9

WELDING AND RELATED PROCESSES

9.1 INTRODUCTION

Welding is a process of joining *similar* metals by application of heat with or without application of pressure and addition of filler material. The result is a continuity of homogeneous material, of the composition and characteristics of two parts which are being joined together. The application of welding are so varied and extensive that it would be no exaggeration to say that there is no metal industry and no branch of engineering that does not make use of welding in one form or another. In fact, the future of any new metal may depend on how far it would lend itself to fabrication by welding.

9.2 WELDABILITY

The term "weldability" has been defined as the capacity of being welded into inseparable joints having specified properties such as definite weld strength, proper structure, etc. This means, of course, that if a particular metal is to have good weldability, it must be welded readily so as to perform satisfactorily in the fabricated structure. However, the real criterion in deciding on the weldability of a metal is the *weld quality and the ease with which it can be obtained*.

Weldability depends on one or more of five major factors : (1) melting point, (2) thermal conductivity, (3) thermal expansion, (4) surface condition, and (5) change in microstructure. If these metallurgical, chemical, physical and thermal characteristics of a metal are considered undesirable with respect to weldability , they may be corrected by proper shielding atmosphere, proper fluxing material, proper filler metal, proper welding procedure, and in some cases by proper heat treatment of the metal before and after deposition.

9.3 TYPES OF WELDING

Modern methods of welding may be classified under two broad headings : (1) plastic welding , and (2) fusion welding. They are also called pressure welding, and nonpressure welding. respectively.

In the *plastic welding* or *pressure welding*, the pieces of metal to be joined are heated to a plastic state and then forced together by external pressure. This procedure is used in forge welding, resistance welding, "thermit" welding, and gas welding, in which pressure is required.

In the *fusion welding* or *nonpressure welding*, the material at the joint is heated to a molten state and allowed to solidify. This includes gas welding, arc welding, "thermit" welding, etc.

It is seen, therefore, that except in *cold-welding* heat is used to bring about a plastic or molten state at the surface of the metal to be joined. In cold-welding, the joints are produced without the application of heat, but by applying pressure which results in intersurface molecular fusion of the parts to be joined. This process is mainly used for welding nonferrous sheet metal, particularly aluminium and its alloys. A classification of the principal processes is presented in Table 9.1.

TABLE 9.1 WELDING PROCESSES.

1. Gas welding		
1. Oxy-acetylene	2. Air-acetylene	3. Oxy-hydrogen
2. Arc welding		
1. Carbon arc	4. Metal arc	7. Gas metal arc (MIG)
2. Plasma arc	5. Electro-slag	8. Gas tungsten arc (TIG)
3. Submerged arc	6. Flux-cored arc	9. Atomic-hydrogen arc
3. Resistance welding		
1. Butt	3. Spot	5. Seam
2. Projection	4. Percussion	
4. Thermit welding		
5. Solid state welding		
1. Friction	3. Ultrasonic	4. Diffusion
2. Explosive		
6. Newer welding		
1. Electron-beam	2. Laser	
7. Related Processes		
1. Arc welding	3. Hard pressing	5. Oxy-acetylene cutting
2. Brazing	4. Soldering	

ISO 4063 Classification of welding processes is listed at the end of this Chapter in Table 9.8.

9.4 METALLURGY OF WELD

A knowledge of what happens in metal when it is welded is necessary for an understanding of the welding operation, and is explained hereunder.

FUSION WELDING

In the weld metal, whether melted from the edges to be joined (autogenous welding), or supplied separately, solidifies from the liquid state and usually below the recrystallization temperature without any applied deformation. *Fusion welds* are, therefore, essentially *castings*. Since the surrounding parts are good conductors of heat the fusion weld may be called a chilled casting, and its structure will, therefore, usually be *columnar* (dendritic). This is illustrated in Fig. 9.1 The actual crystalline structure presents, however, depends primarily on the number of "runs" made to deposit the weld metal.

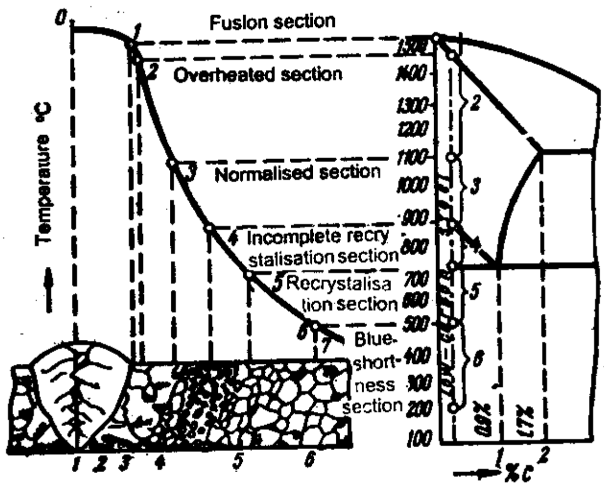


Figure 9.1 Structural changes in welding

In a single-run weld, long columnar crystals will grow outwards from the sides of the weld. If the temperature is high enough these columnar crystals will meet at the centre of the weld deposit forming a plane of weakness. This will eventually cause intercrystalline cracking within the weld. If, on the other hand, the welding temperature is correct, equiaxed grains will form at the centre resulting in an appreciably stronger joint.

A multi-run welding exhibits a quite different structure. The first run, as before, shows the structure for a single-run weld. In ordinary steels, the second run normalises the first layer, causing a considerable degree of grain refinement. Each successive run thus normalises the preceding one so that the final deposits exhibit the coarse cast structure typical of a single-run weld. However, in a multi-run weld the possibility of defects such as slag and gas inclusions will increase.

Slag inclusions are frequently trapped in fusion welds due to bead contour and the difficulty of melting the slag in subsequent runs. In metallic arc welds, in mild steel, microscopic inclusions are also present. Controlled amounts of nitrogen and manganese together with a dispersion of fine nonmetallic inclusions and especially a fine grain size with high dislocation density provide strengths of 43 to 57 kgf/mm^2 (430 to 570 N/mm^2) with adequate ductility to mild steel arc welds.

The *contour of welds* by forming 'notches' can affect both fatigue and low temperature properties of a structure.

Gas solubility in liquid and solid weld metals, and gas reaction, are important in controlling the porosity of a weld. Metallic arc welds made with a bare wire are liable to *contamination by gases* from the atmosphere. The nitrogen of the atmosphere frequently appears as needles on certain planes in the crystals in the long run. This causes low impact strength especially after water quench.

The *stresses* set up in the weld by shrinkage are often of considerable importance as they are found to be responsible for *weld metal cracking*. These stresses may be relieved by annealing the entire object after welding is finished.

In brief, the action of the atmosphere on the melted metal, its fluidity and surface tension, the solidification process including segregation and shrinkage, all play their anticipated important roles as in castings.

PRESSURE WELDING

In pressure welding process, the metal in the joint is heated to the plastic condition, or above, and compressed while hot. The effect is a hot-working treatment, resulting in some grain refinement. All the principles of finishing temperature, internal stresses, recrystallization, grain growth, and physical properties, apply in these cases also. The union is essentially a *forging*.

HEAT-AFFECTED ZONE

The effect of the welding heat upon the metal immediately adjacent to the weld is likewise important and dependent upon the chemical composition and thermal conductivity of the parent metal, the dimension of the article, and the length of welding time.

In general, nonferrous metals and alloys are softened in the heat-affected zone due to annealing of the metal in this area. Grain growth may occur near the weld, or recrystallization if the parts were cold-worked prior to welding. This may weaken the metal to some extent, but is not often critical.

In mild steel, the heat-affected zone ranges from overheated area near the weld metal to an under-annealed structure further away from the weld itself. Structural changes in the heat-affected zone when welding mild steel is shown in Fig. 9.1. In medium and high carbon steels, complex structures are formed within the heat-affected zone due to the rapid rate of cooling of the metals. This results in an increase in hardness across the weld. In alloy steels, austenite may be produced and only partly decomposed during cooling. Such steels are, therefore, cooled at a controlled rate to prevent the formation of martensite.

Preheating is often employed when welding cast iron, high carbon or alloy steels, since preheating slows down the cooling rate of that area of parent metal close to the weld itself and thereby prevents the formation of martensite which accounts for hardness across the weld. The chance of cracking in the heat-affected zone due to unequal contraction during cooling is also minimised by preheating.

GAS WELDING

Gas welding is done by burning a combustible gas with air or oxygen in a concentrated flame of high temperature. As with other welding methods, the purpose of the flame is to heat and melt the parent metal and filler rod of a joint. It can weld most common materials. Equipment is inexpensive, versatile, and serves adequately in many *job and general repair shops*.

9.5 OXY-ACETYLENE WELDING

Oxy-acetylene gas welding is accomplished by melting the edges or surface to be joined by gas flame and allowing the molten metal to flow together, thus forming a solid continuous joint upon cooling. This process is particularly suitable for joining metal sheets and plates having thickness of 2 to 50 mm. With material thicker than 15 mm, additional metal called *filler metal* is added to the weld in the form of *welding rod* (Fig. 9.2). The composition of the filler rod is usually the same or nearly the same as that of the part being welded. To remove the impurities and oxides present on the surfaces of metal to be joined and to obtain a satisfactory bond a *flux* is always employed during the welding except mild steel which has more manganese and silicon that act as deoxidizing agents.

Various gas combinations can be used for producing a hot flame for welding metals. Common mixture of gases is oxygen and acetylene, oxygen and hydrogen, oxygen and other fuel gas, and air and acetylene. The oxygen-acetylene mixture is used to a much greater extent than the other and has a prominent place in the welding industry. The Table 9.2 shows the field of application of various gases.

Figure 9.2 Oxy–acetylene welding

TABLE 9.2 FLAME TEMPERATURE OF DIFFERENT GASES

Fuel gas	*Flame temperature in °C*	*Used for steel sheets having a thickness upto mm*
City gas	1700	3
Hydrogen	1900	7
Methane	2000	7
Water gas	2300	8
Acetylene	3200	50

GAS FLAME

The correct adjustment of the flame is important for reliable works. When oxygen and acetylene are supplied to torch in nearly equal volumes, a ***neutral flame*** is produced.. The heat is generated in accordance with a pair of chemical reactions. The primary reaction occurs at the inner cone, where the temperature reaches in between 3050 to 3450°C. the reaction in the inner cone is:

$$C_2H_2 + O_2 \rightarrow 2CO + H_2 + heat$$

The secondary combustion process is in the outer envelope in which the flame attains a temperature around 2100°C near the inner cone and around 1250°C at the end point of the flame. The secondary combustion equation is:

$$4CO + 2H_2 + 3O_2 \rightarrow 4CO_2 + 2H_2O + heat$$

The temperature developed in the flame as a result of these reactions can reach 3200°C to 3300°C. This neutral flame is desired for most welding operations, but in certain cases a slightly *oxidising flame*, in which there is an excess of oxygen or slightly *carburizing flame*, in which there is an excess of acetylene is needed. The condition of the flame is readily determined by its appearance (Fig. 9.3).

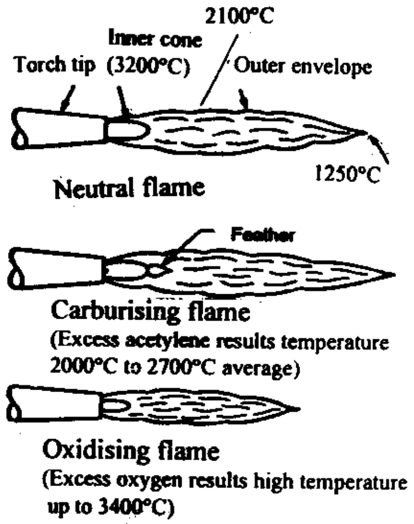


Figure 9.3 Oxy–acetylene gas flame

A *neutral flame* has two definite zones : (1) a sharp brilliant cone extending a short distance from the tip of the torch, and (2) an outer cone or envelope only faintly luminous and of a bluish colour. The first one develops heat and the second protects the molten metal from oxidation, because the oxygen in the surrounding atmosphere is consumed by the gases from the flame. The neutral flame is widely used for welding steel, stainless steel, cast iron, copper, aluminium etc.

A *carburizing flame* is one in which there is an excess of acetylene. This flame has three zones : (1) The sharply defined inner cone, (2) an intermediate cone of whitish colour, and (3) the bluish outer cone. The length of the intermediate cone is an indication of the proportion of excess acetylene in the flame When welding steel, this will tend to give the steel in the weld a higher carbon content than the parent metal, resulting in a hard and brittle weld.

An *oxidizing flame* is one in which there is an excess of oxygen. This flame has two zones : (1) the small inner cone which has purplish tinge and (2) the outer cone or envelope. In the case of oxidizing flame the inner cone is not sharply defined as that of neutral or carburizing flame. This flame is necessary for welding brass. In steel, this will result in a large grain size, increased brittleness with lower strength and elongation. Table 9.3 shows the parameters for gas welding of ferrous metals.

GAS WELDING TECHNIQUE

According to the position of welding all welds are classified into : down hand (or flat) welds deposited in any direction on a horizontal surface so that the flame is above the face of the weld (Fig. 9.4a) ; vertical welds deposited on a vertical surface in a vertical direction (upwards or downwards) as shown in Fig. 9.4b ; inclined welds deposited up or down an inclined surface (Fig. 9.4c) ; horizontal welds deposited on a vertical surface in a horizontal direction (from left to right or from right to left) as shown in Fig. 9.4d, and overhead welds deposited on a horizontal surface in any direction so that the face of the weld is above the flame (Fig. 9.4e).

TABLE 9.3 GAS WELDING PARAMETERS OF FERROUS METALS

Metal	*Flame adjustment*	*Flux needed*	*Welding rod type*
Cast steel	Neutral	×	Steel
Steel plate	Neutral	×	Steel
Steel sheet	Neutral	×	Steel
High carbon steel	Reducing	×	Steel
Wrought iron	Slightly oxidizing	×	Steel
Grey cast iron	Slightly oxidizing	✓	Cast iron
Cast iron pipe	Neutral	✓	Cast iron
Chromium steel	Neutral	✓	Base metal composition

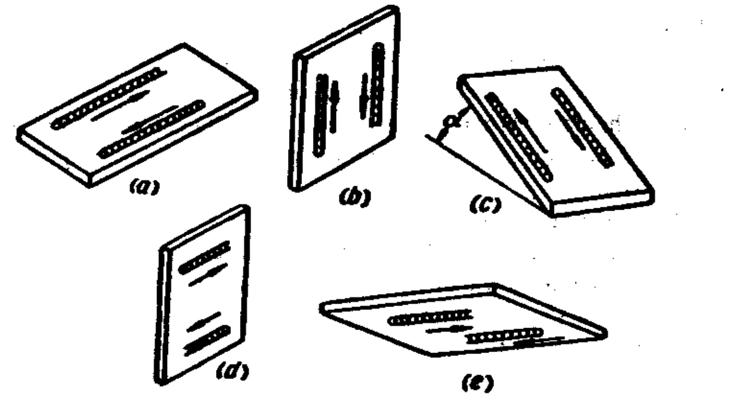
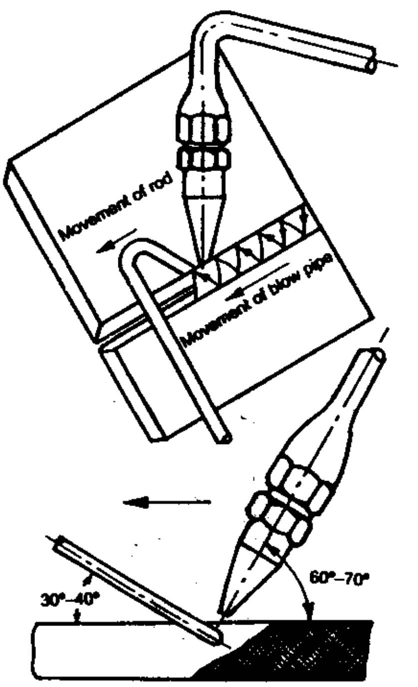


Figure 9.4 Positions of welding

In a gas welding, the direction of travel and the tilt of the torch and the welding rod have appreciable effects on the speed and quality of welding. From the foregoing, three typical procedures that may be employed are : (1) leftward or forward, (2) rightward or backward, and (3) vertical.

In the *leftward* or *forward welding*, illustrated in Fig. 9.5, the weld is made working from right to left. The blowpipe is held in the right hand and the welding rod in the left hand. The blowpipe should be given a small sideways movement, and the rod should be moved steadily without sideways movement. The head of the blowpipe is held at an angle of between 60° and 70° to the plane of the weld, and the welding rod at 30° to 40°. The leftward method is found most advantageous on plates up to about 3 mm and also for thicker plates but, in this case, blowpipe moves from, side to side to fuse the sides of the vee.



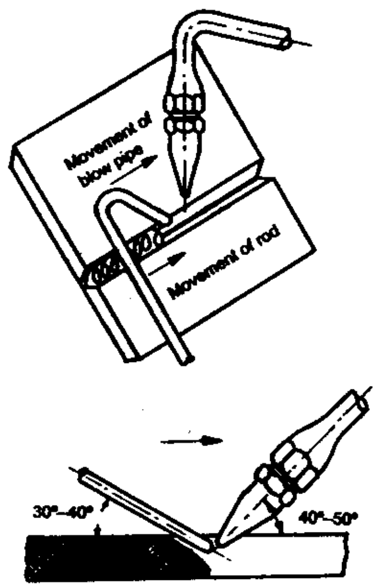


Figure 9.5 Leftward welding **Figure 9.6 Rightward welding**

Rightward or *backward welding* is carried out from left to right, the rod following the blowpipe (Fig. 9.6). It has no lateral movement. The blowpipe should make an angle of between 40° to 50° with the plane of the plate, and welding rod should be at an angle of between 30° to 40°. The angle of blowpipe is 10° to 20° greater than in leftward welding. The edges in rightward welding should be bevelled by approximately 10° to 15° less than for leftward technique. Under the above conditions, the welding speed in 20 to 25 per cent higher and the fuel consumption 15 to 25 per cent lower with rightward welding.

Rightward welding provides better shielding against atmospheric oxidation of the weld metal and slows down its cooling, for which reasons the weld metal is denser, stronger and tougher. This method is very suitable for steel work over 12 mm thick, although it can be used for lower thickness of sheets.

Vertical welding (Fig. 9.7) by one or two operators, is often advantageous for plate thickness of 6 mm and above. It does not require plate edge preparation even for thickness up to about 15 mm, and the amount of filler rod material is, therefore, smaller than with horizontal welding. Here the operator starts at the bottom of the welded joint, and gives an oscillating movement to the blowpipe which points slightly upwards. It is observed that in the case of the single-operator technique, the angle between the blowpipe and plate increases as the plate thickness increases. In the case of two-operator technique, the variation in the angle of the blowpipe to the plate is very less.

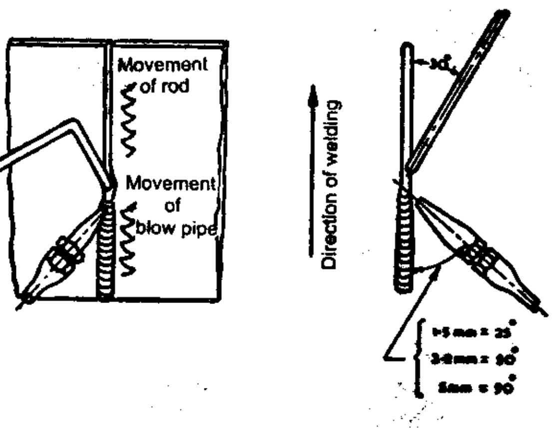


Figure 9.7 Vertical welding

A special technique known as *lindewelding* is chiefly employed for the butt welding of steel pipes. It involves the use of an oxy–acetylene flame adjusted to have an excess of acetylene. The edges of the pipe should be bevelled to an included angle of 70° and butted together with a gap of approximately 2.5 mm. They are then tacked at regular intervals. During the actual welding operation the pipes are rotated so that welding is always done in the horizontal position. This method is based on "rightward welding", that is, the weld is commenced at the left and the direction of travel is towards the right.

WELDING EQUIPMENT

The most commonly used equipment for oxy–acetylene welding consists of the following.

Welding torch. This is a tool for mixing oxygen and acetylene in correct proportion and burning the mixture at the end of a tip. These are available commercially in two general types : (1) equal pressure, and (2) injector type. The medium - or equal-pressure welding torch is the more common of the two types of oxy–acetylene torches. The mixing chamber in the equal pressure torch allows both of the gases to flow together in equal amounts.

Welding tip. It is that portion of the welding apparatus through which the gases pass just prior to their ignition and burning. There is a great variety of interchangeable welding tips differing in size, shape and construction. The tip sizes are governed by the diameter of the opening. The diameter of the tip opening used for welding depends upon the type of metal to be welded, such as whether it is stainless steel, iron, or brass, and the thickness of the metal to be welded.

Pressure regulator. The functions of a pressure regulator are: (1) to reduce the cylinder pressure to the required working pressure and also to produce a steady flow of gas (gas volumetric rate) regardless of the pressure variations at the source.

Regulators may be classified into four main types :

1. The single-stage nozzle type.
2. The single-stage stem, type.
3. The two-stage type.
4. The high capacity high pressure line type.

Regulators for different gases are basically the same, except that the pressure that they control differ vastly.

Regulator pressure for gas welding. The pressure required for gas welding depends on the thickness of the plates to be welded. For plates of thickness of about 1 to 25 mm, the regulator pressure in oxygen and acetylene varies from 0.15 to 0.70 kgf/ cm^2 (15 to 70 kN/m^2) ; and for plate thickness over 25 mm, the pressure of each gas is about 0.98 kgf/cm^2 (98 kN/m^2). This is for *high-pressure welding*, but in the case of *low-pressure welding*, the oxygen pressure exceeds 0.98 kgf/cm^2 (98 kN/m^2) and goes up to about 2 kgf/cm^2 (200 kN/m^2) and acetylene pressure is 0.15

kgf/cm^2 (15 kN/m^2).

Hose and hose fittings. The hose for welding torches should be strong, durable, nonporous, and light. The most common method of piping both oxygen and acetylene gas is the reinforced rubber hose, which comes in black, green and red. *Green* is the standard colour for *oxygen* hose, *red* for acetylene, and *black* hose for *other* industrially availabale welding gases. Special hose fittings, or connections, are provided for attachment to the torch and pressure regulators.

Goggles, gloves and spark-lighter. *Goggles* fitted with coloured lenses are provided to protect the eyes from harmful heat and ultraviolet and infrared rays.

Gloves are used to protect the hands from any injury.

Spark-lighter provides a convenient and instant means for lighting the welding torch.

In addition to the above requirements, *welding rods* and *fluxes* are also employed.

Gas cylinders. *Oxygen gas* in cylinders are usually charged with about 40 litres of oxygen at a pressure of about 154 kgf/cm^2 (15400 kN/m^2) at 21°C. Outside temperature changes will, of course, change the pressure within the cylinder since the volume remains constant. A full cylinder has the weight of about 80 kg. To provide against dangerously excessive pressure, such as could occur if the cylinders were exposed to fire, every valve has a safety device to release the oxygen before there is any danger of rupturing the cylinders. Fragile discs and fusible plugs are usually provided in the cylinders valves in case it is subjected to danger.

Acetylene gas can be manufactured either by the water-to-carbide method (high pressure) or the carbide-to-water method. There are two types of carbide-to-water generators : low pressure and medium pressure. These generators operate on a ratio of 4.5 litres of water to 0.45 kg of carbide. The low pressure generator produces less than 0.07 kgf/cm^2 (7 kN/m^2), and the medium pressure acetylene generator produces from 0.07 to about 1 kgf/cm^2 (7 to 100 kN/m^2). In the low-pressure system, the acetylene is generated at the site in a low-pressure generator by the action of water on calcium carbide. This is supplied to the blow-pipe at low pressure from a gas-holder incorporated in the generator. When this method is used the acetylene has to be cleaned by passing through a purifier. To prevent the possibility of an explosion by oxygen or air blowing back or entering the generating plant, a back pressure valve must be introduced between the blow-pipe and the gas-holder.

High pressure acetylene cylinders are charged to a pressure of about 1 kgf/cm^2 (100 kN/m^2) . It is not allowed to bring acetylene to a pressure over 2 kgf/cm^2 (200 kN/m^2), other-wise it decomposes and explodes. The cylinder is therefore packed with 80 per cent porous material such as asbestos, balsawood, charcoal, infusorial earth, silk fibre or kapok. The packing is saturated thoroughly with acetone which is capable of absorbing acetylene to the extent 35 times its volume per atmosphere of pressure. This enables about 420 volumes of acetylene to be compressed at about 17 kgf/cm^2 (1700 kN/m^2). Under these conditions, the gas is present in the form in which it is to be used. The gas is stored under high pressure to save space, but is used in the blow-pipe at much lower pressure. Reducing valves are provided for this purpose, and are connected to the main outlet valves of the cylinder. Safety fuse plugs are provided to relieve the pressure upon exposure to fire. Figure 9.8 shows a typical oxy-acetylene welding set.

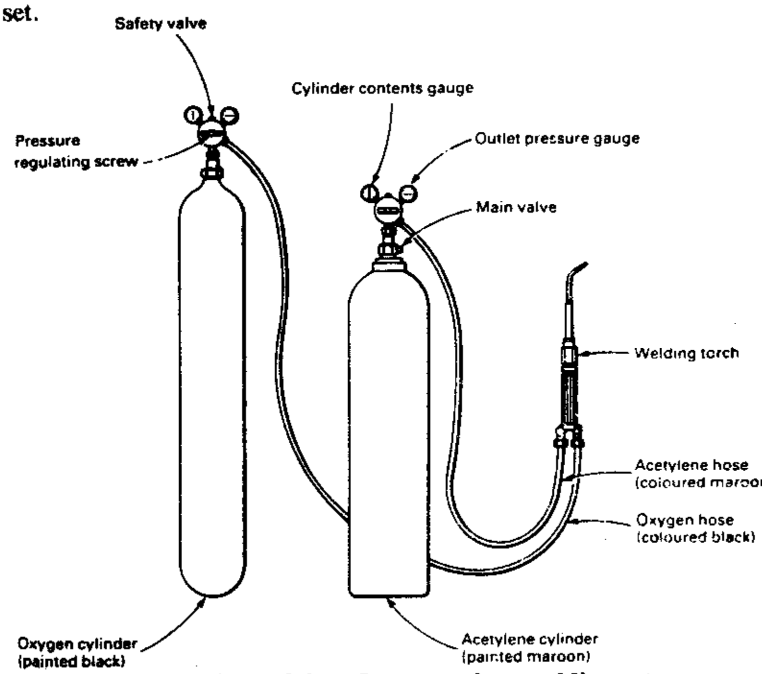


Figure 9.8 Oxy–acetylene welding set

9.6 AIR-ACETYLENE WELDING

This process uses a torch similar to a Bunsen burner and operates on the Bunsen burner principle. The air is drawn into the torch as required and mixed with the fuel flame. The gas is then ejected and ignited, producing an air-fuel flame. The common fuels used in the air-fuel welding are acetylene, natural gas, propane and butane. This type of welding has limited use since the temperature is lower than that attained by other gas processes. The air-fuel welding processes are used successfully in lead welding and many low-melting-temperature metals and alloys such as in brazing and soldering processes.

