WORKSHOP TRAINING NOTES

COURSE: WS1010

Training modules: Power Tools, Turning, Milling, Foundry & Smithy, FRP & Plastics and Welding

CENTRAL WORKSHOP
INDIAN INSTITUTE OF TECHNOLOGY MADRAS
CHENNAI – 600036
GENERAL SAFETY PRECAUTIONS TO BE TAKEN DURING WORKSHOP TRAINING

1. Always listen carefully to the instructor and follow instructions.
2. Before you use machines and equipments or attempt practical work in the workshop, you must understand basic safety rules.
3. Know where the emergency stop buttons are positioned in the machines and trainers. If you see an accident at the other areas of the workshop, you use the emergency stop button to turn off all electrical power connections to the machines.
4. Never touch the running part of machines with your fingers.
5. Do not remove metal chips with your fingers, use brush.
6. Ensure that the work piece and tool are mounted securely before machining.
7. Measure the dimensions only when the machine is not in operation.
8. Keep hands, brushes and cleaning shovels away from the revolving parts of the machine.
9. Keep floor around the machine free of oil and grease.
10. Make sure the power is off before changing or removing job and tool.
11. Always stay at the machine when it is in operation.
12. Report any damage to machines/equipment as this could cause an accident.
13. Use hand gloves, shield during welding practice.
FOR WOOD WORKING AND METAL WORKING

MODULE: POWER TOOLS

WORKSHOP TRAINING NOTES
CHAPTER 15

Wood Working

15.1 INTRODUCTION

Wood is a versatile raw material and has been used by man from time immemorial. Glimpses of various virtues of our timbers are available in our ancient literature and religious text especially the Rig veda, the Upanishads and the Puranas, but the direct evidences of uses of wood were not available till recently. Excavations carried out by the archaeologists at Harappa and Mohenjodaro of the Indus Valley Civilization, Hastinapura—a copper age civilization, Pataliputra, an early historical period and other sites of ancient India have thrown light on various kinds of wood used by the people of those civilizations. The wood used was mostly Pine, Deodar, Rosewood, Sissoo, Teak, Sal and Ber etc.

With the economic development of the country, the rate of anticipated industrial growth, literacy and urbanization, the demand for wood has also increased. India has a rich source of more than 1600 timber species having commercial viability. Currently, the source of wood for wood industry and other purposes is met through the plantation grown timbers and also those which are dead and fallen in the natural forests. The country is facing an acute shortage of raw material for wood based industries due to a shrinking forest cover. The current annual production of industrial wood and firewood in the country is about 12 million cu.m and 40 million cu.m against a demand of 27.58 and 235 million cu.m respectively. When we talk about any work related to wood, we come across words like timber, carpentry and joinery.

15.2 CLASSIFICATION OF TREES

Trees are classified into two categories depending upon the mode of growth. These categories are:

15.2.1. Endogenous or Inward Growing Trees

The endogenous trees grow inwards in a longitudinal fibrous mass such as banana, cane, palm and bamboo trees. The stems of these trees are light or tough but they are too flexible to be used as an engineering material with the exception of bamboo.

15.2.2. Exogenous or Outward Growing Trees

These trees grow outwards from the centre adding one concentric layer of fresh wood every year. These concentric layers are called annular rings. The age of a tree is indicated in years by the number of annular rings as one annular ring is added every year. The timber obtained from exogenous trees is extensively used in engineering works.

The exogenous trees are further classified into two categories:

(a) Conifers or evergreen trees
(b) Deciduous or broad leaf trees.

(a) Conifers or evergreen trees yield soft wood. The leaves of these trees are pointed like needles and the trees are quite symmetrical, with branches radiating from a central trunk. Trees like deodar, pine, chir, kail, fir and larch belong to this category.

(b) Deciduous or broad leaf trees yield hard wood. The leaves of these trees have a wide surface to catch more sunlight. Teak, sal, shisham, oak, mahogany, ebony, mango, neem, babool, etc., are the trees belonging to this category.

15.2.3 Growth of Timber

During the spring season, the roots of the tree suck salts from the soil, which are transmitted, through the trunk, to the branches and leaves. This solution of salts loses some of the moisture due to evaporation and absorbs carbon dioxide from
the air. Due to exposure to sun rays, this solution becomes viscous and is known as sap. In autumn, this sap descends below the bark and leaves a thick layer forming a layer of wood, called cambium layer, which gains strength with the passage of time forming an annular ring.

15.3 STRUCTURE OF TREES

A cross section of the trunk of an exogenous tree is shown in Fig. 15.1. The important parts are:

![Cross section of an Exogenous Tree](image)

1. **Medulla**: It is the first formed portion of the stem of a tree having only cellular tissues. It contains a lot of fluid which nourishes the plant. The annular rings are added around this every year. When the plant becomes old, the medulla dries up and decays.

2. **Annular Rings**: These are the concentric rings of woody fiber around the pith. They are formed every year. The number of annular rings shows the age of the tree.

3. **Heart Wood**: Portion of wood around the pith constitutes the heart wood. This wood is darker in colour, compact, stronger and harder than the remaining wood in the tree.

4. **Sap Wood**: The outer annular rings of the tree constitute sap wood. It is weaker, softer and lighter in colour as compared to heart wood. This wood is unsuitable for engineering purposes as it is prone to decay.

5. **Cambium Layer**: The latest addition to the tree i.e. the annular ring, just under the bark which is in the process of formation, is called the cambium layer. In due course, the cambium layer changes to sap wood and if this layer is exposed by removing the bark, the cells cease to be active and result in the death of the tree.

6. **Medullary Rays**: These are thin horizontal veins radiating from the pith towards the bark. These rays carry sap from the outside to the inner parts of the tree to nourish it. They keep the annular rings tightly gripped together to provide a solid structure to the tree.

7. **Bark or Cortex**: It is the outermost protective covering of cells and woody fibers on a tree. In due course of time, old layers of bark split and scale off.

15.4 TYPES OF WOOD

There are two types of wood: Hard wood and Soft wood.

15.4.1 Hard Wood

Hard wood is comparatively heavier and darker in colour. Due to its close and strong grains, it resists shearing stresses and thus, is difficult to work upon. The annular rings are very closely placed and are less distinct. Hard wood contains a larger percentage of acid and is non-resinous. Some varieties of wood do not catch fire readily and are called refractory wood. Popular hard wood trees are mahogany, sal, babool, shisham etc.

15.4.2 SOFT WOOD

It is light in weight and colour. The annular rings are very distinct. The soft wood is weak across the fibres and thus splits easily. It is strong along the fibers, which renders the wood with more resistance along the axial direction. Some examples of this kind of wood are deodar, pine, chir and teak.

15.5 CHARACTERISTICS OF GOOD TIMBER

Good timber should possess the following characteristics:

1. It should be free from knots, insect attack, resin pockets and twisted fibers etc.
2. It should possess uniform dark colour with close fibres.
3. It should be free from sap and should be from the heart of the tree.
(4) It should be properly seasoned and should not wrap or twist after seasoning.
(5) It should be strong & heavy but easily workable.
(6) It should not split when nails are driven into such wood.
(7) It should be fire resistant
(8) After planning, it should be present in a firm bright appearance with a silky lustre.

While cutting, it should not clog the teeth of the saw.

15.5.1 Defects in Timber

Defects in timber are mostly of two types:

(1) Natural defects developed during the growth of the tree.
(2) Defects developed after felling the tree.

15.5.2 Defects Developed during the Growth of the Tree

(a) Heart shake: These are wide splits running through the heart wood of the tree (Fig. 15.2). These splits radiate from the pith running towards the sap wood. These defects are caused by the shrinkage of the interior parts.

(b) Star shakes: Star shakes are radial splits which are wider on the surface of the tree and become narrower as they move towards the centre. Star shakes are caused by severe frost or by severe heat of the sun.

(c) Cup shakes or Ring shakes: Cup shakes are the cavities appearing in between the annular rings. These cavities can be completely circular or partial. These are caused by strong winds which sway the tree or due to excessive frost which affects the moisture present in the tree when it is still young.

(d) Twisted fibres: The fibres of the wood are twisted by strong winds turning the tree constantly in one direction. Trees on hills are the ones most affected by this defect.

(e) Rind galls: These are swellings caused by the growth of layers of sap wood over wounds remaining after a branch of a tree has been cut off imperfectly. The new layers do not unite properly with the old root, thereby leaving cavities wherein decay starts.

(f) Knots: A knot is either the root of a branch that is embedded in the stem with the formation of annular rings at right angles to those of the stem or the tissues set in elliptical or concentric circles.

If the knot can be separated from the body of the wood, it is called dead knot, and if the knot is firmly attached to the wood and cannot be separated, it is called
live knot. A live knot reduces the strength of the wood. It is hard to plane wood having knots.

(g) Coarse grains: If the annular rings are very wide due to the rapid growth of the tree, the timber is said to have coarse grains.

15.5.3. Defects Developed after Felling the Tree

(a) Dry Rot. This defect is caused by a fungus. The fungus changes the timber into a dry powder. Unseasoned timber is easily attacked by the fungus. To prevent the dry rot, a well seasoned timber should be used.

(b) Wet Rot. Alternating drying and wetting of the timber causes wet rot. To prevent wet rot, the timber should be protected against alternative drying and wetting. It should be either always dry or always submerged under water.

(c) Case Hardening. It is caused by an uneven drying of the timber. The outer portion of wood dries earlier and quicker than the inner portion, causing shrinkage in the outer tissues leading to drying stresses. Due to this, the outer surface of the wood gets hardened.

(d) Honey Combing. This defect is caused during seasoning of wood. Due to imperfect seasoning, the interior wood dries quicker than the outer layer, giving rise to internal stresses. Thus, circular and radial cracks in the wood crossing each other are caused.

15.6. SEASONING OF TIMBER

A newly felled tree contains a considerable quantity of sap. If this sap is not removed, the timber is likely to warp, shrink, crack or decay. Seasoning is the act of extracting the sap under controlled conditions at a uniform rate from all parts of the timber. There are two methods of seasoning the wood.

15.6.1 Air Seasoning or Natural Seasoning

After felling, the tree is converted into logs, planks or battens. These are stacked in a shed on a well drained place in the shade. While stacking, it should be ensured that there is free circulation of fresh air all around each piece. The stacking is done on a concrete platform 30 to 40 cms high, which is perfectly levelled at the top. To prevent the effect of moisture on the wood from the bottom, a layer of sand is spread on the levelled platform before stacking the wood. To accelerate the rate of drying, the stacked wood is turned upside down periodically. The wood gets dried due to the circulation of free air, which dries up the moisture.

This process of seasoning is the best and also cheap but it is time consuming. To season wood, it takes 6 months to 5 years, depending upon the type of wood and its section. Soft wood and thin sections dry up easily whereas hard wood and thick sections take more time.

15.6.2 Kiln Seasoning or Artificial Seasoning

To speed up the seasoning process, kiln seasoning or artificial seasoning is done. It is done in a chamber equipped with arrangements for heating and humidifying the air, to required conditions or relative humidity and temperature, and for the circulation of air across the stacked timber. Usually, steam is used for this purpose. The seasoning is started at a comparatively lower temperature and high humidity. The conditions are changed gradually as the timber dries. At the end of seasoning, the air is fairly hot, and humidity is low. Before removing the wood, the kiln is allowed to cool till the temperature inside the kiln is within 15 to 20°C of the outside temperature. Under normal conditions, seasoning by this method takes about four to five days and is best suited for mass production work.

15.7. SAWING OF TIMBER

After felling, if the logs are not cut for sometime, the outer rings get dried and start shrinking while the centre of the log remains moist, causing star shakes. To avoid this, the logs are immediately cut into slabs, planks, battens, etc. This accelerates the process of seasoning by exposing a larger area of timber for drying.

Commonly adopted methods for sawing the timber are:

15.7.1 Flat Sawn or Slab Sawn

This is the easiest and an economical way of sawing. Parallel cuts are made throughout the length of the log for cutting parallel slices of planks. An allowance of 3.2 to 6.4 mm is included in the marking before sawing the wood as shrinkage allowance. The allowance depends upon the type of wood and the time of cutting.

15.7.2 Quarter Sawing

In quarter sawing, the timber is cut or bent in a transverse direction. In case there are no distinct medullary rays in the timber, this method of sawing, when adopted, gives very fine figure wood.

15.7.3 Radial Sawing

In this method, the timber is cut parallel to medullary rays and perpendicular to annual rings. This method gives least shrinkage but is the most wasteful.
method known as limited rift is adopted when medullary rays are pronounced. To reduce wastage, the timber is sawn radially.

### 15.8 COMMON VARIETIES OF INDIAN TIMBER

The various types of Indian timber, used for wood work are:

1. **Babul**: Babul is a thorny tree with small leaves. Its wood is hard, tough, elastic and close grained and takes on good polish. It grows all over India and is used for making bodies and wheels of carts, handles of tools, agricultural implements etc.

2. **Deodar (Diar)**: Deodar is a tall tree with pointed leaves grown in the Western Himalayas. It is one of the most important timbers of India. Deodar is strong, durable and moderately hard. It is close grained, easily workable and is used in building, construction work, railway sleepers, bridges and piles.

3. **Chir**: This is found in the Himalayas. It resembles deodar but in comparison chir is lighter, softer and coarse grained. Chir wood is easily workable, and is used for interior construction work of buildings and manufacture of matches.

4. **Sal**: Sal grows in sub Himalayan region and in Madhya Pradesh. It is hard, heavy, close grained, very strong and durable. It is an excellent timber and is used for many types of work. Sal does not give a good finish, so it is not used for ornamental work. Sal poles are used for foundation piles.

5. **Teak**: It is a large deciduous tree grown in Madhya Pradesh and South India. The wood is golden yellow to brown in colour. It is strong, very durable, and fire resistant having even grains. It is easily workable and is used for railway sleepers, ship building, furniture and construction of buildings. As it is expensive, its use is limited.

6. **Shisham**: This timber is available in northern India and Madhya Pradesh. It is one of the most valuable timbers of India, and is dark brown in colour with golden and dark brown streaks. It is hard, tough, durable and close grained. Shisham can be polished well and is used for furniture, beams and other important building construction work. It is widely used for decorative carvings.

7. **Mango**: It is a fruit-growing tree, grown all over India. The Mango wood is coarse grained and inferior. It is used for interior work, packing cases and cheap furniture.

8. **Walnut (Akhot)**: It is grown in Himalayas. The timber is strong, hard, tough, elastic and durable when seasoned. It is uniform in texture and takes good polish when seasoned. It is used for high class furniture, cabinets, wall paneling and carvings.

9. **Kail**: Kail is an evergreen tree, grown in the Himalayas. Kail wood is close grained and seasons well. It is used for making poles, match sticks, match boxes and railway sleepers.

10. **Mahagony**: It grows in the Western Ghats. The wood is moderately hard, easy to work, with fine and wavy grains. It is used for making cabinets, furniture, patterns, etc.

11. **Mulberry**: It is grown in Punjab. The mulberry wood is tough, strong and elastic. It is easy to bend and is used for making sports goods like cricket bats, tennis and badminton rackets, hockey sticks, etc.

#### 15.8.1 Market Forms of Converted Timber

Various forms in which logs are converted by sawing are:

- **Log**: A trimmed form of felled tree.
- **Balk**: A squared up log.
- **Plank**: Sawn timber 275 to 450 mm wide and 75 to 150 mm thick.
- **Deal**: Sawn timber, rectangular in cross-section, width up to 225 mm, and 50 to 100 mm thick.
- **Batten**: Sawn timber having width up to 135 mm, and 35 to 50 mm thick.
- **Board**: Sawn timber 150 mm wide and thickness less than 34 mm.
- **Scanting**: Odd cut pieces of varying sizes such as 75 mm x 50 mm, 100 mm x 50 mm and 100 mm x 75 mm, etc.
- **Beam**: Structural timber which is longer in proportion to its width and thickness.
- **Veneer**: Very thin sheet of uniform thickness of wood obtained by slicing, sawing or rotary cutting.

#### 15.9 PRESERVATION OF TIMBER

To protect the timber from internal decay and attack of insects like white ants, some chemical preservatives are used which increase the resistance of wood. Perfect seasoning is the most effective means of the preservation of wood and this must be cheap and safe to use. They should not leave any mark on the surface and must be able to penetrate the wood. The preservatives, mentioned below, are extensively used for the preservation of wood.

1. **Tar oils**: These are very common preservatives used for the embedded portion of timber like fence posts, ends of doors and window frames, etc. Some of these kinds of preservatives are coal tar, wood creosote, etc.

2. **Water Soluble Chemical Salts**: The Forest Research Institute, Dehradun, has developed a new preservative called ASCU. It consists of hydrated arsenic pentaoxide (As$_2$O$_5$, 2H$_2$O), blue vitriol (CuSO$_4$, 5H$_2$O) and Potassium dichromate (K$_2$Cr$_2$O$_7$, 2H$_2$O), dissolved in water, and is applied on the timber in two coats.
Other chemical preservatives are zinc chloride, mercuric chloride, sodium fluoride, etc. After applying the coat of chemicals, the wood is painted to preserve the effect of these chemicals.

3. **Organic Chemicals**: Some toxic chemical salts, naphthol, phenol, etc. are dissolved in alcohol or spirit and applied on the wood. The alcohol or spirit evaporates leaving the salts on the surface of wood. The salts are covered with paint or polish afterwards, to preserve the timber.

### 15.10 ADHESIVES USED IN TIMBER JOINERY

To have a finer and accurate kind of wood working, gluing is preferred to other methods of fastening. Any of the wood adhesives is stronger than the wood itself. Consequently, the glued joint, if properly fitted, becomes the strongest part. All glue joints are made stronger by clamping during setting. The common types of adhesives are as follows:

1. **Animal Glue**: It is made from hides, bones, hoofs and other parts of animals. These materials are refined and are available in sheets, flakes or powdered form. This glue is applied while hot (about 70°C) and it sets rapidly. It is soaked in cold water overnight and then heated before applying. Commercially, animal hide is available in liquid form. These glues are not waterproof and are not suitable for outdoor furniture, boats, etc. The animal glue is not brittle; instead, it is tough and strong. It gives strength even in poorly-fitting joints.

2. **Resin Glue**: It is made from formaldehyde, uric acid and other chemicals and is available in powder form. It gives high strength and stability at high temperature and also resists moisture.

3. **Casein Glue**: It is made by adding an alkali to the curd of skimmed milk. It is available commercially in powder form and can be converted into paste by adding water. It takes about 15-20 minutes to set. It is strong and fills poorly fitted joints.

4. **Vegetable Glue**: It is made from the starch of roots, grains and corn of trees. The viscosity of this glue is very high and so it is applied mechanically in a cold form. It gives strong waterproof wooden joints that withstand weathering well. This glue is best suited for plywood work.

5. **Blood Albumen Glue**: It is made by adding an alkali to beef blood and is available commercially in the form of flakes. These are dissolved in water one hour before its use. This gives a strong and waterproof joint.

6. **Gum Arabic**: It is derived from the acacia tree, is soluble in water and used for joints exposed to tropical conditions.

7. **Contact Cements**: These are used when bonding veneers and resin laminates to wood. After applying a uniform coating, the cement is allowed to dry for about 30 minutes and the pieces are placed together to join. Once the parts are in contact, these cannot be moved. So, care must be taken to position the parts properly before applying the cement. These cements are available commercially. The instructions provided by the manufacturer for their use must be strictly followed. This cement is stainless, moisture resistant, heat resistant and provides a good bond.

8. **Plastic Cements**: Plastic cements are generally available in tubes and dry up quickly. These are useful when the glue area is small. These cements are waterproof and hard when dry and are useful for repair work. The instructions provided by the manufacturer must be followed while using such cements.

### 15.11 OTHER JOINERY MATERIALS

Apart from glue, some other materials, mentioned below, are also used for joining wood and for reinforcing glued joints:

1. **Nails**: Many kinds of nails are available, each designed for a different use. The most common types of nails used in wood working are common finish, casing box, wire brads and wire nails. The first three types of nails are used for building-construction work. The small heads of finish and casing nails make it possible to set these nails below the surface of wood and the cavity that is caused, is levelled with wood putty. Box nails are smaller in diameter and are used in box construction. Wire brads and wire nails are used for light and medium wood work.

2. **Screws**: Wood screws are fastening devices that use screw threads for winding and are available in different lengths, diameters and shapes of head. Wooden screws are specified by numbers. A hole is drilled before putting the screw which is driven into the wood by a screw driver. The diameter of the hole is smaller than the screw diameter.

3. **Bolts and nuts**: Nuts and bolts are used to join very heavy components such as wooden roof trusses etc. These are commercially available, of varying diameters, with the length of the threads and the shape of the heads. Some special types of bolts are also used in wood work such as hanger bolts, toggle bolts and carriage bolts.

4. **Dowels**: There are wooden nails made from bamboo or some other wood. These are made by the carpenter himself. Dowels are used to join or align the wooden parts. A hole is drilled in two parts to be joined and the dowel is driven through them.

### 15.12 HAND TOOLS FOR CARPENTRY

Hand tools are those devices that make it possible to work on materials with hands alone. Machine tools make the work easier and quicker but cannot replace
the hand tools altogether. To give a desired and accurate shape to the work, a carpenter must possess a complete set of tools. These tools are grouped together according to their use.

15.12.1 Marking and Measuring Tools

To transfer the dimensions from the drawing and marking them on the work, some marking and measuring tools are required which are as follows:

(a) Engineers Steel Rule. Steel rule is made of straight, thick gauge of steel having all the true faces. The graduations are in centimeters, which are further subdivided into millimeters. It is used for setting out dimensions on the work.

(b) Try Square: is used to set off lines at right angles to a given edge or to test the squareness of two adjacent surfaces and for making out cuts in the joint. It consists of a steel blade fitted into a metallic or wooden stock at right angles to each other, as illustrated in Fig. 15.5. The working surface of the wooden stock has a protective brass lining. The blade is graduated in centimeters and millimeters.

(c) Bevel Square: This is similar to a try square, with the difference that the scale has a slot which enables it to swivel to any angle between 0 to 180° with respect to the stock and can be locked at any position as illustrated in Fig 15.6. It is used for setting, duplicating, testing and comparing angles.

(d) Framing square: It is a large one piece square used by a carpenter. Various mathematical tables are engraved on it, which are used for computing angles for different cuts.

(e) Mitre Square: It has a metallic blade fixed at 45° in the form of a ‘T’ to a metallic or wooden stock, as illustrated in Fig. 15.7. It is used for checking and marking angles at 45° and 135° to a plane surface.
(f) **Scriber or Marking knife:** It is a steel rod having one end sharply pointed and the other formed into a sharp flat blade, shown in Fig. 15.8. It is used for converting pencil lines into cut lines on wooden surfaces.

![Fig. 15.8: Scriber or Marking knife](image)

(g) **Marking Gauge or Marking Block:** It is an important marking and measuring tool used by a carpenter. It consists of a stem which is a long wooden bar with a square or rectangular cross-section. The stem slides in a stock which is also made of wood. The stem carries one steel marking point or a cutting knife illustrated in Fig 15.9. The stock is set at a desired distance from the steel marking point and fixed by a wooden thumb screw. The face of the stock is butt against the datum edge of the timber. The steel marking point is slightly pressed into the wooden surface and pushed along the datum edge, thus, scribing a line on the surface.

![Fig. 15.9: Marking Gauge](image)

(h) **Mortise Gauge:** It is used to cut two parallel lines. It is similar to a marking gauge with a difference that it has two marking points, one fixed and the other attached to a sliding bar of brass. The movable pin can be adjusted at any point between the stock and the fixed pin, by means of a thumb screw. This enables the scribing of two parallel lines which are at a desired distance from each other and from the datum.

(i) **Cutting Gauge:** It has the same construction as that of a marking gauge with the difference that it carries a steel cutter in place of a marking pin. The projection of the steel cutter can be adjusted according to the depth of cut. It is used for cutting parallel strips out of thin sheets of wood or marking deep lines across the grains of the wood.

(j) **Calipers:** These are used to measure diameters. The inside caliper measures the inside diameters and the outside caliper is meant for measuring exclusively the outside diameters. The distance between the points of a caliper is set against a scale for measuring.

(k) **Wing Compass:** It is used to set off a number of equal spaces, marking arcs and circles and scribing parallel lines on a curved or straight surface. It consists of two finely pointed steel legs and a quadrant, having angles marked on it. The legs after setting to a required angle or distance can be locked by a set screw.

(l) **Trammel points:** These are clamped on a rule and are used as a beam-compass for marking large curves.

(m) **Spirit Level:** It is used to check the level of horizontal surface. It consists of a vial containing a curved tube, filled with spirit having an air bubble. For a truly horizontal surface, the bubble will remain in the middle. If the bubble moves on either side, it will indicate the position of inclination.

(n) **Plumb Bob:** It is used to check the vertical surfaces. It consists of a conical metallic bob tied to a thread. The thread is held against the vertical surface and its position is checked with respect to the thread and the tip of the conical bob. If the plumb bob and spirit level are used together, these can check the right angles of large surfaces where a try square cannot be used.

### 15.12.2 Cutting Tools

There are three types of cutting tools used in carpentry:

1. Those which cut while reciprocating like saws.
2. Those which cut by the action of blows, when driven into the wood, like chisels.
(3) Those which cut, when struck against the surface of wood with a force, like axe and an adze.

(a) Saws: A saw consists of a blade and its handle. The blade is made of spring steel with high percentage of carbon. The edge which carries the cutting teeth is hardened and tempered. The blade is firmly held by a wooden handle. To cut wood, the saw is held in the hand by the handle, pushed forward and pulled backward. The saws which cut during the forward stroke are called push saws and those which cut during the backward stroke are called pull saws or draw saws.

A saw is specified by its length and the number of teeth or points per millimeter, i.e., the pitch of teeth which is stamped on the heel of the blade of a saw. The teeth are bent in opposite directions, i.e., one tooth left to the blade and the next tooth right to the blade. This is called the setting of teeth. It is done to provide clearance between the saw and the cut surface to avoid jamming of the blade into the wood.

The saws which are used for cutting along the grains of the wood are called rip saw and those which cut across the grains are called cross cut saws. The type of saw to be used depends on the type of grains of the wood as the same saw cannot perform both the functions. There are different types of saws used in carpentry which are explained below:

(a) Rip saw is used to cut wood along its grains. It is specified by its length which is about 700 mm and the number of teeth per millimeter. When the pitch, which is 3 to 5 teeth per 25 millimeter is more, it is called a hand saw which is used for medium or light work. The cutting action of a rip saw starts from near the tip of the blade during the forward movement and gradually takes part in the action of cutting. The pressure is applied in the forward stroke and relieved during the backward stroke. Figure 15.10 shows a rip saw, its teeth and how they cut.

(b) Cross Cut Saw or Hand Saw is used for cutting across the grains in thick wood. The length of the blade is 500 to 700 mm and it has 8 to 10 cutting points

25 millimeters apart. A cross cut saw with higher pitch is best suited for fine work even on hard wood. It is a general purpose saw used by carpenters. Figure 15.11 shows the teeth of a cross cut saw and how they cut.

(c) Panel Saw: Panel Saw is like a cross cut saw having 10 to 12 cutting points per 25 millimeter. It is used for accurate work. This can also be used for ripping.

(d) Tenon Saw: Tenon Saw is also called a back saw and is suitable for finer work while cutting across the grains. It is available in various lengths, of 300 to 650 millimeter, having 12 to 18 points per 25 mm. The blade of the tenon saw is parallel and thin which is stiffened by reinforcing with a rigid steel back to prevent the blade from bending or buckling. This saw is best suited for short cuts such as tenon. The tenon saw is shown in Fig. 15.12

(e) Dovetail Saw: Dovetail Saw is just like a tenon saw but is thinner and smaller in size, having an open handle. The length of the blade varies from 200 to 350 mm, having 15 teeth per 25 mm. It is used to cut very fine narrow cuts like cutting tongue for a dovetail joint. Figure 15.13 shows a dovetail saw.

(f) Bow Saw: Bow Saw consists of a wooden frame having a connecting bar, string, wooden lever and two handles which can revolve in their sockets on each
side of the frame. A narrow blade, 250 to 350 mm long, is held in the frame. The tension to the blade is provided by twisting the string with a wooden lever. A bow saw is used for cutting finer curves and profiles having quick changes. This is achieved by revolving the handles and adjusting the blade at any desired position. The blade has about 12 to 24 teeth per 25 mm.

(g) **Compass Saw:** Compass Saw has a long tapered blade fixed to an open handle. The length of the blade varies from 250 to 400 mm and width 25 mm at the tip and 50 mm near the handle. It can be of two types, one with a fixed blade and the other with three inter-changeable blades of different widths. It is used for cutting small external or internal curves. For cutting internal curves, a hole is drilled at the desired position and the saw blade is inserted into the hole to accomplish the cut. Figure 15.14 shows a compass saw.

![Fig. 15.14: Compass Saw](image)

(h) **Key Hole Saw:** Key Hole Saw is the smallest saw of a carpenter. It consists of a very narrow blade having 3 mm width at the tip and 6 mm near the handle with a length of 200 to 300 mm. The blade is fitted to a wooden or metallic handle by means of two screws. The handle is hollow from inside to accommodate some length of the blade. According to the requirement, the length of the blade can be adjusted by pushing it into the cavity after unscrewing the screws. This saw is used for cutting key holes and internal intricate work. Figure 15.15 shows a key hole saw.

![Fig. 15.15: Key Hole Saw](image)

(i) **Coping Saw:** Coping saw is used for cutting curves in thin wood. A very thin blade, which is available in fine, medium and coarse grade, is fitted in a spring metal frame. The tension in the blade is given by tightening the handle. Figure 15.16 shows a coping saw.

![Fig. 15.16: Coping Saw](image)

(j) **Jack Saw:** Jack Saw is a two man saw consisting of a thick blade of hardened and tempered spring steel without a tension. It is used for making rough cuts on thick, square or round timber across and inclined grains of the wood.

![Fig. 15.17: Jack Saw](image)

(II) **Chisels:** To produce desired shapes and cavities in wood, a large number of chisels are used. The chisels are specified by the length and width of the blade. Irrespective of the size, shape and use of chisels, they essentially consist of the following parts. The various parts of a chisel are shown in Fig. 15.18.

1. **Blade:** It is a flat, thick piece of high carbon steel, one edge of which is ground to form a cutting edge.
2. **Tang:** The other end of the blade is made in the shape of a square pyramid.
3. **Wooden Handle:** It is made of hard wood having a hole to accommodate the tang of the blade.
4. **Ferrule:** A brass or iron ring fitted at the bottom of the handle to prevent the handle from splitting due to continuous hammer blows.
5. **Bolster:** It is the portion of the chisel between the tang and the blade, which is slightly enlarged to form a neck so as to prevent excessive entry of tang into the handle.

![Fig. 15.18: Chisel with parts](image)
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(vi) Cutting Edge: It is main working part of the chisel which cuts the wood. Its width provides the size of the chisel.

Various types of chisels are available, which are explained below:

1. Firmer Chisel: It is a medium duty chisel for general work. It is used for wider cuts and to finish flat surfaces inside the grooves. While parting, it is driven by hand pressure, and for mortising, by light pressure of a mallet. It has a flat blade of width ranging from 3 to 50 mm and length 125 mm. Figure 15.18(a) shows this chisel.

2. Dovetail Chisel: To finish sharp corners of a dovetail joint or V-groove, a dovetail chisel is used. Its blade has a bevelled back which reduces the thickness on its sides. Figure 15.18(b) shows this chisel.

3. Paring Chisel: It has a long thin blade used for shaping and preparing long surfaces in the direction of fibres of the wood. It is also used for cleaning the recess while preparing a joint. The width of the blade varies from 5 to 50 mm, and the length ranges from 225 to 500 mm. Figure 15.18(c) shows this chisel.

4. Mortise Chisel: It is a heavy duty chisel used for making heavy and deep cuts, and thereby enabling it to remove more stock while making a mortise (a hole). The blade of a mortise chisel is plane from one side and tapers towards the cutting edge. The thickness of the blade varies from 6 to 15 mm and the width from 3 to 15 mm. To withstand the force of the mallet blows, the blade has a big collar or a shoulder. Sometimes, a leather washer is fitted at the collar to absorb the hard shocks of the mallet. Figure 15.18(d) shows this chisel.

5. Socket Chisel: Like a mortise chisel, it is also used for heavy stock removal. To prevent the splitting of the handle due to heavy mallet blows, the chisel has a socket which receives the handle instead of tang. The blade of this chisel can be firmer than that of the mortise chisel.

6. Gouges: Gouges are chisels with hollow blades for scooping or cutting round holes. The gouges may be outside bevel or inside bevel. For internal curves, inside bevelled gouges are used and for external curves or hollows, outside gouges are used. Gouges for different curves and for different works are made in varying sizes from 4 to 40 mm.

(III) Axe and Adze: Axe and Side Axe: These are very useful tools for wood cutting. They are made of carbon steel with a hardened and tempered cutting edge. Both have a hole to accommodate a wooden handle of convenient size. To cut wood into rough pieces, an axe is used, and to make the surface of the wood roughly plane, a side-axe is used.

Adze: It is similar to a side-axe with the difference that the outer face is convex and the edge is bevelled to form a cutting edge, which is hardened and tempered. An adze is used to produce concave surfaces and to chop extra wood.

15.12.3 Planing Tools

Planing tools are used for making the wooden surface smooth and flat or true. Properly sharpened, adjusted, plane tools will cut end grains as smoothly as flat grains. All planes have a chisel like blade fitted in the wooden or metal block with the help of a wedge. The blade can be adjusted for the required depth of cut. Some of the planes are described below:

(a) Jack Plane: It is a general purpose plane. It consists of a rectangular block of wood having a slot to accommodate the blade. The blade is fixed at an angle of
To prevent the chattering and to curl and break the shaving of the wood, another blade called Back iron or Cap iron is fitted on the cutting blade with the help of a set screw. The cutting blade is rigidly clamped by hammering a wooden wedge in the slot of the block. The cutting edge projects out by 0.8 to 1.6 mm for rough work, and below 0.8 mm for smooth work. Jack planes are available in sizes ranging from 300 to 460 mm in length and 60 to 75 mm square cross-section of the stock, with blade width varying from 50 to 75 mm.

(b) Trying Plane: This plane resembles a wooden jack plane. The length of this plane is 500 to 700 mm, and its cross-section is 85 x 85 mm square. The width of the blade is 60 mm. It is used to trim the surface after it has been planed by a jack plane.

(c) Smoothing Plane: It is smaller in size and has no handle. It is held in both the hands while in operation. It provides better finish and smoothness to the surface levelled by a Jack plane. The length of the stock is 200 to 250 mm with a blade width of 70 mm.

(d) Combination Plane: It is a special purpose plane for cutting shaped moldings, flutes, etc. Cutters of different shapes are inserted and the plane is operated as a hand plane.

(e) Router Plane: It is used for cleaning and leveling of hollow surfaces or grooves. The cutters are adjusted to the desired depth and the plane is operated by pulling or pushing.

(f) Rabbet Plane: The shape of this plane is such that it can cut a recess of desired shape along the edge of the wood as in the case of photo-frames. It can also cut convex and concave edges, by just changing the blades. It has no back-iron and the cutting edge is only on one side of the body of the plane.

(g) Plough Plane: It is used to cut grooves in the wood so as to fit board etc., as is done in the case of doors. The depth of cut is adjusted by a depth gauge operated by thumb screw. Eight to nine blades of varying widths, from 3 to 15 mm, are provided for cutting grooves of the desired width.

(h) Iron Jack Plane: The body of the iron jack plane is of grey cast iron ground to a bright finish. It has a wooden knob at the front and a wooden handle at the back fastened to the body by long screws. The thickness of the cut can be governed by a fine screw adjustment, and to adjust the blade at right angles, a lever is provided. The functions of the metal plane are the same as that of a wooden jack plane.

(i) Block Plane: It is used for planing against the grain. It can be easily handled due its small size. It has only a single cutter which is inclined at 12 to 21°. It is used for small work.

15.12.4 Striking Tools

To drive chisels and nails into wood, some striking tools are needed. The tools used can be light hammers, mallets and claw hammers. The hammers used by a carpenter are similar to those used by a blacksmith but are smaller and lighter.

Mallet: It is a wooden hammer made of hard wood. It can be round or rectangular in cross-section. A convenient wooden handle is fitted to assist in giving blows. It is used to give light blows to the cutting tools having wooden handles, like chisels and gouges.

Claw hammer: It is a dual purpose hammer, i.e. it can drive nails into the wood and also take them out from the wood. It consists of a hammer at one end and a claw at the other end. The hammer drives in and the claw takes out the nails. The claw hammers are specified by numbers from 1 to 4 and weight between 250 to 750 gm.
15.12.5 Boring Tools

To make circular holes or recesses of different sizes in wood, boring tools are used. Some important boring tools are explained below:

(a) Auger and Bradwel: Auger is fluted steel bar up to half of its length from the bottom. A screw point which acts as a pilot is provided at the bottom. The screw point helps in centering the tool. The upper end of the tool has an eye through which a wooden handle passes to rotate the bar manually. It can produce holes upto 25 mm diameter. Bradwel is used for making small holes in soft wood. It can also be operated by a mallet. Figure 15.24 shows Auger & Bradwel.

(b) Gimlet: It is a smaller form of an auger. It is also hand operated to produce smaller holes. Gimlet is shown in Fig. 15.25.

(c) Brace and Bit: Brace is a tool used for holding different types and sizes of bits and for rotating them to produce a hole in the wood. A brace has two jaws to grip the end of the bit.

There are two types of braces which are commonly employed in wood working, a ratchet brace and a wheel brace.

A ratchet brace, shown in Fig. 15.26, consists of a crank made of steel, having a wooden handle in the middle and an oval head at the top. A chuck is provided at the bottom and, just above it, a ratchet arrangement is provided. The chuck holds the bit and rotates when the crank is rotated by hand. The ratchet arrangement does not allow the rotation of the bit, when the crank is rotated in the opposite direction. It allows its use where a complete rotation is not possible due to lack of space. A bit of proper type and size is fitted in the chuck and
centered at the required position. Hand pressure is applied from the top while rotating the crank. Ratchet brace is best suited for heavy cuts and for working in a limited space. Its size is given according to its sweep.

A Wheel brace, shown in Fig. 15.27, is like a hand drill. The rotation to the chuck is given by a handle attached to a gear and pinion arrangement. The chuck can hold round and parallel shank drills. It is used for drilling small holes not more than 6 mm in diameter. To bore holes, bits are the most common type of tools used in a brace. The bits are available in various sizes and shapes.

15.12.6 Holding Tools

To enable the carpenter to perform various operations of cutting, chiseling, gluing, etc., the work piece must be held firmly. For this, some holding and clamping devices are used which are described below:

(a) Bench vice. The bench vice is most commonly used in the carpentry shop. It has a fixed end rather a jaw which is screwed to the worktable. The movable jaw

(b) Bench stop: Bench stop or bench hook is a simple straight flat plank of wood having two projected rectangular sections of wood, screwed on opposite sides of the plank. It can be suitably placed on the work-bench and the work is placed in
such a way that it is always butting against the projected portion so as to resist the work from moving forward in the direction of the applied force. Sometimes, it is made of steel having teeth to hold the work.

(c) Clamps and Screws: Clamps are very handy devices in wood working and are used to hold the work which cannot be held in a vice. These clamps provide necessary pressure for gluing the joints. There are many types of clamps but the ones most often used are bar clamps, C cramp and Hand screws cramp.

Bar Cramp: It is also called T-Cramp or Sash Cramp. It consists of a straight T-section having a series of holes at regular intervals all along its length. A sliding jaw moves over the length of the T-section, which can be locked at any desired

hole by a clamping pin. The other end of the T-section is forged into a head which carries a screw having square threads. The end of the screw carries a movable jaw which moves along the T-section when the screw is rotated. The work is held tightly between the two jaws for gluing or for other carpentry operations. Its size is specified by its maximum opening.

C-Cramp or G-Cramp: It is shaped like the letter ‘C’ or ‘G’ as shown in Fig. 15.31. The malleable iron ‘C’ or ‘G’ shaped frame has a fixed jaw and the other is movable with a long screw having square threads. It is used to hold wood pieces face to face after gluing. Its size is denoted in centimeters (inches) of the opening.

Hand Screw Cramp: Hand screw cramps have wooden jaws and are capable of applying pressure over a large area. The jaws can be moved by two screws moving in opposite directions. This cramp can hold the work when the surfaces are not parallel. The common size has openings, ranging from 150 to 300 mm.

Bench Holdfast: To hold those pieces of wood on a bench, which cannot be held in a vice, a bench holdfast is used. It consists of a cast iron pillar, a steel bar having square threads, a light vice handle and a drop steel forged arm. A handle is provided at the top to move the arm of the screw by boring a number of holes through the top of the bench; a holdfast can secure the work in any desired position.

15.12.7 Miscellaneous Tools

There are other tools, which do not fall in the categories of tools described so far. Some of these tools are described below:

(a) Screw Driver. It is used to drive screws into the wood or to unscrew them. These are available in various shapes and sizes. The most common types are common screw driver, offset screw driver, recessed screw driver and ratchet...
screwdriver. The ratchet type screwdriver is quite useful for turning screws in awkward and confined spaces through a few degrees. The size of a screwdriver is given by the length of the blade from the handle to the tip.

(b) Pincer. The pincer is used for pulling out nails. It consists of two steel forged arms hinged together. The outer faces of the jaws are plane while the inner ones are bevelled. The end of one arm has a ball while the other has a claw end used for levering out small nails.

(c) Rasp and files. Rasp is also called as wooden file. It has sharp cutting teeth to finish and clean small curved surfaces where a spoke shave cannot be used. A file is used for smoothing, finishing and removing scratches left by a rasp. The files can be of various sizes and shapes.

(d) Glass paper. Glass paper is used to finish and smooth away the surface of wood or to remove scratches left by a file. It consists of small particles of glass stuck to a sheet of paper. The sharp edges of glass paper cut the wood when it is rubbed on it. The glass papers are specified by numbers like 00, 0, 1, 10, 100, etc., according to the size of the glass particles.

(e) Scraper. Scrapers are used to scrap very small shavings of wood from the surface. They consist of a thin piece of hardened and tempered steel having a very fine edge made by burnishing.

(f) Oil stones. These are used to sharpen the cutting edges of chisels and other cutting tools. The oil stones can be natural or artificial and are available in fine, medium or coarse grade.

15.12.8 Sharpening of Cutting Tools

Sharp tools make wood working easy and quick. A dull tool produces dirty work and sometimes, causes injuries to the operator. For a good worker, it is necessary to keep his tools sharp to enable him to use these skillfully. To sharpen different cutting tools, different methods are employed which are described below:

Sharpening of Saw: Sharpening of saw teeth involves five steps:

(a) Topping. The saw is held firmly in a vice. The teeth of the saw are kept upward, projecting about 3mm from the top face of the vice. With the help of a flat file, its teeth are leveled in such a way as to make their tops in the same plane.

(b) Shaping. The topped teeth of the saw are shaped with the help of a triangular file. Care must be taken to move the file at right angles to the plane of the teeth.

(c) Setting. After shaping, the teeth are set by bending the alternate teeth in the opposite direction with the help of a saw-set or a hammer. This process increases the width of the blade cutting edges, which enables wider cuts than the thickness of the saw blade. It also gives a free movement of the saw in the cut without clogging. Care must be taken so that the total set is not more than twice the thickness of the blade, otherwise the cut will be wider, resulting in wastage of wood.

(d) Side Dressing. The help of an oil stone is taken to remove the burrs on the sides of the saw, after setting.

(e) Final sharpening. The saw teeth are finished with the help of a triangular file to obtain the required angle included between two consecutive teeth. Care should be taken while sharpening the rip saw.

Sharpening of Chisels: For sharpening chisels, the two angles of the chisels are taken care of. A grinding angle of 20 to 25 is made on a grinder. The sharpening angle of 30 to 35 is made on an oil stone, using plenty of water, so that the cutting edge does not lose its harness. While grinding and sharpening, the tool should be moved to and fro across the grinding wheel and oil stone.

Sharpening of Planes: The efficient working of a plane depends upon many factors.

- The angle set between the blade and the body of the plane; this angle is kept around 45°.
• The space between the cutting edge of the blade and the body of the plane: the thickness of shaving produced depends upon this space. More the gap, thicker is the shaving and vice-versa. The distance can vary from 0.4 to 3 mm.
• The distance of back iron from the cutting edge of the blade; lesser the distance, the finer is the work, more is the distance and coarser is the work. This distance ranges from 0.5 to 3 mm.
• The distance between the sole of the plane and the cutting edge of the blade, i.e., the cut; lesser the distance, the finer is the cut, more the distance and rougher the cut. This distance can be from 0.8 to 1.6 mm.
• To have good results, the proper maintenance of the cutting edge of the blade is very important. Firstly, the grinding angle of 25° is ground on a grinding wheel and the sharpening of 35° is ground on an oil stone (Fig 15.34), using plenty of water to retain its hardness. If some burrs are formed on the cutting edge, they are removed by moving the back of the blade on an oil stone.

**15.13 WOOD WORKING PROCESSES**

To finish a work to the required shape and size in a wood working shop, several operations are performed. These operations are:

1. Marking and laying out: Marking is the process of setting out dimensions on a wooden piece to produce the required shape. Marking is done from drawings or existing models. Marking and measuring are carried out together. The dimensions are measured by a folding rule and laid out with the help of a pencil, calipers, try square, marking gauge, marking knife, bevel protractor, etc. Before marking and laying out, a master surface or a master edge is planed first, to be used as a reference surface or reference edge. All measurements are taken from this master surface or edge for accurate work. The flatness of the surface and the edge is checked by steel rule, try square or straight edge. The master surface is marked by a zig-zag line with pencil so as to distinguish it from other surfaces. Care must be taken to mark the dimensions accurately and correctly as inaccurate marking will produce ill dimensioned parts, which are liable to be rejected. For mass production, work templates are made for marking the work accurately and efficiently.

2. Sawing: Sawing is done to cut the wood into pieces of required shape and size. It may be done across the grains, along the grains, inclined, straight or curved. To start the cut, the wood is fixed in a vice and the left hand thumb is placed against the blade of the saw. This enables the blade to start the cut at the right place and prevents any accident in the event of the saw jumping. As the saw proceeds down, the wood must be moved up to prevent vibrations during sawing. To start with, one or two short movements of the saw are given to the work, taking care that the saw cuts in the right direction, and then full strokes are applied to complete the cut. Care should be taken to keep the waste wood on the right side of the marked line so as to have a clear view of the sawing line while cutting. The saw should never be forced into the wood; the weight of the saw plus some little pressure is sufficient for effortless cutting.

