17

CHAPTER

WELDING

17.1 INTRODUCTION

Welding is a process for joining two similar or dissimilar metals by fusion. It joins different metals/alloys, with or without the application of pressure and with or without the use of filler metal. The fusion of metal takes place by means of heat. The heat may be generated either from combustion of gases, electric arc, electric resistance or by chemical reaction. During some type of welding processes, pressure may also be employed, but this is not an essential requirement for all welding processes. Welding provides a permanent joint but it normally affects the metallurgy of the components. It is therefore usually accompanied by post weld heat treatment for most of the critical components. The welding is widely used as a fabrication and repairing process in industries. Some of the typical applications of welding include the fabrication of ships, pressure vessels, automobile bodies, off-shore platform, bridges, welded pipes, sealing of nuclear fuel and explosives, etc.

Most of the metals and alloys can be welded by one type of welding process or the other. However, some are easier to weld than others. To compare this ease in welding term 'weldability' is often used. The weldability may be defined as property of a metal which indicates the ease with which it can be welded with other similar or dissimilar metals. Weldability of a material depends upon various factors like the metallurgical changes that occur due to welding, changes in hardness in and around the weld, gas evolution and absorption, extent of oxidation, and the effect on cracking tendency of the joint. Plain low carbon steel (C-0.12%) has the best weldability amongst metals. Generally it is seen that the materials with high castability usually have low weldability.

17.2 TERMINOLOGICAL ELEMENTS OF WELDING PROCESS

The terminological elements of welding process used with common welding joints such as base metal, fusion zone, weld face, root face, root opening toe and root are depicted in Fig. 17.1

17.2.1 Edge preparations

For welding the edges of joining surfaces of metals are prepared first. Different edge preparations may be used for welding butt joints, which are given in Fig 17.2.

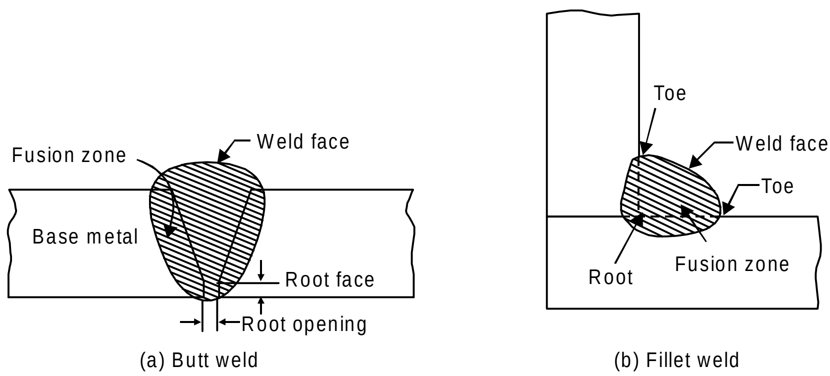


Fig. 17.1 Terminological elements of welding process

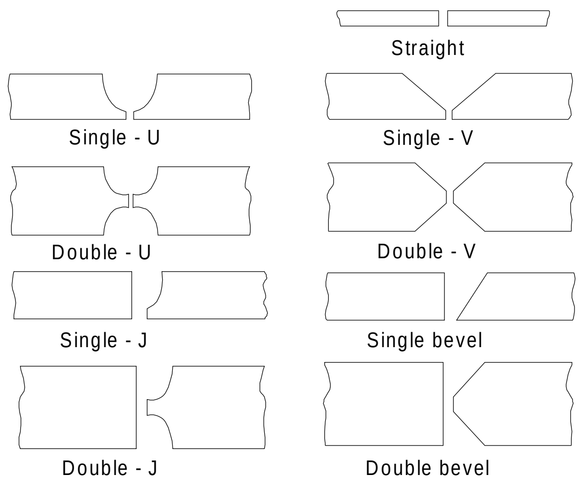


Fig. 17.2 Butt welding joints edge preparations

17.2.2 Welding joints

Some common welding joints are shown in Fig. 17.3. Welding joints are of generally of two major kinds namely lap joint and butt joint. The main types are described as under.

17.2.2.1 Lap weld joint

Single-Lap Joint

This joint, made by overlapping the edges of the plate, is not recommended for most work. The single lap has very little resistance to bending. It can be used satisfactorily for joining two cylinders that fit inside one another.