9.7 OXY–HYDROGEN WELDING

The oxygen-hydrogen process was once used extensively to weld low-temperature metals such as aluminium, lead, and magnesium ; but it is not as popular today because more versatile and faster welding process such as TIG (tungsten inert gas) and MIG (metal inert gas) have replaced the oxygen-hydrogen flame. The process is similar to oxygen -acetylene system, with the only difference being a *special regulator* used in metering the hydrogen gas.

TABLE 9.4 EXAMPLES OF GAS CONSUMPTION IN WELDING

Welding gas	*Gas consumption litres/h*	*Oxygen consumption litres/h*
Sheet thickness 0.5 mm		
Acetylene	50	50
Hydrogen	140	35
Illuminating gas	200	80
Sheet thickness 3.5 mm		
Acetylene	300	325
Hydrogen	1350	300
Illuminating gas	1200	500
Sheet thickness 10 mm		
Acetylene	1100	1200
Hydrogen	–	–
Illuminating gas	–	–

ARC WELDING

Arc welding is the most extensively employed method of joining metal parts. Here the source of heat is an electric arc.

The arc column is generated between an anode, which is the positive pole of dc (direct current) power supply, and the cathode, the negative pole.

When these two conductors of an electric circuit are brought together and separated for a small distance (2 to 4 mm) such that the current continues to flow through a path of ionized particles (gaseous medium), called *plasma*, an electric arc is formed. This ionized gas column acts as a high-resistance conductor that enables more ions to flow from the anode to the cathode. Heat is generated as the ions strike the cathode. This ion theory does not, of course, completely explain the arc column., Perhaps the electron theory of the arc, which is beyond the scope of this book, explains what happens more fully. However, electrical energy is converted to heat energy. Approximately 1 kWh of electricity will create 250 calories (1000 J), the temperature at the centre of the arc being 6,000 to 7,000°C. The temperature of an electric arc, of course, depends upon the type of electrodes between which it is struck.

The heat of the arc raises the temperature of the parent metal which is melted forming a pool of molten metal. The electrode metal (in metal arc welding) or welding rod (in carbon-arc welding) is also melted and is transferred into the metal in the form of globules of molten metal. The deposited metal serves to fill and bond the joint or to fuse and build up the parent metal surface. Two-thirds of the heat is developed near the positive pole while the remaining one-third is developed near the negative pole. As a result, an electrode that is connected to the positive pole will burn away approximately 50 per cent faster than when it is connected to the negative pole. This is helpful in obtaining the desired penetration of the base metal.

The blast of the arc forces the molten metal out of the pool, thus forming a smal' depression in the parent metal, around which molten metal is piled up. This is known as the *arc crater* (Fig. 9.9). The distance through the centre of the arc from the tip of the electrode to the bottom of the arc crater is termed *arc length*. Arc length is a vital variable in a welding process and should be 3 to 4 mm. An important reason for this is that the globules of molten electrode metal in the process of deposition should have the smallest possible chance of coming in contact with the ambient air and should absorb as little oxygen from it as possible, because oxygen has an adverse effect on the mechanical properties of the weld metal. It is obvious that with a shorter arc the time of

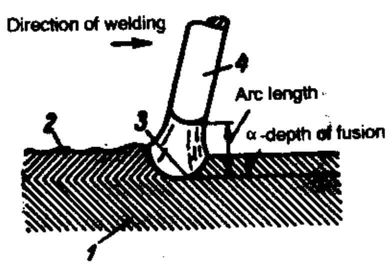


Figure 9.9 A welding arc
1. parent metal, 2. deposited metal, 3. crater, 4. electrode

contact will be shorter than with a longer arc. The arc is extinguished by widening the arc sufficiently.

9.7 METAL TRANSFER IN ARC WELDING

Metal is transferred in arc-welding in three ways. They are ; (1) by dip transfer, (2) by free drop (large drop) transfer, and (3) by spray (small drop) transfer.

In dip transfer a globul of molten metal is formed at the end of the electrode during arcing in the first stage. Subsequently it enlarges, elongates, touches the molten pool and separates from the electrode. The process does not free the globules immediately from the electrode after its formation and as such a temporary short circuit occurs. The process repeats several times to complete welding.

In free drop transfer, a drop of molten metal which is slightly smaller in diameter than the air gap flies off from the electrode end after temporarily (but partial) short circuiting the electrode with the molten pool of metal on the job.

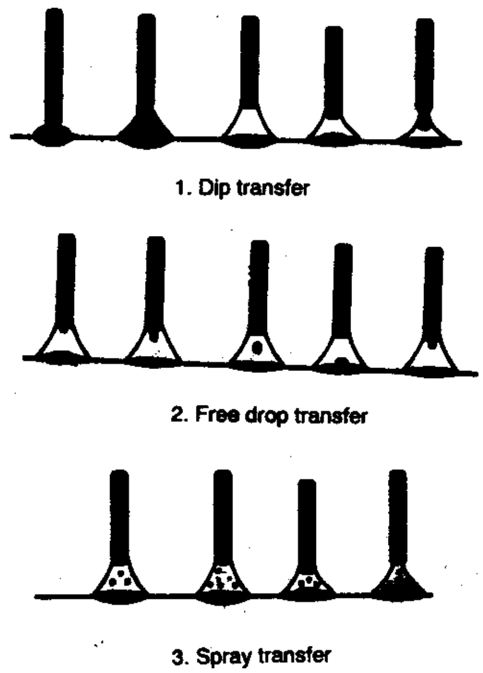


Figure 9.10 Metal transfer in arc welding

Spray or small drop transfer is the best among the three. In this method the transfer takes place in the form of tiny droplets (much smaller in diameter as compared to arc length) which make free flight from the electrode to the molten pool. The transfer rate is steady and the final job will have better mechanical advantages.

The three transfer methods are shown in Fig. 9.10.

9.8 ARC WELDING EQUIPMENT

The most commonly used equipment for arc welding consists of the following :

1. ac or dc machine.
2. Electrode.
3. Electrode holder.
4. Cables, cable connectors.
5. Cable lug.
6. Chipping hammer.
7. Earthing clamps.
8. Wire brush.
9. Helmet.
10. Safety goggles.
11. Hand gloves.
12. Aprons, sleeves etc.

ARC WELDING MACHINE

Both direct current and alternating current are used for electric arc welding, each having its particular applications ; in some cases either is suitable. dc welding supply is usually obtained from generators driven by electric motor or if no electricity is available by internal combustion engines. For ac welding supply, transformers are predominantly used for almost all arc welding where mains electricity supply is available. They have to step down the usual supply voltage (200-400 volts) to the normal open circuit welding voltage (50-90 volts). A 100 to 200 A machine is small but portable and satisfactory for light manual welding. A 300 or 400 A size is suitable for manual welding of average work. Automatic welding requires capacities between 800 and 3000 A either in a single unit or a number of small units in parallel. Some machines have an arc booster that provides a momentary surge of current to give an arc a good start when it is struck. For ac machine usually 60 Hz (hertz) is normal. There are many Indian make arc welding machines in use in industry today. As an illustrative example, a short description of Indian Oxygen's INDARC 400 (S) transformer welding set follows :

It consists of a rectangular steel tank mounted on three-tyred wheels, the front wheel swivelling and steerable by means of a draw bar. An oil-cooled, double-wound step down transformer reduces the supply mains voltage to a welding voltage of 80. All windings are totally enclosed in the steel tank. The output of the transformer can be varied by rotating a hand wheel which alters the air gap in the core of the choke resulting in stepless regulation of the current between 50 and 400 amp. The welding current setting can be directly read at the window on the top cover. The set can be connected to two lines of 400/440 volts, 3-phase 50 cycle ac supply; it requires about 109 litres of Class B transformer oil. The connection diagram of the set is illustrated in Fig. 9.11.

ARC WELDING WITH D.C. AND A.C.

The advantages of dc welding lie in the higher arc stability and the degree to which the work is heated.

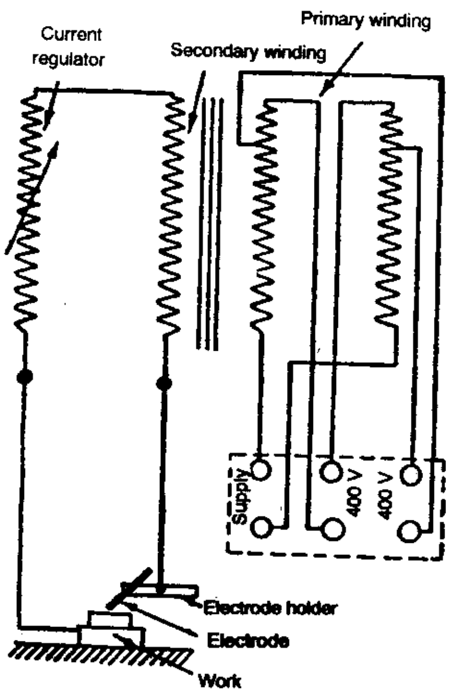


Figure 9.11 Connection diagram of an A.C. welding set (Indian make)

With direct current the greater heat is generated at the positive pole of the arc and in metal-arc welding, it had been the general practice to connect the work to the positive pole of the dc generator and the filler rod to the negative pole, in order to melt the greater mass of metal in the base material. On the other hand, certain types of modern electrodes due to their coating and material properties, are connected advantageously to the positive pole of the generator.

Whilst direct current has the advantage of allowing a desired heat distribution in the arc, alternating current welding is at present gaining considerable ground. The efficiency of ac welding transformers varies from 0.8 to 0.85 while ac outfits have an efficiency from 0.3 to 0.6. The electric energy consumption per kg of deposited metal in ac welding is from 3 to 4 kWh while for dc welding it is as high as 6 to 10 kWh. One disadvantage of ac welding is the comparatively low power factor at the welding station, usually not exceeding 0.3 or 0.4. The motor in a dc welding has a power factor of 0.6 to 0.7. Various advantages and disadvantages of the kind of current are given in Table 9.5

ARC WELDING CURRENT AND VOLTAGE

Open-circuit voltage (no load voltage), i.e., the voltage needed to strike the arc, is higher than the *arc voltage* in order to facilitate easy starting of the arc. With direct current , the open-circuit voltage must be atleast 30 to 35V, while with alternating current is should not be lower than 50 or 55V. Open circuit voltage usually ranges from 50 to 90V. The voltage falls after the arc is established. The voltage across the arc in meal-arc welding ranges from almost zero on short circuit to a minimum of 17V to sustain an arc and to around 40V for an optimum arc. For carbon arc application the voltage range will be about 20 per cent higher. The voltage necessary for proper arc maintenance depends upon the composition of the electrode rod, its coating, the type of current, but the main factor is the length of the arc. In general, arc voltage ranges 15 to 25V with the usual bare or lightly coated electrodes, from 20 to 40V with the usual covered electrodes, and upto 45V with some special electrodes.

TABLE 9.5 COMPARISON OF A.C. AND D.C.

	Direct current (converter)	*Alternating current (transformer)*
No-load voltage	Low (higher safety)	Frequently too high, up to over 70V. That is why the use is limited. Dangerous low (advantageous)
No-load requiremnets	Very high	Low (advantageous)
Efficiency	Low; consequently high cost of electrical energy	High (advantageous)
Prime cost	Two or three times compared to that of transformer	Low
Connected load (cross-sectional areas of conductors & fuse)	Normal	Considerably higher because of phase factor cosϕ (unfavourable). Additional welding condenser required.
Electrodes	Both bare (non-coated) and thus cheap electrodes can be used	Only coated, that is, expensive electrodes can be used (not all types of available).
Welding of nonferrous metal	Suitable	

The current for manual operation of the metal arc usually ranges from 30 to 500*A*, and for automatic operation, from 75 to 600*A*. Table 9.6 gives the usual voltage and current for machines used in arc welding and Table 9.7 gives a survey of permissible intensities of current.

A large current produces arc blow. The space around the arc and in the adjacent metal is always threaded by magnetic fields which tend to deflect the arc. This is known as arc blow. When large currents are used, as the magnetic field intensity is directly proportional to the square of the current, doubling the current will increase the associated magnetic field four times. The presence of arc blow causes the arc to become erratic, unstable, and in general, undesirable for good-quality welds.

TABLE 9.6 USUAL VOLTAGES FOR MACHINES USED IN ARC WELDING

Current (A)	*Voltage (V)*
upto to 100	15
over 100 to 250	20
over 200 to 250	25
over 250 to 350	30
over 350 to 500	35
over 500	40

TABLE 9.7 USUAL WELDING CURRENTS FOR MANUALLY OPERATED SINGLE ELECTRODES

Diameter of electrode mm	*Cross-sectional area of electrode* mm^2	*Mean current intensity total A*	*Per* mm^2 (A/mm^2)
2	3.14	45	14.3
2.5	4.90	70	14.3
3.25	8.29	105	12.7
4	12.56	140	11.1
5	19.63	180	9.4
6	28.27	235	8.3
8	50.26	310	5.9

POLARITY IN ARC-WELDING

With ac, because of the reversal of the current, the heat generated at each pole is the same, and thus changing over the connections to the electrode does not have any effect on its performance. On the other hand, polarity of ac has a great bearing on electrode performance. The conductor from which the direct current passes into the arc is designated as the positive terminal and the other conductor as the negative terminal. The heat generated by the flow of current is split into two parts, in the ratio 66 per cent at the positive pole and 33 per cent at the negative pole. If a light-coated electrode is connected to the positive pole it quickly becomes red-hot and welding is impossible. On the other hand if the light-coated electrode is connected to the negative pole and the work to the positive pole, the molten pool will become the source of the higher heat content, the electrode remaining below the critical heat value. This also provides the reason why ac equipment is not suitable for most light-coated electrodes. With dc, therefore, for welding thin material the work is made negative and for welding heavy material the electrode made negative. This rule is not applicable to carbon-arc welding where carbon rod is *always* made negative.

There are several ways of denoting the connection to the electrode when welding with dc. When the electrode is connected to the positive lead, the term *electrode positive* is employed. This is sometimes referred to as *reversed polarity*. Similarly, when the electrode is connected to the negative lead, the term *electrode negative* is employed. This is sometimes referred to as *straight polarity*.

ELECTRODES FOR ARC WELDING

Both nonconsumable and consumable electrodes are used for arc welding.

Nonconsumable electrodes may be made of carbon, graphite or tungsten which do not consume during the welding operation. *Consumable electrodes* may be made of various metals depending upon their purpose and the chemical composition of the metals to be welded. These consumable electrodes may be classed into bare and coated.

In using the *plain or bare electrodes*, as the globules of the metal pass from the electrode to the work, they (globules) are exposed to the oxygen and nitrogen in the surrounding air. This causes the formation of some nonmetallic constituents which are trapped in the rapidly solidifying weld metal and thereby decreases the strength and ductility of the metal.

Coated electrodes, on the other hand, serve several purposes; (1) to facilitate the establishment and maintenance of the arc ; (2) to protect the molten metal from the oxygen and nitrogen of the air by producing a shield of gas around the arc and weld pool ; (3) to provide the formation of slag so as to protect the welding seam from rapid cooling ; and (4) to provide a means of introducing alloying elements not contained in the core wire.

Coated electrodes can be divided into two general groups : (1) lightly coated (or washed) electrodes with a coating layer several tenths of a millimetre thick, and (2) heavily coated electrodes (Fig. 9.12) with relatively thick high quality covering applied in a layer of 1 to 3 mm. The primary purpose of a light coating is to increase arc stability, so they are also called *ionizing coatings*. For this reason, lightly coated electrodes may only be used for welding non-essential jobs. The welds produced have poor mechanical properties due to the lack of protection of the molten metal. Heavily coated electrodes, sometimes referred to as shielded-arc electrodes, serve all the four purposes described above, and are used to obtain a weld metal of high quality, comparable with, and even superior to the parent metal in terms of mechanical properties. Heavy coatings used are composed of ionising (chalk), deoxidising (aluminium, ferro-manganese, etc.), gas generating (starch), slag-forming (kaolin), alloying and binding materials.

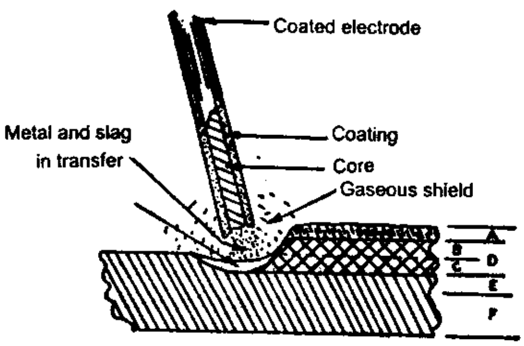


Figure 9.12 Shielded arc welding
1. slag layer, 2. Weld reinforcement, 3. penetration, 4. wled deposit, 5. base metal heat afected zone, 6. uneffected base metal.

Both bare and coated electrodes , for hand arc welding are made in the shape of rods unto 12 mm in diameter and 450 mm long. Semi-automatic and automatic welding use electrode wire in coils. Soft steel wire containing 0.1 to 0.18 per cent carbon, and 0.0025 to 0.04 per cent phosphorus and sulphur is used for electrodes in welding carbon steel. Electrodes for alloy steel are made of low-alloy steel wire containing upto 0.25 per cent carbon.

ANGULARITY OF ELECTRODE TO WORK IN ARC WELDING

The quality of the weld metal may be determined to a marked degree by the angular deposition of the electrode to the work. Upon The latter, may depend the freedom from undercutting and slag inclusion, the ease with which the filler metal is placed in the weld, the uniformity of fusion, and the weld contour as affected by the influence of surface tension and gravity of the molten metal.

In downhand (flat) welding, electrode should be held at not more than 20° from the vertical and about 3 mm away from the work. If less than 20°, the crater is kept molten too long, causing the deposited metal to flow away. If more than 20°, the slag will flow ahead of the deposited metal and be trapped in the weld.

PRECAUTIONS IN ARC-WELDING

Because of the intensity of heat and light rays from the electric arc, the operator's hand, face and eyes are to be protected while the arc is in use. Heavy gloves are worm, and a hand shield or a helmet with window of coloured glass should be used to protect the face. The space for the electric-arc welding should be screened off from the rest of the building to safeguard other workmen from the glare of the arc.

9.10 ARC WELDING METHODS

The main types of arc welding are :

1. Carbon-arc.
2. Metal arc.
3. Metal-inert-gas arc (MIG).
4. Gas-tungsten-arc (TIG).
5. Atomic hydrogen arc.
6. Plasma-arc.
7. Submerged-arc.
8. Flux-cored arc.
9. Electro-slag, welding.

These are described hereunder in the order of their frequency of use.

CARBON-ARC WELDING

In this method, a rod of carbon is used as negative electrode and the work being welded as positive. The arc produced between these two electrodes heats the metal to the melting temperature. This is about 3,200°C on the negative electrode, and 3,900°C on the positive electrode. The reason to use carbon rod as negative electrode is that less heat will be generated at the electrode tip than that at the workpiece, and carbon from the electrode will not fuse and mix up with the job. If this so happens the resultant weld will be rich in carbon, and consequently very much brittle and unsound. In carbon-arc welding dc is always used. The use of ac is not recommended because no fixed polarity can be maintained.

The process is best applied to joints which need only to be melted without the addition of filler metal (e.g., flange or edge joints) but fuller metal, if needed, may be added in the form of a welding rod as in oxy-acetylene welding. Some protection for the molten weld metal may be provided by using a long arc which produces a carbon-monoxide gas envelope. In addition, a flux may be used, and welding rods usually incorporate a deoxidizer such as silicon or phosphorus. This process is used for welding sheet steel, copper alloys, brass, bronze, and aluminium.

METAL-ARC WELDING

In the metal-arc welding a metal rod is used as one electrode, while the work being welded is used as another electrode. The temperature produced is about 2,400°C and 2,600°C on the negative and positive electrode respectively. During the welding operation, this metal electrode is melted by the heat of the arc, and is fused with the base metal, thus forming a solid union after the metal has been cooled. Both ac and dc may be used. A metal-arc welding circuit is illustrated in Fig. 9.13.

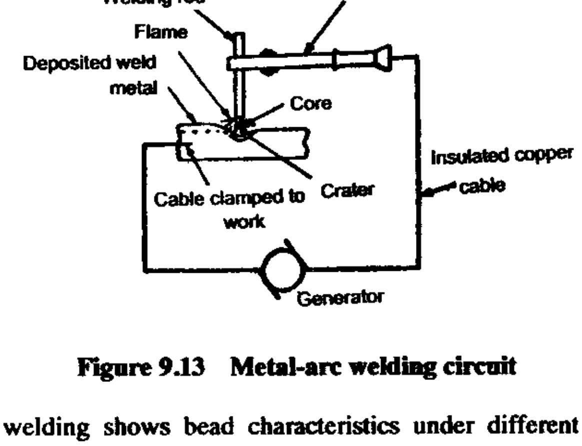


Figure 9.13 Metal-arc welding circuit

The welding operation is started by adjusting the machine to the correct amperage which is determined by the size of the rod to be used. The correct welding speed is important. Various currents can have a deciding effect on the forming of proper *beads*. A welding shows bead characteristics under different conditions :

1. Welding current too low– excessive piling of the metal.
2. Welding current too high – causing excessive splatter.
3. Voltage too high– bead too small.
4. Welding speed too slow– cause excessive piling up of weld

metal.

5. Proper current and timing – create a smooth, regular, well-formed bead.

Undercutting is also a result of too much current. No enough current results in overlapping and a lack of fusion with the metal.

GAS-METAL-ARC WELDING (MIG)

Although *gas-metal-arc* (*GMA*) is the official description of this welding method, The earlier name of *metal inert gas* (*MIG*) is still widely used, especially in the shops.

Gas-metal-arc welding (Fig. 9.14) is a gas shielded metal arc welding process which uses the high heat of an electric arc between a continuously fed , consumable electrode wire and the material to be welded. Metal is transferred through protected arc column to the work.

In this process, the wire is fed continuously from a reel through a gun to constant surface which imparts a current upon the wire. A fixed relationship exists between the rate of wire burn-off and the welding current so that the welding machine at a given wire feed rate will produce necessary current to maintain the arc. The current ranges from 100 to 400 *A* depending upon the diameter of the wire, and the speed of melting of the wire may be upto 5 m/min. The *welding machine* is dc constant voltage, with both straight and reverse polarities available.

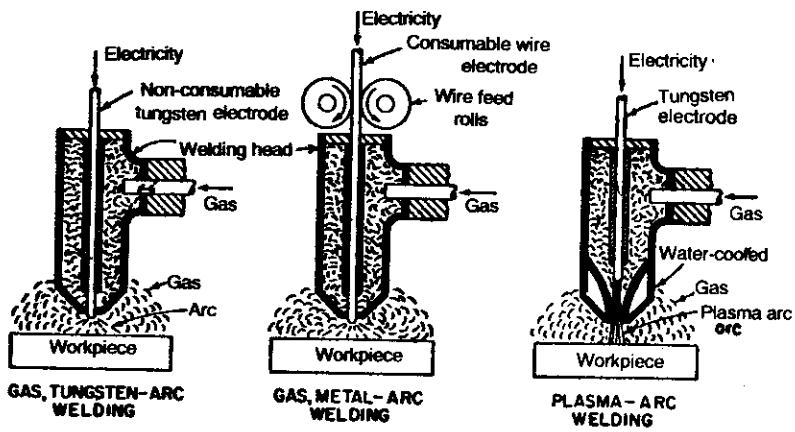


Figure 9.14 Gas-shielded arc welding

The *welding gun* can be either air-or water-cooled depending upon the current being used. With the higher amperages, a water-cooled gun is used. The *welding wire* (continuous electrode) is very often bare. Very lightly coated or *flux-cored wire* is also used. The wire is usually in diameters of 0.09 to 1.6 mm, however, sizes upto 3.2 mm, are made.

In gas-metal-arc welding, the welding area is flooded with a gas (an inert gas) which will not combine with the metal. The rate of flow of this gas is sufficient to keep oxygen of the air away from the hot metal surface while welding is being done. Carbon dioxide (CO_2) is used for working with steel, as GMA is a clean, faster method for welding steel. Carbon dioxide is used principally because it is inexpensive. For welding aluminium or copper, argon or argon-helium mixtures are used. For stainless-steel, MIG welding is done with either argon-oxygen or helium-argon gas mixtures. Titanium requires pure argon gas shielding, and the copper-nickel and high-nickel alloys use argon-helium mixture.

Some advantages of this process are :

1. No flux required.
2. High welding speed.
3. Increased corrosion resistance.
4. Easily automated welding.
5. Welds all metals including aluminum and stainless steel.
6. High economy.

GAS TUNGSTEN-ARC WELDING (TIG)

This process, often called TIG (tungsten inert gas) welding, is similar to MIG in that it uses the gases for shielding. This arc-welding process (Fig. 9.14) uses the intense heat of an electric arc between a nonconsumable tungsten electrode and the material to be welded.

The shielding is obtained from an inert gas such as helium or argon or a mixture of the two. Argon is more widely used than helium because it is a heavier gas, producing better shielding at lower flow rate. The shielding gas displaces the air surrounding the arc and weld pool. This prevents the contamination of the weld metal by the oxygen and nitrogen in the air.

Filler metal may or may not be used. However, it is usually employed, except thin material. When a filler metal rod is used, it is usually fed manually into the weld pool. Automatic feeding of the filler wire into the TIG arc to speed up the process has now been developing.

Electrodes used in this process are made of tungsten and tungsten alloys. The tungsten electrode is used only to generate an arc. The arc does not melt the tungsten, which has a melting point of over 3,300°C. The end of the welding gun where the arc is created either is made of high-impact ceramic or is water-cooled.

