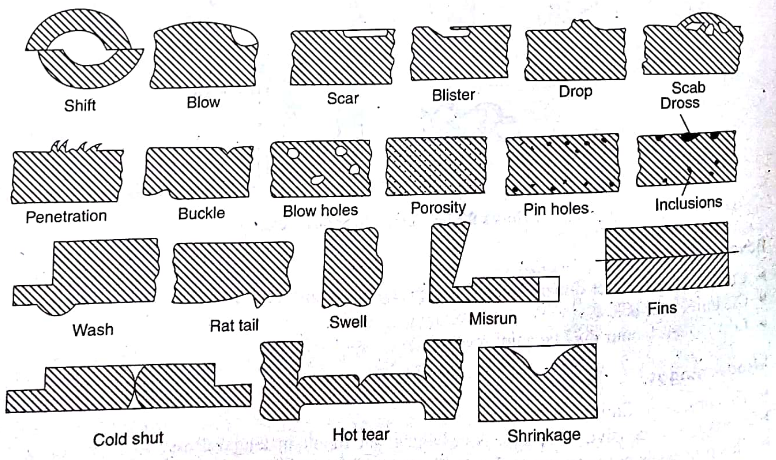


Figure 20.27 Casting Defects

Metal Penetration and Rough Surface: This defect appears as an uneven and rough external surface of the casting. The metal penetration between the sand grains occurs due to low strength, large grain size, high permeability, and soft ramming of sand.

Buckle: This defect is similar to the rat-tail but differs from it in the sense that it is in the form of V-shaped depression in the surface of the casting.

Blowholes: Blowholes are smooth, round holes appearing in the form of a cluster of a large number of small holes below the surface of a casting. Possible causes are excess moisture in the moulding sand, moisture on chills, chaplets, and insufficiently baked and improperly vented core.

Porosity: Porosity is entrapped gases in the form of fine small bubbles throughout the casting.

Pinholes: Pinholes are numerous small holes, usually less than 2 mm, visible on the surface of the casting cleaned by shot blasting. They are caused by sand with high moisture content, absorption of hydrogen or carbon monoxide gas, or when steel is poured from wet ladles.

Inclusions: Inclusion is mixing of foreign particles such as sand and slag in the casting.

Wash: It is a low projection on drag surface of a casting starting near the gate. This results due to displacement of sand by the high velocity metal in the bottom part of gating.

Rat Tails: These defects appear as streaks or slight ridges on large flat surfaces. They occur due to the expansion of sand by the heat of the molten metal.

Mis-run: A mis-run is the incomplete filling of the mould that results when the metal lacks fluidity or temperature.

Fins: Fins usually occur at the parting line of the mould or core sections due to improper clamping of flask. The remedy is to give sufficient weight on the top for proper assembly of the flasks and moulds.

Cold Shut: This type of mis-run occurs in the centre of a casting having gates at its two sides. Imperfect fusion is a result of low temperature of two streams of metal.

Hot Tears: They are internal and external cracks having a ragged edge occurring immediately after the metal has solidified. Hot tears may be produced if the casting is poorly designed and abrupt change in sections takes place, no proper fillets and corner radii are provided, chills are wrongly placed. Incorrect pouring temperature and improper placement of gates and risers are used.

Shrinkage Cavity: Shrinkage cavity is a void or depression in the casting caused mainly by uncontrolled solidification of the metal. They may also be produced if pouring temperature is high.

20.6 SURFACE CLEANING OF THE CASTING

Wire Brushing: Wire brush of hardened steel wires, embedded in a wooden block, is extensively used for cleaning the casting surface.

Tumbling: In this method, the castings to be cleaned are placed together with a number of small cast iron pieces called stars inside a large steel barrel. Both ends of the barrel are closed and the same

20.8 CLASSIFICATION OF WELDING PROCESS

Broadly, welding processes can be divided into the following categories as shown in Figure 20.31.

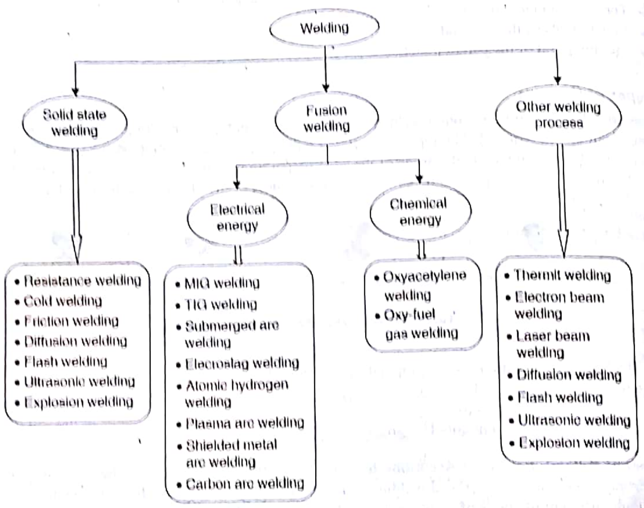


Figure 20.31 Classification of Welding Processes

20.9 GAS WELDING

In this welding process, various types of gases are burnt in combination with oxygen and the flame is applied at the edge of metal plates to be joined. The heat of combustion of the gas melts the metal; filler material may or may not be applied to fill the groove. The molten metal fills the groove which after complete fusion and solidification forms a strong joint. External pressure may or may not be applied at the joint.

The different types of gases used in gas welding are as follows:

- Acetylene
- Hydrogen
- Methane
- City gas
- Natural gas, etc.

The most commonly used gas is acetylene, as acetylene gives highest flame temperature because of its high calorific value.

20.9.1 Oxyacetylene Welding

The highest temperature obtained in oxyacetylene welding is 3,200°C. Acetylene can be used as a gas from a separate cylinder or through reaction of water on calcium carbide. Three different types of flames such as neutral, oxidizing, and carburizing are generated at the tip of welding torch by regulating the amount of acetylene and oxygen with the help of pressure regulators and control valve. These flames are shown in Figure 20.32.

Neutral Flame: Neutral flame is generated at the tip of welding torch with equal volume of oxygen and acetylene mixing in the torch. The two sharply defined zones are inner white cone and outer blue envelope. The maximum temperature occurs at a distance of 3–5 mm from the inner cone.

The reaction at the inner cone is

$$C_2H_2 + O_2 = 2CO + H_2$$

The reactions at outer envelope are

$$2CO + O_2 = 2CO_2$$

$$H_2 + \frac{1}{2}O_2 = H_2O$$

The outer envelope works as a protector and pre-heater of the workpiece. The metals using neutral flame for welding are cast iron, mild steel, stainless steel, copper, aluminium, etc.

Oxidizing Flame: Oxidizing flame is generated with higher proportion of oxygen. The proportion of oxygen and acetylene used is 1.15–1.5. The flame is similar to neutral flame but inner cone is shorter than that of neutral flame; the outer envelope is light blue. In this flame, there is complete combustion of acetylene and it forms carbon dioxide and water vapour. This is oxidizing in nature and used in welding of brass, zinc, bronze, gold, etc.

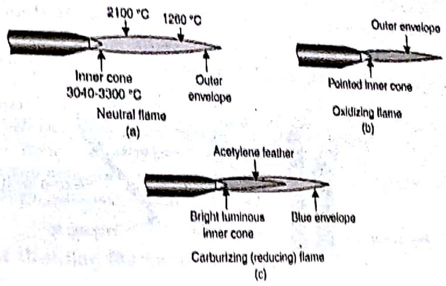


Figure 20.32 Three Basic Types of Flames Used in Oxyacetylene Gas Welding and Cutting Operations: (a) Neutral Flame, (b) Oxidizing Flame, and (c) Carburizing or Reducing Flame

Reducing Flame or Carburizing Flame: In this flame, acetylene is used in excess amount than the theoretically required. The ratio of oxygen and acetylene used is 0.85–0.95. The three zones in this flame are the inner cone, which is not sharply defined; outer envelope is similar to neutral flame; the third zone surrounding the inner cone extends up to outer envelope. It is whitish colour and shows the excess of acetylene used. This flame is used for welding of low carbon steel, aluminium, non-ferrous metals like monel metal, nickel, etc.

Oxyacetylene Welding Equipments: Following equipments are used in oxyacetylene welding (Figure 20.33):

- **Gas cylinders:** Two gas cylinders made of steel are used. One is of black colour used for oxygen and other is of maroon or red colour used for acetylene.
- **Pressure gages:** Each cylinder consists of two pressure gages. One pressure gage shows the pressure of gas inside the cylinder and other shows pressure of gas supplied to blowpipe.
- **Pressure regulator:** Each cylinder is provided a pressure regulator. The function of the pressure regulator is to control the pressure of gas supply to blowpipe or to maintain the constant pressure of the gas.
- **Blowpipe or welding torch:** The cross-sectional view of welding torches is shown in Figure 20.33(a) and (b) as high pressure welding torch and low pressure welding torch, respectively.

