

LECTURE NOTES
On
Industrial Metallurgy



ORISSA SCHOOL OF MINING ENGINEERING
Government of Odisha
ଓଡ଼ିଶା ଶାସି ଯାତ୍ରୀକ ବିଦ୍ୟାଳୟ, କେଉଁଝର

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JOINING of Metals

- Soldering
 - Produces coalescence of materials by heating to soldering temperature (***below solidus of base metal***) in presence of filler metal with liquidus $< 450^{\circ}\text{C}$
- Brazing
 - Same as soldering ***but*** coalescence occurs at $> 450^{\circ}\text{C}$
- Welding
 - Process of achieving complete coalescence of two or more materials through melting & re-solidification of the base metals and filler metal

Diffusion bonding is a solid-state welding technique used in metalworking, capable of joining similar and dissimilar metals. It operates on the materials science principle of solid-state diffusion, wherein the atoms of two solid, metallic surfaces intermingle over time under elevated temperature. Diffusion bonding is typically implemented by applying both high pressure and high temperature to the materials to be welded

Soldering & Brazing

- Advantages

- Low temperature heat source required
- Choice of permanent or temporary joint
- Dissimilar materials can be joined
- Less chance of damaging parts
- Slow rate of heating & cooling
- Parts of varying thickness can be joined
- Easy realignment

- Strength and performance of structural joints need careful evaluation

BRAZING AND SOLDERING require the application of a number of scientific and engineering skills to produce joints of satisfactory quality and reliability. Brazing employs higher temperatures than soldering, but the fundamental concepts are similar, particularly with respect to metallurgy and surface chemistry (Table 1). However, joint design, materials to be joined, filler metal and flux selection, heating methods, and joint preparation can vary widely between the two processes. Economic considerations involving filler metal and process technology are also varied, particularly in relation to automated techniques and inspection and testing. Brazing and soldering are performed in many industries, from exotic applications in the electronics and aerospace field to everyday plumbing applications.


TABLE 1: COMPARISON OF SOLDERING, BRAZING, AND WELDING

Parameter	Process		
	Soldering	Brazing	Welding
Joint formed	Mechanical	Metallurgical	Metallurgical
Filler metal melt temperature, °c (°f)	<450 (<840)	>450 (>840) ^(a)	>450 (>840) ^(b)
Base metal	Does not melt	Does not melt	...
Fluxes used to protect and to assist in wetting of base-metal surfaces	Required	Optional	Optional
Typical heat sources	Soldering iron; ultrasonics; resistance; oven	Furnace; chemical reaction; induction; torch; infrared	Plasma; electron beam; tungsten and submerged arc; resistance; laser
Tendency to warp or burn	Atypical	Atypical	Potential distortion and warpage of base-metal likely
Residual stresses	Likely around weld area

Introduction

WELDING AND JOINING processes are essential for the development of virtually every manufactured product. However, these processes often appear to consume greater fractions of the product cost and to create more of the production difficulties than might be expected. This is often done by melting the workpieces and adding a filler material to form a pool of molten material (the weld pool) that cools to become a strong joint, with pressure sometimes used in conjunction with heat, or by itself, to produce the weld.

First, welding and joining are multifaceted, both in terms of process variations (such as **fastening, adhesive bonding, soldering, brazing, arc welding, diffusion bonding, and resistance welding**) and in the disciplines needed for problem solving (such as mechanics, materials science, physics, chemistry, and electronics). An engineer with unusually broad and deep training is required to bring these disciplines together and to apply them effectively to a variety of processes.



Second, welding or joining difficulties usually occur far into the manufacturing process, where the relative value of scrapped parts is high.

Third, a very large percentage of product failures occur at joints because they are usually located at the highest stress points of an assembly and are therefore the weakest parts of that assembly. Careful attention to the joining processes can produce great rewards in manufacturing economy and product reliability

Fusion welding processes, one of the greatest difficulties for the manufacturing engineer is to determine which process will produce acceptable properties at the lowest cost. There are no simple answers. Any change in the part geometry, material, value of the end product, or size of the production run, as well as the availability of joining equipment, can influence the choice of joining method. For small lots of complex parts, fastening may be preferable to welding, whereas for long production runs, welds can be stronger and less expensive.

Welding

- Advantages
 - Most efficient way to join metals
 - Lowest-cost joining method
 - Affords lighter weight through better utilization of materials
 - Joins all commercial metals
 - Provides design flexibility
 - A large number of metals/ alloys both similar and dissimilar can be joined by welding
 - A good weld is as strong as the base metal

Welding

Disadvantages:

- ❖ Welding emitted harmful radiations (lights), fumes and spatter
- ❖ It results residual stresses and distortion of the work pieces
- ❖ Jigs and fixtures are required for holding and positioning of the work pieces
- ❖ Preparation of work spices specially edges
- ❖ Due to the high temperature, the metallurgical changes to the work pieces.
- ❖ After welding, post treatment are required such as stress-relief heat treatments.

Welding application

Ferrous

1. Wrought Iron
2. Cast Iron
3. Carbon Steel (LMH carbon steel)
4. Alloy steel
5. Stainless steel

Non-Ferrous

1. Aluminum and its alloys
2. Magnesium and its alloys
3. Zinc and its alloys
4. Copper and its alloys
5. Nickel and its alloys

Overview

- Welding is joining two pieces of metal by:
 - Heating to temperature high enough to cause softening or melting
 - With or without application of pressure
 - With or without use of filler metal
 - Melting point same as metals beginning joined or melting point below metals but about 450°C
- New methods, applications and systems
 - Tremendous progress in short time
- Usually best method to use when fastening metal

History of Metalworking

- Henry Louis Le Chatelier discovered Oxyacetylene Flame at 1895.
- Davy in the year 1809, he started with arc welding process.

Classification of Welding Processes:

(i) Arc welding

- ❖ Carbon arc Welding
- ❖ Metal arc Welding
- ❖ Metal inert gas Welding
- ❖ Tungsten inert gas or TIG
- ❖ Plasma arc Welding
- ❖ Submerged arc Welding
- ❖ Electro-slag Welding

(ii) Gas Welding

- ❑ Oxy-acetylene
- ❑ Air-acetylene
- ❑ Oxy-hydrogen

(iii) Resistance Welding

- Butt Welding
- Spot Welding
- Seam Welding
- Projection Welding
- Percussion Welding

(iv) Thermo-chemical Welding-

- ❑ Thermit Welding
- ❑ Atomic Hydrogen Welding

(v) Solid State Welding

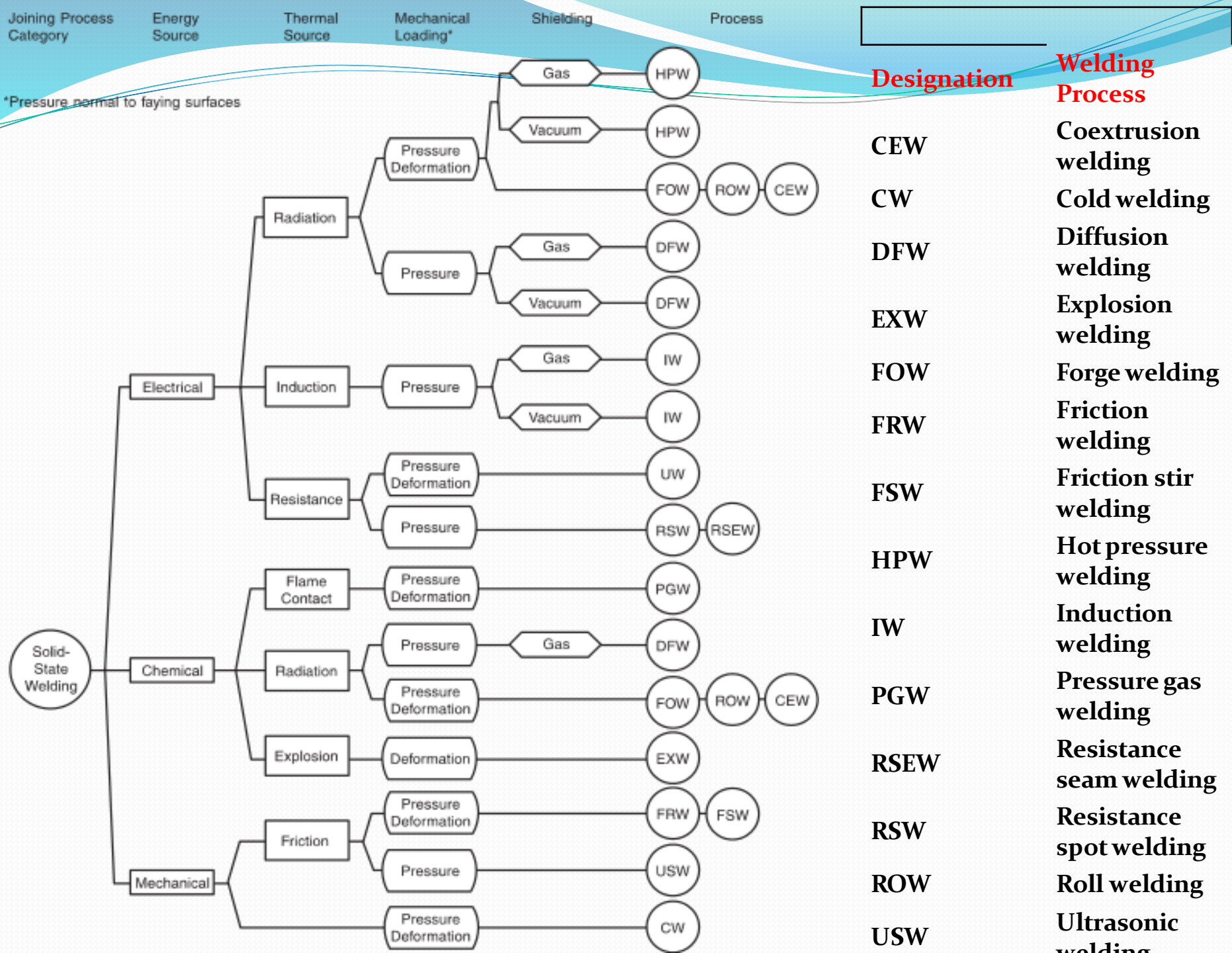
- ✓ Friction welding
- ✓ Cold welding
- ✓ Forge welding
- ✓ Ultrasonic welding
- ✓ Diffusion welding
- ✓ Explosive welding

(vi) Newer Welding or Radiant Energy Welding

- Electron-beam Welding
- Laser Welding

(vii) Related Process

- Oxy-acetylene cutting
- Arc cutting
- Hard facing
- Brazing



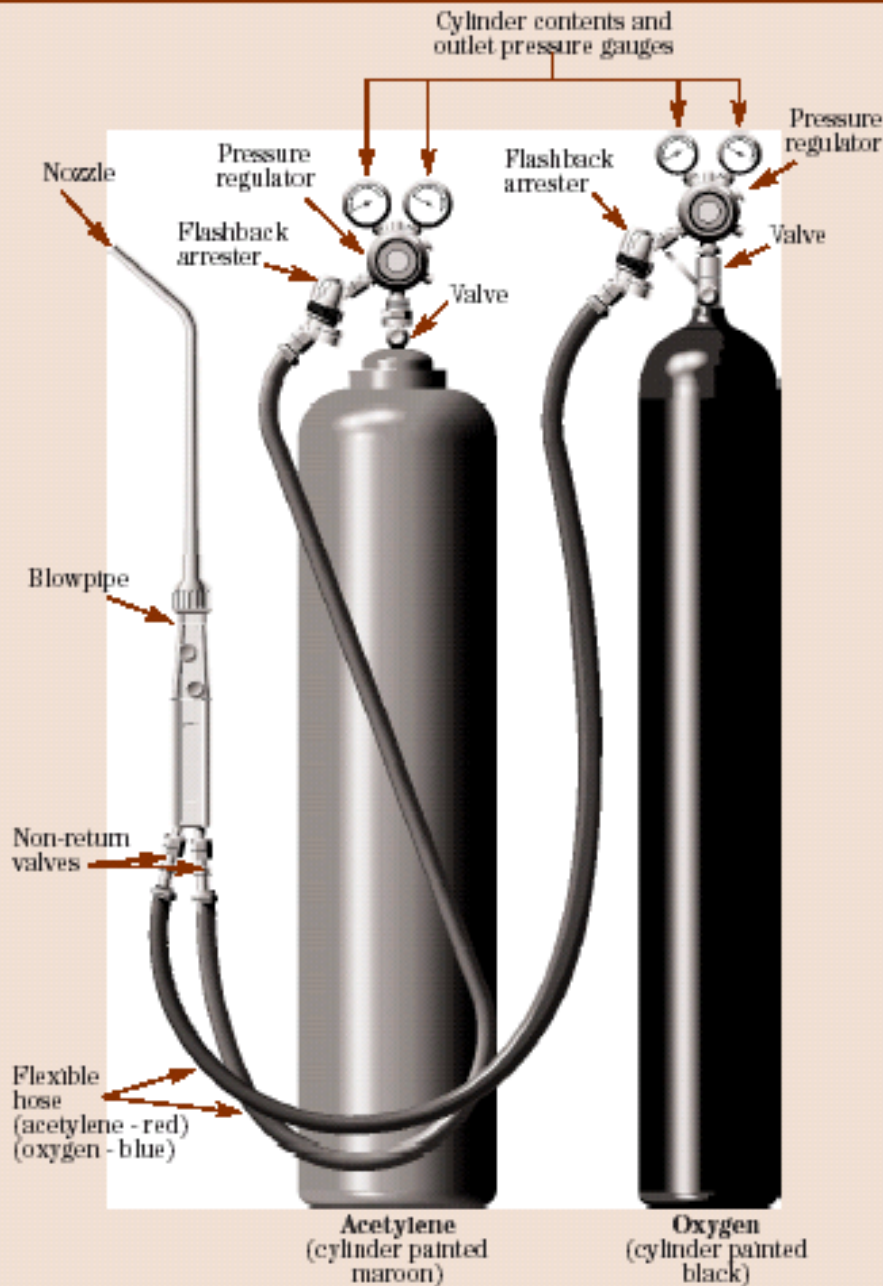
Practical Applications of Welding:

- 1. Aircraft Construction**
- 2. Automobile Construction**
- 3. Bridges**
- 4. Buildings**
- 5. Pressure Vessels and Tank**
- 6. Storage Tank**
- 7. Rail Road Equipments**
- 8. Piping and pipelines**
- 9. Ships**

Gas Welding Processes and Equipments

- Joining of metals
- Using by heat of combustion of an oxygen/air and fuel gas (i.e. acetylene, hydrogen, propane or butane) mixture.
- Intense heat (flame) to produce melts and fuses the metals to be welded
- Addition of filler metals

Equipments used in gas and oxy-acetylene welding processes



Oxygen

Steel cylinder

Contained in compressed form

Supplied 3.4, 5 and 6.8 m³ capacities

Mild steel-13, 660 kN/m²

Alloy steel-17, 240kN/m²

R. H. thread in valve

Acetylene

Steel cylinder

High pressure acetylene is not stable so it dissolved in acetone, which has the ability to absorb a large volume of gas and release it as the pressure falls.