The TIG process lends itself ably to the fusion welding of aluminium and its alloys, stainless steel, magnesium alloy, nickel-base alloys, copper-base alloys, carbon steel and low-alloy steel. TIG welding can also be used for the combining of dissimilar metals, hardfacing, and the surfacing of metals. But this process is not used as often on plate over 6.4 mm thick, but it is easier than MIG welding for thin plates and small parts.

The torch used in this welding method holds the electrode and directs shielding gas and welding power to the arc. Arc spot welds can also be made with a TIG torch fitted with special adapters. In this case a 3 mm electrode is often used for a total cycle time of 1/2 to 3 s depending on the alloy and its thickness.

In general, an ac power source is best for TIG welding nonferrous alloys except deoxidized copper. For ferrous alloys the dc power source with straight polarities (electrode negative) is better for gas tungsten-arc welding because it greatly reduces the volumetric loss from the tungsten electrode. For example, a TIG torch which has a rating of 250 *A* when used with straight polarity (dcsp) must be derated to 15 to 25 *A* when used with reversed polarity (dcrp-electrode positive). As little as 3 *A* may be used for work on very thin metals and intricate parts.

Some of the advantages of TIG welding are : (1) it produces high-quality welds in nonferrous metals, (2) practically no weld cleaning is necessary, and (3) the arc and weld pool are clearly visible to the welder.

ATOMIC HYDROGEN WELDING

In the atomic-hydrogen arc-welding process, an ac-arc is maintained between the two nonconsumable tungsten electrodes while a stream of hydrogen gas under a pressure of about 0.5 kgf/cm^2 (50 kN/m^2) is passed through the arc and around the electrodes (Fig. 9.15).

When hydrogen molecule is broken down into atomic form, the atoms become very active and have a great tendency to recombining to form molecular hydrogen. This is exactly what happens in the atomic-hydrogen process. As the molecules of hydrogen pass through the electric arc, they are changed into the atomic state and thus absorb a considerable amount of energy. But when the atoms of hydrogen recombine into molecules just outside the arc a large amount of heat is liberated. This extra heat, added to the intense heat of the arc itself, produces a temperature of the order of 4,000°C, as compared to 2,000°C produced by the combination of normal hydrogen and oxygen. This heat is used in making fusion welds. When additional metal is required, filler rods are melted into the joint.

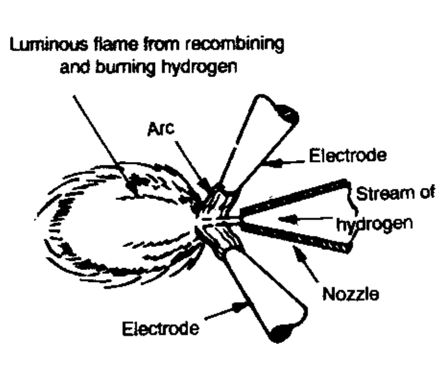


Figure 9.15 Atomic-hydrogen-arc welding

One of the other principal benefits of this process is that the hydrogen excludes all oxygen and other gases which might combine with the molten metal to form oxides and other impurities. It also removes oxides from the surface of the work. Thus, it is capable of producing smooth, uniform, strong, and ductile welds.

This process of welding is employed in welding alloy steel. It is successfully applied for welding stainless steel. Most nonferrous metals can also be successfully welded.

PLASMA ARC WELDING

Plasma is high-temperature ionized (its atoms lose electrons) gas and occurs in any electric arc between two electrodes. The ionized gas plasma gets hotter by resistance heating from the current passing through it. If the arc is constrained by an *orifice*, the proportion of ionized gas increases and plasma-arc welding is created (Fig. 9.14). which causes an intense source of heat primarily due to multiple collisions of the electrons within the particles, and provides greater arc stability.

A non-consumable tungsten electrode within a water-cooled nozzle is enveloped by a gas. The gas is forced past an electric arc through a constricted opening at the end of the water-cooled nozzle. As the gas passes through the arc, it is dispersed. This releases more energy and raises the temperature of the nozzle. Temperatures have been reported to be 10,000 to 30,000 °C. As a comparison, oxy–acetylene welding is limited to the maximum temperature of the chemical reaction and is approximately 3,600°C. The ordinary electric arc, because of its diffuseness, can attain a maximum temperature of 11,000°C.

The main function of the plasma gas is shielding the body of the torch from the extreme heat of the cathode. Any gas or mixture of gases that does not attack the tungsten or the copper cathode can be used ; argon and argon mixtures are most commonly used.

In this process, the penetration is deep and thorough, and much work can be done without filler metal. Again, filler metal may be used if an extra metal supply is needed.

Any known material can be melted, even vaporized, by the plasma-arc process and thus becomes subject to welding. Results are clean and two to five times as fast as TIG welding with same equipment cost. It requires automatic control and is not practical for short welds.

SUBMERGED-ARC WELDING

Submerged-arc welding, sometimes called *hidden arc* or *subarc welding*, is an automatic process developed primarily for the production of high quality butt–welds in thicker steel plate than is normally suited to other manual arc welding processes. The arc is formed between the end of a continuous, i.e., depositing surface, under a layer of protective mineral powder, known as the flux or melt, which can also be used to add alloying elements to the joint ahead of the welding wire and while the weld is being made the arc is submerged under the powder and is invisible. The operator judges the proper location by observing the general direction of the wire and the welded material. Various kinds of equipment are available for clamping the parts in position, and for feeding the wire electrode. The process is illustrated in Fig. 9.16.

The flux may be made of silica, metal oxides, and other compounds fused together and then crushed to proper size. Another group of fluxes is made of similar material "bonded" and formed into *granules*.

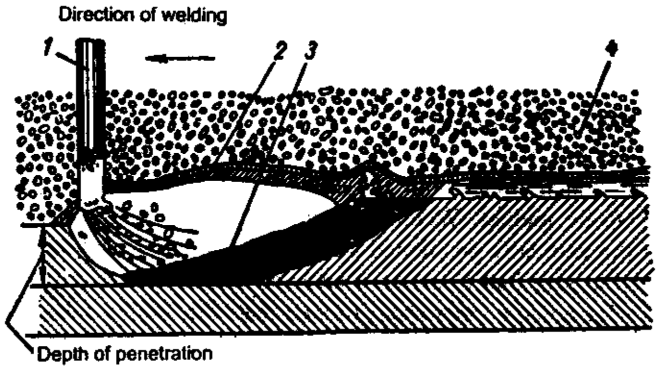


Figure 9.16 Submerged arc welding
1. Electrode, 2. Envelope of flux, 3. Molten metal, 4. Flux

The bare *electrode* is fed from a reel down through the *gun* or *nozzle*. The operator can move it slowly, a little at a time for the start of the arc and then set the proper feed rate on the control box. Wire of several alloys for steel, stainless steel, copper, etc. is available in diameters from 3 to 6 mm. Voltage used is from 25 to 40V. Current used depends considerably on workpiece thickness. Normally dc is employed using 600 to 1000A current for welding alloy and stainless steel, although ac is preferable particularly for low-carbon steel. The current for ac is usually 2,000A.

The advantages of submerged-arc welding are listed below.

1. Partly because it is often automated, it is much faster than regular arc welding. Speeds up to 3800 mm/min are possible on 3 mm thick steel at 100 per cent efficiency.
2. Deep penetration with high quality weld is possible.
3. Less distortion occurs from high speed and uniform heat input, especially when automated.
4. The operator can work more easily without safety equipment.

FLUX-CORED ARC WELDING

The *inner-core-type* welding is an "inside-out" wire with the flux inside a tubular electrode. The *equipment* needed is simple : a constant-voltage dc power source, a wire feeder and a lightweight welding gun, which is like the MIG holder without the gas and cooling attachment. Thus, a continuous welding is possible. Sometimes additional shielding is provided with a gas, and then the process resembles gas metal-arc welding.

The welds are strong and tough. The arc starts easily, and cold wire produces high-quality welds at faster speeds than stick welding even when hand welded.

ELECTRO-SLAG WELDING

This is a welding process which produces coalescence through electrically melted flux which melts both the filler metal and the surfaces of the workpiece to be melted. Welding is initiated on a starting block at the bottom of the vertically positioned joint. Flux poured around the electrode is converted to slag that floats on a layer of molten metal confined in the joint by water cooled copper *shoes* (*dams*) that slide on the sides. The heat of the fusion is provided by resistance heating in the slag. The welding dams and head move upward as weld metal solidifies and new metal is fed in by the wire electrodes.

The consumable wire electrode may be solid or flux coated but most or all of the shielding is provided by an argon and CO_2 gas mixture injected into the gap. The heat is furnished by an electrical arc between the electrode and metal pool. Fig 9.17 shows the process.

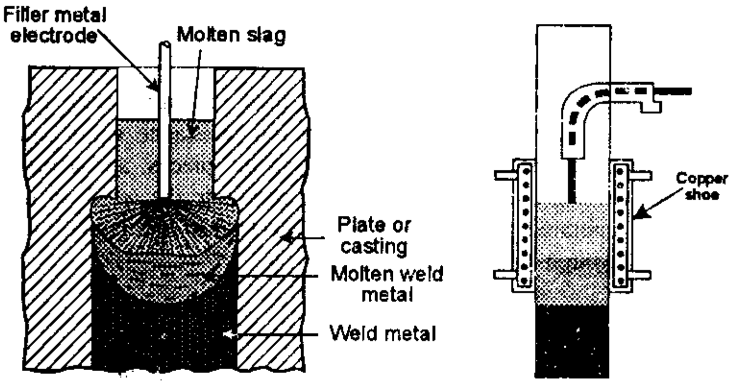


Figure 9.17 Electro-slag welding

Electro-slag welding is used particularly for welding thick (25 mm or over) plates and structures for turbine shafts, boiler parts and heavy presses.

RESISTANCE WELDING

In resistance welding the metal parts to be joined are heated to a plastic state over a limited area by their resistance to the flow of an electric current and mechanical pressure is used to complete the weld. Recently, with air and hydraulic systems for applying pressure at the correct time and in right amount through electronic controls, resistance welding has been advanced. In this process, preferably two copper electrodes are incorporated in a circuit of low resistance and the metals to be welded are pressed between the electrodes. The circuit is thus completed and the electrical resistance at the joint of the metals to be welded is so high, in comparison with the rest of the circuit, that if the current is heavy enough the highest temperature will be produced directly at the joint. The heat generated in the weld may be expressed by

$$H = I^2 RT$$

where H is the heat, I the current, R the resistance of the assembly and T the time or duration of current flow. That is, the heat developed by the current is in proportion to the electrical resistance of the joint.

The electrical pressure or voltage from either 120 or 240*V* is reduced down from 4 to 12 volts, depending on the composition, area, thickness, etc., of the metal being welded. The amount of power supplied to the weld usually ranges from about 6 to 18 kW for each cm^2 of area. Alternating current has been found most convenient for this purpose as it is possible to obtain any desired combination of current and voltage by using a suitable transformer.

A diagram of the electrical circuit for a resistance welder is shown in Fig. 9.18. The machine used for making resistance welds contains a transformer, a clamping device for holding the pieces, and a mechanical means for forcing the pieces together to complete the weld. In machines which are operated continuously, the electrodes are cooled by water circulating through hollow electrodes.

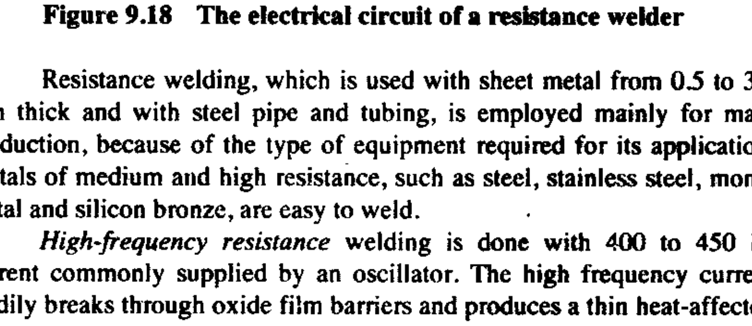


Figure 9.18 The electrical circuit of a resistance welder

Resistance welding, which is used with sheet metal from 0.5 to 3.2 mm thick and with steel pipe and tubing, is employed mainly for mass production, because of the type of equipment required for its application. Metals of medium and high resistance, such as steel, stainless steel, monel metal and silicon bronze, are easy to weld.

High-frequency resistance welding is done with 400 to 450 kc current commonly supplied by an oscillator. The high frequency current readily breaks through oxide film barriers and produces a thin heat-affected zone because it travels on the surface of the material.

9.11 RESISTANCE WELDING METHODS

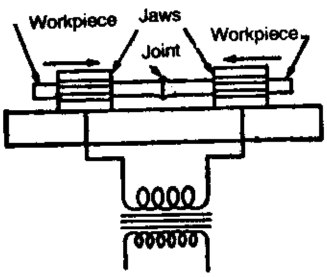
The field of resistance welding can be subdivided into several processes, the most important being : (1) butt, (2) spot, (3) seam, (4) projection, and (5) percussion, welding.

BUTT WELDING

There are two types of butt welding : upset and flash.

In making of *upset butt welding* (Fig. 9.19), the parts to be welded are clamped edge to edge in copper jaws of welding machine and brought together in a *solid contact* so that their point of contact forms a locality of high electric resistance, while current flows to heat the joint. At this point the pressure applied upsets or forges the parts together. Upset butt welding is used principally on nonferrous materials for welding bars, rods, wire, tubing, formed parts, etc.

In the flash *butt welding process* (Fig. 9.20), edges are brought together in a *light contact*. A high voltage starts a flashing action between the two surfaces and continues as the parts advance slowly and the forging temperature is reached. The upsetting action forces out the impurities caused by the flashing. The forced-out metal is called the flash. The inner weld metal is then sound and free of oxides and cast metal. Welding rods, gas, flux, or other materials are unnecessary in this welding. Many different materials and combinations can be flash butt welded ; steels and the ferrous alloys other than cast iron are probably the most easily welded. Those materials that cannot be flash butt welded are lead, tin, zinc, antimony, bismuth and their alloys, and the copper alloys in which these metals are present in large per centage. The flash butt welding process is used extensively in automobile construction—on the body, axles, wheels, frame and other parts.



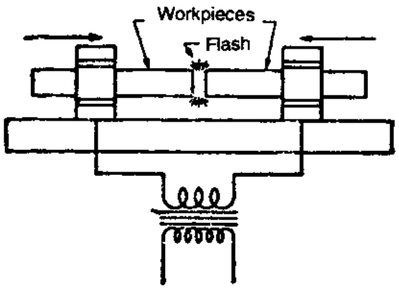


Figure 9.19 Upset butt welding **Figure 9.20 Flash butt welding**

SPOT WELDING

Spot welding is employed to join overlapping strips, sheets or plates of metal at small areas (Fig.9.20). The pieces are assembled and placed between two electrodes, which must possess high electrical & thermal conductivity and retain the required strength at high temperatures. So they are made of pure copper for a limited amount of service, and of alloys of copper or tungsten, or copper and chromium for continuous working. When the current is turned on, the pieces are heated at their areas of contact to a welding temperature, and with the aid of mechanical pressure the electrodes are forced against the metal to be welded. The pressure may be developed by a foot lever or by air pressure or by hydraulic cylinders. This may be used to weld steel and other metal parts up to a total thickness of 12 mm.

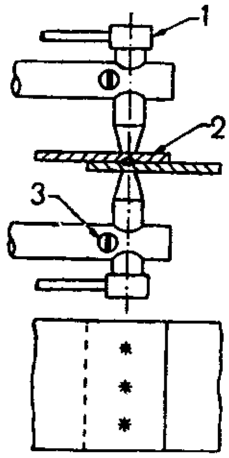


Figure 9.21 Spot welding
1. Electrode, 2. Work welding, and 3. Clamp

Practically all combination of ductile metals and alloys can be spot welded. The spot welding method is used for fabricating all types of sheetmetal structures where mechanical strength rather than water or air tightness is required. This may be applied to all types of boxes, cans, enclosing cases, etc. Spot welding machines are made in capacities from 10 to 150 kVA.

To obtain good welds, the sheet metal should be free of foreign matter and scale. Films of any type have a tendency to cause variations in surface resistance and also increase the heating effect of the metal in contact with the electrodes.

SEAM WELDING

Seam welding is a method of making a continuous joint between two overlapping pieces of sheet metal. The normal procedure for making a seam weld is to place the work between the wheels which serve as conductors for producing continuous welds. As pressure is applied, the drive is started and the welding current switched on. Then at the same time, the over-lapping surfaces of the metal are forced together as fast as they are heated. A coolant is applied to

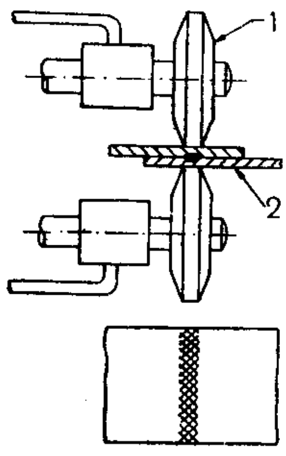


Figure 8.22 Seam welding
1. Wheel, 2. Workpiece

conserve the electrodes and cool the work rapidly to speed the operation. Fig. 9.22 shows the principle of seam welding.

The materials that may be seam welded include most of those that may be spot welded. Steel plates 10 mm thick have been seam welded to hold about 200 kg/cm^2 (20,000 kN/m^2) pressure. Seam welding is used on many types of pressure tight or leakproof tanks for various purposes, and numerous other products.

PROJECTION WELDING

Projection welding is a modification of spot welding. The current and pressure are localised at the weld section by the use of embossed, machined or coined projections on one or both pieces of the work. The flattening out of these projections under pressure results in good welds at all points of contact Fig. 9.23.

Projection welding applies to nearly all the metal combinations that can be spot welded, but the design must be strong enough to support the projection. Annular, or ring projections are often used on screw machine parts such as bosses and studs which are to be welded to sheets up to sheets up to approximately 3 mm thick. For thicker sheets a dome type of projection seems to work out better.

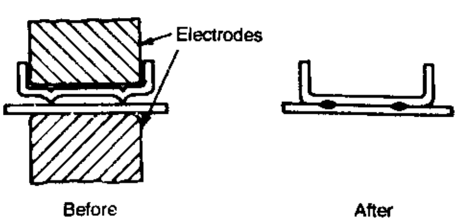


Figure 9.23 Projection welding

Only clean, scale free surfaces should be used in projection welding. A dirty substance will cause much variation in the resistance between the parts being joined, with resulting variation in current flow and weld strength.

Line projection welds are recommended over point welds when sections are subject to heavy static or dynamic loads.

Projection for welding is made on sheet metal, cast, forged or machined parts. A variation is called *stud welding*. A stud with its ends rounded is held in one electrode and pressed against its mating while current flows to heat the weld. The effect of projection welding is obtained with crossed wires, such as might be welded together into a grill.

PERCUSSION WELDING

The operation is performed with one part held in a stationary holder and the other in a clamp mounted on a slide which is backed up against pressure from a heavy spring. In the welding operation, the movable clamp is released rapidly carrying the part forward. When the two parts are approximately 1.5 mm apart, a sudden discharge of electrical energy is released, causing an intense arc between the two surfaces. To complete, it takes about 0.1 second. No upset or flash occurs at the weld. This method of welding is limited to small areas of 144 mm^2 maximum.

Percussion welding is a fast method and it can handle dissimilar metals. This is highly suitable for welding small wires to electrical components.

9.12 THERMIT WELDING

Thermit welding is primarily a fusion-welding process in which the weld is effected by pouring superheated liquid thermit steel around the parts to be united. In the case of thermit pressure welding, only the heat of the "thermit" reaction is utilized to bring the surface of metal to be welded in a plastic state and mechanical pressure is then applied to complete the weld.

The thermit process for welding metal is based on the chemical reaction between finely divided aluminium and iron oxide.

$$8Al + 3Fe_3O_4 = 4Al_2O_3 + 9Fe$$

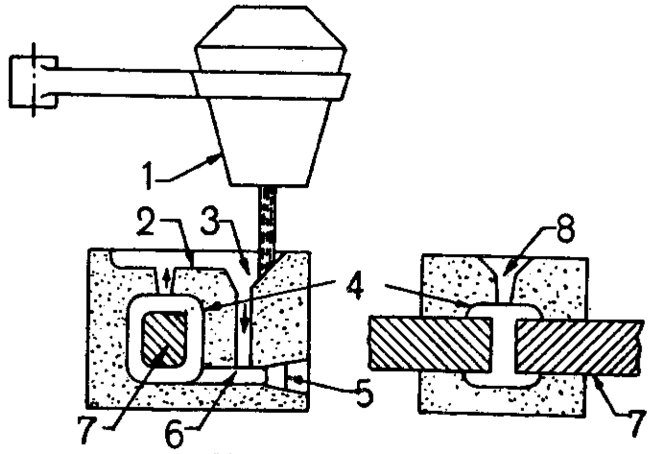


Figure 9.24 Thermit welding

1. Crucible, 2. Slag basin, 3. Runner, 4. Wax pattern, 5. Sand plug, 6. Preheating, 7. Workpiece, 8. Riser.

During the reaction, the oxygen leaves the iron oxide and combines with aluminium, producing aluminium oxide, or slag, and superheated thermit steel.

The thermit is a mixture of finely divided aluminium and iron oxide, the ratio by weight being approximately three parts of iron oxide to one part of aluminium. The mixture, placed in a refractory-lined crucible, is ignited with the aid of a highly inflammable powder composed largely of barium peroxide. The temperature produced by the thermit reaction is approximately 3,000°C or about twice the temperature of the melting point of steel.

In making pressure welds by the thermit process, a pattern of wax is shaped around the parts to be welded (Fig. 9.24). A sheet-iron box is placed around the wax pattern and the space between the pattern and box is filled and rammed with sand. Pouring and heating gates, and risers, are cut in the sand and a flame is directed into the heating opening. The wax pattern melts and drains out but the heating is continued to raise the temperature of the parts to be welded. This preheating is done before the liquid metal is poured into the mould in order to prevent chilling of the steel. Then the burner or torch is removed, and the preheating gate is plugged with sand. The superheated metal produced by the thermit reaction in a crucible is poured into the mould surrounding the surfaces to be welded. After the welding temperature is reached mechanical pressure is applied to complete the weld.

The thermit pressure welding is used to a great extent in the welding of pipes, cables, conductors, rails, shafts and broken machinery frames and rebuilding of large gears, etc.

SOLID STATE WELDING

Interatomic bonds may be established by bringing atoms of two surfaces in close enough proximity to assure adhesion. Relative movement of the surfaces under pressure and controlled roughness are helpful in breaking through surface films. While theoretically *no pressure* would be required for *bonding*, in practice a *certain* normal *pressure* is necessary to assure conformity with the contacting surfaces. In principle, however, any material can be bonded and solid state bonding is often applied when other technique fails.

9.13 SOLID STATE WELDING METHODS

Solid state welding includes : (1) friction, (2) ultrasonic, and (3) diffusion, welding. These are briefly explained hereunder.

DIFFUSION WELDING

Diffusion welding is a process that does not necessarily need heat to produce a fusion weld. Rather it needs two kinds of surfaces that can come into intimate contact under pressure. This pressure is applied for a period of hours. In this process, although heating is not essential, if the temperature is raised, the diffusion rate will be cut sufficiently. It might take many hours to perform a certain bonding, but with heat the time element can be cut to a matter of hours of minutes.

The goldsmith has for centuries made *filled gold* by placing a weight on top of a *sandwich* composed of silver or copper *core* with gold *face sheets*. When this is held in a *furnace* for a prolonged time, a permanent *bond* is obtained. That is what is done in diffusion bonding in principle.

This process makes it possible to join metal to metal, metal to ceramic, and metal to metal with intermediate bonding materials. Temperatures that approach is approximately 900°C. This extreme temperature limits diffusion bonding of steel. Diffusion bonding incorporates three basic techniques practically having the same principle as explained. These are : gas-pressure bonding, vacuum fusion bonding , and eutectic fusion bonding.

ULTRASONIC WELDING

Ultrasonic welding will join similar or dissimilar metals by the introduction of high-frequency vibratory energy (frequency being 20,000 to 60,000 Hz) into overlapping metals into the area to be joined. No flux or filler metals are used, no electrical current passes through the weld metal, and usually no heat is applied.

The parts to be joined are clamped together between a welding tip and a supporting member under low-static pressure. High-frequency vibratory energy is then transmitted into the weld area for a brief interval. This process produces a sound bond without an arc or melting weld metal and in the absence of filler metal or fluxes.

The ultrasonic welding process can be utilized in spot welding, continuous seam welding, etc. The maximum thickness by these processes ultrasonically may vary from 0.38 to 2.5 mm depending upon the metal.

FRICTION WELDING

The frictional energy generated when two bodies slide on each other is transformed into heat ; when the rate of movement is high and the heat is contained in a narrow zone, welding occurs.

In the practical form of friction welding, one part is firmly held while the other (usually cylindrical) is rotated under simultaneous application of axial pressure. The temperature rises, partially formed welded spots are sheared, surface films are disrupted, and the rotation is suddenly arrested when the entire surface is welded. Some of the softened metal is squeezed out into a *flash*, but it is not fully clear whether melting takes place.

The heated zone being very thin, dissimilar metals are easily joined, for example, mild steel shanks can be fastened to high-speed-steel tool ends.

EXPLOSIVE WELDING

In explosive welding, strong metallurgical bonds can be produced between metal combinations which cannot be welded by other methods or processes. For example, tantalum can be explosively welded to steel although the welding point of tantalum is higher than the vaporization temperature of steel.

Explosive welding is carried out by bringing together properly paired metal surfaces with high relative velocity at a high pressure and a proper orientation to each other so that a large amount of plastic interaction occurs between the surfaces. The work piece, held fixed is called the *target* plate and the other called flyer plate. While a veriety of procedures have been successfully employed, the major techniques of explosive welding can be divided into *contact techniques* and *impact techniques*.

In critical space and nuclear application, explosive welding permits fabrication of structures that cannot be made by any other means ; and, in some commercial applications, explosive joining is the least costly method.

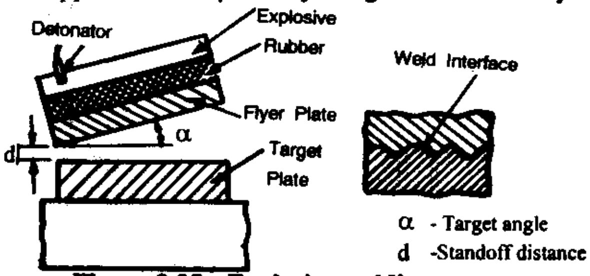


Figure 9.25 Explosive welding

The major advantage of this welding includes the simplicity of the process, and the extremely large surface that can be welded. Also incompatible materials can be bonded, and thin foils can be bonded to heavier plating.

