MODULE 5

SOLDERING, BRAZING AND METALLURGICAL ASPECTS IN WELDING

Formation of different zones in welding

During welding, when the heat interacts with the workpiece material, the flow of temperature in the material varies from region to region resulting in three distinct regions or zones, they are the fusion zone, heat affected zone and the unaffected base metal zone. (fig 5.1 shows the details)

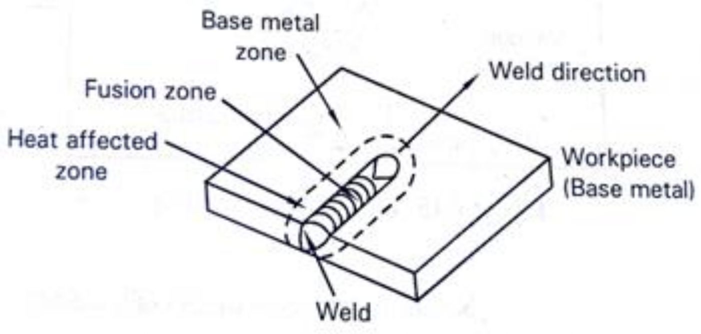


Figure 5.1 Different zones in welding

Zone 1 Fusion zone

Fusion zone is the weld metal itself; more specifically, it is the region where the molten metal of the filler rod combines with the molten metal of the workpicece to form the weld. The fusion zone can be considered similar to a casting process, wherein the workpiece metal reaches the molten state and then allowed to cool. Hence, the metal in the fusion zone has basically, a cast structure with the microstructure reflecting the cooling rate in the weld. The properties of the fusion zone depend primarily on the filler metal used and its compatibility with the workpiece material.

Zone 2 Heat Affected Zone (HAZ)

The fusion zone is surrounded by the heat affected zone, the portion that was not melted, but subjected to elevated temperatures for a brief period of time. As a result, these portions experience changes in its microstructure and mechanical properties. The extent and magnitude to which the changes occur depend primarily on the type of the base metal, and the amount of concentration of heat input at the joint. The metal in this area is often weaker than both the *base metal* and the *weld metal*, and it is also where residual stresses are found.

Zone 3 Base metal zone

Base metal zone is the portion around the heat affected zone which remains unaffected, as it was not heated sufficiently to change its microstructure.

Structure of welds

During welding, a small portion at the edges of the workpiece (fusion zone) will be *melted* followed by immediate and *fast cooling* of the molten metal. Hence, the microstructure development in this region depends on the solidification behavior of the molten metal.

The solidification process is similar to that in casting and begins with the formation of *columnar (dendritic) grains.* Fig. 5.2 shows the grain structure in a deep weld. Along the fusion line, the growth rate is low, while the temperature gradient is steepest. Grains appear at the line of fusion, and as the weld centerline is approached, the growth rate increases while the temperature gradient decreases. Consequently, the microstructure that develops varies noticeably from the edges to the centerline of the weld.

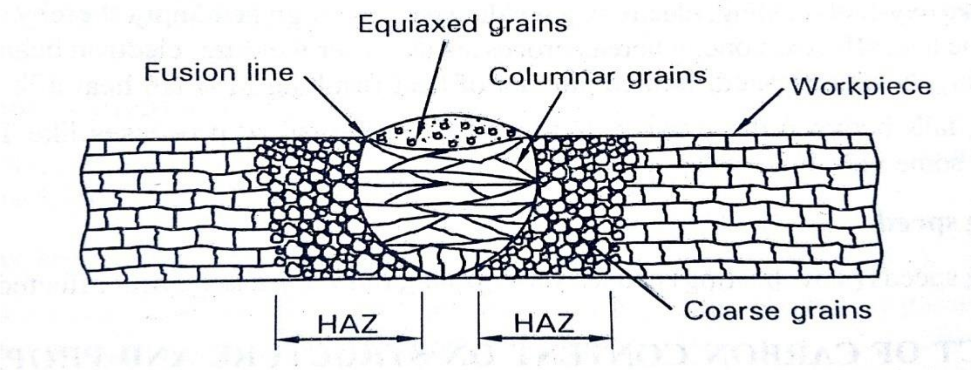


Figure 5.2 Structure of a weld

The grains formed are relatively long and parallel to the heat flow. The grain structure an size depend on the type of welding process employed, filler metal used, and the alloy (metal) being melted.

Adjacent to the portion of the weld metal i.e., in the heat affected zone, coarse grains are formed as a result of overheating. The grain growth will cause this portion to be brittle thereby making it the weakest portion in the weld metal.

Heat Affected Zone

Welding makes use of intense heat to melt the edges of the workpiece material being joined. But during welding, the portion of the base metal adjacent to the edges being joined also gets heated to varying temperatures. As a result, these portions experience changes in its microstructure and mechanical properties. The extent and magnitude to which the changes occur depends primarily on the type of base metal, and the amount and concentration of heat input at the joint.

Thus the heat affected zone can be defined as that portion of the base metal which has not been melted, but, whose microstructure and mechanical properties have been altered by the heat of welding. The heat affected zone is often the weakest part in the welded metal, because it neither possesses the properties of the base metal nor that of the solidified welds metal. Consequently, heat affected zone forms the region for most of the failures of the welded joint. However, the heat affected zone can be reduced by controlling a few parameters described below:

a. Thermal diffusivity

The thermal diffusivity of the base material plays a large role: if the diffusivity is high, the material cooling rate will be high, and hence the heat affected zone will be relatively small. Low diffusivity leads to slower cooling and a larger heat affected zone.

b. Heat input

Processes like oxy-fuel welding, electroslag welding etc., use high heat input thereby increasing the size of the heat affected zone, whereas processes like laser welding, electron beam welding etc., give a highly concentrated, limited amount of heat resulting in small heat affected zone.

Arc welding falls between these two extremes with the individual processes like TIG, SAW, etc., varying somewhat in heat input.

c. Welding speed

Slow welding speeds (slow heating causes slow cooling rates and a large heat affected zone.

Effect of carbon content on structure and properties of steel

Steel is most widely used material in welding compared to other materials. Steel may be defined as refined pig iron, or an alloy of iron and carbon. Various elements like sulphur, manganese, phosphorous, etc., are added to steel in order to impart the properties like hardenability, strength, hardness, weldability, wear resistance, etc.

Of all the constituents, carbon is the most ingredient in steel, because it has a direct effect on the physical properties of steel.

Shrinkage in welds

Welding involves highly localized heating of the metals being joined together. During welding, when the weld metal is deposited, the base metal is heated, and thus it expands, but on cooling the base metal plus the weld metal shrinks. It is obvious that the shrinkage of a welded joint is far greater than the expansion. This shrinkage in turn introduces residual stress distortion which is a major problem in welding.

Shrinkage is the inherent property of any metal, and hence cannot be prevented, but can be controlled. There are various methods that can be used at the design stage, or in welding shops to minimize the effects caused by shrinkage. These include:

a. Do not over weld

The more metal placed in the joint, the greater is the shrinkage forces. Hence, use of right joint preparation avoids excessive gap thereby requiring least amount of weld metal. (Refer Fig. 5.3.a)

b. Use intermittent welding

Another way to minimize weld metal is to use intermittent welding rather than continuous welds. (Refer Fig. 5.3.b)

c. Use as few weld passes as possible

Fewer passes with large electrode are preferable to a greater number of passes with small electrodes. This helps to minimize shrinkage. (Fig. 5.3.c)

d. Place welds near neutral axis

Attempts regarding placing welds near the neutral axis should be done at the design stage itself. Fig. 5.3.d

e. Balance welds around the neutral axis

This practice, will balance one shrinkage force against another thereby minimizing distortion of the weldmate. Fig. 5.3.e

f. Balance shrinkage forces with opposing forces

Pre-bending, as shown in Fig. 5.3.f, makes use of opposing mechanical forces to counteract distortion due to the shrinkage effect. Clamps, jigs or fixtures may be used to hold the workpiece until welding is completed. When the clamps are released, the plates return to the flat shape allowing the weld to relieve its shrinkage stresses.

g. Removing shrinkage forces after welding

One method involves peening or hammering the weld metal with a blunt rounded edge that will cause the weld bead to stretch and make it thinner, thereby relieving the stress induced by shrinkage. But, peening may cause damage to the weld metal and hence has to be used in special cases.

Another method is by thermal stress relieving or heat treatment technique, wherein, controlled heating of the weld metal to elevated temperature is followed by controlled cooling. The residual; stresses that would tend to distort the weldments are thus minimizes.

h. Minimise welding time

It is desirable to finish the weld quickly, before a large volume of the surrounding metal heats up and expands. This helps to minimize the shrinkage effects.