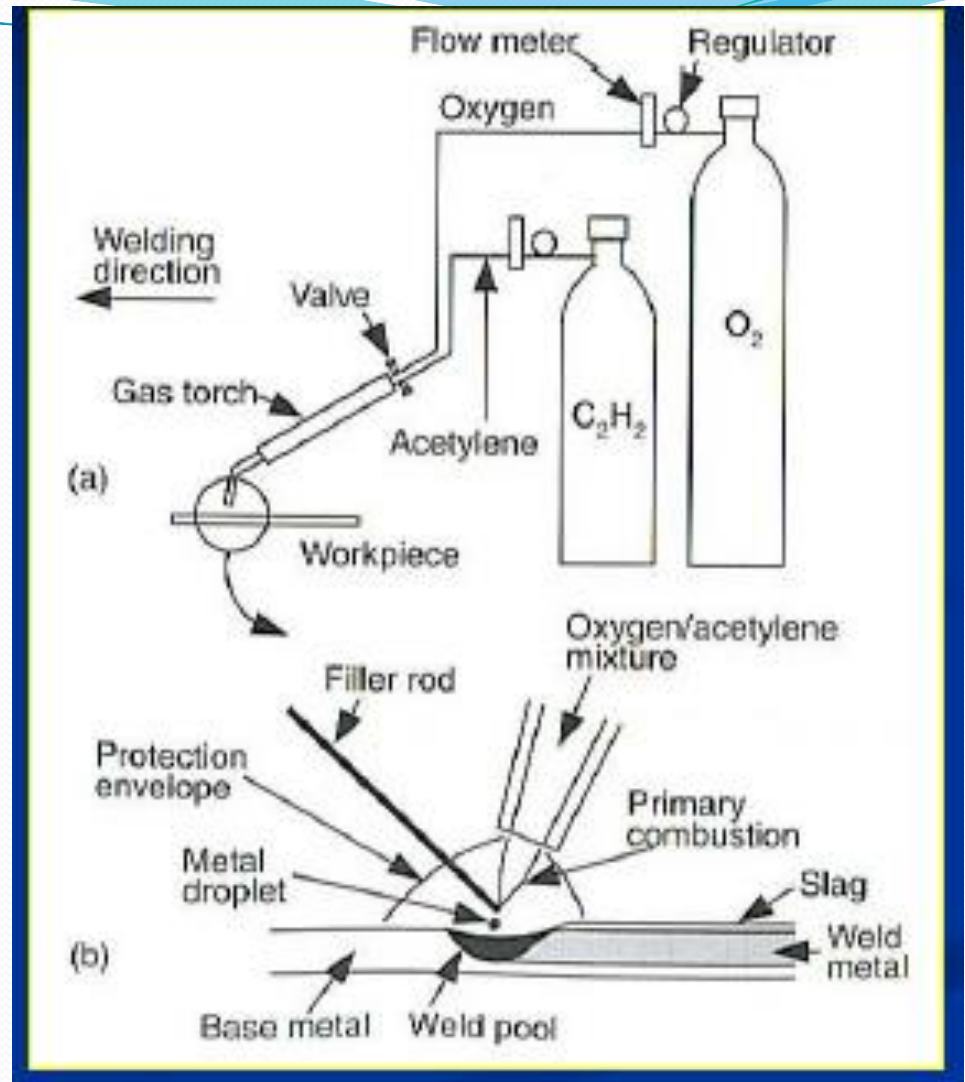
1 volume acetone-25 volume acetylene

Pressure 1, 552 kN/m²

Danger of explosion-porous substance

Gas Welding Processes and Equipments

- Gas welding is a welding process that melts and joints metals by **heating them with a flame** caused by a reaction of fuel gas and oxygen.
- The most commonly used method is **Oxyacetylene welding**, due to its high flame temperature.
- The **flux** may be used to deoxidize and cleanse the weld metal.
- The flux melts, solidifies and forms a **slag skin** on the resultant weld metal.



Welding gas mixture

Fuel Gas

Maximum Flame temperature *with air (°C)* *with oxygen (°C)*

Acetylene	1 755	3 200
Butane	1 750	2 730
Coal gas	1 600	2 000
Hydrogen	1 700	2 300
Propane	1 750	2 500

Oxyacetylene welding

There are three types of flame in oxyacetylene welding:

- **Neutral flame**

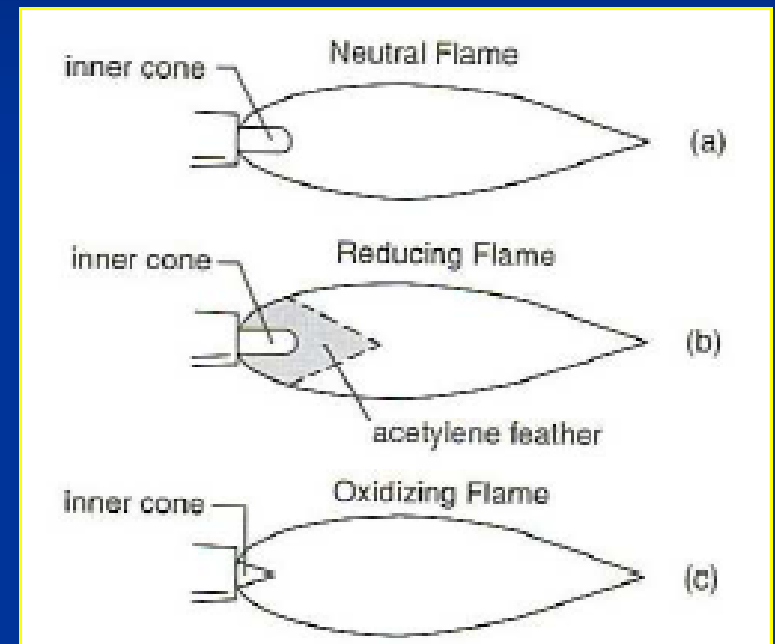
Acetylene (C_2H_2) and O_2 are mixed in equal amounts and burn at the tip of the welding torch. The **inner cone** gives 2/3 of heat whereas the **outer envelope** provides 1/3 of the energy.

- **Reducing flame**

The excess amount of acetylene is used, giving a reducing flame. The combustion of acetylene is incomplete (greenish) between the **inner cone** and the **outer envelope**. Good for welding aluminium alloys, high carbon steels.

- **Oxidizing flame**

The excess amount of O_2 is used, giving an oxidizing flame. Good for welding brass.



Three types of flame in oxyacetylene welding



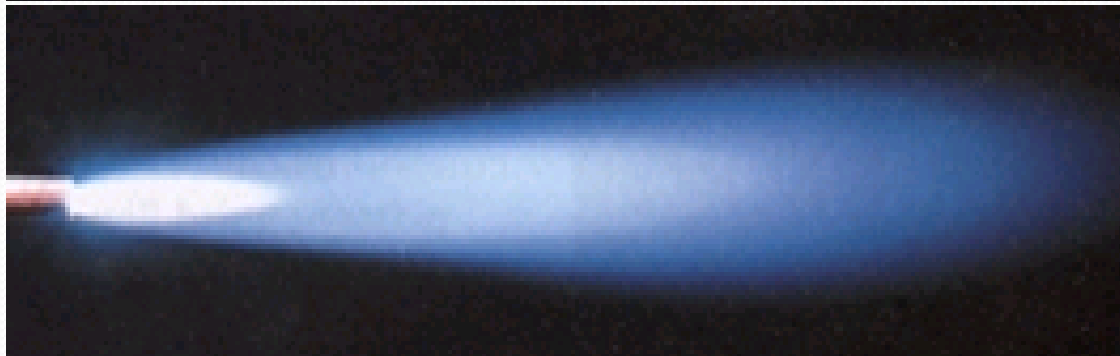
Oxy-acetylene flame



Neutral flame



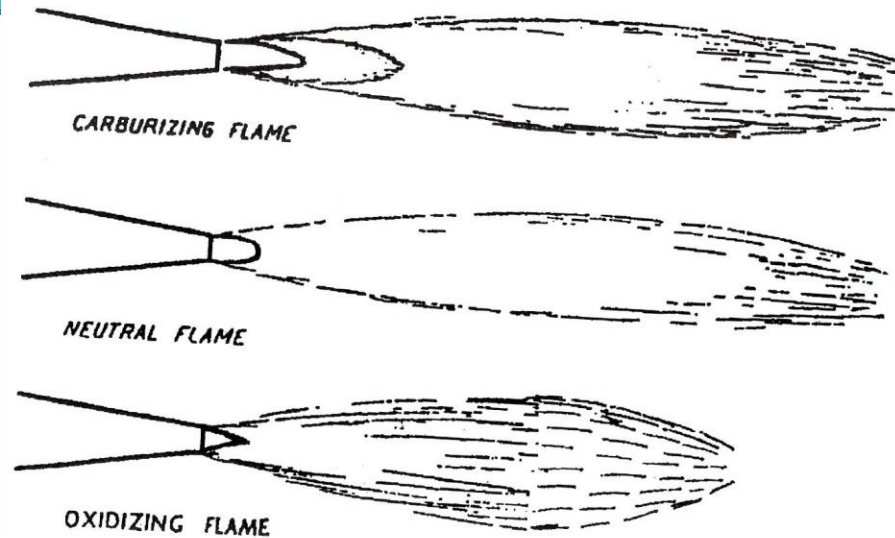
Oxidising
flame



Carburising
flame

Flame Formation and its different Types

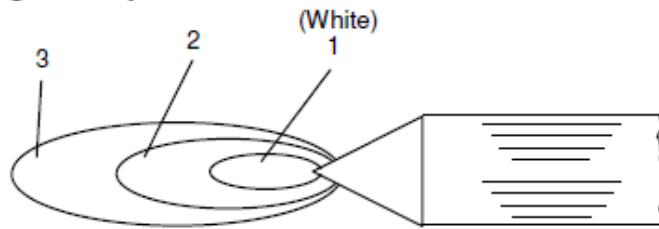
- ❖ Neutral Flame
- ❖ Carburizing Flame
- ❖ Oxidizing Flame



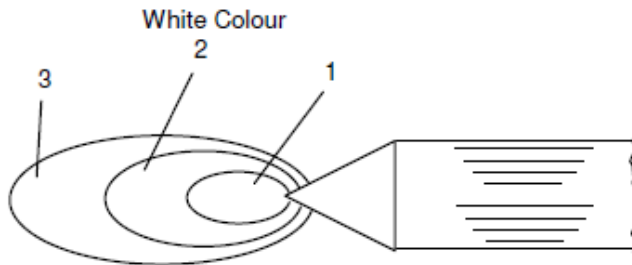
Flame is established by burning (controlled) of the two gases mixture at the outlet of blow pipe or torch. The proportion of gasses in the mixture is controlled by controlling the flow rate of each of the two gasses. Here, it should be clear that burning of acetylene generates heat and oxygen only supports acetylene in burning. Insufficient supply of oxygen leaves acetylene unburnt in atmosphere creating pollution and adding cost of waste acetylene. A general nomenclature of the flame established in oxy-acetylene welding is given in Figure 1. The flame can be divided in to three zones. Zone '1' is very near to the outlet of torch, where oxygen reacts with acetylene and burning of two gases takes place. Zone '2' produces carbon monoxide and hydrogen in ratio 2 : 1 by volume.

1. Neautral Flame: Oxygen: Acetylene

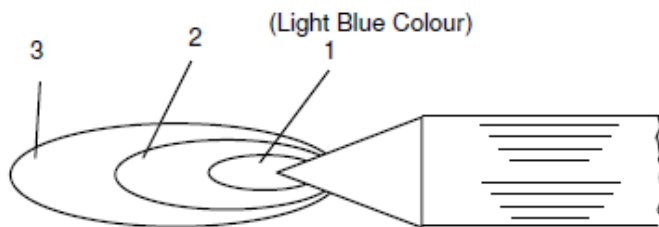
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Neutral Flame



Carburizing or Reducing Flame



Oxidizing Flame

- 1 – Inner Cone
- 2 – Middle Zone
- 3 – Outer Envelope

- ❑ Equal volume of oxygen and acetylene (ratio = 1:1)
- ❑ Temperature of the neutral flame- 5900°F (3260°C)
- ❑ Inner cone is blue color which is surrounded by outer flame envelope
- ❑ A neutral flame is named because it effects no chemical change on the molten metal and therefore will not oxidized or carburize the metal

Application: Commonly used for welding of

- ❖Mild steel
- ❖Cast Iron
- ❖Aluminum
- ❖Stainless Steel
- ❖Copper

2. Oxidizing Flame: Oxygen: Acetylene = 1.15 to 1.50:1

This flame has an excess of oxygen over that required for a neutral flame. The ratio $O_2 : C_2H_2 = 1.15$ to 1.50 . To have this flame set carburizing flame first convert it to neutral flame and then reduce the supply of acetylene to get oxidizing flame. Its inner cone is relatively shorter and excess oxygen turns the flame to light blue colour. It burns with a harsh sound.

Characteristics of Oxidizing flame:

- ❖ It burns with a decided loud roar.
- ❖ It tends to be hotter than the neutral flame because of excess of oxygen.
- ❖ The maximum temperature of this flame - $6300^{\circ}F$ ($3460^{\circ}C$).
- ❖ The excess oxygen plays an important role, at high temperature, tends to combine with many metals to form hard, brittle, low strength oxides which are undesirable in normal welding practices.

For these reasons, it is limited to use in welding. Specially, it is not suitable for welding of steel.

Applications: it is helpful to welding- (i) Copper-base metals, (ii) Zinc-base metals and (iii) few manganese steels and cast iron

3. Reducing Flame or Carburizing Flame: Oxygen: Acetylene = 1:1.15 to 1.50

This flame is obtained when excess of acetylene is supplied than which is theoretically required. This flame is identified by three zones the inner cone which is not sharply defined, an outer envelope as same in case of neutral flamed and middle zone surrounds inner one extended to outer envelope. It is white in colour due to excess acetylene. Larger the excess of acetylene larger will be its length

Characteristics of Reducing flame:

- ❖ It can be recognized by acetylene feather which exists between inner cone and the outer envelop.
- ❖ **Maximum flame temperature**- 5500°F (3038°C)
- ❖ This flame does not completely consume the available carbon; therefore, its burning temperature is lower and the left-over carbon is forced into the molten metal. For welding steel, it produced very hard, brittle phases i.e. carbides.
- ❖ A reducing flame may also be called as carburizing flame because that it contains more volume fraction of acetylene than a neutral flame.

Applications: It is helpful to welding- (i) low alloy steel, (ii) non-ferrous metals

Welding of Lead –carburizing flame is used to increase surface hardening.

Chemistry of Oxy-acetylene

Flame

Stage 1:

Oxygen and acetylene in equal proportions by volume burn in the inner white cone. The oxygen combines with carbon of the acetylene and forms CO.



Stage 2:

Due to excess of oxygen, CO reacts with oxygen formed CO₂ and H₂ burns with O₂ and forms watervapor.



CLASSIFICATION OF WELDING PROCESSES

Welding process can be classified into different categories depending upon the following criteria :

(a) It can be classified as fussion welding or pressure welding depending upon

on the application of heat. If application of heat is not required, it is called pressure welding.

(b) In case of fusion welding it can classified low temperature welding and high

temperature welding. When heat is generated to develop low temperature it is called low temperature welding like soldering and brazing. Other fusion welding methods are high temperature welding methods.

(c) Fusion welding can also be classified on the basis of method of heat generation like gas welding, electric arc welding, resistance welding, thermit welding, etc.

(d) On the basis of the type of joint produced it can be categorized as butt welding, seam welding, spot welding, lap joint welding, etc.

Each of the above type of welding can be further classified depending on other microlevel characteristics.

GAS WELDING TOOLS AND EQUIPMENTS

Tools and Equipment

- (a) Gas cylinders (two)
- (b) Hose pipes and valves
- (c) Cylinder pressure gauge
- (d) Outlet pressure gauge
- (e) Pressure regulators
- (f) Blow pipe or torch and spark lights
- (g) Welding screens
- (h) Goggles, screens, gloves and apron
- (i) Wire brush, trolley, chipping hammer

Consumables

- (a) Oxygen gas
- (b) Acetylene gas
- (c) Filler metal (rod or wire)
- (d) Fluxes.

Flux

Flux is used in every welding operation. Mild steel is exceptional to this. Flux is used to prevent oxidation of hot metal. It converts the oxides and nitrides to slag that can be removed from welding zone easily. Formation of oxides and nitrides make weldment weak. Different fluxes are used for welding of different metals. For the welding of copper and its alloy sodium nitrate, sodium carbonates are used as flux. For welding of aluminium or its alloy chloride of sodium, potassium, lithium or barium are used.