3. Planing: The operation of truing and smoothing a wooden surface with the help of a suitable plane is called planing. This is also known as facing and edging. It is an important operation and the ultimate success of a job depends upon this initial operation. A properly planed surface should be perfectly straight, parallel in width and thickness and all edges square to the face. The direction of the grains should be checked before carrying out this operation and the planing should only be done along the grains. The following sequence of operations should be followed to carry out this operation:

- Choose the surface of wood, which looks best in appearance.
- Use a jack plane to plane a rough surface. Hold the plane from the handle with the right hand, keeping the left hand at the tip. Apply pressure by the left hand and push the plane forward by the right hand, remove as little shaving as possible but attempt should be made to remove the maximum from the higher levels. Pressure should be applied in the forward stroke and relieved in the backward stroke.
- Check the dimensions and surface with a steel rule.
• Mark a zig-zag line with a pencil on this surface which is termed as master surface. Plane an edge straight and square. Check it with a straight edge or a try square. Mark this also with a zig-zag line. This edge is termed as master edge.
• Repeat this till all the edges are planed and squared with reference to the master surface and master edge.
• Plane the second surface to get the required thickness.

4. Chiselling: Chiselling is an operation of cutting small stock of wood to get the required shapes. The following sequence of operations is performed for chiselling:
• Mark the lines where chiselling is required.
• Saw cuts are made on the side of marked lines to prevent the groove from being too wide.
• Hold the chisel in the left hand with the bevelled side facing the groove. Drive the chisel into the wood with the help of a mallet and slice off wood in thin shavings.
• Repeat the process by rotating the work by 180°.
• Turn the chisel so that the flat side is facing the groove. Hammer it with a mallet and remove the middle hump.
• Hold the chisel near the blade end and slice sideways to finish the hole.

5. Mortising and Tenoning: Mortising is the operation of making a rectangular or square cavity or hole, and tenoning is the operation of making a corresponding projection, so that it fits into the mortise to form an assembly. Figure 15.35 shows a mortise and a tenon.
• Mark out the lines for mortise and tenon on two different pieces of wood accurately with the help of a mortise gauge. Perform the mortising by using a firmer and a mortise chisel. The wood is taken out for about half the depth from one side and the remaining wood is taken out from the opposite side. This is done to prevent the splitting of wood at the face.
• For tenoning, a tenon saw is used to cut the extra wood from both the sides. The tenon fits into the mortise and a proper joint is produced only if the marking is done accurately and correctly.

6. Boring: It is the process of producing round holes, which are through, blind, straight or inclined in the wood, according to the requirement. For boring, the following sequence of operations is followed:
• Mark the centre for the hole on the work piece.
• Secure it tightly in a holding device.
• Use a bradawl or a gimlet for small diameter holes.
• For large diameter holes, braces and bits or drills are used.
• Turn the bits and drills in one direction, and withdraw them by turning in the opposite direction, exerting an upward pull in the opposite direction so as to remove the waste core.
• To make the hole in the proper direction, the bit should be guided by a try square or a small straight edge.

7. Grooving and Tongueing: Grooving and tongueing are used in conjunction with each other. Grooving is the process of making a groove on the longitudinal face of the wooden plank, and tongueing is the process of producing a corresponding projection on the longitudinal face of the other plank, to fit in the corresponding groove. This is done to increase the width of the planks. A practical application of this can be seen in drawing boards, floorboards and wooden partitions.

Fig. 15.36: Grooving and Tongueing

Tongueing is done with a mould plane or tongueing plane whereas grooving is done with a plough plane. Sometimes, grooving is done in both the planks and a separate tongue is inserted to fit into the grooves of both the planks.

8. Moulding: Molding is the process of producing convex, concave and other types of curved surfaces along the periphery of pieces of wood by using a molding plane. A cutter blade of the required shape is used in the molding plane. Molding work is done for preparing photo frames and for decorative purposes in doors and window frames.
9. **Rebating**: Rebating is the process of producing a rebate or a step along the edge of a plank longitudinally or transversely with the help of a rebating plane. Examples of rebates are window sash in which the glass is fitted and part of the door frame in which the door fits.

10. **Recessing**: Recessing is the process of producing blind holes in wooden pieces. It is a mortising operation with the difference that in mortising, the hole is through while in recessing, the hole is blind.

11. **Cutting dadoes**: Dadoes are grooves cut across the grains of wood. They are of two types, open or through dadoes, and blind dadoes. The grooves, into which the shelves of bookcases and cabinets are fitted, constitute the most common use of dado joints. The following steps are taken for making an open dado:
   - Measure and mark clearly the section of stock, which is to be removed.
   - Several cuts are made carefully to the desired depth with a hand saw.
   - Trim the stock with a chisel and router for making a blind dado.
   - Measure and mark the dado carefully on the wood.
   - Cut on the marked line with a saw, guided by a straight edge, to the required depth.
   - Remove the stock with a chisel and router. Finish the dado with a router plane.

15.14 **CARPENTRY JOINTS**

In pattern making or in constructional-wood working, two types of joints are used, namely, **frame work** and **case work**. In framework, the joints used are halving joints, mortise and tenon joints and briddle joints. Carcase joints are also known as box like joints, and the joints commonly used in this are butt or rebated joints, dovetail joints, and tongue and groove joints. Joints, used in wood work, can also be classified as:

1. **Longitudinal Joints**: These joints are used to increase the length of wooden pieces. The wooden pieces are joined end to end. Lap, butt and scarf joints are the examples of longitudinal or lengthening joints.

2. **Widening Joints**: Wooden pieces are joined along their sides so as to increase its width. Rebated joint, butt joint, and tongue and groove joints are commonly used as widening joints.

3. **Framing Joints**: Framing joints are used to connect wood pieces at a desired angle in framing work. Commonly used joints in framing work are dovetail (open and secret), lap, scarf, corner halving mitre, mortise and tenon joints.

4. **Box Joints**: Box joints enable joining of wooden pieces at desired inclinations to obtain box like structures and wooden cases. Various joints used for this purpose are open dovetail, secret dovetail, lap, rebate, corner halving mitre, haunched mortise and tenon and corner locking joints.

5. **Circular Joints**: Circular joints are used to connect wood pieces to form a hollow cylindrical structure. Joints commonly used for this purpose are butt, dowel, hammer head key, blind mortise and tenon, scarf and dovetail joints. Some important joints are explained below.

6. **Halving Joints**: Halving joints are used to secure corners and intersections in the same plane as in the case of wooden frames. The halving joints are also called **half lap joints**. The various forms of halving joints are corner halving joint, T-halving joint, cross halving joint, bevel halving joint and dovetail halving joint.

7. **Mortise and Tenon Joint**: Mortise and tenon joint is the most common type of joint used in wood working. It consists of a rectangular peg (tenon), which fits into a corresponding rectangular hole (mortise). If properly constructed, assembled and reinforced with glue, a very strong joint is obtained. The various mortise and tenon joints are simple, blind, barefaced tenon, double tenon, divided tenon and haunched mortise and tenon joint.

8. **Briddle Joint**: Briddle joint is the reverse of mortise and tenon joint and is also called as open mortise and tenon joint. This joint is generally used to connect a rafter to a tie beam in a roof truss.

9. **Dovetail Joint**: A dovetail joint is the strongest, most dependable, rigid and durable joint given at corners. It can take stress and strain in any direction. It is the most common joint used in box making and furniture making. The dovetail joint is so named because of its wedge-shaped pin, which resembles the tail of a dove. The pins fit into the matching sockets. (Fig 15.37).
10. Butt or rubbed joint. To make a wide board from several narrow ones, a butt joint is made: To make a butt joint, several methods are used such as:

- **Edge butt joint.** A plain glue butt joint is adequate when the pieces are short enough to be easily clamped.
- **Dowel joint.** Dowels are thin, small round sticks of hard wood. Dowel pegs in the butt joint make it easy to hold the position while clamping. For a true stock, three dowels are sufficient and for slightly curved surfaces the number of dowels can be increased. The pegs should be 50 mm long, out of which 25 mm. is inserted in the board.
- **Tongue and groove joint.** As already explained, this joint is widely used in making drawing boards and table tops. This is an easy joint to make and assemble. The width of the tongue should not be more than one half of the thickness of the board.
- **Spline joint.** The spline joint involves the use of a slender strip or spline, which is inserted into the matching groove at the edge of the boards.
- **Ship lap joint.** This joint is widely used in ship construction, especially in planking, hence, it is known as shiplap joint. It is a double rabbet or an edge lap joint but is difficult to clamp.
- **Screw and slot joint.** In this joint, one piece carries the screw while the other has slots cut in it. The slot takes the head first and then the body of the screw. Screw and slot joints have far more strength than the glue joints.

11. Corner joint. Corner or angle joints can be prepared in different ways other than by using dovetail joints. The common joints are butt joint, mitre joint, rabbeted joint, cross splined joint, splined mitre and mitred and lipped joint.

### 15.15 WOOD WORKING MACHINES

To produce a high degree of accuracy and efficiency, the use of some power driven machines is also necessary in addition to the hand tools described above. The choice of wood working machines depends upon the quality of work required, the quantity of work to be handled and the type of wood to be worked upon. The machines must be used well and wisely, as it requires a different type of skill than what is required for hand tools. Proper safety precautions must be followed while using these machines. Some of the machines commonly used are now described as follows:

#### 15.15.1 Wood Working Lathe

It is also called as Wood lathe and is one of the most important machines used in a carpentry shop. This machine is used to give round and cylindrical shapes to the wood. External and internal taper turning and threading on wood pieces is done with this machine. Other irregular shapes can also be obtained with the help of special form tools.

**Wood Turning Lathe:** This resembles an engine lathe, which is frequently used in a machine shop. It consists of a cast iron bed, headstock, tail stock, live and dead centres, tool rest, cone pulley, motor and speed control device. The work revolves between the centres and the turning is done by a tool, held and manipulated by the operator. The size of the wood lathe is given by its swing and the maximum distance between its centres. A lathe with 300 mm swing will accommodate a piece of stock as large as 300 mm in diameter and a lathe, with 900 mm between centres, will take a piece that long.
The wood turning tools are specially shaped to make particular cuts. A dull tool is useless, and if used, will produce dust instead of wood shaving. Therefore, the tools must be sharpened frequently, especially, when used on hard wood. The sharper the tools, the easier is the turning. The types of tools used are round nose, spear point, gouge, parting tool and skew wedge chisel. The tools are made of high carbon steel having 0.8 to 1.0% carbon, and are hardened as well as tempered.

15.15.2 Band Saw

A band saw is one of the most versatile machines. It has an endless band (blade), travelling around two or more wheels like a flat belt moving around two pulleys.

The travelling blade makes a continuous cut in the downward direction. It can cut thick or thin stock in straight lines or curves. Apart from the moving blade, the other important part of a band saw is a cast iron table on which the stock is placed and fed to the moving band. The band passes through the centre of the table, having a slot for the free movement of the band. Two guides are provided, one above the table and one below it, to keep the band straight and true. These prevent the band from buckling and running off the wheels. All these parts are housed in a cast iron frame, and for the safety of the operator and others, a wire fence is fitted around the saw.

A band saw is available in two models (a) vertical and (b) horizontal. In a vertical band saw, the two wheels are arranged one above the other, and the moving band cuts the stock in the downward direction. On the other hand, in the horizontal band saw, the two wheels are placed beside by side on the table, and the moving band cuts the stock in the horizontal direction. The table can be tilted to any angle for angular cuts. The size of the band saw is given by the distance from the saw band to the inner side of the frame, e.g., a band saw of 300 mm size, will cut up to the centre of a 600 mm diameter circle.

The blades of a band saw are available in various widths and with different numbers of teeth per mm. Generally, the blade used is as wide as possible with fewer teeth. However, more teeth are needed to cut thin materials. Fine teeth cut heavy stock slowly because the extra friction overheats the blade, and makes it blunt. A narrow blade is used for sharp cuts because a wide blade can get stuck and snap into two pieces.

15.15.3 Circular Saw

A circular saw is one of the basic machines used for wood working. It is also known as a table or bench saw. A number of operations like ripping, mitering,
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beveling, crosscutting, rabbeting and chamfering can be done on this machine. Some other operations like tapering, dedoeing, molding, sanding and shaping can also be done on this machine by using some special attachments.

There are many types of circular saws such as a universal saw, variety saw and bench saw. The principal parts of a circular saw are the frame, arbor, table, circular blade, cut off guide, ripping fence and guard. The circular saw can be either of tilting table type or tilting arbor type. To make certain tilting arbor type, a circular saw is always recommended. The blades of a circular saw are designed for specific cuts such as rip and cross cut. A rip blade is only used for ripping, and cross cut blade for cutting across the grains of wood. A combination of blades is used for general purposes. Blades are made of high carbon steel whereas some blades have tungsten carbide tipped brazed on it. The size of a circular saw is specified by the diameter of the blade; the usual sizes are 200, 250 and 300 mm.

15.15.4 Radial Saw

It is an upside saw, having the motor and blade suspended, above the work, rather than below it. The blade can be raised, lowered, turned or tilted to make different types of cuts. The saw is operated with one hand by gently moving the motor through the work by a convenient handle.

Radial saw requires three adjustments. The depth of cut is determined by lowering or raising the arm at the shoulder. The direction of the cut is set at the elbow by swiveling the motor to any angle upto 360° to cross cut, rip and miter. The motor and the blade can be tilted to any angle for the bevel cut.

The stock in this case remains stationary on the table. This makes it especially convenient for certain cuts. Various attachments are fixed on the radial saw to use it as a shaper, sander, saber saw, wood lathe and drilling machine. The size of the radial saw is specified by the diameter of the blade.

15.15.5 Jig Saw or Scroll Saw

The jigsaw or scroll saw is used for cutting fine internal and external curves on the sheets. With a tilting table, it can make angular cuts. The main parts of a jigsaw are the base, frame or arm, table, upper and lower chucks, guides and tension assembly. The stock is held in the guide assembly. Chucks hold a short blade about 125 mm long with its teeth pointing downward. The rotary motion of the motor is converted into a vertical up and down motion of the blade, cutting only in the downward stroke. The size of a jigsaw is specified by the distance between its blade and arm.

15.15.6 Jointer

A jointer smoothens and straightens the edges and faces of wood as we do with a hand plane. It is also known as a jointer plane. It does very accurate work and is best suited for production work. This machine can rabbet, bevel, chamfer and taper also. It consists of a long revolving cutter head to which three cutting knives are fixed, which, if turned at a speed of 5000 rpm, will give 15,000 cuts per minute, which is impossible by a hand plane. This high speed is responsible for the smoothness of the cut.

15.15.7 Wood Planer

A planer is a machine in which wooden planks and boards are planed automatically to a desired thickness. The stock is fed by means of rollers into the throat of the planer against a revolving cutter. When the cut is completed, the stock is released on the opposite side of the table. It is essential to hold the stock as it leaves the cutter, otherwise, the end can receive an extra deep cut as the free end drops. To accommodate longer and wider stocks, the table of the planer is made much wider and longer as compared to the jointer.

The size of the planer is specified by the width of the stock, which can be accommodated. The common sizes are 300, 450 and 600 mm.

15.15.8 Wood Shaper

The vertical spindle shaper is used for cutting shaped edges, moldings, picture-frame stock and grooves of various shapes. To get the required shape, cutters of
work holding device and various controls for longitudinal table feed, cross feed and vertical table traverse. The mortising head carries two chucks. The upper chuck grips the auger bit whereas the lower chuck holds the hollow chisel. The auger bit revolves at a very high speed inside the hollow chisel.

The chisel is brought down and pressed into the wood by a foot lever. The auger bit and the chisel work together to make a square hole. The rotating bit cuts a round hole and the square chisel cuts off the corners as it is forced through the hole, thus, making all the sides and the bottom square in shape. The longitudinal, cross-ward and vertical up and down movement of the table, facilitates the proper centering of the job and also helps in accommodating stock of different sizes.

(c) Oscillating Bit Mortiser: The oscillating bit mortiser carries a router bit, which makes a comparatively smaller hole with flat bottom. The mortise so produced is suitable for small cabinets and chair work.

15.15.10 Drill Press

Drill press is another important machine in a wood working shop. Though it is designed for drilling accurate holes quickly, but, with many attachments, it can be used for boring, routing, mortising, sanding, shaping, counter sinking and even for planing wood. It can be a hand- or foot-operated machine, having one or several spindles, which permit drilling several holes simultaneously. The size of a drill press is given by the distance from the centre of the drill bit to the post. The speed can be varied by shifting the belt on different steps of step pulleys. The table can move up and down and can tilt for angular drilling.

15.15.11 Sanding Machines

Sanding machines are used to produce smooth surfaces on wooden articles. The sanding machines use abrasive paper or cloth, and is set into motion to do light sanding work. Stationary sanding machines use disc, belts, sheets and sleeves, while portable sanding machines use discs, belts or sheets. There are many types of sanding machines. Some of the common types of sanding machines are:

(a) Disc Sander
(b) Belt Sander
(c) Drum Sander
(d) Spindle Sander.

(a) Disc Sander has a flat disc to which abrasive paper is cemented and is driven by a motor. The work is laid on the table and moved forward and backward across the revolving disc. The disc sander does not require any adjustment except that the table has to be tilted to sand surfaces that are inclined.
(b) **Belt Sander** consists of an endless abrasive belt moving over a pair of drums. It can be used to do sanding on ends, edges, surfaces, inside and outside curved surfaces, etc. The moving belt is pressed against the work by applying pressure on the backside of the belt with the help of a pressure plate held in the hand.

(c) **Drum Sander** is a horizontally revolving cylinder about 300 mm in diameter over which the abrasive material is clamped. Both inside and outside curves and flat surfaces can be finished on this machine.

(d) **Spindle Sander** is a small version of a drum sander. It is set vertically and the spindle revolves and moves up and down. Its table can be tilted for sanding inclined surfaces.

### 15.15.12 Grinding Machines

In smaller wood working shops, hand operated emery wheel meets the need for a grinding machine but in the bigger shops that mass produce, an electric grinder, complete with interchangeable abrasive wheels of varying coarseness, is used as a sharpening device. It consists of two grinding wheels, fitted on a common spindle of an electric motor. One of the wheels is used for coarse grinding while the other for fine grinding.

Edged tools like chisels and plane blades require grinding only when the edges become round after repeated honing. To form a new cutting edge, it is necessary to **hollow grind** the edge on a power grinder. For a proper slant edge, adjustable guides are provided to hold the tool while grinding. The cutting edge is moved from side to side, while the grinding wheel turns into it and a hollow bevel is produced.

### 15.16 PORTABLE MACHINE TOOLS

The portable machine tools have replaced many hand tools in recent years. These tools are easier and more efficient than the hand tools. Most of these tools are two handed-tools; this increases the control on the tool, thus, rendering them safer to operate. These tools must be earthed properly unless they are battery operated. The common types of portable machine tools are described below:

#### 15.16.1 Electric Hand Drill

It is a very useful portable machine and is widely used by carpenters. It can drill holes and can accommodate many attachments such as a disc and belt sander, a screw driver, a saber and circular saws, buffers, polishers, etc.

#### 15.16.2 Saber Saw

It is one of the handiest machines, which cross cuts, tips and cuts scrolls in wood, boards and plastics. It must be carefully guided by hand and pushed ahead with optimum pressure otherwise too much pressure can break its blade. The cutting action of a saber saw is extremely rapid, as high as 3300 strokes per minute. The most important feature of this machine is that it can cut its own starting slot inside the edge of a board or plywood. With the saw nosed over to a perpendicular position, the tip of the blade simply scratches into the wood until a slot is made throughout. Then, the saw is brought down to rest on the surface of the board, where it continues to cut along the internal outline. A variety of
blades are available which can be quickly interchanged to cut other materials and even metals. Some saber saws have the advantage of a tilting shoe, mounted on a calibrated quadrant, which permit bevel cutting.

15.16.3 Portable Power Router

It is a portable shaper which moves over the work instead of the work being moved through the cutter, as happens in the case of a regular shaper. It is light enough to be held in the hands and guided freely over a surface for carving and routing. With a special jig, dovetail joints are easily and accurately made. The spindle of the router revolves at a very high speed, which enables the cutter to produce an entirely smooth machined wood finish that does not require sanding.

15.16.4 Portable Electric Hand Saw

The portable electric hand saw is useful for cross cutting, ripping, mitering, grooving, rabbeting and dadoing. Portable saws are fully adjustable for cuts of different depths. The main parts of a portable saw are the motor, blade, handle with trigger switch, safety guard, rip fence, and bevel adjustment mechanism and the base plate. The size of the machine is determined by the diameter of the blade, which ranges from 125 to 300 mm. The portable hand saw cuts upward as the teeth of the blade point upward.

15.16.5 Portable Power Sander

The portable power sanders are very useful as they have the advantages of doing different jobs. They are available in many types, each suited for a particular type of job. A range of abrasives is available to fit into each type of sander depending upon the work to be performed. The different types of portable sanders are belt sander, disc sander and orbital sander.

(a) The portable belt sander is one of the most useful machines as it surfaces the wood in minimum time due to its endless abrasive belt moving on the rollers. The rapid sanding action of a belt sander produces a lot of wood dust, therefore, a dust collecting bag is attached to the machine. This machine must be allowed to sand freely under its own weight because any pressure applied by the operator may damage the work of the machine.

(b) The portable disc sander has a direct or right angle drive, and the sanding action is so fast and effective that it can be used for shaping wood as well as sanding.

(c) The orbital sander, can produce a fine finish at a faster rate. The abrasive base pad makes about 4500 orbits per minute. This is a light and easily handled useful tool. It can finish those tight corners where other types of portable sander do not reach.

**SUMMARY AT A GLANCE**

(1) Wood suitable for construction and engineering purpose is known as timber, may be in the form of standing or stationary trees. After felling, it is known as rough timber and when it is sawn to various marketable forms such as beams, battens and planks etc. it is called converted wood. Joinery deals with the specific work of joints to form a final product.

(2) The trees are categories into following three classes such as:

(a) Endogeneous or inward growing trees like banana, cane, palm and bamboo trees. These are light and too flexible.

(b) Exogeneous or outward growing trees and these are further classified as:

   (a) Conifers or evergreen trees.

   (b) Deciduous or broad leaf trees.

   Trees such as deodar, pine, chirr & kail belong to evergreen category whereas teak, sal, shisham, oak, mahogany, mango, neem and babool etc. are exogenous.

(c) Growth of timber takes place due to formation of sap which is thick layer forming layer of wood called cambium layer which gains strength with passage of time thus producing an annular ring.

(3) The important parts of endogenous tree are: Medulla, annular rings, heart woo, sap wood, cambium layer, medulary rays and bark or cortex.

(4) There are two types of wood i.e. hard wood and soft wood. Popular hard wood trees are mahogany, sal, babool & shisham where as deodar, pine, chirr and teak fall in category of soft wood.

(5) Growth of timber is virtue of absorption of salt from soil which are transmitted to leaves through branches and truck during spring season. This solution absorbs CO₂ from atmosphere and becomes viscous on exposure to sun rays. Such solution known as sap descends below the back forming a thick layer of wood during the autumn season. It gains strength with passage of time.

(6) Cross section of a exogenous tree consist of following important parts i.e. Medulla. Annular rings: Heart wood, Sap wood, Cambium layer, Medullary rays, and Bark or Cortex.

(7) Types of wood: soft & hard.

(8) Characteristics of good timber are: should be strong & heavy but easily workable. Should possess uniform dark colour with close fibers, should form the heart of tree & free from knots & twisted fibers etc. Should not crack on insertion of nails and planning it should give a firm bright appearance with silky luster.
As far as defects in timber are concerned, these are of two types:
(a) Natural defects developed during the growth of the tree.
(b) Defects developed after felling of the tree.
The natural defects are: Heart shake, Star shake, Cup shake, Twisted fibers, Ring galls, knots and coarse grains. Defects developed after felling of the tree are: Dry rot, Wet rot, Case Hardening and Honey combing.

Seasoning of wood is related with removal of considerable quantity of sap contained in it. If this sap is not removed, the timber is likely to warp, shrink, crack or decay. Seasoning is the technique of extracting sap under controlled condition at a uniform rate from all parts of timber. The following two methods are employed for seasoning of wood i.e. Natural seasoning & Artificial seasoning.

Commonly adopted methods of sawing the timber are: Flat or Slab sawn; Quarter sawing, Radial sawing.

The common varieties of Indian timber are Babool, Deodar, Chir, Sal, Teak, Shisham, Mango, Walnut, Kail, Mahogany and Mulberry converted timber available in market are: Log, Balk, Plank, Deal, batten, Beard, Scantling, Beam and veneer.

Timber is preserved by application of various preservatives such as: Tar oils, Water soluble chemical salts and organic chemicals.

Adhesives used in timber joinery are: Animal glue, Resin glue, Casein glue, Vegetable glue, Blood albumen glue, Gum Arabic, contact cements, and plastics cements. Other jointery materials used in timber industry and for reinforcing glues are: Nails, Screws, Bolts & Nuts and Dowels.

Hand tools used in carpentry fall under the following categories:
(a) Measuring Tools.
(b) Cutting Tools.
(c) Planning Tools.
(d) Striking Tools.
(e) Boring Tools.
(f) Holding Tools.
(g) Miscellaneous Tools
(h) Sharpening of Cutting Tools.

To shaping a work to required shape and size in a wood working shop, the following processes are utilized: Marking & laying out: Sawing, planning, chiseling, Mortising & Tenoning, Boring, Grooving & Tonguing, Moulding, Rebutting, Recessing and Cutting Dadoes.

Joints used in Carpenter work are: Longitudinal joints, Widening joints, Framing joints, Box joints, Circular joints, Halving joints, Mortise & Tenon joints, Bridle joint, Dovetail joint and Butt joint.

Various wood working machines used in carpentry shop are: Wood working lathe, Wood turning tool: Band saw, Circular saw, Radial saw, Jig saw jointer, wood planner, Wood shaper, Mortiser, Drill press, Sanding machine, and Grinding machines. Various portable machine tools used for carpentry work are: Portable electric drill; Saber saw,

Portable power router, Portable electric hand saw and Portable power sander.

REVIEW QUESTIONS

(1) Differentiate between hard and softwood with their characteristics.
(2) Enlist and describe the various methods of seasoning of timber. Which method is best and why?
(3) What are the characteristics of good timber?
(4) Enlist and discuss in brief, the various defects in timber.
(5) Describe the various methods of preservation of timber in brief, and why is it essential.
(6) What are the commercial sizes of timber sold in the market?
(7) Discuss in brief with the help of neat sketches the various measuring and marking tools used in a wood working shop.
(8) Describe with neat sketches, the construction and uses of the following tools in carpentry shop:
   (i) Different Saws
   (ii) Parts of a chisel and its types
   (iii) Various planing tools
   (iv) Striking tools
   (v) Boring tools & miscellaneous tools
   (vi) Holding Tools
(9) Name and discuss in brief, the various wood working processes.
(10) What is meant by the term ‘joinery’? Give the classification of joints used in wood work. Explain them in brief.
(11) Describe, with the help of a neat sketch, the construction and working of a ratchet brace.
(12) Describe with the help of a neat sketch, the working of a wood working lathe.
(13) With the help of a sketch, describe the construction and working of the following:
   (i) Circular Saw
   (ii) Radial Saw
   (iii) Band Saw
(14) Discuss the various portable machine tools used for wood working.
(15) Enlist and explain the various adhesives used in timber joinery work. Name and explain the other joinery materials used for joining wood and for reinforcing glued joints.
24. What are conversion coatings? Discuss their types and applications.
25. What are phosphate coatings? Where are they used?
26. What are chromate coatings?
27. Discuss anodic coating. How is it done and where?
28. What are organic coatings?
29. Write a short note on:
   (a) Oil paint,        (b) Varnish and
   (c) Lacquers
30. What are rubber base coatings? Where are they used?
31. What are fluorocarbons coating? Discuss their application.
32. Why primer or primary coating is required?
33. Name various methods of application of organic finishes.
34. Describe powder coating.
35. What is electrostatic spraying? Discuss with application.
36. What are metallic coatings?
37. Name the common methods of applying metallic coatings.
38. What is hot dipping? Where is it used?
39. What is electroplating? Describe various types of electroplatings.
40. How plastics are plated?
41. What is galvanizing?
42. Describe tin plating.
43. What do you understand by metallizing?
44. What is metal spraying?
45. Describe wire metallizing.
46. What is powder metallizing?
47. Describe the process of vacuum metallizing. Where is it used?
48. Discuss the advantages of vacuum metallizing process.
49. Describe anodic coating.
50. What is sputtering?

CHAPTER 15
Bench Working: Fitting and Traditional Sheet-metal Working

15.1 INTRODUCTION

Bench working involves the use of hand tools like hacksaw, chisel, file, scraper, taps, dies and a variety of making and measuring instruments for performing various bench working processes like cutting, chipping, scraping, threading, etc. on metal pieces. A fitter is supposed to have a sound knowledge of these tools and instruments and a good practice on their use. The bench working processes are mostly carried out on a job held in a vice fitted on the fitter’s working table. But sometimes the use of these processes and hand tools for site works proves quite effective and useful because of the flexibility and ease they provide in tackling difficult situations, particularly where power operated machines may not be used. Further, it is possible to obtain an excellent finish and accuracy in the dimensions of the job by resorting to bench working operations, for example, workpieces machined on a shaper or milling machine are often sent for further finishing by hand filing and scraping to remove tool marks from the machined surfaces and to get a better finish. ‘Bench working’ and ‘fitting’ are the two terms often used synonymously. While bench working, as has been explained above, is related to the ability and practice on the use of various hand tools and instruments in conducting operations of filing, chiseling, threading, scraping, etc., ‘fitting’ in its strict terms is concerned with the process of joining two or more components to form an assembly wherein a required ‘fit’ (or relationship) between the mating components of the assembly is ensured as the functional requirement of the assembly. The trade of bench working and fitting has attained an indispensable status in the whole gamut of engineering works whether related to manufacturing, repair and maintenance and rebuilding of machines. The shop where fitting and bench working operations are conducted is called a fitting shop.

15.2 BENCH WORKING PROCESSES

Bench working processes comprise all those processes or operations which relate to cutting, filing, drilling, reaming and threading of metal pieces and are accomplished with the help of
hand operated bench working tools or the fitter’s tools such as hacksaw, chisel, file, scraper and tap and die. These are conducted on the metal piece to bring it to the desired shape and size of a product, which may form part of an assembly of a device or machine or may find some other direct use. Various bench working processes have been discussed under the following broad classification.

(i) Laying out and marking processes
(ii) Cutting and chipping processes
(iii) Filing and finishing processes
(iv) Drilling and reaming processes
(v) Threading processes
(vi) Measuring processes
(vii) Fitting and assembling

15.2.1 Laying Out and Marking Processes

The raw material in a fitting shop is received in standard market sizes of different sections like angles, channels, rods, flats and plates. A ‘blank’ which is a rough form (of the product to be made) in shape and size is first cut from the available stock. For this, marking and laying out of the blank profile is first done on the stock to provide guidance for cutting the blank from the stock as per the markings. Cutting may be done using a hand shear, reciprocating power saw, chisel and hammer and sometimes even oxy-acetylene flame. The edges of the cut blank (or blanks) are finished by grinding or filing. The cut blank is straightened if it is bent. It is then prepared for marking and laying further details to help subsequent bench working operations.

Laying out relates to developing a guiding profile of the product to be made on the blank and it is achieved by marking or scribing centre points, circles, angles, straight lines, centre distances between holes. Operations of cutting, filing or drilling are later carried out on the blank along these markings. Accuracy is the most important factor in marking a layout, because once a workpiece or blank has been marked out, all the subsequent operations of cutting, filing or drilling, etc. will be done only on the markings. Tools used for marking generally include surface plate, scriber, surface gauge, divider, centre punch and hammer, angle plate, V-block, parallels, clamps, trammels and combination set. The help of a number of measuring instruments like steel scale, callipers, micrometer, bevel protractor and sine bar is taken for measuring dimensions and angles during the process of laying out and marking.

15.2.2 Cutting and Chipping Processes

Cutting and chipping are the two main bench working operations used for removing excess metal from a blank. Cutting is performed with a hacksaw and is done either to cut the blank into pieces or to reduce it in size by removing a part of metal (Fig. 15.1). Similarly, chipping is done to shape the blank by removing extra metal from its edge for reducing it in size. Chipping is also done to cut a chase or slot on the sides (faces) or edges of the blank. The operation of chipping is performed with the help of a chisel driven into the metal with hammer blows (Fig. 15.2). Chipping is also used to cut rivets or nuts which get jammed due to rusting. The chisel and the hammer are sometimes used to cut flats, angles, plates, bars and rods. The process is often used for cutting blanks in the steel yard or store.

15.2.3 Filing and Finishing Processes

Filing is done for bringing to correct size the blanks cut by hacksaw, chisel, or any other method. Besides bringing the job to correct dimensions, filing is also done for imparting a good finish on the faces and edges of the job (Fig. 15.3) which may be flat, slant, curved or circular. This is achieved with files of different shapes and sizes. The files used in the finishing operation have hardened cutting teeth on their faces and edges to cut the metal when the file is pressed and pushed against the job surface.
Finishing is the operation of giving a smooth surface finish on the job free of surface marks, scratches and undulations. Finishing may be done on grinding machines of different types but in a fitting shop, the operation of finishing is accomplished usually with the help of a smooth file and 'draw filing' technique [Fig. 15.19(c)]. Hand scrapers of different types are used for truing flat and curved surfaces by removing high spots on the job surface left during filing or machining operations like shaping, planning or milling. Hand scrapers of different types are shown in Fig. 15.20.

15.2.4 Drilling and Reaming Processes

'Drilling' is the operation of making a hole and 'boring' is the operation of enlarging (in cross-section) the drilled hole. Drilling is done by employing a rotating tool called 'drill', which is pressed into the workpiece to make a hole. Drilling is performed by employing different types of drills such as twist drill, straight fluted drill or flat drill but a twist drill (Fig. 15.21) is most common. Drilling is done with the help of a portable drilling machine (Fig. 15.4) or a bench drilling machine (Fig. 6.31(b)). Drilling with ratchet brace (Fig. 15.5) is sometimes done on large size job which cannot be brought to the drilling machine and the portable drilling machine is either not available or may not be used for some reasons. Boring can be done by using either a bigger size drill or a reamer. The reamer is a precision tool and removes only small amount of metal (Fig. 15.6). Reamers are available in different types and sizes. Reaming is primarily done for sizing and finishing the drilled holes. It is also sometimes used for increasing the diameter of a drilled hole slightly to help fitting a male mating part in the hole.

![Fig. 15.4 Portable electric drilling machine.](image)

![Fig. 15.5 Drilling with a ratchet brace.](image)

15.2.5 Threading Processes

Threading is the operation of cutting threads (or screws) on a workpiece. Threading involves cutting of internal threads with the help of 'taps' and external threading using a 'threading die'. The tap (Fig. 15.7) has hardened cutting teeth. A hole is first drilled, little smaller in size than the size of tapped hole (to be made). The tap is inserted into the drilled hole and rotated with the help of a tap wrench or a handle fitting on the squared shank of the tap. A threading die (Fig. 15.8) is shown in Fig. 15.8. It has a split nut (with cutting teeth) fitted in the die stock. The die stock (usually a rod or pipe) is held in a bench vice and the threading die stock is mounted at the end of the rod where threads are to be cut. The die stock when rotated with its handle moves the rod leaving behind the cut threads.

![Fig. 15.7 Tap for cutting internal threads.](image)

![Fig. 15.8 Die-set for cutting external threads on rods and pipes.](image)

15.2.6 Measuring Processes

Measuring, or measurement of, dimensions, surface finish, level or plainness or trueness of surfaces are important operations carried out by a fitter using various marking and measuring instruments. These instruments not only help in laying out job profiles or working guide on workpieces to the required specifications, they also make possible comparing the fini...
work with the given dimensions, inspection and checking of alignment, trueness or flatness of surfaces and the surface finish on the job. The marking and measuring instruments are of various types according to the function they perform, for example, for the linear measurement, instruments used include steel scale or rule, dividers, callipers, surface gauge, and micrometer. For the angular measurement, instruments used are bevel protector, sine bar, combination set, etc. for measuring planneness of a surface, instruments used are level, straight edge, surface plate, dial indicator and gauge blocks.

15.2.7 Fitting and Assembling Processes

The processes of ‘fitting’ and ‘assembling’ are in a way complimentary to each other. While ‘assembling’ is related to the process of joining together two or more parts to form an assembly, the process of ‘fitting’ essentially aims at making the assembling process possible by trimming, filing or scraping the mating parts, so that they could be assembled and fitted together easily. Another essential feature of the operation of fitting is ensuring a required ‘fit’ (or the relationship) between the mating parts of the assembly as the functional requirement of the assembly. Fitting is a regular process being carried out at various stages of mass production through forming subassemblies of mechanical components. In the final stage when these subassemblies are fitted and joined together, they result into the final machine in the marketable form. Later, during the use of machines, fitting is carried out for the maintenance, repair and replacement of worn out parts.

15.3 BENCH WORKING TOOLS

Bench working tools, also called ‘fitting tools’ or ‘fitter’s hand tool’, have been discussed under the following broad headings:

(i) Job supporting and holding tools
(ii) Striking tools
(iii) Cutting and finishing tools
(iv) Drilling and reaming tools
(v) Threading tools
(vi) Laying out and marking tools and measuring tools
(vii) Miscellaneous tools.

15.3.1 Job Supporting and Holding Tools

Job supporting and holding tools are the devices which help in supporting or holding the workpiece in a position for carrying out on it various operations like cutting with hacksaw, filing, chipping, drilling, reaming, etc. These include fitter’s working table, vices, V-block and clamps.

Fitter’s working table

The working table for fitting jobs should be quite durable and sturdy. Table legs are made of cast iron and the top is made in hard wood. Full wood construction is also used. The table length is kept according to the space available, usually about 1.5 to 3 metres and width about one metre.

The height of the table is also about one metre up to the top of the bench vice fitted on the table. Generally, the top of the vice should level with the elbow of the man or should be kept a bit lower. Shelves or rakes are also provided with the table to keep the tools of frequent use.

Vices

A vice is used for gripping and holding a workpiece in position for carrying out on it various bench working operations. Bench vice (also called engineer’s parallel-jaw vice) is the most commonly used vice shown in Fig. 15.9. The parallel jaws of the vice enable the job to be held in a position which is most suitable for conducting operations like sawing, chipping, filing, or scraping on the job. The vice consists of a cast steel body which carries a fixed jaw at its top and a movable steel jaw with its body capable of sliding inside the hollow of the fixed jaw box through a screw and box nut arrangement. This way, a job can be easily gripped tightly between the two jaws and also taken out of the vice by rotating the screw handle in proper direction. The vice is mounted on the working table and rigidly connected there by bolting the fixed jaw base with the table. The fixed jaw can have a rigid type base or a swivel type base. The swivel base provides flexibility of rotating and setting the vice at any desired angle to provide ease in handling jobs. Two hardened steel jaw plates with serrations (teeth) are screwed on the inner faces of the two jaws, one on each jaw, to improve the gripping power of the jaws when the job is clamped between them. Sometimes when a finished job is held in the vice, jaw covers made of copper, brass or aluminium are used to protect the finished surfaces of the job from being damaged due to the tight grip of hardened and serrated jaw plates.

Other types of fitter’s vices include (a) Pipe vice, (b) Leg vice, (c) Pin vice and (d) h.

pipe vice [Fig. 15.10(a)] is used for holding pipes and round bars and is generally employed for plumbing work like cutting of external threads on the pipes using a pipe threading die. Leg vice has a strongly built forged steel body [Fig. 15.10(b)] and is of very sturdy construction. It is most suitable for carrying chipping out operations on the job. The leg vice is used in smithy shop as well where it withstands against the blows of larger hammers. Pin vice [Fig. 15.10(c)] is used by watch-makers or instrument repairers. It carries a small collect chuck to hold the job which may be a pin wire, nail or such other small components. The three jaws of collect chuck are opened or closed simultaneously by rotating the handle.
Hand vice [Fig. 15.10(d)] is used by tool-makers for holding small items like wire and sheet metal pieces for filing. It is very handy for making keys for the locks.

V-block and clamp [Fig. 15.11(a)] is yet another device employed for supporting and holding the round work for drilling or marking [Fig. 15.11(b)]. V-Blocks are often used in pair. These are made of steel with faces hardened and ground perfectly, square and parallel. Two or more V-blocks can be used for gripping long jobs with the help of U-clamps.

**15.3.2 Striking Tools—Hammers**

A hammer comprises a striking head of steel and a wooden handle [Fig. 15.12(a)]. It is used for striking either a chisel during chipping and cutting operations or a centre punch during marking. Hammers are also used for several other purposes like driving nails in the wood, punching holes in sheet metal, setting and fitting (tightening) of assemblies (or joints), driving of wedge and flattening and straightening of uneven surfaces and also sometimes bending sheet metal and plates, flats and other steel sections. The hammers used in a fitting shop normally weigh between 0.45 kg to 0.7 kg. A hammer has four parts, peen, eye, cheeks and face. The ‘peen’ is the rounded top part of the hammer slightly tapered from the cheeks. When the top part is of ball shape, it is called ‘ball peen’. The ‘face’ is hardened and polished at the edge rounded off to avoid the possibility of giving impression on the job due to the presence of sharp edge. ‘Eye hole’ is usually oval or elliptical in cross-section (Fig. 15.12(b)) to accommodate handle made of hard wood like shisham, or bamboo. After the handle is fitted into the eye, a steel wedge is forced into the handle to prevent slipping out of the hammer head from the handle during striking.
The hammers can be broadly classified as hand hammers or smith hammers. A hand hammer is a small and light tool used by fitters and weighs between 0.45 kg to 0.7 kg. The hand hammers used by a smith are called 'smith's hand hammer' and these weigh between 1 kg to 1.8 kg. Sledge hammers are larger in size and heavier, weighing between 3 kg to 8 kg and are mostly used in smithy shop, or when heavy blows are needed in a fitting shop for straightening steel plates or flats. For using a sledge hammer, the help of a separate man (called hammer man) is required.

Types of hand hammer include (i) Ball peen, (ii) Cross peen and (iii) Straight peen hammer. [Fig. 15.12(b)].

The ball peen hammer is the most widely used hammer for general purpose like laying out, riveting, chipping and forming. Its peen is ball shaped and its face is hardened keeping the middle portion (eye hole) un-hardened to absorb shocks of hammering. Cross-peen hammers are used in fitting shop for heavy works and in smithy shop for hammering and spreading metal. The cross-peen hammer has its peen like a wedge which is perpendicular to the handle of the hammer. The straight peen hammer is also preferred for smithy work for swaging and riveting. Its peen is parallel to the handle.

The hammers commonly used by smiths are either slightly heavier ball peen hammers or light weight straight peen sledge hammers weighing between 1 kg to 1.8 kg. The ball peen hammer is used for general purpose smith's jobs of light nature such as fullering. The sledge hammer is used for jobs which require heavier blows.

Sledge hammers are of straight peen, cross-peen and double faced type [Fig. 15.12(c)], weighing between 3 kg to 8 kg.

Soft hammers are classified (i) Raw hide, (ii) Mallet, (iii) Brass, (iv) Plastic and (v) Rubber hammers. Metal workers use these light weight soft hammers for forming soft metals. In machine shop and fitting shop, these hammers are used when it is required to strike machines and finished parts during repair or assembling.

15.3.3 Cutting and Finishing Tools

The cutting tools are those which are used for shaping the blank to a suitable size and shape of the article to be made by cutting or separating extra metal from it through shearing, sawing, chisel cutting and chipping.

The tools used for cutting include hand shearing machine, circular saws with indexable carbide teeth or abrasive circular saws, power hacksaw, hand hacksaw, chisel, and hammer. The primary use of the shearing machine and reciprocating power saw is in cutting blanks for job from the main stock of the raw material which may be in the form of standard length steel structural like angle, channel, flat, etc. Hand operated shearing machine is used for cutting flats, angles and rods of smaller size, for example, flats up to 12 thickness. Power hacksaw is yet another machine used for cutting blanks from various structural of different size; a machine capable of cutting round bars or square sections up to 150 mm size is quite common. Circular saws are used for mass cutting of metal. The main tool of cutting machine used by a fitter include hacksaws, chisels and hammers. Only hacksaws and chisels will be covered in the following description of cutting tools. The hammers have already been discussed.

The finishing tools are also in a way the cutting tools but these remove only very small amount of metal and are therefore used for finishing purposes only. Filing is done to correct dimensions through filing the job surfaces which might have been rough cut by saw, chipping or shearing and for imparting a good surface finish to the workpiece by removing scratches and tool marks. Besides the files, hand scrapers are also used as finishing tools.

Hacksaws

'Sawing' is a multipoint cutting operation accomplished with the help of a 'hack saw', which is a blade with cutting teeth along one longer edge (Fig. 15.1). Since sawing is a primary operation, the body of the cutting blade should be kept as thin as is practical to avoid waste material in the cutoff operation, yet the blade should be rigid enough to support the cutting forces. During cutting, heavy pressures are required to obtain a cutting action from each tooth throughout the length of the cut. Sawing gives a fairly smooth and flat surface with a slight burr. Hack sawing is used for cutting rod, strips, flats, bars, angles, channels, metal sheet and into desired length. It is used for cutting through castings and other members of structural machines.

The hacksaw consists of a steel frame, a wooden handle at one end and a wing nut threaded metal clip at the other end and a cutting blade [Fig. 15.13(a)]. The cutting blade holes, one at both ends, to fit with the frame of the hack saw through two pins, one in the handle side and the other fitted with the threaded metal clip such that by rotating the nut, the blade can be tightened or loosened in the frame. The hacksaw frame may be 'fixe-
The hacksaw blades are made of hard and tempered alloy steel with ‘set teeth’. ‘All hard’ grade blades are hardened all over. These are used for cutting hard metals such as cast iron. The ‘flexible’ grade blades have only hardened teeth whereas the remaining portion of the blade is made tougher and flexible by tempering. The flexible types are more commonly used. The blade thickness is about 0.7 mm, width 12.7 mm and length (between the two holes) may be 20, 25 or 30 cm.

**Pitch of blade**, i.e. the distance between the two teeth, may be (a) **coarse group** having 5 to 7 blades per centimetre and (b) **fine group** having 8 to 12 teeth per centimetre length of the blade. Blades with different pitch are used for cutting different materials. The following is recommended for general guidance.

(i) About 13 teeth/cm—Thin sheet metals, thin tubings, conduits
(ii) About 10 teeth/cm—Sheet metals with medium thickness, pipes, brass, copper, iron pipes
(iii) About 7 teeth/cm—General cutting of steel, cast iron, aluminium, gun metal
(iv) About 6 teeth/cm—Soft steel, wrought iron, brass, copper, wider or thicker steel sections.