Fig. 9.25 shows the process.

NEWER WELDING METHODS

9.14 NEWER TYPES OF WELDING

These types are called 'newer' since these are not in use for many many years and have been developed very recently. The types are : (1) electron-beam welding and (2) laser-beam welding.

ELECTRON-BEAM WELDING

Electron beam welding utilizes the energy from a fast moving beam of electrons focussed on the workpiece. The electrons strike the metal surface, which gives up kinetic energy almost completely into heat. The beam is created in a high vacuum (10^{-3} to 10^{-5} mm Hg). If the work is done is such vacuum, no electrodes, gases, or filler metals can contaminate it, and pure welds can be made. Moreover, high vacuum is necessary around the filament so that it will not burn up and will also produce and focus a stable beam (Fig. 9.26).

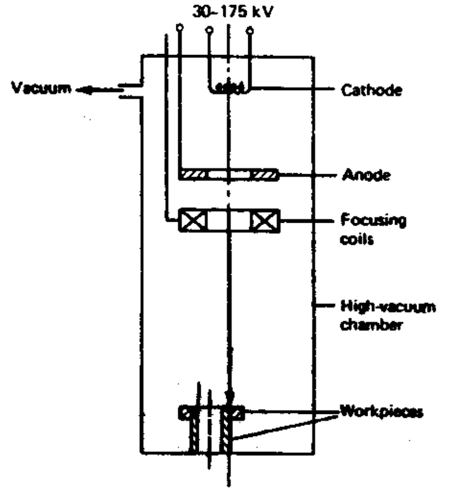


Figure 9.26 Electron beam welding

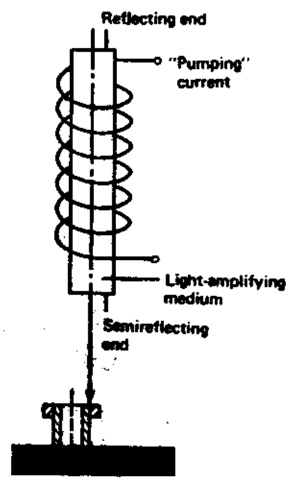


Figure 9.27 Laser beam welding

In all types of electron beam machines, a tungsten filament which serves as a cathode emits a mass of electron that are accelerated and focussed to a 0.25 - 1 mm diameter beam of high energy density upto 0.5

to 10 kW/mm^2. The heat generated is about 2500°C. This is sufficient to melt and vaporize the workpiece material and thus fills a narrow weld gap even without a filler rod (although filler rods may be used).

The speed of the beam is stepped up to one-half to two-thirds of the speed of light by passing it through a high-voltage electrostatic field. An electromagnetic lens is employed to obtain correct focusing of the beam.

Near zero pressure is necessary for the formation of the beam. The chamber is evacuated to a pressure to 10 mm Hg. Welding begins at this point. A similar process, known as *nonvaccum electron beam welding* is rapidly coming into use today. This means that many welds can now be made without elaborate arrangement required for vacuum electron beam welding. In that case, the vacuum chamber in which the beam is created is evacuated to a lower pressure. In situation where contamination of the workpiece must be held to a minimum, the beam should be passed through argon or helium. To make the chamber *high vacuum*, it takes about 5 to 30 min to evacuate the air, depending on the size of the chamber. A medium size electron beam welder operates below 60 kV. The welding head or the work is moved by numerical control or by hand.

Today automobile, airplane, aerospace, farm and other types of equipment including ball-bearing over 100 mm are being welded by the electron beam process.

The advantages of EBW are that the welds are clean, with no porosity since there is no air ; so shielding gas is needed ; and as the energy input is in a narrow, concentrated beam, distortion is almost eliminated. The speed may be as fast as 2500 mm/min, and it will weld or cut any metal or ceramic, diamond, sometimes as thick as 150 mm.

LASER-BEAM WELDING

Lasers are devices which are capable of generating a very intense beam of optical radiation. The word 'laser' is an acronym of *L*ight *A*mplification by the *S*timulated *E*mission of *R*adiation.

An even more concentrated beam is produced, but at a lower overall efficiency, with the *laser beam* (Fig.9.27). A CO_2 laser pumped with 500 W emits far-infrared light (10.6μm wavelength) and develops a peak energy density of 80 kW/mm^2, yet the heat affected zone is only 0.05 to 0.1 mm wide. Oxygen blown on the surface of the metals reduces the heat reflection and increases material removal rates by oxidation ; inert gas increases heat transfer for nonmetals.

The laser has the advantage that vacuum is not necessary and it is finding limited but growing application, particularly for thin gauge metals.

Lasers using for work such as welding very small wires to electronic devices and similar work is called *microwelding*. Welding speed of about 2500 mm/min is achieved on steel sheet 1.5 mm thick.

In practice, numerical control is used to move the workpiece ; and laser's use in heavy production work is still limited.

RELATED PROCESSES

A very important application of fusion welding processes furnishes with an exactly opposite function. Workplaces of varying shape are *cut* out from sheet plate, and even very heavy sections. The heat required for melting may be provided by an electric arc, a high energy beam or a chemical heat, and a flame. Cutting processes are readily automated, and, with suitable tracer mechanisms or numerical control, they can become competitive with various sheet blanking operations.

In addition to cutting processes other related processes include brazing, soldering and hard facing and many others.

9.15 OXYGEN CUTTING

The cutting of iron and steel with the aid of oxygen is extensively used nowadays in industry. This is based upon the ability of certain metals to burn in oxygen with the evolution of a great deal of heat thereby melting the metal and forming oxides.

CUTTING PROCESS

Oxygen cutting process consists of heating the metal to ignition or kindling temperature, causing rapid oxidization by supplying a jet of pure oxygen and blowing away the iron oxide thus formed and molten iron particles under the pressure of the oxygen gas.

From the foregoing, it will be appreciated, that only those metals can be flame cut whose oxidization temperature is below their melting point, as otherwise the metal would melt away before oxidization and no clean-cut edge could be obtained. Carbon steels with a carbon content upto 0.7 per cent and low-alloy steels are cut by this technique. High-alloy steels are preheated from 650 to 700°C before cutting. Metals which cannot be effectively cut by this method are : cast iron, since its melting point is equal to about 1200°C while its ignition temperature is about 1350°C ; high-alloy chromium and chrome-nickel steels, as the elements present in them, i.e., chromium, nickel, etc. retard the formation of oxides, and non-ferrous metals and alloys since the melting point of their oxides is higher than that of the base metals.

Oxygen cutting is performed by means of ordinary gas welding equipment except that the welding torch is replaced by a cutting torch which delivers the gas mixture for preheating and oxygen for burning the metal. This cutting torch has interchangeable nozzles with six small openings surrounding a large opening at the centre. When this torch is used, a mixture of oxy-acetylene gas is supplied through the small opening to preheat the metal at which rapid oxidization takes place. The preheating flame is made to play on the edge of the piece until a small area around the start of the cut is raised to the desired temperature. In practice, the start of a cut is usually heated until the surface layer of the metal is melted. Then oxygen at a high pressure is supplied through the central opening for cutting the metal. A uniformly wide slot, called the *kerf*, is cut by the jet of oxygen. The faster the rate of traverse, the more the bottom lags behind the top of the cut. The amount is called the *drag* and is evidenced by a series of curved lines on the sides of the kerf. Fine lines give a quality cut ; course one a fast or heavy cut (Fig. 9.28). The slag which is produced from the oxidation of the metal is blown off by the pressure of the gas. Cutting oxygen pressure varies with metal thickness, the shape of the cutting orifice, and oxygen purity. When oxygen pressure is insufficient, the progress of cutting is slowed down, slag accumulates on the bottom side of the cut, and the oxygen jet fails to cut through the entire depth of the piece. When oxygen pressure is too high, too much oxygen is consumed, the metal in the path of the cutting jet is cooled and the progress of cutting is likewise slowed down or hampered altogether. In addition the cutting jet diverges, and the cutting edges appear roughly and ragged. Optimum pressure for cutting oxygen in the case of steel 5 to 300 mm thick varies from 3 to 14 atm (300 to 1400 kN/m^2) gauge.

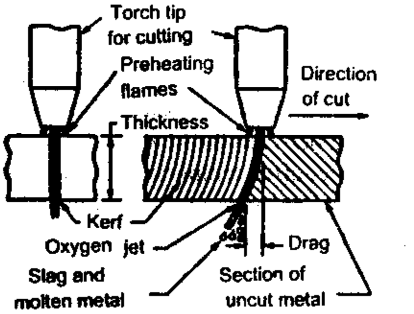


Figure 9.28 Principles of flame cutting

CUTTING MACHINES

Various cutting machines, semiautomatic and automatic have now been developed for the flame cutting of steel of practically any thickness.

In semiautomatic oxygen cutting machines, the torch is traversed by power but is guided by hand with the aid of various devices (tracks or guide bars, templates, disks, etc.). Such machines are widely used in industry and construction.

In automatic machines, not only is cutting torch travel mechanised, but the direction of the cut is controlled automatically. Stationary shape cutting machines can make straight or irregular cuts to produce the required shape. They incorporate mechanisms which either provide longitudinal and transverse movements of the working units or are designed with a jointed swivelling linkage. The cutting torches of these machines reproduce The movement of a magnetic tracing roller which follows the contour of a template, thus cutting out a part of the shape sufficiently accurate to eliminate subsequent machining in many cases.

On certain special machines cutting is performed to the contour of a template by a magnetic tracer head and to drawing or layout lines by means of a hand-guided head.

Machines have been developed with photo-electric tracing devices which follow the lines of a drawing ; machines, for cutting sheet metal ; remote-controlled machines, and machines in which a pantograph in the tracing device enlarges or reduces the size of the shape cut out in relation to the template.

OXYGEN LANCE CUTTING

Oxygen lance cutting is a process by which holes are pierced in heavy blocks of metal by a jet of oxygen passing through a steel pipe when the end is raised to kindling temperature and is placed against the surface of the piece to be cut.

A lance cut is started by raising the tip of the pipe, called the *lance*, to kindling temperature. This may be done with a welding torch, a carbon arc or by using the heat generated when current is passed from a welding source through a carbon plate clamped between the lance and The work.

After the lance is raised to the required temperature, oxygen is made to pass through the lance under a gauge pressure of 1 or 2 atm (100 to 200 kN/m^2). This causes the lance tip and the heated spot on the work to ignite. The oxygen pressure is raised to 5 or 6 atm (500 to 600 kN/m^2), and the lance is advanced into the workpiece. From this moment on, the cutting operation is sustained by the heat liberated by the oxidization of the metal. The slag formed during the operation flows out of the hole through the clearance between the walls of the hole and the lance.

The lance may be made from low-carbon steel. The cross-section of the lance varies with the depth of the hole to be pierced as well as with the pipe sizes available. Good results have been obtained with a thick-welled lance with an outside diameter of 17 to 19 mm and an inside diameter of 8 to 6 mm, respectively, with a low-carbon steel rod 5 mm in diameter inserted in the pipe.

The applications of oxygen lance cutting include the severing of plugs in blast furnaces, the removal of risers and sprues from steel casting, the making of centering holes in shafting, the opening of tap holes in blast-furnaces, etc.

ARC CUTTING

Arc cutting is based on melting the metal at the cut by the heat of an electric arc and blowing molten metal by a jet of air. The air is continually supplied under a pressure of at least 4 atm (400kN/m^2) into the torch (electrode holder), along the electrode and into the cut. In some torches air is supplied from the side. Both carbon and metal electrodes are employed in the arc cutting of metals.

A more recent addition is the *oxy-arc cutting process* using carbon electrodes. By this method, a jet of oxygen is passed on the molten metal some distance from the arc, and the oxygen readily oxidises the metal and removes both the oxidised and molten metal from the cut. The action is similar to that of gas cutting except that the preheat is supplied by an arc instead of a flame. A plasma-arc operation without the addition of filler metal is an effective means of cutting metal. The current is supplied by a dc welding generator.

Arc cutting is inferior to flame cutting both in quality and rate of cutting. This is only resorted to when the appearance of the kerf is not critical, or when for some reasons flame cutting cannot be used. Applications for arc cutting include cutting of cast iron, alloy steels, and nonferrous metals, as well as demolition and scarp cutting.

For the most part, good surface finish and accuracy are not obtained from electric-arc cutting, and the method is not as widely used as flame cutting . It is primarily used for wrought aluminium, copper and its alloys, and stainless steel, which are difficult to cut by gas alone.

9.16 HARD FACING

An important nonjoining application of various welding processes is hard facing, in which a lower strength but tough body is coated with a very hard and sometimes brittle surface layer. It is used not only for repair but also for the initial manufacture of cutting tools, rock drills, forging dies, and, in general, in applications requiring wear resistance.

The alloys used for hard facing resemble cutting tool materials.

They often have a high-alloying-element concentration and cannot be manufactured into welding rod. The ingredients are therefore incorporated in the flux coating or packed inside tubular rods, and the alloy is formed in the welding process itself. Arc as well as oxy–acetylene welding may be used.

Ceramic coatings are deposited from a *plasma arc* or with a special *detonation gun*. In the latter, the powder is shot onto the surface in a thin layer (5 μm) film by detonating an acetylene-oxygen mixture.

9.17 BRONZE WELDING

Bronze welding also called braze welding, is a process which is intermediate between true welding and true brazing. In brazing process, the edges or surfaces are not melted. Instead, a low melting alloy is introduced between them and a joint is produced by adhesion. In welding, the edges or surfaces are melted and a stronger joint is made of two similar metals.

In bronze welding, the edges or surfaces of the materials to be joined are only heated to a temperature which corresponds to the melting point of the bronze-filling rod used. The filler rod used for bronze-welding usually contains 60 per cent copper and 40 per cent zinc, a combination giving high tensile strength and ductility. Additional elements are silicon and tin which act as deoxidisers.

The process consists of cleaning the surfaces to be joined, heating them to a braze welding temperature that depends on the composition of the filler rod, and applying a flux for the purpose of removing any oxide present. Usually the source of heat is the oxy-acetylene flame, although bronze welding may be done with any suitable source of heat, such as muffle furnace, electric induction and the carbon-arc.

Metals with high melting points such as steel, cast iron, copper brass and bronze welded. The main advantage of bronze welding results from the low temperature of the operation. Less heat is needed and a joint can be made faster than by fusion welding. Dissimilar metals that cannot be joined by welding may be joined by bronze welding.

Bronze welding joints are not satisfactory for service at over about 250°C nor for dynamic loads of 1000 kgf per cm^2 (100000 kN/m^2) or more.

9.18 SOLDERING

Soldering is a method of uniting two or more pieces of metal by means of a fusible alloy or metal, called *solder*, applied in the molten state. Soldering is divided into two classifications : soft and hard.

Soft soldering is used extensively in sheet-metal work for joining parts that are not exposed to the action of high temperatures and are not subjected to excessive loads and forces. Soft soldering is also employed for joining wires and small parts. The solder, which is mostly composed of lead and tin, has a melting range of 150 to 350°C. A suitable flux is always used in soft soldering. Its function is to prevent oxidation of the surfaces to be soldered or to dissolve oxides that settle on the metal surfaces during the heating process. Although corrosive, zinc chloride is the most common soldering flux. Rosin is non-corrosive, but it does not have the cleaning properties of zinc chloride. A blow torch or soldering iron constitutes the equipment for heating the base metals and melting the solder and the flux.

Hard soldering employs solders which melt at higher temperatures and are stronger than those used in soft soldering. *Silver soldering* is a hard soldering method, and silver alloyed with tin is used as solder. The temperatures of the various hard solders vary from about 600 to 900°C. The fluxes are mostly in paste form and are applied to the joint with a brush before heating. In hard soldering, a blow torch constitutes the equipment.

There are a number of soldering techniques, but in each and every case the parts to be soldered must be thoroughly cleaned. For small light parts, the heat may be supplied by a soldering iron which must be large enough to carry enough heat to heat up the parts to just above the melting point of the solder. This consists of a copper bit bluntly pointed at one end and riveted to a steel shaft at the other, the steel shaft terminating in a wooden handle. Any source of clean heat is satisfactory for heating the bit. Usually, the bit is heated in gas or coke fire, cleaned, dipped in flux, and then rubbed on the solder to "tin" the bit. This coats the bit with solder and enables it to pick up molten solder and deposit it as required on the joint.

For larger parts, the surfaces may be tinned first by cleaning, heating, dipping in flux, and then by applying solder with a soldering iron or by dipping the parts in molten solder. The parts may then be assembled and heated together until the solder melts, The different compositions of solder for different purposes are as follows :

1. Soft solder - lead 37 per cent, tin 63 per cent.
2. Medium solder - lead 50 per cent, tin 50 per cent.
3. Plumber's solder - lead 70 per cent, tin 30 per cent.
4. Electrician's solder - lead 58 per cent, tin 42 per cent.

9.19 BRAZING

Brazing is essentially similar to soldering, but it gives a much stronger joint than soldering. The principal difference is the use of a harder filler material, commercially known as *spelter*, which fuses at some temperature above red heat, but below the melting temperature of the parts to be joined. Filler metals used in this process may be divided into two classes : copper-base alloys, and silver-base alloys. There are a number of different alloys in each class, but brasses (copper and zinc), sometimes upto 20 per cent tin are mostly used mainly for brazing the ferrous metals. Silver alloys (silver and copper or silver, copper and zinc) having a melting range of 600 to 850°C are suitable for brazing any metals capable of being brazed. They give a clean finish, and a strong ductile joint.

Like soldering, the parts to be joined by brazing are carefully cleaned, the flux applied, and the parts clamped in position for joining. Borax is widely used flux, but many proprietary brands are available. They are then heated to a temperature above the melting point of the spelter to be used, and molten spelter is allowed to flow by capillary action into the space between the parts and to cool slowly. The actual heating may be done in a number of ways. *Torch brazing* in which heating is done by a blow torch is very common. *Furnace brazing*, particularly in controlled atmospheres, is a favourite for production. Induction heating is useful to confine the heat to the joint, if general heating must be avoided. *Resistance brazing* is done on some small parts in production. *Immersion brazing* is used in large-scale production. The parts are cleaned and fluxed, clamped together, and then immersed into a tank of molten spelter.

9.20 WELDING OF VARIOUS METALS

Some welding methods as applied to different metals will now be described briefly.

Carbon steel. Carbon steels can be readily welded by forge welding, resistance welding, arc welding and gas welding. The chief trouble likely to be encountered when welding carbon steels by any fusion welding method is *cracking*, due to carbon " pick-up". Weld penetration into the parent metal causes diffusion of carbon from the work into the weld metal, thus resulting in embrittlement of the weld. Consequently, longitudinal cracks are produced along the centre of the weld. This carbon pick-up in the main weld can be prevented by coating the surfaces with a layer of weld metal before they are joined together, This layer picks up some carbon, but as it is not highly stressed on cooling it does not crack.

Steels containing high proportion of carbon require the preheating to about 400°C to produce reasonably soft weld metal, and to avoid cracking ; but steels with a carbon content of 0.25 to 0.3 per cent can be welded without preheating, provided that large runs are made.

It should also be noted that rapid cooling makes the weld metal hard and brittle, and thus it is advisable to ensure slow cooling by protecting it from chilling effects. It is possible to improve the properties of the weld by *peening*. This consists of subjecting it to a series of light, rapid blows by a small hammer. This should be done after the weld has solidified, but before it is cold. This helps to reduce distortion and to release internal stresses.

A neutral flame is used in gas welding, and different filler rods or electrodes are required for different qualities of carbon steel. A flux is always used except is the case of mild steel because of the presence of comparatively greater amount of silicon and manganese which act as deoxidisers and serve to protect the metal from being oxidized.

Alloy steels. This group of steel contains small amount of nickel, chromium, molybdenum or other elements, in addition to carbon. Preheating is always advisable when welding such steels, and slow cooling is essential if brittle or cracked welds are to be avoided. The use of correct welding rod relative to the composition of the steel is also vitally important.

Stainless steel. For stainless steels which harden on heating and cooling, the best method is electric butt welding, followed by prompt annealing at 750 to 800°C. They can also be welded by oxy-acetylene, and metal-arc welding methods. In all cases, oxidation must be prevented, and when oxy-acetylene welding stainless steel, a very slight acetylene surplus in the blowing flame is sometimes recommended to avoid the risk of having an oxidising flame, although carburisation produces brittle welds. The filler rod is usually fluxed before the for protection operation, of the weld.

A wide range of electrodes is available, in metal-arc welding suitable for welding stainless steel of various composition. They nearly all contain niobium, titanium, columbium, etc., which prevent the occurrence of the defect known as *weld decay*, which is worst hazard when welding this material. Careful cleaning of the edges to be welded and slag removal after each run are essential for obtaining a good quality weld.

Cast iron. Carbon may be present in cast iron in two forms : combined or free. During the formation of a weld in a cast iron base, both free and combined carbon go into the solution in the molten metal. Upon the removal of the welding heat, there is a quick solidification of the melted iron because of the cooling effect of the comparatively cold mass surrounding the place of welding and the cooling effect of the air to which it is exposed. Owing to the sudden cooling, a large amount of combined carbon is retained, and a hard metal in the weld is thus the result. Local preheating and slow cooling can overcome this difficulty. A preheating temperature of 600°C is recommended, and it is important that the full thickness that is to be welded is brought up to and kept at this temperature during the welding operation.

Before welding cast iron, a careful study of the job should be made to prevent uneven expansion or contraction of the casting. When one part of the casting is heated, the part expands, and considerable strain may result in some other parts. Since the metal has low ductility and will not stretch, the strain may be sufficient to break the unheated part. Indirect preheating on the unheated portion will prevent stresses which might cause cracking. A temperature of 200°C is sufficient for this purpose. Fig. 9.29 shows the application of direct and indirect preheat when repairing a crack in a casting by using welding process.

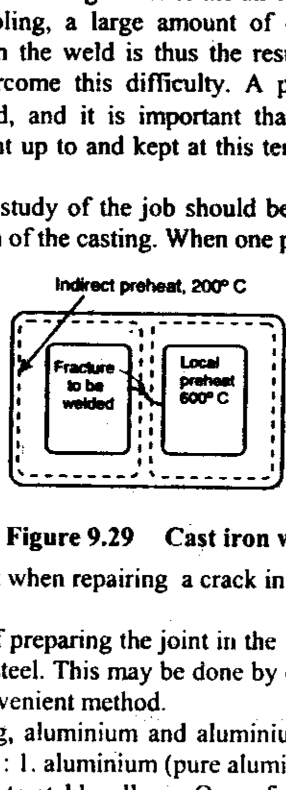


Figure 9.29 Cast iron welding

For welding cast iron, the practice of preparing the joint in the form of a *Vee* is followed in the same way as for steel. This may be done by chipping, machining, sawing, grinding, or any convenient method.

Aluminium. For purpose of welding, aluminium and aluminium alloys may be classified into three main groups : 1. aluminium (pure aluminium), 2. non-heat-treatable alloys , and 3. heat-treatable alloys. One of the most important rules in welding aluminium is to ensure the complete absence of any trace of oil or grease, and for this reason the work must be given a de-greasing treatment or the edges cleaned down to bright metal by filing or wire brushing.

Aluminium and most of the non-heat-treatable and heat-treatable alloys possess good weldability. In the case of hardenable alloys with copper and lead additives, there is a risk of hot cracking and therefore they are difficult to weld. Many casting alloys are also suitable for welding except in the case of those which have high content of copper or magnesium and thus they are unsuitable for welding.

Choosing of MIG or TIG welding depends on numerous factors. The TIG method is better for thin light-gauge materials, when there is a need for good surface finish and when welding is done from one side specially for welding pipes, and repairing castings. TIG welding of aluminium is generally done with alternating current.

The MIG method is used primarily in the case of thicker or heavy-gauge materials when high welding speed is a priority and also for long, continuous welds. Due to the lower heat input, MIG welding results in less distortion in the welding zone. For consistent, reliable feeding of soft aluminium filler wire, the push-pull type of equipment gives the best results.

For sheet aluminium, a neutral flame and a filler rod of the same material of the sheet material should be used. Sheet up to about 3 mm thickness is butt welded without bevelling, whilst for greater thickness bevelling to an included angle of 80 to 90° is necessary. Proprietary fluxes are available, and should be used sparingly by heating the rod and dipping it in the flux as required.

For castings, preheating is *always necessary*. The filler rod should be of the same composition as the casting, especially in the case of alloys containing copper or zinc, and a neutral flame should be used. The edges should be bevelled, wherever possible to an included angle of 80 to 90°. After welding, the castings should be cooled as slow as possible.

Copper. Only deoxidized copper can be welded satisfactorily. The flame should be neutral, and the filler rod should be an alloy of copper and silver. A deoxidising flux should be used and should be applied by coating the rod with it. The principal constituent of copper-welding fluxes is borax, but it is not advisable to use borax alone because it forms a hard scale which is difficult to remove. The work should be preheated owing to the high thermal conductivity of copper. Flanged joint or square edge preparation is usually done for thin plates, while double 'V' preparation is required for plates thicker than about 6 mm. After welding, the weld should be heated to a dull red heat and thoroughly hammered at this heat to restore its ductility.

9.21 INSPECTION AND TESTING OF WELDS

The main objective of inspection or quality control is to find the defects of weldments to ensure the high quality of products through the careful examination of the component parts at each state of manufacture.

The main defects of welded joints include :

1. Poor fusion– the lack of thorough and complete union between the deposited and parent metal. This is due to faulty welding conditions or techniques.
2. Under cut– a groove melted into the base metal adjacent to the toe of the weld. The reasons for undercutting are non-uniform feed of the welding rod, improper position of the electrode or torch tip or excessive heating.
3. Porosity– the formation of blow holes, gas pockets, or roughness on the surface of the weld. This is due to the presence of gases in the metal, moisture in the flux, or rust on the welded edges or filler metal.

4. Slag inclusions– the presence of nonmetallic substances in the metal. Slag inclusions are due to the contamination of the base and deposited metal by oxides, non-uniform melting of the electrode coating, high viscosity of the slag.
5. Cracks in the weld may arise from locked up stresses set up by non-uniform heating and cooling, excess sulphur or phosphorus in the weld metal, and some other causes.

Welds may be inspected and tested in a variety of ways depending on the nature and type of a given welded structure. In most cases weldments are : 1. Inspected visually for defects which can be detected by examination, 2. Tested for tightness, 3. Tested for mechanical strength and 4. Examined for hidden flaws by physical methods. So welded joints may be subjected to destructive and non-destructive testing, using the methods described in Chapter 3.