Composition of Welding Rod

- (a) More 'C' Si, Mn less 'P' and 'S'
- (b) should have 'Cr' and 'V'.
- (c) Copper rods with phosphorus.
- (d) Rods of same metal containing some silicon

Base Metal

Preparation:

Different kind of joints:

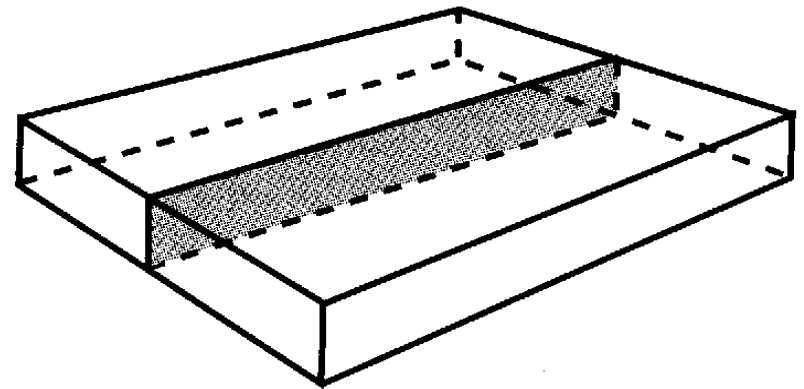
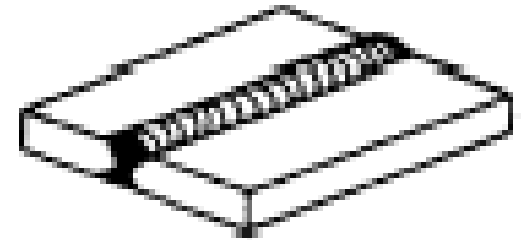
The weld joint is where two or more metal parts are joined by welding. The five basic types of weld joints are the butt, corner, tee, lap, and edge.

- ❖ Butt
- ❖ Lap
- ❖ Edge
- ❖ T Joint
- ❖ Corner Joint

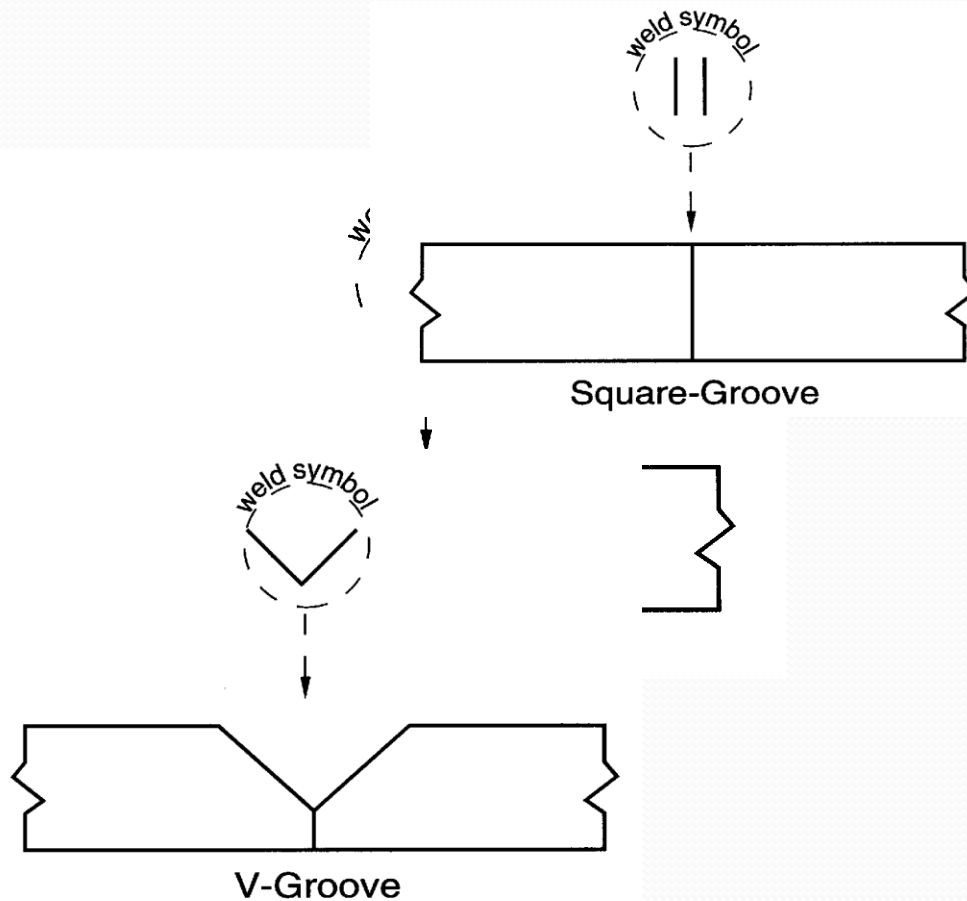
Butt Joint

Butt joint- a joint between two members aligned approximately in the same plane

This joint is frequently used in plate, sheet metal, and pipe work.



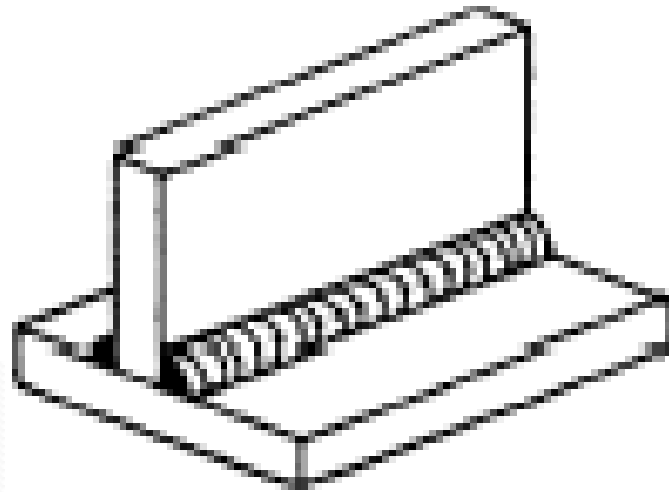
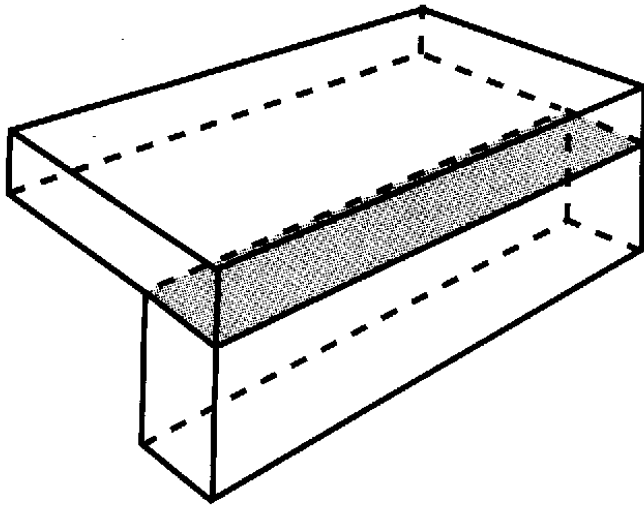
Different Edge Shapes and Symbols for some Butt-Joints



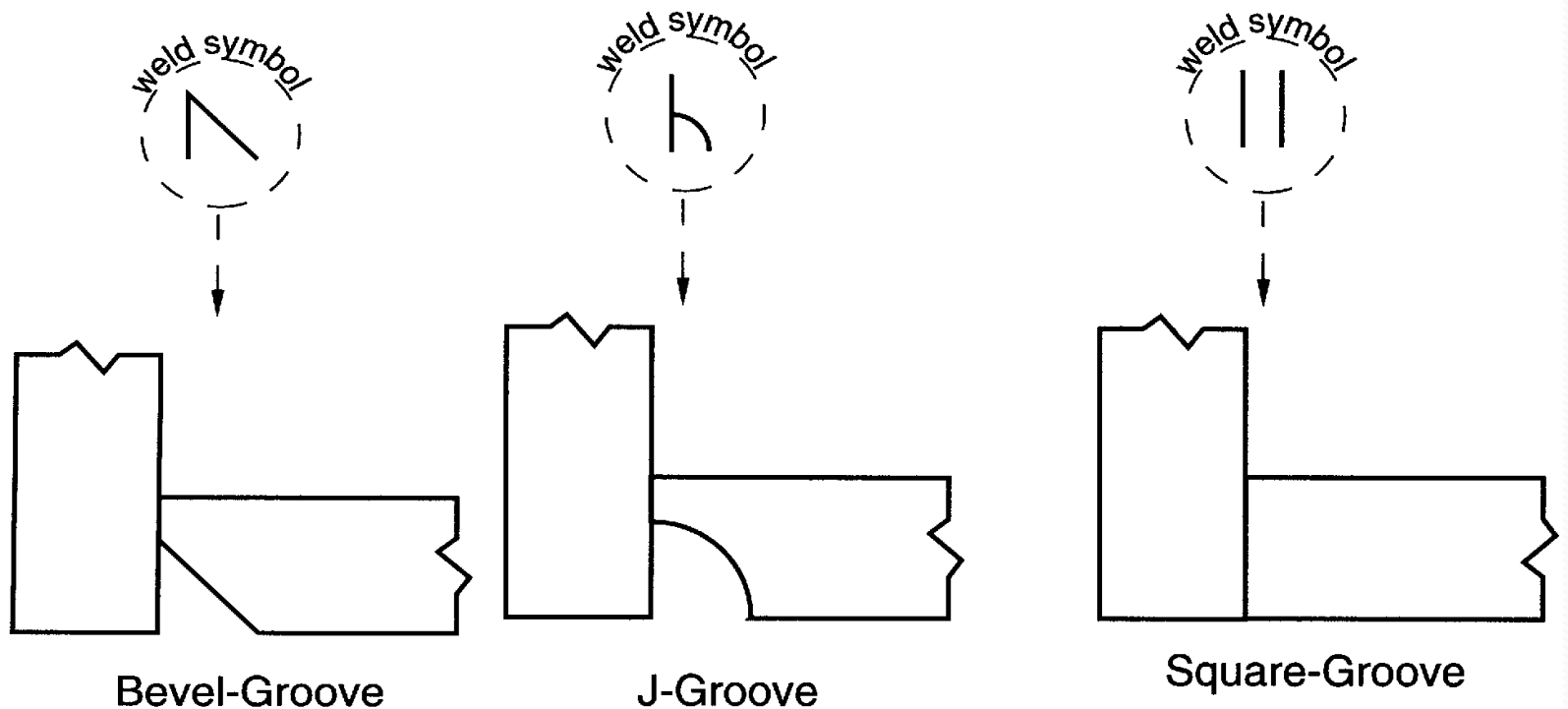
Corner joint

Corner joint - a joint between two members located at right angles to each other

The corner joint forms an L-shape, and the tee joint has the shape of the letter T.



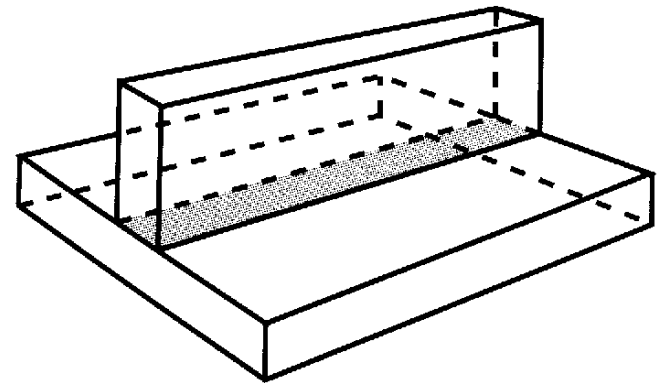
Some Different Edge Shapes and Symbols for Corner Joints



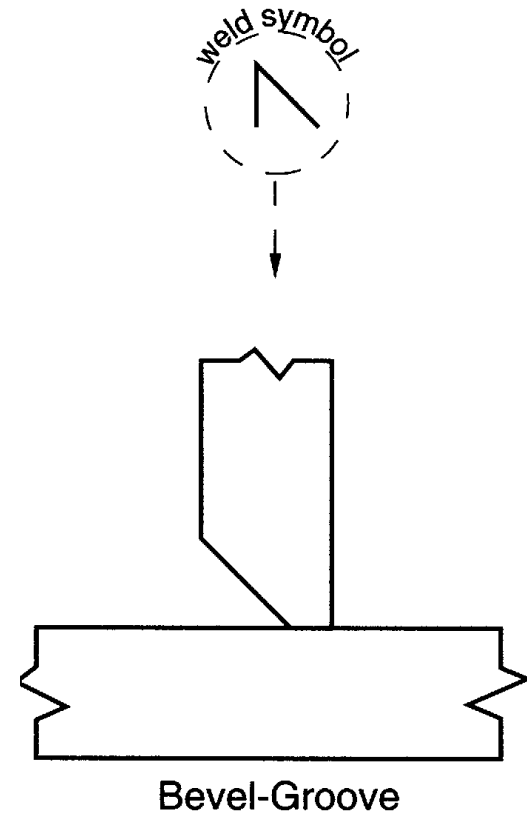
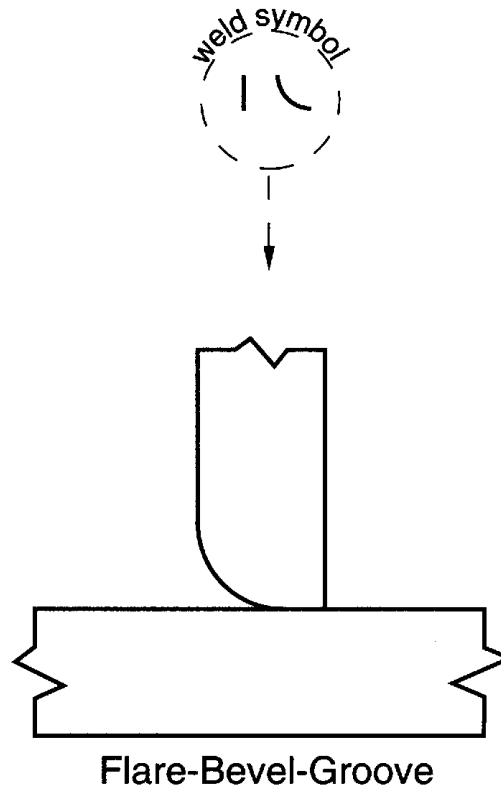
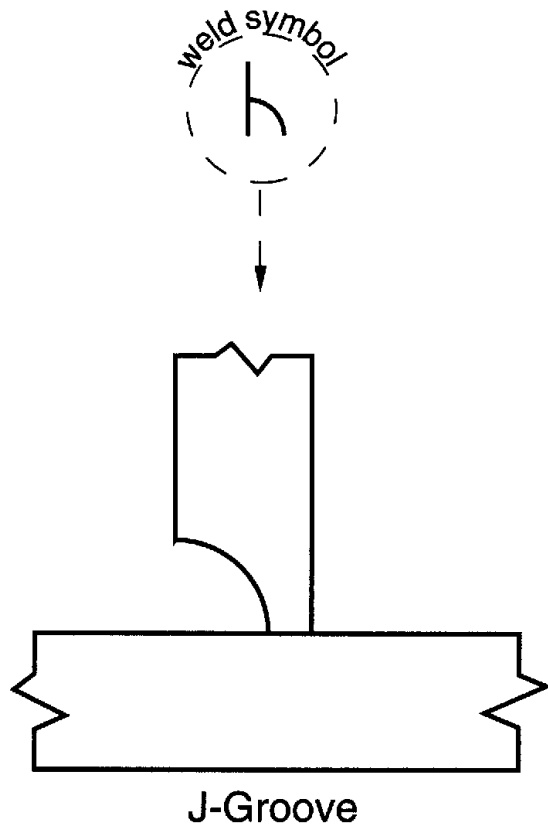
T-Joint

T-Joint

T-joint - a joint between two members located approximately at right angles to each other in the form of a T