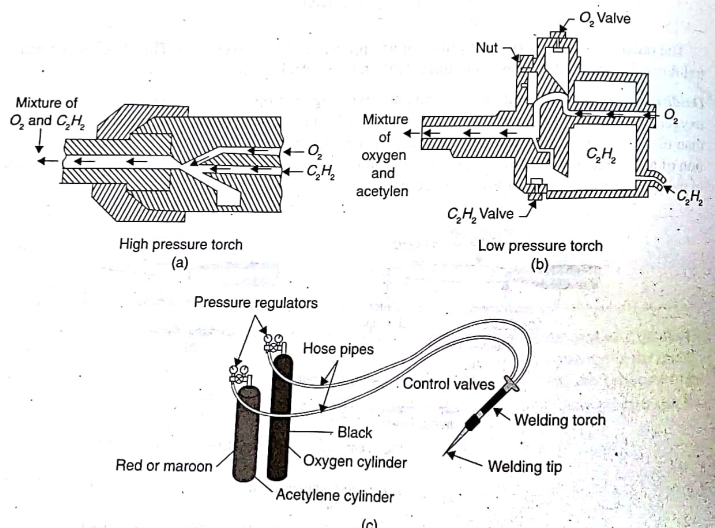


Figure 20.33 (a) Cross-sectional View of High Pressure Torch, (b) Cross-sectional View of the Low Pressure Torch, and (c) Basic Equipment Used in Oxyacetylene-gas Welding

The high pressure blow pipe consists of two passages: one is for oxygen and other is for acetylene. Both the gases are mixed in a chamber and then driven out through the orifice of the blowpipe nozzle with the desired velocity. These nozzles are usually known as tips and are made interchangeable so that the same blowpipe can be used for different sizes of the tips.

The low-pressure torch works on the principles of injector. The pressure of acetylene used is too low but oxygen is supplied at high pressure from 7 to 50 psi.

Note: Acetylene cannot be filled alone in a cylinder due to dissociation at high pressure so it is mixed with small amount of acetone. For mixing at atmospheric pressure, 25 l of acetylene is mixed with 1 l of acetone.

Advantages

- The equipments used in oxy-fuel welding is less costly and easy maintainable.
- It is portable and can be used anywhere.
- It can be used to join most of the common metals.
- The flame temperature can be easily controlled.
- This can be used for cutting purposes.

Limitations

- Due to lack of concentration of heat, large area of the metal is heated and distortion is likely to occur.
- Oxygen and acetylene gases are expensive.
- Storing and handling of gas cylinders involve greater safety measures.

Flux and shielding provided in oxyacetylene welding is not so effective as in inert gas arc welding.

Welding Rod and Fluxes: Welding rod used in a gas welding has similar composition to work material. The diameter of welding rod depends on the thickness of metal plate. Generally, the diameter of welding rod used is half of the thickness of plate. To increase the fluidity of molten metal and to protect the weld pool from the atmospheric gases, fluxes are used. Various types of fluxes are used to weld the different types of metals but for mild steel, no flux is required. The type of fluxes used, depend on the type of metal to be welded, which are listed below.

- **Copper and copper alloys:** Mixture of sodium and potassium borates, carbonates, chlorides, sulphates, borax ($Na_2B_4O_7 \cdot 10H_2O$), boric acid (H_3BO_3), and di-sodium hydrogen phosphate (Na_2HPO_4) are used for dissolving oxides of copper.
- **Ferrous metals**
  - *Carbon steel:* Dehydrated borax, calcium oxide, dissolved in liquid.
  - *Alloy steel:* Boric acid, dehydrated borax, calcium fluoride.
- **Aluminium and aluminium alloys:** Mixture of alkaline fluorides, chlorides and bisulphate of calcium, sodium, potassium, lithium, and barium.

20.9.2 Gas Welding Methods

There are two types of welding methods.

1. Leftward welding (forehand welding).
2. Rightward welding (backhand welding).

The welding rod is held in left hand and blowpipe is held in right hand. Leftward welding is used for the metal plate thickness up to 3 mm. Welding proceeds from right to left. It is also known as forward or forehand welding. The inclination of welding rod with plate is 30°–40° and inclination of blowpipe with plate is 60°–70°.

Right-ward welding is used for thicker plates and proceeds from left to right. The inclination of welding rod is same as in the leftward welding but inclination of blowpipe is 10°–20° less than that in the leftward welding, i.e., at 40°–50°. It is also known as backward or backhand welding.

20.10 ELECTRIC ARC WELDING

In electric arc welding, the heat required for melting the metal is generated by short-circuiting the electrodes. An intense heat is produced in the electric arc. Various types of mechanism are used to produce arc and to stabilize it. The selection of the mechanism, i.e., type of electric arc welding depends on the heat required to melt the metal. A schematic diagram of an electric arc welding is shown in Figure 20.34.

Mechanism of Arc Generation: When two electrodes are brought into contact with each other, electric spark is produced due to short-circuiting. Just after sparking, the electrodes are separated by 2–4 mm distance. The air gap between the electrodes is ionized due to flow of electron from cathode to anode and heavier positive ion from anode to cathode. Thus, arc is continued. The arc length is 0.6–0.8 times of the electrode diameter.

Modes of Metal Transfer in Arc Welding: There are numbers of forces dominant in arc welding, which are responsible for metal transfer. These forces are gravity force, surface tension, electromagnetic interaction, and hydrodynamic action.

Methods of Arc Generation:

- Between consumable electrode and workpiece.
- Between two non-consumable electrode and workpiece.
- Between a non-consumable electrode and workpiece.

Consumable electrode produces arc between electrode and work metal as well as works as a filler material, which fills the groove. During welding, it is consumed and its length decreases. But non-consumable electrode only produces the arc and additional filler material is used in the form of a rod, if it is required. When two non-consumable electrodes are used, the arc is produced between these electrodes and workpiece is not connected with the electric circuit. The workpiece and filler rod get heat for melting from the arc produced between these two electrodes. When a single, non-consumable electrode is used, the electrode and workpiece are connected with electric terminals.

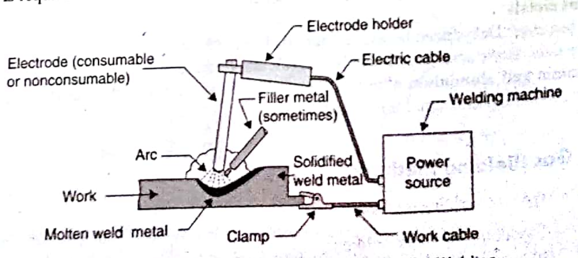


Figure 20.34 Schematic Diagram of an Electric Arc Welding

Polarity: Polarity is concerned with the connection of the electrodes and work metal with particular electric terminals. Polarity is significant only in DC supply. Two types of polarity are used: straight polarity and reverse polarity

In the case of *straight polarity*, workpiece is connected with positive terminal and electrode is connected with negative terminal. About 70% of heat is produced at positive terminal only and 30% of heat is produced at negative terminal. If heat required for welding is large, straight polarity is used. In the case of *reverse polarity*, workpiece is connected with negative terminal and electrode is connected to positive terminal. Reverse polarity is used for large groove size, i.e., for more metal pilling. The difference between AC welding and DC welding is shown in Table 20.1.

Table 20.1 Differences Between AC and DC Welding

AC welding	DC welding
Advantages	**Advantages**
1. Equipment of AC welding is less expansive, light in weight, easy maintainable, and having low operating cost.	1. It has higher arc stability than that of AC welding.
2. It has higher efficiency in comparison to DC welding (85%).	2. Bare electrode can be used easily.
3. It consumes low electrical energy per kg of metal deposited (3–4 kWh/kg).	3. It has high power factor (0.6–0.7).
4. Minor magnetic arc blow problem occurs in comparison to DC welding.	4. Facility of change of polarity is done easily.
Disadvantages	**Disadvantages**
1. It has low power factor (0.3–0.4).	1. It has low efficiency (30–60%).
2. For stability of the arc, voltage/frequency requirement of AC current is high.	2. It involves high cost of equipment and operation.
3. Only coated electrodes can be used with AC. If bared electrode is used, shielding gas must be there to keep the continuous ionized path of arc.	3. It consumes high power (6–10 kWh/kg of metal deposited).
	4. Chances of magnetic arc blow problem are more.

Magnetic Arc Blow Problem in DC Welding: Magnetic arc blow problem occurs when the magnetic flux surrounding the electrode and workpiece becomes unbalanced. In this problem, arc deflects from its path; it occurs generally at the end of workpiece or in the corner welding. Due to flow of electric current in the electrode and workpiece, a magnetic field is established around the workpiece and electrode in the direction perpendicular to the direction of flow of electric current. Due to deflection in path of the arc, heat is not concentrated at the proper location. This problem is circumvented in AC welding as the polarity keeps changing and also the direction of magnetic flux.

Methods to Minimize Magnetic Arc Blow Problem

- Use AC in place of DC if it is possible.
- Reduce the current and the arc length.

- Ground connection of the welding joints.
- For reduction of backward arc blow, ground connection should be placed at the start of the weld.
- For reduction of forward arc blow, ground connection should be placed at the end of the weld.

Types of Electrodes: Two types of electrodes are used in electric arc welding as:

1. Coated electrode.
2. Bared electrode.

Coated electrode consists of coating of flux of various ingredients on its surface. Coating is generally used for arc stability. Normally, sticks of electrodes are available in the sizes of 3.2, 4, 5, 6, 8, 9, and 12 mm of diameter and 350 or 450 mm in length. In the case of coated electrodes, diameter is measured in the bare portion, i.e., without coating.