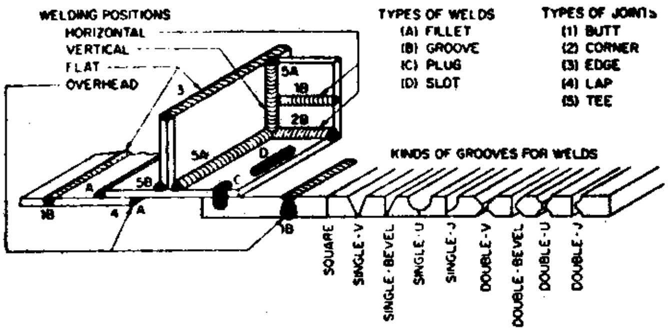


Figure 9.30 Types of welded joints

9.22 WELDED JOINTS AND EDGE PREPARATION

Common gas and arc-welding joints are illustrated in Fig. 9.30. Each joint has several elements. These are the type of the joint, the type of weld, and the penetration of the weld.

WELDED JOINTS

The relative positions of the two pieces being joined determine the type of joint. Five basic types of joints are used in fusion welding. These are ; butt, lap, T, corner, and edge joints. There are also several variations of each of these joints. The nature of the joint depends upon the kind and size of material, the process, and the strength required. A joint is selected in each case to fulfill requirements at lowest cost.

The *butt joint* is used to join the ends or edges of two plates or surfaces located approximately in the same plane with each other. For thickness from 2 to 5 mm, the open square butt should be selected, but thickness upwards of 5 mm, joints with edge preparation on one or both sides may be recommended.

The *lap joint*, as the name implies, is used to join two overlapping plates so that the edge of each plate is welded to the surface of the other. Common lap joints are single lap and double lap. The single-welded lap does not develop full strength, but it is preferred to the butt joint for some applications. The lap joint, however, may be employed for thickness under 3 mm.

The *T-joint* is used to weld two plates or sections whose surfaces are approximately at right angle to each other. Plates or surfaces should have good fit-up in order to ensure uniform penetration and fusion. This is suitable unto 3 mm and is widely employed in thin walled structures particularly.

The *corner joint* is used to join the edges of two sheets or plates whose surfaces are at an angle of appropriately 90° to each other. It is common in the construction of boxes, tanks, frames, and other similar items. Welding can be done on one or both sides, depending on the position and type of corner joint used. This is suitable for both light and heavy gauges.

Lap joints, T-joints, and corner joints are the *fillet weld* connections generally used. The rounding of a corner is known as filleting. Fillet welded joints are favored by designers in the interest of fabrication cost if the load conditions permit. There are three types of fillet welds: convex, flash and concave.

The *edge joint* consists of joining two parallel plates by means of a weld. This joint is often used in sheet metal work. The two edges can be easily and quickly melted down, eliminating the need for any filler metal. In heavy plates, where beveling the edges is done to get deeper penetration, some filler rod is needed.

EDGE PREPARATION

To obtain sound welds, good edge preparation is particularly essential, consisting in suitably beveling the edges, and carefully cleaning the faces to be welded from dust, sand, grit, oil and grease.

Different edge preparation is particularly used in fusion welding processes for welding butt joints are : (1) square, (2) single-V, (3) double-V, (4) single-U, and (5) double-U. The preparation of edges depends upon the thickness of metal being welded.

Square butt weld may be used for thickness of from 3 to 5 mm. Before welding, the edges are spaced about 3 mm apart.

Single-V butt welds are frequently used for metal over 8 mm thickness and up to about 16 mm thick. The edges forming the joint are beveled to form an included angle of 70° to 90° depending upon the welding technique to be used.

Double-V butt welds are used on metals over 16 mm thick, and where welding can be performed on both sides of the plate.

Single- and *double-U* butt welds are used on metals over 20 mm thick. These joints are having reliability and require less filler rod.

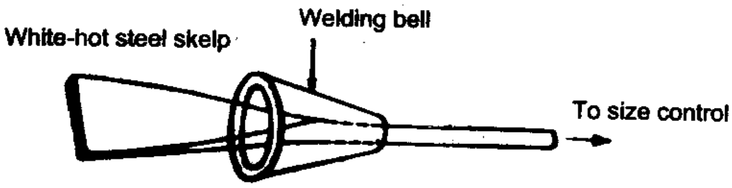


Figure 9.31 Welding bell process for pipe manufacturing

9.23 WELDING OF PIPES

It has been mentioned in Article 7.4 that pipes can be produced by piercing. However, considering economy of manufacturing presently pipes are produced by welding processes. Some of the useful methods of pipe manufacturing are described hereunder.

Welding bell process. The fusion process used in this method limits the manufacturing of pipes up to 80 mm diameter. The setup consists of a conical shape welding bell through which the white-hot steel thin sheet called *skelp* is drawn with the help of pulling tongs. The skelp is heated in a furnace to a state of plasticity. The edges of the skelp are gradually folded inwards to a round shape until the edges come in compression contact and

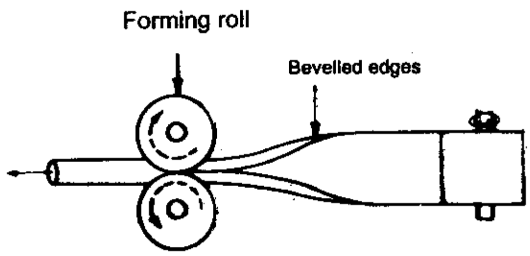


Figure 9.32 Rolled forming welded pipe

butt–welded. Fig. 9.31 shows the method.

Roll forming welded pipes. This is another method of fusion technique where the skelp is rolled through precision rolls which folds the sheet in round shape and the two sides of the edges come in compression contact. This is a continuous process and the manufactured pipe is cut to standard length by using flying sheer or saw. This method is more sophisticated than the previous one and the diameter of pipe upto 400 mm can be produced in this technique. Fig. 9.32 shows the process.

Pipe forming by rolling electrodes. A roll of strip (skelp) is unwound and passed through a set of forming rolls to take the shape of a pipe. The skelp then moves to the resistance welding unit in which electrodes on each side of the joint fuse the joint as compression force is applied. Two guiding rollers thereafter maintain pressure to straight the pipe. High quality steel pipes are produces in this way. As the process is continuous a flying shear is utilised to cut the pipe in standard length. Fig. 9.33 shows the process.

Electric resistance butt seam – welding (ERW Process). In this

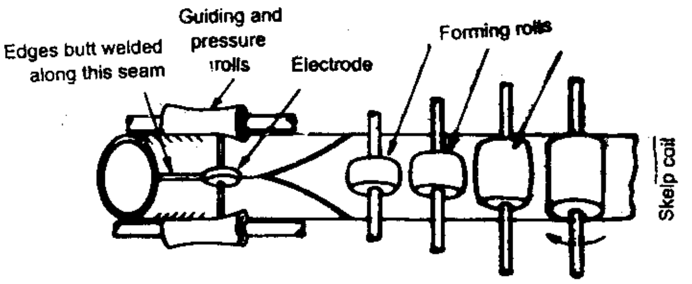


Figure 9.33 Pipe forming by rolling electrodes

process, a metal strip (or plate) of suitable thickness is formed into the shape of a pipe with the help of two pressure rolls. The ends of the plate are brought in contact with two electrodes in the form of split roller wheels.

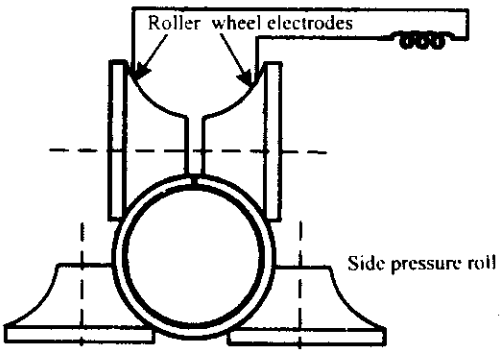


Figure 9.34 Electric resistance butt seam welding for pipe manufacturing.

The high current passes through the electrode to form the butt joint of the welded pipe. Voltage across the electrodes is kept low. Shearing is used in the similar manner as stated in the previous method. Figure 9.34 shows the process. **Roller wheel electrode Side Pressure roll Roller wheel electrode Side Pressure roll**

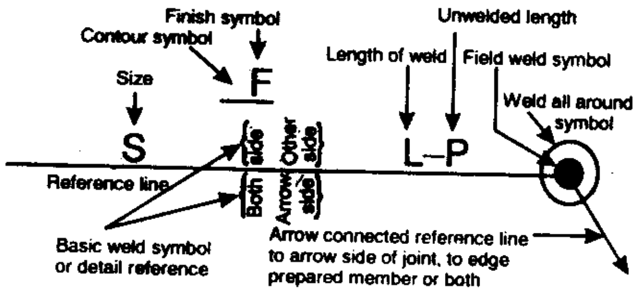


Figure 9.35 Representation of welds (Indian Standard)

9.24 REPRESENTATION OF WELDS (INDIAN STANDARD)

The scheme adapted in this Standard (IS : 813-1961) for representation of welds on drawings of the components, requires the use of the following elements :

1. A basic symbol to indicate the type of weld.
2. An arrow and reference line to indicate the location of the weld in a joint.
3. Supplementary symbol to indicate special instructions, such as finish, weld-all-round, etc.
4. Dimensions of the weld in cross-section and in length, where required.

The elements for the representation of welds shall have specific locations with respect to each other, as shown in Fig. 9.35.

9.25 SAFETY IN WELDING

Welding is associated with several types hazards to health and safety. The workshop / welding shop should be well ventilated to reduce fumes and hazardous gases generated during welding. The following factors must be considered:

1. *Optical radiation*- The welding process produces a large quantity of visible light, ultraviolet and infrared. Exposure to the radiation from an arc causes burns to the skin, and damage to the eyes. For this reason, welders need to wear clothing to protect their bodies and arms, regardless of the weather conditions. They also need efficient eye protection, which is usually supplied in the form of a protective shield. The precise choice of the shade of glass filter in these shields depends on the type of welding operation, since they vary in their light output.

2. *Fumes*- Welding vapourises metals, and other contaminated materials, traced on the surface. This gives rise to fume, which is condensed to fine precipitates. The fume is mostly oxides of the metals, including any alloying elements, but it also contains gases produced in the arc, such as ozone or

oxides of nitrogen, and decomposed products from any paint or coating which was on the metal surface. The nature and quantity of this fume depends critically upon the welding process, the materials and the welding parameters. Some are harmful to health; for instance stainless steel fume contains chromium, and welding galvanised steel produces zinc fume.

3. *Burns and Mechanical Hazards-* Welders need good quality gloves, safety boots or shoes and good quality cap and overalls. A leather apron may also be needed. Welding produces quantities of molten droplets of metal which are scattered in all directions. It is essential that the welder wears clothing which will not burn or melt, and which is stout enough to provide adequate protection.

TABLE 9.8 ISO 4063 CLASSIFICATION OF WELDING PROCESSES

No	*Process*	*No*	*Process*
1	**Arc welding**	**3**	**Gas welding**
11	Metal-arc welding without gas protection	31	Oxy-fuel gas welding
111	Metal-arc welding with covered electrode	311	Oxy-acetylene welding
112	Gravity arc welding with covered electrode	312	Oxy-propane welding
113	Bare wire metal-arc welding	313	Oxy-hydrogen welding
114	Flux cored metal-arc welding	32	Air fuel gas welding
115	Coated wire metal-arc welding	321	Air-acetylene welding
118	Firecracker welding	322	Air-propane welding
12	Submerged arc welding		
121	Submerged arc welding with wire electrode	**4**	**Solid phase welding; pressure welding**
122	Submerged arc welding with strip electrode		
13	Gas shielded metal-arc welding	41	Ultrasonic welding
131	MIG welding	42	Friction welding
135	MAG welding metal-arc welding with non-inert gas shield	43	Force welding
		44	Welding by high mechanical energy
136	Flux cored metal-arc welding with non-inert gas shield	441	Explosive welding
14	Gas-shielded welding with non-consumable electrode	45	Diffusion welding
		47	Gas pressure welding
141	TIG welding	48	Cold welding
149	Atomic-hydrogen welding		
15	Plasma arc welding	**7**	**Other welding processes**
18	Other arc welding processes	71	Thermit welding
181	Carbon arc welding	72	Electroslag welding
185	Rotating arc welding	73	Electrogas welding
2	**Resistance welding**	74	Induction welding
21	Spot welding	75	Light radiation welding
22	Seam welding	751	Laser welding
221	Lap seam welding	752	Arc image welding
225	Seam welding with strip	753	Infrared welding
23	Projection welding	76	Eelectron beam welding
24	Flash welding	78	Stud welding
25	Resistance welding	781	Arc stud welding
26	Other resistance welding processes	782	Resistance stud welding
29	HF resistance welding		

REVIEW QUESTIONS

1. What are the different methods of welding? Describe them in brief.
2. What do you understand by gas welding? (b) Describe in brief the equipment required for oxy-acetylene welding. (c) How are neutral, oxidizing and reducing flames obtained in a welding torch ?
3. What procedure you will follow and what care you will take in operation (i) a low pressure plant. and (ii) a high pressure plant.
4. What is the principle of operation of electric arc welding ?
5. How do you ac and dc compare for arc welding ? (b) What are the advantages of each of the several sources of current for arc welding ? (c) What do you understand by the term 'polarity' and what is the advantage/disadvantage of having different polarities?
6. What are the functions of coatings on shielded electrodes?
7. Describe and explain the following welding methods giving their advantages, limitations and specific applications: (1). MIG, (2). TIG, (3). Plasma-arc, (4). laser-beam, welding, (5). submerged arc, (6). Electro-slag, (7). electron beam.
8. What are principles of operation of resistance welding ? Describe (1). upset-butt, (2). flash-butt, (3). spot, (4). projection, and (5) percussion, welding giving their relative merits and limitations.
9. What are ultrasonic welding, and what ate its advantages?
10. What is solid state welding and what are its advantages?
11. What is the principles of thermit welding? What can it do better than other processes ?
12. Write short notes on : (1) leftward, (2) rightward, and (3) vertical, welding.
13. Describe how flame cutting is done stating its principle. Describe fully the method of oxygen cutting. State the difference in oxygen and arc cutting? Which one is preferred and why ?
14. Describe and explain (1). hard facing, (2). brazing, and (3). soldering stating the principal difference between them. Also state their specific applications.
15. Describe in brief the methods/procedures used for welding different metals.
16. What are welding joints and edge preparation, and welding representation and what they do ?
17. Describe any two methods for producing pipes at high rate.

10

WOOD AND WOOD WORKING

10.1 INTRODUCTION

Carpentry and *joinery* are common terms used with any class of work with wood. Strictly speaking, carpentry deals with all works of a carpentry such as roofs, floors, partitions, etc. of a building, while joinery deals with the making of doors, windows, cupboards, dressers, stairs, and all the interior fitments for a building.

Timber is the basic material used for any class of wood working. The term 'timber' is applied to the trees which provide us with wood. Wood is one of the most valuable bio-degradable raw materials of industry and daily uses. It is available in a wide choice of weights, strength, colours and textures. Wood is having good machining characteristics and can be sliced, bent, planed, sawed and sanded.

10.2 STRUCTURE OF WOOD

The trees are known as outward growers, due to the fact that each year a new layer of tissue is formed on the outside of previous layers. The layers are termed *annual rings*, because most trees produce one ring each year. Each annual ring is composed of an open porous layer known as springwood, due to the rapid growth in spring, and a thinner denser layer called autumn wood, due to the slowing down of the growth in late summer and autumn. In spring the outer rings of the tree known as *sapwood* convey the watery sap from the roots up to the leaves. Here it undergoes certain chemical changes, and on its return journey to the roots in autumn, this perfected sap leaves behind various starchy secretions, gums, or resins, according to the type of tree. These substances fill up the tissues, feed the tree, and help to form a denser wood known as Doormen or *heartwood*. The heartwood is dead as far as the growth of the tree is concerned. The cambium layer situated between the sapwood and the bark is responsible for the formation of new wood each year. It divides up, forming a layer of new wood cells on the inside and a soft layer on the outside which becomes bark. Each year the innermost layer of sapwood becomes transformed into heartwood. Fig.10.1 shows the cross section of a log.

It is generally understood that heartwood is the only part of the tree which should be converted for use, as sapwood is more prone to attack from wood-destroying organisms. If sapwood is properly treated with an effective preservative, it is as durable as heartwood, similarly treated, when used under conditions favourable to decay. The difference in colour between sapwood and heartwood is most important when choosing wood for joinery, the decorative value of which depends on the dark colour and grain of the heartwood. Treating with preservatives is useless and staining is very difficult, as sapwood absorbs stain more readily than heartwood and takes on a much darker shade. Therefore, for all joinery work it is better that sapwood be eliminated altogether.

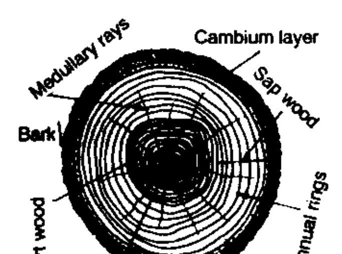


Figure 10.1 Cross section of a log

10.3 GRAIN IN WOOD

The word *grain* as applied to wood is indeterminate in its meaning. Conversationally it refers to the appearance or pattern of the wood on any of its cut surfaces. The figure or pattern of a wood is due to variations of ring growth and of colour in the wood, together with the influence of knots. This pattern is preferably not referred to as "grain".

An *open-grained wood* such as oak has minute pores over its exposed surface. In standard wood-finishing methods, these pores are leveled with a coat of filler. A *close-grained wood* such as fir or pine has no such pores in its surface.

The grain of the wood also refers to the direction of the cellular or fibrous structure of the wood, which is the longitudinal direction. Timbers for structural use must be so cut that the grain runs parallel to the length of the timber ; otherwise there is a marked reduction in strength.

In a traverse section the log of wood looks like a series of concentric circles due to annual rings. The tangential plane is a plane at a tangent to these circles ; the radial plane follows a diameter and passes

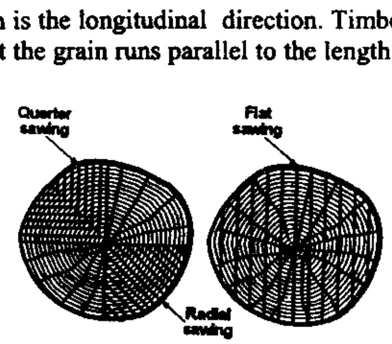


Figure 10.2 Methods of cutting logs

through the centre. Planks sawed tangentially to the annual rings are termed *flatsawn*. Giving a *flat grain*, while radially cut planks are termed *quarter-sawed*, giving an *edge grain*. If the annual rings are approximately at 45° to the face of the plank, the condition is called *angle grain*. *Cross grain* refers to a plank whose fibres are not parallel to the long axis of the plank. Figure 10.2 shows the methods of cutting logs.

10.4 SEASONING OF WOOD

The advantages of seasoning are that it makes the timber lighter in weight, more resilient, and less liable to twist, warp, and split. It is also in a better condition to retain its size and shape after being made into a piece of joinery. Wood increases in strength, hardness and stiffness as it dries. There are two methods of drying or seasoning :

Natural seasoning : This is also known as *air drying*. In this method the balks (roughly squared logs) are stacked under cover with spacers in between, so that a free circulation of air is provided all round them. This method is slow, but gives the best results. A further period of seasoning should take place after the balks are sawn up and converted into planks or boards. This is to help dry out the interior of the timber which has been exposed by sawing.

Artificial seasoning : In the *artificial seasoning* method, the period of seasoning is very much reduced, a matter of two or three weeks being sufficient, according to the size or species of timber to be seasoned. The timber is stacked on a special truck and wheeled into a chamber which is then sealed. Hot air is circulated by fans, and a certain amount of steam is added in order to retain the correct humidity. Samples are tested at intervals to ascertain the percentage of moisture remaining in the timber. Seasoned timber still contains a proportion of moisture, which varies from 16 to 22 per cent according to the seasoning conditions, and this need not be dried out any further if intended for use out-of-doors.

If used for interior work or in a heated atmosphere, the timber should be further conditioned, that is, dried in warm-air kilns, or stored in a similar atmosphere to that in which it will be fixed, until the moisture contents is brought down to the region of 8-12 per cent.

Moisture content is the ratio of amount of water in a sample, and the dry weight of the wood sample itself, expressed as a percentage.

10.5 COMMON DEFECTS IN TIMBER

Seasoning defects : As the moisture evaporates during seasoning, shrinkage of the timber takes place. If a balk is dried too quickly, splits and cracks will appear. Shrinkage in the length is negligible, but it is more pronounced in the direction of the annual rings.

Sapwood shrinks more than *heartwood*, so that a board cut from the outside of a log will shrink more, and have a greater tendency to warp, than one cut from the centre. The timber stored after felling the tree will also undergo the above shrinkages and may show *radial splits* in dry and hot environment.

Timber which has been stored in a damp atmosphere shouid not be converted into a piece of joinery and then fitted into a warm room. The result will be rapid shrinkage, warping, twisting and splitting.

Due to uneven drying during seasoning, the timber may warp or twist. Fig.10.3(a) shows three types of defects : crook, bowing and end splits.

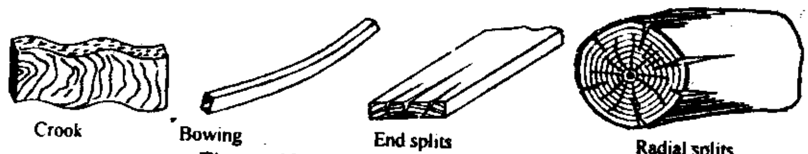


Figure 10.3(a) Seasoning defects

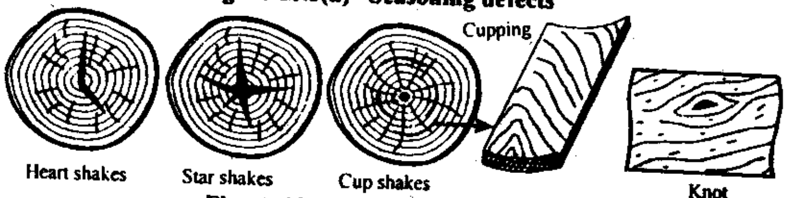


Figure 10.3(b) Natural defects

Source Petit Tom, 1977,Woodwork Made Simple, Heinemann, London

Natural defects : Heart shakes are single splits occurring in the standing tree and cannot be seen till the tree is felled. A number of such shakes radiating from pith is known as *star shakes*. If annual rings separate, cup shake is formed. The growth of branches also form a knot distorting the grain of the timber. Fig. 10.3(b) shows some of the natural defects.

Pitch is another defects in the timber when resinous materials accumulate with in the wood.

Defects due to destructive agents : These defects include *worm holes* and *fungi-decay*. Wormholes are small holes in the wood caused by insects (termite, marine-borer and beetles) boring through the wood.

There are number of wood destroying *fungi* which attack standing timber, felled timber and conditioned timber.

Defects due to manufacturing/cutting : Some of the manufacturing defects are (1) cross grain, (2) machine burn.

Cross-grained wood is defined as wood in which the cells / fibres run at an angle with the axis, or sides, of the piece.

Machine burn is usually caused by planer blades that are dull or spur and can be seen as dark streaks along the face of the boards.

ISO classification : The ISO (The International Organisation for Standardization) classifies the defects as per ISO 2299-1986. These are :

2.1 Knots, 2.2 Shakes, 2.3 Irregularities of wood structures and abnormal colourisation of wood, 2.4 Defects caused by fungi, 2.5 Defects caused by insects, 2.6 Sawing defects and deformation.

Each of the classes is further divided to subclasses and each of the subclasses is further divided in sub-subclasses.

10.6 CLASSIFICATION AND CONVERSION OF WOOD

CLASSIFICATION

Timbers, for commercial purposes, are divided into two classes : (1) soft wood, and (2) hard wood. These two terms however, have no reference to the hardness of the wood and they are only two botanical classifications.

Soft woods belong to conifers which have long narrow leaves. They contain turpentine and resinous matters in their cells. The average soft-wood contains about 42 per cent cellulose, 25 per cent hemicellulose, 30 per cent lignin and 3 per cent miscellaneous items. Lignin also known as 'wood glue' holds the other items together in the wood. It can be converted into vanillin or other resinous materials useful for foundry mould. Soft woods are light in weight and light coloured, have distinct annual rings but no visible medullary rays, and the colour of the sapwood is not distinctive from their heartwood. The fibres are generally coarse but straight, and hence, capable of resisting direct axial stresses ; but they cannot resist any kind of stress developed across their fibres and the timber gets splitted easily.

Hard woods belong to broad-leaved trees. An average hard-wood consists about 45 per cent cellulose, 25 per cent hemicellulose, 23 per cent lignin and 7 per cent miscellaneous items. The annual rings are more compact, thin and less distinct, but the medullarly rays are visible in most, and in some cases very pronounced. Hard woods are darker in colour, comparatively heavy. The fibres are fine grained, compact, properly bonded, and often found very straight. So hard woods are nearly equally strong both along and across the fibres and can resist axial stress as well as transverse strain, shock and vibration quite satisfactorily.

Non-resinous or hard woods like Sal, Pyingads and Ash, which do not readily catch fire, are sometimes classed as *refractory* ; and the resinous or soft wood like Deodar. Pine, and Fir, which readily catch fire and burn because of the presence of resinous matter, are classed as *non-refractory*.

CONVERSION

After a tree is felled it is stripped of its branches and is then known as "log". The cutting of the log into usable pieces of timber is called conversion. The following are the common market forms of timber :

Log is the felled tree after being trimmed.

Balk is the log squaring up.

Planks	:	275 to 450 mm wide and 75 to 150 mm thick.
Deals	:	Unto 225 mm wide and 50 to 100 mm thick.
Batten	:	Unto 135 mm thick and over 150 mm wide.
Quartering	:	25×25 mm^2 unto 150×150 mm^2 stuff.
Scantling	:	Odd-cut stuff, such as 75 mm × 50 mm, 100 mm × 50 mm, 100 mm × 75 mm, etc.

10.7 COMMON VARIETIES OF INDIAN TIMBER

Indian timbers most commonly used for various wood-works are as follows:

Babul. The wood is pale red to brown in colour, close-grained, hard and tough, but elastic, and takes a good polish. They grow abundantly all over India and are used for bodies of carts and wheels, agricultural implements, tool-handles, etc.