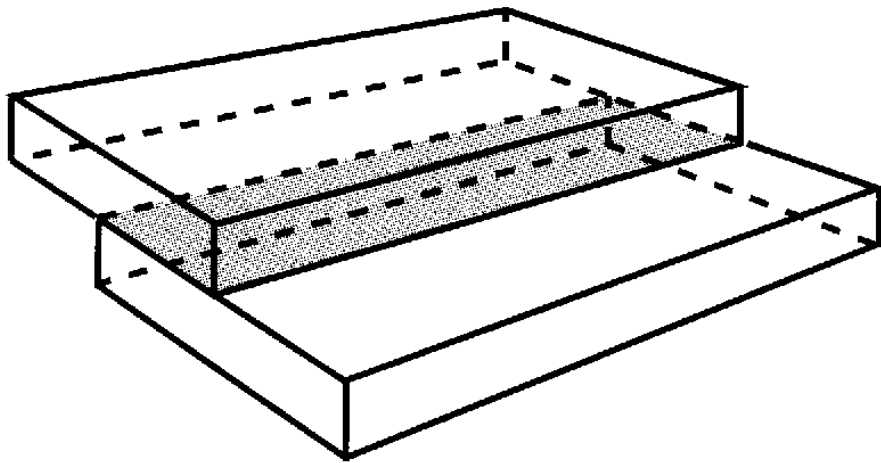


Some Different Edge Shapes and Symbols for T-Joint



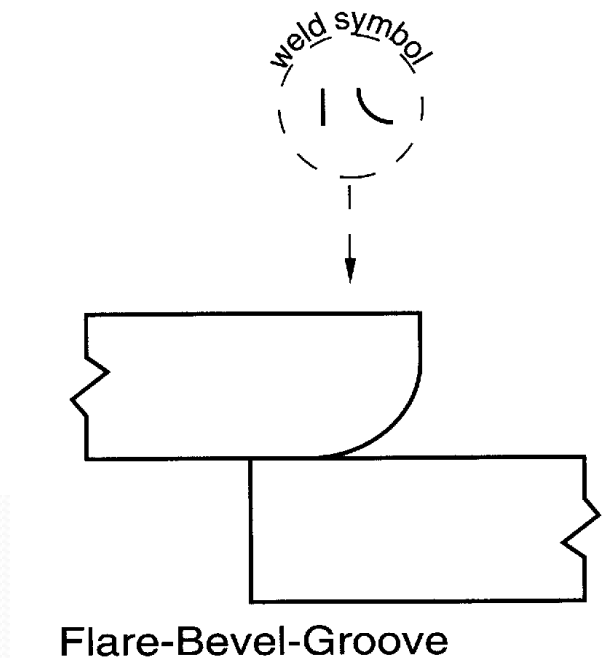
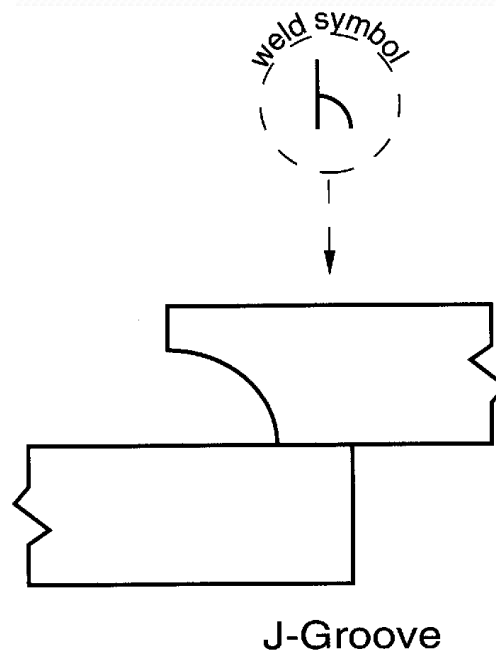
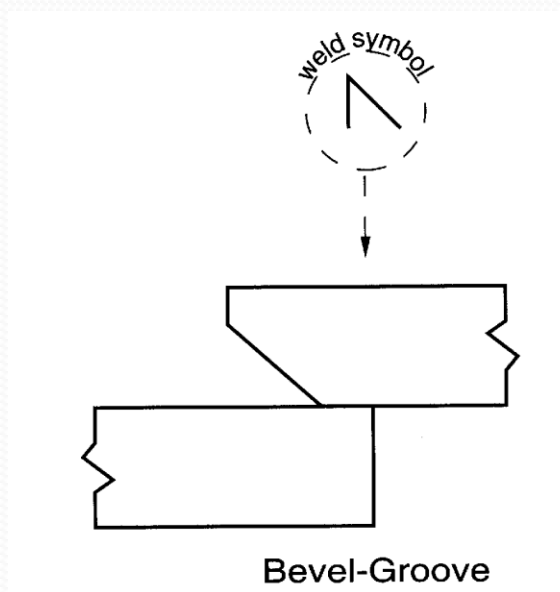
Lap Joint

Lap Joint- a joint between two overlapping members



This is one of the strongest types of joints available; however, for maximum joint efficiency, the overlap should be least three times the thickness of the thinnest member of the joint

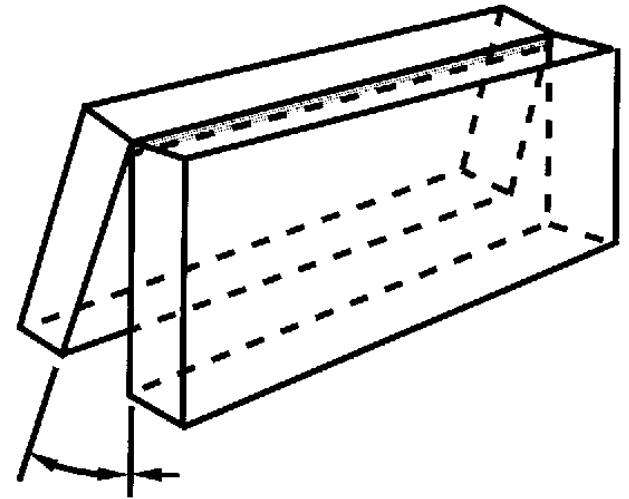
Some Different Edge Shapes and Symbols for Lap Joints



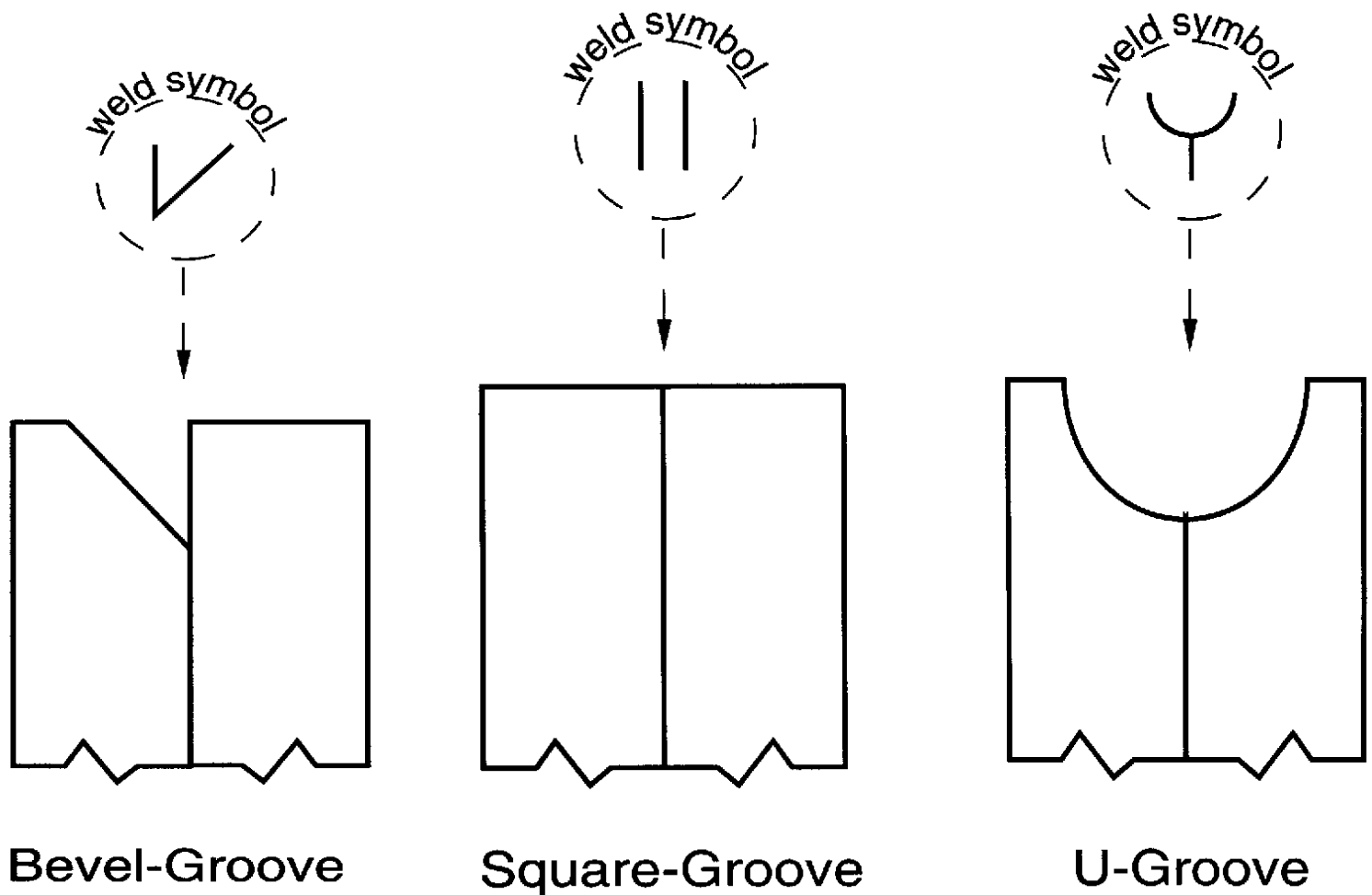
Edge Joint

Edge joint- a joint between the edges of two or more parallel or nearly parallel members

In most cases, one of the members is flanged, as seen in the figure. This type is frequently used in sheet metal work for joining metals $\frac{1}{4}$ inch or less in thickness that are not subjected to heavy loads.



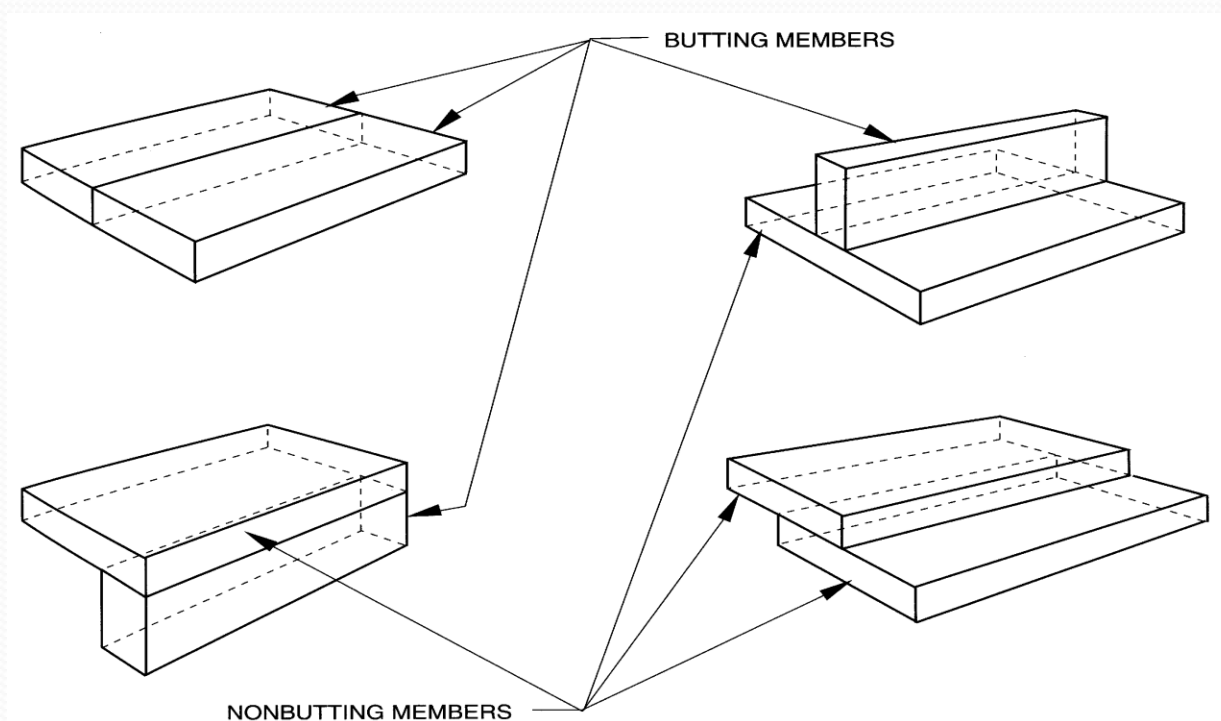
Some Different Edge Shapes and Symbols for Edge Joints



Specifications

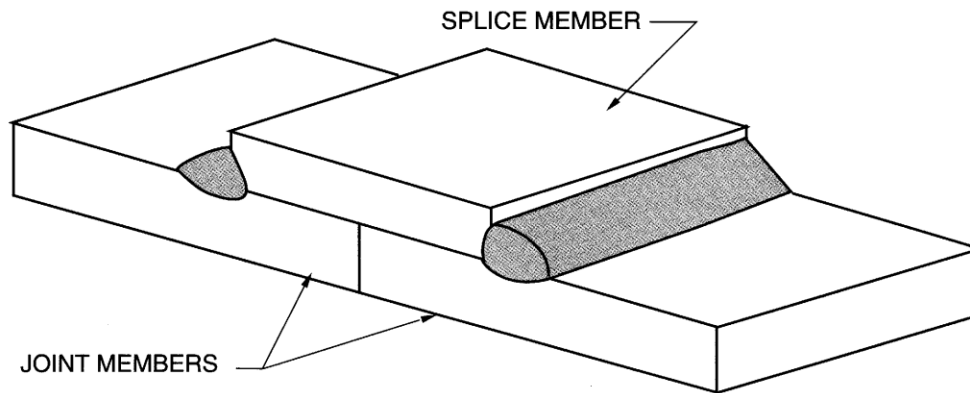
- *Joint design* identifies, “the shape , dimensions, and configuration of the joint
- The individual workpieces of a joint are called *members*
- Three types members nonbutting member, butting member , and splice member

A *butting member* is “a joint member that is prevented, by the other member from movement in one direction perpendicular to its thickness dimension”

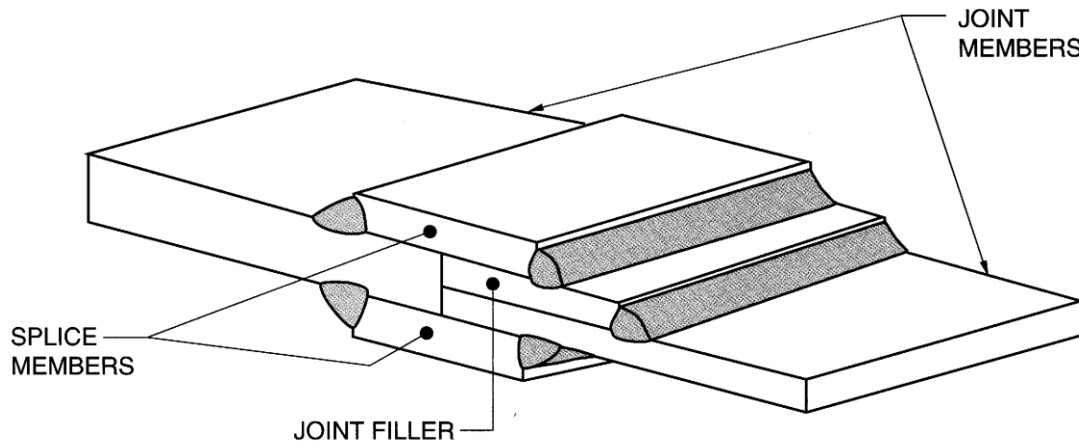


A *nonbutting member* is “a joint member that is free to move in any direction perpendicular to its thickness dimension”

A *splice member* is “the work piece that spans the joint in a spliced joint



Single-spliced
butt joint

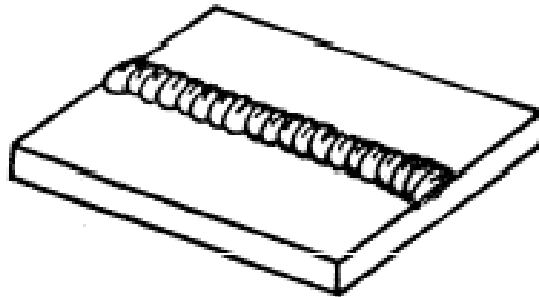


**Double-spliced
butt joint with
joint filler**

Types of Welds

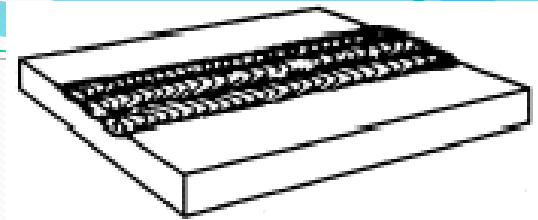
There are many types of welds. The most common types are the bead, surfacing, plug, slot, fillet, and groove.