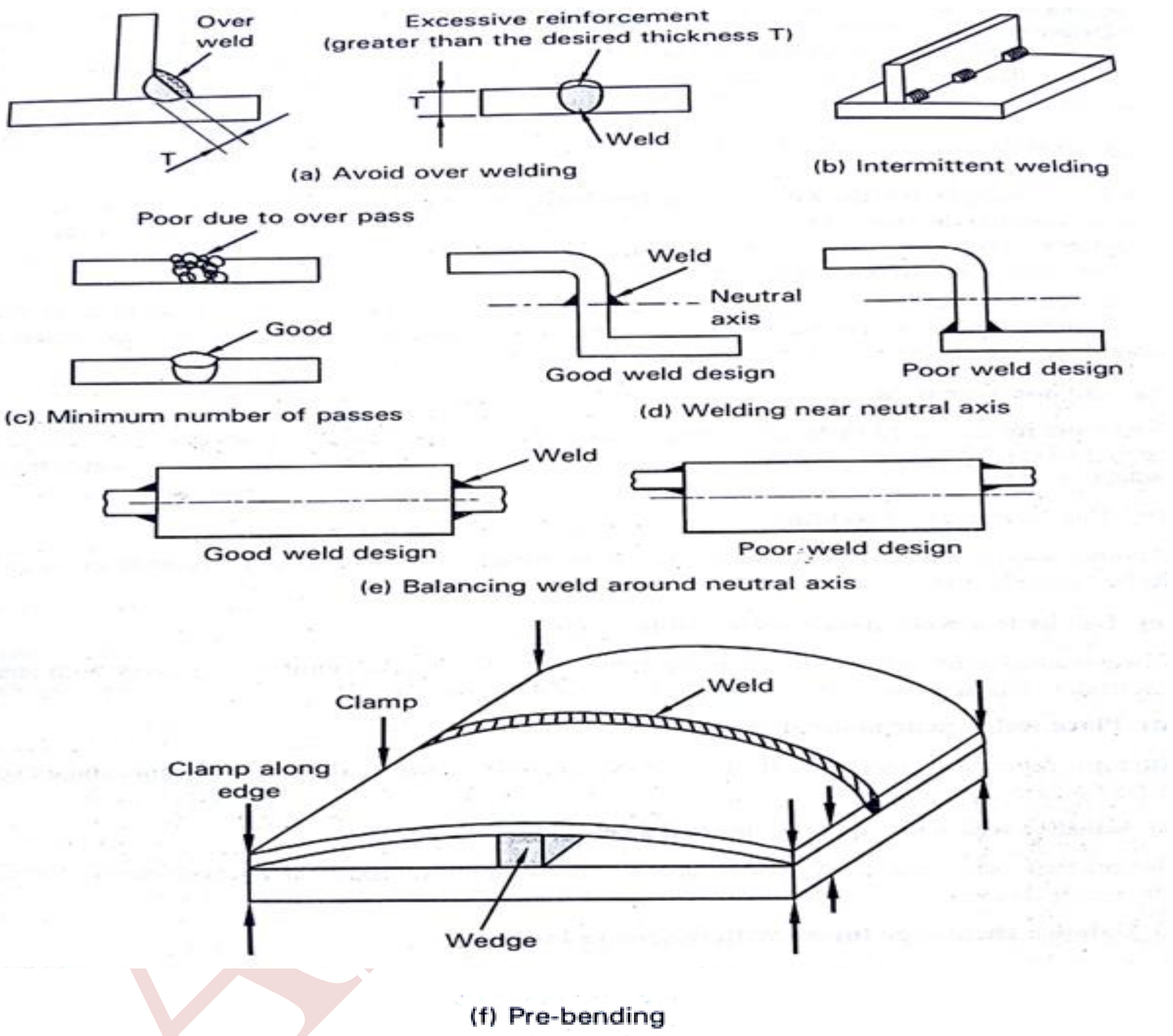


Figure 5.3 Methods to minimize shrinkage effects

Residual stresses

During welding, the metal expands due to heating, and upon cooling, the weld metal solidifies and shrinks, exerting stresses on the surrounding weld metal. In other words, the heating and cooling of the weld metal induces residual stresses in the material. Residual stresses remain in a body (material) and are independent of any applied lead.

Effects of residual stresses

a. Residual stresses can result in visible distortion of a component
b. Residual stresses can reduce the strength of the base material and can lead to catastrophic failure through cold cracking.
c. Lowers the ductility of the metal.
d. Residual stresses may increase the rate of damage by fatigue, creep or environmental degradation.

Control of residual stresses

a. Residual stresses are minimized by reducing the amount of weld metal deposited. Since residual stresses result from the restrained expansion and contraction that occur during welding, the lower the weld metal deposited, the lower will be the induced stress. Example: use of U-groove instead of V-groove consumes less weld metal.
b. Reduce the amount of heat input at the joint.
c. Welding sequence used should not be from one end directly to the other, but, rather in segments.

Relieving residual stresses

Two commonly used methods for relieving residual stresses are discussed below:

a. Peening:

Peening or hammering of the weld metal with a blunt rounded edge will cause the weld bead to stretch and make it thinner, thereby relieving the stresses induced by shrinkage. Peening should be employed on those weld metals possessing sufficient ductility to undergo necessary deformation. Also, peening should be employed carefully so that it will not cause damage to the weld metal.

b. Heat Treatment

Heat treatment (example: Annealing) is a thermal stress relieving technique that employs controlled heating of the weld metal usually in a furnace, followed by controlled cooling so as to relieve the stresses induced in the weld metal. The metal is cooled slowly either inside the furnace or in atmospheric air up to room temperature.

Weldability

- It is the easiness with which a metal can be welded into reliable inseparable joint having proper structure and property.
- Metals with limited solid solubility have lower weldability.
- Metals which are insoluble in each other is the solid state are entirely unweldable by fusion welding.
- Such metals are heated to a plastic state and then a mechanical force is applied to make the bonding between parts.
- In some cases a third metal is introduced at the joint, which is soluble in the metals.
- Metals having higher thermal conductivity are most easily weldable.
- They dissipate heat from the weld fast.

The main problem associated with weldability is the development of cracks in:

The welded portion i.e., the joint

The common surface between the weld metal and the parent

metal The parent metal adjacent to the weld.

Welding results in heating of the parent metal and is suddenly exposed to atmosphere air. This brings about sudden cooling. This induces hardening in the metal and reduces ductility. This induces cracking tendency.

The following factors affect weldability of metal:

- Thermal conductivity of metal
- Thermal expansion of metal
- Microstructural changes in the metal
- Oxidation of the metal
- Surface condition of the metal.

Weldability of metals in descending order:

Wrought Iron (pure iron) Carbon steel
(<0.25%C) Cast iron

Low alloy steel Stainless steel

Concept of Filler metal, Electrode & Flux

A filler metal is a metallic wire used to supply additional material to fill the gap between the two workpieces to be joined. The filler metal is available in the form of rod, and is made of the same material or nearly the same chemical composition as that of the base metal. The filler metal used in arc welding processes is called electrode.
Filler metal is classified into three basic categories:

i. Coated electrode
ii. Plain/Bare or uncoated electrode
iii. Fabricated tubular or cored electrode wire

i. Coated electrode

In coated electrodes, the metallic wire, called core is coated with a flux, Fig. 5.4(a) Coating is done by dipping the heated end of the filler rod in the constituents of flux. The flux sticks to the metallic wire. The detailed description regarding flux coating is provided herein.

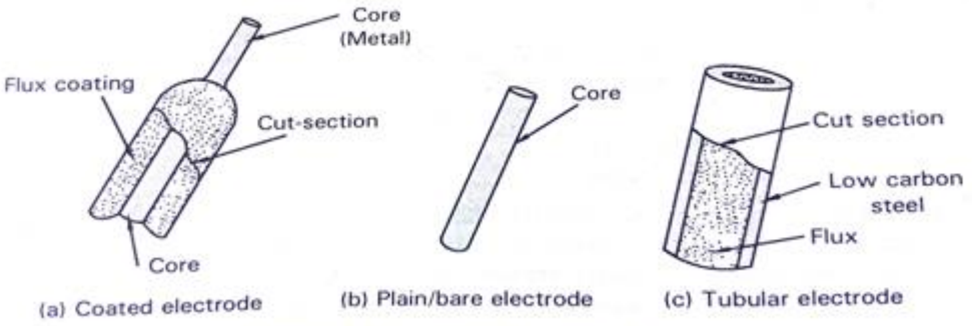


Figure 5.4 Filler metals / Electrode

During welding, the workpieces melts and at the same time, the tip of the electrode also melts. As the globules of molten metal pass from the electrode to the workpiece, they absorb oxygen and nitrogen from the atmospheric air. The causes the formation of some non-metallic constituents which are trapped in the solidifying weld metal thereby decreasing the strength of the joint. In order to avoid this, a flux is coated on the metallic wire. During welding, the flux vaporizes and produces a gaseous shield around the molten weld pool, thereby preventing atmospheric contamination.

The original purpose of the coating was to provide shielding from the oxygen and nitrogen in the atmosphere. It was subsequently found that ionizing agents could be added to the coating which helped to stabilize the arc and made electrodes suitable for welding with alternating current (AC). The flux coated on the electrode performs a variety of functions depending on the constituents from which it is made. Various constituents, like titanium oxide, cellulose, manganese oxide, calcium carbonates, mica, iron oxide, etc., are used as flux materials for coating.

Functions of Flux

- Prevents oxidation of molten metal
- Helps in removal of oxides and other undesirable substances present on the surface of the workpiece.
- Chemically reacts with the oxides and forms a slag. The slag floats and covers the top portions of the molten metal thereby preventing it from rapid cooling.
- Stabilizes the arc.
- Eliminates weld metal porosity.
- Minimum spatter adjacent to the weld.

ii. Plain/Bare or uncoated electrode

In this type of filler metal, the metallic wire (core wire) is left plain or uncoated with flux Fig. 5.4.(b). These electrodes do not prevent oxidation of the weld, and hence the joint obtained is weak. Welding processes that makes use of bare electrodes utilize inert gases for shielding of weld metal during welding. MIG, SAW and other processes make use of bare electrodes.

Bare electrodes in the form of wire were first used for oxy-fuel gas welding processes to supply additional materials to fill the joint. Later on, the wire was provided in coils for automatic welding process. Bare electrodes are so named, because they are uncoated with flux material. However, a very thin copper coating is provided on the wire to improve current pick-up and also prevent rusting of the wire.

iii. Tubular wire

Tubular electrodes are hollow materials containing flux constituents inside and are used in flux-cored arc welding process. The tubular electrode consists of a wire made of a low- carbon steel sheath surrounding a core of flux and alloying materials. The compounds contained in the wire perform essentially the same functions as the coated electrodes.

Electrodes

A welding electrode is defined as a component of the welding circuit through which current is conducted. In other words, the electrode forms one pole of the electric circuit, while the workpiece forms the other pole. Welding electrodes are classified into two types:

a. Consumable electrodes and

b. Non-consumable electrodes

a. Consumable electrodes

Consumable electrodes are those which get consumed during the welding process. These electrodes help to establish the arc and also act as filler metal to deposit additional material to fill the gap between the workpieces. Consumable electrodes may be coated, bare or tubular type.

b. Non-consumable electrodes

Non-consumable electrodes are those which are made of carbon, graphite or tungsten and do not consume during welding. They serve only to strike and maintain the arc during the welding process. TIG, Atomic hydrogen welding process, etc., use non-consumable electrodes.

Welding Defects

Like casting, welding also involves various parameters, viz., type of workpiece material, electrode material, power source, heat input, cooling rate, welding speed, etc. Loss of control in any of these parameters may cause defects in the weld metal. Most of the defects encountered in welding are due to improper welding procedure. Some of the common defects and their causes are discussed below:

a. Crack

Crack is a small, sharp split that occurs in the base metal, weld metal or at the interface between the two and are visible to the naked eye. Crack is a serious defect because they are seen as stress raisers capable to grow until fracture takes place.

Causes

- Incorrect technique for ending the weld
- Poor ductility of the based metal
- Combination of joint design and welding techniques, which results in a weld bead with an excessively concave surface that promote cracking.
- Low welding currents.
- Restrained joints – joint members are not free to expand and contract when subjected to heat.

b. Distortion

Distortion is the change in the original shape of the two workpieces after welding.

Causes

- High residual stresses due to
- shrinkage High heat input
- More number of passes
- Slow welding speed

c. Incomplete penetration

When the molten metal fails to penetrate the entire thickness of the base plate, it forms a bridge across the two plates causing a defect in the weld. Fig

Causes

- Improper joint design
- Low welding current
- Slow arc travel speed
- Incorrect torch angle

d. Inclusions

Inclusions are usually non-metallic particles such as slag or any foreign material that does not get a chance to float on the surface of the solidifying metal and thus gets trapped inside the same Fig.

Causes

- Use of large electrodes in a narrow groove
- Low currents that are insufficient for melting
- metal High viscosity of the weld metal.

e. Porosity

Porosities are small voids or cavities are formed when gases are trapped in the solidifying weld metal. Porosity can occur either under or on the weld surface. Fig. 8(e).

