Welding

Dr. Sunil Jha

Introduction

- **Joining**
  - Welding,
  - Brazing,
  - Soldering and
  - Adhesive bonding
- In these process a **permanent joint between the parts** is formed and cannot be separated easily
- **Assembly** usually refers to **mechanical methods of fastening** the parts together. Some of these methods allow easy disassembly, while others do not

Welding

- Welding is a material joining process in which **two or more parts are coalesced (joined together)** at their contacting surfaces by a suitable application of heat and/or pressure.
- In some welding process a ***filler* material** is added to facilitate coalescence.
- Welding is most commonly associated with **metallic parts** but for plastics also it is used.

Types of Welding Processes

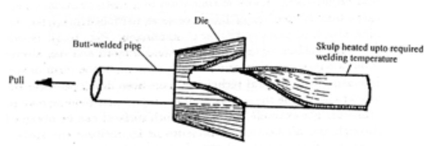
- Solid state welding processes
- Liquid state welding processes
- Solid / Liquid state bonding processes

Solid State Welding Processes

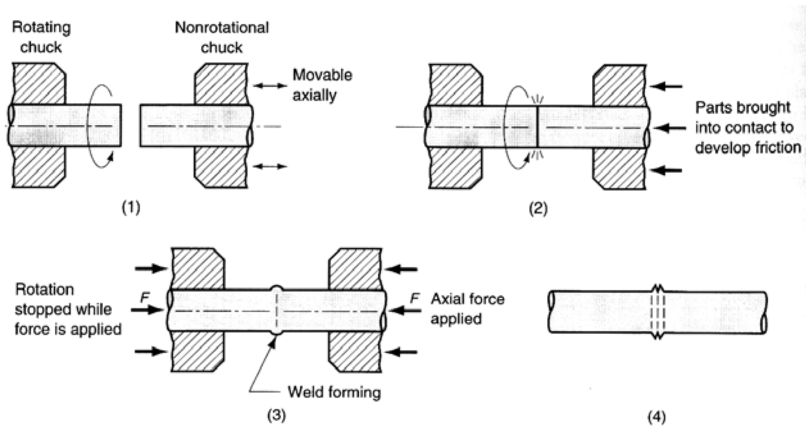
- In solid state welding the surfaces to be joined are brought into close proximity by:
  - Heating the surfaces without causing melting and applying normal pressure
  - Providing relative motion between the two surfaces and applying light normal pressure
  - Applying high pressure without heating
- In these processes the materials remain in solid state and welding is achieved through the application of heat and pressure, or high pressure only

Forge Welding

- Forge welding is the oldest method of welding in the category of solid state welding.
- Surfaces to be joined are **heated till they are red hot** and then forced together by hammering.
- It is a **crude method of welding** and quality depends upon the skill of the welder.
- A modern version of this type of welding is manufacture of **butt-welded pipes**. In this process, the skulp heated up to the required welding temperature is pulled through die which forces the two edges of the heated skulp to contact under pressure and get welded.

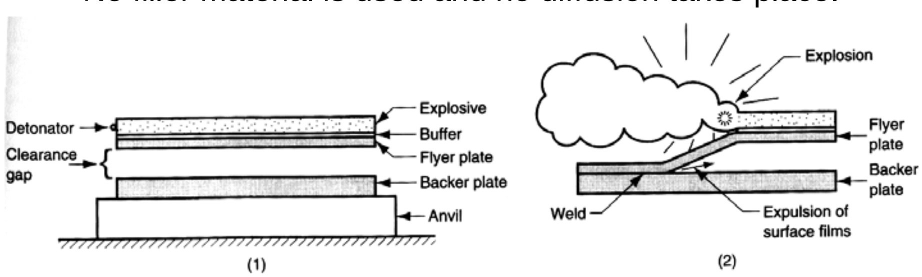


Friction Welding



Explosive Welding

- Very high contact pressure developed by detonating a thin layer of explosive.
- The detonation imparts high kinetic energy to the piece which on striking the other piece causes plastic deformation.
- No filler material is used and no diffusion takes place.