Mahogany. The wood is of red brown colour, very durable when kept dry. Usually, it has fine, wavy grains, and uniform colour, It contains resinous oil which prevents attack of insects. They are available in Himalayas and used for pattern-making and cabinet work.

Mango. The wood is of inferior quality, coarse and open grained and of deep gray colour. They decay readily when exposed to moisture and are greedily eaten by white ants. They are largely found all over India, and being plentiful and cheap, widely used for common doors, windows, and furniture.

Sal. The wood is of a dark brown colour, hard, close-grained heavy, resistant to white ants and durable. It seasons slowly, is hard to work and does not take a high polish, They grow abundantly in the forests at the foot of the Himalayas—in U.P., Bihar, and Assam—also in Central India and South India and largely used for constructional purposes.

Sissu. They wood is dark brown in colour, tough , durable and has well-marked coarse grains. It is one of the best Indian woods for joiner's work—tables, chairs, and other furniture and is widely distribute in Northern and Northern and Central India.

Teak. The wood is brown in colour, straight-grained, and is fragrant when freshly cut, very strong and durable, yet light and easily worked. It shrinks little, takes a smooth polish, and can be seasoned quickly. They are available in large quantities in Burma, Malabar and Central India, and suitable for practically every description of work.

10.8 CARPENTRY TOOLS

In order to successfully work different forms to accurate shapes and dimensions, the wood-worker must know the use of a large number of tools. The principal types which are manipulated by hand are described and illustrated below :

1. Marking &measuring tools.
2. Cutting tools.
3. Planing tools.
4. Boring tools.
5. Striking tools.
6. Holding & miscellaneous tools.

10.9 MARKING AND MEASURING TOOLS

Marking and measuring tools have been developed in order that true and accurate work may be assured. The commonest of such tools are :

Rules. Rules of various sizes and designs are used by wood workers for measuring and setting out dimensions, but they usually work with a *four-fold box-wood rule* ranging from 0 to 60 cm. This is graduated on both side in millimetres and centimetres, and each fold is 15 cm long. All the four pieces are joined with each other by means of hinged joints which make the scale folding.

For larger measurements carpenters use a *flexible measuring rule* of *tape*. Such rules are very useful for measuring curved and angular surfaces. When not in use, the blade is coiled into a small, compact, watch-size, case.

Straight edge. The straight edge (Fig. 10.4) is a machined flat piece made of wood or metal having truly straight and parallel edges. One of the longitudinal edges is generally made leveled. This is used to test the trueness of large surfaces and edges.

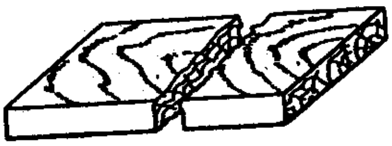


Figure 10.4 Straight edge

Try square. Try squares (Fig. 10.5) are used for marking and testing angles of 90°. It consists of a steel blade, riveted into a hard wood stock which has a protective brass plate on the working surface. Another type is the all-metal square, with steel blade and cast iron stock. Sizes vary from 150 to 300 mm, according to the length of the blade.

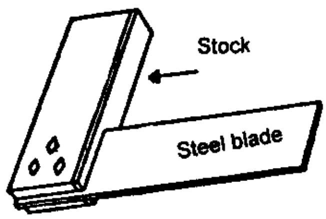


Figure 10.5 Try square

Mitre square. Mitre squares (Fig. 10.6) are used to measure an angle of 45°. They are made of all metal with a nickel-plated finish or with a steel blade, and an ebony or rose-wood stock. The blade varies from 200 mm, 250 mm and so on to a maximum of 300 mm long.

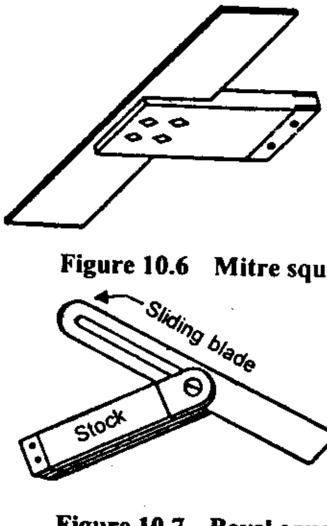


Figure 10.6 Mitre square

Bevel square. The bevel square shown in Fig. 10.7 is similar to the try square but has a blade that may be swivelled to any angle from 0 to 180°. This tool is adjusted by releasing with a turn screw of suitable size in a machine screw running in a slot in the blade.

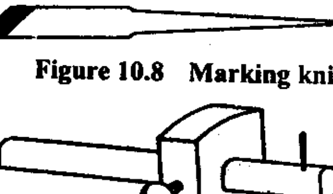


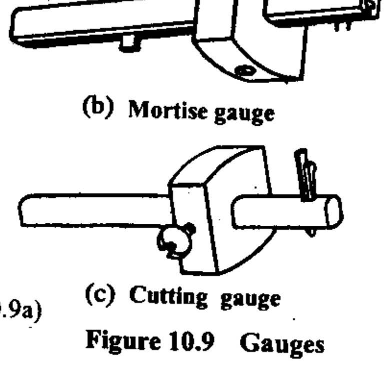
Figure 10.7 Bevel square

Combination square. Some wood workers prefer a combination square which is similar to the combination set used in bench work. It is a combination of a square, 45 - degree bevel, set square, rule, straight edge, and centre finder.

Figure 10.8 Marking knife

Marking knife. Marking knives (Fig. 10.8) are used for converting the pencil lines into cut lines. They are made of steel having one end pointed and the other end formed into a sharp cutting edge.

Gauges. Gauges are used to mark lines parallel to the edge of a piece of wood. It consists of a small stem sliding in s stock. The stem carries one or more steel marking points or a cutting knife. The stock is set to the desired distance from the steel point and fixed by the thumbscrew. The gauge is then held firmly against the edge of the wood and pushed along the sharp steel point marking the line.



(a) Marking gauge

(b) Mortise gauge

(c) Cutting gauge

Figure 10.9 Gauges

The *marking gauge* (Fig.10.9a)

has one marking point. It gives an accurate cut line parallel to a true edge, usually with the grain. The *panel gauge*, is longer than the marking gauge, and is used to gauge lines across wider surfaces.

The *mortise gauge* (Fig. 10.9b) has two marking points-one fixed near to the end of the stem and the other attached to a brass sliding bar. These two teeth cut two parallel lines, called mortise lines.

The *cutting gauge* (Fig. 10.9c) has a cutting knife held in position by a wedge so that its projection may be varied for the depth of the cut. This gauge is useful for gauging fine deep lines for such joints as dovetails on wide wood, for cutting the edges of grooves, for inlaying, cutting through very thin stuff to make small strips, and cutting small rebates.

Wing compass. Wing compasses are composed of two finely pointed steel legs which are set to the desired position and held by a set screw and quadrant. They are used when stepping off a number of equal spaces, marking circles or arcs, and when scribing parallel lines to straight or curved work.

Trammel. The trammel is a form of beam compass, with a wooden beam, to take in work that is beyond the scope of a compass.

Divider. Dividers have both points sharpened in needlepoint fashion for dividing out centres.

Caliper. Calipers are used for measuring outside and inside diameters etc., especially where the sectional measurements cannot be taken.

Spirit level and plumb bob. These are used for testing the position of large surfaces. The spirit level tests for horizontal position. The plumb bob tests for vertical position . A combination of these two gives a right angle, and they are used where a try square would be far too small.

10.10 CUTTING TOOLS

Cutting tools include saws, chisels, and gouges.

Saws. The saw is probably the most abused of woodworking tools, chiefly because inexperienced users force it too much. When cutting across the grain, a different action is required from the saw teeth than when ripping with the grain. Therefore, different types of saws are used, as one type cannot do both jobs successfully. A saw is generally specified by the length of its blade measured along the toothed edge, and pitch of teeth, expressed in millimeters. Fig. 10.10 shows the different types of saws in common use.

Rip saw. Rip saws are used for cutting along the grain in thick wood. The blade is made of high grade tool steel, and may be either straight or skew backed. It is fitted in a wooden handle made of hard wood by means of rivets or screws. Rip saws are about 700 mm long with 3 to 5 points or teeth per 25 mm.

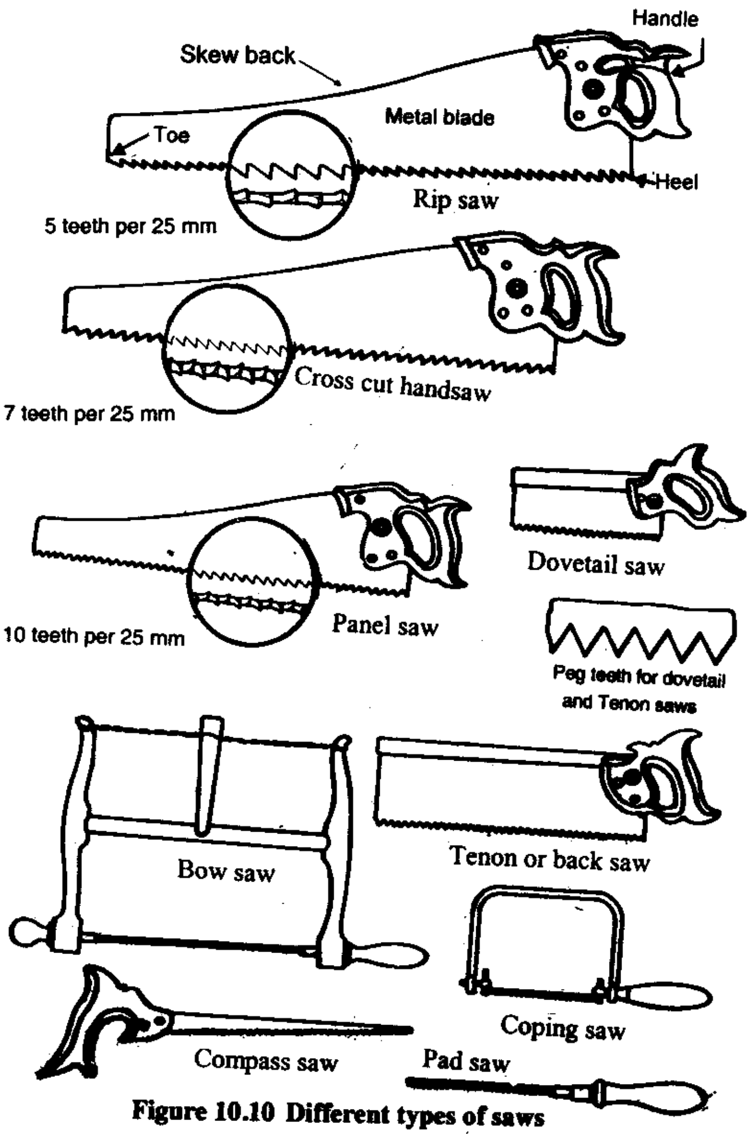


Figure 10.10 Different types of saws

The front or leading edge of the tooth forms a right angle with a line joining the points, and should be filed squared across the saw, with no bevel on front or back of the tooth. The action of these teeth is that of a series of chisels, which tear out shavings each equal to the width of a tooth.

The teeth are bent alternately, one to the right, the next to the left.

Bending the teeth in this manner is called "setting in saw". Please refer Section 14.11. The set of a saw provides clearance to prevent the blade from binding during the sawing operation.

Cross-cut saw. Cross-cut saws, or "hand saws" as they are sometimes called, are used for cutting *across* the grain in thick wood. They are 600 to 650 mm long with 8 to 10 teeth per 25 mm. The action of the teeth is that of a series of knives which sever the fibres and force out the waste wood in the form of saw dust.

Panel saw. A panel saw is about 500 mm long with 10 to 12 teeth per 25 mm and is very much like the cross-cut saw. It has a finer blade and is used for fine work, mostly on the bench. This is often used for ripping as well as cross-cutting. The teeth have slightly more hook than those of a cross-cut saw.

Tenon or back saw. This saw is mostly used for cross-cutting when a finer and more accurate finish is required. The blade, being very thin, is reinforced with a rigid steel back. Tenon saw blades are from 250 to 400 mm in length and generally have 13 teeth per 25 mm. The teeth are shaped in the form of an equilateral triangle and are sometimes termed "peg" teeth.

Dovetail saw. A smaller version of the tenon, this saw is used where the greatest accuracy is needed and fine shallow cuts are to be made. The number of teeth may be from 12 to 18 per 25 mm, while the length may vary from 200 to 350 mm.

Bow saw. The bow saw consists of a narrow blade. 250 to 350 mm long held in a wooden frame. The blade is held in tension by twisting the string with a small wooden lever. These saws are used for cutting quick curves, and, as the handles revolve in their sockets, the blade can be adjusted to any desired position when in use.

Coping saw. The coping saw has a very similar blade, held rigid in spring-metal frame. The blade is tensioned by screwing the handle. This saw is used for small radius curves.

Compass saw. The compass saw is used for sawing small curves in confined spaces and has a narrow tapering blade about 250 to 400 mm long, fixed to an open-type wooden handle. There are two types of compass saw, one having a fixed blade and the other with three interchangeable blades of different widths.

Pad or keyhole saw. This is the joiner's smallest saw, the blade being about 250 mm long. The blade of the pad saw is secured to the handle, through which it passes, by two screws. This arrangement allows the blade to be adjusted to the best length required according to the work. This saw is used for cutting key holes, or the starting of any interior cuts.

Chisels. Wood chisels most commonly in use include firmer chisels, either square of bevel edged, paring chisels, and mortise chisels.

They are usually specified by length and width of the blade.

Firmer chisel. The firmer chisel(Fig. 10.11) is the most useful for general purposes and may be used by hand pressure or mallet. It has a flat blade about 125mm long. The width of the blade varies from 1.5-50 mm.

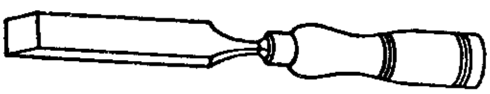


Figure 10.11 Firmer chisel

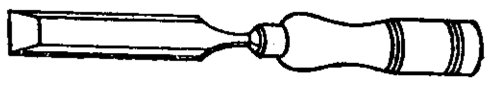


Figure 10.12 Beveled edge firmer chisel

Beveled edge firmer chisel. The beveled edge firmer chisel (Fig. 10.12) is used for more delicate or fine work. They are useful for getting into corners where the ordinary firmer chisel would be clumsy.

Figure 10.13 Paring chisel

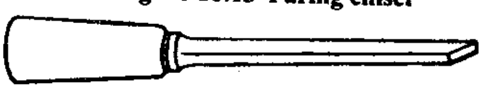


Figure 10.14 Mortise chisel

Paring chisel. Both firmer and beveled edge chisels when they are made with long thin blades are known as paring chisel (Fig. 10.13). This is used for shaping and preparing the surfaces of wood and is manipulated by the hands. The length ranges from 225 to 500 mm and width from 5 -50 mm.

Mortise chisel. The mortise chisel shown in Fig. 10.14, as its name indicates, is used for chopping out mortises. These chisels are designed to withstand heavy work. They are made with a heavy deep (back to front) blade with a generous shoulder or collar to withstand the force of the mallet blows on the oval-sectioned handle. Many mortise chisels are fitted with a leather washer at the shoulder to absorb the hard shocks of the mallet blows. Blades vary in width from 3-16 mm.

Gouges. Gouges (Fig. 10.15) are chisels with curved sections and may be either inside or outside ground. Inside ground gouges are used in exactly the same way for inside curved edges as a chisel would be for straight one ; outside ground gouges are used for curving hollows. Outside ground gouges are known as *firmer gouges* and inside ground gouges are called *scribing gouges.* When the later are made long and thin they are

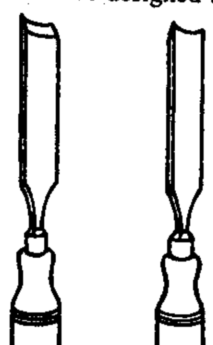


Figure 10.15 Gouges

paring gouges. Gouges are made to a large number of different curves for different work, and the size ranges from 6 mm, with intermediate sizes to a maximum of 40 mm wide.

10.11 PLANES

The plane can be likened to the chisel fastened into a block of metal or wood, and its blade cuts exactly like a wide chisel. The planes, in general use, are the jack, trying, and smoothing planes, and are known as bench planes. Besides, there are other planes which are used for special work.

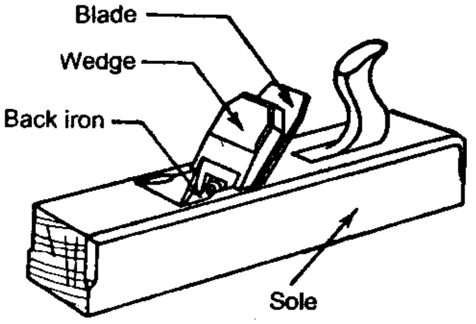


Figure 10.16 Jack plane

Jack plane. A jack plane shown in Fig. 10.16 is the commonest and is used for the first truing-up of a piece of wood.

It consists of a block of wood into which the blade is fixed by a wooden wedge. The blade is set at an angle of 45° to the sole. On the cutting blade another blade is fixed called cap iron or back iron. This does not cut, but stiffens the blade near its cutting edge to prevent chattering and partially breaks the shaving as it is made. It is the back iron which causes the shavings to be curled when they come out of the plane. Some types of planes do not have a cap iron. Jack planes are obtainable from 350 to 425 mm in length and with blades 50 to 75 mm wide.

Trying plane. The trying plane (Fig. 10.17) is a finishing plane, and is set with a very fine cut . It is used for producing as true surface or edge as possible, and is set to cut a shaving as thin as the smoothing plane. The length of the plane varies from 550 to 650 mm and the section of the body is 85 mm by 85 mm, with irons 60 mm wide.

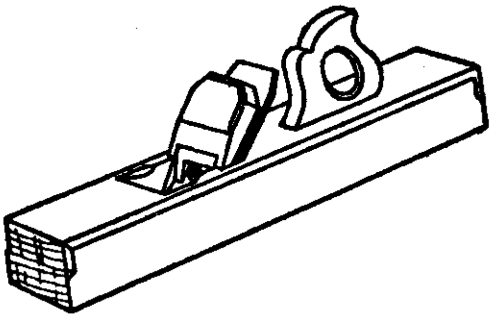


Figure 10.17 Trying plane

Smoothing plane. The plane (Fig. 10.18) is similar in action to a jack plane, except that it is set to cut a much thinner shaving. A smoothing plane, as its name indicates, is used for smoothing or finishing after a jack plane. The cutting edge of the latter is slightly curved, but a smoothing plane has a straight cutting edge. It is 200 to 250 mm long having a blade of 70 mm wide.

Rebate plane. A rebate is a recess along the edge of a piece of wood ; this forms a ledge which is used for positioning glass in frames and doors. The rebate plane shown in Fig. 10.19 is used for sinking one surface below another, and shouldering one piece into another. The blade is open at both sides of the plane, and must be perfectly straight at the cutting edge. Widths range from 12 to 50 mm.

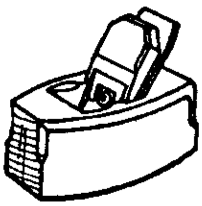


Figure 10.18
Smoothing plane

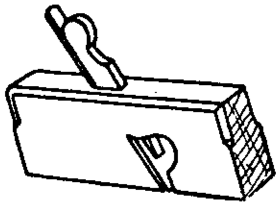


Figure 10.19
Rebate plane

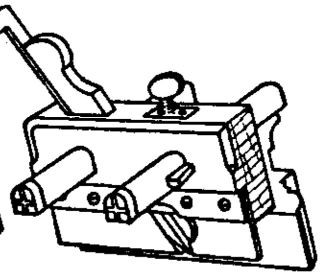


Figure 10.20
Plough plane

Plough plane. Where a panel is needed in a door it is used to fit it into a groove, not into a rebate. The plough plane illustrated in Fig.10.20 is used to cut these grooves. The depth of groove is controlled by a depth gauge which is fixed on the body of the plane and operated by a thumbscrew. These planes are usually supplied with eight to nine blades, vary in width from 3 to 15 mm and, of course, they are all interchangeable.

Spokeshave. This is a form of small plane used for cleaning up quick curves (See Fig.10.21) .There are two types, one which has a flat sole for outside curves and one which has a curved sole for inside curves.

Now-a-days, spokeshaves are made of iron, and some have a screw adjustment for the amount of cut.

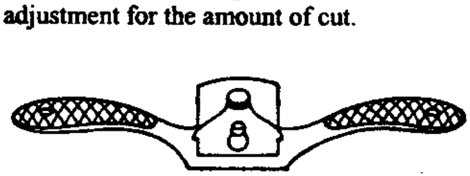


Figure 10.21 Spokeshave

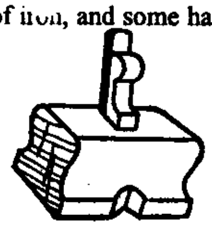


Figure 10.22 Router

Router. The router plane (Fig. 10.22) does not resemble other planes. This is used for cleaning out and levelling the bottom of grooves or trenches to a constant depth, after the bulk of the waste material has been taken out with saw and chisel.

Metal plane. Metal planes serve the same purpose as the wooden planes but facilitate a smoother operation and better finish. The body of a metal plane is made from a gray iron casting, with the side and sole machined and ground to a bright finish. The thickness of the shaving removed is governed by a fine screw adjustment, and a lever is used for adjusting the blade at right angles. A metal jack plane us shown in Fig. 10.23

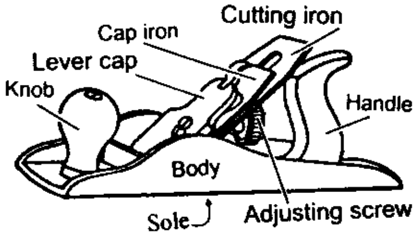


Figure 10.23 Metal jack plane

Special plane. In addition to those described above there are a number of special planes used by the woodworker to do special work. They include *compass* or *circular plane* for planing curves ; *bull nose rebate plane* for cleaning into rebates and corners inaccessible with other planes ; *shoulder plane* for planing across the end grain or hardwood shoulders ; *block plane* for planing small parts, especially when model making ; and *moulding plane* for producing a particular size and shape of moulding.

10.12 BORING TOOLS

Boring tools are frequently necessary to make round holes in wood, and they are selected according to the type and purpose of the hole. They include bradawl, gimlet, brace, bit and drill.

Bradawl and gimlet. The bradawl and the gimlet illustrated in Fig. 10.24 are hand-operated tools, and are used to bore small holes, such as for starting a screw or large nail.

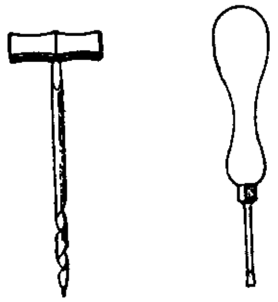


Figure 10.24 Bradawl & gimlet

Brace. The brace is a tool used for holding and turning a bit for boring holes. It has two jaws, which grip the specially shaped end of the bit. There are two types of braces in common use – ratchet brace and wheel brace. The *ratchet brace* is most useful for turning bits and drills of all kinds, being adaptable (a) for working in confined situations, and (b) for when the cut is particularly heavy and it is desirable to pull the handle through a quarter-turn only. A ratchet brace is shown in Fig. 10.25.

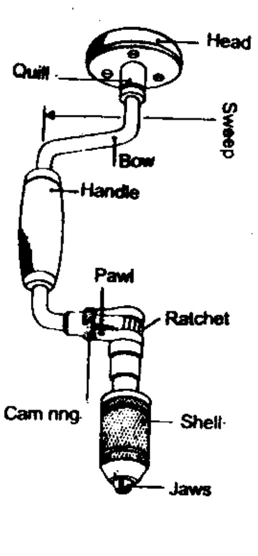


Figure 10.25 Ratchet brace

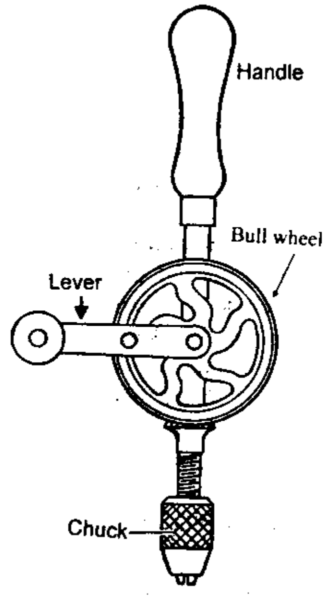


Figure 10.26 Wheel brace

The *wheel brace* (Fig.10.26) is used to hold round and parallel-shanked drills. This tool is invaluable for cutting small hole, accurately and quickly.

Bit. Most other forms of boring tools consist of "bits". The common types of bits used are shown in Fig. 10.27 and described below :

Shell bit. This bit is used for boring holes unto 12 mm diameter and which do not require a high degree of finish or size.

Twist bit or auger bit. It has a screw point and a helical or twisted stem. This bit produces a long, clean, and accurate hole either with or across the grain. This may be obtained in sizes from 6 to 35 mm diameter. The shorter type is called "dowel" bits and is used for preparing true and accurate holes to receive dowels.

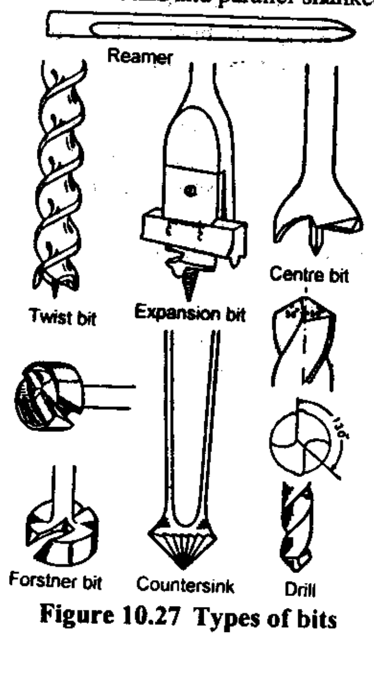


Figure 10.27 Types of bits

Expansive bit. In an expansive bit the main cutter can be adjusted to varying diameter within a certain range. It is fixed to the desired mark on the scale, and clamped in position by the plate and screw. Expansive bits are made in four sizes with interchangeable cutter for boring holes from 12 to a maximum of 125 mm diameter.

Centre bit. The centre bit is the most common. It is used for forming shallow holes across the grain. Centre bits produce an accurate and clean hole and may vary from 3 to 35 mm in diameter.