Causes

- Atmospheric contamination caused due to inadequate shielding gas.
- Excessively oxidized workpiece surface
- Use of wet electrodes
- Excessive gases released during welding.

f. Under cut

Under cut, the worst of all defects is the term given to a sharp narrow groove along the toe of the weld due to the scouring action of the arc removing the metal and not replacing it with the weld metal. Fig.

Causes

- High voltage and welding current
- High arc travel speed
- Incorrect electrode manipulation
- Arc gap too long

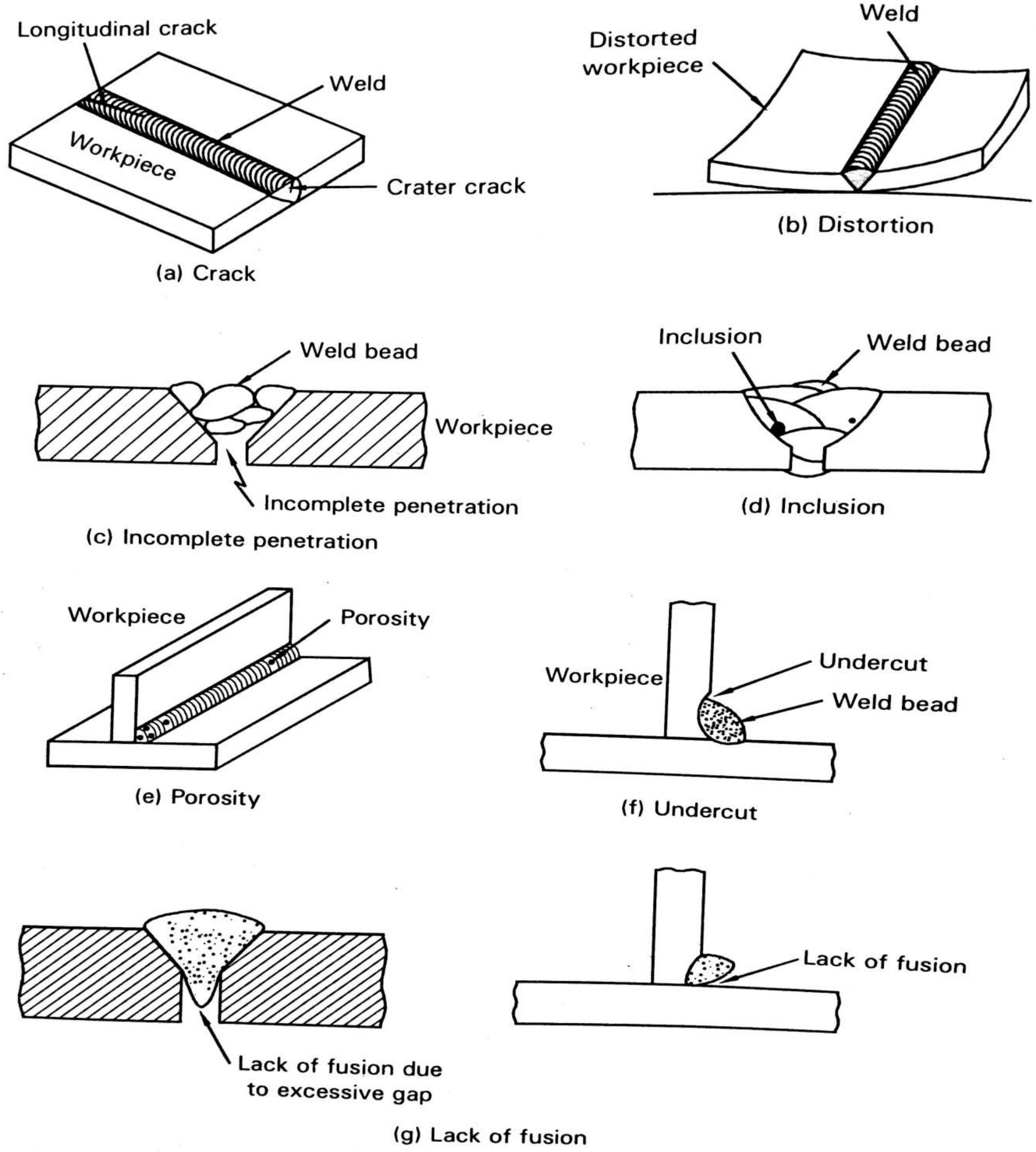
g. Lack of fusion or overlapping

Lack of fusion is the failure of a welding process to fuse together layers of the base metal. The weld metal just rolls over the workpiece surface. Fig.

Causes

- Low welding currents that are insufficient to raise the temperature of the workpiece metal to melting point.

- Excessive surface impurities of workpiece.
- Improper electrode type/size.
- Wrong polarity.
- Low arc travel speed.



(a) Crack

(b) Distortion

(c) Incomplete penetration

(d) Inclusion

(e) Porosity

(f) Undercut

(g) Lack of fusion

Figure 5.5 Welding defects

GAS WELDING

- Gas welding is a **fusion** welding process.
- Here the heat is generated by the combustion of **oxygen** or air and a **gas** (such as acetylene, hydrogen, butane, methane petroleum gas, etc) is used to join metals.
- A strong flame is produced when the mixture of gases are ignited.
- This flame has a very high temperature which melts and fuses the metal parts. The quantities of gases are to be regulated for controlling the weld flame.
- A **filler metal** rod is used to supply molten metal at the joint.
- Gas torch is used for welding hence is referred to as ***welding torch*** also.
- It is used for repair work, for joining thin walled parts of steel and non-ferrous alloys. Two familiar fuel gases used in gas welding are:
- Mixture of **oxygen** and **acetylene** gas – called ***oxy-acetylene*** welding process. Mixture of **oxygen** and **hydrogen** gas – called ***oxy-hydrogen*** welding process.
- Oxy-acetylene welding is the most versatile and widely used gas welding process due to its high flame temperature (upto 3200°C) when compared to oxy-hydrogen process (2500°C).

Reaction in gas welding

The details of reaction involved at each step and the final equation is given below.

First acetylene is decomposed to C and H

Decomposition of acetylene $2C_2H_2 \rightleftharpoons 4C + 2H_2$ Zone I

Then the carbon combines with oxygen to form CO due to partial combustion

Incomplete combustion
of carbon $4C + 2O_2 \rightleftharpoons 4CO + \text{heat}$ Zone II

Finally Co is converted to CO due to complete combustion

Combustion of CO to CO_2

$4CO + 2H_2 + 3O_2 \rightleftharpoons 4CO_2 + 2H_2O$ Zone III

$2C_2H_2 + 5O_2 \rightleftharpoons 4CO + 2H_2O + 31{,}000 \text{ cal/mole}$

Zone I Consists of decomposed products of C_2H_2. A truncated cone flame with rounded end is formed. Solid carbon particles are formed which are incandescent, glow with the brightest flame.

Zone II Heat is evolved mainly due to oxidation of C to CO at a distance of 3-5mm from the end of the inner cone.

Temperature is the highest in this zone greater that 3000°C.

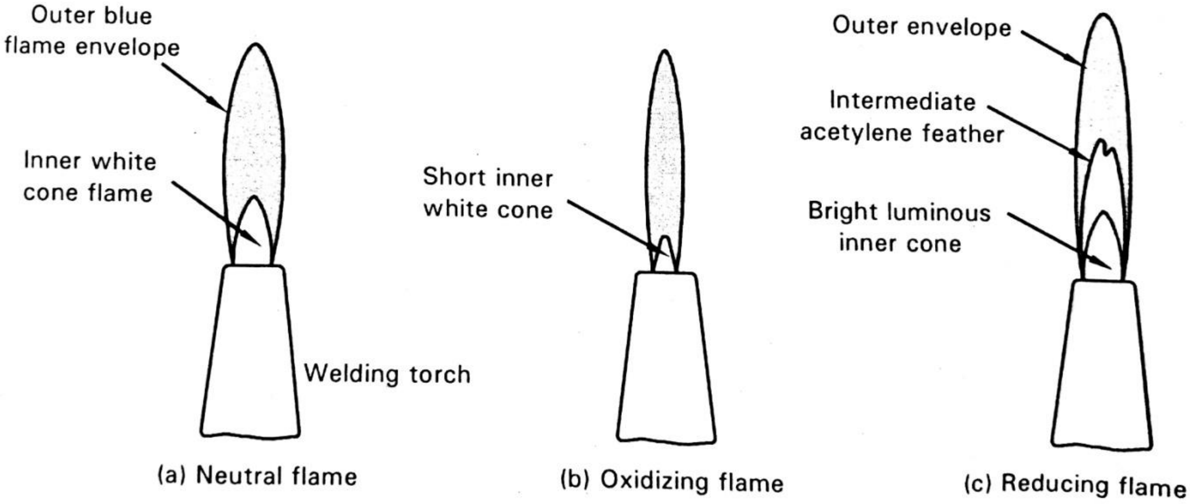
In this reducing zone, the products of combustion CO and H_2 can reduce oxides.

Zone III In this oxidizing zone, CO is burnt and H_2 to water vapour with a surplus) from air.

Flame Characteristics

- When acetylene is mixed with oxygen in correct proportion and ignited a flame is produced.
- The flame will have a temperature of 3200°C.
- A gas torch is used for the purpose.
- Acetylene gas is let out through the torch and ignited first.
- The gas catches fire and a flame is produced.
- Oxygen is then let out sustain the flame.
- By regulating the control valves the quantities of both the gases can be adjusted, so that desired flame is produced.

Three types of flames can be produced. Fig. 5.7 shows the types of flame.



(a) Neutral flame (b) Oxidizing flame (c) Reducing flame

Figure 5.7 Types of flames in gas welding process

1. **Neutral Flame** : ***(Oxygen : Acetylene ::: 1:1)***

- ➢ Approximate volumes of gases are in equal proportions.
- ➢ Temperature of the flame is about 3260°C. Flame is light blue in colour.

- It is surrounded by outer flame produced by the combination of oxygen and Co, H_2 in the inner zone.
- This type of flame does not bring about any chemical change in the molten metal.
- This type of flame is used for welding mild steel, cast iron, aluminium, copper and stainless steel.
- This is the correct flame for welding.

2. **Oxidising Flame** : ***(Oxygen : Acetylene ::: 1.5:1)***
    - After establishing neutral flame, if the oxygen content is further increased the resulting flame is oxidising in nature.
    - The flame will be small short cone, dark blue in colour and more pointed than in the first case.
    - The outer envelope is much shorter than the first.
    - The temperature rise is as high as 3480^{o}C.
    - The excess oxygen at high temperature tends to combine with many metals to form hard, brittle low strength oxides.
    - This type of flame finds limited use in welding.
    - A slightly oxidising flame is used in welding copper base alloys, zinc base alloys.
3. **Reducing flame : *(Oxygen : Acetylene ::: 1:1.5)***
    - After establishing neutral flame, if the volume of acetylene gas is increased then the resulting flame is reducing in nature.
    - The outer flame envelope is longer than that of neutral flame and is usually much brighter.
    - A reducing flame does not completely consume the available carbon, therefore the temperature is lower and the un-consumed carbon is forced into the molten metal.
    - A reducing flame ensures the absence of oxidation, metals that tend to absorb carbon should not be welded with this flame. Ex. Non-ferrous, high carbon steels.
    - A carburizing flame contains excess acetylene than a reducing flame.