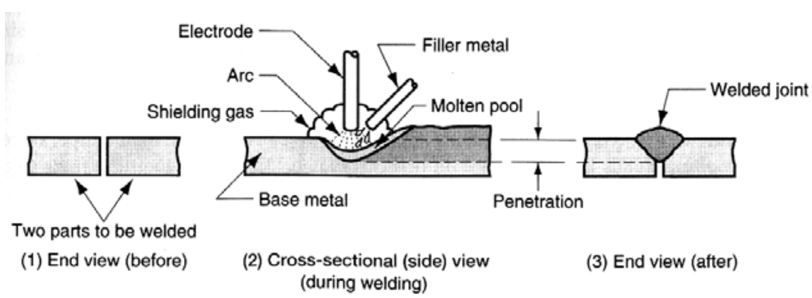


Liquid State Welding

- Arc Welding
- Resistance welding
- Oxyfuel gas welding
- Other processes
- There are two inherent problems with fusion welding
  - Effect of localized heating and rapid cooling on the microstructure and properties of the parent metals.
  - Effect of residual stresses developed in the parent metals due to restrained expansion or contraction. This effect the impact and fatigue life of weldment.

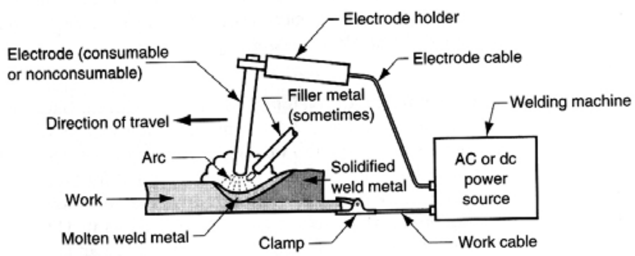
Arc Welding

- In Electric Arc Welding a sustained arc provides the heat required for melting the parent as well as filler material.
- The workpiece and the electrode are connected to the two materials of the power source. The arc is started by momentarily touching the electrode on to the workpiece and then withdrawing it to a short distance (a few mm) from the workpiece.



Arc Welding

- When the electrode and workpiece are in contact, current flows and when they are separated an arc is generated and the current continues to flow.
- The arc is generated by the electrons liberated form cathode and moving towards anode.
- The arc changes electrical energy into heat and light.



Arc Welding

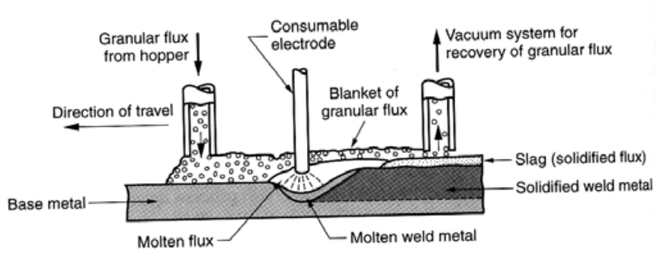
- About 70% of the heat liberated due to **<u>striking of electrons at anode</u>** raises the anode temperature to a very values (5,000 to 30,000ºC). This heat melts the base metal as well as tip of the electrode in the area surrounding the arc.
- A weld is formed when the <u>mixture of molten base and electrode metal solidifies</u> in the weld area.
- Since 70% heat is generated at anode a workpiece connected to **<u>anode will melt 50% faster</u>** as compared to if connected with cathode. This is **<u>why work piece is usually made positive</u>** and electrode as negative and is termed as straight polarity.

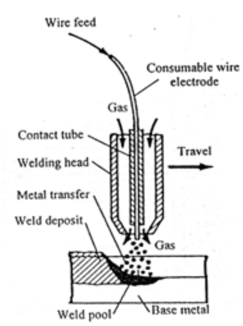
Shielded Arc Welding

- Consumable electrodes usually have a coating on its outer surface which on melting release gases like hydrogen or carbon dioxide to form a protective covering around the molten pool.
- The electrode coating also reacts to from **slag** which is a liquid, lighter than the molten metal.
- The slag therefore rises to the surface and on solidification forms a protective covering over the hot metal.
- This also slows down the rate of cooling of the weld. The slag layer can be removed by light chipping.
- Electric arc welding of this type is known as **Shielded Metal Arc Welding**. More than 50% industrial arc welding is done by this method.