20.10.1 Functions of Electrode Coatings

- To stabilize the arc.
- To provide gaseous atmosphere for protection from atmospheric gases like O, H, N, etc.
- To remove impurity in the form of slag. Slag also protects the molten pool of metal and reduces cooling rate.
- To reduce spatter of weld metal.
- To act as deoxidizer, i.e., to reduce the melting point of metal oxide.
- To include or add the alloying elements.
- To insulate the electrode.
- To slow down the fast cooling rate of the weld.
- To increase the deposition efficiency.

20.10.2 Ingredients of Electrode Coating

- Ingredients for slag formation: Asbestos, fluorspar, mica, silica, titanium dioxide, iron oxide, calcium carbonate, aluminium oxide, magnesium carbonate, etc.
- Ingredients for arc stabilization: Feldspar, sodium oxide, magnesium oxide, calcium oxide, mica, potassium silicate.
- Ingredients for deoxidizing metal oxide: Cellulose, calcium carbonate, dolomite, starch, dextrin, wood flour, graphite, aluminium, ferromanganese.
- Ingredients for binding: Sodium silicate, potassium silicate, asbestos.
- Ingredients for improvement in strength of weld: TiO, Iron power.
- Ingredients for gas formation: Cellulose, carbohydrate, etc.

20.10.3 Selection of Electrodes

Selection of electrodes is based on the following factors:

- Composition of the base metal.
- Thickness of base metal.
- Depth of penetration required.
- Welding position.
- Use of AC or DC
- Mechanical strength required for the joint.

20.10.4 Specifications for Electrodes

There is not a fixed rule of coding for bared electrodes. But there is a six digit code which is used for specification of the coated electrodes. The six digit code has a prefix and suffix letter. For example, **E426413H**

- The first suffix letter shows the method of manufacturing of electrode. This may be solid extrusion—E or extruded with reinforcement—R.
- The first digit (1–7) shows the types of coating, i.e., the high content of coating.
- The second digit (0–4) shows the position of welding.
- The third digit (0–4) shows the electric current conditions (AC or DC), polarity, and voltage required.
- The fourth and fifth digit shows the yield stress. For example, 41 show its yield strength is 410–510 N/mm.
- The sixth digit shows the percentage elongation with impact strength.
- Suffix letters show the special properties of the electrode.

20.11 TYPES OF ELECTRIC ARC WELDING

Various types of electric arc welding process explained in this chapter are given as follows:

20.11.1 Carbon Arc Welding

Carbon arc welding is a very old method, which is still in use today. In this welding process, two electrodes of graphite or one electrode as graphite and other electrode as workpiece may be used for arc creation. Carbon arc is easily affected by magnetic field, therefore for arc stabilization a separate magnetic field is built in the electrode holder. A separate filler rod may be used to fill the groove. Carbon arc welding is done in as an automatic welding machine in which current, voltage, and feed rate are properly controlled. In this process, joint becomes very hard due to automatic addition of carbon from graphite electrodes. Therefore, this is used for welding of cast iron, steel, copper, bronze, galvanized iron, and aluminium. Only DC and straight polarity is used in this welding process.

Advantages

- Very simple equipment is used which involves low cost.
- Less skilled labour may be employed.
- It can be easily automated with controlling current, voltage, and feeding rate.

Limitations

- The disintegrated electrode can transfer carbon to the workpiece making the weld brittle and unsound.
- The process often results in blow holes and porosity which are caused by the turbulence in weld pool due to the arc blow problem.

20.11.2 Shielded Metal Arc Welding (SMAW)

In this welding process, a special electrode that consists of metal wire which has bonded coating containing flux of desired gradients is used. The heat required for welding is generated by an

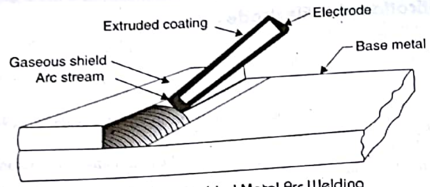


Figure 20.35 Shielded Metal Arc Welding

arc between the flux covered consumable electrode and the workpiece. The process is shown in Figure 20.35. As the coating on the electrode melts and vaporizes, it forms a protective layer of gases that stabilizes the arc and protects. Flux also reacts with impurities of the metal and forms slug which floats on the surface of the molten metal and protects from contamination of atmospheric gases. After solidification the slug is chipped out from the weld.

Advantages

- The equipment required is simple, portable, and less expensive.
- Welds can be used in all positions.

Disadvantages

- The process has to change the electrode frequently due to consumable in nature.
- Low melting metals such as zinc, lead, and tin are not welded by SMAW.

20.11.3 Metal Inert Gas Arc Welding (MIG)/Gas Metal Arc Welding (GMAW)

In MIG welding, a high current density is supplied to the electrode and workpiece. Carbon dioxide gas or any inert gas like helium or argon is supplied to protect the weld pool. The electrode used is consumable and is in the form of wire. Automated feed of the wire is used as shown in Figure 20.36. The welding current is used in the range of 100–300 A. In this welding process, metal transfer rate is very high. Therefore, it is generally used for welding of thick plate. The metals welded by MIG welding are alloy steel, stainless steel, copper, brass, aluminium, magnesium, nickel, lead, silver, tungsten, etc. The current used is direct current and voltage is constant-arc voltage (CAV). Electrode is used as positive pole and work as negative pole.

Advantages

- The rate of weld deposition is very high.
- Quality of the weld is good due to transfer of molten metal under protection of inert gases.
- No frequent change of electrode is required.
- No flux is required; therefore, no slug forms over the weld. This makes the process cleaner.
- It is versatile process and can be used on both light and heavy gauge structural plates.

Limitations

- The cost of equipment and consumable wire is much higher as compared to shielded arc welding.

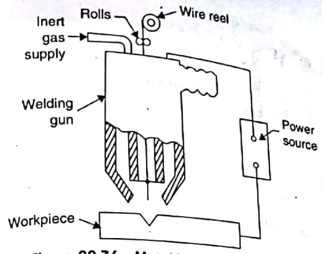


Figure 20.36 Metal Inert Gas Arc Welding

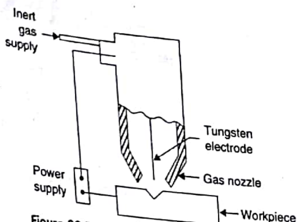


Figure 20.37 Tungsten Inert Gas Arc Welding

20.11.4 Tungsten Inert Gas Arc Welding (TIG)/Gas Tungsten Arc Welding (GTAW)

In this welding process, a non-consumable electrode of tungsten is used as shown in Figure 20.37. Filler material is supplied externally if it is required. The tungsten electrode is connected at negative pole of power supply and work at positive pole of power supply. Inert gas like argon or helium is supplied through a gas nozzle to protect the molten metal pool. The current used in TIG welding is both AC and DC. Gases used as shielding gases are nitrogen for stainless steel and argon for aluminium and magnesium. Reactivity of nitrogen is very high with aluminium and magnesium at an elevated temperature. When an explosion problem does not exist, hydrogen gas may be used.

The TIG welding may be used as fusion welding of aluminium, magnesium, stainless steel, alloy steel, monel, inconel, brass, bronze, tungsten, silver, molybdenum, etc. To avoid the melting of the electrodes, for larger current and better thermionic emission thorium or zirconium is added to the tungsten electrode.

Advantages

- Since no flux is used, no special cleaning or slag removal is required. Most of the fluxes are corrosive in nature which prevents their use in food, drink, and some chemical industries.
- It produces smooth and sound welds with fewer spatters.
- It can be easily automated.
- Welding can be done in all positions.

Limitations

- Cost of inert gases is high.
- Due to slow speed it cannot be used for thick metal plates.

20.11.5 Submerged Arc Welding (SAW)

This welding process is very similar to MIG welding except that a blanket of granular, fusible flux shields the metal arc during the welding operation instead of inert gas. A bare electrode is fed through the welding head into the flux as shown in Figure 20.38. The arc is started either by striking

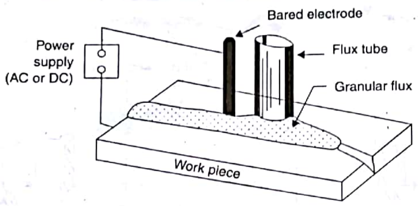


Figure 20.38 Submerged Arc Welding

the electrode on the work beneath the flux or initially by placing some conductive medium like steel wool beneath the electrode. The intense heat melts the flux and produces a pool of molten metal in the joint. The slag floats on the top of molten metal, forming a blanket, which eliminates spatter loss and protects the welded joint from atmospheric contamination or oxidation. This process uses AC or DC, high current 300–4,000 A. It is not suitable for the plate of thickness less than 8 mm and for vertical or overhead welding. The metals which can be welded by this process are carbon steel, alloy steel, stainless steel, nickel, copper, etc. It is not suitable for aluminium and magnesium alloys.

Advantages

- Since the arc is completely hidden under a blanket of flux, there is no flash, spatter, or smoke.
- Very high current can be used. In conventional welding, where the arc is exposed, current above 300 A must be used with care due to high intensity of infrared and ultraviolet light rays. No such problems arise in this process due to arc covered with flux.
- It gives high deposition rate and deep penetration due to high current used in the process.
- High welding speed is possible.
- The quality of the weld is very good because of high cleanliness of the process.