Gas torch construction and working

A gas torch is required for gas welding. The details of gas torch are given below. Fig. 9. Show the details.

- A metal tube „P‟ is attached with a detachable end „A‟.
- This end carries a mixing chamber „B‟ for mixing the gases.
- The mixer is connected to a metallic tube called the tip.
- To the tip is attached a nozzle through which gas mixture comes out.
- Tube „P‟ has separate passages for the entry of O_2 and C_2H_2.
- The passages are connected to the gas cylinders through separate hard rubber hose

tubes.
The quantity of gas can be controlled by valves, independently.

- The pressure of gases are controlled at the cylinder end by operating the regulator and observing the gauges meant for the purpose.
- O_2 enters through the central hole and C_2H_2 enters through the outer holes in the mixing chamber.
- O_2 gas is delivered at pressures approximately 0.17
- N/mm^2. C_2H_2 gas is delivered at pressures 0.07 – 0.1 N/mm^2.

Oxy-acetylene welding

- When the acetylene is mixed with oxygen in correct proportion and ignited a flame is produced. The flame will have a temperature of about 3200°C.
- A gas torch is used for the purpose.
- Acetylene gas is let out through the torch and ignited first.
- The gas catches fire and a flame is produced.
- Oxygen is then let out to sustain the flame.
- By regulating the control valves the quantities of both the gases can be adjusted, so that the desired flame is produced.

Fig. 5.6 shows the oxy-acetylene welding.

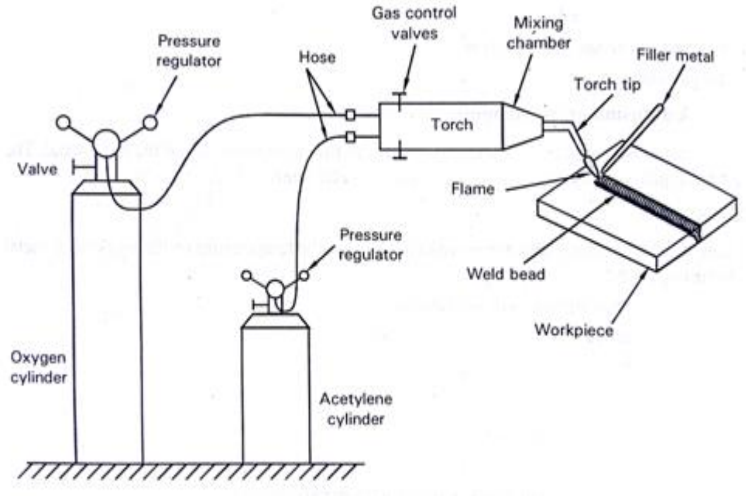


Figure 5.6 Oxy-acetylene welding

Description & Operation

b. The equipment consists of two large cylinders: one containing oxygen at high pressure and the other containing acetylene gas. Pressure regulators are fitted on the respective cylinders to control the pressure of the gas to the welding torch.
c. A welding torch having controlling knobs which mixes both oxygen and acetylene in proper proportions and burn the mixture. A spark ignites the mixture at its tip.
d. The resulting flame at the tip having a temperature of 3200°C which is sufficient enough to melt the workpiece. A slight gap usually exists between the two workpiece, a filler metal is used to supply the additional material to fill the gap.

Advantages

- ✓ Process is simple
- ✓ Controlling temperature is easy.
- ✓ Easy maintenance.
- ✓ Equipment is portable.
- ✓ Eliminates skilled operator
- ✓ Temperature of the flame can be controlled depending upon the type & thickness of the material.

Disadvantages

- Cannot be used for heavy section.
- Flame temperature is less than the arc temperature.
- Acetylene gas is highly explosive and expensive.

Applications

- For joining thin section.
- Most of the ferrous & non-ferrous can be gas welded. Automotive & aircraft industries in sheet metal joining.

5.11 OXY-HYDROGEN WELDING

Oxy-hydrogen welding was the first gas welding process to be developed commercially using a combustion mixture of Hydrogen (H_2) and oxygen (0_2) for producing gas welding flame. The temperature of the hottest part of the flame suitable for welding is around 2500°C against 3200° of an oxy-acetylene flame. The low temperature flame thus obtained was used for cutting and welding thin sheets and low melting point alloys like aluminum, magnesium, lead, etc., and also in some brazing work. Although the temperature of the flame can be varied by varying the oxygen supply, the flame becomes quite unsuitable for welding and as such the proportions of the gas mixture is nearly fixed at a particular value. Further, there is no distinguishing colour to judge the variation in gas proportions as in the case of oxy-acetylene process.

Theoretically, a ratio of 2:1 hydrogen to oxygen mixture (reducing atmosphere) is enough to achieve maximum efficiency, however in practice a ratio 4:1 or 5:1 is needed to avoid an oxidizing flame. Due to competition from the oxy-acetylene and arc welding process, the oxy- hydrogen process is seldom used today for welding applications, but it remains the preferred cutting tool in certain applications due to the resulting clean flame. Forming laboratory glass, polishing flexi-glass, and melting precious metals are common uses of Oxy-hydrogen flames today.

Operation

The apparatus used for oxy-hydrogen welding is similar to that of oxy-acetylene welding and consists primarily of the two steel cylinders: one for storing oxygen and the other for hydrogen at suitable pressures; a mixer and insulator of the gases, together with a regulator; high pressure reducing valves for each of the gases; armored hose; and the special torch.

Note: Since the arrangement for oxy-hydrogen welding is similar to that of oxy-acetylene welding process, except acetylene cylinder is replaced with hydrogen cylinder, Readers are advised to refer figure 5.6 for details regarding the equipment used.

In operation, suitable mixtures of hydrogen and oxygen gases are individually supplied and combined in the mixing chamber and carried to the torch tip through a single tube. This torch is initially cylindrical shaped where the gases enter, and later diminishes in size towards the tip and causes the gas to increase in speed up to the proper velocity. Theoretically, complete combustion of hydrogen requires a hydrogen-to-oxygen ratio of 2:1. When the mixture is ignited at the torch tip, combustion takes place resulting in a flame having temperature around 2500°C. The burning of ***H.,*** and ***0,*** results in two by-products — energy release in the form of heat and eater. The combustion reaction is as follows:

$2H_2 + 0_2 = 2H_2O$ + heat.

The resulting heat of the flame can be used to melt and fuse the metals to form ***a*** single piece of metal. Filler metal may be used as in case of oxy-acetylene process.

Advantages

- Process in simple and inexpensive.
- Results in clean flame, which is free from contaminants like carbon emitted from the combustion of ordinary hydrocarbon fuels
- Process is characterized by the absence of oxides formed on the surface of the weld.

Disadvantages

- Not suitable for welding high melting point alloys.
- Flame adjustment by varying gas proportions cannot be observed visibly. Gas proportions are fixed at particular values.
- The work should be heated first, in order to prevent chilling of the filling material, and the melt bar fused in to make the joint.

5.12 AIR-ACETYLENE WELDING

Air acetylene welding is a type of gas welding process in which the heat required for welding is obtained in the form of a flame, generated from the combustion of acetylene with air. The torch used in air acetylene welding process is similar in construction to a Bunsen burner as shown in figure 5.8. The acetylene gas which is stored in a cylinder under suitable pressure is made to flow into the welding torch through pressure regulator and hose. As the acetylene flows through the torch, it aspirates or draws appropriate amount of air from the atmosphere in order to obtain the oxygen necessary for combustion.

When the mixture at the torch tip is ignited with a spark, air enables the acetylene gas to burn completely to produce a clean, hot, and smokeless flame, which can be used for welding or any other applications. The use of this type of welding is limited, as the temperature attained **is** the lowest of all the gas welding processes. The process is used for lead welding, and low temperature brazing or soldering operations.

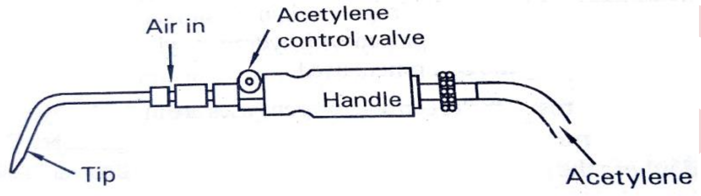


Figure 5.8 Air-acetylene torch

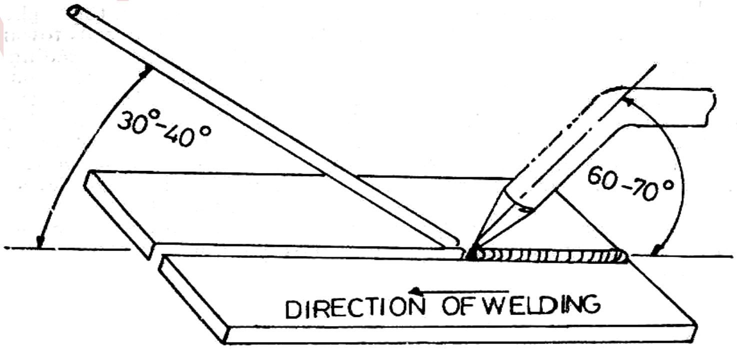
Welding Techniques

There are two techniques in gas welding process depending on the way in which the welding torch is used. They are:-

1. Leftward / Forward welding
2. Rightward / Backward welding

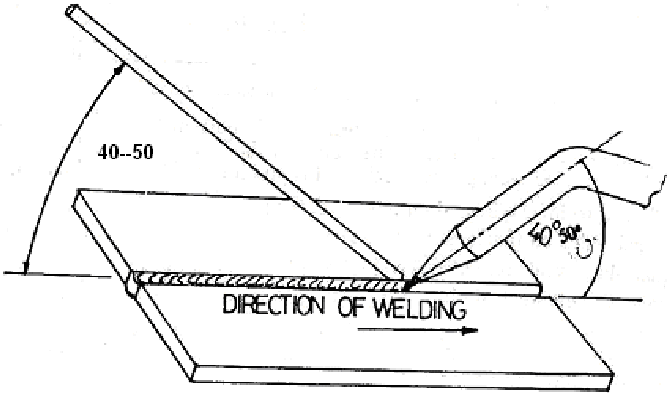
Leftward / Forward welding

The leftward method of welding is also known as forward welding. It is the oldest and most widely established method for the butt-welding of steel plates. Welding is commenced at the right hand edge of the plate and proceeds across the plane in a leftward direction, the blowpipe following the welding rod.