Double-Lap Joint

This is stronger than the single-lap joint but has the disadvantage that it requires twice as much welding.

Tee Fillet Weld

This type of joint, although widely used, should not be employed if an alternative design is possible.

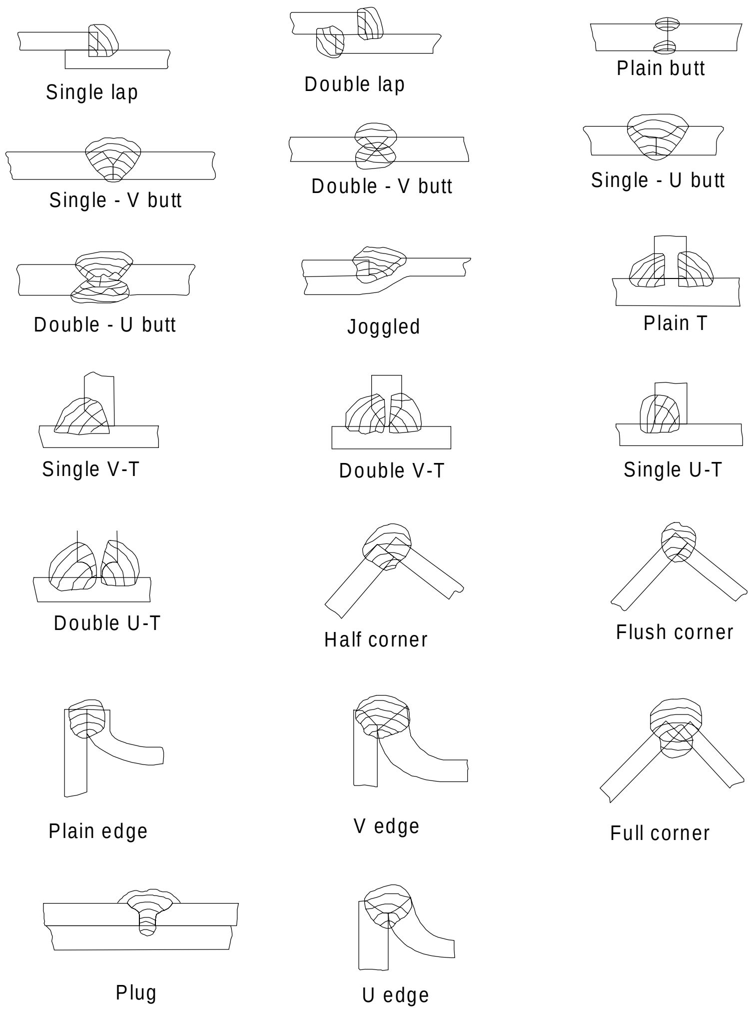


Fig. 17.3 Types of welding joints

17.2.2.2 Butt weld joint

Single-Vee Butt Weld

It is used for plates up to 15.8 mm thick. The angle of the vee depends upon the technique being used, the plates being spaced approximately 3.2 mm.

Double-Vee Butt Weld

It is used for plates over 13 mm thick when the welding can be performed on both sides of the plate. The top vee angle is either 60° or 80°, while the bottom angle is 80°, depending on the technique being used.

17.2.3 Welding Positions

As shown in Fig. 17.4, there are four types of welding positions, which are given as:

1. Flat or down hand position

2. Horizontal position
3. Vertical position
4. Overhead position

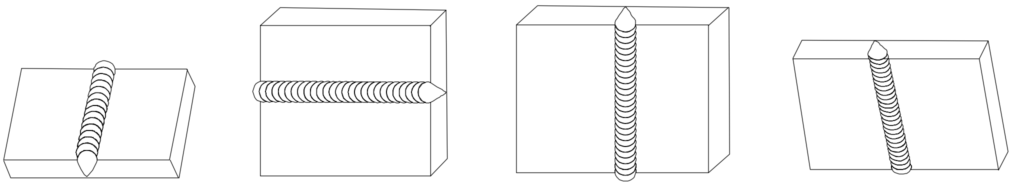


Fig. 17.4 Kinds of welding positions

17.2.3.1 Flat or Downhand Welding Position

The flat position or down hand position is one in which the welding is performed from the upper side of the joint and the face of the weld is approximately horizontal. This is the simplest and the most convenient position for welding. Using this technique, excellent welded joints at a fast speed with minimum risk of fatigue to the welders can be obtained.