A weld *Bead* is a weld deposit produced by a single pass with one of the welding processes. A weld bead may be either *narrow or wide, depending on the amount of* transverse oscillation (side-to-side movement) used by the welder. A weld bead made without much weaving motion is often referred to as a *stringer bead*. *On the other hand, a weld bead made with side-to-side oscillation is*



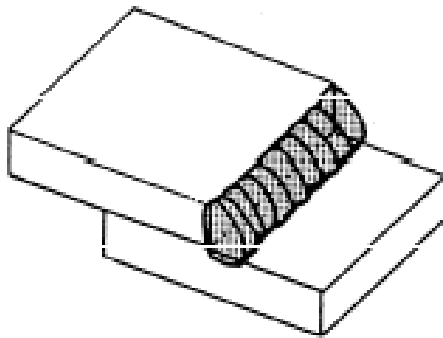
Simple weld bead.

Several weld beads applied side-by-side are usually used in *Surfacing* which is a welding process used to apply a hard, wear-resistant layer of metal to surfaces or edges of worn-out parts.

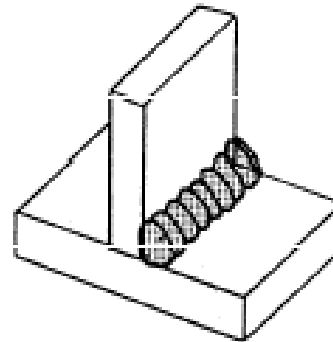


Surfacing welds.

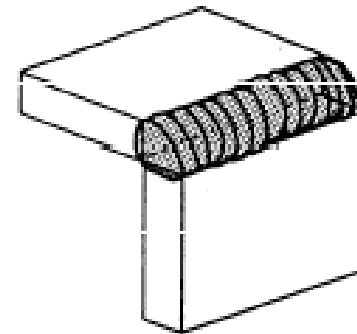
A *Fillet weld* is triangular in shape and this weld is used to join two surfaces that are at approximately right angles to each other in a lap, tee, or corner joint.



LAP FILLET

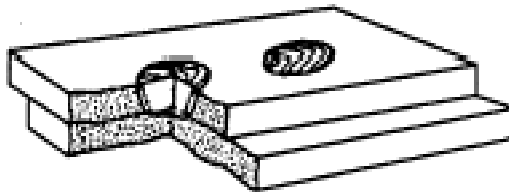


TEE FILLET

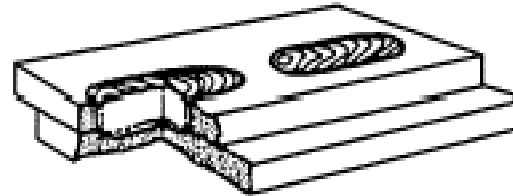


CORNER FILLET

Plug and Slot welds are welds made through holes or slots in one member of a lap joint. These welds are used to join that member to the surface of another member that has been exposed through the hole.

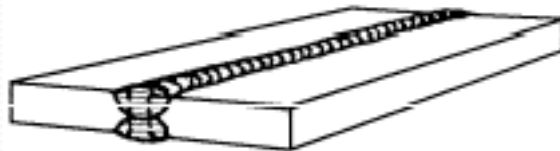


PLUG WELDS

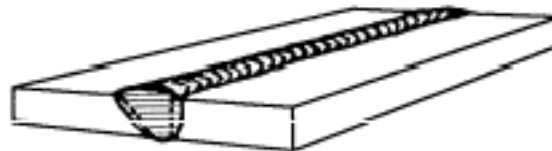


SLOT WELDS

Groove welds (also may be referred to as Butt welds) are simply welds made in the groove between two members to be joined. The weld is adaptable to a variety of butt joints, as seen in the figure



SQUARE GROOVE WELD



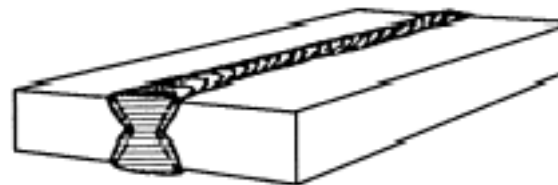
SINGLE - BEVEL GROOVE WELD



DOUBLE - BEVEL GROOVE WELD

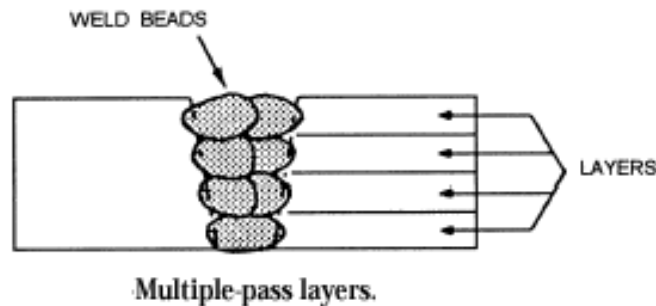


SINGLE - VEE GROOVE WELD



DOUBLE - GROOVE WELD

Groove welds may be joined with one or more weld beads, depending on the thickness of the metal. If two or more beads are deposited in the groove, the weld is made with *multiple-pass layers*, as shown in the figure. As a rule, a multiple-pass layer is made with stringer beads in manual operations.

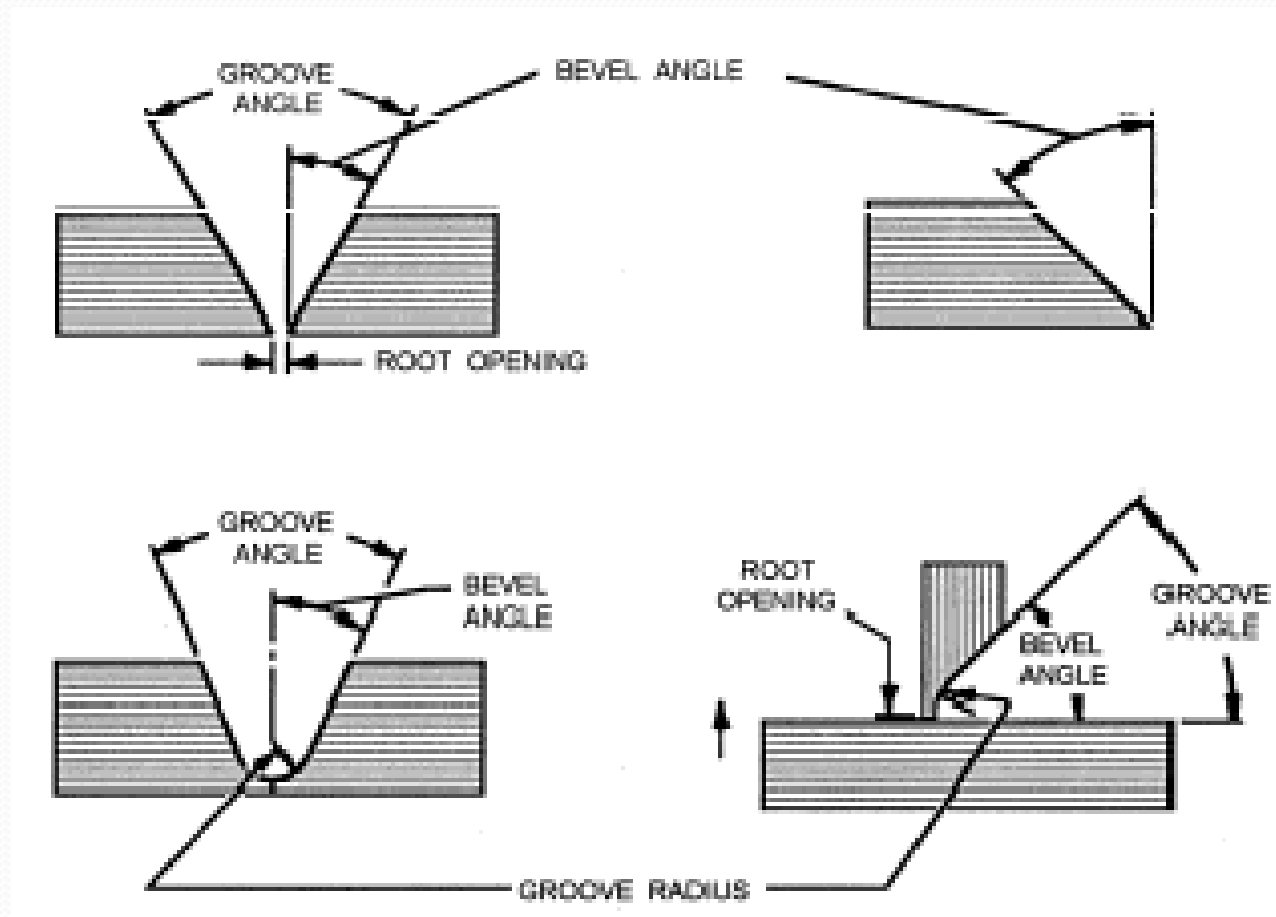


The specified requirements for a particular joint are expressed in terms such as *bevel angle*, *groove angle*, *groove radius*, and *root opening* which are illustrated in the figure.

- ❖ The *bevel angle* is the angle formed between the prepared edge of a member and a plane perpendicular to the surface of the member.
- ❖ The *groove angle* is the total angle of the groove between the parts to be joined. For example, if the edge of each of two plates were beveled to an angle of 30 degrees, the groove angle would be 60 degrees.


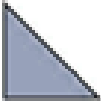



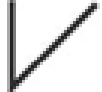
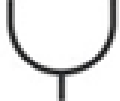

❖ The groove radius is the radius used to form the shape of a J- or U-groove weld joint. It is used only for special groove joint designs.

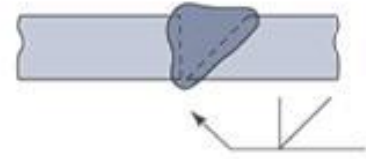
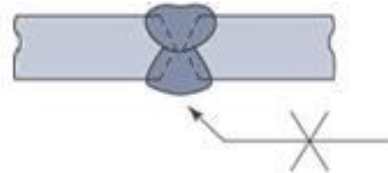
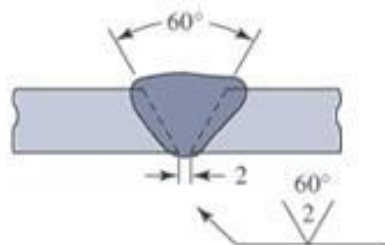
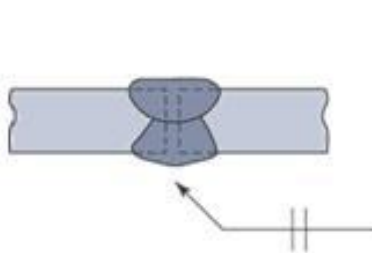
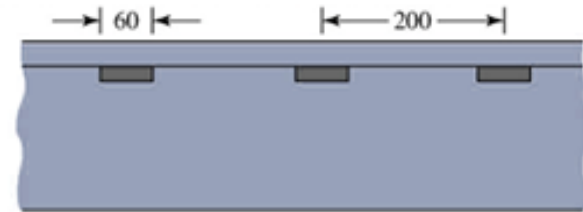
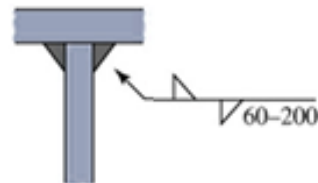
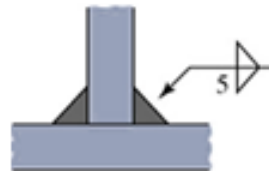
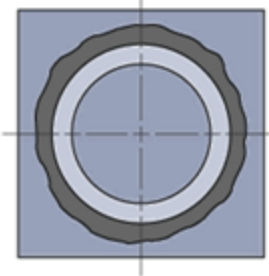
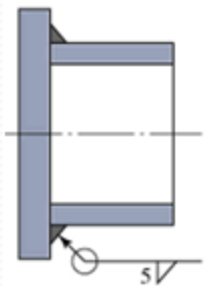
❖ The root opening refers to the separation between the parts to be joined at the root of the joint. It is sometimes called the “root gap”.



Basic weld symbol

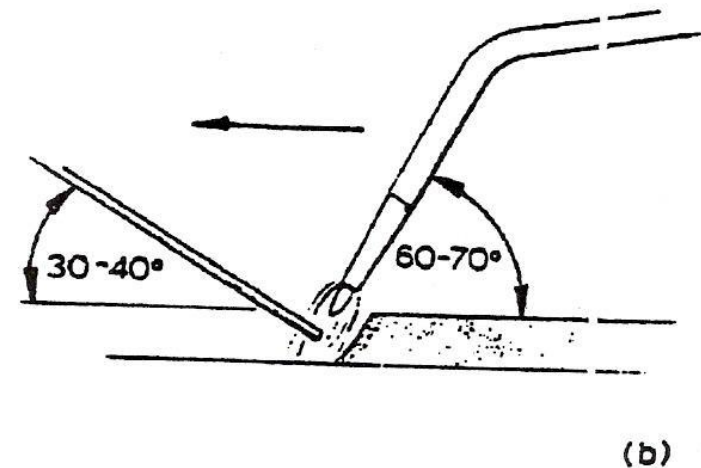
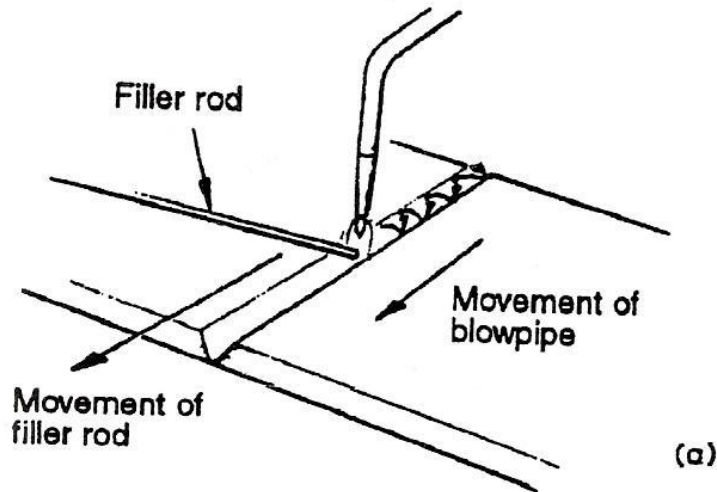
Type of weld

Bead	Fillet	Plug or slot	Groove				
			Square	V	Bevel	U	J
							



Welding Techniques

Leftward Welding



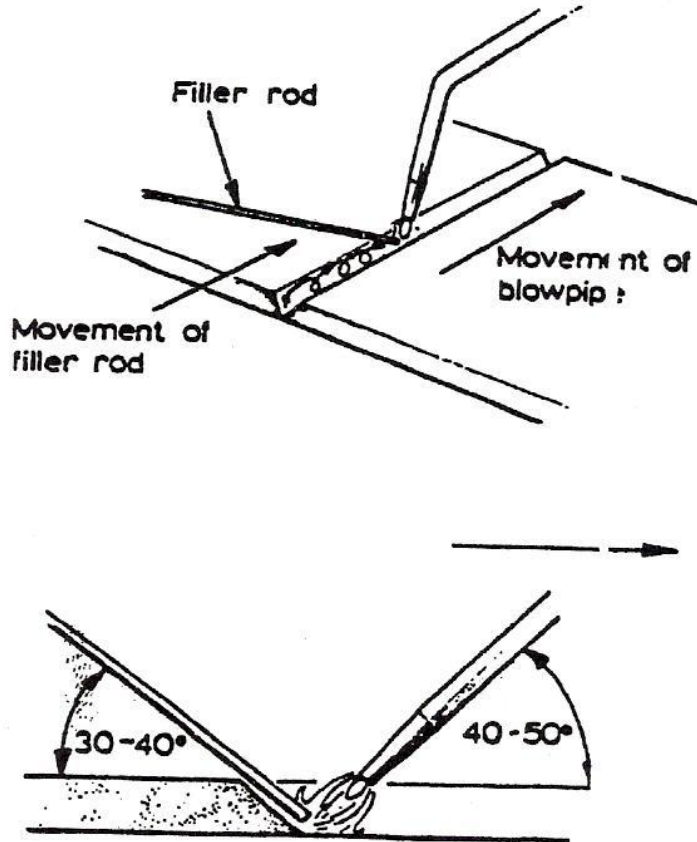
- ❖ The welder holds welding torch in his right hand and filler rod in the left hand.
- ❖ In this method of welding, the blowpipe should be grasped firmly, ensuring that the wrist is free to move.
- ❖ The welding flame is directed away from the finished weld, i.e. towards the unwelded part. Filler rod used, towards directed part of the join as shown in figure above.
- ❖ The weld is commenced on the right-hand side of the seam; working towards the left-hand side, as shown in illustration (a) below.
- ❖ The blowpipe is moved forward with the flame pointing in the direction of the welding, with the filler rod being held in front of the flame. The angles of inclination of the blowpipe and Eller rod are shown clearly in illustration (b).