Rightward / backward welding

The rightward method of welding consists of commencing at the left-hand side of the plate and proceeding towards the right, the filler rod following the blowpipe (Refer Fig 2). It will be observed that the blowpipe point in the direction of the completed weld and that it moves regularly along the seam. There is no lateral movement of the blowpipe, rather the end of the filler rod describes a series of loops and doesn’t progress steadily as in case of the leftward welding. It is not necessary to bevel the edges of the plate between 3/16” to 5/16” and even when a bevel is necessary the included angle should be only 60° and 80° as in the previous case.



Difference between forward and backward welding

Sl. No	Leftward/Forward welding	Sl. No	Rightward/Backward welding
1	Welding operation is done by working from right to left	1	Welding operation is done by working from left to right
2	The torch is held between the filler rod and the weld	2	The filler rod is held between weld and flame of torch
3	The angle of torch is between 60°-70° w.r.t. horizontal to ensure less obstruction to the operator.	3	The angle of torch is between 40°-50° w.r.t. horizontal to ensure less obstruction to the operator.
4	Due to oxidation of metal, the weld is not so strong, tough and dense.	4	Due to non oxidation of metal, the weld is quite strong, tough and dense.
5	Torch is given sideways movement for effective welding.	5	No need of sideways movement to torch for welding.

6	This type of welding is used for low melting metals.		6	This type of welding is normally used for thicker sections.
7	Acetylene requirement 100-120 lit/hr/mm.		7	Acetylene requirement 100-150 lit/hr/mm.

5.13 GAS CUTTING

Gas cutting is a process of cutting metals by means of a flame generated by a combination of fuel gas and oxygen. Although a variety of fuel gases like acetylene, propane, MAPP (methyl-acetylenepropadiene), propylene and natural gas may be used, it is the acetylene gas that is commonly used as it produces a comparatively highest flame temperature, which is approximately around 3,160˚C that is capable of rapid piercing of the materials resulting in quality cutting edges with less heat affected zone and distortion. The process is often referred as oxy-acetylene cutting.

Oxy-acetylene Cutting Process

Oxy-acetylene cutting makes use of a torch as illustrated in figure 5.9. The cutting torch consists fthree orifices for the separate flow paths as: pre-heat oxygen, cutting oxygen, and acetylene as own in figure. The cutting oxygen jet comes from the central bigger orifice and is controlled by the valve lever or trigger.

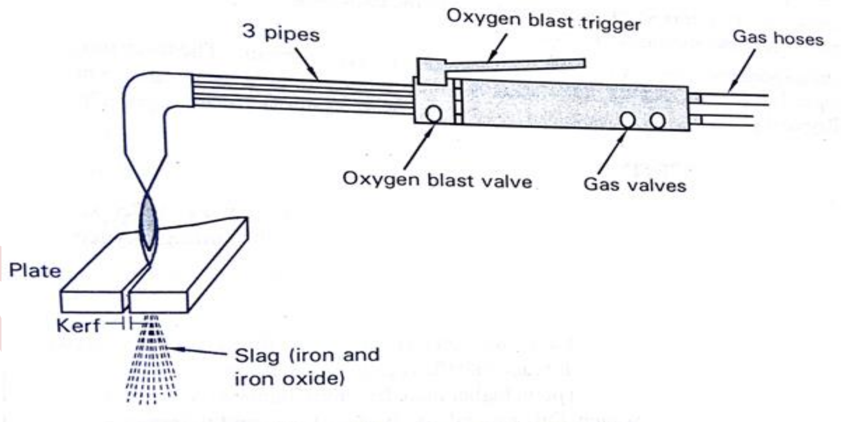


Figure 5.9 Oxy-acetylene cutting

Initially, oxygen and acetylene gas flowing in suitable proportions is mixed and ignited at the torch tip to preheat the workpiece metal to its ignition temperature but well below its melting point. At this point, a jet of pure oxygen released by the lever is directed into the preheated area resulting in an exothermic chemical reaction between the oxygen and the iron workpiece metal to form iron oxide or slag. Continued iron oxide formation requires large volumes of oxygen to be delivered to the cut zone at a controlled preset pressure. The jet of flowing oxygen blows away the slag enabling the jet to pierce through the material producing a narrow cut known as *kerf*

It must be noted that the heat produced by the iron oxide and its contact with the rest of the material is the one that actively continues the cutting process. The torch only heats the metal to begin the process.

Advantages

- Process in simple, inexpensive, and faster than mechanical cutting methods.
- Any desired length and shape for assembly and other processing operations can he carried out effectively.
- The process can cut metals of thicknesses ranging from 0.5 *nun* to 250 *mm.*

Disadvantages

- The process is limited for cutting carbon steel (low, medium, and high) materials only.
- As compared to mechanical cutting, dimensional tolerances are poor.
- Working place needs to have adequate ventilation and proper fume control.
- Cutting operation is risky to the operator, due to the expelling/blowing of the red hot slag and other hot particles during cutting process.
- Cutting speed and quality depends on the purity of the oxygen stream. The torch nozzle must be designed so as to protect the oxygen stream from air entrapment. A decrease in purity of 1% will typically reduce the cutting speed by 25% and increase the gas consumption by 25%.

5.14 POWDER CUTTING

Powder cutting is an *oxygen cutting process* in which a suitable metal powder such as iron powder, or mixture of iron and aluminum powder, is injected in to the cutting oxygen stream to assist the cutting action.

Need for Powder cutting

Materials such as stainless steel, cast iron, and non ferrous metals/alloys cannot be easily cut by oxy-acetylene process. Stainless steels react with the cutting oxygen stream to produce refractory (heat resistant) oxides having melting point higher than the parent material, which tend to prevent further cutting action by the oxygen. Other metals such as cast iron and the non ferrous metals either burn with less heat or they tend to cool the cutting zone to such as extend that it is difficult to start and maintain the cutting action. This barrier to cutting can be overcome by feeding finely divided iron-rich powder separately in to the cutting zone in a gaseous medium. Combustion of the iron powder increases the reaction temperature and the fluidity of oxidation products, which in turn facilitates cutting action.

Principle of Powder Cutting Process

The powder cutting process makes use of the same equipment as that of the oxy-acetylene process with slight modifications.

The equipment consists of the following:

- Oxygen, acetylene cylinders, separate hose and regulators
- A hopper with control valve and regulator for automatic supply of iron powder
- Cutting torch consisting of orifices for separate flow path for pre-heat oxygen, acetylene and

cutting oxygen in addition to a special opening at its tip for supplying iron powder

Initially, oxygen and acetylene gas flowing in suitable proportions is mixed and ignited at the torch tip to preheat the workpiece metal to its ignition temperature. A finely divided 200-mesh iron powder from a hopper is injected in to the oxygen cute ing flame through the torch tip. The powder is pre-heated as it passes through the pre-heal names, and later bursts into a flame in the stream of cutting oxygen. The iron particles are rapidly oxidized resulting in a sudden increase of heat on the work metal surface. As a result of the intense heat supplement, the refractory oxides that form on the metal surface are melted and consequently flushed from the cutting area. This permits the cutting flame of the torch to come in contact with the iron of the metal and thus cutting proceeds without interference.

Advantages

- Process is suitable to cut materials having high affinity for oxygen at the cutting temperature.
- Results in high burning temperature offering excellent flow characteristics.

Disadvantages

- Working environment is polluted due to smoke generated.
- Use of finely divided iron powder adds cost to the process.

5.15 INTRODUCTION TO SOLDERING

Soldering is a group of joining process used for joining similar or dissimilar metals by means of a *filler metal* whose melting temperature is *below* 450°C. The filler metal usually called *solder is* an alloy of tin and lead in various proportions. The flow of molten solder into the gap between the two workpieces is by the *capillary action**. The solder cools down and solidifies forming a joint. The base metals are not fused in the process.

5.15.1 Types of Solder

A solder is an alloy, which melts at low temperatures. There are two types of solder:

(i) Soft solder

- These are alloys of tin and lead. *Example* Lead = 37 % and Tin = 63 %.
- They have low melting points ranging from 150°C — 190°C.
- A very small amount of antimony, usually less than 0.5% is sometimes added to increase the mechanical properties of the solder. But, its addition should be controlled, otherwise which might impair soldering characteristics.
- Soft solders are used in those applications, where the joint is not subjected to heavy loads and high temperatures.

(ii) Hard solder

- Silver alloyed with lead *(Example* lead = 97.5 % and silver = 2.5 %) or silver alloyed with copper and zinc *(Example* Silver = 50 %, copper = 34 %, and zinc = 16 %) are called hard solder.

  ** During soldering, the molten solder is introduced at the joint. A pulling force draws the molten filler between the surfaces of the parent (base) metals. This is known as capillary action.*
  - Melting point of hard solder ranges from 300 - 600°C.
  - Used to make strong joints that can resist high temperatures.

5.15.2 Surface cleaning and Soldering Flux

Capillary action (wettability) is achieved by proper *surface preparation* and *use* of suitableflux for wetting and cleaning the surfaces to be bonded.

Surface preparation includes thoroughly cleaning the workpiece surfaces to remove contaminants like oil, rust, scale, paint, and other impurities either mechanically (wire brushing, abrasion techniques etc.) or chemically (soaking, cleaning or acid etching). Once the contaminants are removed, the next step is to select a suitable flux.

A soldering flux is a substance, either in a liquid or semi-liquid state that melts during the preheating stage and spreads over the joint area, wetting it and protecting the surface from oxidation. The flux also cleans the surface, dissolving the metal oxides.

Different types of flux include rosin-alcohol, zinc chloride, aniline phosphate etc. The flux maybe applied onto the metal surface by brushing, dipping, spraying, or by any other methods.

5.16 TYPES OF SOLDERING

Soldering methods are classified based on the mode of heat application. The heat applied should be such that it should melt the solder and permit the molten solder to flow quickly into the joint. Various soldering methods include:

- Soldering iron method
- Torch method
- Induction method
- Wave method
- Resistance method
- Ultrasonic method etc.

(a) Soldering iron method

It is the most common and widely used method of soldering. The tool used in this method is a *soldering iron with* a copper coated tip (due to good conductor of heat), which may be heated electrically, or by oil/gas flame. The tip of the soldering iron stores and conducts heat from the heat source to the components being joined. Figure 5.10 shows the soldering process.

The surface of the workpiece is cleaned thoroughly to remove any contaminants. Flux is applied at the joint. The soldering iron is heated to a suitable temperature and a little solder is melted at the tip of the soldering iron. The tip of the soldering iron, called the *bit*, is brought at the joint and the molten solder is deposited. The molten solder flows into the joint by the capillary force. The solder cools down and solidifies forming a joint. The joint is cleaned to remove flux residues in order to prevent corrosion.