17.2.3.2 Horizontal Welding Position

In horizontal position, the plane of the workpiece is vertical and the deposited weld head is horizontal. The metal deposition rate in horizontal welding is next to that achieved in flat or downhand welding position. This position of welding is most commonly used in welding vessels and reservoirs.

17.2.3.3 Veritical Welding Position

In vertical position, the plane of the workpiece is vertical and the weld is deposited upon a vertical surface. It is difficult to produce satisfactory welds in this position due to the effect of the force of gravity on the molten metal. The welder must constantly control the metal so that it does not run or drop from the weld. Vertical welding may be of two types viz., vertical-up and vertical-down. Vertical-up welding is preferred when strength is the major consideration. The vertical-down welding is used for a sealing operation and for welding sheet metal.

17.2.3.4 Overhead Welding Position

The overhead position is probably even more difficult to weld than the vertical position. Here the pull of gravity against the molten metal is much greater. The force of the flame against the weld serves to counteract the pull of gravity. In overhead position, the plane of the workpiece is horizontal. But the welding is carried out from the underside. The electrode is held with its welding end upward. It is a good practice to use very short arc and basic coated electrodes for overhead welding.

17.3 ADVANTAGES AND DISADVANTAGES OF WELDING

Advantages

1. Welding is more economical and is much faster process as compared to other processes (riveting, bolting, casting etc.)

2. Welding, if properly controlled results permanent joints having strength equal or sometimes more than base metal.
3. Large number of metals and alloys both similar and dissimilar can be joined by welding.
4. General welding equipment is not very costly.
5. Portable welding equipments can be easily made available.
6. Welding permits considerable freedom in design.
7. Welding can join welding jobs through spots, as continuous pressure tight seams, end-to-end and in a number of other configurations.
8. Welding can also be mechanized.

Disadvantages

1. It results in residual stresses and distortion of the workpieces.
2. Welded joint needs stress relieving and heat treatment.
3. Welding gives out harmful radiations (light), fumes and spatter.
4. Jigs, and fixtures may also be needed to hold and position the parts to be welded
5. Edges preparation of the welding jobs are required before welding
6. Skilled welder is required for production of good welding
7. Heat during welding produces metallurgical changes as the structure of the welded joint is not same as that of the parent metal.

17.4 CLASSIFICATION OF WELDING AND ALLIED PROCESSES

There are different welding, brazing and soldering methods are being used in industries today. There are various ways of classifying the welding and allied processes. For example, they may be classified on the basis of source of heat, i.e., blacksmith fire, flame, arc, etc. and the type of interaction i.e., liquid / liquid (fusion welding) or solid/solid (solid state welding). Welding processes may also be classified in two categories namely plastic (forge) and fusion. However, the general classification of welding and allied processes is given as under

(A) Welding Processes

1. Oxy-Fuel Gas Welding Processes

1 Air-acetylene welding

2 Oxy-acetylene welding

3 Oxy-hydrogen welding

4 Pressure gas welding

2. Arc Welding Processes

1. Carbon Arc Welding
2. Shielded Metal Arc Welding
3. Submerged Arc Welding
4. Gas Tungsten Arc Welding

5. Gas Metal Arc Welding
6. Plasma Arc Welding
7. Atomic Hydrogen Welding
8. Electro-slag Welding
9. Stud Arc Welding
10. Electro-gas Welding

3. Resistance Welding

1. Spot Welding
2. Seam Welding
3. Projection Welding
4. Resistance Butt Welding
5. Flash Butt Welding
6. Percussion Welding
7. High Frequency Resistance Welding
8. High Frequency Induction Welding

4. Solid-State Welding Processes

1. Forge Welding
2. Cold Pressure Welding
3. Friction Welding
4. Explosive Welding
5. Diffusion Welding
6. Cold Pressure Welding
7. Thermo-compression Welding

5. Thermit Welding Processes

1. Thermit Welding
2. Pressure Thermit Welding

6. Radiant Energy Welding Processes

1. Laser Welding
2. Electron Beam Welding

(B) Allied Processes

1. Metal Joining or Metal Depositing Processes

1. Soldering
2. Brazing
3. Braze Welding
4. Adhesive Bonding

5. Metal Spraying
6. Surfacing

2. Thermal Cuting Processes

1. Gas Cutting
2. Arc Cutting

Some of the important and widely used welding processes are discussed in the rest of this chapter.