- ❖ The filler rod metal is added using a backward and forward movement of the rod, allowing the flame to melt the bottom edges of the plates just ahead of the weld pool.
- ❖ It is important that the filler rod is not held continuously in contact with the weld pool, or the heat from the flame cannot reach the bottom edges of the joint.
- ❖ The weld is commenced on right hand side of the seam, working towards the left hand side.
- ❖ Since flame is pointed in the direction of the welding, it preheats the edge of the joint.
- ❖ Good control and a neat appearance are characteristics of the left ward method.
- ❖ This technique is used relatively thin metals, having thickness less than 5 mm.

Disadvantages:

- ❑ The leftward technique requires careful manipulation to guard against excessive melting of the base metal , which results in considerable mixing of base metal on the property of the weld metal and filler metal
- ❑ The leftward technique is that the view of the joint edges is interrupted and it is necessary to remove the end of the rod.

Rightward Welding



❖ In this method, the welding is commenced on the left-hand side of the seam, working towards the right-hand side, as shown in the top illustration.

❖ The blowpipe points in the direction of the welded seam and moves in a straight line along the seam. The filler rod is held at an angle of $30/40^\circ$ (see second illustration) and describes a series of loops as it is moved forward.

❖ During welding filler rod may be moved in circles or semicircles

❖ It produces less fluid and this results slightly difference appearance of the weld surface.

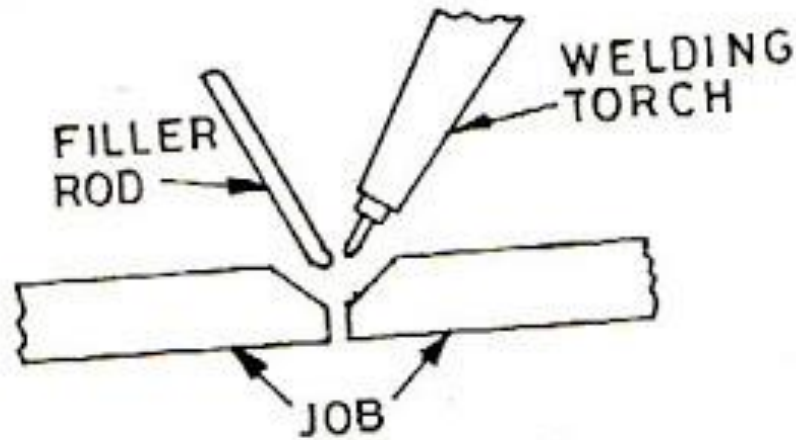
❖ This technique is used relatively thin metals, having thickness greater than 5 mm.

❖ Up to 8.2mm thickness plate has no required bevel which results low cost

Comparison between Rightward and Leftward technique

It is more common to use the rightward technique, in preference to the leftward, on mild steel plate over 3/18 in., because:

- (a) less filler rod is used;
- (b) welding speed is greater
- (c) gas consumption is less
- (d) the mechanical properties of the welds are better, due to the annealing effect of the flame being directed on to the completed weld
- (e) there is less risk of oxidation, due to the reducing flames of the oxyacetylene blowpipe.



Filler metal.

❖ It is the material that is added to the weld pool to assist in filling the gap or groove.

❖ Filler metal forms an integral part of the weld.

❖ Filler metal is usually available in rod form. These rods are called filler rods.

Filler rods have the same or nearly the same chemical composition as the base metal. Welding filler rods are available in a variety of composition and sizes. Some of them are given in the table below: (next slide)

Filler Rods

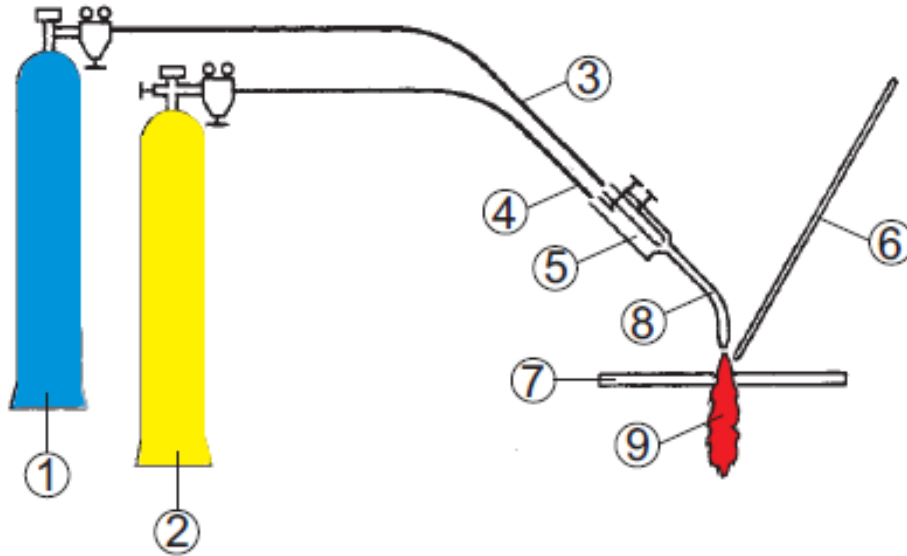
S. No.	Filler Rod	Size (mm)	Melting Point, °C	Flux Required	Applications i.e. for
1.	Copper coated Mild steel IS: 1278 Type 4.1	1.6, 3.15, 5, 6.3	1490	No	Mild steel and wrought iron welding.
2.	High carbon steel	1.6, 3.15, 5	1350	Yes	Building up and repair of cutting edges of paper and leather cutters.
3.	3% nickel steel IS: 1278 Type 4.4	1.6, 2.5, 3.15, 5	1450	Yes	Building up worn cam-shafts, shafts, gears, etc.
4.	Wear resisting alloy steel BS: 1453 A5	5, 6.3	1320	No	Building up worn crossings and rail ends on railway or tramway tracks, crushing tools, etc.
5.	Pipe welding rods IS: 1278 Type 4.2	2.5, 3.15, 5	1450	No	Welding steel pipe.
6.	Stainless steel Decay Resistant IS: 1278 Type 4.6	1.6, 2.5, 3.15, 5, 6.3	1440	Yes	Welding austenitic stainless steel tubes, sheets, tanks, etc.
7.	Super-silicon cast iron IS: 1278 Type 5.1 (Square)	5, 6.3, 8, 10	1147	Yes	Welding high grade castings where subsequent machining is necessary such as lathe beds, cylinder blocks, etc.
8.	Copper-silver alloy IS: 1278 Type 6.1	1.6, 3.15, 5, 6.3	1068	Yes	Welding copper fire boxes and electrical work.
9.	Nickel bronze IS: 1278 Type 6.4	3.15, 5, 6.3	910	Yes	Braze-welding steel or malleable iron. Building up worn surfaces and welding Cu-Zn-Ni alloys of similar composition.
10.	Aluminium alloy 5% copper	1.6, 3.15, 5, 6.3 (Square)	640	Yes	Welding aluminium castings.
11.	Aluminium alloys 5% silicon IS: 1278	1.6, 3.15, 5, 6.3	635	Yes	Welding pure aluminium sheet, tube and extruded sections and aluminium alloy castings not containing zinc.

Fluxes:

- ❖ A flux is a material used to prevent, dissolve or facilitate removal of oxides and other undesirable substances.
 - ❖ A flux prevents the oxidation of molten metal. Flux may be used either by applying it directly on the surface of the base metal to be welded or by dipping the heated end of the filler rod in it.
 - ❖ The flux sticks to the filler rod end. No flux is used in the gas welding of steel.
-
- **Flux for welding cast iron:** Fluxes for gray iron rods usually composed of borates or boric acid, soda ash and small amounts of sodium chloride, etc.
 - **Flux for welding stainless steel:** Flux may contain compounds such as borax, boric acid, fluorspar, etc.
 - **Flux for welding aluminium and its alloys:** The flux may be applied on the base metal by brushing and on the filler rod end by dipping the same into the flux paste just before welding. Fluxes employed for welding aluminium and its alloys are compounds of lithium, sodium and potassium and are obtainable in either paste or powder form

- **Flux for welding copper and its alloys:** Flux is not necessary for gas welding of pure copper, however for copper alloys, borax based fluxes may be used.
- **Flux for welding magnesium and its alloys:** Flux must be applied to all edges to be welded and to the welding rod when welding magnesium and its alloys. A flux may contain sodium chloride, potassium fluoride, magnesium chloride, barium fluoride.
- **Fluxes for welding nickel and its alloys:** Gas welding of pure nickel requires no flux. However alloys of nickel such as inconel and monel require a flux to further clean the base metal and to break up the oxides that are formed as a result of the alloying agents. Flux for inconel may contain Ca(OH)_2 , boric anhydride.

Gas Welding Equipment:



- ① oxygen cylinder with pressure reducer
- ② acetylene cylinder with pressure reducer
- ③ oxygen hose
- ④ acetylene hose
- ⑤ welding torch
- ⑥ welding rod
- ⑦ workpiece
- ⑧ welding nozzle
- ⑨ welding flame

Advantages of Gas

Welding:

- ❖ Versatility - readily applied to a variety of applications and a wide choice of electrodes
- ❖ Relative simplicity and portability of equipment
- ❖ Good control over the temperature of the metal in the weld zone.
- ❖ The rate of heating and cooling relatively slow.
- ❖ Adaptable to confined spaces and remote locations
- ❖ Suitable for out-of-position welding
- ❖ The cost and maintenance of the welding equipment is low as compared to that other welding processes.

Disadvantages of Gas Welding:

- ❖ Heavy sections cannot be joined economically
- ❖ Flame temperature is less than the temperature of the arc
- ❖ Health hazardous: fumes causes irritating eyes, nose and throats and lungs
- ❖ Refractory metal (e.g. W, Mo, Ta etc) and reactive metals (e.g. Ti and Zr) cannot be welded
- ❖ Time taking process
- ❖ Prolonged heating of joint results larger heat-affected area.
- ❖ Safety problem for handling and storing of the equipments
- ❖ Acetylene and oxygen gases are expensive

Applications of Gas Welding:

- ☐ Joining of thin materials
- ☐ Useful for high temperature or rapid heating and cooling of welded joints
- ☐ For joining of ferrous and non-ferrous metals- e.g. carbon steel, alloy steel, cast iron, Al, Cu, Ni, Mg and its alloys etc.
- ☐ Automotive and aircraft industries

Weldability

- Weldability is the ease of a material or a combination of materials to be welded under fabrication conditions into a specific, suitably designed structure, and to perform satisfactorily in the intended service
- Common Arc Welding Processes



Common Arc Welding Processes

1. Carbon –Arc Welding
2. Shielded Metal Arc Welding (SMAW)
3. Submerged - Arc Welding (SAW)
4. Gas Tungsten Arc Welding (GTAW) or, TIG
5. Gas Metal Arc Welding (GMAW) or MIGWelding
6. Electroslag Welding
7. Electrogas Welding
8. Plasma –Arc Welding
9. Arc Spot Welding
10. Stud (Arc) Welding

Common Arc Welding Processes

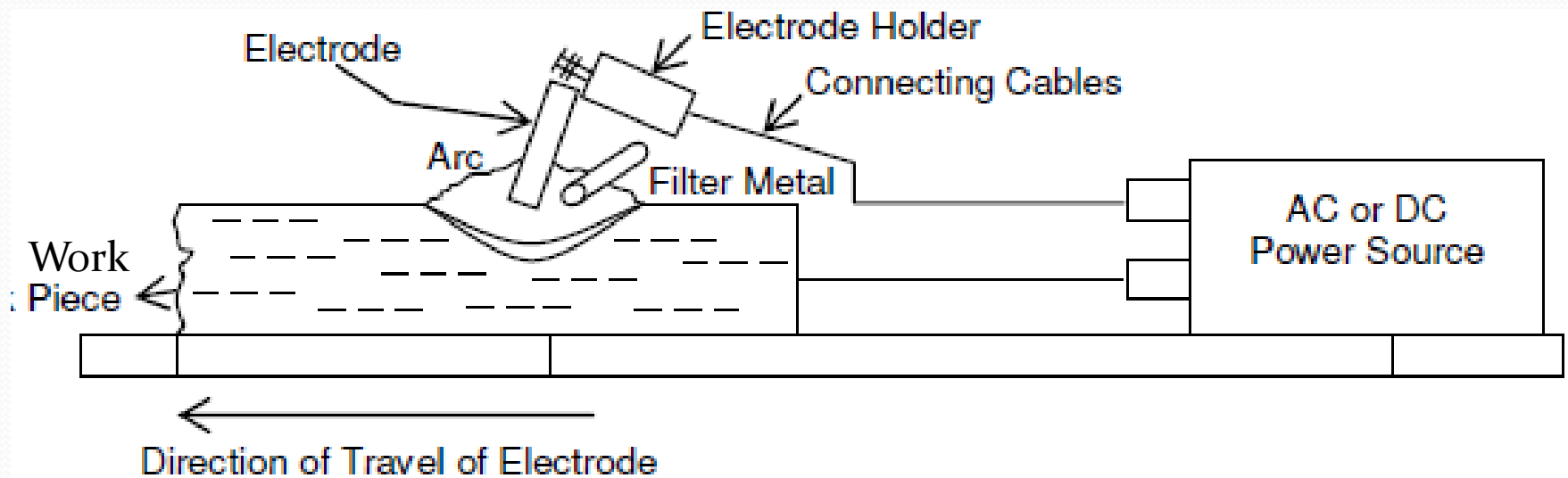


Figure 2: Process of Arc Welding

Difference Between AC and DC arc Welding

	A.C. arc welding	D.C. arc welding
1.	The A.C. welding transformer has no moving parts and is simpler.	The D.C. welding generator has rotating parts and is more complicated.
2.	The transfer costs less and its maintenance cost is low.	The generator costs more and its maintenance cost is high.
3.	Since the distribution of heat is equal therefore there is no need for changing the polarity. Hence only ferrous metals are usually welded by A.C.	Heat distribution in two poles i.e. two two-third in positive and one-third in negative. By changing the polarity all types of metals can be welded by D.C.
4.	All types of electrodes cannot be used in A.C. arc welding because the current constantly reverses with every cycle. Only coated electrodes can be used.	All types of electrodes, bare or coated can be used in D.C. arc welding because the polarity can be changed to suit the electrode.
5.	The problem of 'arc blow' does not arise as it is very to control.	In D.C. the 'arc blow' is servere and cannot be controlled easily.
6.	The arc is never stable.	The arc is more stable.
7.	It can be used only when A.C. supply from the mains is available.	In the absence of A.C. mains supply, an engine driven D.C. generator set can be used.
8.	A.C. is more dangerous.	D.C. is comparatively less dangerous.