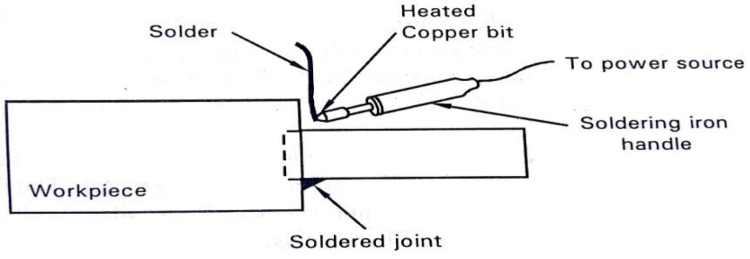


Figure 5.10 Soldering

Soldering irons come with various ratings from 15 W to over 100W. The advantage of using high Wattage iron is that, heat can flow quickly into the joint, so it can be rapidly made. Small irons are used to make joints for small electronic components only, as they might get damaged due to excess heat.

(b) Torch soldering

Torch soldering utilizes the heat of a flame issued from a oxy-fuel gas torch. The *torch* mixes a fuel gas like acetylene with oxygen in suitable proportions, and bum the mixture at its tip. The flame generated at the torch tip is directed at the workpieces with a flux applied on their surfaces. When the workpieces are heated to a suitable temperature, the solder is fed into the joint region to melt and flow into the gap between the two workpieces. The solder cools down and solidifies forming a joint.

(c) Wave soldering

Wave soldering is a very popular approach for soldering through-hole components on printed circuit boards. This method uses a tank full with a molten solder. The solder is pumped, and its flow forms a wave of a predetermined height. The printed circuit boards pass over the wave touching it with their lower sides.

5.16.1 Advantages and disadvantages of soldering

Advantages

- Low power requirements.
- Low temperature process. Hence, no thermal distortions and residual stresses in the joint parts.
- Dissimilar parts can be easily joined.
- Thin parts can be joined.

Disadvantages

- Flux residues should be removed after soldering, otherwise which causes corrosion.
- Thick parts cannot be efficiently joined.
- Soldered joints cannot be used in high temperature applications.
- Strength of joint is low.

5.17 BRAZING

Brazing is a method of joining similar or dissimilar metals by means of a filler metal whose melting temperature is above 450°C, but below the melting point of the base metal. The filler metal called *speller* is a non-ferrous metal or alloy. Copper and copper alloys, silver and silver alloys, and aluminum alloys are the most commonly used filler metals.

The flow of molten filler material into the gap between the two workpieces is driven by the capillary force. The filler material cools down and solidifies forming a strong joint. The base metals are not fused in the process.

Flux used in brazing

Flux performs its usual function as in soldering, i.e., it melts during the preheating stage and spreads over the joint area, wetting it and protecting the surface from oxidation. It also cleans the surface, dissolving the metal oxides.

The flux used in brazing is available in powder, liquid, and paste form. One method of applying the flux in powdered form is to dip the heated end of the filler rod into the container of the powdered flux, and allowing the flux to stick to the filler rod. Another method is to heat the base metal slightly and sprinkle the powdered flux over the joint, allowing the flux to partly melt and stick to the base metal. Sometimes, it is desirable to mix powdered flux with clean water (distilled water) to form a paste.

Flux in either the paste or liquid form can be applied with a brush to the joint. Better results occur when the filler metal is also given a coat. The most common type of flux used is borax, or a mixture of borax with other chemicals. Some of the commercial fluxes contain small amounts of phosphorous and halogen salts of iodine, bromine, fluorine, chlorine, or astatine. When a prepared flux is not available, a mixture of 12 parts of borax and 1 part boric acid may be used.

5.18 TYPES OF BRAZING

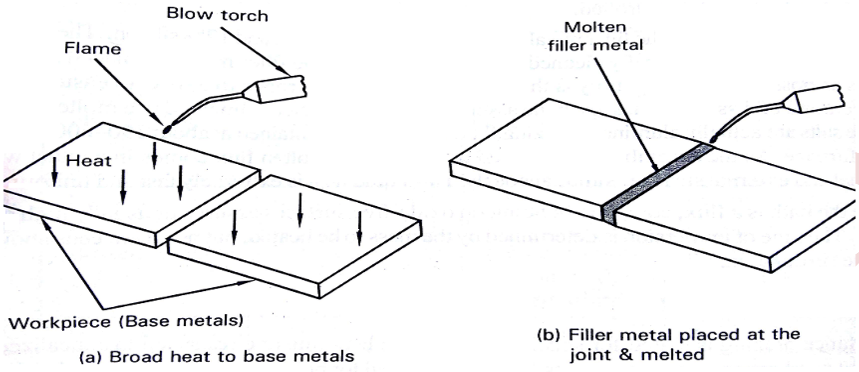
Brazing is similar to soldering, except, the difference is in the melting point of the filler alloy. Brazing methods are classified based on the mode of application of heat. They are:

- Torch brazing
- Furnace brazing
- Dip brazing
- Resistance brazing
- Induction brazing

- Vacuum brazing etc.

(a) Torch brazing

Torch brazing is a brazing process in which the two metals are joined by the heat obtained with a gas flame, and by using a non-ferrous filler metal having a melting temperature of above 450°C, but below the melting temperature of the base metal. Figure 5.11 shows the brazing process.



(a) Broad heat to base metals

(b) Filler metal placed at the joint & melted

Figure 5.11 Brazing

In operation, the surfaces to be joined are cleaned thoroughly in order to remove dirt, grease and other oxides. After cleaning, flux is applied at the joint. The base metals are broadly heated by an oxy-acetylene welding torch as shown in figure 5.11(a). The filler metal is then placed at the joint and is heated with a carburizing flame. The filler metal melts and flows through the joint by capillary action. Refer figure 5.11(b). The workpiece is allowed to cool for some time. The joint is cleaned to remove flux residues in order to prevent corrosion.

(b) Furnace brazing

Furnace brazing is a brazing process in which bonding is produced by the furnace heat and a nonferrous filler metal having a melting temperature of above 450°C, but below the melting temperature of the base metal. The filler metal is distributed in the joint by capillary attraction.

Furnace brazing is suited for fabricating complete brazements, and does not require a highly skilled operator. Pre-fluxed or pre-cleaned parts with filler metal pre-placed at the joints are heated in furnaces. Brazing can be done in an *air furnace* with a flux, though a protective atmosphere usually is needed. The type of atmosphere required depends on the materials being brazed and the filler metals being used. Base metals with readily reducible oxides can be brazed in an atmosphere of combusted natural gas or cracked ammonia. Dry hydrogen, a powerful reducing agent can be used for brazing most stainless steels and many nickel, cobalt and iron-base alloys.

(c) Dip brazing

Dip brazing is one of the oldest brazing processes. The materials to be joined are immersed in a bath of hot liquid, which is either a molten flux or a molten filler metal that usually contains a layer of flux to prevent oxidation. Dip brazing is used on aluminum assemblies, since the temperature of the molten bath can be controlled.

In aluminum dip brazing the filler metal is basically 88% aluminum and 12% silicon. The parts to be brazed after being chemically cleaned, are assembled with the filler metal preplaced as near the joints as possible. The assembly is then preheated in an air furnace to 550°C to ensure uniform temperature of dissimilar masses in the assembly. The part is then immersed in a molten salt bath. These salts are actually aluminum brazing flux. The bath is maintained at about 590-600°C in a salt bath furnace. As the assembly is immersed or dipped, the molten flux comes in contact with all internal and external surfaces simultaneously. This liquid heat is extremely fast and uniform.

Since the bath is a flux, complete bonding on oxide-free surfaces assures unusually high quality joints. The time of immersion is determined by the mass to be heated, but never exceeds above two minutes in duration.

(d) Resistance brazing

Resistance brazing is suited for special joints where heat must be restricted to a localized area without overheating surrounding parts. The heat required for brazing is produced due to the electrical resistance offered by the joint members to the flow of current through them.

(e) Induction brazing

Induction brazing utilizes alternating electromagnetic field ofhigh frequency for heating the workpieces together with the flux and the filler metal placed in the joint region. The technique is used only in those applications, where the entire assembly would be adversely affected by heat. Since the workpieces are heated selectively by the coil, induction brazing reduces unwanted part distortion.

Induction heating brings the joint rapidly to brazing temperature.

Advantages

- Much heat is not involved in the process. Hence, low thermal distortions and residual stresses in the joints.
- Easily automated process.
- Dissimilar parts can be joined.

Disadvantages

- Flux residues must be removed after brazing, otherwise which may cause corrosion.
- Large and thick sections cannot be brazed efficiently.
- Relatively expensive filler materials.

5.18.2 Comparison between Brazing and Soldering

Table 5.1 shows a brief comparison between brazing and soldering.

Sl. No.	**Brazing**	**Soldering**
1.	Filler metal used in Brazing is called *spelter*	Filler metal is called *solder*
2.	Melting point of *filler metal* is above 450 °C but below the melting point of the work piece metal.	Melting point of *filler metal* is below 450 °C
3.	Stronger joints can be obtained in brazing	Strength of the joint is comparatively low.
4.	Brazed joints resist corrosion.	Soldered joints do not resist corrosion to the same extent as that of brazed joints.
5.	Brazing is slightly costlier	Comparatively cheaper

Table 5.1 Comparison between brazing and soldering

5.19 INSPECTION METHODS

Inspection is an art or process, which involves checking dimensions, observation of correctness of operations, and examining the presence and/or the extent of imperfections in a fabricated part to ensure whether the part conforms to the design requirements. The different inspection methods are discussed briefly below.

(a) Dimensional Inspection

In this method, micrometers, automatic gauges etc., are used to check the dimensions of parts against the drawings.

(b) Metallurgical Inspection

Specific equipments like disc sectioning machine, specimen mounting press, grinding, polishing turntables, some acid etching capabilities, and an optical metallurgical microscope with magnification capacity of up to *x500* at least is required for metallurgical inspection. Weld bead shapes, discontinuities, metallographic phases in different areas of the weld and cast materials can be obtained with this method of inspection.

(c) Mechanical Inspection

Mechanical inspection is also called *destructive inspection*, because the parts to be inspected are partly or completely damaged during inspection. Various properties of a material like tensile strength, compression strength, shear strength, hardness, impact strength etc., can be evaluated from this method of inspection.

(d) Non-destructive Inspection

Non-destructive inspection involves assessing the soundness and acceptability of the part without destroying or altering the structure of the fabricated part. Internal defects like cracks, flaws, blow holes, etc., can be effectively determined by this method. The various tests involved in this method include:

- Visual inspection
- Magnetic particle inspection
- Fluorescent particle test
- Ultrasonic inspection.
- Radiography inspection
- Eddy current inspection
- Holographic inspection etc.