Limitations

- It is largely limited to flat position welding.
- This process is not suitable for high-carbon steels, tool steels, aluminium, magnesium, titanium lead, or zinc because of numerous factors including unavailability of suitable fluxes, reactivity at high temperature, and low sublimation temperature.
- It is normally not suitable for welding of the metal plate of thickness less than 8 mm because of chance of burning.
- Possible contamination of the flux by moisture can lead to porosity in the weld.
- Other limitations include extensive flux handling and removal of large volume of slag.
- There is large heat affected zone.

20.11.6 Electroslag Welding

Electroslag welding is used for welding of thick metal plates. Two plates are kept vertical at a distance of 2–3 cm. The filler wires and flux are kept in this gap. Here, the filler wires are used as the electrodes.

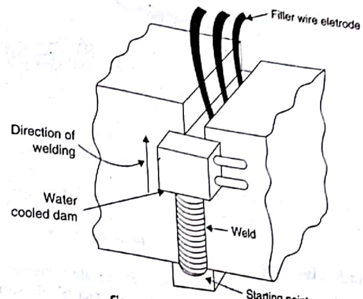


Figure 20.39 Electroslag Welding

The current supplied is AC. Initially an arc is created which melts the flux, and thereafter the molten flux short circuits; arc and heat is generated due to resistance heating of slag, and thus workpiece and electrodes are melted. The molten metal piece and slag are retained by a water cooled dam as shown in Figure 20.39. Since the weld pool formed is large and the welding speed is slow, the cooling rate is quite low. After cooling, heat treatment is required to restore the strength due to large grain size.

Advantages

- This is the most suitable welding process for thick plates ranges from 50 to 900 mm.
- Weld is completed in single pass only. Thus, weld quality is improved.
- It gives high deposition rates.
- Flux consumption is lesser in comparison to submerged arc welding.

Limitations

- Welding is restricted to only vertical positions.
- This is suitable for welding of only thick metal plates.
- Solidification rate is required to be controlled for better quality of weld.
- After welding heat treatment is required.

20.11.7 Atomic Hydrogen Welding

In this welding, arc is created between two non-consumable electrodes (as shown in Figure 20.40) by supplying AC current. When hydrogen gas is passed through the arc, the heat of arc is absorbed by hydrogen molecules and dissociate into hydrogen atoms. When hydrogen atoms reach at cold work surface recombines to form hydrogen molecules with releasing a large amount of heat. Thus, work surface melts by the heat of hydrogen atoms recombination. If filler material is required a filler rod is fed into the arc. The temperature is of the order of 3,000°C.

Advantages

- It gives high heat concentration as hydrogen gas can be passed through narrow slit.
- There is no need to provide additional shielding gas as hydrogen also shields the molten metal pool.
- It is used successfully for many alloys which are difficult to weld by other processes due to need of high heat generation.

Limitations

- It is outdated and rarely used in industry.
- There is hydrogen induced cracking problem.

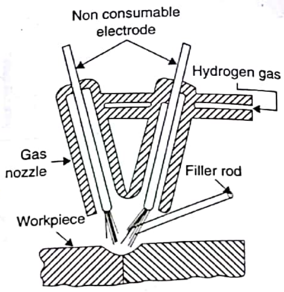


Figure 20.40 Atomic Hydrogen Welding

20.11.8 Plasma Arc Welding

A highly ionized gas is known as plasma. In a plasma arc welding, arc is created between a non-consumable tungsten electrode and workpiece. A water-cooled copper nozzle surrounds tungsten electrode, which is used as cathode as shown in Figure 20.41. A gas (inert gas) like argon is supplied surrounding the tungsten electrode. The gas is forced through the orifice, where it is heated to high temperature through resistance heating and forms plasma. Plasma is ionized hot gas. It conducts electricity. The temperature of plasma gas may be as high as 33,000°C, which is sufficient to melt any workpiece. The copper nozzle is water cooled. A supplementary shielding gas may be used if required. The heat is transferred through the plasma to workpiece.

There are two methods of plasma arc welding—transferred type and non-transferred type. In transferred type, tungsten electrode acts as cathode and workpiece as anode. The arc is transferred from cathode to anode. In non-transferred type, tungsten electrode acts as cathode but copper nozzle acts as anode and arc is not transferred to workpiece. The heat is carried to the workpiece by plasma gas. This method creates high noise during welding (100 dB). But it is a fast method and suitable for a number of metals.

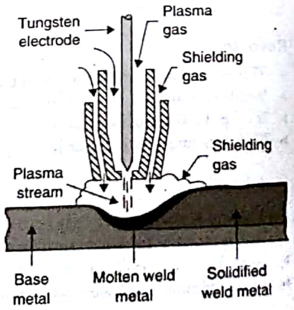


Figure 20.41 Plasma Arc Welding

Advantages

- High heat concentration results in high welding speed.
- It has improved arc stability.
- It minimizes thermal distortion.
- It has lower width-to-depth ratio of the weld.
- The focused heat of plasma results in narrower weld, less heat effected zone, and deeper penetration.

Limitations

- The equipment is very expensive, approximately five times more than TIG equipment.
- Long arc length results in excessive production of ultraviolet and infrared radiations which can harm the skin.

- Gas consumption is high.
- Noise level is very high approximately 100 dB which is more than the permissible limit of 80 dB.
- Nozzle needs frequent replacement.

20.12 RESISTANCE WELDING

In a resistance welding, heat is generated by passing electric current through high resistance. The amount of heat generated depends on the value of current and resistance as shown in the formula.

$$H = I^2 \cdot R \cdot t \text{ Joul}$$

where I = Current in ampere, R = Resistance in ohm, and t = Time in second.

When the electric current is passed through the welding members, they offer maximum resistance at the interface in comparison to other parts of the member. Hence largest heat is generated at the interface. When the proper temperature is reached, the pressure is applied to complete the weld. Because of application of pressure, the process requires lower temperature as compared to oxyfuel gas or arc welding as the metal has to reach the softened state, not in the molten state.

There are six types of resistance welding: *spot welding, seam welding, projection welding, flash welding, percussion welding, Butt welding.*

Advantages

- This is fast process and suitable for mass production.
- No fluxes or filler materials are required.
- Less skilled operators may be employed.
- Practically all conductive materials can be welded by this method.

Limitations

- Few metals like tin, zinc, and lead are difficult to weld by this method.
- Control of pressure and current during the process is critical.
- Equipment cost is high.

20.12.1 Resistance Spot Welding

It is simplest form of resistance welding. In this process, a pair of water-cooled copper electrodes is used. Two overlapping metal plates are held between these electrodes' jaws as shown in Figure 20.42.

The pressure is applied to a very small area, which is known as spot. The resistance at the inner face is very high so applying low voltage and high current melts the inner surface and after solidification make a spot joint. The current used may be 3,000–40,000 A; this depends on melting point of the material to be welded. The voltage applied may be 20–9 0V. The diameter of spot welds (d).

$$d = 1.2t + 4 \text{ mm, for thickness, } t < 3 \text{ mm}$$
$$= 1.5t + 5 \text{ mm, for thickness, } t > 3 \text{ mm}$$

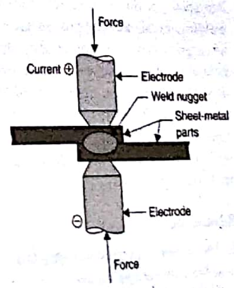


Figure 20.42 Resistance Spot Welding

Spacing of spot weld should be three times of diameter of spot weld. The complete weld cycle is divided into four parts.

1. Squeeze time
2. Weld time
3. Hold time
4. Off time

Squeeze Time: During this time, workpieces are under pressure and the electrodes are in contact with them. The squeeze time is used to bring two pieces together in contact just before current flow. The pressure gradually increases from zero to a certain value during this time interval.

Weld Time: During this period the current is switched on and the temperature at the interface starts rising and attains welding temperature to melt the metal at the interface. The pressure should then be increased considerably just as the proper welding heat is attained. Pressure is the most important variable in resistance welding. Pressure is inversely proportional to resistance. Pressure is high if resistance is low otherwise pressure is low if resistance is high.

Hold Time: During this time weld starts cooling and pressure is further increased.

Off Time: During this period pressure is released and workpiece is removed for other spot.

Advantages

- Similar and dissimilar metals can be welded very easily.
- The time involved in spot welding is very less.
- Sheets of different thickness can be joined easily.
- It can be used for large production run with the help of multiple spot welding machines.

Limitations

- Silver and copper are especially difficult to weld because of their high thermal conductivity.
- Spot welding is limited to overlap welding only.

20.12.2 Resistance Seam Welding

Resistance seam welding is series of continuous spot welding. In this welding process, the electrodes are used as copper rollers in the place of cylindrical copper jaws in spot welding as shown in Figure 20.43. The diameter of the rollers may be from 40 to 350 mm and welding current from 2,000 to 5,000 A. Welding speed ranges from 0.5 to 3.5 m/min. The pressure is applied by the roller on workpiece. Rest of the process is same as in the spot welding.

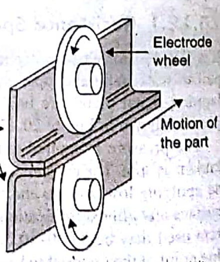


Figure 20.43 Resistance Seam Welding

Advantages

- The power requirement is very low due to use of low voltage power requirement.
- The heat affected zone is very small, hence thermal distortion is negligible.
- Similar and dissimilar metals can be welded very easily.
- Welding speed is high which makes it suitable for large-scale production.