**Teeth of blade** may be push or pull type. Push type blades are those in which during cutting, the teeth always point away from the worker and which cut only in the forward stroke. These are generally used in practice. Details of hacksaw teeth are shown in Fig. 15.13(b). The teeth of the blade are ‘set’ by bending outward to opposite sides such that the resulting width of cut is wider than the thickness of blade. Because of the setting of teeth, the complete width of the blade does not remain in contact with the metal faces during the cutting operation and hence working becomes easier as less force is needed to operate the hacksaw. Besides this, blade life is also increased as friction in working is reduced and so blade wear is reduced.

Fig. 15.13(a) Two types of hacksaws, (i) fixed frame type and (ii) adjustable frame type.

**Pitch of blade**

(i) Straight tooth
(ii) Undercut face tooth

Some hints on using hacksaw are given in the following:

(i) While fixing the blade with the frame, ensure that the teeth are facing away from handle.
(ii) Tighten the blade properly. The job should not be held very high from the vice jaws.
(iii) For easy start of cut, make a V-neck with a file edge at the starting point on the metal and start the cut with easy, light and steady forward strokes.
(iv) No pressure should be exerted in the back stroke.
(v) Use long strokes, 40 to 50 strokes per minute.
(vi) When cut is nearing the end, slow down to avoid hitting your hand when the blade is through.
(vii) A new blade is always thicker than a used one. Try to avoid using a new blade on an old cut.
(viii) If the depth of cut is more than the gap between the blade and the frame, change the position of the blade as shown in Fig. 15.13(c).
Chisels

Chisels of different types (Fig. 15.14(a)) are used for cutting or chipping metals. These are forged out of good grade tool steel bar stock having octagonal or hexagonal cross-section. The cutting edge of the chisel is rough formed by forging and later ground to correct angles (Fig. 15.14(b)). The chisels are employed for cutting metals which may be either cold or hot. A chisel used for cutting hot metal (as in smithy work) is called hot chisel and the one used for cutting metal in cold state (as in bench working and fitting) called cold chisel.

Fig. 15.14(a) Different types of chisels.

Types of chisels according to the shape of their cutting point or cutting edge are shown in Fig. 15.14(a). The width of the cutting edge denotes the size of a chisel. The following are the main types:

(i) Flat chisel
(ii) Side chisel
(iii) Cape or cross cut chisel
(iv) Diamond point chisel
(v) Round nose or grooving chisel
(vi) Gouge or cow mouth chisel

Flat chisel is the most widely used general purpose chisel employed for cutting, chipping large surfaces, cutting of rivets or rusted nuts jammed on a bolt, cutting bars, rods, sheets and many other such similar articles. The cutting edge is slightly ground off for heavy cutting and to avoid the corners from digging.

Side chisel is ground and bevelled on one side only. It is used for cleaning the rough edges of slots (as made by drilling) where flat chisel cannot approach.

Cape or cross-cut chisel has a narrower cutting point than a flat chisel and is used for cutting grooves and key ways. When a wide groove is made in a large flat surface, a cross-cut chisel to cut two parallel grooves and then use the flat chisel to remove the

Approximate cutting angles for cold chisels for different metals are given in Fig. 15.14(b). A general rule, harder the metal to be cut, larger should be the cutting angle of the chisel.

The cold chisels are made from high carbon steel (carbon 0.9%) and the cutting edge hardened and tempered. The head is bevelled to avoid its getting flattened like mushroom to hammering. A mushroom headed chisel may hurt the hand if the chisel is held during chipping or cutting operation. A hot chisel can be made from medium carbon steel as it need not much hardening of its cutting edge as it has to cut metal in plastic state. It also not require tempering as it would be undone and would be of no use because of cutting metal. The other major difference between cold and hot chisel is that the cold chisel has a cutting angle (about 60°) whereas a hot chisel has a smaller cutting angle (about 55° to 60°) for cast steel, 60° to 70° for cast iron, 55° to 60° for mild steel, 50° to 60° for brass and 45° to 50° for cutting copper.
between the grooves (Fig. 15.2). Note that its cutting edge is slightly broader than the blade to keep the blade free to move within the cut made during deep cutting into the metal.

**Diamond point chisel** is made square at the point and then beveled to make a cutting edge. It is used for cutting V-grooves, squaring up the corners of slots, chipping sharp corners and cutting cast iron pipes.

**Round nose or grooving chisel** is used for cutting round or semi-circular oil grooves and channels in the bearing brasses, bushes and for clearing small round corners.

**Gouge or cow mouth chisel** is used for cutting curves or curved surfaces, grooves, etc.

Some hints on using a chisel are in the following:

- When holding a job in the vice for chipping, put a packing of wooden block under the job to prevent its slipping.
- Always watch the cutting edge of the chisel as the chip being removed determines whether the chisel should be raised or lowered to increase or decrease the depth of cut. Never look at the head of the chisel during cutting.
- Never grip the chisel too tightly. Select proper shape and size of the chisel.
- Never use a mushroom head chisel or a dull (blunt) chisel.
- Always chip towards (across) the job with a crosscut chisel and then remove the rest of the rivet with a flat chisel.

**Files**

A file is the oldest cutting tool the development of which dates back to prehistoric times. It is still the principal hand tool used by the fitters either for cutting small amount of metal from the edge or sides of the job for trimming it to correct size or to get a required finish and smoothness on the job surfaces. The files are mostly used in assembling, die making and model work. These are forged out of high carbon steel or tungsten steel with teeth cut upon its body. Having been forged, annealed, ground (or milled to shape) and teeth formed on the file, the files are subsequently hardened and tempered. Files cut in the forward stroke only, i.e. while moving away from the worker.

A file with its various parts is shown in Fig. 15.15. Teeth are cut on the ‘face’. ‘Tang’ is the tapered end of the file which fits into a wooden handle and ‘heel’ is the section of the file wherefrom the tang begins. The ‘length’ of the file is the distance between the ‘tip’ or ‘point’ and the heel and does not include the tang.

![Fig. 15.15 Parts of a file.](image)

**Classification of files:** The classification of the file into different varieties is based on its (a) effective length, (b) geometry of teeth (depth, pitch, etc.) and (c) shape or cross-section of the file.

The **length of files** varies between 10 cm to 45 cm. In common practice, 15, 20, 25 and 30 cm long files are used. The length of the file is selected according to the need of work. For example, files 10 cm and 15 cm long are used for fine work, 15 to 25 cm long for medium work and files above 25 cm length are used for general filing.

**Geometry of teeth** include (a) the cut of file or type of teeth and (b) grade of teeth or pitch (spacing between two teeth).

The **cut of a file** refers to the character of teeth, for example, single cut, double cut, rasp cut or curved tooth (Fig. 15.16). **Single cut files** have teeth in parallel rows running across the face and usually inclined at 60°. Single cut files produce smooth surface finish and are capable of making a keen edge on knives, shears or other cutting implements. ‘Draw filing’ getting very smooth finish is done with single cut files only. **Double cut files** have two sets of teeth, over cut and up cut. The ‘over cut’ is the first of its cuts and is similar to the ‘single cut’ whereas the other, ‘up cut’, runs diagonally across the ‘over cut’. Double cut files are used for fast metal removal and where rough finish is permissible. **Rasp cut files** have a series of individual teeth produced by a sharp, narrow, punch-like cutting chisel during the manufacture of these files. Rasp cut files give extremely rough cut and are used on wood, aluminium, brass and other soft metals for fast removal of material. **Curved tooth files** are seldom used except for filing flat surfaces of aluminium and steel sheets.

![Fig. 15.16 Different cuts (or types of teeth) of a file.](image)
Processes each stroke of the file. A bastard cut file has 12 teeth per centimetre and thus has less coarse teeth than the rough cut file. A second cut file has 16 teeth per centimetre and is a medium pitch file. It gives better finish than the bastard cut file. A smooth cut file has 20 to 24 teeth per centimetre and thus has fine pitch teeth giving more smooth finish. Another version of it, the dead smooth cut file has 40 or more teeth per centimetre and gives exceedingly smooth finish on the job.

The pitch of teeth usually varies as per the length of the file, for example, smaller the file, finer the pitch, and longer the file, coarser the pitch. The files with various grade may have either single cut or double cut teeth.

Cross-section or shape of file is an important consideration in selecting a file for working on jobs having different shapes like flat, triangular, curved or round. Files are also classified according to their shape such as flat, hand (safe edge), square, round, triangular or three square, half round and knife edge. Figure 15.17 gives different shapes and selection of files which are commonly used in practice. There are special purpose files also such as a needle file used in die sinking work, watch making and other delicate work.

<table>
<thead>
<tr>
<th>Shape</th>
<th>Name of file</th>
<th>Description</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat</td>
<td>Rectangular shape</td>
<td>but tapered towards the tip both in length and</td>
<td>General purpose</td>
</tr>
<tr>
<td></td>
<td></td>
<td>thickness. It carries double cut teeth on both</td>
<td>file used for</td>
</tr>
<tr>
<td></td>
<td></td>
<td>flat faces and single cut teeth on edges.</td>
<td>heavy fitting.</td>
</tr>
<tr>
<td>Pillar</td>
<td>Rectangular shape</td>
<td>out narrow width, parallel or tapered in length</td>
<td>General purpose</td>
</tr>
<tr>
<td></td>
<td></td>
<td>and has double-cut teeth on all the surfaces.</td>
<td>filing.</td>
</tr>
<tr>
<td>Hand or safe edge</td>
<td>Rectangular shape</td>
<td>and tapered in thickness only, edges parallel</td>
<td>Filing on flat</td>
</tr>
<tr>
<td></td>
<td></td>
<td>with one edge (safe edge) without teeth</td>
<td>surfaces, useful</td>
</tr>
<tr>
<td></td>
<td></td>
<td>double cut teeth on faces and single cut on only one edge.</td>
<td></td>
</tr>
<tr>
<td>Square</td>
<td>Square shape, may</td>
<td>be tapered for nearly one-third length, double</td>
<td>Filing square</td>
</tr>
<tr>
<td></td>
<td></td>
<td>cut teeth on all four faces.</td>
<td>holes.</td>
</tr>
<tr>
<td>Three square or</td>
<td>Equilateral</td>
<td>tapered towards the end or tip for about two-</td>
<td>Filing grooves</td>
</tr>
<tr>
<td>triangular</td>
<td>triangular shape</td>
<td>third of its length, single cut teeth on all</td>
<td>and sharp corners.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>faces.</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 15.17 Selecting files of various shapes.

Use and care of files: The life of a file is shortened by its improper use and inadequate care. Use and care of files:
- Files should not be thrown in a drawer or tool box and kept mixed with other tools. These should be arranged or hanged in some suitable stand and kept in a dry place to avoid rusting of files.
- The file should not be used without a handle. A handle on the file should be of right size with a hole large enough to accommodate the tang. Insert the tang in the hole and tap the back end of the handle on the bench or flat surface of a vice (Fig 15.18) for fitting the handle on the file.
- Keep the file teeth clean of metal chips that usually get collected between the teeth.
- Remember that a file cuts only in its forward stroke and hence all pressure on the file against the job should be released in back stroke.
- Never use a file in a bending mode. The tang is soft and bends easily. The body of the file is hard and brittle. A light bending will snap the file in two parts.
- Do not use a new file on hard metals. First use it on a soft metal and later use it on the hard metal. Do not use file on oily or greasy surfaces.
Methods of filing: Three main methods of filing are (a) Heavy or rough filing, (b) Draw filing, (c) Lathe filing.

In heavy or rough filing the workpiece should be held as close to the vice jaws as possible, i.e., should not project too much out of the top of vice jaws. The method of holding the file is shown in Fig. 15.19(a), so that the whole weight of upper portion of the body may be thrown on the workpiece. The right elbow is kept close to the body and the body and the left knee are moved with the file. The weight of the body is thrown into the forward stroke of the file and during return stroke, the file is retired of the weight. Maximum metal is removed in cross filing [Fig. 15.19(b)].

**Fig. 15.19(a)** Showing the correct method of holding a file during working.

**Fig. 15.19(b)** Cross-filing for higher rates of metal removal.

**Draw filing** is used to remove rough file marks and to obtain smooth finish. The method of holding the file is shown in Fig. 15.19(c). A single cut smooth grade file is used. Locate the file flat on the workpiece as shown and apply moderate pressure even on the back stroke and during return stroke. Clean the file with brush frequently to achieve good results. Sometimes scratches occur on the surface being filed. To avoid this, clean the file first and rub chalk on it. It should then give good finish avoiding clogging of teeth.

**Fig. 15.19(c)** Draw filing for fine finishing.

Although lathe filing as a production technique is not a recommended practice, still sometimes done for giving better finish on special jobs. The lathe is run fast and filing on is started gently from the tailstock end to the headstock end. A single cut or long-angle lathe file is used for filing.

**Scrapers**

Scraping is the operation of truing flat and curved surfaces with a very sharp tool, a scraper, having no rake. The scraper is used to remove tool marks from the surfaces machined on shaper, planner, or milling machine. Besides fine finishing, scraping is also done to obtain an ornamental effect (frosting) on the surfaces. Scraping is a usual feature of finishing the slot.

**Fig. 15.20** Different types of scrapers.
surfaces of machine tools to develop shallow depressions (at micro level) as pockets for the lubricant. Scrapers are made usually from the rejected old files by heating the file and later bending it to the required shape. It is then ground to have a sharp edge and hardened and tempered. Depending upon the use, shape and size, scrapers may be of various types; some common types have been mentioned in the following with reference to Fig. 15.20.

**Flat scrapers** are used for finishing flat surfaces. The cutting edge is very hard and rounded off slightly. It is used at an angle of 30° to the surface being scraped. **Hook scrapers** are used for scraping small flat surfaces or other surfaces not easily accessible by other scrapers. **Half round scrapers** are used for scraping the bearing halves of babbit metal or white metal when fitting on the shaft. **Triangular scrapers** are used on various curved and bevel surfaces. **Two-handed scrapers** are used for scraping bearing boxes and large curved surfaces.

**Operation of scraping:** As mentioned above, only the high spots on the job surface are removed by scraping. To mark these high spots on the flat surfaces of the job, a thin film of red lead mixed with machine oil is applied on a surface plate. The job is cleaned and placed on the surface plate and rubbed. The high spots on the job surface will have that mark due to rubbing on the surface plate and these marks are scraped. Again the same process is repeated until all high spots are scraped. Scraping needs great patience because a little hurry may spoil the surface of the job.

### 15.3.4 Drilling and Reaming Tools

The process and methods of drilling holes have already been discussed. The common tool used for drilling is the **twist drill** (Fig. 15.21). This tool has progressed through a long history of development in its geometry.

**Nomenclature of twist drill parts** (Fig. 15.21, Fig. 15.22 and Fig. 15.26)

(i) **Body** is that part which is fluted and relieved.
(ii) **Shank** is that part which fits into the spindle of drill press.
(iii) **Point** is the entire cone shaped surface at the cutting end of the drill.
(iv) **Cutting edge** is that part of the point which is sharp like a knife, and cuts the metal during drilling.
(v) **Lip clearance angle** is the surface of the point that is ground or relieved just back of the cutting edge of the drill. For drilling soft metals, this angle is kept 12° and for very hard materials, 6° to 9°.

(vi) **Point angle or included lip angle** is usually kept 118° in standard twist drills. Usually very soft metals are drilled with smaller point angle, 90° and harder material with a larger point angle, 135°.

(vii) **Margin or land** is the narrow surface along the groove that determines the drill and keeps the drill aligned. Land is the part of a cylinder interrupted by the flutes and diameter of the margin at shank end of the drill is 0.01 to 0.05 mm smaller than the diameter at point.

(viii) **Web** is the metal column in the drill which separates flutes. The web runs through the entire length of the drill between the flutes and is the supporting section of the drill. It gradually increases in thickness towards the shank.

(ix) **Helix angle** determines the rake angle of the cutting edge of the drill. Smaller helix angles 10° to 13° are used for drilling harder and 15° to 45° for softer material.

(x) **Chisel edge angle** is the angle between the chisel edge and the cutting lip. It varies from 130° to 145°, larger values for smaller drills.

The drill point geometry for various materials is given in Fig. 15.22(c). The web is the central section of the drill, does not produce cutting action, rather it gives an extrusion action than the cutting action. Heat is generated and power is wasted. For minimizing this action, either the web of the drill is thinned by grinding or a lead hole is used. A lead hole is a small diameter pilot hole which is drilled first before drilling the hole of required size. The web is accommodated in the lead hole. Modifications have been done in the drill by developing a split-point drill giving secondary cutting edge which eliminates the web effect at the cutting edge. Figure 15.22(a) shows the action of a conventional twist drill as it breaks through the bottom side of the workpiece as compared to the radial-lip grind, the latter gives a smooth break-through and burr free hole [Fig. 15.22(b)] along with increased drill life.

![Diagram of a twist drill with labels for different parts](image-url)
Standard twist drills or fluted twist drills are made of cobalt or other high-speed steels and high carbon steels, the latter being cheaper type. The drill has two main parts, (a) a cylindrical body with spiral flutes, (b) shank which may be a parallel shank or a taper shank. Parallel shank drills are of smaller size (up to 13 mm diameter) and those above this size, have a tapered shank carrying Morse taper. The shank is held in the drill chuck of the drilling machine. Drills with taper shank have a ‘tang’ at the end of shank.

Drill holding devices
The spindle of a drill press (Fig. 15.23) has Morse taper bore at its bottom end [Fig. 15.24] and hence the taper shank drills (or reamers) are fitted in the spindle directly. In cases where drill shank is loose in the spindle hole, a collet (or sleeve) is used in between the drill and spindle. The collet (and hence drill) may be removed by driving a drift through the slot of spindle. For securing the drill (and collet) in spindle, put a wooden block on the table of drill press and bring the drill down to touch the wooden block and press it further with the help of feed handle. Holding of straight shank drills in the self-centring chuck (which is later fitted with the drill press spindle in the same way as described for taper shank drill) is shown in Fig. 15.25.

Types of drills
Drills have great variety and sizes. The most commonly used drill is the twist drill (Fig. 15.22, Fig. 15.24 and Fig. 15.26). Some drills are made from high speed steel or carbon steel with others have inserts of cemented carbides. The important types of drills are as follows.
(i) **Taper shank drills** are general purpose twist drills having a Morse taper on shank.
(ii) **Straight shank drills, jobber’s length** have straight shank of the same diameter as the drill body and are general purpose drills.
(iii) **Heavy duty drills** are used for drilling tough materials and deep holes and have heavier webs.
(iv) **Straight fluted drills** [Fig. 15.27(a)] are used for drilling soft metals such as brass, copper because the twist drills tend to dig into these metals.
(v) **Flat drills** [Fig. 15.27(b)] are also used for drilling soft metals. Flat drills make fine chips instead of long coils as in case of twist drills. When a twist drill of proper size is not available, a flat drill (forged from carbon steel) may be prepared and used.

![straight-fluted-drill](image)

![flat-drill](image)

(vi) **Three fluted drills** work as reamers and are used for enlarging already made holes by punching or drilling.
(vii) **Multi-cut drills** perform multi functions, for example, drilling, counter boring and counter sinking.
(viii) **Core drills** are used for enlarging and correcting the location of already drilled holes because the cutting edge of core drills does not extend up to the centre of the drill.
(ix) **Oil-tube drills** are used for drilling deep holes. The drill has a central hole through which cutting fluid is forced to cool the cutting edge of the drill.

**Reamers**

The holes made by drilling are not often true to their exact size. Reaming is the operation of sizing, enlarging and finishing the drilled holes to accurate dimensions with the help of a reamer, which is a rotary cutting tool of cylindrical shape. A reamer is a precision cutting tool and removes only very small amount of metal. It has two or more peripheral grooves (or flutes). **Straight flute reamers** have flutes parallel to axis. The **spiral or fluted reamers** have right or left hand helix and produce better finish in reamed holes due to the smooth shearing action with spiral cutting edges. Spiral flutes prevent chattering and binding in a hole having a long key way or slot. The flutes of the reamer perform two acts, (i) cutting action and (ii) work as grooves for accommodating the chip removed during reaming (cutting) the metal.

Reamers are made from high carbon steel, high speed steel or cemented carbide tipped tool materials. The size of a reamer is measured by the diameter across two margins at the cutting edge. A reamer has a body, a neck and a shank [Fig. 15.28(a)]. The body has (a) a cutting section (starting taper portion) with a 90° bevel and (b) a sizing section which is cylindrical and a back-tapered section. The starting taper portion (main cutting section) is much longer in hand reamers than the machine reamers. The sizing section guides the tool and also sizes the hole by slight cutting. The back-tapered section reduces friction against the reamed hole and prevents cutting of oversized holes. Reamers are either hand type or machine type [Fig. 15.28(a)]. They may have cylindrical or tapered section depending on the hole to be made and may have 6 to 16 flutes irregularly spaced along periphery to have better quality of reamed hole.

**Types of reamers:** Reamers can be classified into the following categories.

(i) **Hand reamers** [Fig. 15.28(a)] are ground straight on the whole length but taper at the end to facilitate entry of the reamer into a hole. The shank end is machined square to receive the wrench with which the reamer is rotated (or operated). During working, the reamer should be started true and kept straight in the hole. The hand reamers may be solid type, adjustable type or expandable type (having limited expansion).

(ii) **Machine reamers** have a 45° chamfer at the cutting edge [Fig. 15.28(a)] and are employed on screw cutting machines or turret lathes. Machine reamers are either straight shank or tapered shank and have narrower lands and backed (longitudinal relief) in whole length. Shell reamers, solid type or having insert carbide blades [Fig. 15.28(c)], are examples of machine reamers. Different types of machine reamers, also known as chucking reamers, are shown in Fig. 15.28(b).

(iii) **Adjustable reamers** have separate blades mounted on the grooves in the rear body and these can be moved up and down to increase or decrease the effective cutting diameter of the reamer. These are both hand reamers and machine reamers.

(iv) **Expansion reamers** have their body with a tapered bore and slitted to permit slip expansion. A taper plug which runs through the hole, works like an expander.

(v) **Shell reamers** are used with the machine arbor or a mandrel with driving pins for use on machine. These may be solid shell type or with inserted carbide blades [Fig. 15.28(c)].

(vi) **Taper reamers** are available both as hand reamers and machine reamers and are used for tapered holes and production of taper sleeves and sockets. **Taper rough reamer and taper finishing reamer** are shown in Fig. 15.28(d).

![fig1528](image)

![fig1528](image)
A set of hand taps have three taps with different starting ends, (i) taper tap, (ii) plug tap, and (iii) bottoming tap [Fig. 15.29(b)]. The taper tap is tapered at its starting end for about 1/8 of the depth of threads. This is done for easy entry of the tap in the hole to be threaded.

As the taper tap advances into the hole, each successive tooth of the tap increases the depth of threads. The plug tap is also chamfered a little for few threads at its front end. It is used only after the first tap has been withdrawn out of the partially threaded (not to full depth) hole. The use of plug tap or second tap further increases the depth of threads to the finished required size. But if the hole is blind, then a bottoming tap is used (after the second tap) to thread right up to the bottom of the hole.

Types of taps:
(i) Hand tap is the most commonly used tool and has been explained above.
(ii) Machine screw taps are the hand taps under 15.5 mm diameter. These are used in the form of plug tap (or second tap).
(iii) Tapered taps have a uniform taper and are used for tapping in a tapered hole. P tap is an example.
(iv) Pulley taps are longer type of hand taps for threading holes for set screws in pulley hub or for oil cup, etc.
(v) Machine taps are used on machines for threading components in mass production.

A tap [Fig. 15.29(a)] is made from tool steels (of which the drills are made) and has a toothed body with flutes on the surface. Usually four flutes are there on a tap to provide cutting edges and also for removal of chips. The square end of the shank is for receiving the tap wrench or handle to rotate the tap.

Fig. 15.29 Geometry of a tap is shown at (a) and the three different taps (forming part of a set of taps) are shown at (b).
MODULE: Machining Processes - Turning

WORKSHOP Training Notes
CHAPTER 6

Metal Machining: Processes and Machine Tools

6.1 INTRODUCTION

Various manufacturing processes used for transforming metals into some usable products, are based on some basic properties of metals, for example, the process of casting is based on the property of 'feasibility' (or melting), forging on the property of 'malleability', and rolling or forming on the property of 'ductility'. Likewise, the process of machining is based on the property of 'divisibility', which is the capability of metal for getting divided into small bits and separated from the work piece in the form of chips. Blank is the piece of metal out of which a product or component of some use is machined out. Machining consists of too! of harder material through the excess surplus) material on the workpiece in the form of chips and into a transformed product machined to the desired shape and size.

6.2 MACHINE TOOL

The term machining (or metal cutting) includes a large number of metal cutting operations such as sawing, turning, facing, boring, taper turning, threading, knurling, milling, slotting, shaping, grinding, etc. All these operations are performed on various types of machine tools as will be discussed in the following. The cutting tools used for removing the excess metal may be operated by hand (as in case of hacksaw cutting or filing operation) or by machine (i.e. power) (as in case of lathe, shaper). Machine or power actuated metal cutting tools and systems (or machines) are called machine tools. The machine tools are provided with facility for holding and rotating (or reciprocating or moving) the work piece or job as also for supporting, guiding and feeding the cutting tool into the work piece. They also have facilities for transmitting power to their various sections to perform various operations.

More commonly used machine tools in a machine shop are as follows.

1. Lathe
2. Drilling machine
3. Milling machine
4. Shaper
5. Planer
6. Grinding machine

A machine shop is the shop in a workshop where all the above machine tools (along with other metal cutting machines) are installed for conducting various machining operations with the purpose of giving the desired shape to the work piece.

6.2.1 Functions of a Machine Tool

A machine tool performs the following functions.

(i) Holding, supporting and rotating (or moving) the work piece as desired during machining.
(ii) Holding, rotating and guiding (and feeding) the cutting tool in relation to the work piece.
(iii) Providing power drives to the work piece and the cutting tool as also to other components of machine tools to help performing various metal cutting operations.
(iv) Regulating cutting speed, feed, etc. for various machining operations.

6.2.2 Types of Machine Tools

Machine tools can be broadly classified as (a) Standard machine tools and (b) Special purpose machine tools. Standard machine tools are those which are capable of performing a number of machining operations to produce a large variety of jobs with different shapes and sizes. They form part of any machine shop. Examples include: lathe, milling machine, shaper, planer, drilling machine, etc. Special purpose machine tools are those which perform only some specified machining operations so as to produce a large number of identical items, such as automatic machines used for mass production. Transfer machines and numerically controlled (NC) machines are also automatic machines. Transfer machines consist of a group of machine tools arranged in a sequence to work as a single unit which is automated. Numerically controlled machines (NC machines) have systems for controlling the relative movements of cutting tools and work piece, cutting feeds, speeds, depth of cuts, sequencing and proper tools for a particular operation and all the machining parameters automatically with the help of a prearranged programme fed to the control unit. Much closer dimensional tolerances on job and higher productivity are ensured with these machines.

6.3 PRODUCTION OF GEOMETRICAL SHAPES ON MACHINE TOOLS

The geometrical shape of the machined surface depends on the shape of the tool and its path during the machining operation. Most machine tools are capable of producing or machining various components of different geometry. Production of machined surfaces can be broadly divided into two major categories: (i) production of round or tapered or formed surfaces that are symmetric about their axis (of rotation) and (ii) production of flat or plane surfaces (including slots, keyways, splines, etc.).
6.3.1 Production of Round or Tapered (Conical) Surfaces Using a Single Point Cutting Tool

When a rough (unmachined) cylindrical job resolves about its central axis and the tool penetrates beneath its surface and travels parallel to the axis of rotation, a surface of revolution is produced and the operation is termed turning (Fig. 6.1(a)). When a hollow tube is machined on its inside in the similar way (as turning), the operation is termed boring (Fig. 6.1(b)). Making an external conical surface of uniformly varying diameter, is called taper turning (Fig. 6.1(c)). When the tool point travels in a path of varying radius, a contoured surface is produced (Fig. 6.1(d)). When a short length contoured surface is turned using a shaped tool normal to the job, the process is termed contour forming (Fig. 6.1(e)).

6.3.2 Production of Flat or Plane Surfaces Using a Single Point Cutting Tool

Flat or plane surfaces can be produced by facing or radial turning (Fig. 6.2(a)) wherein the tool moves normal to the axis of rotation of the work piece. In other cases, the work piece is held steady on the machine tool table, and the tool is allowed to reciprocate (as in case of a shaper) in a series of straight line cuts with crosswise feed increment before each cutting stroke (Fig. 6.2(b)). In case of a planer, the work piece mounted on the machine tool table reciprocates past the tool which is given cross feed after each stroke of reciprocation of the work piece (Fig. 6.2(c)). Both shaper and planer are also capable of cutting slots and splines on a job, besides generating flat or plane surfaces.

6.3.3 Production of Round and Flat Surfaces (or Contours) Using Multi-edged Cutting Tools

The examples of machine tools that employ multi-edged cutting tools include drilling machines, milling machine, broaching machine, etc. A drilling machine employs a drill bit, usually a twin drill bit which is a twin-edged fluted tool, employed for making holes. When drilling is performed on the drilling machine, it is the drill which rotates, but when drilling is carried out on a lathe, it is the work piece which rotates (Fig. 6.3(a)). In milling operations (Fig. 6.3(b) to Fig. 6.3(e)), a rotary cutter with a number of cutting edges, engages the work piece, which is moved slowly and fed to the cutter. Plane or contours surfaces can be generated in milling depending upon the geometry of the cutter and the type of feed. Horizontal or vertical axes of rotation are used for the milling cutters, and the feed of the work piece may be in any of the three coordinate directions.

6.4 LATHE

Lathe is the most basic machine tool available in any machine shop. The working principle of a lathe is shown in Fig. 6.4 wherein the job is rotated and the tool is fed to the job to cut metal. The lathe produces surfaces of revolution by a combination of single point cutting tool moving parallel to the axis of job rotation (as in case of turning shown in Fig. 6.1(a) and 6.4) or normal to the rotating job (as in case of facing, Fig. 6.2(a)) or sometimes the combination of both (as in contour turning, Fig. 6.1(d)). The job is held and rotated on a lathe by holding it either between the two centers of lathe (live center and dead center, Fig. 6.4) or by holding the job in a chuck as for facing operation (Fig. 6.13(b)). It may be noted that in a lathe, power for
rotating the job is transmitted to the lathe spindle which projects out of the head stock as spindle (Fig. 6.5(a)) with threads on it, on which either the face plate (Fig. 6.5(b)) or the chuck (Fig. 6.13) is screwed on.

6.4.1 Components of a Lathe

A lathe can be simply divided into the following subassemblies (Fig. 6.5(a)).

(i) Head stock  (ii) Tail stock

(iii) Carriage  (iv) Bed

1. Head stock: This section comprises mechanisms for providing power to the lathe spindle (Fig. 6.5 and Fig. 6.6), which is used to rotate the work piece or job at different speeds. The spindle is the main component of the head stock and is long enough to cover the entire length of head stock. The spindle is hollow like a pipe and accommodates the live center at its front end (spindle nose). The face plate (used to rotate the job through lathe dog, Fig. 6.21(e)) is screwed on the spindle nose. Longer stock such as bright bars and other round sections used as raw material for machining, are easily fed through the hollow section of the spindle from its rear end to its front end, where these materials are held in position (for machining) with the help of three jaw (or four jaw) chuck screwed on the spindle nose. When a chuck is used to rotate the job, the live center is not used. The 'live center' is called so because during working, the center revolves with the job, whereas the 'dead center' fitted with tail stock, normally remains stationary while allowing the job to rotate during machining.

The major components of head stock include cone pulleys, speed change gears, back gear, bull gear and spindle. Power flows from motor (31)(Fig. 6.5(b)) through a counter shaft cone pulley (32) to another cone pulley (5) mounted on the spindle (3). For further explanation, the cone pulley (5) will henceforth be called cone pulley (P) (Fig. 6.6). The gear (A) forms an integral part of the cone pulley (P) and hence both the cone pulley (P) and the gear (A) run free on the spindle. Bull gear (D) is rigidly fixed with spindle and it can be engaged with cone pulley (P) with the help of pin (G). Hence, with pin (G) engaged, the bull gear (D), cone pulley (P), gear (A) and the spindle, all rotate as one unit. Different spindle speeds are obtained by shifting the belt on various steps of cone pulley (P) and motor pulley (32) [Fig. 6.5(b)].

Spindle is sometimes required to be rotated at much lower speed while handling large diameter jobs and managing various other machining operations. In that case, back gear (B) (Fig. 6.6) is used. The pin (G) is taken out to disengage bull gear (D) from cone pulley (P). Later, with the help of lever (F), the back gear (B) is engaged with gear (A) attached with cone pulley (P). This results in engaging the gear (C) with the bull gear (D). It may be noted that gear (C) is much smaller in size than bull gear (D). With this arrangement, power at much reduced rpm will flow from cone pulley (P) to gear (A), then to gear (B), then to gear (C), and finally to bull gear (D) which rotates the spindle. This arrangement of varying spindle speed is normally available in change-gear type lathes but in geared-head lathes, spindle speed is varied by just shifting the lever of speed gear box to a proper setting as directed in the chart normal given with the lathes.
2. Tail stock: The tail stock fits on to the opposite end of the lathe bed and carries the dead center, which is used to hold and support the job when rotated between the two lathe centers, live center and dead center. The dead center does not revolve with the job (as the live center) and hence called dead center. The sectional view of a tail stock is shown in Fig. 6.7. The tail stock consists of a sleeve, nut, hand wheel, dead center and arrangement for holding the tail stock rigid with lathe bed during machining, besides the tail stock set over system for taper turning is also there. The tail stock serves several functions, for example, it holds the job through its dead center during the machining operations, enables taper turning (by tail stock set over method) and supports the drill (with drill holder) for drilling hole in a job held in chuck (Fig. 6.13(e)).

Refer Fig. 6.7, when the hand wheel (A) is rotated, the nut (D) slides along its axis taking the sleeve (C) with it. The dead center is a tapered piece fitted in the sleeve. Thus, by rotating the hand wheel (A), the dead center can be moved forward to hold the job tight between centers or moved backward to loosen the job held between the two centers. The insert (H) does not allow the rotation of the sleeve (C). The tail stock can be clamped with the lathe bed using bolts (E) and (F). Bolt (G) can be loosened for tail stock set over across the lathe bed during taper turning.

Note that the height of both the live center and the dead center is exactly the same from the top of the lathe bed, and the axial movement of the dead center is in perfect alignment parallel to the bed ways and in line with both the centers of the lathe.

3. Carriage: Devices for controlling the motions of tool are included in this section. Carriage has two parts, (i) saddle and (ii) apron (Fig. 6.8). The portion which takes on it the cross-slide and compound rest and slides along the bed ways, is called saddle. The other one which covers the controls for hand and power feed of tool and also the thread cutting controls, is called apron.

It is the hanging part in front of carriage (attached to saddle) and houses a number of gear trains through which power feeds can be given to the saddle (carriage) and the cross-slide. Schematic details of apron mechanisms are given in Fig. 6.9. Note that the splined feed shaft always keeps rotating when lathe is running, and so also the lead screw gear (Q) and the gear (N) which is a sliding gear. The gear (N) gets attached with gear (P), worm (L) and worm wheel (M) mounted on the splined shaft (K) and thus all interconnected and rotating always with gear (N). Longitudinal hand feed to the tool along the bed can be given by the hand wheel (C) attached through gear (I). Note that gears (G) and (F) are power gears and always keep rotating while lathe is running as they (Gears G and F) get power from gear N. For power movement
carriage (hence the tool) along the bed, push knob (E) to engage power gear (G) with gear (H). Gear (H) is connected with gear (I) which while moving along the rack (fitted with lathe bed), gives longitudinal power movement to the saddle. Similarly, cross slide hand feed to the tool can be given by rotating the hand wheel (D) but for power feed of the cross slide, pull knob (E) to engage gear (F) and (R). While cutting threads on a job held between the centers (or in a chuck), half-nut A is engaged with the lead screw with lever (B), and this moves the saddle (and hence the tool) in a particular relationship based on the pitch of threads cut on the lead screw and the pitch of threads to be cut on job and the RPM of both, the lead screw and the job.

It will be seen that all feeds for the tool are in fact controlled by the lead screw which is the main source of power for movements of saddle or cross slide. The lead screw gets power from the spindle. Although the spindle moves only in one direction, the lead screw can be made to move in both the directions, clockwise and anticlockwise. The mechanism of transmitting power from spindle to lead screw and the method of reversing the direction of lead screw of an engine lathe is illustrated in Fig. 6.10, where spindle gear (E) transmits power to stud gear through the direction reversing gears (A) and (B) which are used to rotate the stud gear (D) in the same or opposite direction to that of the spindle gear (E) since the spindle gear (E) always has a fixed direction of rotation. Gear L is the gear mounted on the lead screw. The gears between the stud gear D and lead screw are all called intermediate gears and are used to vary the RPM and direction of lead screw with respect to the shaft of stud gear (D) (and thus the spindle). In a change gear type lathe, the gear train for intermediate gears is calculated based on pitch of the threads to be cut on job and the pitch of lead screw, whereas in geared head lathe, a control chart helps in operating the required lever for this purpose. Remember that lead screws have acme threads with included angle of 29° for easy engagement and disengagement of half nut.

4. Bed: Bed gives support to all the mountings of lathe, such as tail stock, carriage, head stock, etc. Bed is made of nickel alloy cast iron and is carefully seasoned, machined as scrapped because the accuracy of working on a lathe largely depends upon the trueness of bed. The bed carries bed ways or guide ways which are of two types, inverted V-type with included angle of V as 90° and flat type (Fig. 6.11). Flat ways give larger bearing surface with corresponding reduction in wear but need special care for cleaning the bed ways from metal chips and other foreign matter. The V-type guide ways give better guide to the carriage and ensure proper alignment. Chips also do not get collected over the V-guide ways. Lathes usually have both the guide ways to take their best advantage. Ribs give strength and rigidity to the lathe bed structure.

6.4.2 Defining the Lathe Size

Lathe size is defined in one or more of the following ways (Fig. 6.12).
(i) Swing or maximum diameter of the job that can be rotated over the bed ways (E) or over the carriage (D).
(ii) Maximum length of job that can be held between the lathe centers, A and/or the center height (C).
(iii) Bed length including the head stock.
(iv) Swing in gap (B). It is applicable only in case of specially designed gap bed type lathes.

Lathes are available in sizes ranging from 700 mm to 3000 mm between centers.

6.4.3 Types of Lathe

Lathes can be broadly categorized as follows.

(a) **Speed lathe** is a power driven simplest lathe often used for wood turning. Tools are hand operated.

(b) **Center lathe or engine lathe** is the most commonly used general purpose lathe found in all machine shops. Stepped cone pulley arrangement with motor is used for varying the speed of lathe spindle. Tool is fed by power.

(c) **Geared head lathe** is a type of center lathe wherein changes in the spindle speeds are accomplished by a set of gears (housed in a gear box) operated by a lever.

(d) **Bench lathe** is a small lathe that can be mounted on a workbench for doing small jobs or repair jobs.

(e) **Turret and capstan lathes** are production lathes which carry several tools mounted on the revolving turret or capstan to facilitate performing a number of machining operations without wasting time in changing the tool (as different tools are needed for different types of operations).

(f) **Tool room lathes** are precision lathes suitable for fine tool room work.

(g) **Automatic lathes** are high speed, heavy duty and semi or fully automatic lathes. Fully automatic types are designed to perform the complete scheduled operations without much involvement of the operator.

6.4.4 Operations Performed on Lathe

Although a very large variety of machining operations can be performed on a lathe, the major ones are given in the following.

1. **Turning (plain turning and step turning):** It is the operation of reducing the diameter of cylindrical jobs (Fig. 6.13(a)). The job may be held between the lathe centers and driven with the help of face plate (screwed on lathe spindle) and a dog carrier. Sometimes turning is done by holding the job in a chuck (as shown in Fig. 6.13(b) for performing the facing operation). Turning may be (a) plain turning and (b) step turning. The plain turning results in uniform reduction in the diameter of the job throughout its turned length (as shown in Fig. 6.14(a)). A job may have two or more diameters to be turned on it, each involving shoulders or steps of different diameters. Turning of such steps is called step turning (Fig. 6.14(b)).

2. **Facing:** It is the operation of finishing the end face of a turned cylinder (Fig. 6.13(b)).

3. **Boring:** It is the operation of enlarging the existing hole in the job (Fig. 6.13(c)).

4. **Threading:** It is the operation of forming the thread (Fig. 6.13(d)).

5. **Drilling:** It is the operation of drilling the hole into the job (Fig. 6.13(e)).

**Form turning** involves the use of a form tool for turning different contours as shown in Fig. 6.14(c).
Taper turning (Fig. 6.14(d)) is the operation of turning conical or tapered shapes, i.e., cylindrical shapes gradually reducing in diameter along their axis. Taper turning will be discussed later in more detail.

Fig. 6.14(a) Plain turning between centers.

Fig. 6.14(b) Step turning operation.

Fig. 6.14(c) Form turning with a form tool.

Fig. 6.14(d) Taper turning using combined longitudinal and cross feed.

2. Facing (Fig. 6.13(b)): It is the operation of making the ends of a job flat when the job is usually held in a chuck, and the tool is fed perpendicular to the axis of job rotation.

3. Boring (Fig. 6.13(c)): It is the operation of enlarging the hole (or bore) of a workpiece having its initial bore made either by drilling or by putting a core during casting or the bore made during forging.

4. Threading (Fig. 6.13(d)): Threading on lathe is the operation of making or cutting threads (of different types and pitches) on a job. Threads may be male threads (external threads) and female threads (internal threads). The tool used for cutting threads is a single point threading tool.

5. Drilling (Fig. 6.13(e)): It is the operation of making a hole in the end face of the job held in a chuck. The tool used is a drill bit held in a drill chuck, which itself is mounted in the tail stock sleeve in much the same way as the dead center.

6. Knurling (Fig. 6.15(a)): It is making of roughened surface on a smooth surface of cylindrical jobs using hardened steel knurles in place of a usual lathe tool. Knurled surface of the job helps in holding the job tight by hand. Examples include knurled knobs of measuring instruments such as surface gauge or micrometer screw gauge.

7. Grooving or under cutting (Fig. 6.15(b)): It is the operation of reducing the diameter of a job for a very short length. The reduced surface produced is called groove.

8. Parting off (Fig. 6.15(c)): It is the operation of separating (or cutting off) usually the finished (or machined) component from the work piece blank. It is a very common operation on lathe.
Other lathe operations include **reaming** (finishing drilled hole with reamer), **tapping** (cutting internal threads with taps), and **grinding** (finishing with a grinder).

### 6.4.5 Taper and Taper Turning

A cylindrical job which decreases gradually in diameter from its one end to the other so as to assume a conical shape, is said to be **tapered**. **Taper** on jobs is expressed as the ratio of the difference in end diameters of the tapered job to the axial length of the tapered section. For example, a taper of 1 mm per cm means that there is a difference of 1 mm in the end diameters of a tapered job having a tapered length (along axis) of 1 cm. **Taper angle** is the included angle between the tapering sides of a job when extended to meet at a point (Fig. 6.16). Taper is also given as, say 1 in 20 which means that the difference in major diameter \((D)\) and minor diameter \((d)\) of the tapered length \((l)\) of 20 mm is 1 mm or \((D - d)/l = 1/20\) or tan of half of taper angle \(= 1/(2 \times 20) = 0.025\) or 1°26'.

**Taper turning** is a type of turning operation in which the diameter of the job is gradually reduced as the turning proceeds along the job length. Common methods of taper turning on lathe are discussed in the following.

1. **Compound rest method**: Compound rest has a circular base graduated in degrees (Fig. 6.8). Set the compound rest by swiveling it from the center line of the lathe centers (or edge of bed ways) through an angle equal to half of the taper angle \((\alpha/2)\) as shown in Fig. 6.17. By clamping the lathe carriage in place and after adjusting and clamping the tool, take several cuts for turning the taper. Feeding of tool is done with the compound rest feed handle while the depth of cut is taken with the help of cross slide. The method is suitable for turning steep and short tapers, both external and internal type.

2. **Tail stock set over method**: In this method, the tail stock is set over (as shown in Fig. 6.1) from its center line equal to half of the taper. Calculating the 'set over' of the tail stock depends upon whether the taper is to be given on entire length or part length. The following example will help in calculating the tail stock set over. The method is used for making long taper leng on full length of job.

   For giving taper 1 in 10 on a job 80 mm long, find taper on 80 mm length = 80/10 = 8 mm. Then, tail stock set over = 8/2 = 4 mm.

   For a taper of 12° on a job 80 mm long, here sin of half of taper angle,

   \[
   \frac{\text{Set over}}{\text{Taper length}} = \frac{80 \sin 6^\circ}{80} = 8.36 \text{ mm}
   \]

3. **Taper turning with a form tool**: Short external tapers can be turned using a form tool as shown in Fig. 6.19. It should be noted that a form tool when used for turning tapers on long lengths, generates vibrations and chattering.

   For a taper of 12° on a job 80 mm long, here sin of half of taper angle,

   \[
   \frac{\text{Set over}}{\text{Taper length}} = \frac{80 \sin 6^\circ}{80} = 8.36 \text{ mm}
   \]

   For a taper of 12° on a job 80 mm long, here sin of half of taper angle,

   \[
   \frac{\text{Set over}}{\text{Taper length}} = \frac{80 \sin 6^\circ}{80} = 8.36 \text{ mm}
   \]

   For a taper of 12° on a job 80 mm long, here sin of half of taper angle,
4. Taper turning with taper turning attachment: These attachments are available for turning tapers on lathe. Longer tapers are easily turned with these. The attachment is also useful for cutting threads on tapered sections.

The attachment is shown in Fig. 6.19(a). The nut (C) is loosened to disconnect the motion of cross-slide (having tool post on it) from the control of cross-feed screw, and thus the cross-slide is made floating by disconnecting it from the saddle so that it can move along its ways. The link (D) connects cross-slide and the block (E) (which can slide in slot (H) through an adjustable clamp (A)). During normal turning operations, nut (C) is kept tightened to connect cross-slides with cross-feed screw and the motion cross to the bed length may be given by simply loosening the clamp nut (A), so that nut (A) becomes free over the slot (B) provided in the block (F). The link (F) is hinged on one end and has a guide (H) through which block (E) can travel. On the other end of the link (F), an indicator is provided which is graduated in degrees.