Submerged Arc Welding

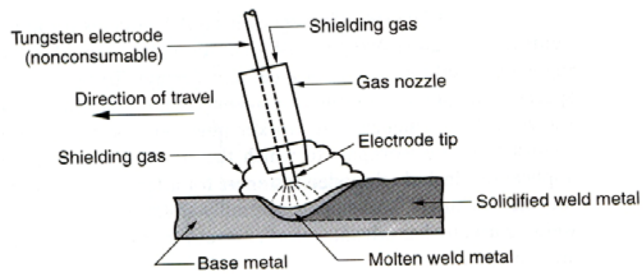
- For **continuous arc welding operations**, the consumables electrode is bare wire in the form of a coil and the flux is fed into the welding zone, or the weld area is covered by an inert gas. In **Submerged Arc Welding** the base electrode is shielded by granular flux supplied from a hopper, while is **Gas Metal Arc Welding** shielding of the area is provided by an inert gas such as argon, helium, carbon dioxide , etc.



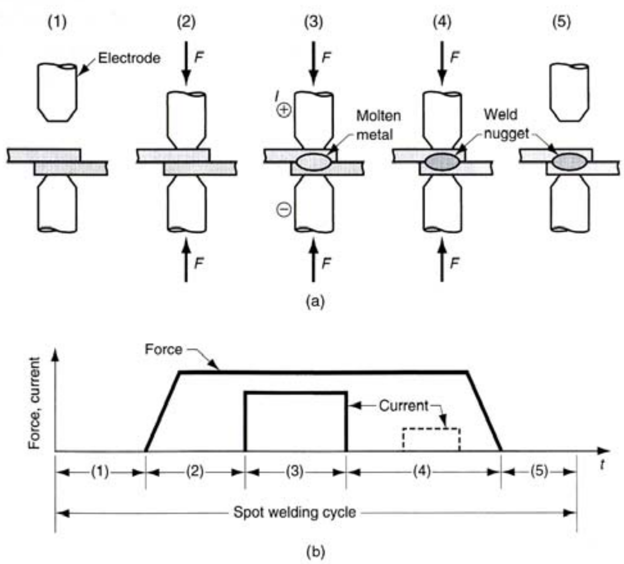


Tungsten Inert Gas Welding

- Non consumable arc welding processes use tungsten electrodes and shielding is provided by an inert gas around the weld area. Once such process, the Gas Tungsten Arc Welding (GTAW) is also called as **Tungsten Inert Gas (TIG)** welding.
- It uses tungsten alloy electrode and helium gas shield. Because of inert gas atmosphere tungsten is not consumed. Filler materials supplied by a separate rod or wire.



Resistance Spot Welding



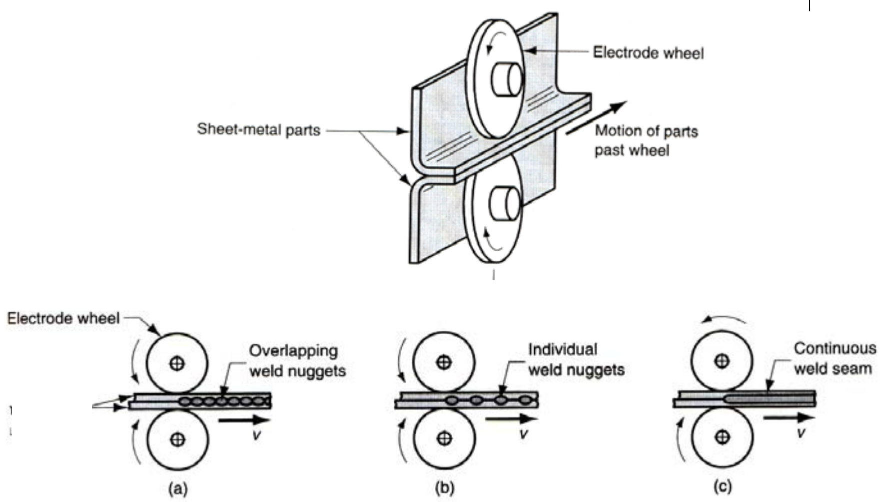
Resistance Spot Welding

- Two opposing solid cylindrical electrodes are pressed against the lap joint and two metallic sheets to be welded.
- Current ranges **3,000 to 40,000 Ampere** depending on the requirement causes a weld nugget of size varying from **6 to 10 mm diameter** to be formed at the metallic interface.
- The current is switched on for a duration lasting **0.1 to 0.5 sec**.
- **At low pressures**, the resistance and heat are high and melted metal tend to squeeze out of the weld.