Limitations

- This method is suitable for overlap welding only.

20.12.3 Resistance Projection Welding

Projection welding is a variation of spot welding. Small projections are embossed at the plate where welds are desired as shown in Figure 20.44. The workpieces are then placed between large-area electrodes and current is switched on. High temperatures are generated at the projections. During the process, the projections collapse, owing to heat and pressure, and workpieces are brought in close contact. The shape of projection may be circular or oval depending on the design.

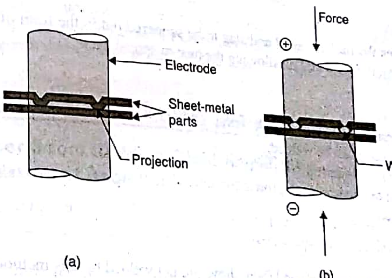


Figure 20.44 Resistance Projection Welding

Advantages

- This is faster process as the number of welds is made simultaneously.
- Small amount of current is required due to large density of current at the projection only.
- The pressure required on the electrode is low.
- Thermal shrinkage and distortion are less.

Limitations

- Correct application of pressure and current are very important.

20.12.4 Flash Welding

Flash welding is used to make an end-to-end joint of two thick metal pieces as shown in Figure 20.45. In this method, current is switched on and then the ends to be welded are brought closer slowly to make contact. Thus, heat is localized at the ends and reaches at the welding temperature. The ends, after they have contact with each other are then forced against each other by applying mechanical

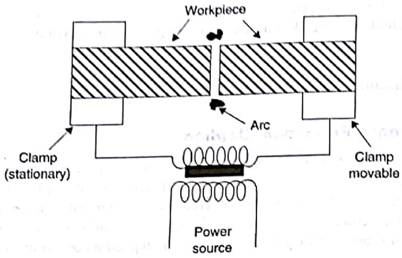


Figure 20.45 Flash Welding

pressure which forces the molten metal and slag to be squeezed out in the form of sparks enabling the pure metal to form the joint and disallowing the heat to spread back.

Advantages

- It consumes less current.
- Large area (end to end) can be welded.
- Edge preparation is not required.
- Excellent weld can be made at high production rate.
- The joint is stronger.

Disadvantages

- Metals like lead, zinc, tin, copper, and their alloys are not welded by this method.
- The equipment is expensive.

20.12.5 Percussion Welding

In percussion welding, the welding heat is obtained by an arc produced by a rapid discharge of stored electrical energy in capacitor. The parts to be joined are placed in position similar to flash welding. The intense heat of arc melts the parts. The heated parts are then pressed together to complete the weld. This process is very fast on account of rapid discharge of power to the arc. The arc durations are only 1–10 ms, after which it is extinguished by the percussion blow of the two parts coming together. The use of this process is limited to very thin wires of diameters from 0.05 to 0.38 mm. It can also be used for joining wires of dissimilar metals such as copper to nichrome and copper to stainless steel.

Advantages

- There is no thermal distortion due to small heat affected zone.
- The metal of different thermal conductivity can be welded easily as heat is concentrated at the two surfaces only.

- No upsetting occurs at the joint.
- Heat treated part may be welded without being subjected to annealing.

Disadvantages

- Only small areas can be welded.
- Part should have regular section.

20.12.6 Resistance Butt Welding

In a resistance butt welding process, the workpieces which are to be joined are placed end to end between two clamps and required pressure is applied (Figure 20.46). The high resistance at the joint generates heat on supplying high current and causes fusion to take place at the interface. The pressure applied ranges from 15 to 55 MP. The ends of two pieces are slightly upset and hence term upset welding. In this process, cross-section areas of workpieces used are same. The current density used is 2,000–5,000 A/in.^{2}.

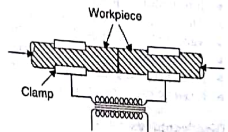


Figure 20.46 Resistance Butt Welding

20.13 UNCONVENTIONAL WELDING METHODS

20.13.1 Laser Beam Welding (Light Amplification by Stimulated Emission of Radiation)

Laser is a highly coherent beam of electromagnetic radiation with wavelength varying from 0.1 to 70 mm. It may be used for machining or welding purposes depending on the wavelength of radiation used.

Figure 20.47 shows schematic diagram of laser beam welding. A coiled xenon flash tube is placed around the ruby rod and the internal surface of the container is made highly reflective. A very high voltage is applied from charged capacitor to triggering electrode for flashing. The reflected rays from the surface of container on the ruby rod help in pumping operation. The emitted laser beam is

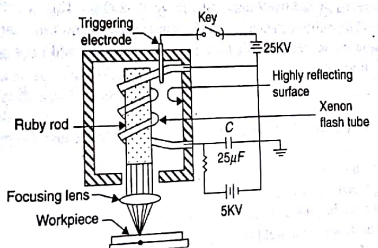


Figure 20.47 Laser Beam Welding

focused on the work surface with the help of a lens system which results in melting of the metal. The average duration of the laser beam is 0.002 s. During this short duration, two welding methods may be adopted—the workpiece is rotated or moved fast enough so that the entire joint is welded with a single burst of light or method where many pulses are used to form the weld joint. With the pulsed technique, the weld is comprised of round solidified weld puddles. An advantage of laser pulse method is the multiple laser pulses approximately 10 times per second because of that the workpiece does not even get hot except at one point, which is one of the metallurgical advantages of laser welding.

Advantages

- It provides deep penetration without affecting the base metal.
- The process is fast due to instantaneous increase in temperature of workpiece.
- Vacuum is not required as in electron beam welding.
- Welding can be done in inaccessible locations.
- It has very small thermal distortion.
- It can be easily automated.

Disadvantages

- Better edge preparation and close dimensional tolerance are required.
- Equipment cost is very high.
- It can be used only for thin sheet.
- Laser rays are dangerous for skin as well as for eyes.

20.13.2 Electron Beam Welding

In the welding technique, a stream of high-speed electrons strikes on work surface where the kinetic energy of electrons transferred to the work material produces intense heat. The metal can melt or vaporize depending on the intensity of heat generated. The same process is also used for machining purposes.

The electron beam is produced in a high vacuum environment by an electron gun, usually consisting of a tungsten or tantalum cathode, a grid or forming electrode and anode as shown in Figure 20.48. A stream of electrons coming out from cathode are accelerated to high velocity and shaped into a beam by the potential difference between cathode and anode. The beam is collimated and focused by passing through the field of an electromagnetic lens. The focused area is 0.25–1 mm diameter and power density of 10 kW/mm and voltage 20–200 kV. This is sufficient to melt and vaporize any metal. The entire operation is carried out in a vacuum to prevent tungsten filament from oxidation, to prevent the scattering of electrons from air molecules, and to prevent the weld from atmospheric contaminations.

Advantages

- Depth-to-width ratio is very high (up to 25:1). This is possible because the process confines the heat to a narrow area.
- No shielding gas, flux, or filler material is required.
- Higher welding speed is possible.
- Dissimilar metals can be joined effectively as similar metals.
- Distortion and shrinkage in the weld area is minimal.
- Heat-sensitive materials can be welded without damage to the base metal.

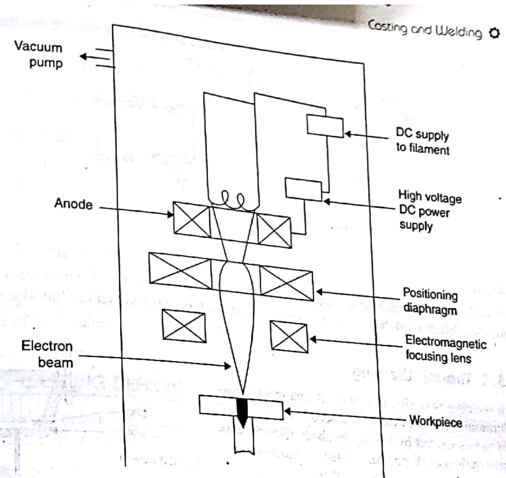


Figure 20.48 Electron Beam Welding

Disadvantages

- The equipment is costly.
- Wide gap cannot be filled economically by this process.
- Vacuum is essential for the entire process.
- Joint preparation is essential because of the deep and narrow weld profile.

20.13.3 Ultrasonic Welding

This method of welding is suitable for thin strips and foils. The core of a magnetostriction ultrasonic generator is coupled to the work through a bar having a suitably shaped tip. The tip applies a transverse pressure between the workpieces and simultaneous application of ultrasonic vibration to the tip results in a spot weld (Figure 20.49). The welding takes place due to a combination of fracturing of the brittle oxide layers and softening of the surfaces because of localized heating by high velocity rubbing.

Advantages

- Similar and dissimilar metals can be joined easily. It is possible to join metals to non-metals such as aluminium to ceramics or glass.
- It is advantageous in welding of heat-sensitive electronic components.
- It is very fast and consumes very little time for making a spot weld.
- There is no contamination of the weld zone or surrounding area.

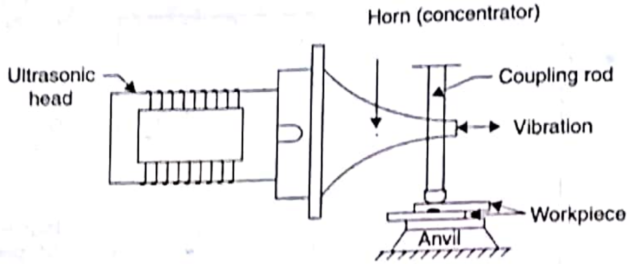


Figure 20.49 Ultrasonic Welding

Limitations

- Ultrasonic welding is limited to lap join of thin sheet; maximum thickness is limited to 3 mm.
- Equipment life is short due to fatigue encountered by the horn, the front part of transducer.