17.6 ARC WELDING PROCESSES

The process, in which an electric arc between an electrode and a workpiece or between two electrodes is utilized to weld base metals, is called an arc welding process. The basic principle of arc welding is shown in Fig 17.9(a). However the basic elements involved in arc welding process are shown in Fig. 17.9(b). Most of these processes use some shielding gas while others employ coatings or fluxes to prevent the weld pool from the surrounding atmosphere. The various arc welding processes are:

1. Carbon Arc Welding
2. Shielded Metal Arc Welding
3. Flux Cored Arc Welding
4. Gas Tungsten Arc Welding
5. Gas Metal Arc Welding
6. Plasma Arc Welding
7. Atomic Hydrogen Welding
8. Electroslag Welding
9. Stud Arc Welding
10. Electrogas Welding

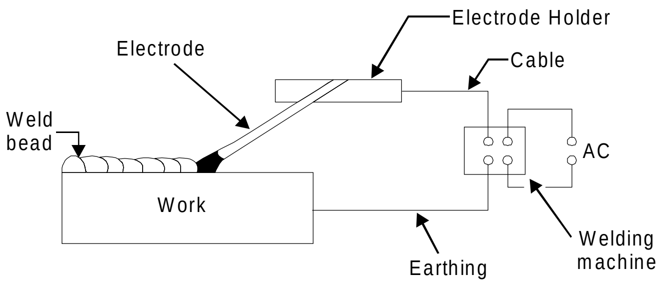
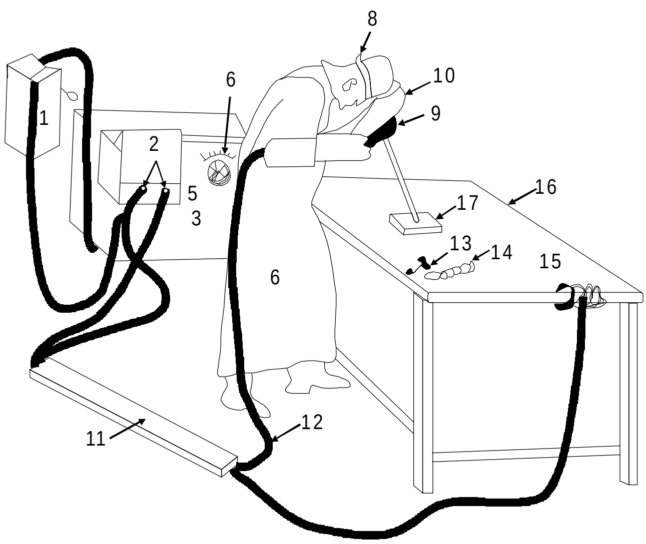


Fig. 17.9(a) Principle of arc welding



(1) Switch box.
(2) Secondary terminals.
(3) Welding machine.
(4) Current reading scale.
(5) Current regulating hand wheel.
(6) Leather apron.
(7) Asbestos hand gloves.
(8) Protective glasses strap.
(9) Electrode holder.
(10) Hand shield.
(11) Channel for cable protection.
(12) Welding cable.
(13) Chipping hammer.
(14) Wire brush.
(15) Earth clamp.
(16) Welding table (metallic).
(17) Job.

Fig. 17.9(b) Arc welding process setup

17.6.1 Arc Welding Equipment

Arc welding equipment, setup and related tools and accessories are shown in Fig. 17.9. However some common tools of arc welding are shown separately through Fig. 17.10-17.17. Few of the important components of arc welding setup are described as under.