Indicator Link F

To turn a taper, hold the job properly between the lathe centres and set the link (E) at desired angle to give the required taper on the job. Loose nut (C) and tight the clamp (A). The tool will now be restricted to work parallel to the centre line of link (F) and will be guided by the movement of block (E) through the guide (H). This will vary the depth of the cut of the tool while moving along the job length and will render a taper on the job. The feed to the tool is given by working the handle of compound rest. The compound rest is positioned at 90° to the axis of job. The feeding of the tool is given by compound rest because the cross-screw is disconnected.

Advantages of using a taper turning attachment are as follows:

1. The attachment can be quickly and easily set.
2. With the use of this attachment, tapers are turned without disturbing the normal set-up of the lathe.

3. External and internal tapers can be turned.
4. Tapers are turned with the longitudinal power feed and thus the work can be machined quickly and with better finish.
5. Long tapers are easily given.
6. Taper turning attachment is also used for cutting threads on a tapered surface.

Sometimes taper on a job is turned using combined tool feed both longitudinal and cross-feed [Fig. 6.14(d)].

6.4.6 Thread Cutting on Lathe

External or internal threads may be cut on lathe either with the help of a die or a tap respectively or by using a thread cutting tool which can cut both external and internal threads. For cutting threads using a thread cutting tool, a certain relationship is needed between the speed (revolutions) of the job and the speed (revolutions) of the lead screw to control the linear movement of the threading tool parallel to the job length when half nut (A) (Fig. 6.9 and Fig. 6.20) is engaged with the lead screw. Many lathes are provided with quick-change gear box in which different ratios of the speed of spindle (hence job) and lead screw (hence tool) are readily obtained with shifting of the gears. On simple lathes (change gear type), one has to calculate and arrange change gears (intermediate gear, also refer Fig. 6.10) to be arranged between the stud gear (driver gear) and the driven gear (the gear on lead screw) to cut threads of different pitches.

The general set-up for cutting thread is shown in Fig. 6.20, wherein it should be noted that only the stud gear (or driver gear) and lead screw gear (driven gear) along with the intermediate gears are changed for cutting threads of different pitches.

**Lead** is the axial movement of the screw travelled in its one revolution. In case of single start threads, lead is equal to **pitch** which is the distance from one point on one thread to the corresponding point on the adjacent thread. In multiple start threads, lead is equal to

\[
\text{Lead} = \text{No. of start} \times \text{Pitch}
\]
For thread cutting, the ratio of gears between the **stud gear (driver)** to the **lead screw gear (driven)** is found from the following relation.

\[
\frac{\text{Driver}}{\text{Driven}} = \frac{\text{Lead of threads to be cut on job}}{\text{Lead of threads on lead screw}}
\]

and when threads on lead screw are in inch system,

\[
\frac{\text{Driver}}{\text{Driven}} = \frac{5}{127} \times \frac{\text{Lead of threads of job in mm}}{\text{Lead of threads on lead screw in inches}}
\]

### 6.4.7 Cutting Speed, Feed and Depth of Cut

**Cutting speed** in lathe means the number of metres measured on the circumference of a rotating job that passes the cutting edge of the tool in one minute. The length of the chip removed per minute is its measure.

\[
\text{Cutting speed} = \frac{\pi DN}{1000} \, \text{metres per minute}
\]

where \( D \) = Job diameter, mm

\( N \) = RPM of job

For cutting different metals with a tool made of a particular material, there are recommended specific 'average cutting speeds' for performing various machining operations. For example, with a high speed tool, turning of mild steel is done at a cutting speed of 25–30 m/min and that of cast iron, at 16–22 m/min and of brass at 60 to 80 m/min. The cutting speeds will be different for different operations also such as the cutting speed for drilling will be different than that for turning, threading, reaming, etc. Maintaining correct cutting speed (i.e. the speed at which a particular tool and job material combination is most effective) enhances the tool life greatly.

**Feed** is the amount of advancement of tool (parallel to the surface being machined) per revolution of the job. It is usually given in millimetres per revolution of the job. The amount of feed depends upon the finish required, depth of cut, and the rigidity of the machine tool. On lathe, a feed of 0.3 to 1.5 mm per revolution is often used for roughing operations and 0.1 to 0.3 mm per revolution for finishing operations.

**Depth of cut** is the advancement (or digging) of tool in the job in a direction perpendicular to the surface being machined. It may be expressed as the thickness of the chip of metal removed by the tool in one cut and is measured in mm. The depth of cut depends upon the amount of metal to be removed, tool material and the power and rigidity of machine tool.

\[
\text{Depth of cut (t)} = \frac{d_1 - d_2}{2}
\]

where \( d_1 \) = dia of job before machining

\( d_2 \) = dia of machined surface

For normal roughing operations, the depth of cut may vary from 2 to 5 mm and for finishing operations, from 0.5 to 0.1 mm. The depth of cut also depends upon the material of job as deeper cuts can be taken in soft metals.

### 6.4.8 Lathe Accessories and Attachments

**Accessories** are the devices used for holding or supporting job on a lathe during machining. These include: lathe centers, face plate, dog carrier, chucks, angle plate, mandrel, steady rest, follower rest, etc.

**Attachments** are special devices used for special jobs, for example, taper turning attachment used for turning taper, gear cutting attachment used for cutting gear on lathe or grinding attachment for performing grinding operations.

**Lathe centers** (Fig. 6.21(a)) are used for turning job between the centers. The center which is fitted in spindle nose and which revolves with the job is called **live center**. The one fitted with tail stock, is called **dead center** as it does not rotate with the job. The job is held between two lathe centers, can be tightened or loosened by advancing or retracting the dead center by revolving the tail stock hand wheel. The dead center is set rigid in a particular position by clamping the sleeve of the tail stock before starting the work.

**Face plate** (Fig. 6.21(b)) is screwed on the spindle nose. Slots are provided on face plate for bolting **angle plate** for holding typical right angled bend jobs for boring, etc. (Fig. 6.21(c) or the job itself bolted on face plate. An open slot in the face plate is provided for the **dog carrier** (Fig. 6.21(d)) which at one end grips the job with its bolt and at the other end, is hooked with the open slot of the face plate (Fig. 6.21(e)).
Manufacturing Processes

Chucks are screwed on to the nose of lathe spindle. These are four independent jaw type or three jaw type (or self centring chuck). The four jaw chuck (Fig. 6.22) can even hold irregular shaped jobs as all its four jaws have independent movements to help accommodating and holding irregular shaped jobs. A three jaw chuck (Fig. 6.23) can, however, hold only the cylindrical jobs as all its three jaws moves forward or backward simultaneously. By rotating the key (Fig. 6.22), the jaws of both four jaw chuck and three jaw chuck can be moved forward or backward parallel to the face of the chuck.

Fig. 6.21(b) A face plate. It carries a number of slots for bolting jobs directly on the face plate or through the angle plate on which the job is mounted. The open slot (or gap) is for engaging the tail of the lathe dog carrier.

Fig. 6.21(c) Showing the use of face plate with the job mounted on angle plate for carrying out boring operation on it.

Fig. 6.21(d) Different types of lathe dog carriers.

Chucks are screwed on to the nose of lathe spindle. These are four independent jaw type or three jaw type (or self centring chuck). The four jaw chuck (Fig. 6.22) can even hold irregular shaped jobs as all its four jaws have independent movements to help accommodating and holding irregular shaped jobs. A three jaw chuck (Fig. 6.23) can, however, hold only the cylindrical jobs as all its three jaws moves forward or backward simultaneously. By rotating the key (Fig. 6.22), the jaws of both four jaw chuck and three jaw chuck can be moved forward or backward parallel to the face of the chuck.

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Other types of lathe chucks include the following. Collect chucks, magnetic chucks, hydraulic or pneumatic chucks are also used for holding jobs on lathe.

Mandrels are hardened steel pieces of round bar and are used for holding the bored jobs (jobs having drilled or bored holes) for the purpose of turning them at outside. These are of various types, for example, screwed mandrel, taper collar mandrel, expansion mandrel, etc. A typical tapered collar mandrel is shown in Fig. 6.24.

Steady rest (Fig. 6.25(a)) is used when a long job is machined or drilled at its end by holding the job in a chuck. The use of steady rest avoids the deflection of job under its own weight or cutting forces of the tool. The steady rest is fixed in one position with lathe bed.

Follower rest (Fig. 6.25(b)) is used for turning a long and thin job which may be held between centers and may thus deflect under cutting forces of the tool. The follower rest is connected with the carriage and hence moves with the tool as turning operation proceeds. It is fitted right opposite to the cutting tool.

6.4.9 Lathe Tools

The lathe tools never peel the metal away from the job like a knife. The tool has a cutting edge which is blunt and needs sufficient force to pry the chip from the job (Fig. 6.26). In fact, the cutting edge causes the internal shearing action in the metal such that the metal below the cutting edge of the tool yields and flows plastically. First of all, the compression of the metal under the tool edge takes place (Fig. 6.27(a)), which is followed by the separation of the metal in the form of chip (Fig. 6.27(b)) when the compression limit of the metal just under the tool edge has been exceeded. The cutting tool used on lathe has only a single cutting edge or 'point' at one end of its body, it is thus called single point tool. The 'point' which is wedge shaped portion, forms the cutting part of the tool.
1. **Nomenclature of a lathe tool**: A tool may be a **solid or forged tool** (Fig. 6.28(a)) made from high carbon steel or high speed. **Cutting bits or tips or inserts** made of high speed steel, stellite or cemented carbide are available, which can be brazed on a high carbon steel shank and tools thus made are called **brazed tools**. The cutting bits can be held with the tool shank with some clamping system. **Nomenclature of a cutting tool** refers to the systematic naming of various parts and angles of the cutting tool (Fig. 6.28(b)). Various lathe tools are shown in Fig. 6.28(c).

**Shank** is the body of the tool and is usually rectangular in cross-section. **Face** is the surface against which the chip slides upward. **Flank** is that surface which faces the work piece. **Heel** is the lowest portion of the side-cutting and end-cutting edges. **Nose** is the conjunction of side-and-end-cutting edge. **Base** is the underside of shank. **Rake** refers to the slope of the tool from top away from the cutting edge. Tool has side rake and back rake.

**Cutting tool signature** is a numerical method of identification of a tool and according to the American Standards Association, it gives a fixed sequence of numbers listing various angles and the size (mm) of nose radius of a single point tool as follows:

- Back rake angle, side rake angle, end relief angle, side relief angle, end cutting edge angle and nose radius, example: 8-14-6-6-20-15-4.

2. **Cutting tool materials**: The characteristics of an ideal cutting tool material should be as follows.

- **Hot hardness**: It is the property that keeps the tool material hard enough even at higher operating temperatures.
- **Wear resistance**: The tool material must withstand wear due to the rubbing of chip on the tool.
- **Toughness** to withstand shocks and vibration during cutting of metals.
6.4.10 Cutting Fluids

A good amount of heat is generated during machining. Sources of heat generation in metal cutting are: (a) slipping of metal grains or crystals under pressure of cutting tool wherein internal friction, during slipping, generates heat of deformation, (b) the curling of chips during metal cutting generates internal friction which in turn generates heat of chip distortion, and (c) friction heat generated between chip and tool interface, etc. Although quite a bit of heat generated in cutting metal is lost through the chips (about 60%) but still the remaining heat may harm the tool or the job and reduce tool life considerably. Cutting fluids or coolants are used for serving the following purposes.

- To reduce friction between tool and job.
- To reduce various types of tool wears.
- To increase tool life.
- To help easy removal of chips away from tool tip.
- To permit the use of higher cutting speeds and depth of cut for quick removal of large volume of metal without adversely affecting tool life.
- To minimize the machining time and thus reduce the cost of machining.

Various types of cutting fluids are available to work as coolants. A cutting fluid should be cheap, easily available, should not be toxic, should not corrode the job or machine tool and should not generate unpleasant order, fog or smoke. Cutting fluids are available as (i) cutting oils, (ii) soluble oils, and (iii) gaseous type cutting fluids.

Cutting oils include mineral cutting oils, active or inactive type. Active type cutting oils are used for machining ferrous metals and inactive type oils for nonferrous metals.

Soluble oils or emulsions are used for machining both ferrous and nonferrous metals. The mixture is composed of one part of oil and 4 to 8 parts of water. Soda water mixtures are also used. The mixtures contain sal soda (carbonate of soda) and water, and lard oil or soft soap added to thicken the consistency of the mixture and also to increase lubricating properties.

Gaseous type cutting fluids such as air or carbon-di-oxide are more common. Air under pressure is quite effective when used in subzero cooled state. Carbon-di-oxide finds use in machining low machinable and high strength thermal resistant alloys.

6.5 DRILLING MACHINE

Drilling is the operation of making holes in a job by employing an end-cutting rotating tool called a drill. A hole is drilled deeper by giving an axial downward movement to the rotating drill. The operation of drilling is performed on a specially designed machine, called drilling machine. The size of the drilling machine is designated by the largest drill size (diameter) which the machine is capable of handling.

The drills used on drilling machines may be of the following types:

(a) Flat or spade drill (Fig. 6.29(a)) is forged from tool steel to the shape as shown, and hardened and tempered. The cutting angle varies from 90° to 120°. This drill has to be ground to correct cutting edge very frequently, hole made also may not be true (vertical), and chips do not come out of the drilled hole.

(b) Straight fluted drill (Fig. 6.29(b)) has grooves or flutes running parallel to the drill axis. Chips do not come out of the drilled hole automatically and hence it is not very popular. However, for drilling soft metals such as brass, copper or aluminium, the straight fluted drill is preferred as the twist drill tends to advance faster than the rate of feed and the drill digs into the metal.

(c) Twist drill (Fig. 6.29(c)) is the most commonly used drill. Earlier, the twist drills were manufactured by twisting a flat piece of tool steel longitudinally for several revolutions, followed by grinding the diameter and making two cutting edges at the end face of the drill. Twist drills are now made by machining two spiral flutes running lengthwise around the drill body. The flutes help in removing the chips upward from
Module: Machining Processes - Milling

Workshop Training Notes
T 118 Tapers in accordance with DIN 254 (extract).

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4. MILLING OPERATIONS

Features of workpieces manufactured by milling

Workpieces of all materials, e.g. of steel, cast iron, non-ferrous metals and synthetic plastics can be provided with plane and curved surfaces, slots, grooves, teeth, etc. (B 119,1) by the process of milling. The surface condition of parts manufactured by milling is roughed or finished. Parts which must have a higher surface quality, e.g. guide gibs for machine tools, are frequently finished by scraping or grinding.

The milling process (B 119,2)

The chips are cut off by the rotating milling cutter, the cutting edges of which are arranged in a circular way. The milling cutter is a multiple-point tool. To enable the cutting edges of the milling cutter to penetrate into the material, the cutting edges have the shape of a wedge (cf. turning tool). The circular motion of the cutter is called main or cutting motion. To form the chip thickness, the workpiece performs a straight-lined feed movement. Main and feed movement are caused by the milling machine. During the operation, each cutting edge takes part in cutting only during a part of the cutter revolution. During the remaining time it runs idle and can cool off. Therefore, the stress is not as heavy as with the turning tool, the cutting edge of which is constantly remaining in the cut.
Milling methods

Plain milling and end milling

During plain milling the cutter axis is situated parallel to the machined surface of the workpiece. The cutter has the shape of a cylinder and removes the chips with the peripheral cutting edges. The resulting chips have the shape of a wedge.

During end milling the cutter axis is situated vertical to the machined surface. The cutter does not only cut with the teeth on the circumference but also with the front teeth. The chips turn out evenly thick.

Comparison of plain milling with end milling

During plain milling, the milling machine is irregularly stressed by the wedge-shaped chips. It is difficult to prevent a slight beat of the cutter. This, however, contributes to the fact that on the milled surface, at each rotation of the cutter, a milling mark is produced. During face-milling, each tooth cuts off an evenly thick chip. Therefore, the milling machine is evenly stressed.

Generally, the cutting capacity is 15-20% higher than with plain milling. A slight beat of the face mill is of no consequence to the planeness of the surface. The produced surfaces have, therefore, a better grade of planeness. If ever possible, plane surfaces should be machined by end milling.

Conventional and climb milling

During plain milling, the feed movement is usually directed against the sense of rotation, but can also run parallel to the rotary direction. Accordingly, it is distinguished between conventional and climb-milling.

The conventional milling is the usual method of peripheral milling. Hence the chip is first cut off at the thinnest place. Before the cutting teeth enter the material, they slide on the machining surface. Thereby, a strong friction is caused. The cutting force attempts to lift the workpiece.

During climb milling, the cutter points attack the chip at the thickest place. Since the workpiece is pressed tightly against the machine table, the process is suitable for thin workpieces. For deep cuts it is also suitable. However, the machine must be built specially for climb milling. The spindle of the table must have, above all, no play, otherwise the workpiece is drawn into the cutter.

Horizontal milling machine

The machine is suitable for general milling work. Its characteristic is the horizontally mounted milling spindle. The column bears the horizontally mounted milling spindle, the main and feed drive, the knee with cross slide and milling table, and the supporting arm which is frequently supported by the supporting brackets.

The milling spindle. It is mounted in sliding or in antifriction bearings. To guarantee a smooth operation, it is kept in sturdy dimensions. For mounting the milling tools, the spindle head has an outside and an inside taper.

The main drive gives the rotary or main motion to the milling spindle. To enable the milling cutter to run with a proper cutting speed, the nos. of revolutions are variable. Older machines have a pulley drive. Modern machines are driven by a single pulley or flange mounted motor. By means of a gear drive, up to 12 or more nos. of revolutions can be set by lever control.

The feed drive. The workpiece is mounted on the milling table. To enable the advance to the milling cutter, the knee is vertically movable, the cross-slide laterally and the milling table in longitudinal direction. Screw spindles with hand wheels will be used for manual control. Moreover, the milling table can be moved by a feed gear. This is driven directly from the main drive or by a separate feed motor. By drive key or shifting gear transmissions various feeds can be selected. An extendable shaft and a worm gear connect the feed gear with the screw spindle of the milling table. The travel distance of the feed can be limited by stops.

Bigger machines are frequently provided with rapid traverses by which the workpiece can be advanced quickly towards the milling cutter.
MILLING OPERATIONS

B 122.1 Vertical milling machine (left).
B 122.2 Plano-milling machine (centre).
B 122.3 Horizontal milling machine (right).

Vertical milling machine

This machine is used in most cases for end milling work. The milling spindle is mounted vertically in the milling head. The milling head can be swivelled, thus the spindle can also be set in an oblique position. The main and the feed drive do not differ from those of the horizontal milling machine.

Universal milling machine

The main characteristic of this machine is that the milling table can be swivelled to the left or right. Thereby, a more versatile use is possible, e.g. milling of helical flutes.

Other milling machines

The plano-milling machine (B 122.2) is used for machining of heavy parts.

The horizontal milling machine (B 122.3) is suitable for mass production. The spindle head with the milling cutter is vertically adjustable. The feed movement is performed by the table. Very often, bigger horizontal milling machines have several milling spindles.

Thread milling machines of various designs are used for milling of threads (cf. p. 204).

Gear milling machines are also found in various constructions (cf. p. 214).

Copy milling machines are used for the manufacture of workpieces with irregular surfaces, e.g. of dies in accordance with master specimens (templates).

Milling tools

Milling cutters are preferably made of high-speed steel, because this permits the application of higher cutting speeds than plain tool steel. Frequently the cutting edges consist of cemented carbide. Since high speed steel is expensive, the cutter body of bigger milling cutters is made of structural steel in which cutting edges of high speed steel are inserted. Milling cutters with carbide tips are suitable for machining of such materials which exert a heavy abrasive effect on the cutting edges.

Types of milling cutters

According to the shape of the tooth, it is distinguished between milled tooth cutters and form-relieved cutters. The customary milling cutters are standardized.

Milled tooth cutters

Cutting capacity of the cutter and surface quality of the workpiece depend mainly on the cutting edges of milling cutters. These are wedge shaped and are manufactured by milling (B 123.1). The size of the angles depends on the material to be machined (B 123.2) (T 126.1, p. 126). The tooth pitch is also depending on the material (B 123.2). While milling soft materials, big amounts of chips accumulate which will pass off through the large gaps between the teeth of the course pitch cutters. The standardized milling cutters are distinguished by the tool types N, H and W (B 123.2) (German standards).

The cutting edges can be parallel or helical to the milling cutter axis (B 123.3).

Helical cutting edges, either with left hand or with right hand spiral, cause a pushing force in direction of the cutter axis during the removal of chips (B 123.4). The pushing force (axial thrust) must be directed against the spindle head, otherwise the milling arbor will loosen itself from the spindle.

As per DIN, a milling cutter is called left-hand cutting, if, seen from the main drive, it runs counter-clockwise, and right-hand cutting, if it runs clockwise.

Thread milling tools

B 123.1 Angles on the cutting edge of the milling cutter. a) Clearance angle, b) wedge angle, c) rake angle, d) chip face, e) clearance face.

B 123.2 Angles and tooth pitch for machining of various materials. a) Small tooth pitch for milling of hard steel, b) medium tooth pitch for milling of soft steel, c) big tooth pitch for milling of light metal.

B 123.3 Course of the cutting edges. a) Straight cutting edges, (parallel to cutter axis) take the chip in its entire width. Thereby, the cutter works jerkily. The cutting capacity is low. b) Helical cutting edges work smoother. When a tooth emerges from the material, another one is cutting. The chips flow off to the side.

B 123.4 (right) Cutting direction and lead of cutting edges. a) Right hand spiral — left hand cutting, b) left hand spiral — right hand cutting.
B 123.5 (left) Milling cutters with small diameters are advantageous. a) Short feed allowance, low torque; (torque = cutting force X cutter radius; \( M = F \times r \).) b) Long feed allowance, high torque.
MILLING OPERATIONS

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Shell end mills are suitable for milling machines. Side milling cutters are used for milling of narrow recesses. Circular saws are suitable for cutting off and for milling of narrow slots, e.g. in screw heads. Slotting cutters with straight teeth suffice for milling of shallow slots. Staggered tooth milling cutters have cutting edges, directed alternately to the left and the right. Straddle milling cutters can, after regrinding, be brought to propel' width by spacers.


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Gang milling cutters (straddle mills) The combination of several milled-toothed or form-relieved milling cutters with different diameters is called gang milling cutter. Profiles of all shapes can be milled in one operation. By the use of gang milling cutters many working possibilities are provided. The use of the expensive profile cutters can be avoided.

Face milling cutters with inserted blades The teeth are fastened individually in the body of the cutter and, therefore, are easily replaceable after damage. Inserted blade cutters are used for face milling of larger surfaces.

Form relieved cutters (B 125,2 & 3) Milled-tooth cutters cannot be used for milling of curved surfaces, since the profile would change during regrinding. Form-relieved cutters are used for curves, circular arcs and other profiles, frequently also for milling of slots. The relief is necessary to retain the clearance angle. Usually, the rake angle amounts to 0°. The regrinding is performed on the chip (top) face (B 127, page 127); thereby the profile is retained.

Gang milling cutters (straddle mills) (B 125,4 & 5) The combination of several milled-toothed or form-relieved milling cutters with different diameters is called gang milling cutter. Profiles of all shapes can be milled in one operation. By the use of gang milling cutters many working possibilities are provided. The use of the expensive profile cutters can be avoided.
### Milling Operations

**T 126.1 Reference values for numbers of teeth and angles on the cutting edge of milling cutters of high speed steel.**

<table>
<thead>
<tr>
<th>Type of cutter</th>
<th>Normal steels up to 75 kg/mm² tensile strength</th>
<th>Tough materials up to 100 kg/mm² tensile strength</th>
<th>Light metals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of teeth</td>
<td>Lip angles</td>
<td>Number of teeth</td>
</tr>
<tr>
<td>Cylindrical cutters</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>40 6</td>
<td>Conventional</td>
<td>40 4</td>
</tr>
<tr>
<td>50 6</td>
<td></td>
<td>50 4</td>
<td></td>
</tr>
<tr>
<td>60 6</td>
<td></td>
<td>60 4</td>
<td></td>
</tr>
<tr>
<td>Shell end mills</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>40 6</td>
<td>Conventional</td>
<td>40 4</td>
</tr>
<tr>
<td>50 6</td>
<td></td>
<td>50 4</td>
<td></td>
</tr>
<tr>
<td>60 6</td>
<td></td>
<td>60 4</td>
<td></td>
</tr>
<tr>
<td>Plain Milling cutters</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>75 6</td>
<td>Conventional</td>
<td>75 5</td>
</tr>
<tr>
<td>90 8</td>
<td></td>
<td>90 5</td>
<td></td>
</tr>
<tr>
<td>110 8</td>
<td></td>
<td>110 6</td>
<td></td>
</tr>
<tr>
<td>End milling cutters</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>10 4</td>
<td>Conventional</td>
<td>10 3</td>
</tr>
<tr>
<td>12 4</td>
<td></td>
<td>12 3</td>
<td></td>
</tr>
<tr>
<td>14 5</td>
<td></td>
<td>14 3</td>
<td></td>
</tr>
<tr>
<td>16 5</td>
<td></td>
<td>16 3</td>
<td></td>
</tr>
<tr>
<td>20 6</td>
<td></td>
<td>20 4</td>
<td></td>
</tr>
<tr>
<td>24 5</td>
<td></td>
<td>24 4</td>
<td></td>
</tr>
<tr>
<td>30 6</td>
<td></td>
<td>30 4</td>
<td></td>
</tr>
<tr>
<td>36 6</td>
<td></td>
<td>36 5</td>
<td></td>
</tr>
<tr>
<td>40 6</td>
<td></td>
<td>40 5</td>
<td></td>
</tr>
</tbody>
</table>

#### Maintenance of milling tools

During the milling process, the teeth of the milling cutter wear out. Blunt teeth cause inaccurate and unclean surfaces. Therefore, it is necessary to regrind the milling cutter in time on a tool and cutter grinder.

**Milled-tooth cutters** are regrind on the clearance faces (B 127.1). A cylindrical cutter, e.g., is mounted on a mandrel which is clamped between the centres of the grinding machine.

During grinding, the cutter is pressed with one hand on the tooth stay. The other hand moves the table with the cutter along the grinding wheel. All cutter teeth will, one after the other, be rough-ground and then, one after the other, finish ground. A cup wheel is used as grinding tool. Since only one side of the cup wheel is permitted to grind, the grinder axis must be declined by about 3° towards the cutter axis. In order to obtain the proper clearance angle, the tooth stay is set under the cutter centre by the distance h (T 127.1).

### Form-relieved cutters

**Form-relieved cutters** have to be reSharpened on the chip face (B 127.2). Since usually the rake angle is zero, the grinding wheel will be set to the centre of the cutter.

The sharp ground milling cutters are sensitive. To avoid damages, they must not be placed on hard surfaces.

**B 127.2 Sharpening of a form-relieved cutter.**

a) Dish grinding wheel, b) Tooth stay.
Mounting of milling cutters

The milling cutter must run without beat, otherwise the teeth, which are sticking out, wear out heavily; the tool life will also be reduced considerably. Moreover, each tooth of a cutter which does not run true cuts a different depth, thus undesired milling marks are produced on the surface of the workpiece. Mounting of milling cutters must be done with great care (B 128,1 - 4).

Mounting of milling cutters

The cutter is connected with the arbor by a feather key (milling key) and held in its position by plane parallel spacers (g). There must be no foreign bodies between the faces of the cutter and the spacers, otherwise the arbor will bend during tightening of the arbor nut (l). In that case, the cutter does not run without beat. The arbor nut should only then be tightened when the supporting bracket (f) is adjusted and locked in position. To avoid bending of the milling arbor which runs in an arbor bearing sleeve (e) on the left hand side due to the cutting force, its diameter has to be selected as big as possible. Furthermore, the distance from the cutter to the supporting bracket and spindle head (x, y) should be kept small.

Rules for mounting of cutters.
1. The proper cutter and corresponding milling arbor must be selected, feather key must not be forgotten.
2. Tapers on milling arbor and milling spindle head must be protected against damage.
3. Before the assembly, all fitting surfaces have to be cleaned, e.g. milling arbor, taper on spindle head, spacers and milling cutter (true running).
4. The rotary direction of the milling machine and cutting direction of the milling cutter must correspond with each other (breakage of cutter).
5. The axial force of spiral toothed milling cutters must be directed against the milling spindle.

Checking for concentric running. The rotating milling cutter should have a beat not more than 0.05 mm. The dial indicator is used for checking. The milling spindle is turned backward slowly by hand for this purpose (B 128,5).

Clamping of workpieces

The workpieces must be clamped firmly and securely; if they become loose during machining, rejections and breakage of the cutter may result.

Single workpieces are clamped in machine vices, or they are fastened on the machine table with clamps and clamping screws (B 129,1 - 4).

For machining of many parts of the same size clamping devices (B 129,5) are used. These have the advantage that the adjustment has not to be repeated every time. To save time, duplicate work holding fixtures may be used. While the cutter machines one workpiece, another workpiece is clamped in the second fixture. This working method is called reciprocal milling (B 129,5).

Workpieces which are to be provided with equally distributed milled or milled-out portions, e.g. hexagon, gears etc., will be clamped with the help of the dividing head (cf. p. 140).
Selection of the R. p. m.

The number of revolutions depend on the permissible cutting speed and the diameter of the cutter. Cutting speed of the cutter means the travel of one cutting tooth in meter/min. The permissible cutting speed will be taken from the cutting speed table (T 130.1).

Cutting speed too high: Cutter teeth will become blunt prematurely.

Cutting speed too low: Low cutting capacity.

\[ v = \text{Cutting speed in m/min.} \]
\[ d = \text{Diameter of cutter in mm.} \]
\[ n = \text{Nos. of revolutions of the cutter per min.} \]

Revolutions of the milling cutter per min.

\[ n = \frac{1000 \times v}{\pi \times d} \]

Example: A plate has to be machined with a plain milling cutter by rough milling. Calculate the number of revolutions of the cutter per min.

Material of the plate St 50, diameter of cutter 75 mm.

Result: Cutting speed as per table 130, 117 m/min.

As a rule, only certain nos. of revolutions can be selected. The number of revolutions can also be selected from a table, see T 142.1, page 142.

<table>
<thead>
<tr>
<th>Material</th>
<th>R. p. m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon steel</td>
<td>57 - 99</td>
</tr>
<tr>
<td>Alloy steel</td>
<td>64 - 113</td>
</tr>
<tr>
<td>Cast iron</td>
<td>131 - 167</td>
</tr>
<tr>
<td>Brass</td>
<td>147 - 276</td>
</tr>
</tbody>
</table>

T 130.1 Reference values for cutting speed (v) and feed (s' in mm/min.).

### Table 130.1

<table>
<thead>
<tr>
<th>Material</th>
<th>R. p. m.</th>
<th>R. p. m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon steel</td>
<td>57 - 99</td>
<td>64 - 113</td>
</tr>
<tr>
<td>Alloy steel</td>
<td>64 - 113</td>
<td>124 - 167</td>
</tr>
<tr>
<td>Cast iron</td>
<td>131 - 167</td>
<td>147 - 276</td>
</tr>
<tr>
<td>Brass</td>
<td>147 - 276</td>
<td>167 - 400</td>
</tr>
</tbody>
</table>

### Table 131.1

Selection of the feed

For milling operations, the feed means the rate of feed in mm/min. It is the distance in mm which the milling machine table and hence the workpiece travels in one min. (B 131.1).

The rate of feed (s') depends on the cutter, the material of the workpiece, the cutting depth and the required surface quality (T 130.1). To avoid overloading of the machine, the rate of feed has to be calculated occasionally. It will be based on the biggest possible amount of chips which the cutter is able to cut off in one min. from the workpiece. By experiments, the permissible amount of chips has been ascertained in cm³ per kilowatt machine capacity (T 142.3, p. 142).

\[ V = \frac{V'}{P}; V' = \text{biggest possible amount of chips in cm}^3/\text{min.} \]
\[ V' = \text{permissible amount of chips in cm}^3/\text{kw min. (cf. T 142.3,)} \]
\[ P = \text{machine driving capacity in kW.} \]

The biggest possible amount of chips per min. is equal to the permissible amount of chips per kw in one min. (cm³/kW min.) multiplied by the machine driving capacity.

Possible biggest amount of chips in cm³/min.

**Example:** For plain milling of steel with 35-90 kg/mm² strength the permissible amount of chips amounts to 15 cm³/kW min. (T 142.3).

What amount of chips will be cut off in one min. on a milling machine with 2.5 kW driving capacity?

Result: \[ V = \frac{V'}{P} = \frac{12 \text{ cm}^3/\text{kW min.} \times 2.5 \text{ kW}}{36 \text{ cm}^3/\text{min.}} \]

The amount of chips V (B 131.1) can also be calculated from the depth of cut (a), the milling width (b) and the rate of feed (s')

\[ V = \frac{a \times b \times s'}{1000} \]

By rearranging the equations (1) and (2)

Rate of feed in mm/min.

\[ s' = \frac{V \times 1000}{a \times b} \]

**Example:** A plate of St 50.11 has to be machined by plain milling. The cutting depth is 4 mm, milling width 80 mm, and driving capacity of machine 3 kW. Calculate the biggest possible rate of feed.

Result: 1. Biggest possible amount of chips

\[ V = \frac{V'}{P} \]
\[ V = 12 \text{ cm}^3/\text{kW min.} \times 3 \text{ kW} = 36 \text{ cm}^3/\text{min.} \]

2. Rate of feed

\[ s' = \frac{V \times 1000}{a \times b}; s' = \frac{36 \text{ cm}^3/\text{min.} \times 1000}{4 \text{ mm} \times 80 \text{ mm}} = 112 \text{ mm/min.} \]

Usually only certain rates of feed can be set on the milling machine, e.g. 12 - 20 - 33 - 45 - 60 - 90 - 112 mm/min.

Thus a rate of feed of 98 mm/min. has to be selected.

\[ P \text{ (derived from power) is the formula symbol for efficiency as per DIN 1304.} \]

<table>
<thead>
<tr>
<th>Milling width b</th>
<th>Cylindrical milling cutter (plain)</th>
<th>End milling cutter</th>
<th>Inserted blade cutter</th>
<th>Slitting Saws</th>
</tr>
</thead>
<tbody>
<tr>
<td>b = 100 mm</td>
<td>Roughing</td>
<td>v</td>
<td>a = 5 mm</td>
<td>s'</td>
</tr>
<tr>
<td>Carbon steel up to 65 kg/mm²</td>
<td>17</td>
<td>50</td>
<td>22</td>
<td>120</td>
</tr>
<tr>
<td>Alloy steel, annealed up to 75 kg/mm²</td>
<td>50</td>
<td>49</td>
<td>19</td>
<td>100</td>
</tr>
<tr>
<td>Alloy steel, tempered up to 100 kg/mm²</td>
<td>13</td>
<td>20</td>
<td>17</td>
<td>65</td>
</tr>
<tr>
<td>Cast iron up to 168 Brinnell</td>
<td>15</td>
<td>60</td>
<td>19</td>
<td>120</td>
</tr>
<tr>
<td>Brass (MS 58)</td>
<td>30</td>
<td>80</td>
<td>55</td>
<td>120</td>
</tr>
<tr>
<td>Light metal</td>
<td>160</td>
<td>90</td>
<td>180</td>
<td>120</td>
</tr>
</tbody>
</table>
Rough and finish milling (B 132,1)

During rough milling the excessive material has to be removed in the shortest time possible. Therefore, a big rate of feed has to be selected. For the subsequent finish milling operation 0.5 ... 1 mm will remain. With regard to the life of the milling cutter a small cutting speed has to be selected (T 130,1).

4. No blunt cutters should be used.

In finish milling, the workpiece must be accurate in size and must get the required surface quality. For this purpose, a higher cutting speed and a small rate of feed is necessary. If the machining allowance is not too big, the workpiece can be milled accurately and smoothly in one cut. In this case, medium values will be selected for the cutting speed and rate of feed.

Cooling during the milling operation (B 132,2; T 142,2, p. 142)

Cooling with suitable media contributes to the improvement of surface quality and to the length of the life of the milling cutter. Moreover, the coolant which is conveyed with strong force to the surface under machining, washes away the accumulating chips, thus preventing jam between work surface and cutter teeth.

Rules for milling.
1. The proper machine has to be selected.
2. Proper milling tools have to be selected.
3. The milling cutter must run true.
4. No blunt cutters should be used.
5. The workpiece has to be clamped tightly and safely, however, it must not be clamped in a wrong way, and suitable clamping screws should be used.
6. The correct number of revolutions and feed have to be selected.
7. Before setting the feed check whether the workpiece or milling table do not touch anywhere.
8. Coolant has to be given in time.

Accident prevention during milling
1. Never touch the running cutter with your fingers.
2. Do not remove chips with your fingers but with brush or chip hook only.
3. Measure only when the machine is at rest.

Calculating the machining time for milling

Machining time = \( \frac{\text{Travelling distance of the milling table (mm)}}{\text{Rate of feed (mm/min.)}} \)

The travelling distance \( (L) \) depends on the length of the workpiece \( (l) \), the feed allowance and the over travel \( (t_a) \) and \( (L) \) (B 133,3).

Example: A strip of St 42 with a length of 350 mm has to be rough milled by plain milling. Calculate the machining time.

Given: \( l = 30 \text{ mm}, \quad t_a = 5 \text{ mm}, \quad \text{rate of feed} = 100 \text{ mm/min.} \)

Result: \( L = l + t_a = 250 \text{ mm} + 30 \text{ mm} + 5 \text{ mm} = 285 \text{ mm}, \quad t_a = \frac{L}{s'} = \frac{285 \text{ mm}}{100 \text{ mm/min.}} = 2.85 \text{ min.} \)

MILLING OF PLANE SURFACES

Plane surfaces are found on almost all workpieces and serve various purposes (B 133,1). Machining besides milling can be performed, also by planing, turning or grinding. The surface quality depends on the respective application. Bearing surfaces can, e.g. be roughed, finished or fine finished.

Surface milling

The surface is to be roughed in one operation. While clamping the workpiece, it will be aligned in accordance with the marking line. The number of revolutions of the cutter depends on the cutting speed and the diameter of the cutter. The milling depth is set by moving the table upwards. After milling the punch marks of the marking line must be half visible. Cross slide and knee have to be locked in position after setting. Upto 100 mm/min. feed can be selected. Before starting the cutting operation, the longitudinal carriage with the workpiece has to be moved close towards the cutter, then the feed is engaged and the coolant pump will be started. During milling, the machine must not be stopped, otherwise undesired steps will be caused.

Testing of the surface

The planeness can be checked by the light gap method with the bevelled steel straight edge (B 133,3).
Testing of plane surfaces

The light gap method. To test the planeness, a steel rule is placed on the surface of the workpiece with the narrow face. The out-of-flatness is recognized from the light gap (B 134.1). Testing with the light gap method is very accurate. After some training and at good lighting, a light gap of 10 μ is still visible.

The edges of steel rules are ground and have the shape of a bevel, or narrow face (B 134.2). The straight edges are distinguished by 4 degrees of accuracy. For protection against wear, bevel steel straight edges, three-square and narrow edge straight edges are hardened. For testing a roughed surface, the steel straight edge is sufficient. It must be applied squarely (B 134.3). By deflection of the rule, the light gap is better visible, but the test result may be wrong, because the side faces might be uneven and the rule might be bent. For testing the rule is applied successively at several places and in various directions. A finished or fine finished surface is tested in the same manner with rules, having an accuracy of grade 1 or 2.

The surface contact method (blueing). The surface which has to be tested for planeness will be moved to and fro on a surface plate, rubbed in with prussian blue. Thereby, the elevated spots on the workpiece are outlined. This method is usually applied in connection with scraping.

MILLING OF KEYWAYS

The hubs of clutches, belt pulleys, gears etc. are connected with the shaft by keys or feather keys (sliding keys) (B 135.1).

Keys are used for fastening. They are slightly tapered and are driven in or put into the keyway while the machine part is to be fixed over it. Feather keys are used for driving connections and have no taper. They are used where shifting of the hub is desired, e.g. shiftable clutches.

Height and width of keys and feather keys as well as depths of shaft keyways and sliding keyways on hubs are standardized.

Example:

Work order: A keyway for a sliding key has to be milled into the shaft (B 135.2) by means of the keyway cutter on the horizontal milling machine.

Operation plan

<table>
<thead>
<tr>
<th>Operations</th>
<th>Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mounting of cutter and testing of run</td>
<td>Keyway cutter 63x8, cutter arbor 23 1</td>
</tr>
<tr>
<td>2. Clamping of workpiece and milling of keyway</td>
<td>Machine vice</td>
</tr>
</tbody>
</table>

Measuring and testing instruments: Slip gauges, try square, depth gauge

Machining of keyway

A slitting saw or a form relieved cutter can be used for milling. The shaft is to be aligned carefully in horizontal and longitudinal direction (B 135.3). After setting of the workpiece to the centre of the cutter, the cross slide is locked in position (B 135.4).
For the adjustment of the depth of the keyway, the index ring on the spindle for the height adjustment of the table is used (B 136,1).

Testing of keyway
The width of the keyway can be tested with slip gauges (B 136,3). For the measuring of the keyway depth, the depth gauge for keyways is suited (B 136,4 & 5). The centre position of the keyway is tested with slip gauges and dial indicator (B 136,7 & 8).

MILLING OF SLIDES
Workpieces with parallel and angular surfaces are frequently used as guideways (B 137,1). A proper fitting is only guaranteed if the surfaces are not only plane, but also parallel and angular. The guideways will frequently be scraped or ground after milling.

Example:
Work order:
A slide (B 137,2) has to be milled on a vertical milling machine.

Operation plan

<table>
<thead>
<tr>
<th>Operations</th>
<th>Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milling of four narrow sides</td>
<td>Right-hand spiral end mill 50 N</td>
</tr>
<tr>
<td>1. Chucking of milling cutter</td>
<td>Machine vice</td>
</tr>
<tr>
<td>2. Clamping and adjusting of workpiece</td>
<td></td>
</tr>
<tr>
<td>3. Milling of upper surfaces</td>
<td>Inserted blade cutter 100 Ø</td>
</tr>
<tr>
<td>4. Milling of lower surface of slide</td>
<td>Inserted blade cutter 100 Ø</td>
</tr>
<tr>
<td>5. Milling of dove-tail guides</td>
<td>Right-hand spiral end mill 50 N</td>
</tr>
<tr>
<td>6. Chucking of inserted blade cutter;</td>
<td>Right-hand dove-tail cutter 50 X 14 X 55°</td>
</tr>
<tr>
<td>7. Clamping and adjusting of workpiece;</td>
<td></td>
</tr>
<tr>
<td>8. Milling of dove-tail guides</td>
<td></td>
</tr>
</tbody>
</table>
Manufacture of a slide

For milling of the slide, the number of revolutions of the cutters and rate of feed should be ascertained. It is assumed that a vertical milling machine with the number of revolutions, listed on page 130 and rate of feed listed on page 131 is available.

End milling with a shell end mill 50 Cbc.

a) Cutting speed as per T 130.1: Roughing 12 m/min., finishing 18 m/min.
b) Number of revolutions as per T 142.1; Roughing 76 per min., selected 64 per min.; finishing 115 per min., selected 113 per min.
c) Rate of feed as per T 130.1: Roughing 140 mm/min., selected 167 mm/min.; finishing 70 mm/min., selected 99 mm/min.

In this case, the calculation of the rate of feed is dispensed with.

In like manner, nos. of revolutions and rates of feed for milling with inserted blade cutter and dovetail milling cutter have to be ascertained.

Measuring and testing of the slide

For measuring the length, width and thickness, the usual measuring instruments, e.g. vernier caliper, depth gauge, and micrometer are used. Planeness, angularity and parallelism can be tested in various ways (B 138.1-8).

Milling of hexagon

Workpieces which have equally distributed surfaces or milled areas on the circumference are used in all varieties of shapes (B 139.1).

Example:

Work order: A hexagon head has to be milled on the bolt (B 139.2) on a vertical milling machine. It is assumed that a dividing head (cf. p. 141) is not available.

Milling of hexagon

During milling attention has to be paid to an equal distribution of the faces (B 139.2).

Note: Milling with the Vee block for clamping is only a substitute. A more accurate distribution of faces will be obtained with the dividing head.

Measuring and testing of hexagon

The width across flats is measured with the vernier caliper. For checking the positions of faces the 120° square is used.
Dividing with indexing attachments

In order to distribute faces and milled areas accurately on the circumference of a workpiece, dividing heads are used. In this way, marking is not necessary.

The plain indexing attachment (B 140.1) suffices when a small number of divisions has to be produced. The workpiece is clamped between the centres of the indexing head and the tail-stock. On the index spindle an interchangeable index plate is situated which has as many slots as the workpiece shall be provided with divisions.

The dividing head (B 140.2 & 3) is used for a large number of various divisions. In the housing, a worm gear with a ratio of 40:1 is installed. The worm wheel is fitted tightly on the index spindle. The interchangeable index plate is fixed and plates; the hole circles of which have different nos. of holes (T 140.1). The handle connected with the housing by a spring bolt. A dividing head has three index plates, the hole circles of which have different nos. of holes (T 140.1). The handle for turning the worm is adjustable towards the centre. It has an index pin by means of which the division on the index plate is set. The brace saves the counting of holes while indexing. Since, the workpiece is shifted by means of the worm gear, the procedure is known as compound indexing.

Indexing with the dividing head

To be able to perform divisions, the number of revolutions of the handle must be ascertained.

Designations:
- \( nk \) = numbers of revolutions of the handle.
- \( z \) = number of teeth of the worm gear (usually 40).
- \( f \) = indexing number (e.g. 4, 6, 8, 10, 12 divisions).

The numbers of revolutions of the handle result when the number of teeth of the worm gear are divided through the index number.

Example: A hexagon has to be milled. How many revolutions have to be made so that the workpiece turns \( \frac{1}{4} \) after each milling of a face?

Result:
Numbers of revolutions of the handle \( nk = \frac{z}{f} \); \( nk = 6 \frac{4}{6} \) revolutions;
I.e. the handle must be turned around \( \frac{6}{3} = 2 \) times.

Performance: A hole circle which can be divided by 3, will be selected, e.g. a hole circle with 15 holes (T 140.1). (B 141.1).

Differential indexing. Divisions which cannot be performed by direct or compound indexing, will be made possible with the help of change gears by differential indexing.

During differential indexing the index plate is loose. It receives an advancing or retarding movement from the index spindle via the change gears. The number of teeth of the change gears will be ascertained by calculation.

| Number of teeth of the change gears. |
|---|---|---|---|---|---|---|---|
| 24 | 28 | 32 | 36 | 40 | 44 |
| 48 | 56 | 64 | 72 | 80 | 100 |
The chips will be cut off in strips from the workpiece by the ultra straight main stroke (8143,2). For machining short or long workpieces there are planing machines of various designs.