20.13.4 Thermit Welding

Thermit welding is similar to casting. A mixture of powered aluminium and iron oxide is placed inside a vessel. The mixture is ignited by heating to about 1,550°C with the help of barium oxide powder. A chemical reaction takes place in a vessel as shown in Figure 20.50.

Due to the chemical action, a bright white heat is produced and reaction leads to molten iron. The molten iron is tapped from the vessel and made to run in the cavity of the joint. The temperature attained is about 3,000°C.

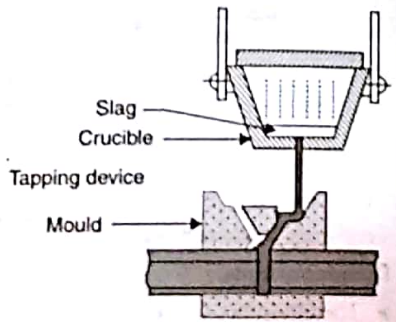


Figure 20.50 Thermit Welding

Advantages

- It produces high quality welds because the metal solidifies from the inside towards the outside, and all air is executed from around the moulds.
- There is no limit to the size of welds that can be made by thermit welding.

Disadvantages

- It is an extremely old process and has been replaced to a large degree by alternative method such as electroslag welding.

20.14 WELDING ALLIED PROCESSES

20.14.1 Soldering

Soldering is a process of joining two metals by applying low melting point metal or alloy in the gap between the joining parts. The metal or alloy used for filling or joining is known as solder. The melting point of solder is less than 450°C. Solders are divided into two categories.

1. Soft solder is alloy of tin and lead.
2. Hard solder is alloy of copper and zinc.

Flux Used: Chlorides fluxes (zinc chloride, ammonium chloride, zinc ammonium chloride).

This joining process forms a weak joint.

20.14.2 Brazing

Brazing is a hard soldering process, but in this process, metal pieces are heated which are to be joined in this place of the bit as in soldering. In a brazing, spelter is used. It is a mixture of copper, zinc, and tin. It is stronger in comparison to soldering joint.

20.14.3 Braze Welding

In braze welding, the molten filler metal is not distributed at joint by capillary action as it happens in brazing or soldering but it is deposited at the point where the weld is required to be made as in the case of gas welding.

20.15 WELDING DEFECTS

A number of defects can occur during the welding processes, some of them are shown in Figure 20.51. There are many other defects which are discussed in the following paragraphs.

Cracks: Cracks occur in the welded joint due to improper welding and solidification of different metals. Cracks may be of the following types.

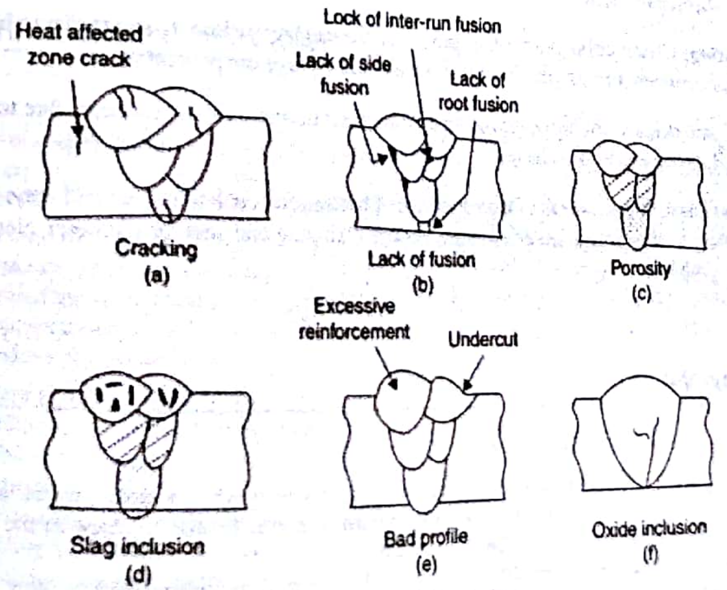


Figure 20.51 Welding Defects

19

Machine Tools

Chapter Objectives

In this chapter, you will learn about:

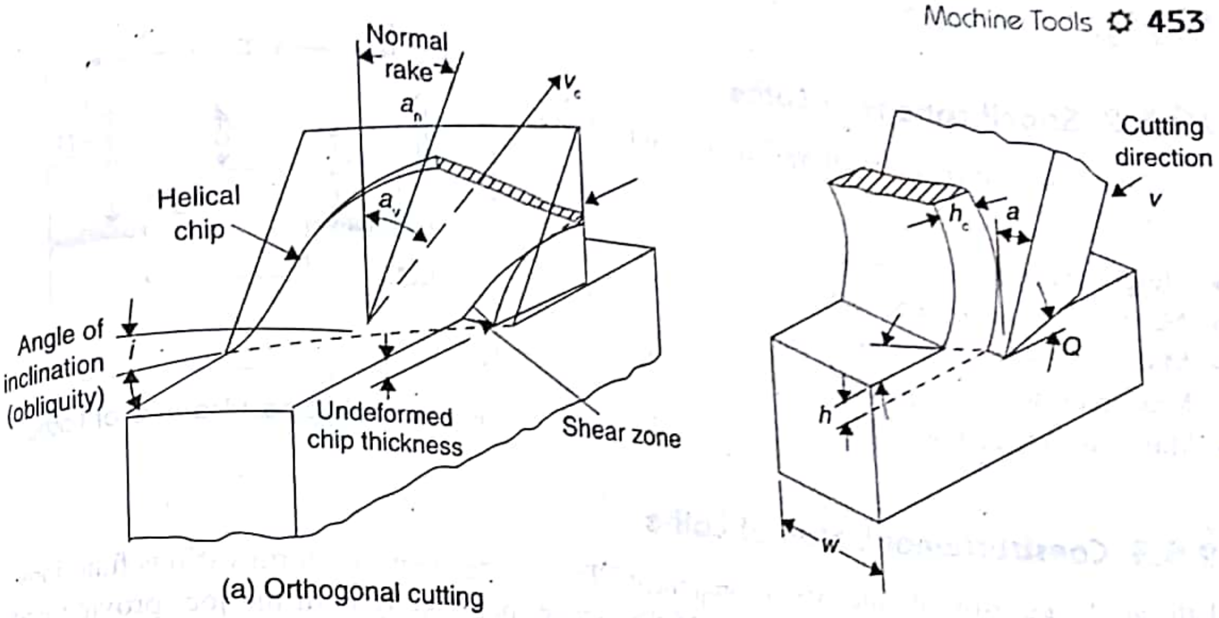
- Mechanism of metal cutting
- Machine tools and cutting tools
- Lathe machine, its construction, driving mechanism, and operations
- Shaper, its construction, driving mechanism, and operations
- Slotter and its applications
- Planer, its construction, driving mechanism, and operations
- Drilling machine, its construction, driving mechanism, and operations
- Milling machine, its construction, operations, and milling cutters

19.1 INTRODUCTION

Machine tools that give a shape to parts/products by removing metal chips from a workpiece include lathes, shapers and planers, drilling machines, boring machines, milling machines, grinders, etc. Before the Industrial Revolution of the 18th century, hand tools were used to cut and shape materials for the production of goods such as cooking utensils, wagons, ships, furniture, and other products. After the advent of the steam engine and material; goods were produced by power-driven machines that could only be manufactured by machine tools. Jigs and fixtures (for holding the work and guiding the tool) were the indispensable innovations that made interchangeable parts realities in the 19th century.

19.2 MECHANISM OF METAL CUTTING

The removal of extra material from a metal surface by shearing or cutting action is known as machining or metal cutting. The cutting takes place along a plane, which is known as shear plane. There is a cutting zone; if it is examined carefully we find that the severe plastic deformation occurs in this zone due to compressive force applied by the sharp-edged cutting tool. The extra material due to this deformation flows over the tool surface, known as chip, and this shearing zone is known as primary shear zone.



(a) Orthogonal cutting

(b) Oblique cutting

Figure 19.3 Schematic View of Orthogonal and Oblique Cutting

19.5 LATHE

Lathe is an oldest machine tool. The entire machine tools are developed from the lathe, therefore it is also known as mother of machine tools. A number of cutting operations can be performed on lathe with or without some attachments. On lathe, a rotational motion is provided to the job and translational motion is provided to the cutting tool. Lathe machines can be classified on the basis of speed and purposes of applications.

19.5.1 Classification of Lathes

According to the construction and design lathe can be classified as follows:

Bench Lathe: It is small in size and mounted on a separate table. It has all the attachments, which a larger lathe has. It is used to perform a precise work.

Speed Lathe: This may be bench type or legs supported lathe. It has no gear box, carriage, and lead screw. Therefore, tool is actuated and fed by hand. This lathe is used for wood turning, polishing, and spinning purposes.

Engine Lathe: This is most widely used lathe. In early days, during the development phase of the lathe, this lathe was driven by steam engine, therefore named as engine lathe. Nowadays all the engine lathes have separate engines or electric motors. Various speeds are achieved using cone pulley and gears.