Forstner bit. It is extremely useful for sinking clean hole partly through a piece of wood and for cleaning out recesses. It has a small centre point for commencing and is then guided by its outer rim.

Countersink bit. It is used to shape a hole to fit the head of a countersunk headed screw.

In addition to the foregoing there are, of less importance, *nose bit, spoon bit, lip* and *spur bit, screw driver bit,* etc.

Drill. Morse drills are very convenient for making screwholes, especially when used with a wheel brace. This is adapted for drilling holes when wood working bits would be spoiled.

Reamers are tapered bits shaped like shell bits and used for enlarging holes.

10.13 STRIKING TOOLS

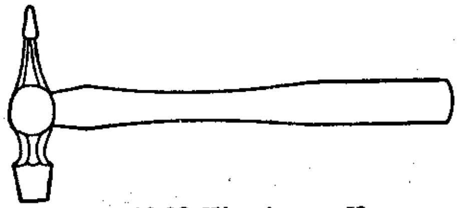


Figure 10.28 Warrington Hammer

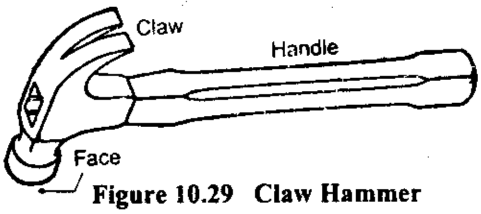


Figure 10.29 Claw Hammer

Striking tools include hammers and mallets.

Hammer. Engineers use ball-peened hammers, woodworkers cross-peened and claw hammers. The *Warrington hammer* shown in Fig. 10.29 is the type mostly used for bench work and all light jobs. The head is cast steel, the face and peen being tempered ; the shaft which is wedged tightly into the head is made of wood or bamboo. These hammers are identified by size numbers and weight, No. 00, 200 gm up to No. 6,550 gm.

The carpenter more often favours the *claw hammer* (Fig. 10.28) because it serves the dual purpose of a hammer and a pair of pincers. The claw is used for pulling out any nails accidentally bent in driving. These hammers are made in numbers sizes from 1 to 4, weighing 375, 450, 550 and 675 gm.

Mallet. The mallet shown in Fig. 10.30 is a wooden-headed hammer of round or rectangular cross-section. The striking face is made flat to the work. A mallet is used to give light blows to the cutting tools having wooden handle such as chisels, and gouges.

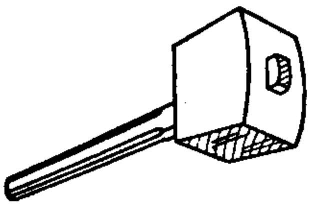


Figure 10.30 Mallet

10.14 HOLDING TOOLS

To enable the woodworker to cut his wood accurately, it must be held steady. There are a number of tools and devices to hold wood having its own purpose according to the kind of cutting to be done.

Bench vice. The bench vice illustrated in Fig. 10.31 is the most commonly used. Its one jaw is fixed to the side of the table while the other is kept movable by means of a screw and a handle. The whole vice is made of iron and steel, the jaws being lined with hardwood face which do not mark and which can be renewed as required.

Bench stop. The bench stop is simply a block of wood projecting above the top surface of the bench. This is used to prevent the wood from moving forward when being planed.

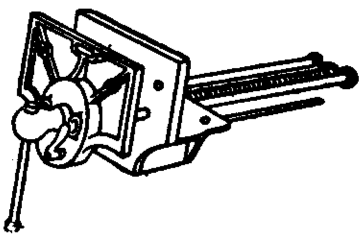


Figure 10.31 Bench vice

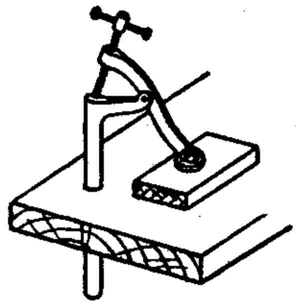


Figure 10.32 Bench holdfast

Bench holdfast. The bench holdfast shown in Fig. 10.32 is made with a cast iron pillar, square-cut screw threads on a steel bar, with a light vice handle and a drop-forged steel arm. By boring a series of holes through the top of the bench, holdfasts can secure the work in any desired position. This is useful for holding a piece of wood down on the bench when a vice is not advisable.

Sash cramp. The sash cramp or bar cramp in Fig. 10.33 is made up of a steel bar of rectangular section, with malleable iron fittings and a steel screw. This is used for holding wide work such as frames or tops.

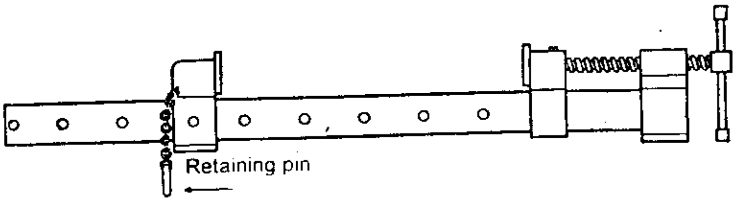


Figure 10.33 Sash cramp

G-cramp. The G-cramp in Fig. 10.34 is used for smaller work. It consists of a malleable iron frame that can be swivelled and a steel screw to which is fitted a thumbscrew.

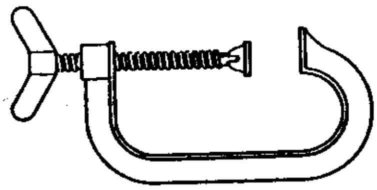


Figure 10.34 G-cramp

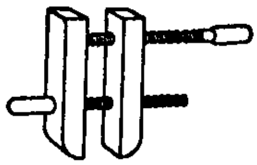
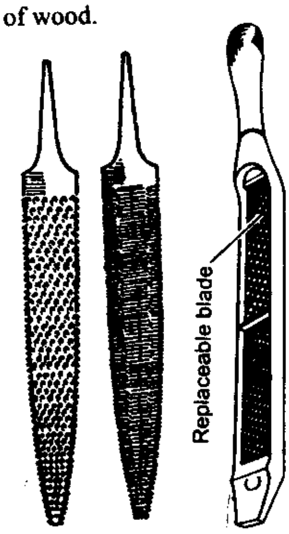


Figure 10.35 Hand screw

Hand screw. The hand screw in Fig. 10.35 is used where a wider area of pressure than that provided by a G-cramp is required. It consists of two steel screws fitted to two jaws made of wood.

10.15 MISCELLANEOUS TOOLS

Rasps and files. These are useful for cleaning up some curved surfaces. For instance, certain concave shapes are so small that the spokeshave cannot enter them and here a file is invaluable. Scratches left by the file can be removed with the scraper and glass paper. Surform tools introduced by Stanley Tools contain many small cutting teeth, each of which acts rather like a chisel or small plane. The teeth are not inclined to choke easily. The blades are disposable and when blunt must be replaced. Flat, convex and round blades are available. Illustrations are given in Fig. 10.36.



Rasp File Surform tool

Figure 10.36 Rasp , file and Surform tool

Scraper. As its name implies it scrapes (or, more accurately, cuts) very small shavings off the wood. The scraper in Fig. 10.37 consists of a piece of thin steel, hardened and tempered. A fine edge is made by pushing over or burnishing the edge of the metal to form that what is called a "burr"

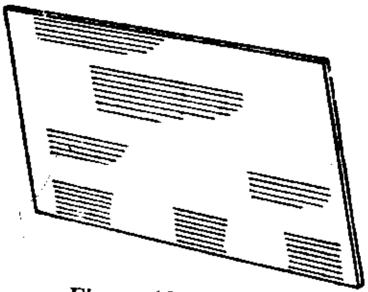


Figure 10.37 Scraper

Oilstone. An oilstone is an essential part of a carpenter's kit of tools. Oilstones may be either natural or artificial. The best-known varieties of stones are carborundum, Washita, Turkey and India. These may be obtained in various grades known as coarse, medium, or fine.

Glass-paper. Where a surface is covered with innumerable minute imperfections so small that no other cutting tool will do, then glass-paper should be used. It consists simply of small particle of glass stuck to sheets of paper ; it is the sharp edges of these particles which cut the wood. Glass-paper is made in varying grades according to the size of glass particles. These grades are denoted by numbers such as 00, 1, etc.

Pincer. The pincer in Fig. 10.38 is mainly used for pulling out nails, tacks, etc. It consists of two arms one arm has a ball end and the other arm has a claw end for levering out small tacks.

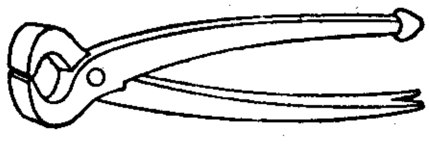


Figure 10.38 Pincer

Screw driver. Screw drivers are used for screwing or unscrewing screws used in woodwork. These may be obtained in various shapes and sizes but the one shown in Fig.10.39, known as a "cabinet screw driver", is considered to be the best type.

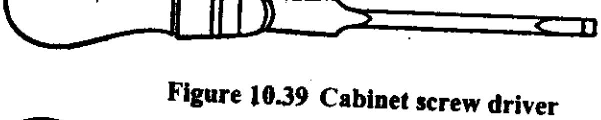


Figure 10.39 Cabinet screw driver

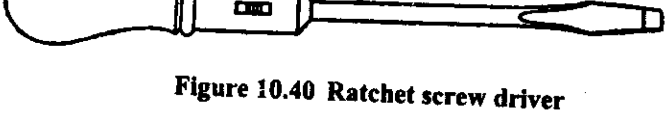


Figure 10.40 Ratchet screw driver

The *ratchet screw driver* (Fig. 10.40) is very useful for turning screws through a few degrees in awkward and confined spaces.

10.16 SETTING AND SHARPENING OF TOOLS

Saws. Saws are re-set by slightly bending each tooth the first tooth one way, the next the opposite way and so on. This is done so as to make the cut wider than the thickness of the blade, and ensure that it clears the sides of the cut as it passes through. A tool called *saw set* is used for this. There are different methods of setting the teeth of a saw but one by using a *gate* or *lever type hand set* is very common. It is shown in Fig. 10.41 and consists of a steel plate and handle. Along the edge of the plate are gaps or gates numbered according to the gauge or thickness of various saws. In use a suitable gap is slipped over the tip of a tooth, which is then bent over by using the handle of the set as a lever. The amount of set depends upon the type of work being done. Green or damp timber will require that the teeth have plenty of set, whilst dry wood requires less.

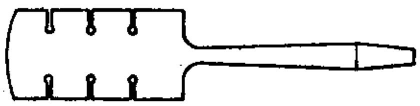


Figure 10.41 Saw set (gate type)

Normally, saws are sharpened after setting. A double-ended, single cut, three-cornered file, of suitable section size is the usual type of file used for sharpening saws. Great care must be taken to maintain the angle of the teeth as well as any cutting angle on the leading edge of each tooth. The saw is held with the tooth projecting about 3 mm. Before commencing to file the teeth it is a good plan to pass a flat file lightly along the tops of the teeth to put the points in a straight line. The teeth can then be filed individually.

Planes. The setting or cutting adjustment of planes is most important. The efficient working of planes depends on several factors :

1. The angle at which the blade is set in the body of the plane fixes the *cutting angle*. In the case of planes with a back iron these are 47.5° and 42.5° respectively.
2. The space between the cutting edge and the body of the plane has an important bearing on its working qualities. Coarse working planes, e.g., jack planes need at least 3 mm gap so that a thick shaving can bend easily through the opening. This gap may be as small as 0.4 mm for very thin shaving.

3. The back iron is set 3 mm to 0.4 mm from the cutting edge, depending upon the coarseness or fineness of the work. The nearer the back iron can be set to the cutting edge the better.
4. The distance between the cutting edge of the blade and the sole of the planes, called the *cut*, is kept from 0.8 mm to 1.6 mm for heavy cut and below 0.8 mm for fine cut. Of course, this depends on the quality of wood to be cut.

To obtain fine cutting edges of planes, a grindstone and an oilstone are used.

The bevel is first obtained by being ground on a rotating grindstone at an angle of 25°. The tool is pressed lightly against the wheel which revolves towards the tool and the latter is moved sideways. Wet or dry grinding both may be employed during the operation.

The edge obtained in grinding is very uneven because the particles of grit which do the cutting are larger in a grindstone. The edge is, therefore, brought to a fine condition by being rubbed on an oilstone using oil. But instead of rubbing the whole of the ground bevel, the chisel is raised slightly so as to give a slightly larger angle of about 30 to 35°. The smaller angle of 25° is known as the "grinding angle" and the larger one as the "sharpening angle". They are shown in Fig. 10.42.

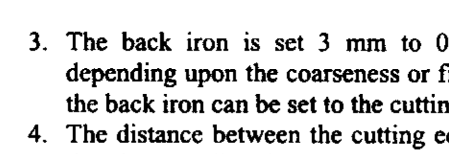


Figure 10.42 Approximate grinding and sharpening angle

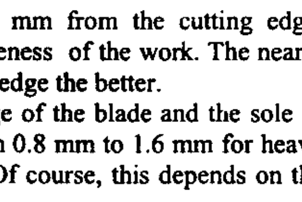


Figure 10.43 Oilstone slip

Chisels. Chisels are sharpened in the same way, but more care will be needed to keep the edge square.

For the sharpening of gouge, shaped stones (Fig. 10.43) called oilstone slips are used.

Bits. Centre bits and twist bits may be re-sharpened by filing with a small flat fine-toothed file, care being taken to maintain the cutting angle already on the tool.

10.17 CARPENTRY PROCESSES

Carpentry and joinery work involve a number of hand operations to finish the work to the desired shape and size with required accuracy. The following is the principal processes used in wooden construction :

1.	Marking.	5.	Boring.
2.	Sawing.	6.	Grooving.
3.	Planing.	7.	Rebating.
4.	Chiselling.	8.	Moulding.

10.18 MARKING

Marking is the process of setting out dimensions on a piece of wood for producing the required shape. These dimensions can be measured from an existing model or can be set out from the drawing prepared for the purpose. Each dimension is taken out with a folding rule which is the most convenient for general use, and is set out with the help of various instruments such as caliper, try-square, marking knife, marking gauge, etc. When marking a size the pieces are first planed true and square and then marked according to the desired dimension. The trueness of the surface is tested every time with the straight edge or the blade of the try-square or the steel rule. A zig-zag pencil mark is made on the true surface to distinguish it from the other faces.

10.19 SAWING

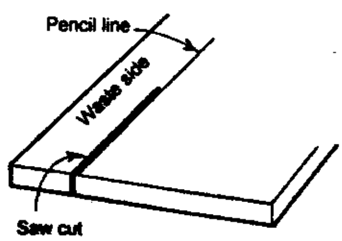


Figure 10.44 Sawing to pencil line

Sawing is one of the basic operations carried out in a carpentry shop. A wood is required to be sawn along the grains or across the grains and in many shapes such as straight inclined or curved. To start the cut, the thumb of the left hand is placed against the blade. This steadies the blade, enabling it to start in the right place, and prevents any accident in the event of the saw jumping. One or two short movements are first given, taking care that the saw works in the right direction and then full, easy strokes are applied to cut the wood. A point to note in all sawing is that the cut is made on one side of the line already marked and that is on the waste side, as in Fig. 10.44. A saw should never be forced and it is kept moving steadily for nearly its full length. Its own weight plus the slightest pressure is all that is needed.

10.20 PLANING

Planing is the operation of truing up a piece of wood by a planer. This is known as "facing and edging", and the future success of most pieces of work is dependent on this preliminary operation being properly carried out. A properly planed surface should be perfectly straight in all directions, parallel in width and thickness, and with edges square to the face. This is achieved by carrying out the following sequence of operations.

First choose what apparatus to be the best face. Next plane off the rough surface with the jack plane, taking off as little as possible, but at the same time attempting to plane the surface by taking more off the high parts. Each time the pressure is applied on the forward stroke and relieved on the return stroke. At the start of the stroke, maximum force is applied to the handle for driving the plane. This force is balanced by pressing the other hand on the tip. For heavy work the pressure on the tip is applied with the palm of the hand, but for light work the tip is held in hand with the thumb on the top and the two centre fingers at the bottom of the sole. As planing proceeds, the material should be checked to see if it is straight across the face. This may be done with a try-square or by using the edge of the jack plane.

10.21 CHISELLING

Chiselling is the process of cutting a small stock of wood to produce the desired shape.

To cut horizontally *with* the grain the chisel is held slightly tilted to one side and pushed forward in the direction of the grain. For roughing down to size, the bevel side is down ; for the finish cut the bevel side is up. To chisel horizontally *across* the grain, the work is clamped in the vice. The blade of the chisel is grasped with the thumb and forefinger to act as a brake. The handle is slightly lowered down and chiselled from both sides to avoid splintering the corners. With the chisel held flat the high spot in the centre is removed. In vertical chiselling across the grain the chisel is controlled with the left hand pressing firmly on the blade of the chisel and resting on the wood. The chisel is tilted slightly to one side to give a shearing cut. In rounding or shaping a corner, chiselling should commence at the edge of the board and work round to the end, that is, with the grain, otherwise the corner of the chisel will bite into the grain and split the wood. Firmer chisels are used for heavier work and should be hit with the mallet ; in fact, the mallet should be used on all chisels and gouges whenever necessary.

A mortise and a tenon which are made in almost all wooden construction can be produced with the chiselled and mallet. A *tenon* is the projected part of a piece of wood and is cut squared and finished to the desired size to suit the corresponding *mortise*, which is a recess, through or blind, of any shape except round, cut on the wood.

10.22 BORING

Boring is the process of producing round holes, through or blind, in the wood. This boring can be done straight or inclined to suit the type of work. While boring, the work is firmly secured in a holding tool in order to avoid production of an eccentric hole. Small holes can be made by using a bradawl and gimlet, but large holes require braces and bits or drills. These bits and drills should be turned constantly in one direction and withdrawn at intervals, to remove the waste core, by turning in the apposite direction and exerting an upward pull. When using the brace and twist bit to bore rather deep holes. the direction of the bit should be carefully checked at the start. The bit should be guided by sighting either with the try square or small straight edges. The operator must stand in a suitable position while boring in order to do this sighting. Correct marking and location of the centre are also very important to produce a hole of the correct size.

10.23 GROOVING

The grooving is a term which is almost always used with the term tongueing. These are operations of making grooves and tongues that are usually cut on the edges of planks and boards to join them together to form big boards of large width. A groove is a channel cut to any shape, and a tongue is the corresponding projection formed to fit into it. Actual application of grooves and tongues can very well be seen in drawing boards, floor boards, wall partitions and in other articles where considerably large sizes are needed. The groove is cut with a plough plane, and a tongue with tongueing plane or a moulding plane.

10.24 REBATING

Rebating is the process of making a rebate or recess taken out of the edge of a piece of wood. Examples of the rebate are : that part of the door frame in which the door fits, or the recess in a window sash which contains the glass. A rebate is made by a rebating plane. Rebates which are too wide for the rebate plane may be worked by running a few grooves with the plough plane to the correct depth, and then cleaning out the bulk of the waste with mallet and chisel.

10.25 MOULDING

Moulding is the process of cutting concave, convex and other curved surface along the length of a piece of wood. This is done by a moulding plane ; fixing a cutter iron of the shape required. Moulding work is done for preparing photo-frames and other decorative works.

10.26 CARPENTRY JOINTS

Constructional woodwork can be divided into two main classes : framework and carcase work. In framework, typical joints used, are the various *halving joints, mortise* and *tenon joints,* and *bridle joints.*

Carcase work is characterized by box-like shapes of solid wood or laminboard. Typical joints used, are *butt* or *rubbed joint, dowel, tongue and groove,* and the *screw* and *slot joint* ; other joints include *dovetail joints,* and *corner joints.*

Before any joints can be attempted it is necessary to prepare the stuff. This means planing the wood to size and getting four true surfaces.

Halving joint. The aim of this joint is to secure the corners and intersections of the framing, and at the same time keep all the face flush, that is, in the same plane. The halving joint, also termed a *half-lap joint,*

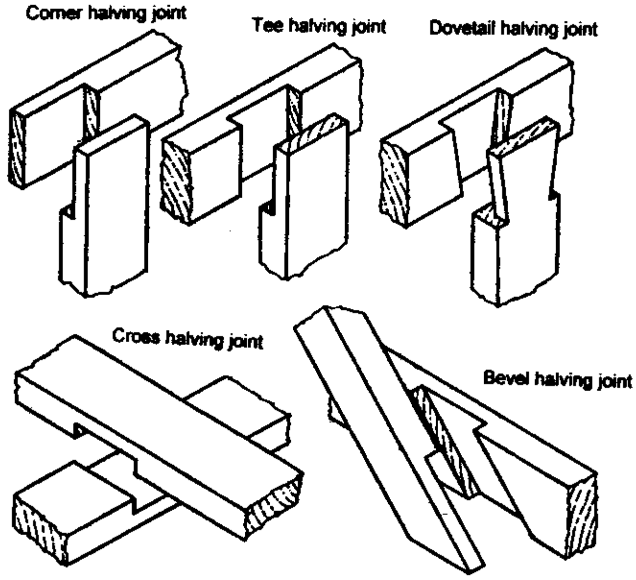


Figure 10.45 Halving joints

may be usefully employed in many types of framing where strength and appearance are of secondary consideration. Various forms of halving joint are shown in Fig. 10.45.

Mortise and tenon joint. This family of joint is a large one and is probably the commonest used by the woodworker. It consists of a rectangular peg (tenon) fitting into a rectangular hole (mortise). Various forms of mortise and tenon joints are illustrated in Fig. 10.46.

In making these joints the tenon is made by shaving only, except that in very wide ones the shoulders may be finished with a plane. After preparing the stuff the position of the tenon and mortise is squared on the

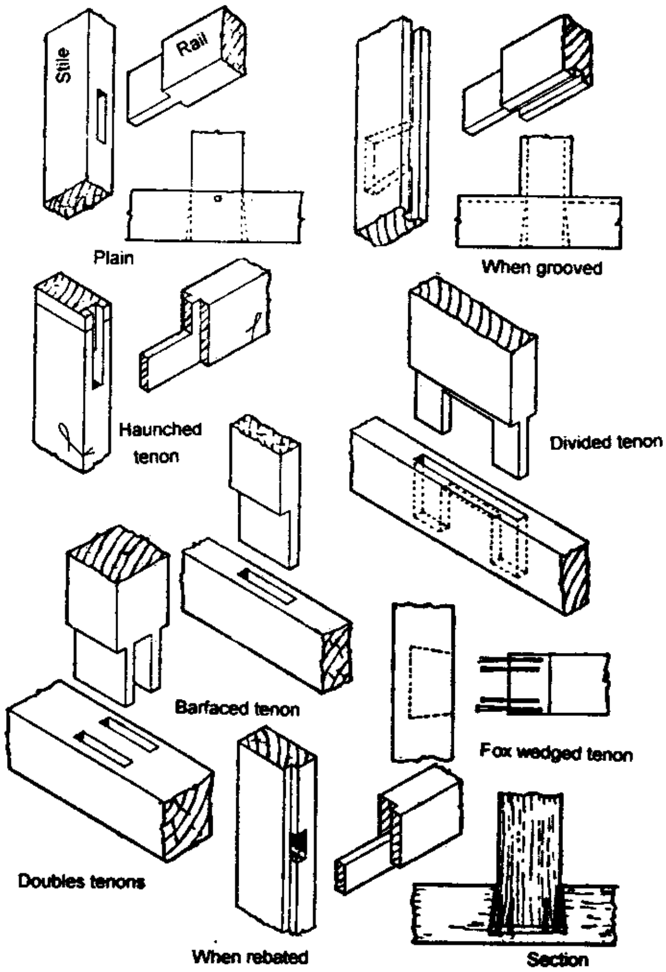


Figure 10.46 Mortise and tenon joints

wood with the pencil and then cut to prepare the pieces for making joints.

Two tools have been developed solely for making the joints : (1) mortise chisel, and (2) mortise gauge. For general framing work the width of a mortise is about one-third the thickness of the material to be mortised, and the length should not exceed six times the width.

Bridle joint. This form of joint is really the reverse of the mortise and tenon joint and is often called the open mortise and tenon. Different forms of bridle joints are shown in Fig. 10.47

The marking out is the same as for the through mortise and tenon joint, except for the placing of the cut lines. It will be noticed that there is no mortise, but two grooves ; and what was a tenon now becomes a slot.

The joint is often used where the members are of square or near-square section and thus unsuitable for making a mortise and tenon joint of good proportions.

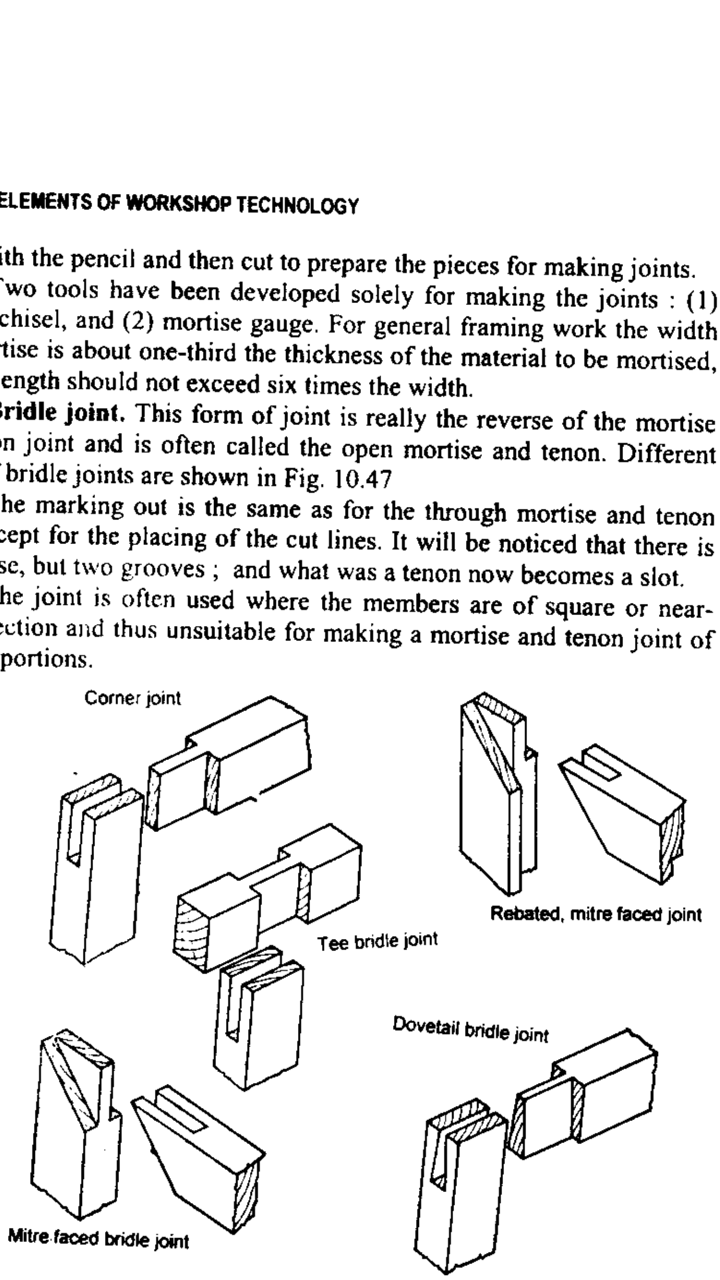


Figure 10.47 Briddle joints

Butt or rubbed joint. The fastening of boards edge to edge is frequently necessary to give a wider board, for example, drawing board, table top, counter top, etc. The commonest form of edge joint is the butt or rubbed joint (Fig. 10.48) in which two true edges are joined with glue. If properly done, this joint is very strong. For stuff thicker than 25 mm, additional strength is often provided by the use of dowels or screws and slots. The rubbed joint is made by planing the two edges true with a trying plane.