**Example: Cutting speed \( v = 22 \text{ m/min} \), cutter diameter \( d = 60 \text{ mm} \).**

**Result:** At \( v = 22 \text{ m/min} \) to the right, at \( d = 60 \text{ mm} \) downwards. At the intersection the R. p. m. of the milling cutter will be found 117 R. p. m.

**5. SHAPING AND PLANING OPERATIONS**

Next to milling, planing is an important working method for the manufacture of straight and curved surfaces (B 143,1).

The chips will be cut off in strips from the workpiece by the straight main stroke (B 143,2). For machining short or long workpieces there are planing machines of various designs.

**Shaping machine (B 143,5)**

The machine is suitable for machining workpieces up to 800 mm length. Owing to the horizontal main stroke, it is also called horizontal slotting m/c.

For cutting off the chips, the main stroke, feed and adjustment movement are necessary (B 143,4 & 5).

**The main or cutting motion is performed by the shaping tool.** There is a difference between working stroke and non-cutting stroke. During the working stroke (forward stroke) the chip will be cut off. During the non-cutting stroke (backward stroke), the tool travels backwards without cutting the material. Both strokes together form a cycle.

**The feed motion** produces the chip thickness. For shaping in horizontal direction, the clamped workpiece will be moved against the tool. For shaping in vertical direction, the tool must be moved towards the workpiece.

**The adjustment** produces the cutting depth. During the horizontal shaping process, it will be achieved by moving the tool downwards. During the vertical shaping process, by moving the workpiece sideways.
Module: Foundry and Smithy

Workshop training notes
5.1 INTRODUCTION

The art of foundry (from Latin fundere means ‘melting and pouring’) is fundamental to civilization as it had been in use even during 4000–3000 B.C., when bronze arrow heads were cast in open-faced clay molds. It is still the most popular method of manufacturing machine components and other products out of a variety of metals and alloys. The process of casting is known for its versatility of producing very heavy components (weighing in tonnes) on one hand, and highly complicated light components on the other.

The process of metal casting (or simply casting) involves pouring of molten metal into a mold, which is a cavity formed in some molding material such as sand. The mold cavity exactly resembles in shape and size with the product to be made by casting. The molten metal poured into the mold and allowed to freeze there, takes up the shape of the mold cavity and the product thus cast, is called a casting. The process of casting is based upon the property of flowability of molten metal by virtue of which it flows into all parts and corners of the mold and on solidifying, takes the shape of the mold cavity.

A mold cavity may be formed in some suitable molding material such as moist sand mixed with clay and other ingredients. It is then called a sand mold. A pattern with its shape and size similar to the desired casting, is embedded in molding sand which is compacted around the pattern and thus the pattern is used to make a mold cavity (or mold) after being withdrawn from the sand. Besides the sand molds, metal molds (called permanent molds) are also used. Whereas a sand mold is used only once to produce a casting (since the casting is taken out of the sand mold only by breaking the mold), a metal mold is so designed that it is used repeatedly for producing a large number of castings (in thousands) without damaging the mold. Although most metals can be cast by one method or the other, the metals most adaptable to casting include: cast irons of all types, steels (carbon steels and alloy steels), stainless steel, nonferrous metals (and their alloys) such as aluminium, copper, magnesium, zinc, brasses and bronzes and bearing metals.

5.2 A FOUNDRY SHOP

A foundry shop is that shop where molding (making of mold), metal melting and casting molds and their related processes such as fettling and cleaning of castings, are conducted. To function properly, the foundry shop is divided into the following departments.

(i) Molding department, where operations related to making of molds and their baking are carried out.
(ii) Core department, where operations related to making and baking of cores are carried out.
(iii) Metal melting department, where melting of metal for casting purposes is carried out in a cupola or other furnaces.
(iv) Casting treating or fettling department, where cleaning of castings and removing gates, risers or fins from castings are done.
(v) Quality control department is responsible for maintaining a particular quality standard of foundry products (casting) through proper inspection at various stages of production, right from material procurement to the inspection and testing of castings.

5.3 TYPES OF FOUNDRIES

Foundries are usually categorized according to the type of metals or alloys cast in a particular foundry, for example,

(a) Cast iron foundries involve casting of different types of cast irons.
(b) Malleable iron foundries are devoted to the casting of malleable cast iron products.
(c) Steel foundries involve casting of carbon steels and alloy steel products.
(d) Nonferrous foundries involve casting of nonferrous metals and alloys.

5.4 PREFERENCE FOR CASTING OVER OTHER PRODUCTION METHODS

A product can be made in several ways by following different methods of production such as casting, forging or machining. The choice of a particular production method depends upon factors such as mechanical and other properties of the final product, intricacy of its shape and dimensional tolerances, available manufacturing capability and market support, and the number of products to be made within a given time. In the following are given some distinct features of the casting process that make it a more favourable production method in many respects.

(i) It is possible to cast the products with intricate external shapes and complex internal profiles making use of the ability of molten metal to fill completely the cavities in
Casting may be advantageous when a large number of similar parts are produced, thus covering the cost incurred on patterns.

Casting permits the designer to place bulk of metal in a product where it is most needed and remove it from the place where it is in excess, for example, as in case of cast crank shafts and machine tool components.

Casting is a suitable process for making very heavy components of structures or machine tool frames. Casting is easier and cheaper in such cases.

Parts requiring the property of damping of sound and mechanical vibrations are best made by casting, grey cast iron castings usually.

Components made of refractory metals or highly creep resistant metals and alloys (for the parts of gas turbine) which are difficult to forge or machine are easily cast to close dimensional tolerances.

Casting minimizes anisotropic qualities (or directional qualities found in most wrought or rolled and forged products) which render the rolled component poor in fatigue and impact in the transverse direction of rolling.

Casting of precious metals such as gold and silver does not suffer from the problem of loss of material in the form of chips, flash or scrap.

Castings usually suffer from problems such as internal porosity, dimensional variation due to metal shrinkage, solid or gas inclusions, etc. These can, however, be taken care of by proper designing of the cast product and using good foundry practice. Nevertheless, there may be times when it may not be advisable to go in for casting, such as in the following cases.

- When a product can be easily stamped out on a punch press.
- When a product can be deep drawn on a press.
- When a product can be made by direct extrusion.
- When a product is to be made from some highly reactive metals.

5.5 FOUNDRY PROCESSES

Various processes or operations carried out in a foundry shop for producing a metal casting, can be broadly divided into two separate groups of activities, namely, (i) molding and (ii) casting. These are discussed in the following.

5.5.1 Molding

A mold is a void or cavity created in a compact sand mass with the help of a pattern, which is the near replica of the casting to be made. This cavity is filled with molten metal, which, on solidification, results into a casting. The pattern nearly resembles with the shape and size of the casting to be made. The process of creating the cavity or making of mold (in the sand) is termed molding. It consists of compacting molding sand around a pattern (made of wood, plastic or metal) enclosed in a mold box or flask. Molding related activities include: pattern making, preparing molding sand mixture, core making, baking of mold and core and preserving molds in case of dry sand molds and metallic molds. Essential features of a sand mold and few terms related to the mold are explained in the following in reference to Fig. 5.1.

Pouring basin or pouring cup is an enlarged cup shaped cavity made at the top end of a vertical sprue to help easy feeding of molten metal into the mold from the ladle during the process of casting.

Sprue is a vertical entry for the molten metal to flow downward to runners and finally to the mold cavity.

Runners are the channels to carry molten metal from the sprue to the mold cavity.

Risers are specifically designed to store some additional metal during pouring so that when the casting shrinks during its solidification, the metal from the risers may flow to the casting to compensate for its shrinkage. Risers are designed to keep the metal in them in molten state until the casting is fully solidified. This way, the risers are the last to solidify. Risers help in escaping out (from the mold) of the entrapped gases and slag which may be dissolved or in suspension with the molten metal. Risers may be open risers or blind risers. Open risers indicate the complete filling of the mold by over flowing the molten metal from the top of risers during casting (Fig. 5.2(b)).

Core is the insert (made of sand) placed in the mold cavity to form hollow regions within the casting or to define the interior surfaces of casting. Cores are also used on the outside casting to form features such as deep external pockets or contours. Cores are made of sand having additives which, on burning, generate lots of gases.

Vents are passages to carry off air and gases produced in the mold cavity when the molten metal comes in contact with the mold walls and the cores, since both are usually made from sands having additives which, on burning, generate lots of gases.

In gates are the entry ends of the runners connecting the mold cavity or runners with the main runners.

Various casting processes (discussed later) need different types of molds which may broadly categorized as follows.

- Expendable molds such as sand mold, plaster mold, shell mold investment casting mold, etc., which are used only once (for casting) as these have to be broken up removing the casting from them.
(b) **Permanent molds** are made from steel or graphite and are so designed that they can be used repeatedly for a number of times to produce a large number of castings (as the casting can be removed from the mold without breaking it). Examples of such molds include: molds for die casting, continuous casting and centrifugal casting.

(c) **Composite molds** are made of two or more different materials, such as sand and graphite molds are used for casting aluminium alloy torque converters.

### 5.5.2 Casting

The process of **casting** involves (a) pouring of molten metal into the mold cavity patterned after the product to be made, (b) allowing the metal to cool and solidify in the mold, and (c) removing the cast metal or **casting** from the mold. During casting, the molten metal may flow through a variety of passages (such as pouring basin, sprue, runners, risers and gating system) in reaching the actual mold cavity. **Casting related activities** include: melting of metal and its handling during pouring into the molds, shake out (of the mold) for removing the casting from the mold, cleaning the casting surface by removing sand and cutting the gates and risers unwanted with the final casting, inspection and testing of castings and their heat-treatment in some cases.

The process of casting is primarily a function of the type of mold used, not only in terms of the mechanics of making the mold and filling it, but also in terms of the metallurgical results brought about by the wide range of heat-extracting qualities of the mold materials. For example, metal molds have high rate of heat extraction which results in making tough fine-grained castings. On the other hand, plaster molds extract heat very slowly and hence are suitable for casting even thin sections (as they are easy to fill in plaster molds in comparison to metal molds wherein quick solidification of metal may choke the flow of metal). The resulting castings in plaster molds tend to be softer and coarse-grained. The normal sand molds lie in between these two types and hence are considered most versatile in performance.

### 5.6 CASTING IN GREEN SAND MOLD

The method of sand mold casting is an ancient process. It is still the most widely used process. **Sand mold casting** consists of (a) placing the pattern in the molding sand and making an imprint in the sand compacted around the pattern, (b) taking out the pattern from the sand leaving behind the mold cavity in the sand, (c) preparing the mold ready (for pouring metal) by cutting or making metal pouring basin, gating system and risers in the sand and connecting them to the mold cavity, (d) filling the resulting mold cavity in the sand with molten metal, (e) allowing the metal to cool in the mold until it solidifies, (f) breaking away the sand mold and removing the casting. There are different types of sand molds, such as green-sand mold, skin-dry sand mold and dry sand mold. The selection of a particular mold depends on the type and temperature of the metal to be cast, size of casting, surface finish and dimensional accuracy required on the casting. The outline of a green sand mold casting process is given in the following.

Steps involved in making a green sand mold for casting a cylindrical block are described below with reference to Fig. 5.2(a).

(i) Take the turnover board and sprinkle a little amount of parting sand on it. Place mold box (drag) and pattern on the turnover board, pattern in the centre of mold box. Fill molding sand around the pattern to a height of about 13 cm using a hand sand presser and smoothen the sand evenly with rammer. Four more sand till it covers the pattern completely and then ram the sand properly around the pattern and in the box. Fill and compact the sand in the molding box to its top.

(ii) Add more sand so as to raise its level by about 4 cm over the edges of the mold box. Ramming of sand may be done using a flat rammer to make a flat surface of dressed sand extending about 6 mm above the box.

(iii) Level up the top of the mold box using a strickle bar. Then sprinkle a little amount of parting sand on the top leveled face of the sand box. Use a venting rod to prick the sand so as to provide a number of vent holes in the sand to allow escaping of the gases generated within the mold when the molten metal comes into contact with moist sand.

(iv) Now lift up the sand filled mold box from the turnover board and turn it upside down and place it again on the turnover board. Use a trowel to smoothen the surface and to make it in line with pattern face. Then sprinkle a little amount of sand on the face of the sand box (except the pattern). Place the cope on the box and clamp both the cope and the drag together. Insert two tapered wooden rods, rod (A) and a riser rod (B), in the sand of the drag. Then pour sand and fill the mold cavity with sand. Ram the sand properly keeping both the rods (A) and (B) at well vertical. Level the top surface with smoother. Vent the mold sand at necessary points around the mold.
places with the venting rod. Later, take out both the tapered rods (A) and (B) resulting in the formation of two holes, out of which one will work as 'sprue' for the entry of molten metal in the mold and another as the 'riser hole' for escaping the gases or slag in suspension with the molten metal. Later, using a gate knife, make the pouring cup at the top of sprue for receiving metal at the time of casting.

(v) After removing the mold box clamps, pick up the cope box and turn it over and place it on the floor. Brush off all parting sand from the top face of drag and later dampen up the pattern edges (in contact with sand) with a water dipped swab. Gently drive a pattern lifter or spike in the pattern, loosen the pattern in the sand by tapping laterally all round and take it out of the sand. Make necessary connections or channels for the flow of molten metal from the bottom of pouring sprue to the mold cavity and also to the riser hole. Repair the mold with the help of trowel, cleaner or slicker as per the conditions of breakages in the mold. Later, use a hand blower to clean the sand or dirt, if any, from the mold. Then carefully place the cope over the drag and clamp the two boxes together (Fig. 5.2(b)) and put some weight on the top of sand filled cope so that during the process of casting, due to the pressure of metal, the sand in the cope may not get disturbed. Weight should not cause hindrance to vents. This completes the operation of making the mold.

The next operation is casting, i.e. pouring molten metal in the mold through the pouring cup and seeing that it fills the mold completely and later comes to the top of riser hole. Allow the contents of the mold boxes to cool. After the solidification and cooling of the casting, take it out from the sand mold by breaking the mold. The cast product will have a shape as shown in Fig. 5.2(c). Remove the surplus metal of sprue, riser and runners (shown shaded) with the help of a chisel and hammer leaving the casting free. Grind the casting if so required.

5.7 FOUNDRY TOOLS AND EQUIPMENT

A large variety of tools, gadgets and equipment are used for conducting various operations related to molding, casting and testing of mold materials and castings. These can be categorized as follows:

(i) Hand tools
(ii) Containers or flasks
(iii) Equipment for machine molding
(iv) Sand testing equipment
(v) Metal melting equipment
(vi) Fettling and finishing equipment
(vii) Inspection and testing equipment for castings.

Only the hand tools and containers have been discussed in the following and all equipment from the above list, have been discussed elsewhere in this chapter.

5.7.1 Hand Tools

- **Shovel** is used for mixing foundry sand and filling it in the mold boxes.
- **Hand riddle** is a sorting device used for riddling of sand to remove foreign items (like nails, wires) when sand is sieved through it.
- **Water sprinkler** is a handy device for wetting and tempering the sand.
- **Rammers** are used for packing and compacting molding sand floor or molding in the molding box. Different types may include: floor rammer, hand rammer, orbital rammer.
- **Molding board or turn over board** is used either for bench molding or for molding a small mold on foundry floor. Wooden boards are quite common.
- **Strickle bar or strikeoff bar** is a flat bar of wood or metal and is used for striking off the excess sand from the mold box after ramming. It has one edge bevelled to the surface perfectly smooth.
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Fig. 5.3 Hand tools used by a molder.

- **Vent wire** is a thin steel rod with a pointed edge and is used to prick the rammed sand filled in the mold box for making small holes or vents for the escape of gases and steam during casting.
- **Trowels** of different shapes are used for the repair or mending the broken portion of the sand mold after the pattern is taken out from it. These are also used sometimes for filling sand in small mold boxes.
- **Slicks** are also used for repairing the mold, particularly the external or internal round and square corners of the mold.
- **Brush** usually made from cotton is used for clearing the parting sand from the surface of the pattern.
- **Swab** has small bulk of fibres and is used to dampen the outer edges of the pattern before it is taken out from the mold or compacted sand.
- **Cleaner or lifter** are finishing tools and used for repairing the mold in deep places after the withdrawal of pattern from the mold. They are also used to remove loose sand from the mold cavity.
- **Beads** are also used for repairing the mold.
- **Draw spike or screw** is a steel rod with a loop at one end and pointed or screw portion on the other end. These are used to rap and lift or pull out the pattern from the mold.
- **Smoother** is a rectangular wooden block used to smoothen the upper surface of the mold box filled with sand. Metallic smoothers are also used.
- **Mallet** is a wooden hammer used to drive draw spikes in the pattern for pulling it out of mold (or sand).
- **Gate knife** is used to make pouring basin or cup by enlarging and giving appropriate shape to the metal receiving end of the pouring sprue in the mold.
- **Sprue rod and riser rod** are tapered cylindrical wooden rods used for making risers in pouring sprue and riser hole in the cope (upper half of the mold).
- **Bellows** are used to blow out dust and sand particles from the mold cavity and clean it by air pressure.
- **Shake bag** is used to sprinkle parting compound on the mold and is made of canvas cloth.
- **Gaggers** are bent pieces of wires and rods used for reinforcing the down projecting sand mass in a cope (or top portion of mold) in making large size molds.
- **Nails and wire pieces** are used to reinforce cores or thin projections of the sand in the mold.

5.7.2 Containers

Containers include (a) Molding boxes, (b) Ladles and (c) Crucibles. Molding boxes are used for making molds (or mold cavity) in the molding sand rammed in molding boxes. Both ladles and crucibles are used for melting and handling the molten metal during the process of casting.

**Molding boxes or flasks** have box-like structure made of rectangular walls (sometimes circular also) and without any bottom or top cover. These are mostly made of cast iron although wood is also used sometimes. When a mold is made within two boxes, the upper box is called **cope** and the lower one **drag** (Fig. 5.4(a)). When three molding boxes are used, the middle one is called **cheek**. Small molding boxes do not need strengthening cross bars for giving support to the molding sand in the cope part of the mold but the bigger boxes used for large size molds (where the distance between mold walls is too large), essentially need the provision of cross-bars (Fig. 5.4(b)). A **snap flask** (Fig. 5.4(c)) is a wooden box hinged at one corner having clamping arrangement at the opposite corner. It is used for bench molding of small molds. The molds carry projecting handles for holding of the mold as also the provision of clamping the cope and drag together (through the projecting portions or lugs on the boxes).

**Laddies** are used to receive molten metal from the furnaces or cupola and to transport to the casting place and also to pour the molten metal into the mold. These are made in different capacities, varying from 20 kg to 150 kg. A **hand shank ladle** handled by two persons shown in Fig. 5.5(a). Very large size ladles, capacity up to 1000 kg, are handled by a crane. These have geared system to tilt the ladle for pouring molten metal into the mold (Fig. 5.5(b)).
and these are used for very large castings where metal requirement is very high. Bottom pour laddies are also available.

Crucibles are made from refractory materials (such as silicon carbide) and are used as metal melting pot (Fig. 5.5(c)). The metal charge in broken pieces is placed in the crucible which is later placed inside a pit furnace or other furnace for melting the metal charge. Pouring of molten metal from the crucible may be done directly into the mold or by first receiving into a laddle and later poured in the mold.

5.8 MOLD MATERIALS AND THEIR SELECTION

Molds are made from heat resisting materials such as sand, clay or graphite. Varieties of clays mixed together with suitable binders, provide a wide range of mold materials. Green sand molds (moist) and dry sand molds (baked) are in fact the sand molds but the types only differ in the state of the mold just before pouring metal. Permanent metal molds mostly used in die casting and centrifugal casting processes. Plaster molds and ceramic molds are made from fast setting plasters, fibres and water mixture. Sometimes and mercury (Mercast process) are also used for making molds.

The choice of a mold material depends mainly on the cost as mold should be made cheaper and easily available materials. Molds are also selected on the basis of metal to be cast (high melting point or low melting point), for example, low melting point metals and alloys like aluminium, zinc, magnesium, lead, etc. are cast easily in metal molds by die casting processes.
Size and shape of the casting is also important in selecting mold material with proper thermal conductivity. Metallic molds have higher thermal conductivity than sand molds and thus can produce castings at a faster rate. But heavy and thick castings need extra time during solidification and cooling and hence these are best produced in sand molds.

Among all the available mold materials, sand is the most versatile and commonly used mold materials in all foundries since it fulfills the basic requirements of casting materials. It is also readily available. When properly mixed with suitable binders and additives, sand contributes to be one of the best and cheapest materials for making molds. All castable metals can be cast in sand molds irrespective of their size, shape and weight.

5.9 MOLDING SANDS (OR FOUNDRY SANDS)

Molding sands or foundry sands are the sand mixtures or molding mixtures used for making molds in a foundry shop. Different types of molds such as green-sand mold, skin-dry sand mold, dry sand mold, CO₂ hardened sand mold, etc. are all made from foundry sands of various types and grades.

Molding sands are broadly classified in the following major groups, according to the nature of their origins.

5.9.1 Natural Sands

Natural sands are collected from natural resources like rivers, lakes, seas or deserts. Natural sands constitute the major part of all foundry sands. They contain silica sand, clay substances and water. Silica sand has 80 to 90% silicon oxide (SiO₂) obtained from quartz rocks or by decomposition of granite. The silicon oxide is characterized by having very high softening temperature and thus having high thermal stability, which imparts refractoriness, chemical resistivity and permeability to the molding sands to stand well when they come in contact with molten metal. Natural sands contain sufficient amount of binding clay (10 to 15% or more) which imparts bonding property, plasticity and cohesionness to the silica particles in moist state. Water plays an important role in molding sands. When present up to 5 to 8%, water imparts green strength to the sand in the presence of clay, besides improving workability and permeability. Because of being moist, natural sand is also called green sand.

The size and shape of silica sand grains are responsible for several important properties of the molding sand. The size of sand grains varies considerably over a wide range, from 50 microns to 3360 microns and accordingly the sands are classified as fine, medium or coarse grained. Fine sands are used for small and intricate castings but they have poor permeability. Medium size grains are preferred for light work. Large grained sands are more permeable and hence used for large size castings. They have better refractoriness also. The shape of the sand grains may be angular, round, sub-angular or compounded. Round grains give poor strength to the mold but high permeability. Angular grains give better strength but reduced permeability of the molding sand. Sub-angular grains are less permeable than rounded grains. Compounded grains are in the form of hard lumps and their presence in molding sands is considered undesirable.

5.9.2 Synthetic Sands

Synthetic sands are prepared from silica sands which are relatively clay free. They need some binder to make them suitable for foundry work. When mixed with suitable binders and additives, the silica sands are converted into synthetic sands. These are considered better sands (than natural sands) as their properties can be easily controlled by varying the contents of sand mixture.

None of the natural sand possesses the required qualities to the extent necessary for being a good foundry sand, since these sands lack one or more importantly required properties which are always covered up by blending or mixing other sands or materials (like additives) with them. Natural sand, so that the resulting sand mixture turns out to be a good sand for foundry purposes.

All foundry sands generally used for molding purposes are in a way blended sands. For example, a typically blended sand mixtures for making a green sand mold for casting grey cast iron, may contain: natural sand (river) 50 to 60%, clay 12 to 15%, bentonite – 2 to 15%, coal dust – 5 to 15% and water – 4 to 6%.

5.9.3 Special Sands

In addition to the natural sands and synthetic sands which are primarily based on silica sand, there are certain other varieties of special sands such as zirconite and olivine which are better in performance than silica sand but being costlier, these are used only for special applications.

5.10 CONSTITUENTS OF MOLDING SANDS

The principal constituents of a molding sand are:

- Silica sand
- Binders
- Additives
- Water

1. Silica sand: It forms the bulk of the foundry sands and imparts refractoriness and other properties to the molding sand.

2. Binders: Binders give cohesiveness and strength to the sand to enable it to retain the shape of the mold cavity after the withdrawal of the pattern from the sand. Binders may be organic type (such as linseed oil, molasses, dextrin, pitch or resins) and inorganic type (such as clays, cement). Clay binders include: bentonite, limonite, fire clay, etc.

3. Additives: These are used to improve the properties of the sand, either by improving the existing properties of the sand or by imparting new properties to make the sand mixture more useful. Common additives are: coal dust, sea coal, cereals, silica flour, pitch, dextrin, molasses, wood flour, etc. Coal dust when present (up to 10%) in the sand mold, reacts with oxygen present in sand pores at the time of casting and produces a reducing atmosphere of CO₂ at the mold-metal interface, which gives smooth castings. Cereal flour improves strength and collapsibility of sand (to allow free contraction of casting). Silica flour increases hot strength of mold and decres
metal penetration into mold walls and thus gives smooth castings. Both dextrine and molasses improve dry strength (after baking the mold) and decrease metal penetration into mold walls.

Wood flour reduces expansion defects in grey cast iron castings by promoting mold wall movement and collapsibility. The grey cast iron expands (up to 2.5%) during solidification and cooling, because of the period of graphitization that occurs during the final stages of solidification.

Cooling, because of the period of graphitization that occurs during the final stages of solidification. The grey cast iron expands (up to 2.5%) during solidification and cooling, because of the period of graphitization that occurs during the final stages of solidification.

As mentioned earlier, none of the naturally available sand possesses the desired qualities to the required degree for being considered a good molding sand. By the process of blending or mixing varieties of sands together and by adding binding materials or additives to this mixture, a new suitable sand mixture is produced for foundry purposes.

New sands as well as used floor sand (which has been used several times in making castings) are properly prepared and mixed in a suitable ratio, for example, the ratio of used floor sand to new sand may be more for light castings but it decreases for medium and heavy castings.

Conditioning of the sand is essential. Proper conditioning means uniform distribution of clay bond and other additives over sand grains, even distribution of proper moisture and sorting out of foreign matter like nails, and other metal pieces (which might have been used for strengthening previous mold walls) by riddling and a thorough mixing of sand mass. The operation of conditioning is carried out manually by mixing the sand mixture and other additives with hand shovels. Modern foundries have appropriate equipment for conditioning of the sand such as circular pan sand mixer using rotating stone wheels and paddles. Testing of sands is also carried out for strength, permeability and moisture content, etc. to predict its performance during use.

5.12 CHARACTERISTICS (OR PROPERTIES) OF MOLDING SANDS

A good molding sand must possess the following characteristics, which are determined by the various constituents present in a particular molding sand mixture.

1. Refractoriness is the property which makes the molding sand capable of withstanding high temperatures of molten metal without the fusion of the sand. Silica sand present in the molding sand is primarily responsible for imparting this property. Also, the higher contents of impurities such as lime, magnesia, metallic oxide, etc. present in some sands, tend to lower the fusion point of silica sand. Larger grains of silica increase refractoriness.

2. Permeability or porosity is that property of sand which allows easy escape of gases during solidification and steam through the sand mold when molten metal comes in contact with moisture in the form of coal dust, oils, resins and other gas forming agents. Most molten metals have dissolved gases in them which are evolved on solidification. Insufficient porosity of molding sand leads to several casting defects such as porosity, honeycombing. Permeability depends on the shape and size of sand grains, the amount of moisture contents and ramming of sand (around the pattern during molding) preventing the venting of the mold.

3. Cohesiveness is the ability of sand particles to stick together and thus give a proper strength to the moist molding sand in maintaining the shape of mold (or mold cavity) after the pattern has been withdrawn from the sand. Cohesiveness depends upon the size, shape and distribution of sand grains, type and contents of clay and other bonding materials and the moisture contents.

4. Plasticity is that property of a molding sand by virtue of which it takes easily the desired shape (as per the pattern) under pressure and retains it after the pressure is removed. Fine-grained sands give good plasticity. Plasticity also depends upon the moisture content, which absorbs moisture and helps improving the plasticity.

5. Flowability is that property due to which the sand flows under the effect of ramming (during molding) to all portions or corners of the molding box and packs properly around the pattern while distributing the ramming pressure evenly on the sand in all parts of the molding box.

6. Adhesiveness provides the sand the capability of easily adhering to the surface of other materials such as the walls of molding boxes and thus helps in retaining the pattern (filled in the molding box) in tact during molding (when mold boxes filled with sand may be lifted or overturned during the process).

7. Collapsibility is that property because of which a sand mold (or core) collapses automatically, giving way to free contraction of the solidifying casting and thus preventing hot tears and cracks in castings.

Other properties may include: low coefficient of expansion; property of non-sticking of mold casting; non-reaction chemically with molten metal; low cost and easy availability.

5.13 SOME COMMONLY USED FOUNDRY SANDS

Sands of following types are used for making molds and cores and serve various other special purposes.

1. Green sand, also known as tempered sand, refers to a moist molding sand which is available in foundry shops for general molding purposes. Molds made with this sand are called green sand mold in which molten metal is poured during casting without any prior drying or baking of the mold. Green sand is a well prepared foundry mixture made by mixing natural sand and other sands (including used floor sand...
additives and contains just enough moisture (up to 8% or so) to give sufficient bonding strength to the mold. Small and medium sized castings of ferrous and nonferrous metals are made in this sand as it is the least expensive foundry sand and takes less time in making the mold ready for casting (as no drying or baking of mold is involved).

2. **Dry sand** refers to that molding sand which at the time of making a mold, had excess moisture but the same has been evaporated by drying the internal mold face or the full mold in an oven. The mold thus made is called **dry sand mold**. The sands used for these molds are fine-grained and mixed with proper binders and additives that give strength to the mold on baking. Dry sand molds are used for casting large size steel and cast iron components.

3. **Floor sand or black sand or backing sand** is that molding sand which is used over and over again for molding purposes, and is usually black in colour due to the addition of coal dust and also due to burning as a result of coming in contact with the molten metal repeatedly during casting. It usually forms the bulk of the molding sand as it supports the facing sand filled only to a certain depth around the pattern during molding. Floor sand is also mixed in certain proportion with the natural sand, clay or other binders and additives while preparing the new green sand molding mixture.

4. **Facing sand** is a fine textured sand used to form the face of the mold cavity when used around the pattern to a thickness of about 5 cm. A certain amount of floor sand and new molding sand properly tempered with moisture and suitable additives give a good facing sand. The facing sand has better strength and high refractoriness than the floor sand.

5. **Parting sand** is usually a natural dry silica sand sprinkled onto the pattern and also on the parting surfaces of the mold (when made in two or more boxes), so that the sand mass of the molding boxes may not stick to each other or to the pattern. A parting compound made from phosphate rock is also used sometimes as parting sand.

6. **Core sand (or oil sand)** is a high silica sand bonded with organic binders such as linseed oil, light mineral oil, pitch or corn flour, etc. It finds use in making cores and molds for nonferrous castings.

7. **Loam sand** comprises a mixture of ordinary clay (about 50%), fire clay and silica sand and water milled to a thin paste which in the form of plaster, is applied on the face of a roughly carved mold made by using burnt clay bricks. The mold is brought to the final shape with a rotating sweeping pattern which molds the plastered face to the required shape and size of the mold. The plaster hardens on drying. Usually, symmetrical objects (cylinder, barrels, kettles) are made in such molds.

5.14 **FOUNDRY BLACKINGS**

Foundry blackings (or dressings or mold and core facings) are applied to the mold face and core face to increase refractoriness and smoothness. Blackings are used dry (by dusting) or in the form of a paste (made using water and a binder) and applied with a brush or swab. Blackings are highly refractory materials such as plumbago (mineral graphite), coke powder, china clay, zircon flour or French chalk. **Mold washes** are slurries of fine ceramic grains applied over the mold faces to minimize fusing of the facing sand grains during casting. Blacking powder with plumbago is the commonly used blacking in iron foundries. Blackings used in steel foundries comprise zircon flour, china clay, calcined magnesite with bentonite or silica as binder. For nonferrous metal castings of small and medium size, no blacking is used in green-sand molds.

5.15 **PATTERNS**

A **pattern** is used for molding a cavity (or mold) in the molding sand mixture such that the formed cavity is similar to the shape of the casting (Figs. 5.2(a) to 5.2(c)). The pattern is a replica of the desired article to be cast but differs from the actual article in certain ways; for example, pattern carries (a) additional allowance in its dimensions to compensate for the metal shrinkage during casting; (b) allowances for machining or finishing the castings; (c) draft on its exterior and interior surfaces for its easy removal from the molding sand; and (d) additional projections (core prints) to produce seats in the mold for the setting of core print. Patterns are made from wood, metals, rubber, plaster, wax, plastics etc. The selection of particular material for making pattern depends on factors such as number of castings to be made, method of molding (hand or machine), quality of castings and degree of finish desired and dimensional accuracy desired on castings, design of the casting with possibilities of change in the design of the pattern and expectations of repeat orders.

5.16 **PATTERN COLOURS**

The following information regarding the colour of the pattern is a general guide or helps in identification of parts of patterns:

- **Yellow**—Core prints
- **Red**—Surfaces (of the resulting casting) to be machined
- **Black**—Surfaces (of the resulting casting) to be left unmachined
- **Red strips on yellow base**—Seat for loose pieces of the pattern
- **Clear or no colour**—Parting surface

5.17 **MATERIALS FOR PATTERNS**

Pattern material should be cheap and readily available. It should be hard, strong and light with resistance to corrosion. It should be capable of taking good surface finish. And it should be easy to work upon by normal manufacturing methods used in making the pattern or mold. The following materials are used for making patterns:

1. **Wood** is commonly used because it is cheap, easily available, can be shaped light in weight and can have good surface finish. Wood, however, is affected by moisture and changes its shape and size on drying out. It also wears out quickly by abrasion by molding sands and hence has comparatively shorter life because of wood patterns are not used for the production of large quantities of castings. They are used for patterns include: white pine, deodar, tun, walnut, teak, etc.
2. **Metals** used for making patterns include cast iron, brass, white metal, aluminium, etc. Metallic patterns are preferred when a very large number of castings are to be made. These patterns are costlier than wooden patterns but have much longer life.

3. **Plaster of paris** and **gypsum cement** are also used for making patterns. They are easily cast into intricate shapes. Small patterns of complicated shapes are made of plaster of paris by pouring and setting the plaster slurry into the pattern molds.

4. **Plastics** of different types are used for making patterns. Among thermoplastics, polystyrene is commonly used for patterns (known as *consumable pattern* as heat of molten metal vaporizes the pattern which leaves behind the formed mold cavity). Thermostetting plastics such as phenolics and epoxies are also used for patterns.

5. **Wax** as a pattern material is used in investment casting process (or lost wax process).

### 5.18 PATTERN ALLOWANCES

1. **Shrinkage allowance**: Most metals when they cool down from molten state to room temperature, shrink or contract in three different stages, namely, (i) **Liquid contraction**, (ii) **Solidifying contraction**, and (iii) **Solid contraction**. The first two types of contractions (involving change from liquid to solid), are compensated by the feeding of metal from risers where the metal remains in molten state till the casting gets solidified. It is for the third type of contraction, the solid contraction (contraction of solidified casting to room temperature), for which allowance is provided on the patterns. Different metals have different contraction allowance. The solid contraction of the metal is influenced by the metal to be cast and the pouring temperature of the molten metal, design, geometry and size of casting, type of mold material and method of molding and resistance of mold to shrinkage. Although the contraction of the castings is volumetric contraction, the contraction allowance is, however, given in linear measures as shown in Table 5.1 which works as a general guide only.

<table>
<thead>
<tr>
<th>Metal to be cast</th>
<th>Allowance mm/metre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grey cast iron</td>
<td>10.5</td>
</tr>
<tr>
<td>Malleable cast iron</td>
<td>10.5</td>
</tr>
<tr>
<td>Steel</td>
<td>21.0</td>
</tr>
<tr>
<td>Brass</td>
<td>16.0</td>
</tr>
<tr>
<td>Aluminium</td>
<td>16.0</td>
</tr>
<tr>
<td>Zinc</td>
<td>24.0</td>
</tr>
<tr>
<td>Lead</td>
<td>24.0</td>
</tr>
<tr>
<td>Copper, Magnesium</td>
<td>16.0</td>
</tr>
<tr>
<td>Silver</td>
<td>10.0</td>
</tr>
<tr>
<td>White cast iron</td>
<td>21.5</td>
</tr>
</tbody>
</table>

2. **Machining allowance**: Machining allowance is given on a pattern only when the casting being made needs machining and finishing. This allowance is given in addition to the shrinkage allowance and varies from 2 mm to 5 mm according to the location and nature of casting, method of machining and the degree of finish required. In large castings the machining allowance may be 12.5 mm or more.

3. **Draft allowance**: Patterns are given slight taper on their vertical surfaces (both external and internal) which are parallel to the direction of their withdrawal from the mold (Fig. 5.6). This taper or draft is expressed either in degrees or in terms of linear measurements, amount of draft being more on internal surfaces. The draft amount may vary from 10 mm to 25 mm per metre on external surfaces and from 40 mm to 70 mm per metre on internal surfaces.

![Fig. 5.6 Tapering a pattern for its easy removal from the compacted sand mold without breaking the mold.](image)

4. **Rapping or shake allowance**: To take the pattern out of the compacted sand mold, the pattern is first rapped or shaken by striking over it side to side, so that the pattern surfaces may be made free of the adjoining sand walls of the mold. This operation obviously enlarges the size of the mold cavity and hence a negative rapping allowance is provided on patterns to compensate, at least in case of large castings.

### 5.19 TYPES OF PATTERNS

Patterns are of great variety because of their different designs, construction and methods of More commonly used types are discussed below.

1. **Solid or single piece pattern**: It is the simplest one piece pattern (Fig. 5.7) and be molded in one box or two boxes depending on its shape.

![Fig. 5.7 A solid pattern.](image)
Die casting is a permanent mould casting technique which involves the preparation of components by injecting molten metal at high pressures into a metallic die. Both the processes i.e. permanent mould casting and die casting use reusable metallic dies so these are closely related to each other. In comparison with gravity die casting (Permanent mould casting discussed earlier), in die casting since the metal is forced in under pressure, it is also known as pressure die casting. In view of high pressure involved in die casting, complex shapes and narrow sections and fine surface details can be achieved easily. In a die casting machine, the die consists of two parts. One part is known as the stationary die or cover die which is fixed to the machine. The second part is known as the ejector die and is moved out for the extraction of the casting. The casting cycle is initiated when the two parts of the die are apart. The lubricant, (refractory material), is sprayed on the die cavity manually or by the auto lubrication system in order to prevent the die wear and sticking of the casting to it. The two halves are closed and clamped. Within a fraction of the second, the required amount of molten metal is fed into the die under pressure so that it fills the entire die including all minute details. Rapid cooling of the metal takes place since the die is water cooled. After the casting solidifies, the die is opened and the component is forced out automatically by an ejector pin. The accuracy attained is so high that the pressure die cast component parts are normally assembled without any machining. A multicavity die may be employed for manufacture of small sized components.

The two main types of processes used in die casting are:

(i) Hot chamber die castings
(ii) Cold chamber die castings

### 3.59.1 HOT CHAMBER DIE CASTING

The hot chamber die casting machine is illustrated in Fig. 3.70(a).

The metal is kept into a heated holding pot. A pot is provided near the top of the cylinder to allow the entry of the molten metal. As the plunger ascends, the valve of the cylinder opens and molten metal enters the cylinder. The stroke length of the plunger is adjustable to enable a specific amount of molten metal to enter the cylinder or goose neck. As the plunger descends, the valve closes and the molten metal is forced through the nozzle into the die. A nozzle at the end of the goose neck is kept in close contact with the die through a sprue.

As illustrated in the figure, the casting cycle starts with the closing of the die when the piston plunger is in the highest position in the goose neck, thus allowing the molten metal to fill the goose neck. When the plunger starts moving down, the molten metal in the goose neck is forced to be injected into the die cavity. The metal is solidified when held at the same pressure. The piston/plunger then moves back returning the unused molten metal.

This process is limited in applications to low melting point metals that do not chemically attack the plunger and other mechanical components. These metals include zinc, tin, lead and sometimes magnesium. Moulds in die casting operations are usually made of tool steel and mould steel. In special attempts to use cast steel and cast iron, tungsten is also employed. Ejector pins are required to remove the part from the die when it opens as illustrated in Fig. 3.70(a). These pins help to push the component/part away from the mould surface so as to remove it. Lubricants must be sprayed into die cavities for easy removal or to prevent sticking.

Venting holes and passage way must be built into the die at the parting line to evacuate air and gases present in the cavity because the die materials have porosity and molten metal rapidly flows into the die during injection process. These small vents are filled with metal during injection which is later trimmed from the part.
3.59.2 Cold chamber die casting

The hot chamber process is employed for most of the low melting temperature metals and their alloys such as zinc, lead and tin. The cold chamber die casting process is used for casting metals and alloys which require high pressures and have high melting temperatures such as brass, aluminum and magnesium. The metal melting unit is not an integral part of the machine in this case and metals are melted in a self contained pot in an auxiliary furnace.

After closing the die with the cores in position, molten metal is ladled into the horizontal chamber through the metal inlet. The plunger is pushed hydraulically to force the molten metal into the die. After solidification, the die is opened and the casting is ejected. The pressure used in cold die casting process is considerably higher than in hot die casting process. This high pressure leads to high squeezing action while solidification takes place. The process is illustrated in Fig. 3.70(b).

The material used in cold chamber dies consist of high grade resistant steel, that is capable of withstanding high temperatures as well as pressures. The life and efficiency of this machine is greater than the hot chamber die casting machine.

3.60 ADVANTAGES AND LIMITATIONS OF DIE CASTING

Advantages

(i) Very high rate of production can be achieved e.g. with the hot chamber process 300 to 400 castings per hour and with cold chamber 100 to 150 castings per hour can be produced.

(ii) Close dimensional tolerances of the order of \( +0.025 \text{ mm} \) can be achieved.

(iii) It is possible to obtain fairly complex castings than that feasible by permanent mould casting due to the use of movable cores.

Surface finish of 0.8 microns can be obtained by the use of metallic dies. Such surface of die casting can be directly electroplated without any further processing.

(v) It is a very economical process for large scale production.

(vi) Components with very small wall thickness, up to 3mm to 6mm can be produced only by this process.

(vii) Less floor space is required for this process.

(viii) Dies employed for die casting retain their accuracy for a very long time.

3.60.1 Limitations of die casting

(i) Normally zinc, aluminum, copper and magnesium alloys are die cast. This is not suitable for all materials due to the limitations of die material.

(ii) Die casting generally contains some porosity because of the entrapped air.

(iii) The machinery and other equipment used are very costly.

(iv) The process cannot be used for economical production of small quantities.

(v) The process cannot be employed for heavy castings. In fact, the maximum size is limited by the size of the dies and the capacity of the die casting machines available.

(vi) Large size castings tend to be less compact.

3.60.2 Applications of die casting

Die casting process is employed for the production of items such as decorative items of automobiles, carburetors, crank case and similar components (consist of aluminum) of scooter, motor cycles and mopeds.

3.61 CENTRIFUGAL CASTING PROCESS

Centrifugal casting is the process of rotating a mould at high speeds as the molten metal is poured into it due to the centrifugal force of the rotation towards the periphery or inside surface of the mould with considerable pressure. Due to the centrifugal force, a continuous pressure will be acting on the metal as it solidifies. The impurities i.e. slag, oxides and other inclusions being lighter are separated from the metal and segregates towards the centre. The process produces casting with greater accuracy and better physical properties due to directional solidification compared to sand castings. Castings of symmetrical shape lend themselves particularly to this method, although many other types of castings can be produced. Due to the pressure exerted on the metal, thinner sections can be cast. Centrifugal casting is often more economical than other methods. Coreless cylindrical shapes and risers or gates are both eliminated, thus making the metal.
(iv) Fillers
(v) Elastomers
(vi) Stabilizers
(3) What are the common properties of plastics?
(4) Describe the production and properties of thermosetting plastics.
(5) Give the properties and uses of some popular varieties of thermoplastics.
(6) Describe with the help of neat sketches the following plastic processing methods stating their advantages and applications.
   (i) Compression Moulding
   (ii) Injection Moulding
(7) What are the benefits of injection moulding process over the compression moulding process of plastics?
(8) Write short notes on the following.
   (i) Slush moulding
   (ii) Transfer moulding
   (iii) Calendering
(9) What are laminated plastics? Give their important properties and uses.
(10) Explain the difference between high pressure and low pressure plastic laminating processes. Describe any one of them.
(11) Write short notes on machining and joining of plastics.
(12) Name five common thermoplastics and four common thermosetting plastics.

CHAPTER 9

Smithing and Forging

Forging is a deformation process in which the workpiece is compressed between two dies by applying gradual pressure or hammered with the help of a hammer or forged into a plastic state. The plastic state of workpiece can be obtained by heating it up to the recrystallization temperature of its material. There is evidence that forging was used in ancient Egypt, Greece, Persia, India, China and Japan to produce weapons and a variety of implements. During these times, craftsmen in the art of forging were held in high regards. These days forging is utilized for automotive, aerospace and other applications. These components include engine crank shafts, connecting rods, gears, aircraft structural components and jet engine turbine components. The basic form of large components can also be produced by forging, which are further given final shape and dimensions by machining and finishing.

9.1 INTRODUCTION

Forging is the oldest shaping operation used for producing small items for which size is insignificant. It is an operation where the metal is heated and then a force is applied to manipulate the metal in such a manner that the required final shape is obtained.

Forging is a deformation process in which the workpiece is compressed between two dies by applying gradual pressure or hammered with the help of a hammer or forged into a plastic state. The state of workpiece can be obtained by heating it up to the recrystallization temperature of its material. There is evidence that forging was used in ancient Egypt, Greece, Persia, India, China and Japan to produce weapons and a variety of implements. During these times, craftsmen in the art of forging were held in high regards. These days forging is utilized for automotive, aerospace and other applications. These components include engine crank shafts, connecting rods, gears, aircraft structural components and jet engine turbine components. The basic form of large components can also be produced by forging, which are further given final shape and dimensions by machining and finishing.

Forging can be classified in many ways. One way of classification is the working temperature during forging. It is classified as cold forging and hot
forging. Cold forging is carried out at room temperature. Hot forging is performed by heating the workpiece up to its recrystallization temperature. The difference between hot forging and cold forging is the same as comparison of hot and cold working of metal already discussed in chapter 4 (last topic).

The other way of classifying forging is whether impact or gradual pressure is applied. The distinction derives more from the type of equipment used than difference in the process of forging. A forging machine which applies an impact load is known as a forging hammer while the one that applies gradual pressure is called a forging press.

Another difference among forging operations is the degree to which the flow of work metal is constrained by the dies. Under this classification, there are following three forging operations:

1. **Open Die Forging**: In this forging operation, the workpiece is impressed between two flat faces of dies, thus allowing the metal to flow without constraint in a lateral direction relative to the die surfaces.