Tool Room Lathe: This is very similar to engine lathe but equipped with some extra attachments for more accurate and precise works. The usual attachments are taper turning attachment, follower rest, collets, chucks, etc.

Capstan and Turret Lathes: This is semi-automatic type lathe and a wide range of operations can be performed on them. It can hold a large number of cutting tools compared to engine lathe.

19.5.2 Specifications of Lathe

Lathe machine can be specified by following dimensions (Figure 19.4):

- Height of centre over bed (A).
- Maximum swing over bed (B).
- Maximum swing over carriage (C).
- Maximum swing in gap (D).
- Maximum length of work (E).

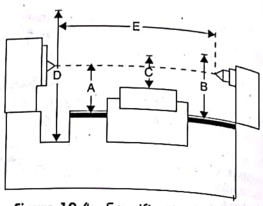


Figure 19.4 Specifications of Lathe

19.5.3 Constructional Detail of Lathe

A lathe machine consists of a number of components. These components perform various functions, for example, facilitate variation in speed, hold the cutting tool, rigidly hold the job, provide end support to the job, automatic movement of tool, etc. A lathe with nomenclature of various parts is shown in Figure 19.5.

Bed: All the fixed and moving parts of lathe are mounted on bed. It is made of cast iron in single piece, it may be in two or three pieces for large size lathe which are bolted together. It has v-ways for collection of chips produced during machining.

Head Stock: Head stock is housing of cone pulleys, back gear, main spindle, live centre, and feed reverse livers. It provides driving mechanism to the job and tool post, carriage, apron, etc.

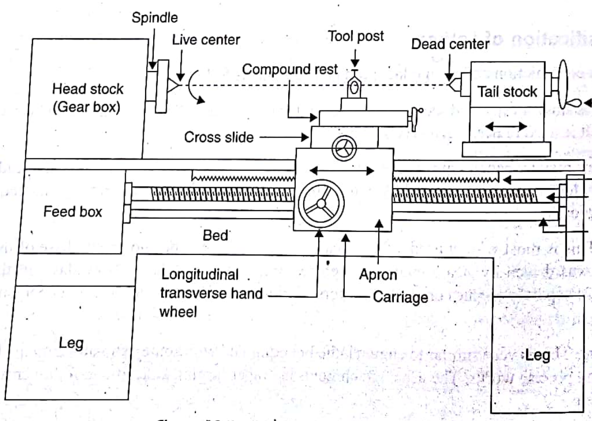


Figure 19.5 A Lathe with Nomenclature of Its Parts

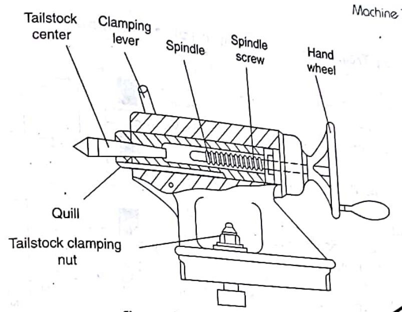


Figure 19.6 Tailstock of a Lathe

Tail Stock: The function of tail stock is to support the job at the end. It slides over the bed. It may have dead centre or live centre for point support to the job as per requirement. A tailstock is shown in Figure 19.6.

For tapping, drilling, or boring, a tape or drill/boring tool may be used in place of dead centre. The dead centre moves forward or backward with sleeve by rotating the hand wheel manually.

Carriage and Tool Post: It provides support to the tool post, cross slide, compound rest, apron, etc. The function of tool post is to hold cutting tool rigidly; tool post moves in both axial and transverse directions on compound rest. The function of swivel plate is to give angular direction to the tool post whereas the function of cross slide is to give the linear motion to the tool by rotating the attached hand wheel. Apron is a hanging part in front of the carriage. It is housing of gear trains and clutches. It gives automatic forward and reverse motion to the tool.

Legs: The legs provide rigid support to the entire machine tool. Both the legs are firmly secured to the floor by means of foundation bolts in order to prevent vibrations in the machine.

Chucks: The function of the chuck is to hold the job. There may be three- or four-jaw chuck as shown in Figure 19.7. In three-jaw chuck, all the jaws move inwards or outwards simultaneously and there is no problem of centring hence it is also known as universal chuck. Whereas in four-jaw chuck each jaw moves independently. It may accommodate irregular shape of job but there is problem of centring which is to be done manually. A magnetic chuck is also used to hold the job, which works on the principle of electromagnetism.

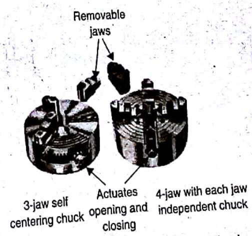


Figure 19.7 Three- and Four-jaw Chucks

19.5.4 Power Transmission System in Lathe Machine

Head stock spindle drive system may include stepped or cone pulley drive or all geared head drive. In stepped pulley, the number of speed equals to number of steps in pulley. In all geared head drive, total nine various speed can be obtained.

Stepped Pulley (Cone Pulley) Drive: V-belt is used to transmit the power from driver shaft to spindle shaft. In four-stepped pulley drive, four different speeds of the head stock can be attained. Spindle speeds are varied in arithmetic progression (Figure 19.8).

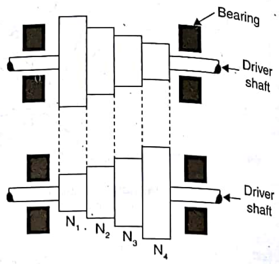


Figure 19.8 Stepped Cone Pulley Drive

Let driver shaft rotates at the speed of N rotation per minute (rpm) and the stepped diameters of the pulley are D_1, D_2, D_3, and D_4. Driven shaft has pulley of same steps diameters but in reverse order as shown in Figure 19.8. We know the speed is inversely proportional to the diameter, therefore,

$$\frac{N_1}{N} = \frac{D_4}{D_1}; \quad \frac{N_2}{N} = \frac{D_3}{D_2}; \quad \frac{N_3}{N} = \frac{D_2}{D_3}; \quad \frac{N_4}{N} = \frac{D_1}{D_4}$$

where N is speed of driver shaft and N_1, N_2, N_3, N_4 are speeds of spindle shaft. Here $D_1 < D_2 < D_3 < D_4$.

All Geared Head Drive: This drive comprises of nine gears on three shafts. By operating two levers attached with two cluster gears on pulley shaft and head stock main spindle, respectively, nine speeds can be obtained. Three gears 2–4–6 are fixed on intermediate shaft. Spur gear, 10 is fixed on head stock spindle to transmit power to the feed shaft and lead screw. The constructional detail of all geared head drive is shown in Figure 19.9.

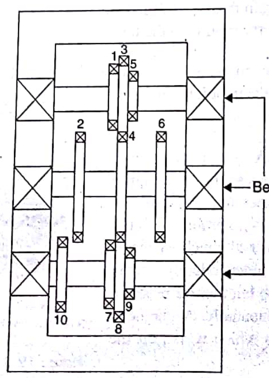


Figure 19.9 A Constructional Detail of All Geared Head Drive

The gear combinations for nine different speeds are given below:

$$\frac{T_1}{T_2}\times\frac{T_2}{T_7}; \quad \frac{T_1}{T_2}\times\frac{T_4}{T_8}; \quad \frac{T_1}{T_2}\times\frac{T_6}{T_9}$$

$$\frac{T_3}{T_4}\times\frac{T_2}{T_7}; \quad \frac{T_3}{T_4}\times\frac{T_4}{T_8}; \quad \frac{T_3}{T_4}\times\frac{T_6}{T_9}$$

$$\frac{T_5}{T_6}\times\frac{T_2}{T_7}; \quad \frac{T_5}{T_6}\times\frac{T_4}{T_8}; \quad \frac{T_5}{T_6}\times\frac{T_6}{T_9}$$

where T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, and T_9 are number of teeth on gear 1, 2, 3, 4, 5, 6, 7, 8 and 9, respectively.

19.5.5 Cutting Tools Used in Lathe

A number of cutting operations are performed on a lathe machine. Therefore, various cutting tools are used in lathe such as left-hand and right-hand turning tools, facing tools, threading tools, parting-off tool, etc., as shown in Figure 19.10.

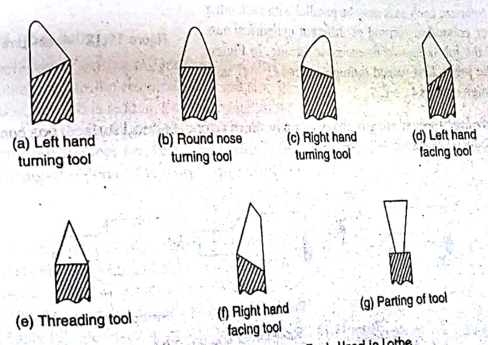


Figure 19.10 Various Cutting Tools Used in Lathe

19.5.6 Types of Operations on Lathe Machine

Following are the various types of operations performed on the lathe machines.

Turning

Turning is a metal removal process in which job is given rotational motion while the cutting tool is given linear (feed and depth of cut) motion. Different types of turning operations are mentioned as follows:

Straight Turning: It is the operation of producing a cylindrical surface of a job by removing excess material. In this operation, the job rotates and tool is fed longitudinally by giving the desired depth of cut (Figure 19.11).