Resistance Spot Welding

- **At high pressure**, the resistance decreases and heat is less and smaller weld formed provides lower weld strength. Thus, for a given set of conditions, **optimum electrode current and electrode pressure** are indicated.
- The **time duration of current flow** should not be beyond certain critical, because the heat then has a chance to spread out and harm work piece and electrode.
- Optimum values of current, pressure and their application timing are dependent on weld size and material.

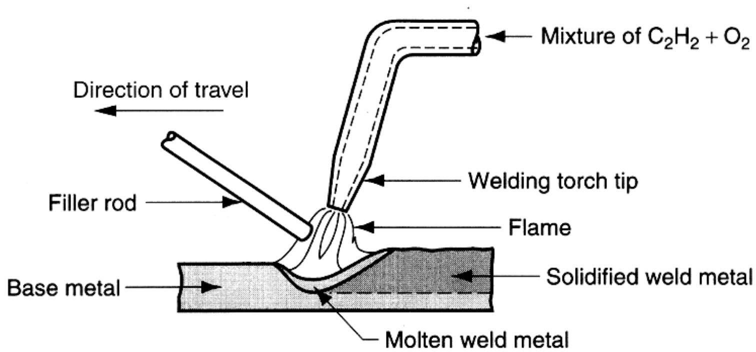
Seam Welding



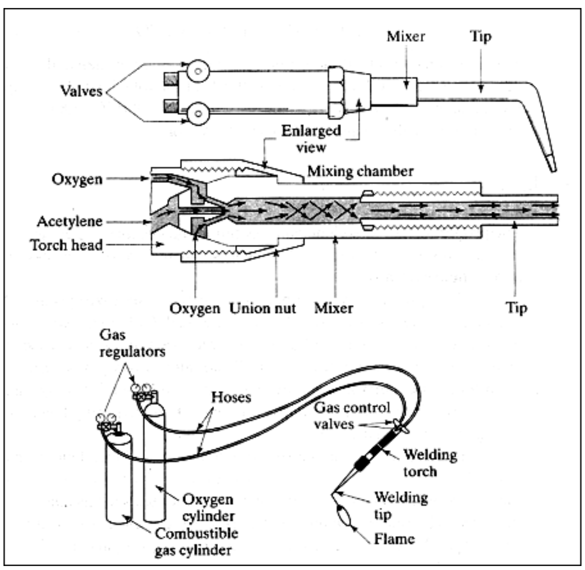
Oxy fuel Welding (OFW)

- OFW is the term to describe the group of fusion operations that burn various **fuels mixed with oxygen** to perform welding.
- The OFW processes employ several type of gases, which is the primary distinction among the members of this group.
- The most important OFW process is **oxyacetylene welding**.

Oxy Acetylene Welding



Oxy Acetylene Welding



Oxy Acetylene Welding

- Filler materials are used to supply additional material to the weld zone.
- Flux is often used to clean the surfaces and to retard oxidation by providing inert gas shield around the weld area.
- Flux also helps in removing oxide and other impurities. **Borax**, is the most common flux, but sometimes other substances are added to improve its effectiveness.

Salient points about oxyacetylene welding

- The heat is obtained by **combustion of acetylene and oxygen**. Here primary combustion occurring in the inner zone gives:

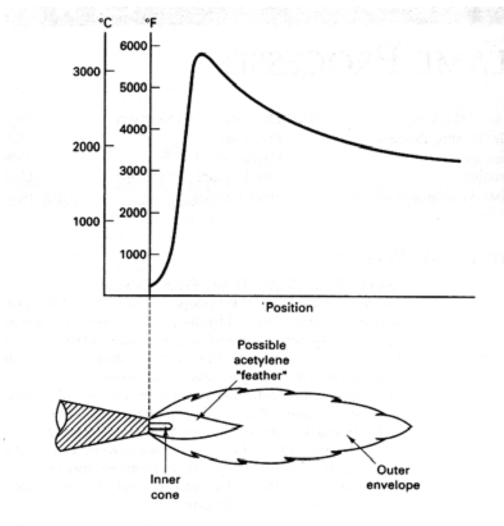
$$C_2H_2 + O_2 \rightarrow 2CO + H_2 + Heat$$

and the second reaction in the outer zone gives

$$2CO + H_2 + 1.5O_2 \rightarrow 2CO_2 + H_2O + Heat$$

- The maximum temperature at the **tip of inner cone reaches up to 3000-3500°C**. Therefore, most gas welding is performed by keeping this **inner zone tip just above the metal** to be welded so that maximum temperature is available for welding.

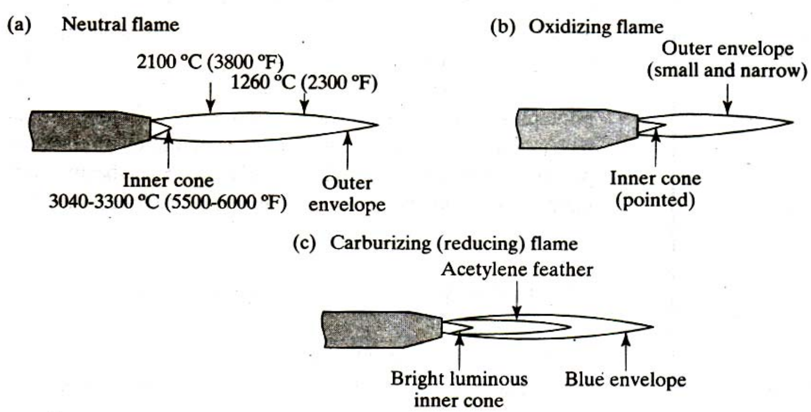
Temperature distribution along the flame



Flame Types

- A ***neutral flame*** is obtained when the ratio of is oxygen and acetylene is 1. Most gas welding operations are carried out by this flame.
- An ***oxidizing flame*** is obtained when this ratio is more than 1. This type of flame is **not suitable for welding of steels** since excess oxygen present reacts with carbon in steel and is generally **used for welding of copper** and its alloys.
- When the ratio in mixture is less than 1 a ***carburizing flame*** is obtained. In this type of flame acetylene decomposes into carbon and hydrogen and the flame temperature gets reduced. Joining operations such as brazing and soldering which require lower temperature generally use this flame.

Flame Types



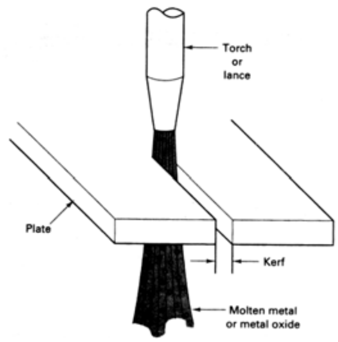
Flame Cutting

- Metal is melted by the flame of the oxyfuel gas torch and blown away to form a gap or kerf.
- When ferrous metal is cut, actually burning of iron takes place according to one or more of the following reactions.

$$Fe + O \rightarrow Feo + Q$$
$$3Fe + 2O_2 \rightarrow Fe_3O_4 + Q$$
$$4Fe + 3O_2 \rightarrow 2Fe_2O_3 + Q$$

Flame Cutting

- Because, these reactions cannot take place below **815°C**.
- Oxyfuel flame is first used to **raise the metal temperature** where burning can be initiated. Then a **stream of pure oxygen** is added to the torch (or the oxygen content of the oxyfuel mixture is increased) to oxidize the iron.
- The **liquid iron and iron oxides** are then expelled from the joint by the kinetic energy of the oxygen gas stream.