2. **Impression Die Forging**: In this forging operation, the die surfaces contain a shape or impression that is imparted to the work during compression, thus restricting the metal flow to a significant degree. In this type of operation, a portion of work metal flows beyond the die impression to create flash. Flash is excess metal that must be removed after completion of the forging operation.

3. **Flash Less Forging**: In this type of forging, the work is completely constrained within the die and no excess flash is produced. The volume of the starting workpiece must be controlled very closely so that it matches the volume of the die cavity. In case the workpiece volume is small, it would not fill the die cavity.

The other way round, if the volume is larger, it may damage the die or the press. Depending upon the method of applying pressure, forging may be categorized in different classes. In case, pressure is applied manually i.e. by hand tools, it is known as hand forging; when pressure is applied with power hammers, it is called power forging; and when pressure is applied by means of drop hammers, such forging is termed as drop forging.

### 9.2 TOOLS AND EQUIPMENT USED IN HAND FORGING

Three types of tools and equipment are used in forging for different purposes. The first is to heat the workpiece up to its recrystallization temperature, the second is to hold the workpiece to perform the required operation and the third is to apply the required pressure. The principal tools and equipment used in hand forging are discussed as follows:

#### 9.2.1 Smith's Forge or Hearth

It consists of a robust cast iron or steel structure supported on four legs, bottom known as hearth, a hood at the top and tuyere opening into the hearth either from the rear or the bottom as indicated in Fig. 9.1.

The hearth is provided with a lining of fireproof bricks to withstand the extensive heat produced due to combustion of coal. A nozzle pointing into the centre of the hearth known as tuyere is used to direct air stream with the help of air power into the burning coke. Since the hottest part of the fire in the hearth is near the tuyere opening, this is provided with a water jacket to prevent overheating. The hood provided at the top of the hearth collects the smoke, fumes and directs them into the atmosphere through a chimney. The workpiece is heated by putting it just below the upper burning coal layer to prevent oxidation. Impurities are collected as clinker and removed from the bottom of the fire when the hearth is cool. The hearth can also be made with masonry construction providing all its attachments like chimney, tuyeres, blower and water tank etc. This type of furnace is very efficient. The main limitation is that these furnaces are not portable.

The amount of heat developed depends upon the availability of air or oxygen by increasing the supply rate of air. The white colour of the heating zone is an indication of very high temperature. The place where air is injected into the furnace is known as an air blast zone. The workpiece should not be placed exactly in the air blast zone since continuous impinging of cool air on to the workpiece surface results in lowering of its temperature. For efficient forging work, the supply of air at an appropriate rate and the proper placement of workpiece should be done by experienced operators. As far as possible, a uniform flame should be maintained in the hearth. In order to prevent the cool air from impinging directly on to the workpiece, the tuyere must remain covered with coal during operation. The tuyere opening should be cleaned from time to time in order to avoid the choking of the same due to slag collection.

#### 9.2.2 Open Fire and Stock Fire

Commonly used methods of firing a smith's forge are (i) Open fire (ii) Stock fire
Open Fire: Open fire illustrated in Fig. 9.2 is the type of fire that is highly convenient for general heating work and is made up in a hollow space in front of the tuyere nozzle covered with fresh coal. After the combustion of the supplied coal, the fire extends outwards, the coal from the top and the sides move towards the centre of the hearth and more fresh coal is added over the fire. This is done after removing the ash as well as clinkers left behind by the previous fire. In order to generate localize heat around the workpiece, it should be covered by coal from all sides and water showered it to break into pieces. Sprinkling water on red hot coal helps in breaking it into pieces which is favourable for the complete combustion of coal.

Stock Fire: When heating a larger workpiece, stock fire is required for a longer period and a stock fire is recommended. Stock fire is illustrated in Fig. 9.3. Such fire is produced around a prepared wooden block of desired size that is placed near the tuyere. To generate this fire, wet coal in small size pieces is stacked around the wooden block. This is done to obtain a compact packing of coal. After preparing the compact packing, the wooden block is removed by turning and gradually pulling it out. The whole exercise develops a well shaped uniform cavity into the compact mass of coal, called a tunnel. Coal from the bottom of tunnel is removed to provide space to accommodate clinkers and ash which may fall down during heating. This created tunnel is used to blow air into the compacted coal coming through the tuyere. To heat the workpiece, it is placed into the tunnel, fire is lighted and the blower is switched on.

9.3 VARIOUS FUELS USED IN FURNACES

For forging work, various types of fuels can be employed. Before their description, a study of their classification is essential which is described as follows:

1. Fuel should possess high calorific value so as to generate high temperatures up to 1400°C.
2. It should be completely combustible to provide better fuel efficiency.
3. It should be eco-friendly and should provide proper atmospheric conditions.
4. Should be cheap and easily available and easy to fire.

The fuels used in furnaces are broadly classified as gaseous, liquid and solid fuels and are described as follows:

1. Gaseous Fuels: Common gaseous fuels are natural gas and producer gas. Most of gaseous fuels are artificial gases obtained by either burning solid fuel in gas producers or as by product of coke oven or blast furnace etc.

2. Liquid Fuel: The residue left after filtering kerosene oil and petrol from crude oil cannot be used for I.C. engines but is an economical fuel for forging purposes. Liquid fuel is also used along with solid fuel to start a fire. The only difficulty in use of liquid and gaseous fuels is the design of a complex fuel injection system to the furnace to have a controllable combustion.

3. Solid Fuels: Solid fuel is widely utilized in forging furnaces. Common solid fuels are coal, coke, charcoal and lignite. Coal is the main fuel used in forging furnaces. A good quality coal contains high proportion of volatile substances and produces long flames when burnt. Here, the meaning of volatile substance is having a high carbon percentage. This type of coal is nomenclatured as anthracite coal. Coke is another solid fuel which lacks in volatiles but has high calorific value and is recommended when high temperatures are required. Charcoal is another variety of fuel that provides a clean fire, free from ash and sulphur. However, it does not find much favour in forging work on account of its high cost and inability to hold heat for longer periods as compared to coke and coal.
9.4 OTHER FORGING FURNACES

In addition to the best hearth furnace discussed earlier, some other furnaces can be utilized for forging work which are described below:

9.4.1 Muffle Furnace

It is an indirect type of furnace in which the workpiece to be heated do not come in direct contact with the combustion of the fuel. It consists of an outer metallic shell with a refractory lining inside. A heating chamber known as muffle is incorporated inside with space all around it. Workpieces are loaded inside the heating chamber whereas the combustion of fuel takes place in the empty area. The heating chamber is kept surrounded by burning gases but these are not allowed to enter the chamber. There are no chances of scaling and decarburization of workpiece since the furnace provides a clean heating environment to the workpiece.

9.4.2 Continuous Type Furnace

Such furnace is utilized for mass production of components / parts. This type of furnace consists of a horizontally moving conveyer or rotary conveyer or rotary hearth on which the workpiece is loaded at one end and taken out at the other end automatically / mechanically. The exposure time of the workpiece to be heated decides the movement rate of the conveyer. These furnaces are normally equipped with the facility of multi stage heating of the workpiece. These furnaces are normally employed or preferred for heat treatment of workpieces rather than forging.

9.5 SUPPORTING TOOLS

Different types of supporting tools are used in the process of forging as follows:

9.5.1 Anvil

Anvil is a supporting tool utilized to provide support to the job or workpiece during the forging operation. An anvil is designed in such a manner that it can withstand heavy blows of the hammer given to a workpiece. An anvil is illustrated in Fig. 9.4 and is made of wrought iron or cast steel mounted on a cast iron stand. Hot jobs are placed on the anvil face to forge them with hand hammers. The top portion of the anvil (the working face and cutting face) is made of tough steel to withstand the blows of hammers. Square as well as round holes are provided at the top face known as hardie hole and pritchel hole respectively. These holes are used to bend the workpiece by inserting one end in the hole. The horn like front portion of the anvil is meant for bending the job. An anvil is used to carry out all smith operations and is available in various sizes but the commonly used size vary upto about 100 to 150 kg approximately.

9.5.2 Swage Block

It is usually made of forged steel or cast steel having a number of slots of different shapes and sizes along its four side faces. There are through holes from its top to bottom face which also vary in shapes and sizes. Swage block is shown in Fig. 9.5. The through holes are used to produce holes of various shapes in the workpieces. Sometimes, the block recesses can be used to shape the work according to the recesses.

9.5.3 Tongs

These are used to hold the workpiece in the desired position during forging operation. These are made with different type of holding jaws, which can hold a wide variety of jobs. They are shown in Fig. 9.6.
Tongs are produced in two identical (mirror-image) pieces which are hinged together to form a complete tong. The hinge helps in widening and narrowing the opening of jaws to hold the jobs. The size and shape of a tong is fixed according to the size and shape of the job to be held by it. The whole length of a tong varies from 400 to 600 mm. The different types of jaws with their uses are given in Table 9.1.

**Table 9.1: Different types of Tongs and their Uses**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Type of Tong</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Flat Tong</td>
<td>To hold thin section and flat plates</td>
</tr>
<tr>
<td>2.</td>
<td>Round Hollow Tong</td>
<td>Used to hold round work and have curved surfaces inside.</td>
</tr>
<tr>
<td>3.</td>
<td>Flat Bar Tong</td>
<td>To grip thin sections but has got stronger grip than flat tongs.</td>
</tr>
<tr>
<td>4.</td>
<td>Square Hollow Tong</td>
<td>Its jaws are hollow and square in cross section. It is used to grip square or hexagonal cross sections.</td>
</tr>
<tr>
<td>5.</td>
<td>Side Bit Tong</td>
<td>Used to grip inserted bit from one of its side or the disc.</td>
</tr>
<tr>
<td>6.</td>
<td>Pick up Tongs</td>
<td>Have their jaws so shaped that even small sections and objects like nails and pins can be easily picked.</td>
</tr>
<tr>
<td>7.</td>
<td>Pincer Tong</td>
<td>It is equipped with edge shaped jaws and used for precise gripping of small jobs or objects.</td>
</tr>
<tr>
<td>8.</td>
<td>Chisel or belt Tong</td>
<td>It has flat jaws at its opening and used to strongly grip thin as well as heavy objects such as chisels.</td>
</tr>
</tbody>
</table>

**9.5.4 Bick Iron**

It is also a supporting tool as shown in Fig. 9.7. It consists of a round tapered bick or horn, similar to that of an anvil at one end and a flat tapered tail at the other. It is made of hardened steel.

It carries a tapered square shank at the bottom (as shown) and can be fitted into the hardie hole of the anvil. This is utilized to perform different forging operations on small jobs in the same way as on an anvil.

**9.6 PROCESSING TOOLS**

These are the tools meant for carrying out forging work in forging shop. The tools are as follows:

**9.6.1 Hammers**

These are the principal striking tools made of forged steel, used in forging operation. The hammers are classified largely according to their weight and size and utilization in forging operation. The classification of hammers is as follows:

(A) **Hand Hammer or Smith’s Hammer**

1. Ball Peen Hammer
2. Cross Peen hammer
3. Straight Peen hammer

(B) **Sledge Hammer**

1. Straight Peen sledge hammer
2. Cross Peen sledge hammer
3. Double faced sledge hammer
(c) Power Hammer

(1) Spring hammer
(2) Pneumatic hammer
(3) Steam hammer
(4) Drop hammer

A hammer mainly consists of four parts known as peen, eye, cheeks and face. Eye is the place where the handle is fitted to a hammer. Peen and face are the two ends of a hammer which are hardened and polished. Cheeks are the ends which are perpendicular to the face containing the eye. A steel wedge is always forced into the handle after it is fitted into a hammer to avoid slippage between the hammer and handle during its use.

Hand Hammers: Classification of these hammers has already been discussed. The various types are shown in Fig. 9.8.

These hammers are of relatively small size and their weight normally varies from 1.0 kg to 1.8 kg. As shown in Fig. 9.8, ball peen hammer consists of a ball peen at one end and a flat face at other end. In the case of straight peen and cross peen hammers, one end is flat known as the face and other end is given a triangular shape with its edge at the top. In case of straight peen hammers, the top edge is parallel to the hammer handles while in the case of cross peen hammer, the top edge is across it handle.

Sledge Hammer: A sledge hammer is much heavier than a hand hammer and weighs from 3 kg and goes upto 8 kg. They are employed when heavy blows are needed in forging and other similar operations performed on heavy jobs. Sledge hammers can be of straight peen, cross peen or double faced type as shown in Fig. 9.8. Double faced sledge hammer consists of a flat face at both of its ends.

Power Hammers: Power hammers are utilized for forging of heavy workpieces where hand hammers as well as sledge hammers are not sufficient. The capacity of power hammer is decided by the total weight of its falling part which is known as ram and this can range from a few hundred kg to a few tons. These heavier parts are allowed to fall on the workpiece suitably under gravity or with predetermined velocity. The capacity of a power hammer can be increased by making the falling parts heavier or increasing the height for which they fall or increasing the intensity of the blow. The classification of power hammers has already been discussed.

9.6.2 Punches and Drifts

A punch is a tool for producing a hole in a red hot job. The hole is made after supporting the hot job on an anvil and hammering the punch over the marked center of the hole to be made. Generally, a punch can be driven into the hole upto its length. A punch can generate both blind as well as through holes. A punch is shown in Fig. 9.9.

A drift is similar to a punch and is utilized to generate very fine slits or to enlarge an already punched hole in a hot workpiece or job. The drift is slightly larger in size as compared to a punch and can shape and enlarge a hole precisely. A drift is shown in Fig. 9.10.

9.6.3 Chisel

A chisel is generally made of high carbon steel with a cutting edge at one of its ends and a flat face at the other end. The flat face of the chisel is kept soft whereas the cutting edge is hardened and tapered. Chisels can be utilized for cutting the
workpiece in a hot as well as cold state. According to the application, the chisels are categorized as hot chisel and cold chisel respectively. Hot and cold chisels are shown in Fig. 9.11.

These chisels are different from each other on account of the inclined angle at the cutting edge. The cutting edge angle of hot chisel is between 30° to 35° whereas for a cold chisel it varies from 60 to 65°.

9.6.4 Hardie and Gouges

A hardie is a cutting tool used in conjunction with a chisel for precise cutting of a workpiece. A hardie has a wedge shaped body with a sharp cutting edge supported by a square shank. The square shank of the hardie can be fitted into the hardie hole of an anvil. The cutting edge of the hardie is kept upright and it cuts the workpiece from bottom while the chisel cuts the same at the top simultaneously. Gouges are wedge shaped tools with a curved cutting edge. A gouge is shown in Fig 9.12.

These are utilized to cut the material along a curve. A gouge carries a curved cutting edge at one end and a flat face at the other end to strike on with a hammer. A gouge may be held in a vertical position with the help of a handle meant for this purpose.

9.6.5 Fullers

Fullers are striking tools consisting of high carbon steel available in different sizes according to the various sizes of jobs. Fig 9.13 shows a fuller.

Generally, fullers are used in pairs. Lower portion is known as bottom fuller and provides support to the workpiece. The upper portion is known as top fuller used to strike on the workpiece. These are utilized for making slots, finishing edges and increasing the length or the width of the workpiece.

9.6.6 Flatters

Flatters are made of high carbon steel. As shown in Fig. 9.14, a flatter consists of one flat end with a rectangular cross section, i.e. flat square bottom and a handle. Fig. 9.14 shows a flatter.

The flat end of the flatter is known as a working face. Flatters are also known as smoothers and are used for leveling and finishing a flat surface after drawing out or any other forging operation.

9.6.7 Swages

Similar to fullers, swages are also made in pairs known as top swage and bottom swage as shown in Fig. 9.15.

These are made of high carbon steel. Each pair of swages consists of a circular groove of compatible size. A shank is provided at the bottom swage so that it can be fixed on an anvil and the top swage carries a handle to strike on the
Fig. 9.15: A Pair of Swages

workpiece. They are utilized to increase the length of a circular rod or for finishing the circular surface of a job.

9.6.8 Set Hammer

This tool is not meant for striking purpose but works like a flatter. A set hammer consists of square flat face at the bottom (not as enlarged as in the case of a flatter) and a smaller circular face at the top as shown in Fig. 9.16. It is made of tool steel and hardened.

It is employed for finishing corners of workpiece and setting two adjacent surfaces at right angles.

Fig 9.16: Set Hammer.

Table 9.2 shows the forging temperature for some common metal alloys and steel. The higher value of the range indicates the temperature at which the forging operation should start and the lower value is the temperature at which it must be completed.

Table 9.2: Temperature Range and Colour of Metals

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Metal/Alloy Colour.</th>
<th>Temperature Range (°C)</th>
<th>Metal/Alloy Colour.</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Aluminum and Magnesium Alloy</td>
<td>360-510</td>
<td>High carbon</td>
<td>880-1140</td>
</tr>
<tr>
<td>2.</td>
<td>Copper/Brown Red</td>
<td>580-660</td>
<td>Steel Stainless</td>
<td>900-1290</td>
</tr>
<tr>
<td>3.</td>
<td>Brass &amp; Bronze Cherry Red</td>
<td>660-810</td>
<td>Steel Dark yellow</td>
<td>940-1180</td>
</tr>
<tr>
<td>4.</td>
<td>Mild Steel</td>
<td>1260 &amp; above</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Medium Carbon steel</td>
<td>750-1230</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

9.8 DEFECTS IN FORGINGS

Forging defects occur due to many reasons such as poor quality of stock, incorrect die design, improper heating, improper forging conditions, uneven cooling of stock after forging etc. The common defects in forgings are discussed below:

(1) Cold shuts or laps: These are short cracks which usually occur at the corners of the surfaces and at right angles to the surface. Cold shuts are caused by the surface of the metal folding against itself in forging.

(2) Pitting: This defect occurs on the surface of a forging metal and is caused by scale, which if not removed thoroughly from the die cavities, is worked into the surface of forging. When this scale is removed/ cleaned from the forging, depressions appear, which are called scale pits.

(3) Die shift: This defect is caused due to misalignment between two holes of forging dies. This may also occur due to loose wedges.

(4) Dents: These are the marks appearing on forging due to improper hammering. Dents are the result of careless work.

(5) Fins and Rags: Fins and rags are small projections or loose metal driven into the surface of forgings.

(6) Incomplete filling of dies: This defect is the result of many reasons such as wrong amount of metal, insufficient number of blows during forging, too low working temperature resulting in poor plastic flow of metal, and incorrect die design.
(7) Cracks: These cracks are longitudinal or transverse in nature which occur on the forging surface. The cause of their occurrence may be bad quality of ingot, improper heating forging at low temperature or incorrect cooling of alloy steel forging.

(8) Hair Cracks: These are very fine surface cracks not exceeding a fraction of a millimetre noticed in forgings. Hairline cracks are produced due to defective metal stock as well as rapid cooling of the forging.

(9) Incorrect size of forging: These are due to mismatch of dies, worn out dies or incorrect dies. Such forging dimensions do not correspond to those specified in drawings.

(10) Burnt and Overheated metal: As the metal approaches higher temperatures, incipient fusion and oxidation takes place at grain boundaries. Such steel is known as burnt and thick oxide film is formed. This is caused by improper heating conditions.

(11) Ruptured Fiber Structure: A ruptured fiber structure means discontinuity in the flow lines for the forging which is revealed by microscopic examination of forgings. This defect is caused due to the rapid working of material, inadequate stock size and improper die design.

(12) Internal Cracks: These cracks occur due to a drastic change in the shape of the workpiece or an improper flow of metal.

(13) Inclusions: These may occur either on the surface or inside the forgings and may be due to defects in ingots or incomplete discard of the ingot.

(14) Flakes: These are internal breaks or ruptures occurring in some grades of alloy steel. Flakes are revealed by a microscopic examination and are caused by rapid cooling from the forging temperature.

(15) Decarburization: It occurs due to overheating of stock. If the raw stock is subjected to a temperature that is too high for long periods, it produces decarburized surface on the forging, particularly consisting of the high carbon steels.

9.9 CLEANING AND FINISHING OF FORGINGS

The following methods are used for cleaning and finishing the forgings:

(1) De-oxidation: A thin layer of scale (iron oxide) is formed on the surface of the forgings due to heating of steel with air. Amount of scale depends upon the forging temperature and length of time of the forging operation. The removal of the scale is carried out by forcing a stream of air or steam that blows away the scale from the surface as well as the cavities in the forgings.

(2) Pickling: This process is used to remove hard oxide film formed on the surface of the forgings. The process consists of dipping forging for a sufficient period in a tank of dilute sulphuric acid solution i.e. 12% to 15% concentrate sulphuric acid in water. The acidic solution reacts with the scale to loosen it from the forging surface and removes it. An inhibitor agent is added to the acid solution so that it should not react with the clean metal while removing the scale.

(3) Sand or shot blasting: Blasting is the process of striking a jet of sand grit or metallic shots against the forgings. The blasting force is obtained either from compressed air or centrifugal force from a suitably designed arrangement. This process removes scale and imparts a smooth surface finish to the forgings.

(4) Tumbling: Tumbling process is used to remove scale and the general cleaning of forgings. In this process, the forgings along with some abrasive materials like metallic oxide particles or coarse sand particles are placed in a barrel. The barrel is closed after inserting the forgings and abrasives and is kept in a tilted position. The forgings and the abrasives roll over themselves. This action removes scale from the surface of the forgings and very thin fins or burs are also removed along with the scale. Dimensional accuracy is given to forgings by the process of machining after their manufacture. Later, it is finally treated to impart certain desirable properties to the forgings for the service intended. Heat treatment process of forging may involve annealing or normalizing hardening and tempering of forgings. It is done for the following purposes:

(1) To relieve the forgings from stresses set up by alternate heating and cooling during forging.
(2) To improve mechanical properties of forgings.
(3) To equalize the structure of the metal of forgings.
(4) To impart requisite degree of hardness to the forging so that machinability is easy.

9.10 FORGING OPERATIONS

To mold the workpiece into the desired shape, some forging operations being carried out are as follows:

i. Bending
ii. Cutting
iii. Drawing out
iv. Upsetting and heating
v. Setting down
vi. Punching and drifting
vii. Fullering
viii. Forge welding.
ix. Flattening
x. Edging
xi. Cutting off
xii. Swaging
xiii. Coining
xiv. Piercing
xv. Special forging operations.

The processes have been discussed in chapter 4 under mechanical working of metals.

SUMMARY AT A GLANCE

(1) Forging is the process where metal is heated and then a force is applied to manipulate the metal in such a manner that the required final shape can be obtained. The various forging processes are: open die forging, impression die forging, and flash less forging.
(2) Tools and equipment used in hand forging are: smith’s forge or hearth. Open fire and stock fire furnaces.
(3) Fuels used in forging furnaces should possess high calorific value so as to generate high temperature upto 1400°C, should be eco-friendly and should be cheaply and easily available. These fuels are broadly classified as gaseous liquid and solid fuels.
(4) Other forging furnaces used are: Muffle and continuous type furnaces.
(5) Supporting tools used in forging are: Anvil, Swage block, tongs, and bick iron.
(6) Processing tools used in forging shop are: hammers, (hand, sledge and power hammers), punches and drifts, chisels, hardies & gouges fullers, flatters, swages, and set hammers.

REVIEW QUESTIONS

(1) Define forging. What are the advantages of the forging of metals?
(2) What do you understand by “open fire” and “stock fire”? Which one of the two is more useful and why?
(3) Differentiate between the following:
   (a) Hand forging and machine forging.
   (b) Hot forging and cold forging.
   (c) Hand hammer sledge hammer and power hammer.
   (d) Hot chisel and cold chisel.
AND PLASTICS

Module: Fiber Reinforced Plastics (FRP)

Workshop Training Notes
1.1 DEFINITIONS

A composite material is defined as a material system which consists of a mixture or combination of two or more distinctly differing materials which are insoluble in each other and differ in form or chemical composition.

Thus, a composite material is labelled as any material consisting of two or more phases. Many combinations of materials may, therefore, be termed as composite materials, such as concrete, metal reinforced rubbers, conventional multiphase alloys, fibre reinforced plastics, fibre reinforced matrix and similar fibre impregnated materials.

Two-phase composite materials are classified into two broad categories: particulate composite and fibre reinforced composites. Particulate composites are those in which particles having various shapes and sizes are dispersed within a matrix in a random fashion. As the distribution of particles is random and as the particles are of varying shapes and sizes, these composites are treated as quasi-homogeneous and quasi-isotropic. Examples of particulate composites are mica flakes reinforced in a non-metallic matrix, lead particles in copper alloys (metallic particles in a non-metallic matrix), and silicon carbon particles in aluminium (non-metallic particles in a metallic matrix).

Particulate composites are used for electrical applications, welding, machine parts and other purposes. Particulate composites made of tungsten and molybdenum particles dispersed in silver copper matrices are used for electrical contact applications as well as electrodes welding. Lead particles mixed with copper alloy and steel improve machinability. In machine parts where surface hardness is required particulate matrix is formed by mixing tungsten carbide particles in a cobalt matrix. Titanium carbide in cobalt or nickel is very much suited for high temperature applications.

Fibre reinforced composite materials consist of fibres of significant strength and stiffness embedded in a matrix with distinct boundaries between them. Both fibres and matrix maintain physical and chemical identities, yet their combination performs a function which cannot be done by each constituent acting singly. Fibres of fibre reinforced plastic (FRP) may be short or continuous. It appears obvious that FRP having continuous fibres is indeed more efficient.

Classification of FRP composite materials into four broad categories has been done according to the matrix used [1.1]. They are polymer matrix composites, metal matrix composites, ceramic matrix composites and carbon/carbon composites [Table 1.1]. Polymer matrix composites are made of thermoplastic or thermoset resins reinforced with fibres such as glass, carbon or boron. Metal matrix composites consist of a matrix of metals or alloys reinforced with metal fibres such as boron or carbon. Ceramic matrix composites consist of ceramic matrices reinforced with ceramic fibres such as boron or carbon.
silicon carbide, alumina or silicon nitride. They are mainly effective for high temperature applications. Carbon/carbon composites consist of graphite carbon matrix reinforced with graphite fibres. In addition to the above, there are other types of composites as well. The flake composites consist of a matrix reinforced with flakes which may be of different types such as glass flakes, mica flakes and metal flakes. The distribution of the flakes throughout the matrix provide a considerable barrier to moisture, gas and chemical transport. It can suitably be used for obtaining high thermal and electrical resistance or conductivity.

### Table 1.1 Classification of FRP composite materials

<table>
<thead>
<tr>
<th>Matrix type</th>
<th>Fibre</th>
<th>Matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polymer</td>
<td>E-glass</td>
<td>Epoxy</td>
</tr>
<tr>
<td></td>
<td>S-glass</td>
<td>Polyimide</td>
</tr>
<tr>
<td></td>
<td>Carbon (graphite)</td>
<td>Polyester</td>
</tr>
<tr>
<td></td>
<td>Aramid (Kevlar)</td>
<td>Thermoplastics</td>
</tr>
<tr>
<td></td>
<td>Boron</td>
<td>Polysulphone</td>
</tr>
<tr>
<td>Metal</td>
<td>Boron</td>
<td>Aluminium</td>
</tr>
<tr>
<td></td>
<td>Borsil</td>
<td>Magnesium</td>
</tr>
<tr>
<td></td>
<td>Carbon (graphite)</td>
<td>Titanium</td>
</tr>
<tr>
<td></td>
<td>Silicon carbide</td>
<td>Copper</td>
</tr>
<tr>
<td></td>
<td>Aluminium</td>
<td></td>
</tr>
<tr>
<td>Ceramic</td>
<td>Silicon carbide</td>
<td>Silicon carbide</td>
</tr>
<tr>
<td></td>
<td>Alumina</td>
<td>Alumina</td>
</tr>
<tr>
<td></td>
<td>Silicon nitride</td>
<td>Glass-ceramic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Silicon nitride</td>
</tr>
<tr>
<td>Carbon</td>
<td>Carbon</td>
<td>Carbon</td>
</tr>
</tbody>
</table>

In-filled or skeletal composites or continuous three-dimensional structural matrix is filled by a second material. Laminate composites consist of thin layers of different materials bonded together.

Of all the types of composites discussed above, the most important is the fibre reinforced composites or filamentary type composites – this is from the application point of view. This book will deal with fibre reinforced polymer matrix composite materials.

### 1.2 HISTORY OF FIBRE REINFORCED COMPOSITES

For millenniums, fibre had been used as reinforcement for making components of structural construction. There are Biblical references dating back to 2000 b.c. or earlier, to the straw reinforced mud bricks and composite bows found in Egypt and Mongolia. The development can be traced through to the 'daub and wattle' construction of buildings in Europe in the Middle Ages. The Japanese Samurai warriors used laminated metals in their swords in order to obtain the desirable material properties. In the nineteenth century, iron rods were used as reinforcements for masonry resulting in reinforced masonry construction. Asbestos fibres were used for reinforcement in phenolic resins in the early part of this century. The process of obtaining strong glass fibres was developed in the late 1930s and the development of the first commercial unsaturated polymer resins came a little later. The first glass fibre boat was built at the time of the Second World War in 1942. Reinforced plastics started to be used more or less at the same time in electrical components and aircrafts. Filament winding was invented in 1946 and incorporated into missile application in the 1950s. Advanced composites stem from the development of the first boron and then high strength carbon fibres in the 1950–1965 period. The first application of advanced composites to aircraft components was made in 1970. Kevlar or aramid fibres were developed in 1973 by Du Pont. From the 1970s, the area of application of composites has expanded in many directions. Among them are aerospace, structures, automotive, sports equipment, biomedical products, high performance vessels and many other areas. The current emphasis is on the development of metal matrix, ceramic matrix carbon/carbon composites.

### 1.3 CONSTITUENT MATERIALS

The major constituents of a fibre reinforced composite material are reinforcing fibre, matrix, coupling agents, coatings and fillers. Fibres are the principal load carrying members while the matrix which surrounds it, keeps them in proper location and correct orientation. Matrix acts as a medium by which the load is transferred through the fibres by means of shear stress. Matrix protects the fibre from environmental damages caused by elevated temperature and humidity. Coupling agents and coatings applied to the fibres improve their wettings with the matrix and also facilitate bonding across the fibre–matrix interface. The major purpose of using fillers in some polymeric matrices is to reduce cost and achieve a better dimensional stability.

#### 1.3.1 Fibres

Materials in fibre form are stronger and stiffer than that used in a bulk form. There is a lesser presence of flaws in bulk material which affects its strength while internal flaws are mostly absent in the case of fibres. Further, fibres have strong molecular or crystallographic alignment and are in the shape of very small crystals. Fibres have also a low density which is advantageous.

Fibre is the most important constituent of a fibre reinforced composite material. They occupy the largest volume fraction of the composite. Reinforcing fibres as such can take up only tensile load. But when they are used in fibre reinforced composites, the surrounding matrix enables the fibre to contribute to the major part of the tensile, compressive, flexural or shear strength of FRP composites.

Tensile stress–strain curves of a few typical fibres are presented in Fig. 1.1. They are linear to failure for all reinforcing fibres. Further, the strains at the failure of the fibres are exceedingly low. Fibres exhibit brittle mode at failure. They are, however, prone to damage while handling as well as during contact with other surfaces. Properties of some important fibres are presented in Table 1.2.

![Fig. 1.1 Stress – strain curve of fibres](image-url)
Fibres are used either as a single or as a combination of two types—chopped strand mat (CSM) or woven roving (WR). By chopping strands to short lengths (5–75 mm), they can be directly used in spray-up lamination. CSM consists of randomly-oriented fibres bound with an emulsion or powder binder. In both construction, weights of CSM vary from 300 to 900 g/m².

A fabric is constructed of interlaced yarns, fibres or filaments. Typical glass-fibre fabrics are manufactured by interlacing warp (lengthwise) yarns and fill (crosswise) yarns on conventional weaving looms. By the weave of a fabric we can understand the way the warp yarns and fill yarns are interlaced. The popular weave patterns are plain, twill, leno and unidirectional. Plain weave is the oldest and most common textile weave. In this, one warp end is woven over one fill yarn and under the next and the process is repeated.

Woven roving material is of plain weave and is balanced. They are also available in biased form. Fibre orientation of WR may be ± 45° direction. They are also obtained with equal distribution of fibres in 0/90° and ± 45° directions. Weights of WR vary from 200 to 900 g/m². The cost of S-glass is 20–30 times that of E-glass. The tensile strength of S-glass is 33% greater and the modulus of elasticity is 20% higher than that of E-glass. The principal advantages of S-glass are its high strength-to-weight ratio, its superlative relation at elevated temperatures and its high fatigue limit. In spite of its high cost, its main application area is in aerospace components such as rocket motors.

### Table 1.2 Raw fibre properties

<table>
<thead>
<tr>
<th>Fibre</th>
<th>Typical diameter (µm)</th>
<th>Specific gravity</th>
<th>Tensile modulus GPa (Msi)</th>
<th>Tensile strength GPa (ksi)</th>
<th>Ultimate elongation %</th>
<th>Coefficient of thermal expansion 10⁻⁶°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E-glass</td>
<td>10</td>
<td>2.54</td>
<td>72.4 (10.5)</td>
<td>3.45 (500)</td>
<td>4.8</td>
<td>5.0</td>
</tr>
<tr>
<td>S-glass</td>
<td>10</td>
<td>2.49</td>
<td>86.9 (12.6)</td>
<td>4.30 (625)</td>
<td>5.7</td>
<td>2.9</td>
</tr>
<tr>
<td>Aramid</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kevlar 49</td>
<td>11.9</td>
<td>1.45</td>
<td>131 (19)</td>
<td>3.62 (525)</td>
<td>2.8</td>
<td>-2.2</td>
</tr>
<tr>
<td>Kevlar 149</td>
<td>11.9</td>
<td>1.47</td>
<td>179 (26)</td>
<td>3.45 (500)</td>
<td>1.9</td>
<td>-</td>
</tr>
<tr>
<td>Carbon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T-300</td>
<td>7</td>
<td>1.76</td>
<td>231 (33.5)</td>
<td>3.65 (530)</td>
<td>1.4</td>
<td>-0.55</td>
</tr>
<tr>
<td>8</td>
<td>1.80</td>
<td>395 (57)</td>
<td>2.48 (360)</td>
<td>0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>2.15</td>
<td>758 (110)</td>
<td>2.45 (350)</td>
<td>0.32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boron</td>
<td>0.93</td>
<td>400 (60)</td>
<td>3.4 (500)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* mega pound per square inch

1.3.1.1 Glass fibres

The most common fibre used in polymeric fibre reinforced composites is the glass fibre. The main advantage of the glass fibre is its low cost. Its other advantages are its high tensile strength, low chemical resistance and excellent insulating properties. Among its disadvantages are its low tensile modulus, somewhat high specific gravity, high degree of hardness and reduction of tensile strength due to abrasion during handling. Moisture decreases the glass fibre strength. Glass fibres are susceptible to sustained loads, as they cannot withstand loads for long periods.

Two types of glass fibres are used in FRP industries. They are E-glass and S-glass. E-glass has the lowest cost among all commercial fibres.

S-glass has high tensile strength. Its typical composition is 65% SiO₂, 25% Al₂O₃ and 10% MgO. The cost of S-glass is 20–30 times that of E-glass. The tensile strength of S-glass is 33% greater and the modulus of elasticity is 20% higher than that of E-glass. The principal advantages of S-glass are its high strength-to-weight ratio, its superior strength relation at elevated temperatures and its high fatigue limit. In spite of its high cost, its main application area is in aerospace components such as rocket mortars.

1.3.1.2 Carbon fibres

Carbon fibres are characterised by a combination of high strength, high stiffness and low weight. Carbon fibres are produced by polymeric fibre precursors or pitch fibre precursors.

The advantages of carbon fibres are their very high tensile strength-to-weight ratio, high tensile modulus-to-weight ratio, very low coefficient of thermal expansion and high fatigue strength. Carbon fibres have very high tensile strengths and low densities. Due to the high cost of carbon fibres, the use of carbon fibres is justified only in weight critical structures, that is, mostly applied in aerospace industry.

Carbon fibres are categorised into two types: high strength and high modulus. The high modulus type is more expensive as it requires higher production temperature while the high strength variety is more popular.

Carbon fibres are commercially available within a wide range of tensile modulus: from 207 GPa (30 × 10⁶ psi) to 802 GPa (125 × 10⁶ psi). In general, low modulus fibres have many advantages of high modulus fibres such as having lower specific gravity, lower cost, higher tensile and compressive strengths and higher ultimate strains.

Until relatively recently, the fabrics for use with resin matrices have been two-dimensional: crimped weaves with warp and fill yarns going over and under one another in a manner similar to classical forms of clothing materials. Modern advances have been made in a number of directions, which include the following:

1. Multi-dimensional weaving
2. 3-D weaving to provide greater transverse strength
3. Crimpless weaves with secondary yarns knitted to hold together collimated straight primary yarns in one or more unidirectional plies

These advancements are mainly related to carbon fibres.

1.3.1.3 Aramid fibres

The first significant group of polymeric reinforcement fibres is polyaramid fibres developed by Kevlar by Du Pont [1.14]. Kevlar aramid is made of carbon, hydrogen, oxygen and nitrogen and is essentially an aromatic organic compound. The advantages of aramid fibres are their low density, high tensile strength and low cost. Of all the available commercial fibres, it has the highest tensile strength-to-weight ratio. Glass-fibre composites weigh 65% more than composites made of aramid fibres of equivalent stiffness.

Characteristics of Kevlar 49 are its high strength and stiffness, light weight, vibration dampening resistance to damage, fatigue and stress ruptures.

These is another variety of aramid fibre available — Kevlar 29 which is of low density and high strength. Kevlar 29 is used in ropes, cables and coated fabrics for inflatables.

The principal disadvantages of aramid fibres are their low compressive strength and difficulty in cutting or machining. These fibres have complex anisotropic structure due to which crumpling and fibrillation of individual fibre takes place. This further reduces the strength and stiffness. For structures or structural components where compression and bending are predominant such as in a shell, aramid fibres can be used only when it is hybridized with glass carbon fibres.

A more advanced variety of Kevlar fibre is Kevlar 149. Of all commercially available aramid fibres, it has the highest tensile modulus as it has 40% higher modulus than Kevlar 49. The stress failure for Kevlar 149 is, however, lower than that of Kevlar 49.
Aramid fibres are costlier than E-glass, but are cheaper than carbon fibres.

1.3.1.4 Boron fibres

Boron fibres are characterized by their very high tensile modulus, the range of which is 379-414 GPa (55-60×10^6 psi). Boron fibres have relatively large diameters and due to this they are capable of withstanding large compressive stress and providing excellent resistance to buckling. Boron fibres are, however, costly and in fact are costlier than most varieties of carbon fibres. The application area of boron fibres at present is restricted to aerospace industries only.

Close to the outer surface of the boron layer, a state of biaxial compression exists, which makes the fibre less sensitive to mechanical damage. The adverse radioactivity of boron fibres with metals is reduced by chemical vapour deposition of silicon carbide on boron fibres, which produces borosic fibres.

1.3.1.5 Ceramic fibres

Ceramic fibres are mainly used in application areas dealing with elevated temperature. Examples of ceramic fibres are silicon carbide (SiC) and aluminium oxide (Al₂O₃). In metal matrices where boron fibres exhibit adverse radioactivity, both the above ceramic fibres are found suitable. Continuous ceramic fibre has an added advantage in that they have properties such as high strength, high elastic modulus with high temperature capabilities and are free from environmental attack.

1.3.2 Polymeric Matrix

Polymers are divided into two broad categories: thermoplastic and thermoset. Thermoplastic polymers are those which are heat softened, melted and reshaped as many times as desired. But a thermoset polymer cannot be melted or reshapcd by the application of heat or pressure. Depending on the particular thermoplastic material used, thermoplastic matrix components can, however, be used over a wide range of temperature – from 100°C to 300°C. The advantages of thermoplastic matrices are their improved fracture toughness over the thermoset matrix and their potential of much lower cost in the manufacturing of finished composites.

There are various reasons why thermoplastic polymers are not used for the manufacture of FRPs. Some of them are mentioned here. Perhaps the greatest drawback of the thermoplastic polymer is that it can be used only at ambient temperature. A significant problem is encountered when mixing fibrous material with a thermoplastic matrix due to the high viscosity of the latter at normal temperature. To make matters worse, thermoplastic polymers exhibit considerable strain at relatively low stresses. However, in the chemical industry, they are used in a range of products due to their property of chemical inertness, toughness and pleasing appearance.

Traditionally, thermoset polymers (also called resins) are widely used as a matrix material for fibre reinforced composites in structural composite components. The wetout from simple mixing of fibres and matrix is good. Thermoset polymers improve thermal stability and chemical resistance. The main disadvantages are their limited storage life at low temperature, the considerable time wastage using this matrix in fabrication in the mould and low value of strains to failure. The properties of both these types of matrices are given in Tables 1.3 and 1.4.

For the purpose of a simple classification, we may divide the thermosets into five categories

(i) Polyester resin, (ii) epoxy resin, (iii) vinyl ester resin, (iv) phenolic resin and (v) high performance resin.

### Table 1.3 Typical properties of thermosetting resins

<table>
<thead>
<tr>
<th>Properties</th>
<th>Polyester</th>
<th>Vinyl ester</th>
<th>Epoxy</th>
<th>Phenolic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>1.1 - 1.5</td>
<td>1.2</td>
<td>1.2</td>
<td>1.15</td>
</tr>
<tr>
<td>Tensile modulus</td>
<td>2 - 4.5</td>
<td>2 - 4.5</td>
<td>2 - 6</td>
<td>2 - 6</td>
</tr>
<tr>
<td>Tensile stress</td>
<td>0.36</td>
<td>0.37</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>35 - 130</td>
<td>50 - 75</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Compressive strength</td>
<td>127</td>
<td>200</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Elongation (%)</td>
<td>2.5</td>
<td>1 - 5</td>
<td>1 - 8.5</td>
<td>2</td>
</tr>
<tr>
<td>Coef. of thermal expansion (10^-6/°C)</td>
<td>53</td>
<td>45 - 70</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Water absorption (%)</td>
<td>0.1 - 0.3</td>
<td>-</td>
<td>0.1 - 0.4</td>
<td>-</td>
</tr>
</tbody>
</table>

### Table 1.4 Typical properties of some structural thermoplastic resins

<table>
<thead>
<tr>
<th>Material</th>
<th>SG</th>
<th>Young's modulus (GPa)</th>
<th>Tensile yield stress (MPa)</th>
<th>Tensile failure strain (%)</th>
<th>Heat distortion temp. (°C)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABS (acrylonitrile butadiene)</td>
<td>1.05</td>
<td>3</td>
<td>35</td>
<td>50</td>
<td>100</td>
<td>Used in some small craft surfboards; poor weather</td>
</tr>
<tr>
<td>PEI (polyethylene terephthalate)</td>
<td>1.35</td>
<td>2.8</td>
<td>80</td>
<td>80</td>
<td>75</td>
<td>Used mainly in injection moulding; creep susceptible</td>
</tr>
<tr>
<td>HDPE (high-density polyethylene)</td>
<td>0.95</td>
<td>0.9</td>
<td>30</td>
<td>600-1200</td>
<td>60</td>
<td>Low-cost, tough, water-resistant, creep and fatig susceptible</td>
</tr>
<tr>
<td>PA (polyamide, nylon 6/6)</td>
<td>1.15</td>
<td>2.2</td>
<td>75</td>
<td>60</td>
<td>75</td>
<td>Tough, fatigue-resistant; susceptible to moisture</td>
</tr>
<tr>
<td>PC (polycarbonate)</td>
<td>1.2</td>
<td>2.3</td>
<td>60</td>
<td>100</td>
<td>130</td>
<td>Good impact and fatigue resistant</td>
</tr>
<tr>
<td>PES (polyethersulphone)</td>
<td>1.35</td>
<td>2.8</td>
<td>84</td>
<td>60</td>
<td>201</td>
<td>Tough, temperature and resistant; used in aerospace components</td>
</tr>
<tr>
<td>PEI (polyetherimide)</td>
<td>1.3</td>
<td>3.0</td>
<td>105</td>
<td>60</td>
<td>250</td>
<td>as PES</td>
</tr>
<tr>
<td>PEEK (polyetherether ketone)</td>
<td>1.3</td>
<td>3.7</td>
<td>92</td>
<td>50</td>
<td>140</td>
<td>as PES</td>
</tr>
</tbody>
</table>

*specific gravity

The main advantages of polyester resins are their reasonable cost and ease with which the resin can be used.

1.3.2.2 Epoxy resins

Epoxy resins are mostly used in aerospace structures for high performance applications. It is used in marine structures, rarely, though, as cheaper varieties of resins other than epoxy are available.
The extensive use of epoxy resins in industry is due to: (1) the ease with which it can be processed, (2) excellent mechanical properties in composites and (3) high hot and wet strength properties (150°C). Performance of epoxies is superior to polyester resins due to their superior mechanical properties and better resistance to degradation by water and other solvents.

The chemistry of the epoxy resin components is such that it gives a better adhesion to reinforcing fibre than polyester resins.

1.3.2.3 Vinyl ester resins

Being a combination of the principles of both epoxy and polyester resin chemistry, vinyl ester resins have a close resemblance to polyester resins, but has a chemical similarity to epoxy resins. Vinyl ester resin is superior to polyester resin because it offers greater resistance to water. These resins provide superior chemical resistance and superior retention properties of strength and stiffness at elevated temperature.

In construction and marine industries, vinyl ester resins have been widely used in boat construction. The application of vinyl ester is limited mainly in the USA to small high performance hulls such as racing canoes and speed boats.

Vinyl ester resins are between polyester resins and epoxies from the cost point of view.

1.3.2.4 Phenolic resins

The main characteristics of phenolic resins are their excellent fire resistance properties. As such, they are now introduced in high temperature application areas. The recently developed cold-cure varieties of phenolic resins are used for contact moulding of structural laminates.

Phenolic resins have inferior mechanical properties to both polyester resins and epoxy resins, but have higher maximum operating temperature, much better flame retardant and smoke and toxic gas emission characteristics. Due to the above advantages, phenolic resins are the only matrix used in construction. The application of vinyl ester is limited mainly in the USA to small high performance hulls such as racing canoes and speed boats.

Phenolic resins are increasingly used in internal bulkheads, decks and furnishings in ships.

1.3.2.5 High performance resins

Attempts are on for the development of matrices with better properties at elevated temperatures. It has been observed that processing characteristics deteriorate with the increase of thermal stability.

The general chemical approach is to devise resins which incorporate aromatic, hetero-cyclic, and ladder polymer elements. The most highly developed systems are bismaleimide (BMI) and polimide (PI).

1.3.3 Prepegs

If fibre and matrix were available commercially as one entity, it avoids the procurement of fibre and matrix separately. Partly cured matrix resins act as a binder to a well laid out fibre system. These fibres are known as prepegs. They may be unidirectional or woven [5]. Due to its tacky texture, it is easy to handle and can best be used in moulding of complex geometrical shapes. The prepeg, however, have a limited shelf life. The manufacturers of these materials specify the condition at which they need to be stored in freezers.