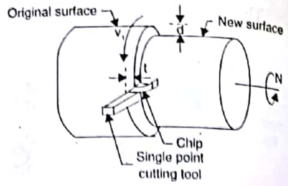


Figure 19.11 Straight Turning on Lathe

Face Turning or Facing: Face turning is also known as facing operation. It is the operation of making the ends of a job to produce a square surface with axis of operation or to make a desired length of the job. In this operation job rotates and the tool advances in perpendicular direction to the axis of the job rotation (Figure 19.12).

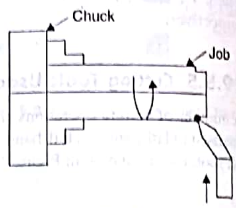


Figure 19.12 Face Turning on Lathe

Shoulder Turning: If a job is turned with different diameters, the steps for one diameter to the other so formed, the surface is known as shoulder turning. There are several types of shoulder turning such as square, radius, bevelled, etc., as shown in Figure 19.13. It is also known as step turning.

Eccentric Turning: When a job having more than one axis of rotation, each axis may be parallel with each other but never coincides; turning of different cylindrical surfaces of the job is known as eccentric turning. In Figure 19.14, the job is first turned through centres $C_1 - C_1$ and then through centres $C_2 - C_2$.

Taper Turning: Taper turning is an operation in which taper cylindrical surface, i.e., cone type surface is produced as shown in Figure 19.15.

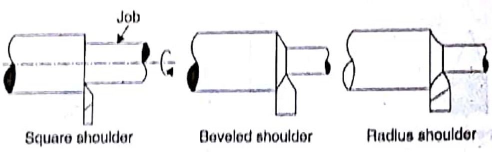


Figure 19.13 Shoulder Turning on Lathe

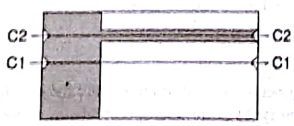


Figure 19.14 Eccentric Turning on Lathe

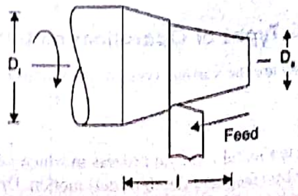


Figure 19.15 Taper Turning on Lathe

Taper on a cylindrical surface of a job can be produced by the following methods:

- **Taper turning by swivelling compound rest:** Job rotates on lathe axis and tool moves on angular path. It can be applied from any angle 0° – 90° for short length of taper up to 150 mm (approximate) $\tan\alpha = \frac{D_1 - D_2}{2l}$. It is used for shorter length and steeper angle. Here, D_1 and D_2 are larger and shorter diameters, l is length of the job, and α is angle of taper.
- **Taper turning by off-setting the tailstock:** Job rotates at an angle to the lathe axis and the tool travels longitudinally to the lathe axis. Any angle 0° – 8°, long job of smaller diameter can be turned by this method. It is also used for internal taper turning.
- **Taper turning attachment:** Job rotates on lathe axis and tool moves in guided angular path. Long jobs of steeper angle of taper (0° – 12°) can be done by this attachment. Guide rail is set as per angle of taper. It is applied for mass production.
- **Taper tuning by a form tool:** Job rotates on lathe axis and tool moves crosswise direction, perpendicular to the lathe axis. Very small length of taper and any angle 0° – 90°. Tool itself designed as per requirements. It is used for mass production for Chamfering on bolts, nuts, bushes, etc.
- **Taper turning by combination fed:** Job rotates on lathe axis and tool travels on resultant path, for any length and any angle. Taper angle is to be determined by trial and error method. It is applied by hand feeds by combined feeding of tool (axial and perpendicular) for taper turning.

Parting-off (Grooving)

It is the operation of cutting-off/grooving a bar after it has been machined to the required shape and size. In this operation, the job is held on a chuck, rotates to the turning speed and the parting-off tool is fed into the job very slowly until the tool reaches to the centre of the job. The parting-off operation is shown in Figure 19.16.

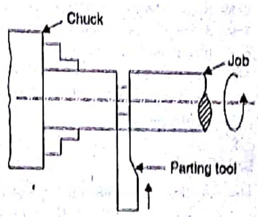


Figure 19.16 Parting-off Operation on Lathe

Knurling

Knurling is the process of embossing, producing a roughened surface on a smooth surface of a cylindrical job to provide effective gripping, for example, thimble and ratchet of micrometer and plug gauge handle. Knurling tools (single, two, or three sets of rollers) are held rigidly on tool post, pressed against the rotating (one third speed of the turning) surface of a job, leaving exact facsimile of the tool on the surface of the job as shown in Figure 19.17.

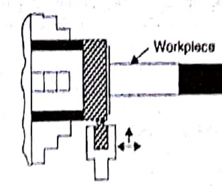


Figure 19.17 Knurling Operation on Lathe

Thread Cutting

For thread cutting on the lathe, there is definite relationship between the speeds of the job and tool. The relationship is obtained by gear ratio selection which depends on the pitch of the job, pitch of the lead screw, number of start of thread on the job. Every machine is supplied with a spur gear box (a set of 23 gears) having teeth from 20 to 120 with an interval of 5 and a special gear or transfer gear is of 127 teeth for cutting metric thread. Two 20 teeth spurs are available. Lead screw has single start thread. The simple process of thread cutting on lathe is shown in Figure 19.18.

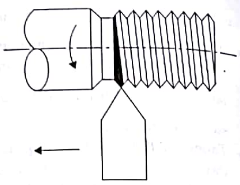


Figure 19.18 Thread Cutting on Lathe

Steps for Thread Cutting on Lathe

1. Hold the job on machine and turn up to major diameter of the thread.
2. Choose suitable thread cutting tool.
3. Select slower speed of the lathe spindle.
4. Calculate the change gear ratio based on the following formula:

$$\text{Change gear ratio} = \frac{\text{pitch of the job} \times \text{No. of start}}{\text{Pitch of the lead screw}}$$

5. Fix the calculated change gear ratio to the head stock spindle, intermediate shaft, and lead screw shaft.
6. Choose suitable depth of cut. Three or four cuts are necessary to complete the thread.
7. Arrange job and tool proper position and give desired depth of cut.
8. Engage half nut with respect to chasing dial according to odd/even threads.
9. Allow the movement of the tool up to the portions of the job necessary for thread cutting then lifting the tool from the job.
10. Disengage the half nut, move the carriage to the right side up to the position from where second cut will start. Allowing the second depth of cut again engages the half nut with respect to chasing dial.

Drilling

The operation of producing a circular hole by removing metal by rotating the cutting edges of a drill is known as drilling. But on lathe drill is static and only feed motion is given through the movement of tail stock and rotating motion is given to the job. Metal is removed by shearing and extrusion. Drilled hole will be slightly oversized than the drill used due to the non-alignment of the drill and vibration of the spindle. For producing accurate hole, the drill bit should be chosen slightly undersize and subsequent reaming or boring operation is essential after drilling. Drilling on lathe is very easy. Drill bit is held in tail stock in place of dead centre and moved in forward direction applying pressure at the end of the rotating job. Drill moves up to the length of the hole required as shown in Figure 19.19.

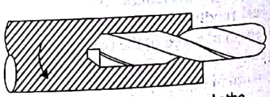


Figure 19.19 Drilling on Lathe

Tapping

Tapping is an operation for producing internal thread. A hole of minor diameter is produced in the job by holding the drill tool in tail stock and applying pressure on the rotating job in chuck. After drilling the hole, tap is hold in tail stock and inserted in drilled hole of the rotating job as shown in Figure 19.20.

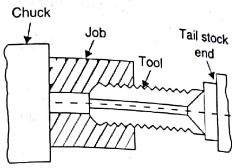


Figure 19.20 Tapping on Lathe

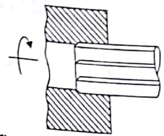


Figure 19.21 Reaming on Lathe

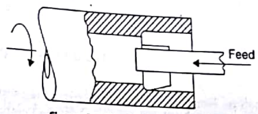


Figure 19.22 Boring on Lathe

Reaming

The operation of finishing and sizing a previous drilled hole using a multi-edges straight cutting tool named as reamer is known as reaming. Very small amount of material (0.4 mm) removal is possible by this operation. Reaming operation on lathe is very similar to drilling on lathe as shown in Figure 19.21.

Boring

The operation of enlarging and finishing a previous drilled hole throughout its length by means of an adjustable single edge cutting tool (named as boring tool) is known as boring. Boring on lathe is also very similar to drilling but this process is used to enlarge the drilled hole as shown in Figure 19.22.

Spinning

Spinning is a process to produce a circular homogeneous pot or household utensil. In this operation, the sheet metal job is held between a former attached with headstock spindle and the tail stock centre and rotates at high speed with the former. The long round nose forming tool fixed rigidly on special tool post presses the job on the periphery of the former as shown in Figure 19.23. Thus, the job is deformed exactly in the shape of former and the operation is known as spinning. It is chipless machining process.

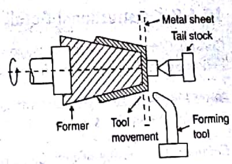


Figure 19.23 Spinning on Lathe

19.6 SHAPER, SLOTTER, AND PLANER

Shaper and planer are very old machine tools. They are used to produce a plane surface, inclined surface, and slots. But due to consumption of excess time, they are replaced by milling machines in large production. In shaper, cutting tool is provided reciprocation motion and job is provided only