Flame Cutting

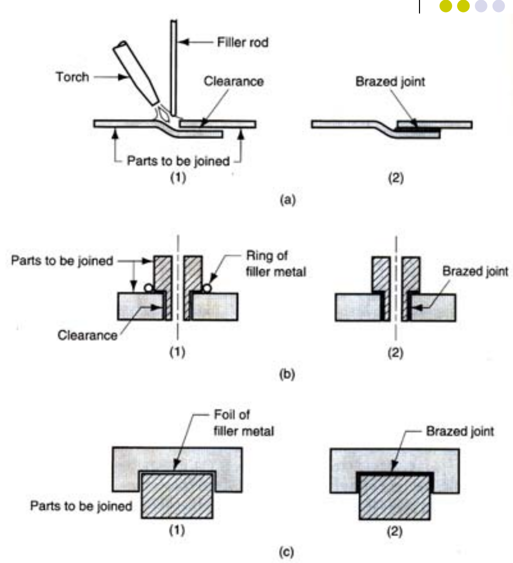
- Low rate of heat input, and need of preheating ahead of the cut, oxyfuel produces a relatively **large heat affected zone** and thus associated distortion zone.
- The process is suitable when edge finish or tolerance is not critical.
- Theoretically heat generated due to burning of Fe is sufficient to continue cutting, however due to losses additional heat supply is needed.
- If the work is **already hot** from the other processes, supply of oxygen through a small diameter pipe is needed to continue cut. This is called **Oxygen Lance Cutting**. A workpiece temperature of **1200°C** is needed to sustain the cutting.

Brazing

- In brazing the joint is made by **heating the base metal red hot and filling the gap with molten metal** whose melting temperature is typically above 450°C but below melting temperature of base metal.
- The filler metals are generally **copper alloys**. **Cu-Zn** and **Cu-Ag** alloys are used for brazing because **they form alloy with iron** and have good strength.

Brazing

- Brazing methods
- Torch and filler rods
- Ring of filler metal at entrance of gap
- Foil of filler metal between flat part surfaces



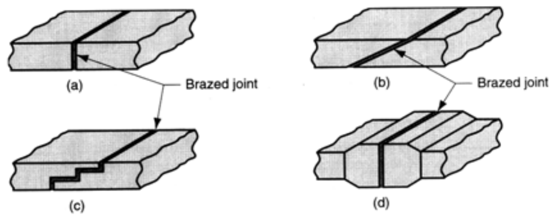
Brazing Joints

(a) Conventional butt

(b) Scarf joint

(c) Stepped joint

(d) Increased crossection

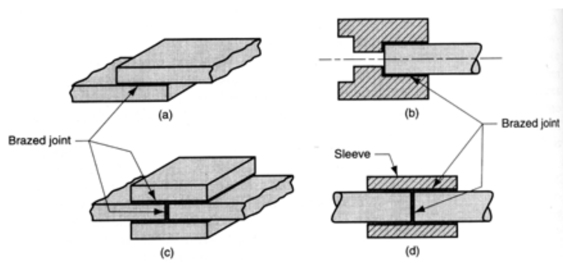


(a) Conventional Lap

(b) Cylindrical part

(c) Sandwiched part

(d) Use of sleeve



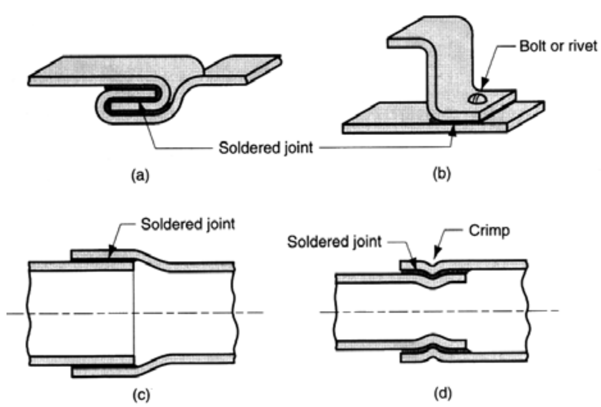
Common braze metal families

Filler Metal	Typical Composition	Approx. Brazing Temperature °C	(°F)	Base Metals
Aluminum and silicon	90 Al, 10 Si	600	(1100)	Aluminum
Copper	99.9 Cu	1120	(2050)	Nickel copper
Copper and phosphorous	95 Cu, 5 P	850	(1550)	Copper
Copper and zinc	60 Cu, 40 Zn	925	(1700)	Steels, cast irons, nickel
Gold and silver	80 Au, 20 Ag	950	(1750)	Stainless steel, nickel alloys
Nickel alloys	Ni, Cr, others	1120	(2050)	Stainless steel, nickel alloys
Silver alloys	Ag, Cu, Zn, Cd	730	(1350)	Titanium, monel, inconel, tool steel, nickel