1. Arc welding power source

Both direct current (DC) and alternating current (AC) are used for electric arc welding, each having its particular applications. 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). The following factors influence the selection of a power source:

1. Type of electrodes to be used and metals to be welded
2. Available power source (AC or DC)
3. Required output
4. Duty cycle
5. Efficiency
6. Initial costs and running costs
7. Available floor space
8. Versatility of equipment

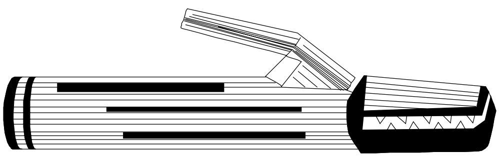


Fig. 17.10 Electrode holder

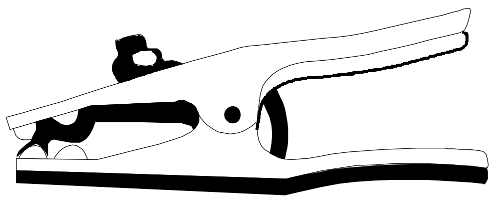


Fig. 17.11 Earth clamp

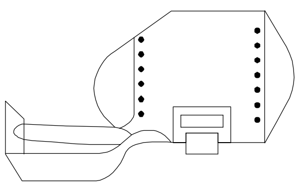


Fig. 17.12 Hand screen

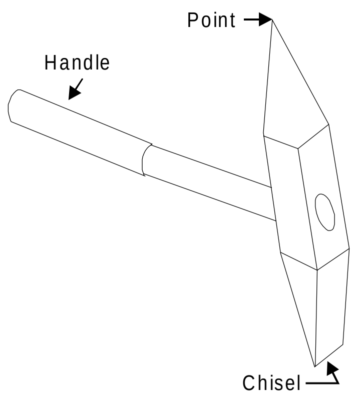


Fig. 17.13 Chipping and hammer

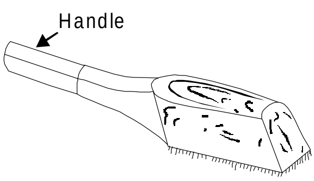


Fig. 17.14 Wire brush

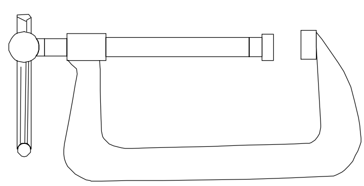


Fig. 17.15 C-clamp

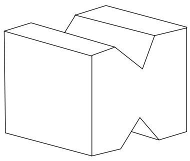


Fig. 17.16 V-block

Fig. 17.17 Scriber

2. Welding cables

Welding cables are required for conduction of current from the power source through the electrode holder, the arc, the workpiece and back to the welding power source. These are insulated copper or aluminium cables.

3. Electrode holder

Electrode holder is used for holding the electrode mannually and conducting current to it. These are usually matched to the size of the lead, which in turn matched to the amperage output of the arc welder. Electrode holders are available in sizes that range from 150 to 500 Amps.

4. Welding Electrodes

An electrode is a piece of wire or a rod of a metal or alloy, with or without coatings. An arc is set up between electrode and workpiece. Welding electrodes are classified into following types-

(1) Consumable Electrodes
   (*a*) Bare Electrodes
   (*b*) Coated Electrodes
(2) Non-consumable Electrodes
   (*a*) Carbon or Graphite Electrodes
   (*b*) Tungsten Electrodes

Consumable electrode is made of different metals and their alloys. The end of this electrode starts melting when arc is struck between the electrode and workpiece. Thus consumable electrode itself acts as a filler metal. Bare electrodes consist of a metal or alloy wire without any flux coating on them. Coated electrodes have flux coating which starts melting as soon as an electric arc is struck. This coating on melting performs many functions like prevention of joint from atmospheric contamination, arc stabilizers etc.

Non-consumable electrodes are made up of high melting point materials like carbon, pure tungsten or alloy tungsten etc. These electrodes do not melt away during welding. But practically, the electrode length goes on decreasing with the passage of time, because of oxidation and vaporization of the electrode material during welding. The materials of non-consumable electrodes are usually copper coated carbon or graphite, pure tungsten, thoriated or zirconiated tungsten.

5. Hand Screen

Hand screen (Fig. 17.12) used for protection of eyes and supervision of weld bead.

6. Chipping hammer

Chipping Hammer (Fig. 17.13) is used to remove the slag by striking.

7. Wire brush

Wire brush (Fi. 17.14) is used to clean the surface to be weld.

8. Protective clothing

Operator wears the protective clothing such as apron to keep away the exposure of direct heat to the body.