Dowel joint. The dowelled joint is often used as farming joint in the place of the mortise and tenon joint. This may be used to advantage in many cases, such as the joints in circular work, butt jointing two edges or positioning movable fittings. A typical dowel joint is shown in Fig.10.49.

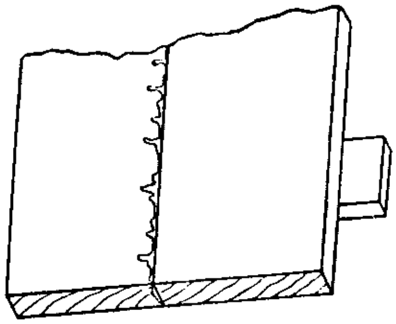


Figure 10.48 Butt or rubbed joints

Tongue and groove joint. Commercially machined boards for edge to edge jointing, such as drawing boards, floor boards, and match boards, are tongued and grooved. the tongues are used to provide extra support and additional gluing surface. These may be either self-tongues or loose as shown in Fig. 10.50. Self-tongues are prepared by cutting a tongue on one edge and a suitable groove on the other with the aid of a matching plane. In those tongues, both edges are trued and then plough grooved.

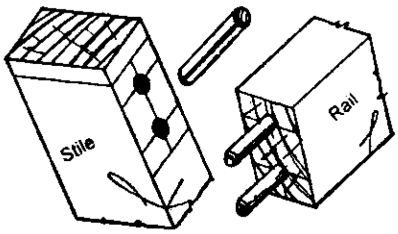


Figure 10.49 Dowel joints

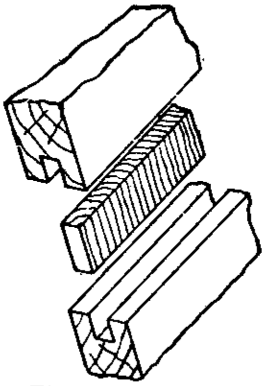


Figure 10.50 Self tongue or loose tongue

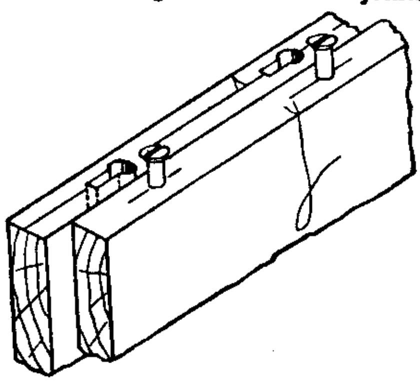


Figure 10.51 Screw and slot joint

Screw and slot joint. Where two pieces are to be secured secretly and glue may not be advisable, screw and slot joint can be used. One piece carries the screw, while the other piece has slots cut in it (Fig. 10.51) to take first the head and secondly the body of the screw.

Dovetail joint. The dovetail joint is probably the strongest of all corner joints. It was primarily a joint intended to take a strain in one direction, but it has several variations and many applications, particularly in making box or carcase-like constructions—form small boxes to large pieces of furniture. Various forms of dovetail joints are shown in Fig. 10.52.

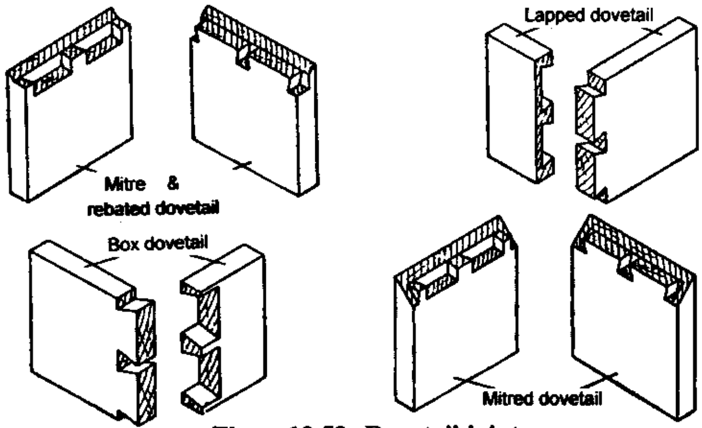


Figure10.52 Dovetail joints

There are two methods of this : one is to cut the pins first and then mark the sockets from them, and the other is to cut the sockets first. In the first method the marking out may be done neater, but each piece must be delt with separately, whereas by cutting the socket first, a number of pieces may be delt with in one operation, This is perhaps the best method, as the sockets are easier to cut straight and there is saving of time.

Corner joints There are many ways of joining angles or corners together other than by dovetailing. A few of these are shown in Fig.10.53.

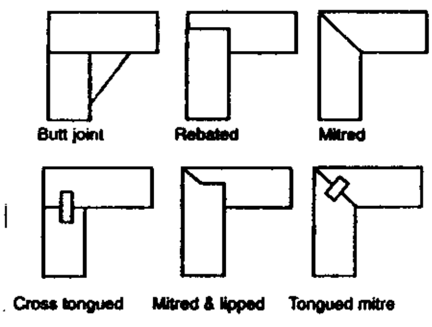


Figure 10.53 Corner joints

10.27 WOODWORKING MACHINES

Modern carpentry shop, in addition to the hand tools described earlier, requires the use of some power-driven machines, particularly where large-scale production is to be obtained. The size and capacity of the machines used depend on the size of the general run of the work to be done. Machines chosen for carpentry shop must be well built, and their accuracy should be dependable. They should be well guarded to protect the worker from the hazards of operation. The machines commonly used are briefly described below.

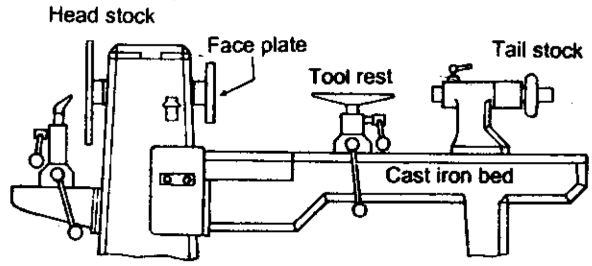


Figure 10.54 Wood turning lathe

WOOD WORKING LATHE

The woodworking lathe is one of the most important machines used in a carpentry shop. This is employed primarily for turning jobs in making cylindrical parts. However, by suitably manipulating the tools, tapers, radii, and other irregular shapes can also be easily turned.

It resembles the 'engine lathe' most frequently used in the machine shop, and consists of a cast iron bed, a head stock, tail stock, tool rest, live and dead centres, and a speed control device (Fig. 10.54). The drive, in modern lathes, is individual motor driven ; and a cone pully on the head stock spindle is connected by a belt to a cone pully on the motor shaft.

In practice, the workpiece is either clamped between two centres or on a face plate. Long jobs are held between the centres and turned with the help of gouge, skew chisel, parting tool, etc. Generally, the lathe is supplied together with a number of accessories for making it useful for a variety of jobs. The size of a woodworking lathe, as in the engine lathe, is usually specified in terms of the so-called "swing" of the lathe and the maximum distance between centres.

CIRCULAR SAW

Probably the second most important single machine in a carpentry shop is the circular saw. It can be used for ripping, cross cutting, mitering, bevelling, rabbeting, and grooving.

Although there are many types of circular saws such as universal saw, variety saw, bench saw, the basic working parts are common to all. Each has a flat surface or table upon which the work rests while being cut, a circular cutting blade, cut-off guide, and a ripping fence that acts as a guide while sawing along the grains of the wood. The circular saw usually has provisions for tilting the table upto an angle of 45° to enable the machine to cut at different angles required during mitering. levelling, etc.

The size of a circular saw is determined by the diameter of the saw blade.

BAND SAW

The band saw is designed to cut wood by means of an endless metal saw band that travels over the rims of two or more rotating wheels. Other parts of a band saw are frame, table, saw guides, saw tensioning arrangement, etc. Although the number of operation that can be performed on a band saw is less than those of a circular saw, it is most useful for making curved or irregular cuts in wood.

The band is available in two models, vertical and horizontal. In the former, two wheels are arranged side by side and the table is mounted underneath. In the latter model, illustrated in Fig.10.55, the wheels are arranged one above the other in a vertical plane below the table and the band passes through the table. As in the case of the circular table, angular cuts are obtained by tilting the saw table. The size of the band saw is specified as the distance from the saw band to the inner side of the frame. This distance is roughly equal to the diameter of the wheels.

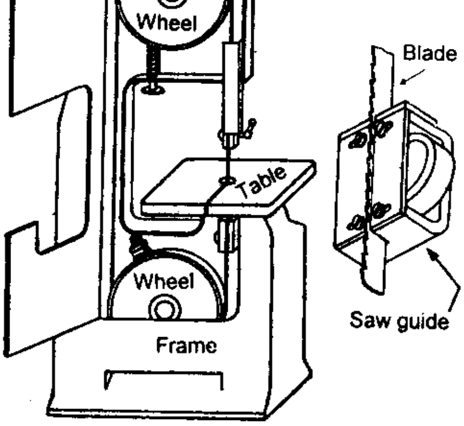


Figure 10.55 Band saw and guide unit

JIG SAW OR SCROLL SAW

The jig saw, which is also known as a scroll saw, is used for making intricate and irregular cuts on small jobs. On thin wooden pieces, jig saw can cut in a curvilinear path. The machine is actually a type of band saw of much smaller size and specially adapted to irregular work.

It consists of a base, frame, table, upper and lower chucks, guide assembly, and blade. Chucks hold the blade with its teeth pointing downward. The blade resembles a hand hacksaw blade in regard to its shape. The blade reciprocates vertically up and down and shapes the wood. The table of the jig saw can be tilted for angular work. The special feature of the saw is that it can be used to cut inside curves. A jig saw is specified by its blade-to-arm distance.

JOINTER

A jointer is used for planing straight edges and surfaces of boards. In practice, it performs the work of a hand planer and is capable of producing a true surface with sufficient accuracy and speed.

In consists of a frame, table, feed rollers, revolving head fitted with two or three cutter knives. With the help of feed rolls, the plank is fed to the cutter head which removes the wooden chips as the board advances and makes its surface smooth and plane. By means of an adjustable fence, the jointer can also be used for angular and level cuts. A jointer is specified by the length of the cutting blade.

WOOD PLANER

The wood planer is designed for planing large and heavy stock at a comparatively faster rate. The boards to be planed are fed by means of feed rolls along a table against a revolving cutter head. The cutter head is mounted on an overhead shaft which is adjustable for regulating the depth of cut . The table of the planer is much wider and longer than that of a jointer for accommodating large and heavy stock.

MORTISER

A mortise is a square slot cut in the direction of depth for the purpose of making a mortise and tenon joint in a wooden piece. The mortising machine is used for cutting mortise and tenon joints which are very laborious and time consuming operations. There are three types of mortisers, namely (1) hollow chisel mortiser, (2) chain mortiser, and (3) oscillating bit mortiser.

The *hollow chisel mortiser*, the most commonly used machine, consists of a revolving spindle carrying an auger bit at the bottom end. The auger bit rotates at a high speed inside a hollow chisel of square section. When the chisel is forced into the wood, the bit bores a square hole by the sharp end of the chisel. the auger bit and chisel thus work together and perform boring of a square hole. The depth of the mortise is regulated by means of an adjustable depth stop. The spindle is

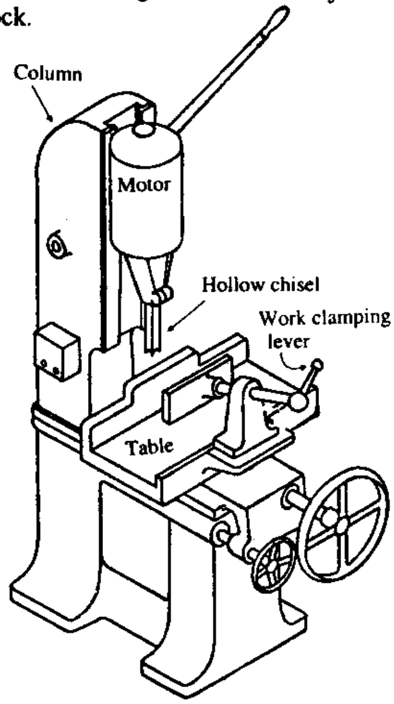


Figure 10.56 Power mortiser

rotated by an electric motor, and tool-feed is obtained by pressing foot-lever. This is illustrated in Fig. 10.56.

The *chain mortiser* is primarily used for making mortises in doors and windows. It carries an endless chain which has saw type teeth on its outer surface. The chain revolves around a guide bar and cuts the stock. The mortise of the desired length is produced with round bottom corresponding to the profile of the revolving chain.

The *oscillating bit mortiser* carries a oscillating router bit and produces comparatively small mortises suitable for small cabinet and chair work.

SANDING MACHINES

Sanding is the operation of finishing wooden items after they have been machined. Essentially, a sanding machine performs a sand papering job to produce a uniformly sanded surface. Three common types of sanding machines are :

1. belt sander. 2. spindle sander. 3. disc sander.

Belt sander. It has an endless cloth backed abrasive belt which runs over two drums and is used for sanding and shaping flat surfaces. One of the drums is rotated by an electric motor and serves as the driver, while the other supports the belt and keeps it in proper tension. For sanding work by the abrasive belt, the workpiece is supported by an adjustable table that may be tilted to any desired angle.

Spindle and disc sanders. They are employed for curved surfaces and use abrasive disc and vertical abrasive spindle. During operation , the disc or the spindle as the case may be, rotates and performs the work.

GRINDER

A small tool grinder is a must for all woodworking shops for sharpening and shaping various tools used in the shop. The grinder has two grinding wheels fastened on to the two ends of a rotating spindle which is driven by a small electric motor. Generally, one of the wheels is used for coarse grinding while the other for fine grinding. Sometimes one of the wheels, particularly which is softer, is provided with a wet-grinding attachment.

10.28 PLYWOOD AND VENEER MANUFACTURING

Plywood is basically made up of an odd number of thin layers of wood, called veneers bonded together with an adhesive (synthetic or natural). The veneers are placed on each other in such a way that grain of each alternate layer crosses the adjacent layer at right angle. The plywood becomes extremely strong, stable, rigid for such arrangement of veneers. It is having high resistance to impact also.

The number of veneers used in making plywood is never less than three and may be as many as 15. The art of veneer peeling and slicing has been refined with minimum thickness of 0.2 mm and maximum of 6 mm now possible.

Fig. 10.57 shows some varieties of plywood.

When the middle veneer is thicker than the outer ones, the board is known as *stout-heart*. Boards with more that three laminates are known as *multiply*. Standard plywood may have thickness ranging from 3 mm to 25 mm. But thinner or thicker plywood can be manufactured for special purposes.

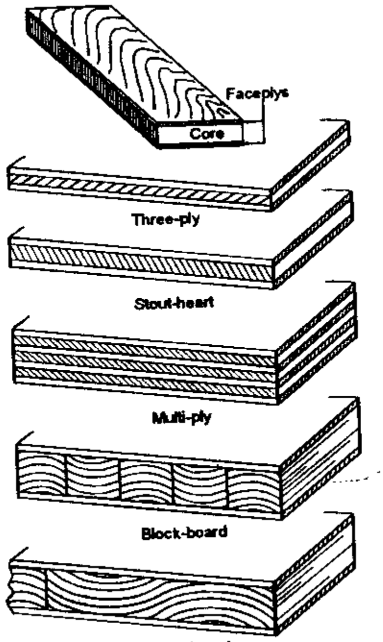


Figure 10.57

Block boards are manufactured in similar length and width as plywood and in thickness of 12, 16, 18, 24 and 25 mm. The core consists of 25 mm wide wooden strips and outer faces are good quality veneers of thinner sections (1-3 mm). In *batten board* the core is more than 40mm wide.

Chipboard is manufactured from fine wood particles or wood wastes from other timber-processing systems, bonded together with synthetic resin glue under heat and pressure. *Oriented-strand-boards* (OSB) are engineered, mat-formed panel products made of strands from small diameter round wood logs and bonded by phenol-formaldehyde under heat and pressure. They are stronger than chipboards and meet nearly all the specifications of ply-wood.

Plywood Manufacturing. The manufacture of plywood consists of nine steps and are shown in Fig.10.58.

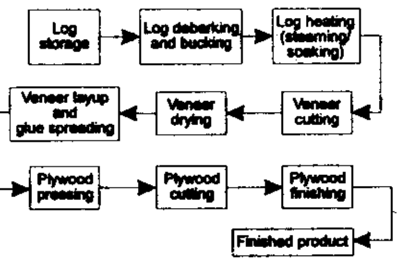
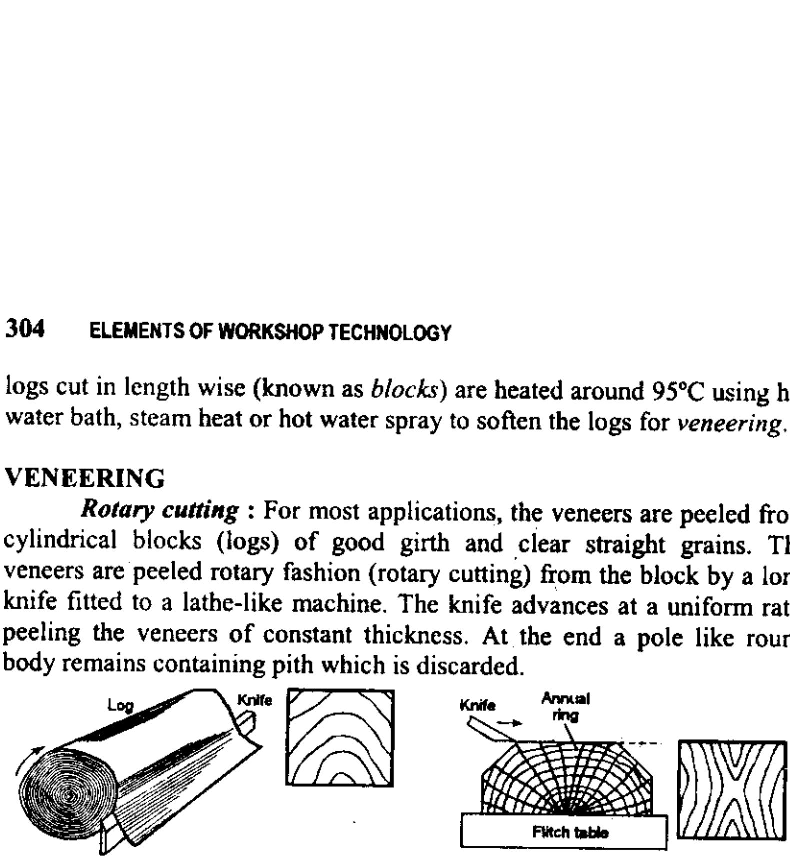


Figure 10.58 Process of manufacturing of plywood

As veneers are made from softwood and hardwood only, the log is first *debarked* i.e. outer bark is removed. In the next step the log is cut to appropriate length known as *bucking*. The logs cut in length wise (known as *blocks*) are heated around 95°C using hot water bath, steam heat or hot water spray to soften the logs for *veneering*.

VENEERING

Rotary cutting : For most applications, the veneers are peeled from cylindrical blocks (logs) of good girth and clear straight grains. The veneers are peeled rotary fashion (rotary cutting) from the block by a long knife fitted to a lathe-like machine. The knife advances at a uniform rate, peeling the veneers of constant thickness. At the end a pole like round body remains containing pith which is discarded.



Rotary cutting Slicing

Figure 10.59 Methods of veneering

Slicing : For producing decorative, high quality veneer, a veneer slicer is used. In this method the block is first cut diametrically in two parts known as flitch. The flitch is then mounted on the flitch table and sliced. Fig.10.59 shows the methods of veneering using *flat slicing* method.

Veneer drying and other operations : Veneers so produced contain high level of moisture, and thus are sent to a drier to dry them in the range of 150°C to 250°C. Once the veneers reach the desired level of moisture content, they are cut to size and conveyed for *layup* operation, where a thermosetting resin is spread evenly on the veneers either by a glue spreaders on a spray system. Assembly of the plywood panels must be done such that the grains of alternate layers are at right angle.

The assembly is then hot pressed, cut in size and the edges trimmed. The face and back may be sanded if necessary.

10.29 AUXILIARY MATERIALS USED IN CARPENTRY

Some of the materials utilised in carpentry operations are :

1. Nail (Fig. 10.60)
   (a) Hand-wrought – forged by hand from hot iron.
   (b) Cut nails – cut from iron strip by machine.
   (c) Cast nails – molten iron run into moulds.
2. Wood Screws (Fig.10.61)
3. Raw plugs : Used to fix items like cabinet, mirrors , racks etc. on walls.

4. Wood preservatives.
5. Glue and adhesives.
6. Wood polish.

Wood preservatives : Wood deteriorates by exposure, moisture, human contact, airborne pollutants and the effects of time. Wood preservatives are used to minimise the *deterioration*. These can be divided into two general

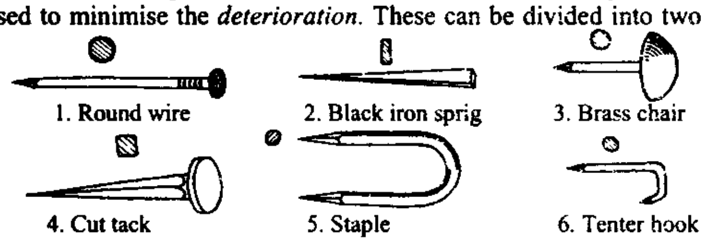


Figure 10.60 Types of nails

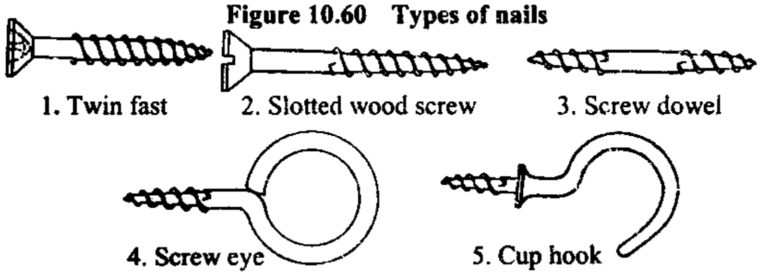


Figure 10.61 Wood screws

classes : (1) Oil borne preservatives such as creosote and petroleum solutions of pentachlorophenol and (2) Water-borne preservatives that are applied as water solutions.

Coal-tar *creosote* is a black or brownish oil made by distillation of *coal tar* that is obtained after high temperature carbonation of coal. Its various advantages include : (a) high toxicity to wood-destroying organism; (b) ease in application; and (c) relative low cost.

Glue and adhesives : Glues and adhesives are used to strengthen the bond of wooden parts after the joinery is made. They are :

1. Animal glue derived from the bones and hides of animal.
2. Casein derived from milk.
3. Synthetic resins urea-formaldehyde formulation.
4. Aerodux resorcinol-phenol-formaldehyde resins which can be used as gap-filling adhesive in wood joints, preventing fungus and insect attack.
5. Polyvinyl acetate, cold setting resin glue used for furniture assembly.

Wood polish : A large number of wood polishes in the form of liquid and paste are available in the market. They increase the look of the wooden parts / furniture and prolong (shelf) life of the items. The types of wood polishes are :

1. *French polish* : made by dissolving shellac in methylated spirits with hardening additives.
2. *Oil polish:* linseed oil, to be applied in numerous coats till a desirable finish.
3. *Wax polish:* applying successive coats of wax directly applied on bare wood. It is generally used for hard wood.
4. *Clear varnishes and lacquers* : may include traditional varnish like copal varnish or modern polyurethane varnish. Applied on warm and dry wood.

REVIEW QUESTIONS

1. What is the difference between hard wood and soft wood ?
2. Why preservation of timber is necessary ? Describe in brief a few methods of preservation.
3. What do you understand by "grains in wood" ? State the different types of grain that wood possesses and explain their characteristics.
4. Classify wood defects. Draw sketches of natural defects in timber.
5. State the commercial sizes of timber.
6. Describe with neat sketches the construction and uses of the following : (a) Tenon saw, (b) Bow saw, (c) Key-hole saw, (d) Firmer chisel, (e) Socket chisel, (f) Wooden jack plane, (g) Iron jack plane, and (h) Smoothing plane.
7. What is "setting" of saw teeth ? Why is it done ?
8. Sketch and describe giving uses of commonly used : (a) holding and supporting tools, (b) striking tools, (c) bits and braces.
9. What do you understand by the term "Joinery" ? What are the different joints used in wood working ? Describe any two with neat sketches.
10. Sketch and describe the following joints made in a carpentry shop : (a) Mortise and tenon joint, (b) Lap dovetail joint, (c) Briddle joint, (d) Through dovetail joint, (e) Rafter joint, and (f) Notching joint.
11. What is the specific use of wood turning lathe? (b) Sketch and describe its working in detail.
12. Sketch and describe in brief the construction and working of the following : (a) Circular saw, (b) Jig saw, (c) Band saw and (d) Jointer
13. What are the common types of mortising machine used in wood working ? Describe the working of a hollow chisel mortiser.
14. What are machine sanders? How does a belt sander differ from a disc sander ? Which sander will you prefer and why ?
15. Name various wood preservatives. Describe one briefly.
16. Write in brief the making of plywood.
17. How veneers are prepared? Write one method in full.
18. Write short notes : (1) OS boards and chipboards. (2) Block boards.