1.3.4 Fillers and Other Additives

Fillers may be added to the polymeric matrix for one or more of the following reasons: (a) reduction of cost, (b) increase of modulus, (c) control of viscosity and (d) production of a smoother surface.

The most common filler in polyester and vinyl ester resins is calcium carbonate. It not only reduces the cost, but also lessens mould shrinkage. Examples of other fillers are clay, mica and glass microspheres. Although fillers increase the modulus of an unreinforced matrix, they also tend to reduce its strength and impact resistance.

The impact strength and crash resistance of brittle thermosetting polymers can be improved by mixing them with small amounts of elastic elastomeric tougheners.

In addition to fillers and tougheners, colourants, flame retardants and ultraviolet absorbers may be added to the matrix. Tougheners are used for improving impact strength. Typical examples of tougheners are silicon, rubber and butadiene styrene. The purpose of the colourant is to obtain the required colour. Typical examples are titanium dioxide, barium sulphate, magnesium carbonate and cadmium reds and yellows. Addition of flame retardants give fire retardant properties to the composites. Typical examples are red phosphorous, antimony trioxide, butyl acid phosphate and aluminium hydroxide. To prevent discolorisation of the composite from exposure to sunlight ultraviolet absorbers are used. Typical examples are acetyl salicylic acid and benzotriazol hydroxynyl.

1.4 LAMINA AND LAMINATE

A lamina or a ply is formed by a combination of a large number of fibres in a thin layer matrix. Fibres in the lamina may be continuous or discontinuous, arranged in a specific direction or a random orientation. A unidirectional lamina is one where the fibres in a lamina run parallel to each other in a particular direction. It is natural that discrete fibre composites will have lower strength and modulus than continuous fibre composites. However, with the random orientation of the fibre it is possible to obtain nearly equal mechanical and physical properties in all directions in the plane of the lamina. The thickness of the lamina ranges from 0.1–1 mm. The standard thickness of a unidirectional ply is 0.125 mm whereas typical thickness of the woven ply is 0.25 mm.

The principal coordinate axes of an orthotropic lamina are shown in Fig. 1.2. The three principle axes are: axis 1, the longitudinal axis in the direction of fibre, axis 2, the transverse axis in the direction normal to the fibre and axis 3 in the direction normal to the plane of the lamina.

A laminate is formed by stacking several laminas (Fig. 1.3). It is the most common form of fibre reinforced composites. It is made of a desired thickness so as to support a given load and maintain a given deflection. Fibre orientation of each lamina and stacking sequence of various layers can be varied to obtain a wide range of physical and mechanical properties of composites.

1.5 GENERAL CHARACTERISTICS OF FRPS

Traditional structural materials like steel and aluminium are considered as isotropic. The properties of the fibre reinforced composites are, however, strongly dependent on the direction measurement. For example, properties such as the tensile strength and the tensile modulus in unidirectional FRP attain maximum values in the longitudinal direction of fibres. At any other angle of measurement, mechanical properties attain lower values, being minimum at perpendicular to the longitudinal direction of fibres. Similar angular dependence is observed for other physical and mechanical properties such as the coefficient of thermal expansion, thermal conductivity and strength. Bi- or multidirectional reinforcement gives a more balanced set of properties. Although the magnitude of these properties is lower than the longitudinal properties of unidirectional composite, they represent a considerable advantage over common structural materials on a unit weight basis.
Mechanics of Composite Materials and Structures

The design of metal structures is more or less straightforward, but not so for FRPs which exhibit different properties in different directions. But due to this anisotropy, properties of the FRP can be tailored to meet the design requirement. This flexibility enables the designer to selectively reinforce a structure in the direction of major stresses, increase its stiffness in a preferred direction and produce structures with zero coefficient of thermal expansion.

1.6 WHY FRPS?

The development of advanced fibre reinforced composite materials has been considered as the biggest technical revolution after the jet engine [110]. Fibre reinforced composites possess high strength and stiffness. Some of these materials perform equally well or better than many traditional metallic materials. In addition, fatigue strength-to-weight ratios as well as fatigue damage tolerance of many composite laminates are excellent.

Coefficients of thermal expansion for many fibre reinforced composites are much lower than those of metals. As such composite structures exhibit a better dimensional stability over a wide range of temperature variation. However, differences in thermal expansion between metals and composite materials may create undue thermal stresses when they are used in conjunction, for example, in attachment.

Fibre reinforced composites possess high internal damping. This leads to a better vibration energy absorption within the material, and results in reduced transmission of noise, vibration and harshness (NVH).

In unfavourable environments, metals are usually susceptible to corrosion. The non-corrodible behaviour of fibre reinforced composites is an added advantage. Cracks and flaws in metals grow during the service life of the structure. Though they are easy to detect, their repair work may not be simple. Damage of composite structures is usually internal in nature and can be detected only by sophisticated non-destructive testing. Protective coatings are applied on the surface of composite structures to take care of likely damages on the surface. Many polymer matrix composites absorb moisture from the surroundings which creates dimensional changes as well as adverse internal stresses in the material.

A significant advantage of the FRP construction is its low maintenance cost. The cost of raw materials of composite structures such as fibres and auxiliary materials are high in fabrication and assembly operations. Though composite structures are much lighter, their tooling costs are also less and they usually possess less number of parts. In conventional structural materials, though the cost of raw materials is less, more often the cost involved with tooling, machinery and assembly is high, thus offsetting the initial advantage.

Structures made of fibre reinforced composite are lighter than those made of conventional metals. In space vehicles, reduction in weight is linked to fuel savings. Spacecraft may have weight savings as much as 40 percent if fibre reinforced composite structures are used.

1.7 MICROMECHANICS AND MACROMECHANICS

Micromechanics deals with the deformation and stress in the basic constituents of a structure and deals with local failures such as matrix failure, fibre failure and interface/interphase failure. As such the constituent materials are examined on a microscopic scale without recourse to their internal structure.

Macromechanics deals with the behaviour of the composite material presumed as homogeneous and the effects of the composite material are detected only as average apparent properties of composites. In macromechanics, properties along the length and perpendicular to the fibre direction are considered.

1.8 PROPERTIES OF TYPICAL COMPOSITE MATERIALS

Various types of composite materials are possible by choosing different constituents mixed in different proportions. Mechanical, thermal and electrical properties of some typical composite laminates are given in Table 1.5. It can be seen from Table 1.5 that composites have higher specific modulus and higher specific strength than steel.

Fibre properties dictate the stiffness of unidirectional composites. Figure 1.4 indicates the stress–strain curves of a typical unidirectional composite. The stress–strain curve for aluminium...
presented in the figure for the sake of comparison. For higher strength of unidirectional composites, the ultimate strain is generally lower at failure. For some composites, the increase of stiffness has resulted in lowering the strength (curves 4, 5, 6, 7). The stress-strain curve for unidirectional composites in general is linear.

![Stress-strain curves of typical unidirectional composites in the fibre direction](image)

**Fig. 1.4** Stress-strain curves of typical unidirectional composites in the fibre direction

### 1.9 APPLICATION OF COMPOSITES

Commercial and industrial applications of fibre reinforced composites are diverse and varied. Some of these applications are ships and submarines, aircrafts and spacecrafts, trucks and rail vehicles, automobiles, robots, civil engineering structures and prosthetic devices. The main application areas may be broadly classified as follows:

1. **Marine field**
2. **Aircraft and space**
3. **Automotive**
4. **Sporting goods**

#### 1.9.1 Marine Field

Use of composites in the marine field is growing steadily since the early 1950s. Initial applications of FRPs were limited to small crafts such as lifeboats and pleasure boats. Now, structures of several hundred tonnes are regularly produced and used. Potential applications in the marine field range from small components such as radar domes, masts, and piping to large-scale structures, submersibles and offshore structure modules.

Glass reinforced plastics (GRP) are extensively used in the construction of boat hulls including yachts, lifeboats, dinghies, canoes, speed boats, fishing boats and passenger launches. The popularity of GRP with boat builders lies in its competitive low cost (in comparison to wooden hulls), a trouble-free performance, low maintenance cost and aesthetics.
GRP has been successfully used in military and commercial hovercrafts. Feasibility studies have indicated substantial savings in hull weight by using hybrid glass/carbon laminates in place of steel and aluminium for the construction of hydrofoils and fast patrol boats. Construction of a GRP vessel proves to be costly, but their maintenance works out to be cheaper.

Ultra-high performance sailing craft and power boats have advanced composite construction. FRP vessels may be constructed for special purposes, such as transportation of corrosive cryogenic bulk cargo, requirement of a non-magnetic hull or requirement of considerable savings in weight for better performance.

Naval applications of FRP include mine countermeasure vessels (MCMV), landing craft, fast patrol boats and submersibles. GRP has found a favourable application in MCMVs where a hull with negligible magnetic signature is required in order to avoid the activation of magnetic mines. Additional developments in naval application include weapon enclosures, gun enclosures, rudders, dry dock shelters, missiles, blast shields, ladders, deck drains, rails, radomes, masts and stacks.

FRP is used in submarines for flooded nose fairings using planes and non-pressure hull decks. A specific requirement for an underwater vessel is that of high specific compressive strength. Care should be exercised while designing to check failure against buckling, under fatigue and impact loads and against creep.GRP submersibles have been successfully used in offshore operations.

Other marine applications of FRP include submarine casings and appendages, superstructure of ships, warship radomes, sonar domes, ship's piping and ventilation systems, oil and water storage tanks, floats and buoys for fishing and mine sweeping purpose.

Hull-superstructure interaction can be avoided by using a low modulus material like the GRP. The elastic modulus of GRP is less than 10% that of steel, while the strength of the GRP is comparable with that of steel.

GRP sheathing is used to protect wooden hulls from bores, leakage and rot. Sheathing is a cover made by one or two plies of CSM attached by polyester or epoxy resin.

1.9.2 Aircraft and Space
Optimally an aircraft requires a reduction in weight to attain greater speed and increased payload and fibre-reinforced composite have been found to be ideal for this purpose. No doubt for one of the most important application areas of FRP is in the field of civil and commercial aircrafts. Carbon fibres either alone or in the hybridized condition is used for a large number of aircraft components. Carbon and Kevlar have become the major material used in many wing, fuselage and empennage components. They are also used in secondary structures such as elevator facesheets, horizontal stabilizers, upper rudder et al., of many commercial aircrafts.

FRP with epoxy as the resin is used for the manufacture of helicopter blades. One of the main reasons why FRP is used for rotor blades is the ability of the material to tailor the dynamic frequency of the blade to its operating parameters. FRPs are more suitable for blade application than metals, as with this material, blades of any shape can be manufactured without any additional cost, an advantage which does not hold good for metal blades whose shapes are limited to those which can be extended, machined or rolled.

A missile structure, when made of FRP is light, and has an increased range of action and payload. A missile structure made of FRP reduces the weight of the structure considerably. In ICBMs and other missile systems, graphite composites are used for its high stiffness, strength and minimum weight.

There is a wide variation of temperature in space and as such the dimensional stability of spacecraft components to maintain precise alignment of communication and sensor systems is a major requirement. Graphite and Kevlar fibres are well suited for space applications because of their specific strength and modulus and low coefficient of thermal expansion. Strength and stiffness of composites are major considerations for the aircraft whereas stiffness and low coefficient of thermal expansion are the major requirements for space applications.

Some of the application areas of FRP to spacecraft are antennas, booms, support trusses etc. Carbon-epoxy composite tubes are used in constructing truss structures for Low Earth Orbit (LEO) satellites and interplanetary satellites.

1.9.3 Automotive Field
FRPs have been used in many parts of the car.

The exterior part of the car such as hood or door panels requires sufficient stiffness. The major requirement is that it should offer maximum resistance to dent formation (damage tolerance). Epoxy, like polyurethane, enable the damage tolerance to be limited to acceptable values. Further, a cosmetic surface finish is highly desirable.

Application of FRPs include the chassis components as well, such as corvette rear leaf spring and unileaf E-glass reinforced epoxy.

In racing cars, parts of the engines are made of graphite-epoxy. Connecting rods which are subjected to fatigue are now made of composites for better performance. Other parts of the engine where composites are used are push rods, rocker arms, pistons, cylinder heads and engine block. The advantage of using advanced composites in engines is higher speed with the production of less power and the simultaneous reduction of engine weight.

Use of FRP components in automotive industries is much less than the aircraft industries. Aircraft components, the basic technique used for manufacture is the hand lay-up, whereas in the automotive industries more sophisticated techniques of fabrication such as compression moulding, filament winding and pultrusion are used.

1.9.4 Sporting Goods
Many sporting goods are made of FRPs nowadays. One of the major advantages of using FRP is the reduction of weight.

Tennis rackets or snow skis are made as a sandwich structure – FRP with carbon or boron fibres as the skin and the core formed by soft and light urethane foam which enables the structure to have low weight reduction without any decrease in stiffness.

FRPs enable damping of vibrations. Therefore, shock resulting from the impact of the ball on a tennis racket which is transmitted to the arm of the player will dampen out at a quicker rate.

Other applications of fibre reinforced polymers in sports are fishing rods, bicycle frames, archery bows, sail boats and kayaks, oars, paddles, canoe hulls, racket balls, rackets, javelins, hockey sticks, golf club staff, hockey sticks, athletic shoe soles and heels, surfboards and many other items.

REFERENCES AND SUGGESTED READINGS


PROCESSING OF FRP COMPOSITES

An extensive range of well-established processing methods is available for FRP composites. They vary from simple labour intensive methods suitable for one-off products to automated methods producing large numbers of complex components. The method of processing selected by the manufacturer depends on factors such as shape, cost, number of components and required performance.

2.1 CONTACT MOULDING

2.1.1 Mould Preparation

By far the most common method of fabrication for large structures such as ship hulls is contact moulding in an open female mould using cold curing polyester resin and E-glass reinforcement. The first step in the fabrication process is the mould preparation. For small to medium size structures moulds are usually fabricated in GRP, in which case a male plug, commonly of wooden construction, is first assembled whose external shape defines the structure to be built. Very small moulds for ship construction may be of steel or aluminium construction lined with an epoxy paste or similar filler to allow fairing out of welded distortions. Mould preparation is usually completed by wax polishing and application of polyvinyl alcohol (PVA) or an equivalent release agent. Lamination is usually started by application of a pigmented gel coat of good quality resin, deposited in the mould by brush or spray (to a thickness between 0.3-0.5 mm), the main purpose of which is to provide a smooth external surface. Lamination is then continued, before the gel coat has fully cured, using one of the following two methods—spray-up or hand lay-up.

2.1.2 Spray-up

Glass fibre rovings, chopped to a length of 25-50 mm, are sprayed simultaneously with the polyester resin, the latter being mixed with catalyst and accelerator at the spray gun. Small-resin mixture is consolidated by manual rolling, providing a laminate with a fibre volume fraction of 0.25-0.3. Much of the labour involved in hand lay-up is eliminated by this fabric process, which tends itself to automated, production line manufacture of large numbers of small performance hulls. Control of thickness, however, is difficult and the quality of laminate is generally lower than can be obtained by hand lay-up.

2.1.3 Hand lay-up

Resin mixed with a catalyst is deposited liberally on the gel coat or on a previous ply of impregnated reinforcement by a roller-dispenser, brush or spray gun. Each ply of reinforcement in the form of CSM with a real weight of 300-600 g/m² or woven rovings with a real weight in the range of 400-800 g/m², is dispensed from a roll, typically 1-1.5 m wide, and is wetted out in consolidated by rolling or brushing into the wet resin. In WR adjacent strips of reinforcement wi
ply may be lapped or butted; in either case the strips of reinforcement forming the subsequent plies must be staggered to avoid a continuous line of weakness in the material. The resulting laminate usually has a fibre weight fraction between 0.45 and 0.55.

This requires little capital equipment but is labour intensive. It is particularly suited for a limited number of a particular structure. The main disadvantages of the method are the low reinforcement content and the difficulty in removing all the trapped air; hence the mechanical properties are not as good as in other processes.

2.2 COMPRESSION MOULDING METHODS

2.2.1 Matched Die Moulding

This method is widely used for long production runs for components ranging in size from small domestic items to doors and cab panels for large commercial vehicles. The material to be shaped is pressed between heated matched dies, as illustrated in Fig. 2.1. The pressure required depends on the flow characteristics of the feed material and may be as high as 50 MPa but is usually less than 10 MPa. The feed material flows into the contours of the mould and when the temperature is high enough, rapidly cures. The time for the complete moulding process depends on the feed material, on the dimension of the components and on whether pre-heating of the feed has been employed to shorten the time. The time required typically range from several seconds to several minutes. Good mould detail and dimensional accuracy are possible although the cost of a complex tool steel die has to be considered.

Two forms of feed which are particularly suited to matched die moulding are sheet moulding compounds (SMC) and dough moulding compounds (DMC). SMC is a prepared sheet of resin-fibre blend which contains all the necessary additives such as curing agent, release agent, and pigment. It reduces the number of components to be stored, is clean to use and results in a good consistancy in the finished component. As all the constituents are pre-mixed, SMC has a shelf life of around three to six months at room temperature. DMC is also a blend of all the necessary constituents, but only short fibres are used. The resulting fibrous mixture has the consistency of a dough or putty and can be readily made into accurately measured quantities for the feeding process. The shelf life of DMC is less than that of SMC.

2.2.2 Forming Methods Employing Gas Pressure

These forming methods are sometimes known as bag moulding processes and can be categorised under three broad headings.

The first of these is vacuum bag moulding in which, unlike the case of matched die moulding, only one mould is required. This process, [see Fig. 2.2(a)], may be regarded as an extension of the contact moulding process. It involves placing over the mould a flexible membrane, separated from the uncured laminate by a film of PVA, polythene or equivalent material, sealing the edges and evacuating the air under the membrane so that the laminate is subjected to a pressure of up to 1 bar. Curing may be accelerated by placing the component in an oven or employing a heated mould.

Autoclave moulding is a modification of vacuum forming that uses pressures in excess of atmospheric pressure (e.g., 5–15 bar) to produce high density, reproducible products for critical applications such as those needed in the aerospace industry. The mould is situated in an autoclave (pressurised oven), [see Fig. 2.2(b)], which has facilities for heating and pressurising by a gas, usually nitrogen.

The pressure bag works on a similar principle in that a pressure in excess of atmospheric pressure is used for shaping but it is cheaper as it does not require an autoclave. A flexible bag is placed over the lay-up on the mould. Inflation of the bag by compressed air, forces the lay-up into the mould as shown in Fig. 2.2(c).

[Fig. 2.1 Matched die moulding]

2.2.3 Low Pressure, Closed Mould system

The methods considered in this section consist of placing the reinforcement in a closed mould, and then inserting the resin material into the mould to infiltrate the reinforcement.

In resin transfer moulding (RTM), the low viscosity resin is injected into the closed mould under low pressure and is subsequently cured. A consequence of the use of low pressures is that inexpensive moulds, made for example from GRP, have sufficient strength. Such moulds facilitate the manufacture of complex shapes and large components without the need for high cost too
However, as the mould material does not have good high temperature properties, curing has to be carried out slowly, to restrict any temperature rise which could damage the mould. In fact, the production cycle is long. For large components it may even take days, as the infiltration stage is also slow owing to the low pressures involved.

Fig. 2.2 Open mould forming methods employing gas pressure: (a) Vacuum forming; (b) Autoclave moulding; (c) Pressure bagging

The low pressures required for RTM may be obtained by extracting the air from the mould and allowing atmospheric pressure, or even lower pressure, to force the resin into the mould. This variant of RTM is called vacuum-assisted resin injection moulding (VARIM).

Instead of using pre-catalysed resin with a slow cure, it is possible to mix two fast reactive components to make the resin just prior to injection into the mould containing the pre-form. Components are mixed at high pressures in an impingement mixing chamber and then injected into the mould where the pressure is usually less than 1 MPa (Fig. 2.3). This is followed by a rapid cure, so that the cycle time for this process, which is known as reinforced reaction injection moulding (RRIM), is far less than that for VARIM and is typically 1–2 minutes.

Fig. 2.3 Diagram of reinforced reaction injection moulding

It is important to appreciate the relative merits of the different processing methods and to understand under what circumstances a particular method is likely to be selected for manufacture. It is appropriate to recap some of the main features of the methods discussed so far. Hand lay-up is used to produce complex and/or large structures and components in small quantities. The properties obtained are variables depending on the ratio of constituents used. Capital costs here are low, but labour intensive and slow. Therefore these methods are used in region A of Fig. 2.4. The equipment for matched die moulding methods is expensive, but components can be produced rapidly, and related methods, are especially suited for the production of large number of components, of which is limited by the need to use steel dies (region C). RTM processes lie between the two extremes (region B); they are employed for relatively small runs on simple components for longer runs on more complex components.
22 Mechanics of Composite Materials and Structures

2.2.4 Pultrusion

Rods of uniform cross-section can be produced in long lengths by pultrusion. Continuous rovings of reinforcement are impregnated with resin by passing through a bath of resin (Fig. 2.5). The impregnated fibres are then pulled through a heated die which compacts and shapes the required profile in a manner reminiscent of extrusion. However, since the action relies on a pulling action, the name pultrusion has been devised. Curing takes place in a heated die but is sometimes completed in an oven. Pultrusion is a continuous process, and depending on the size and complexity of the section, rates of several metres per minute may be achieved.

A comparison of pultrusion with other methods is given in Table 2.1.

A comparison of pultrusion with other methods is given in Table 2.1.

**Table 2.1** Comparison of costs and efficiencies of FRP production processes

<table>
<thead>
<tr>
<th>Process</th>
<th>Typical cycle time</th>
<th>Equipment capital (Rs. 100,000)</th>
<th>Mould capital (Rs. 100,000)</th>
<th>Product value per cycle (Rs.)</th>
<th>Product value per hour (Rs.)</th>
<th>Process efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression</td>
<td>3 min</td>
<td>3.5-14</td>
<td>0.75-3.75</td>
<td>14-75</td>
<td>365-1140</td>
<td>8.35</td>
</tr>
<tr>
<td>Autoclave</td>
<td>8 h</td>
<td>105</td>
<td>0.75</td>
<td>7.5-75</td>
<td>1-9</td>
<td>8.35</td>
</tr>
<tr>
<td>Filament</td>
<td>4 h</td>
<td>14-75</td>
<td>0.75</td>
<td>7.5-75</td>
<td>2-18</td>
<td>119</td>
</tr>
<tr>
<td>VARIM</td>
<td>10-60 min</td>
<td>3.5-7</td>
<td>0.2-0.75</td>
<td>0.75-7.5</td>
<td>4.5-7.5</td>
<td>120</td>
</tr>
<tr>
<td>Pressure Bag</td>
<td>1 h</td>
<td>3.5</td>
<td>0.08-0.35</td>
<td>0.75-3</td>
<td>0.75-3</td>
<td>200</td>
</tr>
<tr>
<td>Spray</td>
<td>3 h</td>
<td>3.5</td>
<td>0.08-0.75</td>
<td>3.75-19</td>
<td>1.5-6</td>
<td>400</td>
</tr>
<tr>
<td>Hand Lay-up</td>
<td>5 h</td>
<td>0</td>
<td>0.08-0.75</td>
<td>3.755-19</td>
<td>1.2</td>
<td>100</td>
</tr>
<tr>
<td>Pultrusion</td>
<td>0.5-3 m/min</td>
<td>37.5-75</td>
<td>1.5-7.5</td>
<td>2.25</td>
<td>68-405</td>
<td>2884</td>
</tr>
</tbody>
</table>

* Process Efficiency = (Product value per hour × 10⁶) / Total capital

2.3 FILAMENT WINDING

Structures in the form of bodies of revolution, including cylindrical and spherical shells, cylinders with hemispherical or torispherical end closures may be fabricated economically and to performance standards by filament winding. Fabrication is carried out by winding reinforcing fibre in the form of a continuous roving, which may be impregnated with resin just prior to winding (wet-winding) or may be pre-impregnated with partially cured resin (dry-winding), on to a mandrel (Fig. 2.6) which defines the internal geometry. Winding may be helical, in which case the mandrel and fibre-feed arm shuttle back and forth at speeds regulated to provide the required winding angles. Or the winding may be polar, in which case the usual process comprises rotation of the fibre-feed arm in a longitudinal plane around a stationary mandrel. Mandrels, must be able to withstand compression induced by the winding tension and possibly also high temperatures, may be steel tubes in the case of tubular windings.

Filament wound components include underwater pipelines and ships pipework, oil and storage tanks, air bottles, buoys, radomes, torpedo hulls, helicopter blades, etc.
MICROMECHANICAL ANALYSIS OF COMPOSITE STRENGTH AND STIFFNESS

3.1 INTRODUCTION

Elastic properties of fibre reinforced plastic materials are considered as a function of properties of fibres and resins. Properties of the fibre-reinforced composite on the basis of its constituent elements can be done by a variety of methods [3.1].

1. Strength of materials approach
2. Self-consistent model
3. Variational approach
4. Numerical methods
5. Empirical equations

Earlier attempts made for the evaluation of mechanical properties are based on strength materials approach. The derivation is based on simple assumptions, such as the existence of uniform stress or uniform strain in its constituents. It has resulted in a fibre–matrix interaction [3.2] or a mixtures formulation [3.3], where the constituents – the fibre and the matrix, are assumed to function together in series or parallel. Though the estimation of the longitudinal properties on this basis has been found to be adequately accurate, the transverse and shear properties of the composite are underestimated by this approach.

The theory of elasticity solution has been obtained for the elastic components by modelling FRP to consist of a fiber surrounded by a cylindrical matrix [3.4, 3.5]. This self-consistent model neglects the interaction between fibers and as such underestimates the composite properties for high fiber volume fractions.

Application of energy theorems to the composite has shown that the assumption of series parallel connection yields upper and lower bounds of properties. Subsequent work dealt primarily with the requirement of the energy methods to achieve closer spacing of bounds and to provide solutions for a range of possible fibre–matrix geometries [3.6, 3.7, 3.8].

The difficulty in applying numerical methods such as the finite difference method, the finite element method etc., is that they do not yield a closed bound solution [3.9]. The result may at best be available in graphical form.

Empiricism has been introduced for the prediction of properties of composites. Some empirical factor based on experiments is introduced between the upper and lower bound solutions for closing the gap in the exact prediction of properties.

In the following, a single layer of fibre-reinforced composite material is considered – the fibre and the matrix are placed side by side alternately [Fig. 3.1].
CHAPTER 8

Plastics and Their Processing

8.1 INTRODUCTION

Plastics may be defined as "that material which contains an organic substance of large molecular weight as an essential ingredient, is solid in its final/finished state at some stage of its processing/manufacturing and can be shaped by flow. Plastics possess following characteristics superior to metals:

1) They possess good resistance to corrosion.
2) They have good surface finish
3) Some plastics are transparent
4) Plastics possess good thermal and electrical insulation properties
5) They possess good colouring properties and hence can be used in manufacturing of furniture and decoration products
6) They can be easily shaped as per requirement

8.1.1 General Characteristics of Plastics

1) Easy workability: They can be easily processed such as cast, moulded, machined, drilled etc.

(2) High corrosion resistance.
(3) Light in weight. The specific gravity varies from 1 to 2.5
(4) Possesses high abrasion resistance.
(5) They have good insulating properties (thermal and electrical)
(6) Good absorbent of sound and vibrations
(7) Require low cost of fabrication.
(8) Impermeable to water.
(9) Possess good strength as well as rigidity.
(10) Possess good dimensional stability.
(11) Can be processed as transparent and coloured.
(12) Possess good resistance to a majority of chemicals.

8.2 CLASSIFICATION OF PLASTICS

Plastics are broadly classified as:

1) Thermosetting Plastics
2) Thermoplastic Materials

8.2.1 Thermosetting Plastics

The plastics which can be melted and moulded once and cannot be remoulded again are called thermosetting plastics. These are formed to the desired shape with heat, with or without pressure, ending in a product that is permanently hard. The heat first softens the material/resins but, as additional heat or special chemicals brings a change by the polymerization process, it cannot be softened. Compression or transfer moulding, laminating, casting and impregnating are the processes utilized for manufacturing products from thermosetting plastics. The thermosetting plastics are soluble in alcohol and some other organic solvents when they are in a thermoplastic stage. This property is used in producing paints and varnishes from plastics.

8.2.2 The Thermoplastic Materials

These are also known as cold setting materials. Thermoplastic materials undergo no chemical change in moulding operation and do not become permanently hard with the application of heat and pressure. They remain soft at elevated temperatures and become hard on cooling. They may be re-melted repeatedly by successive applications of heat, just like melting paraffin. These plastics are considered superior than thermosetting plastics since they can be used again and again. These plastics are processed principally by injection or blow moulding, thermoforming and extension. The scrap obtained from moulding operations and rejections can be shaped into granules and reused to make first quality
products. Thermosetting can be further classified into two categories: (a) amorphous and (b) crystalline.

(a) Type of Thermosetting Plastics: The following are the various types of thermosetting plastics:

(1) Phenolics: Phenolic resin is one of the principal thermosetting plastics used in the industry. It is obtained by condensing the phenol with formaldehyde in the presence of a catalyst. The popular name of this plastic is Bakelite. It is a hard, rigid and scratch resistant material. It is highly resistant to heat, water and many organics solvents. It also possesses excellent electrical properties and is one of the cheapest materials among all the thermosetting resins. It is used in manufacturing coating materials, laminated products and as adhesives for grinding wheels. It can be cast into many useful items such as moulded cases and electrical components like switches, plugs, switch boards, telephone parts, cabinets for radio and television, and handles for knives and cooking pots etc.

(2) Amino Resin: The two most important resins are urea and melamine-formaldehyde: These compounds, also thermosetting in nature, are condensation products obtained by the reaction of urea or melamine with formaldehyde. These can be obtained in the form of moulding powder or in a solution for bonding and adhesive use. Both of these when compounded with a variety of fillers, improve mechanical as well as electrical characteristics. The amino resins can be manufactured in a wide range of colours and are hard, rigid and durable. They possess good heat, electrical and scratch resistant characteristics. The good flow characteristics of melamine make transfer moulding processes useful for items like tableware, knobs, ignition parts, electric-shaver etc. Urea resins have a hard surface and high electrical strength, so they are suitable for compression and transfer moulding can be processed in all colours. The urea formaldehyde resin is widely used in the production of domestic electrical fittings such as circuit breaker parts and buttons etc. Both resins are widely used as coatings and adhesives. Interesting uses are for laminating wood or paper.

(3) Furnace Resins: These are obtained by processing frame waste products such as cotton seeds, rice hulls, corn cobs with certain acids. These thermosetting resins are dark in colour, water resistant and have good electrical properties. These are also utilized as core sand binders, hardening adhesives for gypsum plaster as well as bonding material for floor compositions and graphite items.

(4) Epoxy Resins: These resins are obtained by condensation of polymerisation in the reaction of organic compounds specifically epichlorhydrin and biphenoxy (double phenol) It is cured or cross-linked by the addition of a hardener. The cured epoxy resins possess good flexibility, excellent chemical resistance, low shrinkage and electrical insulating properties. The coatings made from these resins are better than coatings of other materials. As adhesives they are employed to replace other forms of fastening. Regarding the application, they are used for surface coatings, adhesives for glass and metals and laminating materials used in various electrical equipments. The moulds made from epoxy resins are now finding applications in aircraft, automobiles and in name appliances. Likewise, in producing laminates, they are utilized with glass fibres to make panels for printed circuits, tanks, jigs and dies etc.

(5) Silicons: Silicon base resins differ materially from other plastics which are based on carbon atom. They are chemically hybrid, a cross between organic and inorganic materials. Thus they possess the stability of inorganic products. On the other hand, they carry the versatility of organic products. The silicon resins may be in the form of liquids, semi-solids, (such as greases) solids and rubbers. Thus, they possess the requisite desirable combination of characteristics for a large group of industrial products similar to it e.g. greases, resins, adhesives as well as rubber compounds. The outstanding characteristics of silicon resins include stability, resistance to high temperatures over long periods of time, good low temperature and high electrical resistance properties and water repellence. They are used in lubricating oil and greases operating between 40 to 60°C. Silicon rubbers are utilized in mouldings, extrusions, gaskets, and electrical connectors and as shock absorption material. Special silicon fluids are fast becoming an ingredient in cosmetics. Silicon resins can be processed by extrusion, casting, compression and transfer moulding. As they are expensive, the use of silicon products is often limited in applications where their unusual characteristics would be most useful.

8.2.3. Types of Thermoplastics

The followings are the various types of thermoplastics:

(i) Cellulosics: These are thermoplastics produced from various treatments of cotton and wood fibers. The family of cellulosics consists for a wide variety of following derivatives of cellulose:

   (i) Cellulose nitrate
   (ii) Cellulose acetate
   (iii) Cellulose acetate-butyrate
   (iv) Ethyl cellulose
   (v) Cellophane
   (vi) Cellulose propionate

   These are very tough and can be produced in a wide variety. The cellulosic possess good strength, transparency, surface finish, chemical resistance and mouldability. The various varieties of cellulosics are employed for making moulded parts such as toys, electrical parts, knobs, packaging material etc. Similarly, these cellulosics find applications in the production of spectacle frames, fabric coatings and electrical insulating tapes etc.

(ii) Polystrene: It is produced by polymerization of styrene in the presence of benzoyl peroxide. It is available in colours from clear to opaque. The other
outstanding characteristics, resistance to water as well as most chemicals, dimensional stability and insulating ability. Polystyrene has an excellent tensile strength but can be utilized from 60 to 90°C. It can be cast and moulded or extruded into a sheet, film or pipe. It possesses excellent electrical resistance. It is widely employed in moulding of items like buttons, combs, toys, radio and television parts, battery cases, high frequency electric insulators and indoor lighting panels etc.

(3) Polyethylene: It is also called polythene and is produced by the polymerisation of ethylene. It is leader among all plastics produced each year as far as the volume of production is concerned. These may be of low, intermediate and high density depending upon the process used in its manufacture. All these polyethylenes possess the properties of resistance to solvents, excellent dielectric properties, good colour ability, toughness and low cost. They are normally blow and injection moulded and extruded into a wide range of products. Applications include the production of ice cube trays and developing trays. Film or packaging, collapsible nursing bottles, flexible tubing, paint brush handles and squeeze bottles etc.

(4) Polypropylene: It is achieved by polymerizing propylene in the presence of ziegler-Natta catalyst. It is one of the lightest plastics available. It is an excellent insulator and is stiffer than polyethylene. Polypropylene can be moulded or extruded into a sheet, film or pipe. It possesses excellent electrical resistant properties, high impact and tensile strength. It is resistant to chemicals and heat. It is employed for the production of toys, furniture, electrical insulation, and television cabinets and for hospital as well as lab or tray equipment.

(5) This is a latest plastic material available in the market by trade name iaxan, Merdon and polycarbhill. It can be easily moulded, extruded and machined. It can be subjected to riveting and nailing without development of any cracks. The production of excellent safety glasses for street lamps, machine guards and windows is possible due to the toughness of polycarbonates. These are crystal clear or may be coloured as desired. These resins are able to maintain their toughness and strength in the temperature range of 141 to 220°C. They find applications for housing for shavers, blow mould bottles, other household goods and power tools.

(6) Polyamides (Nylons): These are generated by the reaction of a diamine with an organic acid. There are various grades of nylons available, but the most commonly used is 6/6 which is obtained by reacting hexamethylenediamine with adipic acid. It possesses excellent wear properties along with high temperature stability and good abrasion resistance. Nylon can be successfully moulded, extruded, formed into a sheet or a film. Nylon may be utilized for the production of engineering components. Gears, bushes, bearings, luggage and nylon ropes are also produced from polyamides.

(7) Acrylic Resin: It is light in weight and carries special value due to its excellent light transmitting power, resistance to moisture and ease of fabrication. It can be cast, sown or turned. It is a thermoplastic material which can be cast, moulded, stretch-formed and extruded into various products such as airplane windows, gage covers, and can be transparent if required. Typical applications of this material include transparent sheets, plates, and coating of tubes. These are also utilized as adhesives, laminates, optical instruments, lenses, display cases and valves etc.

(8) Vinyl Resins: A large number of vinyl and polyvinyl resins are available. Polyvinylchloride (P.V.C.) is the most frequently used of this group. The other types of plastics made from vinyl resins are polyvinyl acetate. Polyvinyl resins are polyvinyl acetate, polyvinyl butyrates and polyvinylidene chloride. P.V.C. can be produced by heating the outer emulsion of vinyl chloride in the presence of a small amount of hydrogen peroxide or brezily in an autoclave under pressure. All these PVC resins are capable of being processed into a variety of products by compression or injection moulding, blow moulding or extrusion. The various varieties of vinyl resins (i.e. polyvinyl butyrate chloride and polyvinylidene chlorides) possess different characteristics such as stability toward light, heat resistant towards moisture, toughness, electrical resistance chemical resistance or a combination of two or more. They are often blended with other resins and can be made in different colours and forms like sheets, liquids as well as small solid pieces. They are generally utilized for the production of items/articles such as raincoats, floor and wall covering, hose and tubing, toys, laminated safety glass plugs, wire insulation electrical plugs and abrasive resistant linings etc.

(9) ABS Plastic: (Acrylon: Trile-butanadiens-styrene). Three chemicals acrylonitrile, butadiene and styrene are combined to generate ABS plastic, which are compounded to produce the ABS plastic. It possesses characteristics such as high impact strength, resistance to low temperatures and chemicals. These resins can be provided a wide range of colours with good surface finish. In case toughness is required, ABS can replace PVC and polystyrene. ABS plastics find applications in the production of cameras, electrical hand tool housings, instrument panels on cars, telephone hand sets, liners for refrigeration and gas pipes. For the manufacture of suitcases and furniture, grained finish sheets of ABS can be produced and utilized.

(10) Elastomers or Synthetic Rubber: These are polymers which are less tightly bound together. They possess the unique characteristic of high elasticity, stretching six to ten times their original length on loading in tension and returns to its original dimensions as soon as the load is released. The best known elastomer is natural rubber, obtained in the form of viscous milky fluid (known as latex) which contains a linear polymer of polyisoprene. Natural rubber, although not very useful, is useful in its natural form and becomes a very useful elastomer for several purposes after it is vulcanised. It is less prone to tearing and cracking.
Various varieties of synthetic rubbers have been developed which possess comparable properties to natural rubber. These possess greater stability of dimensions and show a very high resistance to oils and oxidation process. The following are the commonly used types of synthetic rubber:

1. **Styrene Rubber**: It is the most common variety of synthetic rubber which is obtained from copolymerization of butadiene and styrene. It is similar to natural rubber as far as processing characteristics. It has a high abrasion resistance, high load bearing capacity as well as resilience. It is mainly employed for manufacturing of motor tyres.

2. **Nitrile Rubber**: These are the butadiene-acrylonitrile copolymers. Due to resistance to oils, these are principally employed in such products as oil hoses, gaskets and diaphragms, printing rollers, tank lining and automobile components.

3. **Silicone Rubber (Poly Siloxane)**: These rubbers are extremely resistant to both high and low temperatures as well as sunlight, lubricating oils and dilute acids. Where other synthetic rubbers do not perform satisfactorily, these are employed in such applications like o-rings and seals for oil and gas lines, sealing doors on air planes, and insulation of wire & cable.

4. **Polychloroprene Rubber**: It is produced by the polymerization of chloroprene, a chlorinated butadiene. The trade name of this rubber is Neoprene. It is heat, light and oil resistant. The general properties of this rubber can be improved by compounding it with metallic oxides such as MgO or ZrO. It is utilized for producing tubes, hoses, gaskets for carrying corrosive gases and oils, adhesives and conveyor belts.

5. **Butyl Rubber**: It is an isobutylene copolymer and possesses many properties and characteristics of natural rubber. It carries a small amount, usually (1 to 4%) of isoprene. It possesses excellent resistance to heat, chemicals and abrasion. It has good electrical insulation capability. It is employed for the manufacture of the production of conveyors belts, tank linings, insulation for high voltage cables, hoses and cycle well as automobile tubes.

6. **Polysulphide Rubber**: The organic polysulphides, popularly known as thiokol, are very resistant to gasoline, oils and paints along with sunlight. These are coated fabrics and insulation coatings. Polysulphide rubber obtained by a reaction between sodium polysulphide and ethylene dichloride is resistant to fuels, mineral oils, solvents, gaskets, cable coverings and oil tank lining etc.

### 8.3 MOULDING COMPOUNDS

The following are the moulding compounds generally used with granular resins before moulding under heat and pressure:

1. **Fillers**: These fillers are added to reduce the cast and improve certain properties such as a compressive strength of the final plastic product. It is often essential for reducing mould shrinkage. The commonly added fillers are silica sand, sawdust, ground granite, clays and powdered metals.

2. **Reinforcements**: These are added for improving the mechanical strength of the plastics. The generally used reinforcements are fibreglass, asbestos, synthetic fiber and cellulose.

3. **Stabilizers**: In order to prevent deterioration due to the action of heat and light and improve the thermal stability during processing, stabilizers are added. Normally, zinc soap and phenols are used in vinyls and the styrenes.

4. **Catalysts**: These are meant for accelerating the chemical reaction involved in the process of polymerization of plastics. They act as hardeners and accelerators.

5. **Pigments**: These are employed to impart decorative and colouring effect to the plastics. They also act as fillers for plastics.

6. **Plasticizers**: These are added to plastics to impart softness, improve toughness and flexibility of the final product. Camphor, paraffins, naphthalenes and phosphates are the commonly used plasticizers.

7. **Solvents**: The solvents are utilized for dissolving the plasticizers and to mould. For example, camphor in cellulose is dissolved by adding alcohol.

8. **Modifiers**: The chemicals added to plastics for varying the mechanical properties of base resin are tuned to improve the mechanical properties of plastics.

9. **Elastomers or Natural Rubber**: These materials, when added to plastics provide maximum property of elasticity to the final product or plastic under consideration. They exhibit the unique feature of high elasticity, stretching even up to ten times their original length and regain their original dimensions when the loads are removed. The best known elastomer is Natural rubber and the raw material is latex, a viscous milky fluid, obtained from trees. The meaning ‘radiant in latex’, which enables production of natural rubber, is a linear polymer of isoprene. Other examples are silicon, urethane and chlorinated polyethylene. Although, natural rubber is not very useful in its natural form, it becomes a very useful and suitable elastomer for various purposes after it is vulcanized. It possesses fairly high strength and does not crack. Several varieties for synthetic rubber having very high resistance to oils and oxidation have been developed which are quite comparable in the inherent properties to the natural rubber. This is the reason, they are employed in more applications than natural rubber.
8.4 Moulding Compounds for Processing Plastics

Most plastic resins have to be chemically treated or compounded with processing materials before they are ready for processing. The various moulding compounds which are usually mixed with the granular resins before moulding are one of the following additives:

(1) Stabilizers: To improve the thermal stability during processing, stabilizers are added to plastics i.e. to improve net deterioration due to the action of heat and light.

(2) Plasticizers: The plasticizers are added to plastics to make them soft to improve toughness and flexibility of the end product. Organic solvents, resin and even water are used as plasticizers. For example, vinyls are generally hard and brittle materials. After adding plasticizers, they become soft and flexible.

(3) Fillers: The fillers are added to reduce the cost and to improve certain features of the final product such as compressive strength and impact resistance. These are normally essential for thermosetting plastics to reduce mould shrinkage. Typical fillers which are added in high proportions to many plastics include wood flour, asbestos, fiber, glass fiber, slate powders, cloth fiber and mica etc.

(4) Catalysts: These are utilized to promote the chemical reaction during the process of polymerisation of plastics. They are also known as accelerators and hardeners.

(5) Elastomers: These are the materials added to plastics in order to improve elasticity.

(6) Modifiers: These are the chemicals added to improve mechanical properties of the base resin.

(7) Pigments: The pigments and dyes are added to impart decorative and bright colours to plastics. The commonly used pigments are zinc oxides, barites etc.

(8) Antioxidants: These provide resistance to ultraviolet rays when added to plastics. They also provide melt flow retention for easy moulding.

(9) Initiators: These are utilized to initiate the reaction i.e. to allow the polymerization to begin. They stabilize the reaction sites of the molecular chain. Hydrogen peroxide ($H_2O_2$) is a normal initiator.

8.5 Plastic Processes

8.5.1 Casting of Plastics

For creating casting of plastics, a mixture of monomer syrup, catalyst and other additives are required. The mixture is then heated and poured into a mould at atmospheric pressure. Polymerization takes place in the mould and the finished part is obtained. The plastic materials that can be cast are nylons, epoxies and acrylics.

8.5.2 Advantages

1. Accurately contoured products like gears can be produced.
2. The weight of plastic products is about one-seventh the weight of steel.
3. Plastic products have good sound and vibration damping qualities.
4. The surfaces of plastic products are harder because of slower cooling cycle of the casting process. So they are more wear resistant.
5. Cost of casting plastic products is quite low as compared to casting of metals.

8.5.3 Disadvantages

1. Products can absorb moisture.
2. They cannot be used for higher temperature applications.

8.6 Compression Moulding

For compression moulding, thermosetting material is used. The powder or granular form of the thermosetting material is placed in a heated die. The upper half of the die compresses the material which melts and fills the die cavity. After compression, the part solidifies and the upper half of the die moves back and the part is removed. The pressure used for compressing is from 0.7 to 55 MPa and temperature range is 120° to 205°. The selection of pressure and temperature depends upon the material and size of the product.

8.7 Transfer Moulding

Transfer moulding is similar to compression moulding and makes use of heat and pressure. In this method, the plastic powder or granules are placed in the plunger. When the mould plunger moves down towards and presses the material in the cavity, because of temperature and pressure the material is in semi-liquefied state. This material is transferred to the mould cavity through the sprue. After
Fig. 8.1: Compression Moulding

(a) Mould open

(b) Mould closed

(c) Part ejected

Fig. 8.2: Transfer Moulding

(a)

(b)

(c)
curing the plastic in the mould, the mould is opened and the part is removed. This method is used to produce intricate parts and parts which have a variation in section thickness. The disadvantage of the process is that the material is wasted in runner sprue. The die cost is also more as compared to compression moulding.

### 8.8 Injection Moulding

Injection moulding is used for thermosetting as well as thermoplastic materials. It is also known as jet moulding. The nozzle is used in this process which is both heated and cooled during the moulding cycle, the material (resin) is first heated in the cylinder surrounding the plunger making it plastic. The plunger forces the resin through the nozzle to the mould and additional heat is applied. When the mould is completely full, the nozzle is cooled rapidly by water to prevent further polymerization. Several methods are used to impact the molten plastic into the mould.