5.20 VISUAL INSPECTION

Visual inspection is the most widely used method of all the non-destructive tests. It is a simple test that consumes less time, but is useful only to detect the presence of defects on the *surface of the fabricated part.*

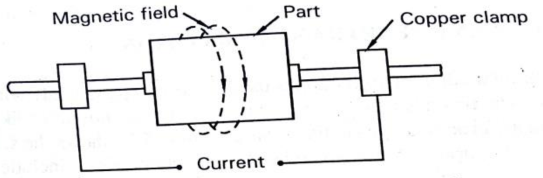
The part is illuminated with light and then examined with naked eyes, or sometimes a magnifying lens or a low power microscope may be used as an aid to the eye. Visual inspection is often overlooked, but it provides a wealth of information about surface defects like cracks, porosity, fusion, edge melt and incomplete penetration. A weld that passes a visual inspection has a much higher probability of passing further non-destructive evaluation tests.

5.21 MAGNETIC PARTICLE INSPECTION

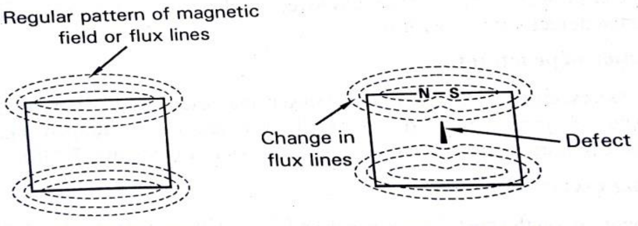
Magnetic particle inspection method uses *magneticfields* and *small magnetic particles* to detect surface defects or near-surface defects *in ferrous materials.* Figure 5.12 shows the principle of magnetic particle inspection. The various steps involved in the inspection process include.

(a) Magnetizing the part

The part to be inspected is cleaned thoroughly from dirt, rust and oxides, and held between two copper damps as shown in figure 5.12(a). When a high current is passed through the part, magnetic flux is produced at right angles to the flow of current. If the material is sound or detect free, most of the magnetic flux is concentrated below the materials surface. Refer figure 5.12(b). However, when a defect/discontinuity is present in the part, the magnetic flux get diverted and leak through the surface of the part creating magnetic poles or points of attraction. The crack edge becomes magnetic attractive poles: *north* and *south* as shown in figure 5.12(c).



(a) Circular magnetisation of the part by current flow



(b) Defect free part

(c) Part with defect

Figure 5.12 Magnetic particle inspection

(b) Detection of defect

The presence of the leakage field and therefore the presence of the discontinuity is detected by dusting finely divided iron oxide particles on to the surface, so that the particles cling to the leakage area indicating the location of discontinuity.

The part is demagnetized and cleaned by suitable process.

Advantages

- Easy, fast, economical and reliable way to locate discontinuities.

* *Magnetic particles may be coloured with red or black, and are usually applied as suspension in water or paraffin. This enables the particles to flow over the surface and to migrate to any flaws/discontinuities.*

- Even non-metallic inclusions close to the surface can be detected.
- Can be automated.

Disadvantages

- Restricted to ferromagnetic materials.
- Restricted to surface or near-surface flaws.
- Skilled operator is required for efficient inspection
- Parts should be demagnetized and cleaned prior to use.

5.22 FLUORESCENT PENETRANT INSPECTION

Fluorescent penetrant method of inspection is used for testing parts made with ferrous and nonferrous materials. The process is preferred for parts with discontinuities like cracks, porosity, shrinkage etc. that are clear and open to the surface. Figure 5.13 shows the steps involved in the inspection process. The various steps involved in the inspection process include:

(a) Surface preparation

The part to be inspected is cleaned thoroughly to remove dirt, oxide and other impurities for efficient detection of the defect. Refer 5.13(a).

(b) Application of penetrant

A coloured (fluorescent) penetrant liquid is applied to the surface of the part being tested by either dipping, brushing or spraying method. After sufficient time is allowed, the penetrant easily enters into the flaw due to capillary action and low surface tension. Refer figure 5.13(b).

(c) Removing excess penetrant

The excess penetrant on the part surface is washed away with water or a solvent, and then dried with air. Refer figure 5.13(c). Care should be taken not to remove any penetrant from the flaw.

(d) Developer application

A developer in the form of dry powder (*Example* $CaCO_3$), or suspension of powder in liquid (alcohol or spirit) is applied on the surface. The developer acts like a blotter and draws the penetrant out of the flaw. Refer figure 5.13(d).

(e) Inspection

The part is inspected in a dark enclosure under ultraviolet or black light. The blotted out fluorescent particles will give a visible glow under ultraviolet light revealing the precense of the defect.

Fluorescent penetrant test is very effective for machined and finished parts.

Advantages

- Simple, easy to use, and also low cost.
- No need for skilled inspector.
- Useful for both ferrous and non-ferrous materials including glass and ceramics.
- Flaws are clearly visible due to the bright fluorescent against a dark background.

Disadvantages

- Only cracks open to the surface can be inspected.
- Surfaces of parts should be extensively cleaned before testing.

- Penetrant dyes stain clothes and skin while in use.

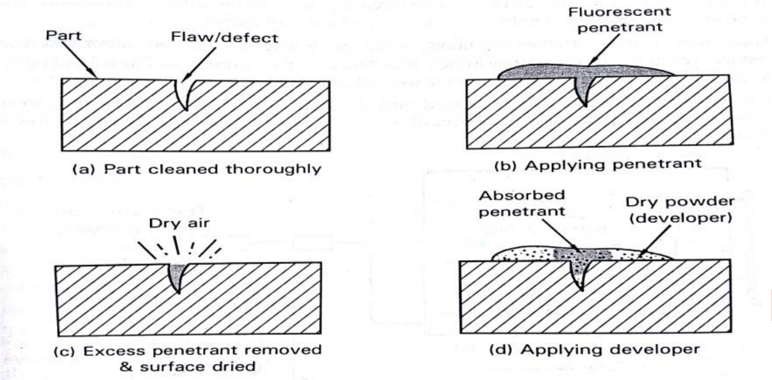


Figure 5.13 Fluorescent penetrant inspection

5.23 ULTRASONIC INSPECTION

Ultrasonic inspection is used to detect surface and sub-surface defects in both ferrous and nonferrous materials. Figure 5.14 shows the simplified diagram of the testing procedure.

Steps involved in the inspection process

a) The surface of the workpiece to be tested is cleaned thoroughly to remove dirt and other oxides. The transducer placed above the workpiece converts electrical energy into mechanical vibrations (sound energy), and vice-versa.

b) The sound energy from the transducer propagates through the couplantt and strikes the upper surface of the workpiece metal in the form of waves.

c) The waves from the upper surface travel and strike the other end surface of the workpiece and will be reflected back to the transducer. In simple words, the transducer sends the waves and also receives the reflected waves.

d) The reflected waves are transformed into electrical signals by the transducer and are displayed on the CRO (cathode ray oscilloscope) screen as a sharp peak (point A).

e) When the propagating wave strikes a defect, the wave get reflected in the mid-way, back to the transducer, and as a result, an echo is displayed at point B on the CRO screen before another echo given by the wave at point C striking at the far end of the job.

f) Thus, imperfections or other conditions in the space between the transmitter and receiver reduce the amount of sound transmitted, thus revealing their presence. The echo at point B is an indication of the defect present in the workpiece.

g) Ultrasonic inspection not only helps to identify the defect, but also gives information about the location, size, and distance from the surface of the workpiece, orientation and other features of the defect.

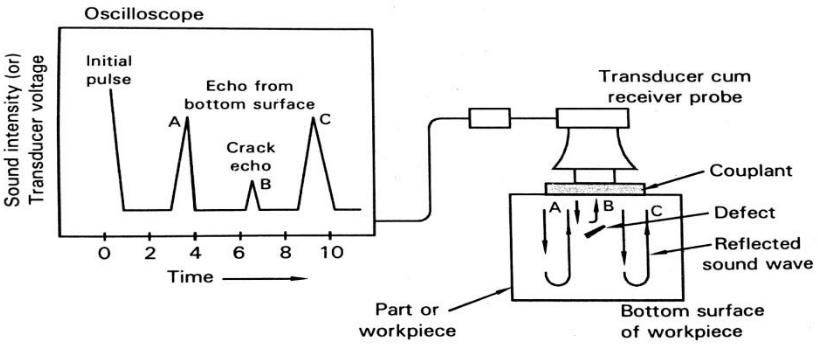


Figure 5.14 Ultrasonic inspection

Advantages

- Method is fast and allows detection of even small flaws deep in the part. Lengths up to 30 feet can be tested.
- Instant test results.
- Can estimate size, shape, orientation, and other features of the defect.
- Only one surface of the workpiece is sufficient for inspection.
- Equipment is portable.
- Greater accuracy compared to other non-destructive inspection methods.

Disadvantages

- Requires skilled inspectors with extensive technical knowledge.
- Parts that are rough, very small, thin or non-homogenous are difficult to inspect.
- Extensive surface preparation of workpiece is required.
- Cast iron and other coarse grained materials are difficult to inspect due to low sound transmission and high signal noise.

The couplant is an oil film maintained between the transducer and the workpiece to ensure proper contact between them and better transmission of waves into the workpiece material.

5.24 RADIOGRAPHY INSPECTION

Radiography inspection, also known as *X-ray inspection* is one of the oldest and widely used method for detecting *sub-surface cracks* and inclusions in both ferrous and non-ferrous materials.

Description and Operation

a) The equipment consists of an evacuated bulb inside which there is a *filament* that acts as cathode, and the *target* as anode.

b) When the filament is heated bypassing current, it emits electrons, which in turn are accelerated towards the *target* due to the high potential difference.

c) The electrons strike the *target* and are suddenly stopped; a part of their kinetic energy is converted to energy of radiation or x-rays.

d) The x-rays then deviate to pass through the workpiece material containing a defect.

e) Since the defect possesses low density, they transmit x-rays better than the adjacent sound metal that possesses high density.

f) The x-rays after passing through the workpiece are allowed to fall on a light-sensitive film placed at a suitable distance behind the workpiece.

g) Interpretation ofx-ray film is only about distinguishing between areas of film blackness. Defects in the form of cracks or voids are recorded as blackened areas on the film compared to the adjacent portion of less black areas.