Soldering

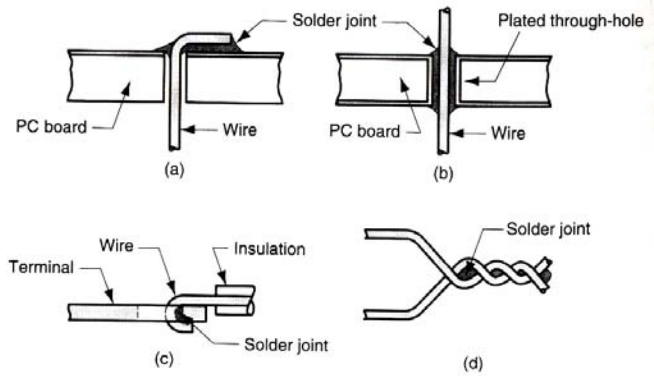
- Soldering is very similar to brazing except that **filler material is usually a lead-tin based alloy** which has much lower strength and melting **temperature around 250°C**.
- In this process **less alloying action between base metal and filler material** as compared to brazing takes place hence the strength of joint is lesser.
- It is carried out using electrical resistance heating.

Joints in Soldering



(a) Flat lock seam (b) Bolted or riveted joint (c) Copper pipe fitting (d) Crimping of cylindrical lap joint.

Joints in Soldering



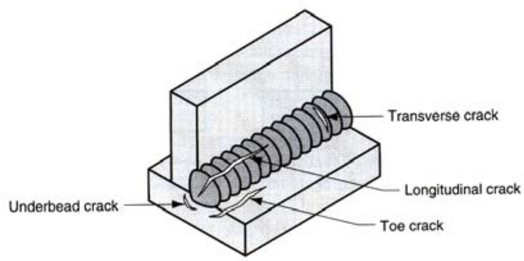
a) Crimped lead wire PC board
b) Plated through hole on PC board to maximize solder contact area
c) Hooked wire on flat terminals
d) Twisted wires

Some common solder alloy compositions

Filler Metal	Approximate Composition	Approx. Melting Temperature °C	(°F)	Principal Applications
Lead-silver	96 Pb, 4 Ag	305	(580)	Elevated temperature joints
Tin-antimony	95 Sn, 5 Sb	238	(460)	Plumbing & heating
Tin-lead	63 Sn, 37 Pb	183	(361)	Electronics[a]
	60 Sn, 40 Pb	188	(370)	Electronics
	50 Sn, 50 Pb	199	(390)	General purpose
	40 Sn, 60 Pb	207	(405)	Automobile radiators
Tin-silver	96 Sn, 4 Ag	221	(430)	Food containers
Tin-zinc	91 Sn, 9 Zn	199	(390)	Aluminum joining

Welding Defects

- Cracks
  - This causes significant reduction in the strength of weldment. Welding cracks are caused by embrittlement or low ductility of the weld and/or base metal combined with high restraint during contraction.



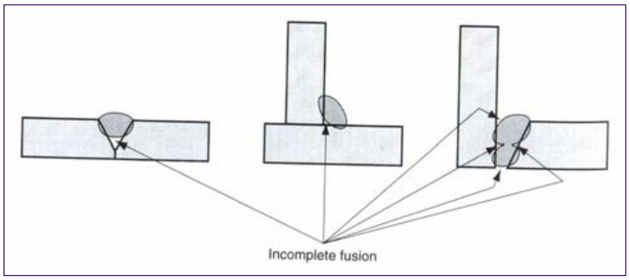
Various forms of Welding Cracks

Welding Defects

- Cavities
  - These includes porosity and shrinkage voids.
- Solid inclusions
  - These are metallic or non-metallic solid material particles entrapped in the weld metal. The most common form is slag inclusion or metallic oxides.

Welding Defects

- Incomplete fusion
  - A similar defect is lack of penetration.



Several form incomplete fusion

Welding Defects

- Imperfect shape