17.6.3 Shielded Metal Arc Welding (SMAW) or Manual Metal Arc Welding (MMAW)

Shielded metal arc welding (SMAW) is a commonly used arc welding process manually carried by welder. It is an arc welding process in which heat for welding is produced through an electric arc set up between a flux coated electrode and the workpiece. The flux coating of electrode decomposes due to arc heat and serves many functions, like weld metal protection, arc stability etc. Inner core of the electrode supply the filler material for making a weld. The basic setup of MMAW is depicted in Fig. 17.9 (a), (b) and the configuration of weld zone is shown in Fig. 17.18. If the parent metal is thick it may be necessary to make two or three passes for completing the weld. A typical multi pass bead in this case is shown in Fig. 17.19.

Advantages

1. Shielded Metal Arc Welding (SMAW) can be carried out in any position with highest weld quality.
2. MMAW is the simplest of all the arc welding processes.

3. This welding process finds innumerable applications, because of the availability of a wide variety of electrodes.
4. Big range of metals and their alloys can be welded easily.
5. The process can be very well employed for hard facing and metal resistance etc.
6. Joints (e.g., between nozzles and shell in a pressure vessel) which because of their position are difficult to be welded by automatic welding machines can be easily accomplished by flux shielded metal arc welding.
7. The MMAW welding equipment is portable and the cost is fairly low.

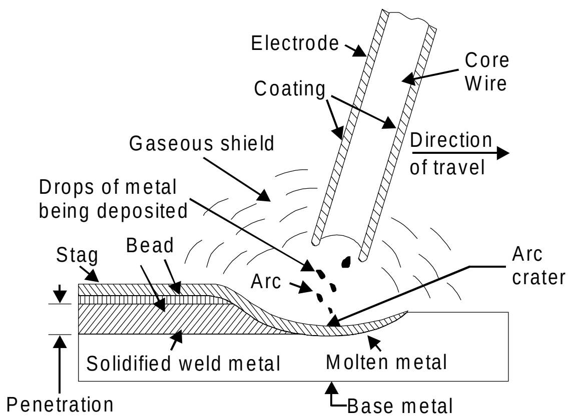


Fig. 17.18 Arc welding operation

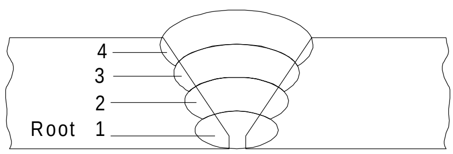


Fig. 17.19 A typical multi pass bead

Limitations

1. Due to flux coated electrodes, the chances of slag entrapment and other related defects are more as compared to MIG and TIG welding.
2. Duo to fumes and particles of slag, the arc and metal transfer is not very clear and thus welding control in this process is a bit difficult as compared to MIG welding.
3. Due to limited length of each electrode and brittle flux coating on it, mechanization is difficult.
4. In welding long joints (e.g., in pressure vessels), as one electrode finishes, the weld is to be progressed with the next electrode. Unless properly cared, a defect (like slag inclusion or insufficient penetration) may occur at the place where welding is restarted with the new electrode
5. The process uses stick electrodes and thus it is slower as compared to MIG welding.

Applications

1. Today, almost all the commonly employed metals and their alloys can be welded by this process.

2. Shielded metal arc welding is used both as a fabrication process and for maintenance and repair jobs.
3. The process finds applications in
   (*a*) Building and Bridge construction
   (*b*) Automotive and aircraft industry, etc.
   (*c*) Air receiver, tank, boiler and pressure vessel fabrication
   (*d*) Ship building
   (*e*) Pipes and
   (*f*) Penstock joining

17.6.3.1 Functions of Electrode Coating Ingredients

The covering coating on the core wire consists of many materials which perform a number of functions as listed below:

1. Welding electrodes are used to join various similar and dissimilar metals as plain carbon steels, cast iron, copper, aluminium, magnesium and their alloys, stainless steels and other alloy steels.
2. Slag forming ingredients, like silicates of magnesium, aluminium, sodium, potassium, iron oxide, china clay, mica etc., produce a slag which because of its light weight forms a layer on the molten metal and protects the same from atmospheric contamination.
3. Arc stabilizing constituents like calcium carbonate, potassium silicate, titanates, magnesium silicates, etc.; add to arc stability and ease of striking the same.
4. Gas shielding ingredients, like cellulose, wood, wood flour, starch, calcium carbonate etc. form a protective gas shield around the electrode end, arc and weld pool
5. Deoxidizing elements like ferro-manganese, and ferro-silicon, refine the molten metal.
6. It limits spatter, produces a quiet arc and easily removable slag.
7. Alloying elements like ferro alloys of manganese, molybdenum etc., may be added to impart suitable properties and strength to the weld metal and to make good the loss of some of the elements, which vaporize while welding.
8. Iron powder in the coating improves arc behavior, bead appearance helps increase metal deposition rate and arc travel speed.
9. The covering improves penetration and surface finish.
10. Core wire melts faster than the covering, thus forming a sleeve of the coating which constricts and produces an arc with high concentrated heat.
11. Coating saves the welder from the radiations otherwise emitted from a bare electrode while the current flows through it during welding.
12. Proper coating ingredients produce weld metals resistant to hot and cold cracking. Suitable coating will improve metal deposition rates.

17.12 WELDING DEFECTS

Defects in welding joints are given in 17.31 (*i-viii*)

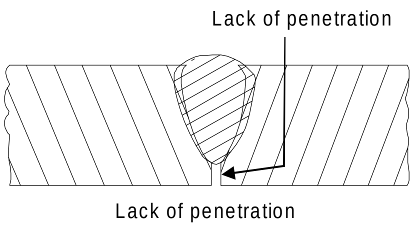


Fig. 17.31(i)

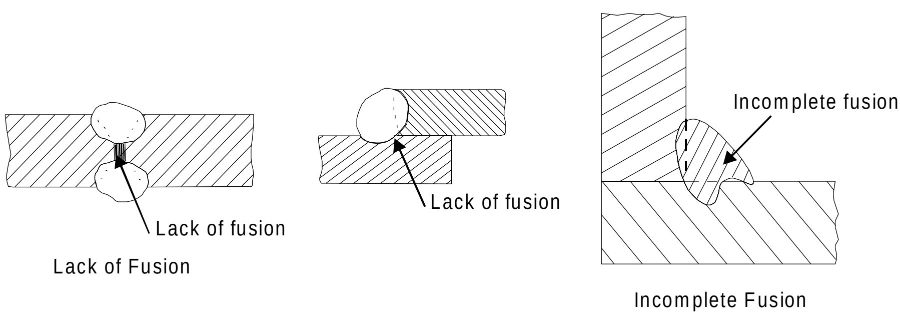
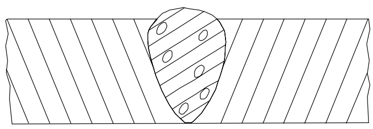
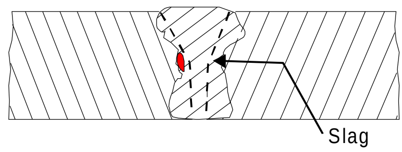


Fig. 17.31(ii)



Porosity

Fig. 17.31(iii)



Slag Inclusion

Fig. 17.31(iv)

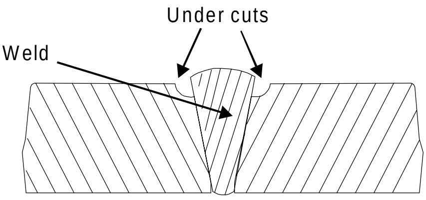
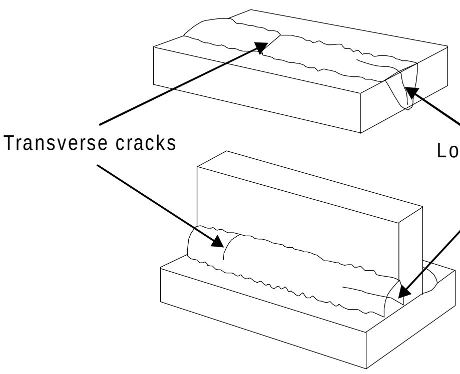
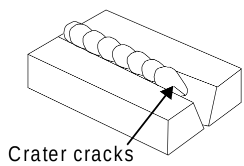


Fig. 17.31(v)