A.C. Welding

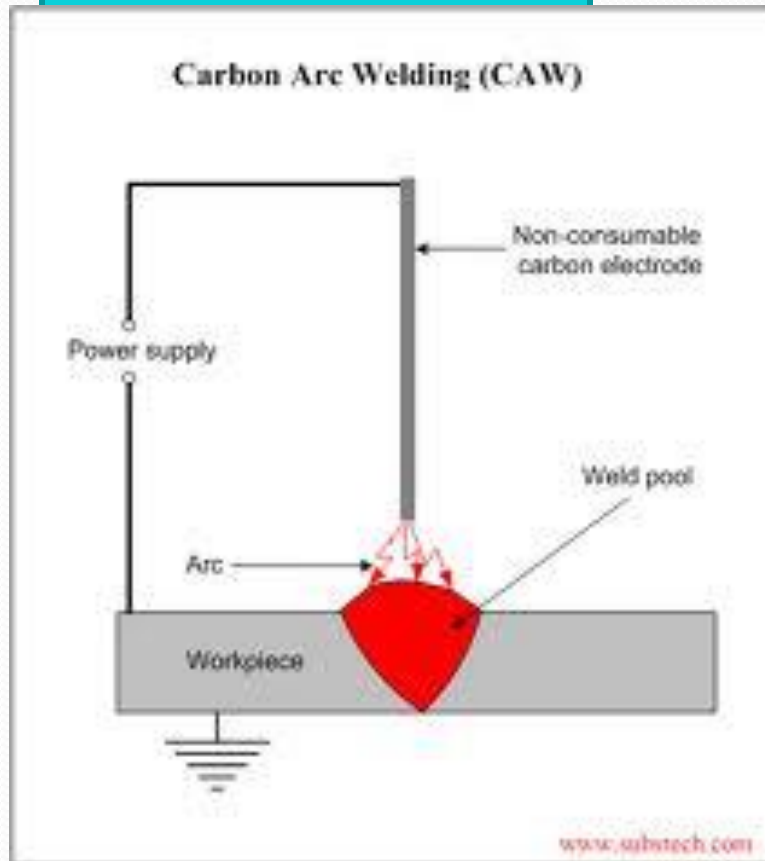
1. At higher currents AC gives a smoother arc.
2. Once established the arc can be easily maintained and controlled.
3. It is suitable for welding thicker sections.
4. AC is easily available.
5. AC welding power source has no rotating parts.
6. It does not produce noise.
7. It occupies less space
8. It is less costly to purchase and maintain.
9. It possesses high efficiency (0.8).
10. It consumes less energy per unit weight of deposited metal.
11. Melting rate of electrode cannot be controlled in AC as equal heat generates at electrode and job.
12. An AC welding power source is *Transformer*

D.C. Welding

1. DC arc is more stable.
2. DC is preferred for welding certain non-ferrous metals and alloys.
3. It has lower open circuit voltage and therefore is safer.
4. ARC heat can be regulated (i.e., through DCRP and DCSP)
5. A DC welding equipment is a self contained unit. It can be operated in fields where power supply is not available
6. DC welding power source is a transformer-rectifier unit or a DC generator (motor or engine driven)

Carbon Arc Welding Processes

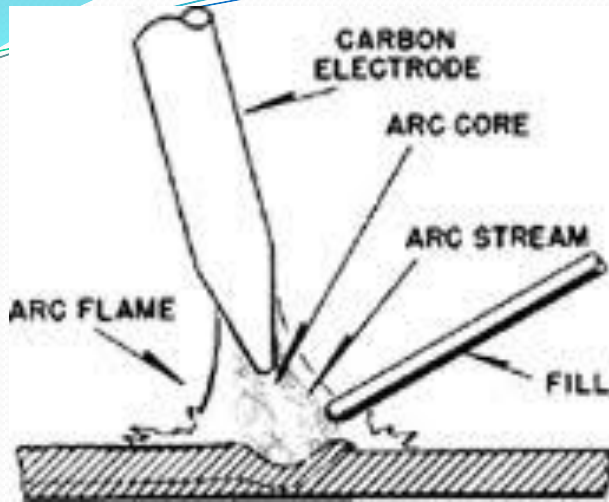
Single Carbon Arc Welding



Twin Carbon Arc Welding

Carbon **arc welding** (CAW) is a process which produces coalescence of metals by heating them with an arc between a non-consumable **carbon** (**graphite**) **electrode** and the work-piece

Single Carbon Arc Welding

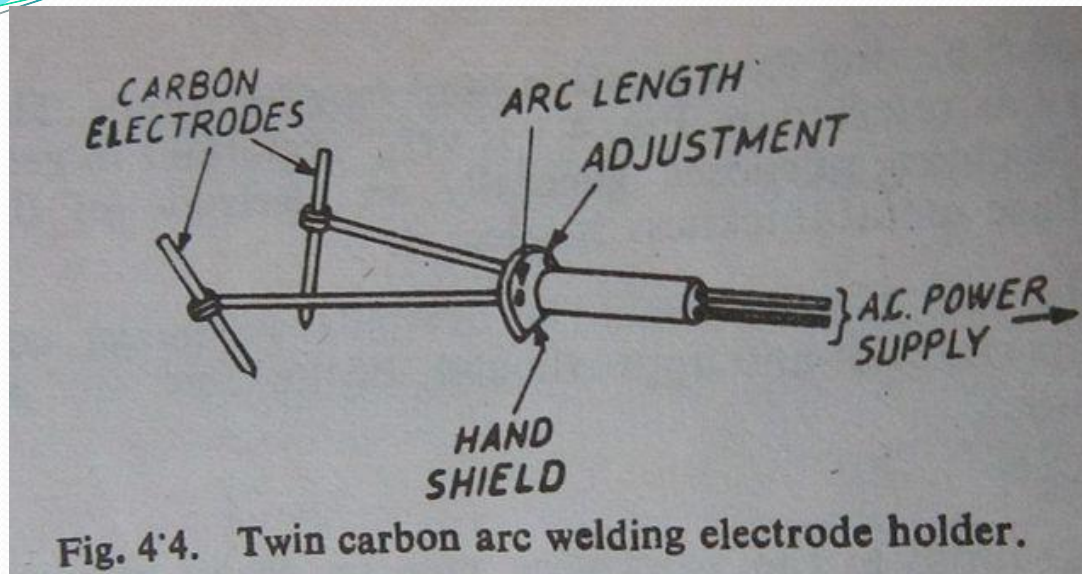


The electrodes that are used in carbon arc welding consisted of baked carbon or pure graphite which was placed inside a copper jacket

D -1.5-15mm, d (Tip of electrode)-0.5-2.0mm,
 α -20-90° L-300mm,l-20mm

- ❖ **The technique of single-carbon arc welding uses a direct current power supply which is connected using a straight polarity.**
- ❖ **The arc is struck by touching the electrode with the job momentarily and then taking away the electrode a definite distance (approx. -15mm) apart.**
- ❖ **The arc is allowed to impinge on the surface to be welded till a molten pool forms and then the holder is moved along the joint as like gas welding process.**
- ❖ **Filler and flux may or may not be used, depending upon the type of joint and materials.**

Twin Carbon Arc Welding



AC supply is recommended for twin carbon arc welding. Because alternative reversal polarity, both the electrode will be affected equally and produce stable arc.

Advantages of Carbon Arc Welding:

- ❖ Heat input to the work piece can be easily controlled by changing the arc length
- ❖ Low cost of equipment and welding operation
- ❖ High level of operator skill is not required
- ❖ The process is easily automated
- ❖ Low distortion of work piece
- ❖ The process is very suitable for butt welding of thinner work-pieces (1-2 mm thickness)

Disadvantages of Carbon Arc

Welding:

- ❖ Unstable quality of the weld (porosity);
- ❖ Carbon of electrode contaminates weld material with carbides.
- ❖ There is a chance of carbon being transferred from electrode to weld metal, thus causing harder weld deposit in case of ferrous materials.

❖ A carbon arc can be used to heat up the work piece and to preheat the work piece before the welding

Applications of Carbon Arc

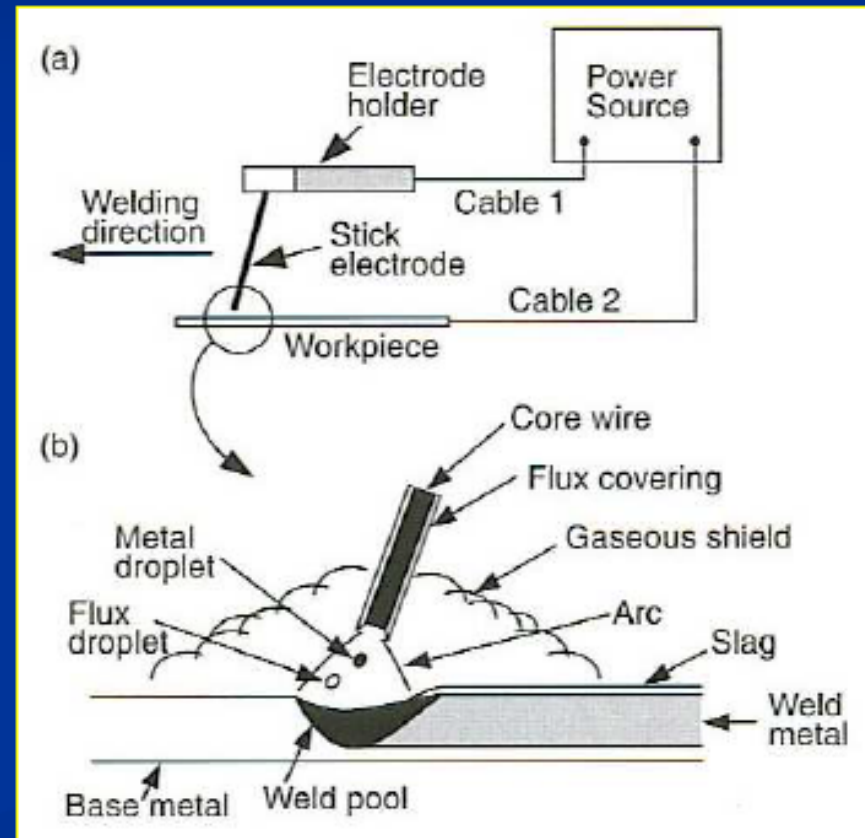
Welding:

- ❖ It is used for welding of steel, aluminum, nickel, copper and a good number of other alloys
- ❖ It can also be used for brazing, preheating and post heat of the weld joints
- ❖ It can be used for repairing castings.

Shield metal arc welding

Shield metal arc welding (**SMAW**) is a process that melts and joins metals by heating them with an arc established between a **sticklike covered electrode** and the **metals**.

- The **core wire** conducts the **electric current** to the arc and provides **filler metal** for the joint.
- The **electrode holder** is essentially a metal clamp with an electrically insulated outside shell for the welder to hold safely.
- The heat of the arc melts the core wire and the flux covering at the electrode tip into **metal droplets**.
- Molten metal in the weld pool solidifies into the **weld metal** while the lighter molten flux floats on the top surface and solidifies as a **slag layer**.



Shielding gas

Mixture of H_2 , CO , H_2O and CO_2

Shield metal arc welding

Functions of electrode (flux) covering

Protection Provide the gaseous shield to protect the molten metal from air.

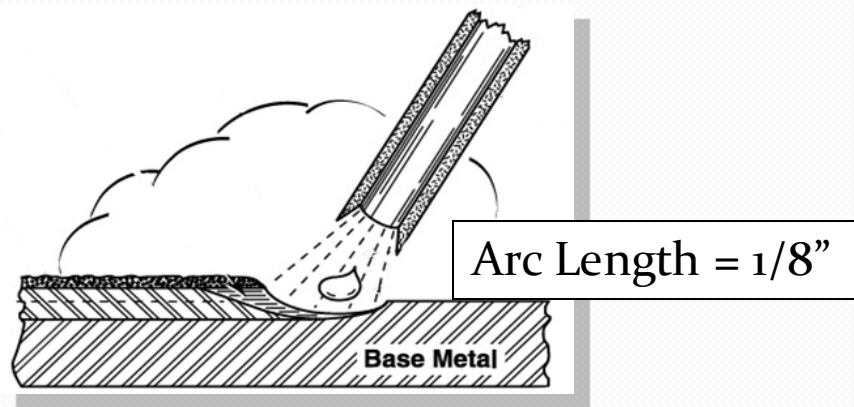
- Cellulose-type electrode $(C_6H_{10}O_5)_x$, providing gas mixture of H_2 , CO , H_2O and CO_2 .
- Limestone-type electrode $(CaCO_3)$ – low in hydrogen and it is used for welding metals that are susceptible to hydrogen cracking such as high-strength steels.

Deoxidation Provide deoxidizers and fluxing agent to deoxidize and cleanse the weld metal. The solid slag also protects the weld metal from oxidation.

Arc stabilization Provide arc stabilizers which are compounds such as potassium oxalate and lithium carbonate. They readily decompose into ions in an arc, which increase electrical conductivity.

Metal addition Provide alloying elements (for composition control) and metal powder (increase deposition rate) to the weld pool.

- After striking the arc, maintain a $1/8$ " distance between the electrode and the workpiece
 - If the arc length becomes too short, the electrode will get stuck to the workpiece or 'short out'
 - If the arc length becomes too long; spatter, undercut, and porosity can occur



Advantages of SMAW

- Low initial cost
- Portable
- Easy to use outdoors
- All position capabilities
- Easy to change between many base materials



What safety precautions should be taken by these welders?

Limitations of SMAW

- Lower consumable efficiency
- Difficult to weld very thin materials
- Frequent restarts
- Lower operating factor
- Higher operator skill required for SMAW than some other processes

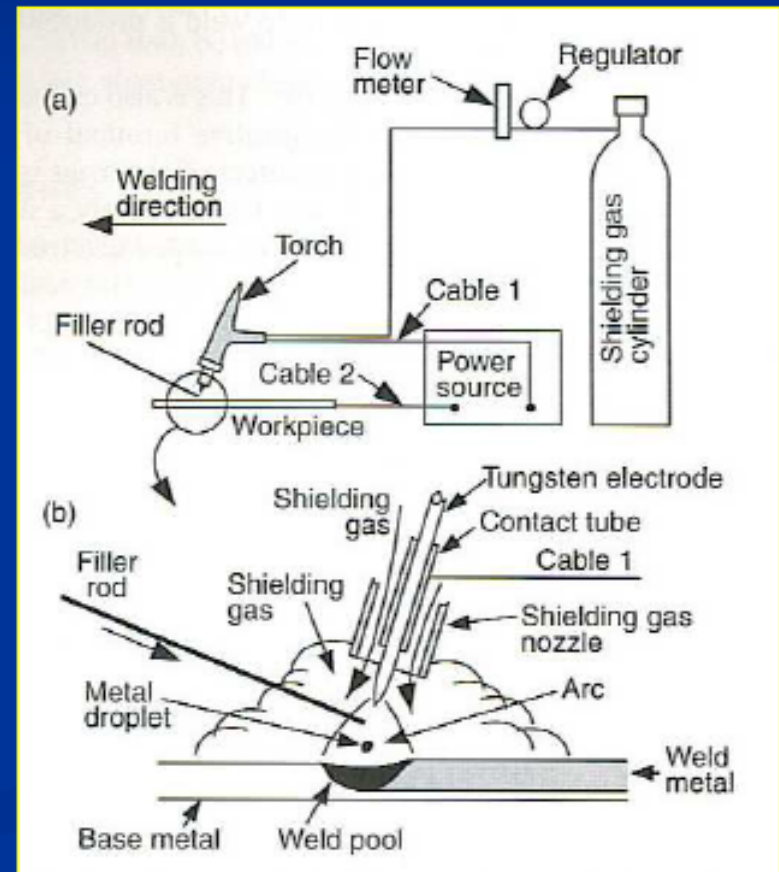


Building a barge in a large shipyard

Gas-tungsten arc welding

Gas-tungsten arc welding (**GTAW**) is a process that melts and joins metals by heating them with an arc established between a **nonconsumable tungsten electrode** and the **metals**.