#### 8.8.1 Plunger Injection Moulding

It is one of the oldest types of injection moulding generally used for thermosta plastics. The material is placed in the hopper which is gravity fed. In the operation, the ram forces the plastic to a spreader which causes heating and mixing and then it is pushed through the nozzle into the mould. For processing of thermoplastics, this machine is modified by cooling the nozzle and the barrel and thereby eliminating the spreader. This prevents heat buildup that could cause the compound to cure prematurely in the barrel.

#### 8.8.2 Reciprocating Screw Injection Moulding

In this system, the plastic materials are fed by the gravity from an overhead hopper. The material is carried from the hopper to the nozzle by the screw through the heated cylinder. The material in the cylinder becomes fluid. The injection nozzle is blocked by the previous shot and this causes the screw to move backwards. The volume of the plastic shot is controlled by a limit switch that shuts off the screw when it has reached the end of the stroke. When the press has locked, the injection takes place. In this process, the screw advances and acts like a ram. At the same time, the non return valve closes the outlet passage in the screw. This makes the screw to act like a solid plunger and pushes the plastic into the mould cavity. After filling the mould cavity, the screw plunger is kept at that position for sometime and this period is called the holding period. Then the screw is energized to return and the non return valve opens. This will allow the plastic to move forward from the cylinder again, thus repeating the cycle.

#### 8.8.3 Two Stage Injection Moulding

This machine was used before the invention of the reciprocating screw machine. The first stage is plasticizing step, the melting or mixing of the plastic material takes place with the help of a long rotating screw. The screw is not provided with a reciprocating motion. The melting material is conveyed into the cylinder via a diverter valve. When enough melt has filled the cylinder, the screw stops and the diverter valve shifts. This stops the reverse flow of the plastic material while working in the second stage.

In the second stage, melted plastic is forced out of the injection cylinder by a hydraulically driven piston plunger. When the injection stage is over, the plunger moves backward and opens the diverter valve to connect the flow path from the rotating screw to the injection cylinder. This allows the transfer of plasticized material into the mould. Since both stages are performed by different mechanisms, the operation of each can be optimized. The disadvantage of this machine is that it is not suited to heat sensitive materials what may degrade rapidly after reaching the operating temperature.
Module: Welding

Workshop Training Notes
CHAPTER 7

Electric and Gas Welding Processes

7.1 INTRODUCTION

The two methods of metal working, namely, casting and forging, are the most primitive methods of mass production. Although these processes are still in vogue, welding as a new method of fabrication has very effectively superseded both casting and forging, particularly for the production of those machines and structures which require light, compact but strong design. Besides providing simplicity, ease and speed in production, welding ensures overall reduction in production cost and, consequently, enjoys wide acceptance by the craftsman and users.

Fabrication is the name given to a process (or combination of processes) of making a marketable product by cutting metal pieces to suitable sizes and later joining them together to form the product. The metal pieces are normally cut from standard structurals available in the market in the form of plates, rods, angles or channels and later assembled and jointed together by bolts, rivets or welding.

7.2 PREFERENCE FOR WELDING

Among various processes of joining metals, welding has gained considerable popularity because of the following reasons.

(i) Welding has replaced riveting because of being faster and noiseless. It gives a stronger and leakproof joint. It also results in saving in self-weight of the fabricated structure and is thus more economical.

(ii) Big components of the machine (for example, lathe beds and columns of machine tools) which were previously made by casting, are now steel fabricated bringing lots of saving in the self-weight, besides speed and economy in production. Welding provides flexibility in making in-process changes in the design of the structure.

(iii) Welding can be used for joining dissimilar metals to form a composite metal with special properties.

(iv) Fabrication of welded structures is much easier and cheaper than that of complicated castings since the standard readily available structurals like angles, channels, I-sections are effectively made use of by welding in making a product.

(v) Number of operations involved in welding are much less in comparison to casting and riveting and hence there is saving in time, labour and overall cost.

(vi) The appearance of a welded structure is better than that of a cast or riveted one.

(vii) It has been possible only due to welding that some metals such as copper, stainless steels, aluminium and many others have found useful applications in various industries for their specific properties like resistance to corrosion and oxidation. Welding as an effective method of fabrication has thus led to the development of chemical, petroleum, fertilizer and steel fabrication industries.

7.3 APPLICATIONS OF WELDING

Welding is used in industry as an effective tool in the form of (a) regular method of production of metal structures and components for automobile, aircraft, railway and many other construction industries and (b) an easy and effective method of on-site repairs and maintenance or rebuilding of broken parts of a machine or structure. Industries where welding finds most extensive use, are given below.

(i) Automobile and transport industry wherein cars, trucks, jeeps and many other transportation machines and equipment are fabricated.

(ii) Material handling equipment such as overhead cranes, jib cranes and tower cranes are manufactured by welding along with their auxiliary equipment like trolleys, lifting aids and gadgets.

(iii) Rail-road industry wherein major fabrication and welding is involved in the production of locomotive underframes, bogies, trolleys, railway bridges, electrification network, signaling equipment, lighting tower, platform sheds and godowns, storage tanks and bodies and frames of railway coaches.

(iv) Bridge construction industry utilizes welding as the most popular means of joining steel-bridge components or structurals, in a factory or at the construction site. Joining of steel reinforcement for cast-in place concrete bridges is also done by welding.

(v) Ship building industry uses welding in the construction of ship body or structure including decks, supporting girders and framework, platforms and many other structures.

(vi) Aircraft industry involves considerable use of welding for joining aircraft components of alloy steels, stainless steels and aluminium alloys. Besides the fabrication of the aircraft body, frames mounts, fuel tanks, ducts and fittings, welding is used for the production of all equipment that help aircraft operations and maintenance like material handling systems, transport means for man and luggage sheds, fuel storage tanks and many such structures.

(vii) Building industry has great use of welding in traditional buildings for joining frames of doors and windows, reinforcement in concrete works, railings and staircases. Whe
the building is a steel frame construction comprising steel roofing frames covered with asbestos sheets or galvanized iron sheets, welding has still greater role to play in joining the structural components for making buildings and trusses.

(viii) **Chemical and petroleum industry** makes good use of welding for the fabrication of plant and machinery, stainless steel vessels and storage tanks, besides many other structures.

(ix) **Pressure vessels and tanks** are used in various industries for storing fuel, and other liquids. These are made by welding together the bent steel plates. Oil, gas and water storage tanks are also steel fabricated.

(x) **Pipings and pipelines** for oil, gas and gasoline involve welding for their fabrication and assembly.

(xi) **Construction equipment manufacturing** largely depends on welding for the fabrication of earth moving machineries like bulldozers, loaders, trenchers, and drilling rigs for oil exploration and water tubewells and other such machinery.

(xii) **Manufacturing of machine tools and production tools** include mass production of machine tool frames, columns, beds and other auxiliary supports, press and die equipment for cold and hot forming of steel and nonferrous metals. These involve welding as a major means of fabrication.

(xiii) **Other fabrication industries** involving the use of welding include (a) Industries engaged in the manufacturing of steel furniture like beds, tables, chairs, almirah, and many other frames and gadgets for household and office usage, (b) Farm machinery manufacturing units engaged in the production of tractors, trolleys, wheat thrashers, farming implements and tools, (c) Repairing of components of automobiles and two wheelers, hard facing and rebuilding of worn out machinery parts, fabrication of jigs and fixtures and many other aids and gadgets.

### 7.4 WELDING-A METAL WORKING PROCESS

**Welding** may be defined as a metal working process in which two similar or dissimilar metal pieces are joined together by heating them to molten state and allowing their molten portions to flow together to develop coalescence (or intimate fusion) which, on cooling and solidifying, forms a firm joint. The 'fusion' refers to intimate intergranular mixing of two metals to be joined. The operation of welding may be carried out with or without the application of pressure on the mating components and also with or without the use of a filler metal (often called electrode). The heat required to melt the metal pieces is obtained either from electric arc, oxy-acetylene (or oxy-hydrogen) gas flame or from the exothermic chemical reaction (as in the case of thermit welding).

### 7.5 BROAD CLASSIFICATION OF WELDING PROCESSES

Welding processes when categorized based on the material of filler rod used during welding, include (a) **autogenous welding** in which no filler rod is used (such as resistance welding or cold welding processes), (b) **homogeneous welding** wherein the filler rod used is of the same material and composition as that of the base metals being welded (such as arc welding processes), and (c) **heterogeneous welding** in which the filler rod used is of different material than the base metal welded (such as in soldering or brazing).

However, a more widely accepted classification of welding processes is given in the following:

(a) Fusion welding processes (or non-pressure welding processes).
(b) Pressure welding processes (resistance welding processes and solid state welding processes).
(c) Thermo-chemical welding processes.
(d) Radiant energy welding processes.
(e) Under water welding processes.

#### 7.5.1 Fusion (or Non-pressure) Welding Processes

Fusion welding processes involve heating the work pieces to be joined to molten state allowing their molten portions to fuse and flow together to develop coalescence, which, on cooling results into a strong joint. No pressure is exerted on the work pieces to make a joint. Further, the welded joint may be obtained with or without the use of a filler rod (electrode).

Fusion welding processes are further classified as below:

(a) **Arc welding processes** such as shielded metal-arc welding, submerged arc welding, gas metal-arc welding, electroslag welding, gas tungsten-arc welding, plasma welding, etc.

(b) **Gas welding processes** include Oxy-fuel gas welding such as oxy-acetylene welding, oxy-hydrogen welding, etc.

(c) **Brazing and soldering**

#### 7.5.2 Pressure Welding Processes

Pressure welding processes involve heating of work pieces to the temperature range in which the base metal of the work pieces becomes plastic, and then the two work pieces are joined together by applying pressure on them. The work pieces are heated only along the edges where the joint is to be formed. Heating may be sometimes concentrated only at a spot (or number of spots) on the edges of the joint. No additional filler metal (or electrode) is used in forming the weld.

Pressure welding processes are further divided as below:

(a) **Resistance welding processes** such as spot welding, seam welding, projection welding, resistance (upset) butt welding, flash butt welding and percussion welding.

(b) **Solid state welding processes**

A solid state welding process produces coalescence at temperatures below the melting point of the base metals being joined, without the addition of a filler metal but with application of pressure only. Various types of solid state welding processes include:

(i) Cold welding
(ii) Diffusion welding
7.5.3 Thermochemical Welding Processes

The two main thermochemical welding processes are (a) thermit welding and (b) atomic hydrogen welding. Thermochemical welding is, in a way, a fusion welding process in which no outside heat source is required for melting the work pieces to be joined, for example, the exothermic reaction of the burning thermit mixture in thermit welding, provides heat required for melting the joint edges of the work pieces. Similarly, atomic hydrogen welding possesses the features of both arc and flame welding processes. Arc is struck between two non-consumable tungsten electrodes in an atmosphere of hydrogen where dissociation of hydrogen results in an exothermic reaction providing heat for welding.

7.5.4 Radiant Energy Welding Processes

Radiant energy welding processes involve focusing an energy beam on the mating edges (or surfaces) of the two work pieces to be joined. Heat is generated as a consequence of the energy beam striking the work pieces.

Radiant energy welding processes include:
(a) Electron beam welding
(b) Laser beam welding

7.5.5 Underwater Welding

The development of off-shore gas and oil fields, mining in sea bottom and repairing of structures under water has called for the development of underwater welding. It is done in two ways: (i) Wet welding and (ii) Dry welding.

7.6 ARC-WELDING PROCESSES

Arc-welding includes those welding processes wherein heat required for welding is derived from an arc powered by electrical energy, may be AC or DC. Very high temperatures (up to 30,000°C and more) are obtained in the welding arc developed between the tip of electrode and the work piece. In arc-welding, the electrodes used may be consumable type or non-consumable type and accordingly the arc-welding processes may be categorized in two groups. They are as follows.

(a) Arc-welding processes (consumable electrode type): In these processes, the electrode used is in the form of thin small rods or sticks (bare or coated with flux) or coil of bare round wire, which during welding is fed continuously to the welding zone wherein due to high heat, the electrode melts and is consumed, forming the part of deposited weld metal. Examples of arc-welding processes (consumable electrode type) include: Carbon-arc welding, shielded metal-arc welding (SMAW), submerged arc welding (SAW), gas metal-arc welding (GMAW), electroslag welding (ESW) and electrogas welding (EGW).

(b) Arc-welding processes (non-consumable electrode type): In these processes, the electrode used is not consumed during welding forming the part of weld deposition. Typically, a non-consumable tungsten electrode is used which, as one pole of the arc, generates high heat for welding. The electrode and the welding zone are protected against oxidation using some shielding gas such as argon or helium. Examples of arc-welding processes (non-consumable electrode type) include: gas tungsten arc-welding (GTAW), atomic hydrogen welding (AHW) and plasma-arc welding (PAW).

The salient features of the welding processes discussed before will be taken up in brief elsewhere. However, in the following is given the detailed description of the shielded metal-arc welding, because this process is the oldest, simplest and most versatile and hence highly popular among the welders. Use of this process alone accounts for over 50% of all industrial welding jobs related to fabrication, production and maintenance.

7.7 SHIELDED METAL-ARC WELDING (SMAW)

Shielded metal-arc welding (SMAW) (or manual metal-arc welding or stick welding or simply manual arc welding) is the most commonly used welding process in fabrication and maintenance jobs. Arc is developed between a consumable coated metal electrode and the work piece (Fig. 7.1). Under the intense heat of arc (temp. about 5000°C), a small part of the base metal of the work piece melts. At the same time, the end of metal electrode also melts giving tiny globules or drops of molten metal which pass through the arc and reach the joint, where they develop coalescence with the molten part of the work piece metal after cooling. Burning of flux coating on the electrode produces protective gaseous shield for the weld bead and the molten flux forms a slag (after cooling) that protects the weld bead from oxidation. This slag is later chipped off to get the clean weld.
Equipment consists of AC transformer welding set or DC welding set (motor-generator type, AC-DC transformer rectifier type) having constant current characteristics and coated electrodes covered with a flux coating. The set-up for shielded metal arc welding is shown in Fig. 7.2, which shows the essentials of this welding process.

All common metals and alloys can be welded by shielded metal-arc welding process. It is the most popular and simplest method of welding used extensively for fabrication and maintenance jobs. It may be slower than CO₂ process for welding mild steels because it cannot be mechanized due to the use of short electrodes. Slag inclusion in weld due to coated electrodes is also a problem in making long joints. Shielded metal-arc welding may not be suitable for welding very thin jobs.

### 7.8 MAIN FEATURES OF SHIELDED METAL-ARC WELDING

The following makes a welding circuit for the shielded metal-arc welding process.

(i) Welding plant or machine,
(ii) Electrode.
(iii) Two electric leads,
(iv) Work pieces,
(v) Electrode holder, and
(vi) Earth clamp.

The essentials of shielded metal-arc welding set-up are shown in Fig. 7.2 wherein two plates A and B are to be joined along the edge PK (or mating line). An electric arc is established between the bottom end of the electrode and the work pieces when the electrode is brought down, touched with the work pieces (at any point along line PK) and withdrawn rapidly upwards to a distance sufficient to maintain the arc. The arc thus established melts the base metal of two work pieces as also the electrode. During welding, while the electrode is moved gradually along the joint PK from its one end to the other, it is also continuously fed into the molten weld puddle or pool as the welding operation proceeds. When one electrode is consumed, another is picked up and used. The flux coating on the electrode melts and generates shielding gas which envelops the weld area and protects the weld from the oxygen of the atmosphere.

![Fig. 7.2 Essentials of an electric arc welding process. The mating edges of the two work pieces (Plates A and B) are first prepared for welding by grinding them slant such that when placed parallel and touching to each other along the mating line PK, a V-groove is formed to receive molten metal. The electrode is usually inclined to about 20° from the vertical position towards the direction of weld travel.](image-url)

#### 7.8.1 Electric Arc

The phenomenon of jumping of current (or electric charge) between two terminals with a small air gap is termed as electrical discharge, which appears in the form of sparking. Under suitable conditions of the power source supplying power to the circuit, it is possible to have a continuous electrical discharge (or flow of current through air gap) between the two terminals. This electrical discharge will then appear in the form of an arc.

An electric arc (which is an electric discharge in air) is formed when two conductors carrying current are brought closer to make electric contact and then separated such that a small air gap is maintained between them. In an electric circuit having its two terminals arranged close to each other with a very small air gap between them, a current (or charge) may jump across the air gap when either a sufficient high voltage or very heavy current is applied to the circuit.

Air or any gas at normal temperature is a bad conductor of electricity, but during the phenomenon of electrical discharge, the air between the two terminals becomes ionized, which is a state in which air temperature attains very high value, over 5000°C. The high temperature causes the electrons to emerge from the negative electrode. These electrons collide with the molecules and atoms of the air (between electrode and work piece) breaking it up into free electrons and ions and thereby rendering the air gap good conductor of electricity due to ionization. Thus, heated air becomes a good conductor of electricity. Electric arc or welding arc is thus a sustained electrical discharge through an ionized gas (called plasma) between the two terminals (electrode and work pieces) of the welding circuit.

The electric arc used for welding purposes is essentially a high current, low voltage electrical discharge and can be considered as a flexible conductor carrying current through the plasma. The current in the welding arc may vary from 100 amperes to 2000 amperes and voltage of the arc may be as low as 10 to 50 volts. The arc contains very high amount of heat at high temperature over 5000°C and thus can be effectively employed for fusion welding of metals.

#### 7.8.2 Arc Initiation

Arc initiation refers to generating or starting an arc between the electrode and the work piece. During welding, the electrode is kept a little away from the work piece maintaining more or less a constant gap sufficient enough to maintain the arc. But the arc can only be ignited or initiated by first providing a conducting (or ionized) media in the air gap between the electrode and the work piece. The initial conducting media (i.e. the ionized air gap in the beginning) for arc initiation is obtained by the following methods:

(a) Touch start for arc initiation
(b) High voltage discharge for arc initiation

(a) Touch start for arc initiation: In touch start, the electrode is first touched with the work piece (Fig. 7.3) and later immediately withdrawn apart. The electrode is touched with the work piece for a very short time, creating short-circuiting conditions, i.e. resistance becoming zero and thus the current increasing to a very high order. With the rise of exceedingly high current, temperature increases at the point of contact of the electrode with work piece, causing local melting and vaporization of the electrode tip and the work piece metal besides emission of electrons from the cathode (negative...
These electrons collide with the molecules and atoms of the air (existing between the gap of electrode and work piece) breaking them up into free electrons and ions and thereby rendering the air gap to become ionized and hence good conductors of electricity. The metal vapours are also produced (due to melting) and these also get easily ionized. Under these circumstances, even a small amount of electron emission is enough to initiate a transitory arc as the electrode is pulled apart. The elements present in the flux coating of electrode (titanium dioxide, calcium carbonate and potassium compounds) are all arc stabilizers, which on melting help maintaining the arc properly. After the initiation of a transitory arc, regular welding arc may then be established if a suitable power circuit is available.

**Fig. 7.3** Touch start or short-circuiting method of arc initiation. 1. Electrode being lowered towards work piece, 2. Electrode touching the work piece, 3. Electrode withdrawn to maintain a gap for arc formation.

(b) **High voltage discharge for arc initiation:** Touch start method of arc initiation may contaminate the electrode where non-consumable electrode is used, (as in TIG welding) and hence under such circumstances, arc is initiated by incorporating a high frequency unit which superimposes a high frequency voltage in the welding circuit, thereby producing an electric field of very high strength of the order of $10^6$ to $10^7$ volts per centimetre (of air gap). The high frequency, high voltage oscillators supply a pulse of high voltage to initiate the arc.

**7.8.3 Arc Stability**

A stable arc is uniform and steady and gives good weld bead and defect-free weld nugget. An unstable arc results in slag entrapment, porosity, blow holes and lack of fusion of the weld. For the stable arc, the welding plant should be such that a little variation in arc length (i.e. voltage) should not extinguish the arc. Continuous and proper emission of electrons from the electrode (cathode) and thermal ionization in the arc column should be ensured. Proper flux coating on the electrode with arc stabilizing elements can help making the arc stable.

**Arc length** is the distance between the tip of the electrode and the workpiece surface upon which the molten globules (of electrode material) are deposited (Fig. 7.1). The short arc deposits more weld metal with advantages such as maximum penetration, maximum strength, slight overlay, minimum porosity, maximum ductility and better behaviour of alloy steel electrodes.

**Fig. 7.4** Judging the arc length by (a) the shape and size of arc and by (b) the type of weld bead. With short arc the molten metal is well protected all around by the neutral flame (of gas envelop generated from the burning of flux coating on the electrode). In case of long arc, the neutral flame (of gas envelop) whirls around exposing first one side and later the other side of the molten metal (molten electrode) which results in the oxidation of the metal being deposited and finally in a porous and burnt weld bead, poor penetration and overlap.

**7.8.4 Polarity**

The terms electrode positive and electrode negative are called polarity. Polarity indicates the direction of current flow. The positive terminal in DC liberates more heat. When the electrode is on positive pole, it is called reverse polarity, and when the electrode is on the negative pole it is called straight polarity. Polarity consideration is applicable to DC power only (and not AC power).

**Polarity in DC welding:** One of the big advantages of a DC welding set is that either straight or reverse polarity can be used. Polarity indicates the direction of current flow. In straig
polarity (DCSP), the electrode is negative and the work is positive. In reverse polarity (DCRP), the electrode is positive and the work is negative. Polarity can be changed by a switch on the welding machine or by changing the cable connections. Most of the heat is liberated in the positive side of the arc.

**DCSP:** Refer Fig. 7.5. Note the deep penetration, a special feature of DCSP.

![Fig. 7.5 DC Straight Polarity (DCSP).](image)

(i) Current up to 1000 amperes can be used with 6 mm electrode.
(ii) 66.66% heat is generated at job and 33.33% at electrode and hence usually bare and medium coated electrodes are used in DCSP.
(iii) Deep penetration.
(iv) Average arc voltage in argon atmosphere is 12 volt.
(v) Electrode runs colder than AC or DCRP.
(vi) No arc cleaning of base metal (job).
(vii) Used for most welding jobs, particularly for thicker sections.

**DCRP:** Refer Fig. 7.6. Note the shallow penetration, a special feature of DCRP.

![Fig. 7.6 DC Reverse Polarity (DCRP).](image)

(i) Currents used are usually lower than 125 amp. for up to 6 mm dia electrodes to avoid overheating.
(ii) 66.66% heat is generated at electrode and 33.33% at job.
(iii) Least penetration.
(iv) Average arc voltage in argon atmosphere is 19 volts.
(v) More chances of electrode over-heating and melting and hence heavy coated electrodes are used with DCRP.

**Penetration:** Penetration is the depth from the surface of the work piece to the bottom of molten metal (Fig. 7.1).

**Crater:** During welding, the arc forces the metal out of the molten metal pool, and this sometimes piles up around the edges of a small depression which gets formed in the weld bead. This depression on cooling appears as a small cavity and is called a *Crater* (Fig. 7.7). The crater can appear anywhere along the weld bead and is a weld defect.

![Fig. 7.7 Showing good weld bead ripples. The presence of a crater at the end of weld bead is, however, not desirable. It should be properly filled up by the welder.](image)

**Arc blow:** Arc blow is a phenomenon in which a strong magnetic field sets up around the electrode and it tends to deflect the arc as though a strong wind were blowing, hence the name 'arc blow'. The arc may be deflected to the side but it is usually deflected either forward or backward along the direction of travel. Arc blow is specially noted when the electrode is in a corner or towards the end of a joint (Fig. 7.8). Arc blow is encountered in DC welding machines since AC prevents formation of a strong magnetic field.

![Fig. 7.8 The phenomenon of arc blow (deflection of arc). The effect of arc blow is most pronounced at the two ends of the joint.](image)

Under arc blow, the arc may distort, deflect or rotate. The factors affecting the arc blow include magnetic fields produced in the work piece adjacent to welding arc due to current through arc, presence of bus bars in the neighbourhood of welding place, operating machines, welding heads affecting each other, and magnetic field produced in the work piece around earth connection.

Increased arc blow results in unstable arc, poor weld appearance, under-cutting, over deposition, spattering, slag entrapment and porosity of weld. Arc blow can be avoided...
changing the position of earth clamp, avoiding presence of magnetic materials around the work piece, lowering arc current, putting earth clamp away from the joint to be welded, using short arc, decreasing arc travel speed or pre-heating the work piece before welding.

7.9 A FILLET WELD

A fillet weld is a fusion weld of triangular cross-section and deposited in a tee joint, inside corner joint or lap joint. A strong fillet weld bead has usually concave shape. Making of a typical fillet weld is shown in Fig. 7.9 wherein two overlapping plates are first tack welded (to keep them intact in a set position) at few places along the joint and later the joint is welded full length. The angle of electrode (work angle) should be 30° to 45° to the horizontal.

![Fig. 7.9 Making a fillet weld. The work angle between the electrode and work piece taken in a plane normal to the plane of joint being welded, should be limited to 30° to 45° (as shown).]

7.10 BUILDING A WELD PAD (OR BUILDING UP)

Building up involves making a series of parallel and overlapping weld beads and layer upon layer until the required thickness or size of the built-up pad is obtained (Fig. 7.10). The technique is used for repair jobs wherein worn-out parts are brought back to the original size by building up weld pad.

![Fig. 7.10 Building a weld-pad.]

7.11 EFFECT OF WELDING VARIABLES ON WELD QUALITY

Welding variables include: arc voltage, current, length of arc, and welding speed. Optimum welding variables ensure best quality welds. Effect of welding variables on the weld quality given in Table 7.1.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Condition of welding variables</th>
<th>Effects on weld quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Optimum voltage, current, arc length and welding speed</td>
<td>Stable arc, smooth and even weld bead with fine ripples, little or no spatter, no under-cutting or overlapping</td>
</tr>
<tr>
<td>2.</td>
<td>Voltage in excess of optimum</td>
<td>Fierce wandering of arc, porosity in weld, more spatter, weld deposit flat and irregular spattering</td>
</tr>
<tr>
<td>3.</td>
<td>Voltage less than optimum</td>
<td>Frequent arc extinction with spattering sound, sticking of electrode, little penetration, irregular piling of weld bead metal</td>
</tr>
<tr>
<td>4.</td>
<td>Current in excess of optimum</td>
<td>Overheating of electrode, red hot electrode, excessive spatter, flat wide bead with deep crater, arc fierce with loud crackle</td>
</tr>
<tr>
<td>5.</td>
<td>Current less than optimum</td>
<td>Piling up of weld metal, poor bead shape, poor penetration, unstable arc and difficult slag control</td>
</tr>
<tr>
<td>6.</td>
<td>Faster welding speed</td>
<td>Under-cutting and narrow thin weld bead</td>
</tr>
<tr>
<td>7.</td>
<td>Slower welding speed</td>
<td>Wide thick weld metal deposit and difficult slag control</td>
</tr>
</tbody>
</table>

7.12 ARC WELDING MACHINES

The important arc welding processes discussed in the following include: shielded metal arc welding, carbon arc welding, submerged arc welding, tungsten inert gas welding and metal inert gas welding. All these processes need welding plants with different VI characteristics. The description in the following will, however, be confined only to the welding plants or machines used in shielded metal arc welding using both AC and DC.

7.12.1 Need for a Welding Machine

The regular electric power supply (hydrel power or thermoelectric) uses high voltage and low current. It cannot be used directly for welding purposes without a welding machine, which specially designed and constructed to change the high voltage low ampere current into a suitable low voltage (which is usually between 50 to 100 volts) and a heavy current supply (150 to 5
7.25.1 Oxygen

Oxygen is a clear gas without any colour, odour or taste. Oxygen for industrial use is produced by (a) liquid air process or (b) electrolytic process. In liquid air process, the air is first cleaned of dust and other carbonic gases and later cooled to liquify at -180°C. Nitrogen is separated from this by gradual warming. In electrolytic process, electric current is passed through water containing an electrolyte such as caustic soda for increasing conductivity. As the current passed, oxygen is produced in the form of bubbles on the surface of the positive pole and hydrogen on the negative pole. However, this system of making oxygen is costlier than the liquid air system.

Oxygen is filled in solid drawn steel (mild steel or alloy steel) cylinders of different capacity. The oxygen is filled in the cylinders to a pressure of 125 to 140 kg per cm². The volume of oxygen in its cylinder is proportional to its pressure, for example, if during use, the pressure of oxygen cylinder drops by 5%, it shows that 1/20th of the cylinder contents have been used. Oxygen cylinders are painted black and the valve outlets are screwed right handed. A safety nut is provided at the top of cylinder (Fig. 7.45) to allow leakage of oxygen at the time when due to increase in temperature, the gas pressure increases beyond safety load of the cylinder. Oxygen cylinders should not be stored near the combustible gas cylinders.

7.25.2 Acetylene

The acetylene gas for welding or cutting is obtained from the following sources:

(a) Acetylene cylinders filled with acetylene gas from some gas producing plant. Such acetylene is called 'dissolved acetylene' which, in fact, is the compressed acetylene filled into steel cylinders.

(b) Acetylene generators which could be fabricated locally and installed in the shop. In the generator, calcium carbide and water are brought in contact to produce acetylene:

$$CaC_2 + 2H_2O \rightarrow C_2H_2 + Ca(OH)_2$$

(c) Acetylene is also produced by the reaction of methane with oxygen.

7.24.1 Types of Gas Welding Process

Gas welding includes all those welding processes in which gas flame is used as a heat source for melting metals. It is further divided into three main types: (a) Air-acetylene welding, (b) Oxy-acetylene welding and (c) Oxy-hydrogen welding.

(a) Air-acetylene welding involves the use of mixture of acetylene gas and oxygen from atmospheric air. A lower temperature flame is obtained. The process is used for welding lead or for brazing and soldering operations.

(b) Oxy-acetylene welding is the most popular process because of higher flame temperatures (about 3200°C). A mixture of acetylene and oxygen is burnt for making flame. Both the gases are readily available in cylinders of different capacity. The combination is used for both welding and cutting of metals.

(c) Oxy-hydrogen welding involves burning of the mixture of hydrogen gas and oxygen for producing flame. The hydrogen flame, however, does not attain that high temperature as obtained by burning oxygen and acetylene. It is with this reason that oxy-hydrogen welding is used for welding metals with low melting point such as aluminium, magnesium or for brazing purposes. Since hydrogen itself is a reducing agent (anti-oxidation), its flame minimizes oxidation of metal during welding. Hydrogen has no odour and is available in cylinders. Hydrogen connections need to be checked regularly as hydrogen makes a powerful explosion with air or oxygen. It is used for under water gas cutting and welding at depth greater than 5 metres to 50 metres as hydrogen can sustain high pressures than acetylene.

Since the oxy-acetylene welding (and cutting) is the most popular method used in industry, this will be dealt in detail in the following.

7.25 OXY-ACETYLENE WELDING

In oxy-acetylene welding, the flame is obtained by burning acetylene (which is a fuel gas) and oxygen which supports the compulsion of acetylene. When mixed with oxygen and ignited, acetylene burns explosively, undergoing oxidation to carbon-dioxide and water and release of heat. The reaction is given below. The chemical name of acetylene is Ethyne (C₂H₂).

$$2C_2H_2 + 5O_2 \rightarrow 4CO_2 + 2H_2O + 620 \text{ calories}$$
The most popular and simplest way to procure acetylene is through compressed acetylene cylinders (or dissolved acetylene). The acetylene cylinders are also solid drawn steel type and filled with a porous substance soaked with acetone, which is a hydrocarbon liquid capable of dissolving large quantities of acetylene and this helps in increasing the storing capacity of acetylene. The pores of the porous spongy material (like charcoal, asbestos, pith from corn stalk or balsa wood, etc.) remain completely filled with acetone in which acetylene is dissolved under pressure. At atmospheric pressure and temperature, acetone can dissolve acetylene about 25 times of its own volume. Hence at 15 atmospheric pressure, which is the normal charging pressure of dissolved acetylene, this is increased to about 375 times. It has been observed that compressing free acetylene to a pressure more than one atmosphere is not safe. Hence, if acetylene is compressed to a pressure of 16 to 20 kg/cm² into ordinary cylinders (without acetone), it may explode even at 1.4 to 2 kg/cm². The presence of porous material soaked with acetone in the cylinder, divides acetylene into small globules as it enters the small pores of the porous material which helps in sudden decomposition of acetylene for its safe storing.

Acetylene cylinders are painted maroon and their outlet valves are screwed left handed. The cylinder is charged with acetylene to a pressure of about 16 kg/cm². An acetylene cylinder, shown in Fig. 7.46, has a number of fusible plugs at its bottom which may melt and give way to acetylene to escape out at 104°C if the cylinder is exposed to excessive heat. The spindle valve of the cylinder can be opened with a special wrench.

Acetylene generators are used for local production of acetylene at the shop itself. In these, acetylene is produced by action of water on calcium carbide. Acetylene generators are of two types: (i) low pressure generator and (ii) medium pressure generator. The low pressure generator gives acetylene at a pressure of 0.10 kg/cm² (about 0.1 bar). It is considered portable and gives acetylene at the rate of 15 litres per minute. The medium-pressure generator gives gas at a pressure of up to 0.1 to 1.5 kg/cm² and at the rate of up to 3000 litres per minute. This type of generator is stationary type and is the most commonly used one.

Acetylene generators are: (a) carbide to water type and (b) water to carbide type. The carbide to water type generator is preferred over water to carbide type as the former uses complete reaction of water and calcium carbide and is more efficient. A typical carbide to water type acetylene generator is shown in Fig. 7.47. In this, carbide is fed to the water for generating gas. The generator is partially filled with water. The calcium carbide in proper size pieces is stored in the hopper provided at the top of the generator, where calcium carbide is fed down to the water by a feed mechanism and acetylene is produced as a result of action of water on calcium carbide. No sooner is the pre-determined pressure of gas attained, the feed of calcium carbide is stopped automatically. The calcium hydrate (carbide sludge) is collected at the bottom of the generator.

![Fig. 7.46 Acetylene cylinder.](image)

![Fig. 7.47 Carbide-to-water type acetylene generator.](image)

### 7.25.3 Special Precautions for Acetylene Cylinder

The following precautions are needed for safe use of acetylene cylinders.

(i) Acetylene is highly inflammable, so no naked flame should be brought close to the cylinder.

(ii) Leaks can be detected by smelling or by applying soap bubbles on the cylinder body and should be attended immediately. The gland nut should be tightened.

(iii) In case of fire, the spindle valve on the cylinder should be shut.

(iv) The cylinders should be stored and used in upright (vertical) position to contain dust particles. After attaching the regulator, see that adjusting screw of the regulator is released and then cylinder valve should be opened.

(v) Never attempt to transfer gas from one cylinder to another.

(vi) Never strike an arc on the cylinder.

(vii) When cylinder not in use or is being transported, keep the cap screwed on it.

(viii) Acetylene should never be used at a pressure more than one kg per cm².

(ix) Before fixing regulator on the spindle valve, open the valve for an instant to clear dust particles. After attaching the regulator, see that adjusting screw of the regulator is released and then cylinder valve should be opened.

(x) Never attempt to transfer gas from one cylinder to another.

(xi) When empty cylinders are returned for refilling, make sure that the valves are closed to avoid evaporation of acetone.

(xii) It must be remembered that an acetylene cylinder absorbs heat as acetylene is released from it. Hence, the rate of flow of acetylene from cylinder is somewhat limited. Acetylene should not be drawn very fast.
7.26 OXY-ACETYLENE FLAMES

Oxy-acetylene flame can be defined as a phenomenon produced at the surface of the nozzle tip (of the welding torch) where two gases (oxygen and acetylene) meet and undergo combustion with evolution of heat and light. The chemical reaction for complete combustion is as follows:

\[ 2C_2H_2 + 5O_2 \rightarrow 4CO_2 + 2H_2O \]

(acetylene) (oxygen) (carbon dioxide) (water vapour)

The structure of the flame is shown in Fig. 7.48. There are three different cones in an oxy-acetylene flame.

(a) The inner or luminous cone is formed right at the front of torch tip. This is the zone where two gases burn with a brilliant light and the primary chemical reaction takes place in this zone as follows:

\[ C_2H_2 + O_2 \rightarrow 2CO + H_2 + \text{Heat} \]

(acetylene) (oxygen) (carbon monoxide) (hydrogen)

The temperature in the luminous inner cone may vary from 3200°C to 3500°C for different types of flame with maximum temperature occurring at the pale blue tip (vertex) of the cone. A neutral flame has a well-defined white inner cone. In oxidizing flame, the inner cone is purple in colour and is shorter than the inner cone of neutral flame.

(b) Outer cone envelops the inner cone and provides a reducing atmosphere that helps protecting molten weld metal against oxidation during welding. Oxygen from atmosphere is derived within this zone to complete secondary chemical reaction as below:

\[ 2CO + O_2 \rightarrow 2CO_2 \quad \text{(carbon dioxide)} \]

\[ 2H_2 + O_2 \rightarrow 2H_2O \quad \text{(water vapour)} \]

Any free oxygen available at the welding point is also absorbed in this cone, thus giving a reducing atmosphere. The temperature in this cone may be up to 2100°C and at the tip of the cone, it is about 1280°C.

(c) Secondary luminous cone exists only in a carburising flame (Fig. 7.49) and surrounds the luminous inner cone while extending into the outer cone. This happens because of the excess quantity of acetylene.

Among the three types of oxy-acetylene flames, the neutral and oxidizing flames have only two cones (inner cone and outer cone) but the carburising flame has all the three cones as discussed above.

7.26.1 Types of Oxy-acetylene Flames

For complete combustion of acetylene, the following reaction takes place:

\[ 2C_3H_2 + 5O_2 \rightarrow 4CO_2 + 2H_2O + 620 \text{ calories of heat} \]

It shows that two volumes of acetylene combine with five volumes of oxygen and produce four volumes of carbon dioxide, two volumes of water vapours and heat. In other words, for complete combustion of one volume of acetylene, two and a half volumes of oxygen are required. The primary reaction that takes place in the luminous cone, consumes one volume of oxygen supplied through the torch (from cylinder) but to complete the secondary reaction (in the outer cone), the balance oxygen supply of one and a half volume is met with oxygen derived from the atmosphere. It is with this reason that more oxygen supply in the torch is needed while working in confined places.

The following three types of oxy-acetylene flames are obtained by mixing acetylene and oxygen in various proportions.

Neutral flame: The neutral flame is the result of a nearly perfect equal proportion of oxygen and acetylene. The flame has two cones—the inner cone and the outer cone as shown in Fig. 7.49(a). Different temperatures attained are shown. Among all the three types of flame, the neutral flame is said to be the correct flame as it neither gives oxidizing effects nor too much of carburising (or reducing) effect.

Oxygen 1.04 to 1.14
Acetylene

(a) Neutral flame

Oxygen 1.13 to 1.17
Acetylene

(b) Oxidizing flame

Oxygen 0.85 to 0.95
Acetylene

(c) Carburising flame

Fig. 7.49 The three types of oxy-acetylene flames: (a) Neutral flame, (b) Oxidizing flame and (c) Carburising flame.
Neutral flame is used for most welding operations and is highly suited for welding mild steels and cast irons, stainless steel, copper and aluminum. Even during flame cutting of steels, the pre-heating flame may be a neutral flame.

**Oxidizing flame:** It is obtained when oxygen is burnt in excess of acetylene [Fig. 7.49(b)]. The inner cone is shorter and pointed with a sharp hissing sound. It gives maximum temperature among all the three oxy-acetylene flames. Since oxygen is a rapid supporter of combustion, when oxidizing flame is fed to a red hot steel, the iron present in steel burns up rapidly. The oxidizing flame is, therefore, not used for general welding purposes (at least for welding ferrous metals, steels and cast irons).

The oxidizing flame is used where maximum temperature is desired or in situations where oxidizing effect is not harmful, rather proves beneficial, for example, a slightly oxidizing flame is used in welding of non-ferrous metals particularly copper base metals as brasses and bronzes and zinc base metals, where it is desirable to have oxidizing flame giving oxide film to check vaporization of zinc and also to reduce further oxidation after oxide film is formed. This flame is also used for pre-heating purposes during flame cutting of steels.

**Carburising flame:** It is obtained by burning acetylene in excess of oxygen. It has three cones [Fig. 7.49(c)], wherein the secondary luminous cone is extra in comparison to the two other types of flames. The secondary luminous cone gives reducing effect in the welding area.

A carburising flame is mostly used for welding aluminum, monel metal, stainless steel, die cast metals and several other non-ferrous metals, besides the high carbon steels. The carburising flame prevents excessive formation of oxides on non-ferrous metals which interfere with proper fusion of metal, since oxides of non-ferrous metals have very high melting points because of which they are difficult to melt by oxy-acetylene flames. Carburising flame gives a slight case-hardening effect on certain steels. It is also used for hard-facing of steels with stellite rods.

### 7.27 BACKFIRE OR POPPING

Backfire or pop is a small explosion of the torch flame followed by either extinguishing of flame or continued burning of gases. It usually occurs due to pre-ignition of gases. The causes of backfire are:

(a) When gases come out too slowly from the torch under low pressure due to small tip used, pre-ignition or burning of gases may take place within torch, showing that the speed of flow of gases is less than the speed of burning gases.

(b) The tip may become overheated. It may be clogged also.

(c) Carbon or hot metal particles that get deposited inside the torch tip, work like ignitors when they become overheated. This results in pre-ignition of gases within the torch. Tip should be cleaned regularly.

(d) Popping may also result when accidentally the inner cone of the flame is submerged in the weld puddle.

### 7.28 FLASHBACK

A flashback occurs when the flame disappears from the tip of the torch and travels back in the hose. The flame makes a hissing sound at that time. The remedy is that both the gases should be shut off immediately to avoid combustion within the torch. The torch should be allowed to cool before re-lighting. The flashback may be caused by a clogged barrel or mixer passage and excessive pressure of oxygen. Sometimes, accumulation of organic oxides in oxygen hose may also trigger the flashback.

### 7.29 OXY-ACETYLENE WELDING OUTFIT

The oxy-acetylene welding outfit refers to the equipment and gadgets required to carry out gas welding operations. It comprises the following (Fig. 7.50).

(i) **Gas supply equipment** comprises oxygen cylinder and acetylene cylinder or acetylene generator. Cylinders are accommodated on a trolley for easy movement from one location to another.
(ii) **Regulators** complete with high and low pressure gauges. Two sets of regulators with pressure gauges are required, one for oxygen and another for acetylene.

(iii) **Hoses**, two numbers, one for oxygen and one for acetylene. The hose for oxygen supply (from pressure regulator to welding torch) is coloured blue and has right handed thread connections. The acetylene hose is coloured red and has left handed thread connections, with chambers or grooves on the nuts. The welding hose has a seamless lining made from rubber compounds and reinforced or wrapped with cotton piles. The hose is resistant to gases used in welding and can withstand high pressures. It has metal clamps or clips to attach welding hose to a nipple. The clamp squeezes the hose around the nipple to prevent it from working loose. A nut on the other end of the nipple is connected to the regulator or torch. Hose couplers are used to join two pieces of welding hoses.

(iv) **Welding torch (or blow pipe)**: The two gases, oxygen and acetylene, having been reduced in pressure by the gas regulators are fed through their hoses to the welding torch or blow pipe. The torch mixes and controls the flow of gases to the welding nozzle or tip of the torch where the gas mixture burns and produces flame (Fig. 7.51).

(v) **Welding nozzles or tips** are fitted on the front end of the welding torch. These may be: (a) interchangeable type tip screwed on the head of the blow pipe or (b) goose neck extension type fitted directly onto the mixer portion of the blow pipe.

(vi) **Pressure regulators** reduce the pressure from the cylinder and maintain it at correct value regardless of the pressure variations at the source. These are also helpful in adjusting the pressure of gas to torch.

(vii) **Goggles** protect eyes from harmful heat and radiation (of infrared and ultraviolet rays) with the help of coloured glasses fitted in them.

(viii) **Spark lighter** provides instant and convenient means for lighting the welding torch. It consists of a pointed stone and a rough surface to produce spark when rubbed together.

(ix) **Apron and gloves** are for the protection of clothes and hands of the welder.

### 7.29.1 Welding Torch (or Blow Pipe)

As mentioned before, the welding torch is a tool for mixing two gases in the desired proportions and burning the mixture at the end of torch tip. It has a handle to hold it and two inlet connections for two gases at one end such that each inlet has a valve to control the volume of oxygen and acetylene. The two gases from the two paths mix up in the mixer in the torch, and the gas mixture that comes out of the tip of torch, is ignited to produce the flame.

The welding torches are of two types:

(a) **High pressure (or Equal pressure type)**

(b) **Low pressure (or Injector type)**

1. **High pressure (or equal pressure type) torch**: This is the most commonly used torch (Fig. 7.52) and is used when the delivery of both gases (oxygen and acetylene) is from the cylinders. The construction of the torch is such that each gas is required to be supplied under enough pressure to the mixing chamber. The torch carries two needle valves, each for controlling the supply of individual gases. The torch may be made from brass, aluminium, stainless steel and the torch tips are made from copper. The tip size is given by the manufacturer for various job thicknesses. The torch hand carries packing of asbestos or impregnated leather. Depending upon the thickness of the work piece to be welded, the torch tip of proper size is selected and the gas pressure is accordingly adjusted with the help of pressure regulator. The gases in the torch are delivered at a pressure generally above 0.7 kg/cm²; the acetylene pressure is about 0.7 to 1 kg/cm² and oxygen pressure varying up to 1.7 kg/cm², depending upon the tip size.

2. **Low pressure (or injector type)**: This torch is shown in Fig. 7.53. It is used when acetylene is drawn from the generator. It has an injector nozzle inside its body through which high-pressure oxygen flows. The low-pressure acetylene generated in generator is not sufficient to force it through the small passage in the torch. The high-pressure oxygen draws the low-pressure acetylene with it in the mixing chamber and gives it a required velocity to keep up a steady flame. The arrangement works as a means to make acetylene flow to the mixing chamber and also helps in preventing backfiring. The acetylene pressure is less than 0.7 kg/cm² and that of oxygen is from 0.7 to 2.7 kg/cm², depending upon the tip size. The low pressure blow pipe is costlier than the high pressure blow pipe.

In both the torches, oxygen tends to draw in acetylene and mix with it due to high pressure. The gas mixer in the torch should be able to perform the following functions:

(i) **Mixing of gases thoroughly before they leave out of the nozzle**.

(ii) **Arrest flashback** that might occur through improper operation.

(iii) **Arrest any flame** from traveling further back (towards hose pipe) than the mixer.

(iv) **Permit a range of tip sizes** to be operated from one size of the mixer.
REFERENCES:

3. All about machine tools (1965), Georg Westermann Verlag, Braunschweig, West Germany.