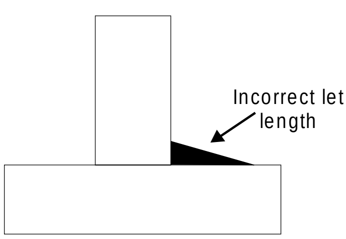


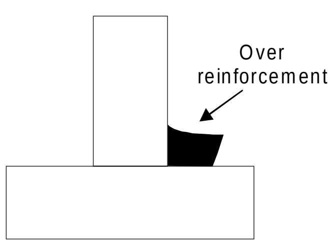
(a) Longitudinal and Transverse Crack

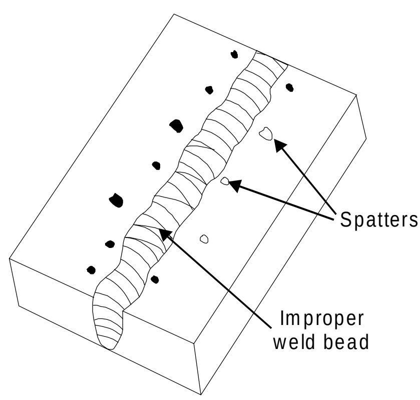


(b) Crater cracks

Fig. 17.31(vi)







Poor Weld Bead Appearance

Fig. 17.31(vii)

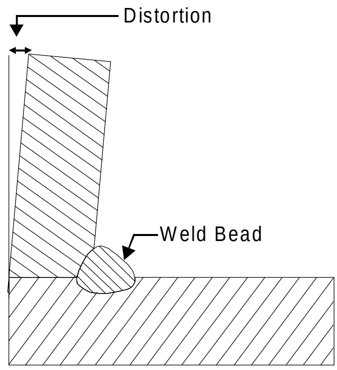


Fig. 17.31(viii)

Fig. 17.31 Types of welding defects

1. Lack of Penetration (Fig. 17.31 (i))

It is the failure of the filler metal to penetrate into the joint. It is due to

(*a*) Inadequate de-slagging

(*b*) Incorrect edge penetration

(*c*) Incorrect welding technique.

2. Lack of Fusion (Fig. 17.31 (ii))

Lack of fusion is the failure of the filler metal to fuse with the parent metal. It is duo to

(*a*) Too fast a travel

(*b*) Incorrect welding technique

(*c*) Insufficient heat

3. Porosity (Fig. 17.31 (iii))

It is a group of small holes throughout the weld metal. It is caused by the trapping of gas during the welding process, due to

(*a*) Chemicals in the metal

(*b*) Dampness

(*c*) Too rapid cooling of the weld.

4. Slag Inclusion (Fig. 17.31 (iv))

It is the entrapment of slag or other impurities in the weld. It is caused by

(*a*) Slag from previous runs not being cleaned away,

(*b*) Insufficient cleaning and preparation of the base metal before welding commences.

5. Undercuts (Fig. 17.31 (v))

These are grooves or slots along the edges of the weld caused by

(*a*) Too fast a travel

(*b*) Bad welding technique

(*c*) Too great a heat build-up.

6. Cracking (Fig. 17.31 (vi))

It is the formation of cracks either in the weld metal or in the parent metal. It is due to

(*a*) Unsuitable parent metals used in the weld

(*b*) Bad welding technique.

7. Poor Weld Bead Appearance (Fig. 17.31 (vii))

If the width of weld bead deposited is not uniform or straight, then the weld bead is termed as poor. It is due to improper arc length, improper welding technique, damaged electrode coating and poor electrode and earthing connections. It can be reduced by taking into considerations the above factors.

8. Distortion (Fig. 17.31 (viii))

Distortion is due to high cooling rate, small diameter electrode, poor clamping and slow arc travel speed

9. Overlays

These consist of metal that has flowed on to the parent metal without fusing with it. The defect is due to

(*a*) Contamination of the surface of the parent metal

(*b*) Insufficient heat

10. Blowholes

These are large holes in the weld caused by

(*a*) Gas being trapped, due to moisture.

(*b*) Contamination of either the filler or parent metals.

11. Burn Through

It is the collapse of the weld pool due to

(*a*) Too great a heat concentration

(*b*) Poor edge preparation.

12. Excessive Penetration

It is where the weld metal protrudes through the root of the weld. It is caused by

(*a*) Incorrect edge preparation

(*b*) Too big a heat concentration

(*c*) Too slow a travel.