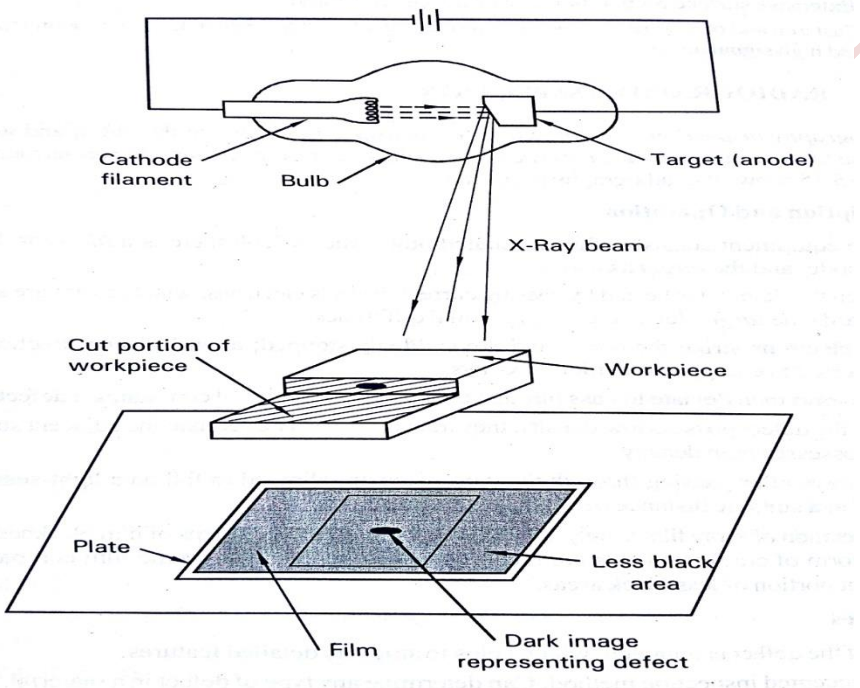


Figure 5.15 Radiography inspection

Advantages

- Image of the defect is obtained, which helps to study its detailed features.
- Widely accepted inspection method. Can determine any type of defect in a material.
- Parts to be inspected need not be disassembled. This reduces labour and time.

Disadvantages

- Expensive method compared to other non-destructive methods. Involves high cost in equipment, film and processing.
- Film processing requires time. Hence, defect cannot be analyzed on the spot.

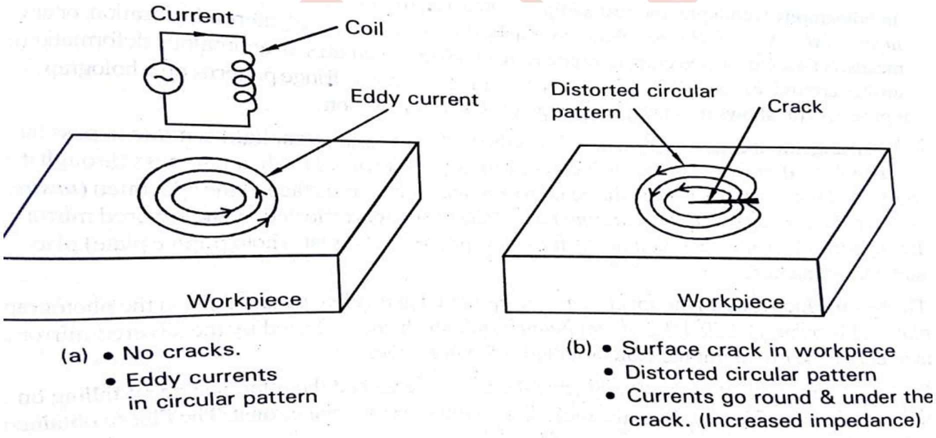
- Skilled inspector is required to analyze defect.
- Not suitable for surface defects.
- No indication about the depth of the defect.

5.25 EDDY CURRENT INSPECTION

Eddy current inspection uses the principle of *electromagnetism* as the basis for conducting examinations. When a circular coil (also called probe) carrying alternating current is brought *near* the workpiece metal, the magnetic field of the coil will induce circulating (eddy) currents in the workpiece surface. Refer figure 5.16(a).

The magnitude and phase of the eddy currents will affect the loading on the coil, and thus its impedance. For example, when the workpiece metal is defect free, the eddy currents will be uniform and consistent (circular shape) as shown in figure 5.16(a). However, if there is some defect such as a crack in the workpiece, the eddy currents will be disturbed from their normal circular pattern as shown in figure 5.16(b). This will reduce the eddy current flow, thereby decreasing the loading on the coil and increasing its effective impedance.

The resulting change in phase and magnitude of the eddy currents can be displayed on a cathode ray tube (CRT) type displays. This gives the operator, the ability to identify defect conditions in the workpiece. The size of the defect can also be determined to a certain extent (by the absence of metal).



(a) • No cracks.
• Eddy currents in circular pattern

(b) • Surface crack in workpiece
• Distorted circular pattern
• Currents go round & under the crack. (Increased impedance)

Figure 5.16 Eddy current inspection

Advantages

- One of the major advantage of this method is that, a variety of inspections and measurements can be performed like defect detection, hardness, material thickness measurements, coating thickness measurements, conductivity measurement for heat damage detection, case depth determination, heat treatment monitoring etc.
- Test probe or coil used need not contact the part to be inspected.
- Very sensitive to small cracks.

- Inspection gives immediate results.
- Equipment in portable.

Disadvantages

- Only conductive materials can be inspected.
- Surface must be accessible to probe.
- Skill and training required is more extensive than other techniques.
- Surface finish and roughness may interfere.
- Depth of penetration is limited.
- Cracks lying parallel to the current path are undetectable.

5.26 HOLOGRAPHY INSPECTION

In holography technique, the test sample is interferometrically compared in two different states: *unstressed* and *stressed state.* Stressing can be done by mechanical, thermal, vibration, or any other means. A flaw can be detected, if by stressing the object, it creates an anomalous deformation of the surface around the flaw. The deformations are made visible as fringe patterns on a holographic film. Figure 5.17(a) shows the arrangement for holography inspection.

The arrangement consists of a *laser* from which a beam of coherent light is made to pass through a half-silvered mirror. The half-silvered mirror allows *a part* of the beam to pass through it, then through the lens which diverge the beam before falling on the surface ofthe specimen *(unstressed state)* to be inspected. The *remaining part* of the beam gets reflected by the silvered mirror, pass through the diverging lens, and finally fall on the photographic plate (holographic plate) placed in a suitable orientation.

The beam which falls on the specimen to be inspected gets reflected and falls on the photographic plate. This beam is called the *object beam,* while the beam reflected by the silvered mirror and incident on the photographic plate is called *reference beam.*

The interference effect of the two beams; the object beam and the reference beam falling on the photosensitive surface results in the recording of interference fringes on it. The film so obtained is called *hologram.*

Reconstruction of Image

The hologram is fixed in the same place where it was a photographic plate during the first recording stage. The specimen and the source are also positioned in their same places. The specimen is now subjected to the required stress. Stressing can be done by mechanical, thermal, vibration or any other means. The procedure for recording the hologram is repeated.

The light (reference beam) which falls directly on the hologram (reference beam) leads to reconstruction of the image of the object in the unstressed state. This light interferes with the light reflected from the stressed object and produces bright and dark fringe pattern as shown in figure 5.17(b).

The resulting interference pattern contours the deformation undergone by the specimen in between the two recordings. Surface as well as sub-surface defects show distortions in the otherwise uniform pattern. In addition, the characteristics of the component, such as vibration modes, mechanical properties, residual stress etc., can be identified through holographic inspection.

Holographic interferometry possesses high sensitivity to surface displacements and allows visual monitoring of interference fringe patterns that characterize surface deformation and the presence of non-contact areas in objects of complex shape.

Holographic technique is widely applied in aerospace to find impact damage, corrosion, delamination, debonds, abradable seals, brazed honeycomb seals, and cracks in high performance composite aircraft parts as well as turbine blades, solid propellant rocket, motor casings, tyres and air foils. With the advent of using mega-pixels CCD* cameras and digital image processing, holography technique offers tremendous flexibility and real-time visualization. Furthermore, image-processing schemes can provide computerized analysis of patterns for automated defect detection and analysis.

Advantages

- Automated process.
- Suitable for surface as well as sub-surface defects.
- High quality images can be obtained for thorough inspection.
- Used to detect wide range of abnormalities other than defects in the workpiece.

Disadvantages

- High equipment cost.
- Skilled operator is required.
- High-resolution films are necessity for holograms. However, use of CCD cameras allows the results to be viewed on a video monitor. But, the process is still expensive.

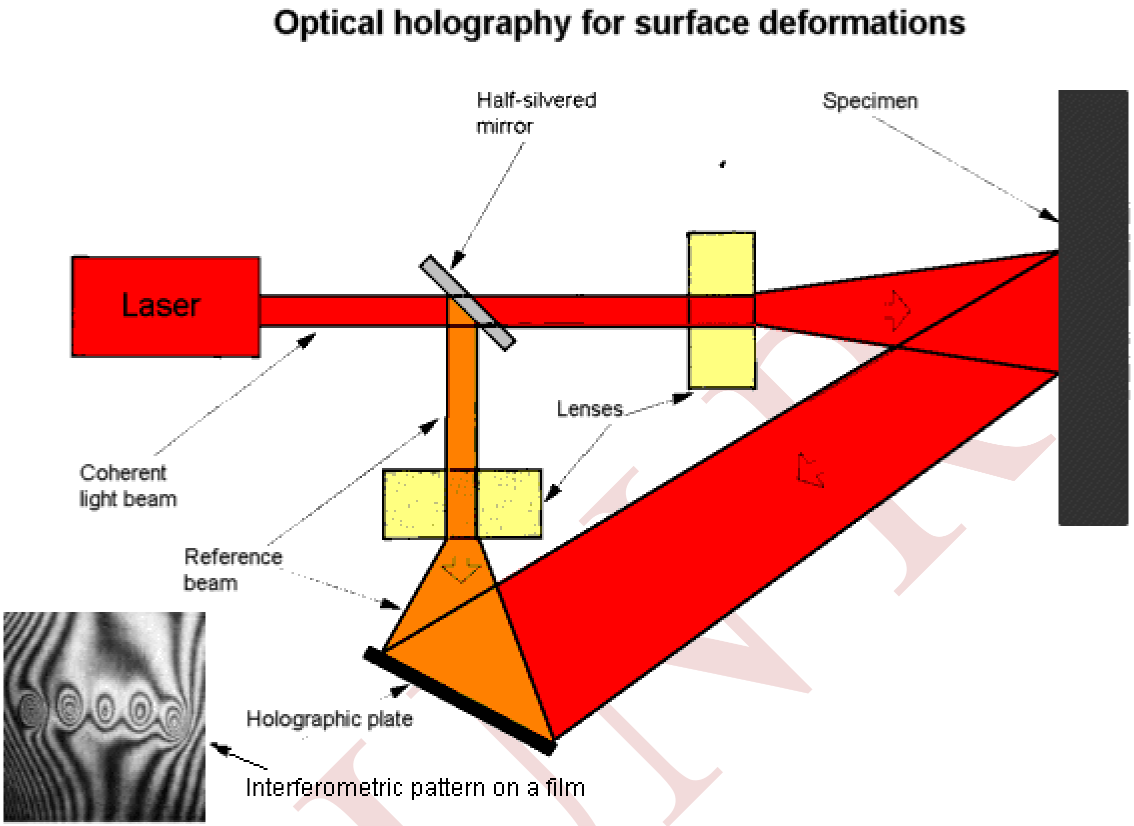


Figure 5.17 Holography Inspection