- The **tungsten electrode** is normally contacted with a water cooled copper tube, which is connected to the welding cable. → prevent **overheating**.
- The **shielding gas** (**Ar, He**) goes through the torch body and nozzle toward the weld pool to protect it from air.
- **Filler metal** (for joining of thicker materials) can be fed manually or automatically to the arc.
- Also called **tungsten inert gas (TIG)** welding.



Gas tungsten arc welding

Electrodes and shielding gases

Electrodes

Tungsten electrodes with 2% cerium or thorium give better electron emissivity, current-carrying capacity, and resistance to contamination than pure electrodes. → the arc is more stable.

Shielding gases

TABLE 1.2 Properties of Shielding Gases Used for Welding

Gas	Chemical Symbol	Molecular Weight (g/mol)	Specific Gravity with Respect to Air at 1 atm and 0°C	Density (g/L)	Ionization Potential (eV)
Argon	Ar	39.95	1.38	1.784	15.7
Carbon dioxide	CO ₂	44.01	1.53	1.978	14.4
Helium	He	4.00	0.1368	0.178	24.5
Hydrogen	H ₂	2.016	0.0695	0.090	13.5
Nitrogen	N ₂	28.01	0.967	1.25	14.5
Oxygen	O ₂	32.00	1.105	1.43	13.2

Source: Reprinted from Lytle (6).

Ar is heavier and offers more effective shielding and cheaper than He.

Advantages of GTAW

- Suitable for joining thin section due to its limited heat inputs.
- Can weld metals without fillers (autogenous welding).
- Very clean welding process, which can be used for welding reactive metals such as titanium, zirconium, aluminium and magnesium.

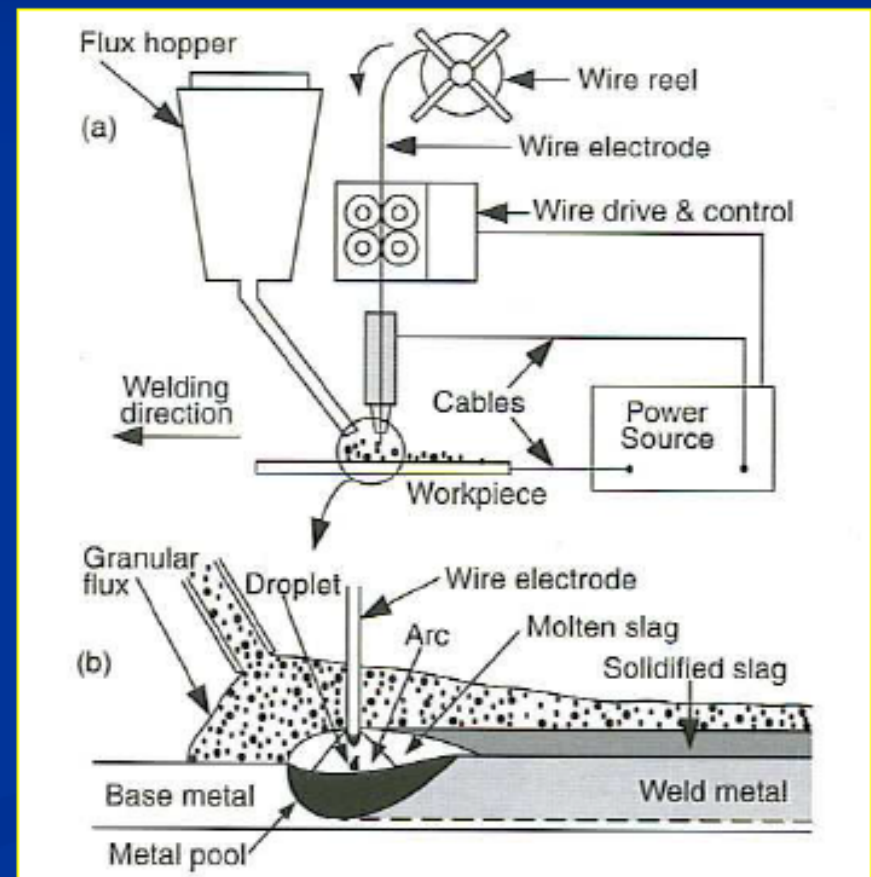
Disadvantages of GTAW

- Deposition rate is low.
- Excessive welding current causes melting of the tungsten electrode and results in brittle tungsten in the weld pool.
- Multiple passes
- Low welding speed

Submerged arc welding

Submerged arc welding (SAW) is a process that melts and joins metals by heating them with an arc established between a **consumable wire electrode** and the **metals**, with the arc being shielded by a **molten slag** and **granular flux**.

- The arc is **submerged** and invisible.
- The **flux** is supplied from a hopper, which travel with the torch.
- The **shielding gas** may not be required because the molten metal is separated from the air by the **molten slag** and **granular flux**.



Submerged arc welding

Advantages and disadvantages

Advantages

- Clean welds are obtained due to protecting and refining action of the slag.
- At high welding current, spatter and heat loss are eliminated because the arc is submerged.
- Alloying elements and metal powders can be added to the granular flux to control the composition and increase the deposition rate respectively.
- The deposition rate can be increased by using two or more electrodes in tandem.
- Can weld thick section.

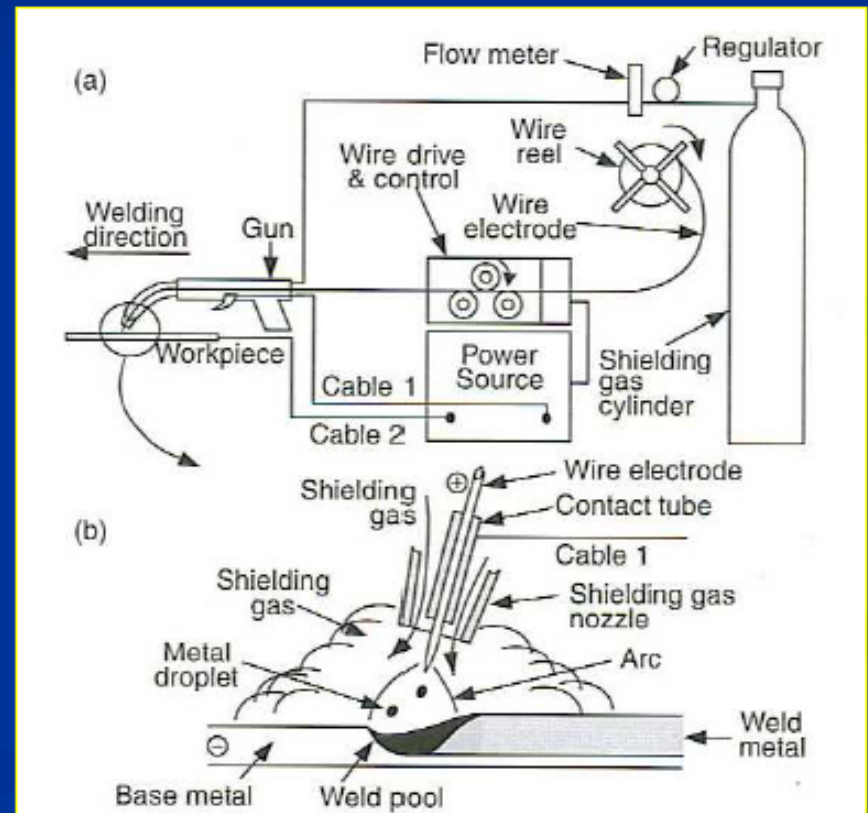
Disadvantages

- Cannot weld in a flat-position and circumferential (pipe).
- High heat input can reduce the weld quality and increase distortions.

Gas-metal arc welding

Gas metal arc welding (GMAW) is a process that melts and joins metals by heating them with an arc established between a continuously fed filler wire electrode and the metals.

- **Ar** and **He** are also used as **inert shielding gases** to protect the molten weld pool. → often called metal inert gas (**MIG**). However, non-inert gases, i.e., **CO₂** are also used for carbon and low alloy steels.
- **Ar**, **He** or Mixtures of (25%)**Ar**, (75%)**He** are used for non-ferrous (mostly **Al**) as well as stainless and alloy steels.
- The **Ar arc plasma** is stable and beneficial for transferring **metal droplets** through the arc plasma.



Gas metal arc welding

Modes of metal transfer

The molten metal at the electrode tip can be transferred to the weld pool by

1. Globular transfer

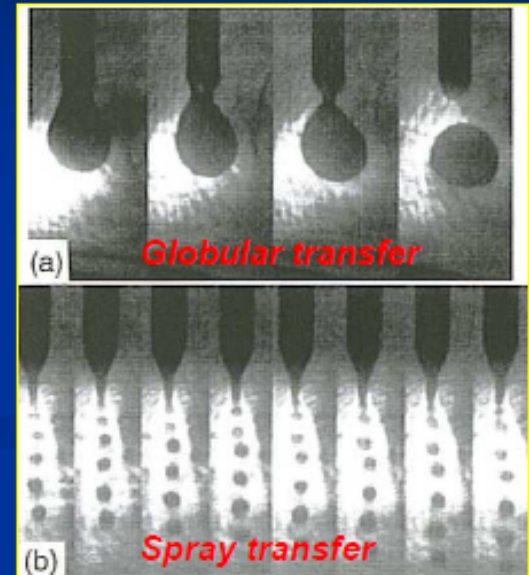
- Metal droplets travel across the arc gap under the influence of **gravity**.
- Often not smooth and cause **spatter**.
- **Low welding current** (180A).

2. Spray transfer

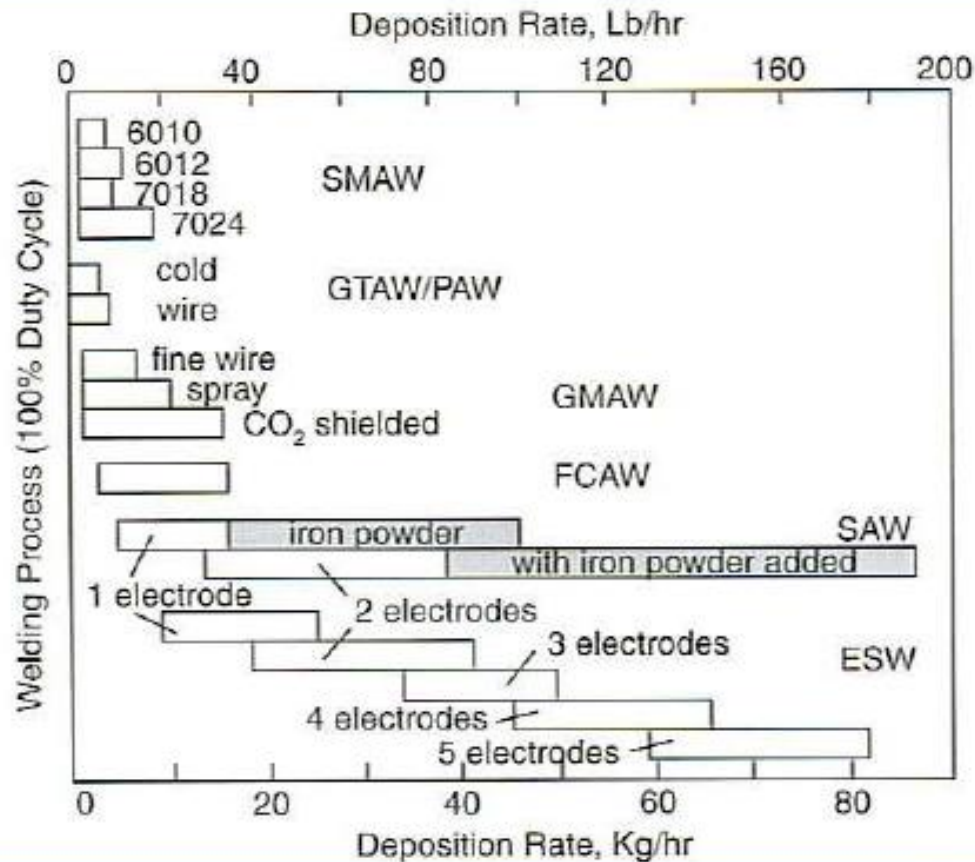
- Occur above a critical current level (280-320A).
- Small metal droplets travel across the gap under the influence of the **electromagnetic force** at much higher frequency and speed than in the globular mode.
- More **stable** and **spatter free**.

3. Short-circuit transfer

- Molten metal droplets are transferred from electrode tip to the weld pool when it touches the pool surface (**short-circuit**).
- Require **very low current** and electrode diameter, giving **small and fast-freezing weld pool** desirable for welding thin section or out of position welding.



Comparison of deposition rate in different arc welding processes



Thermit Welding

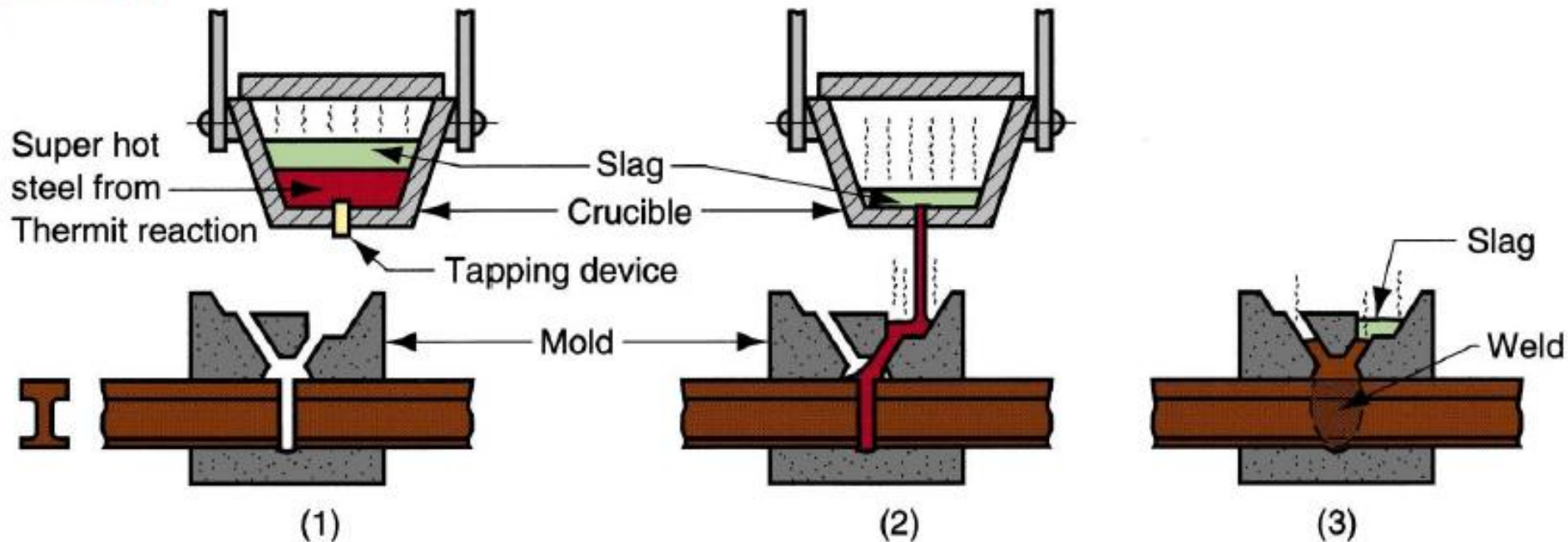


Figure 31.25 Thermit welding: (1) Thermit ignited; (2) crucible tapped, superheated metal flows into mold; (3) metal solidifies to produce weld joint.



TW Applications

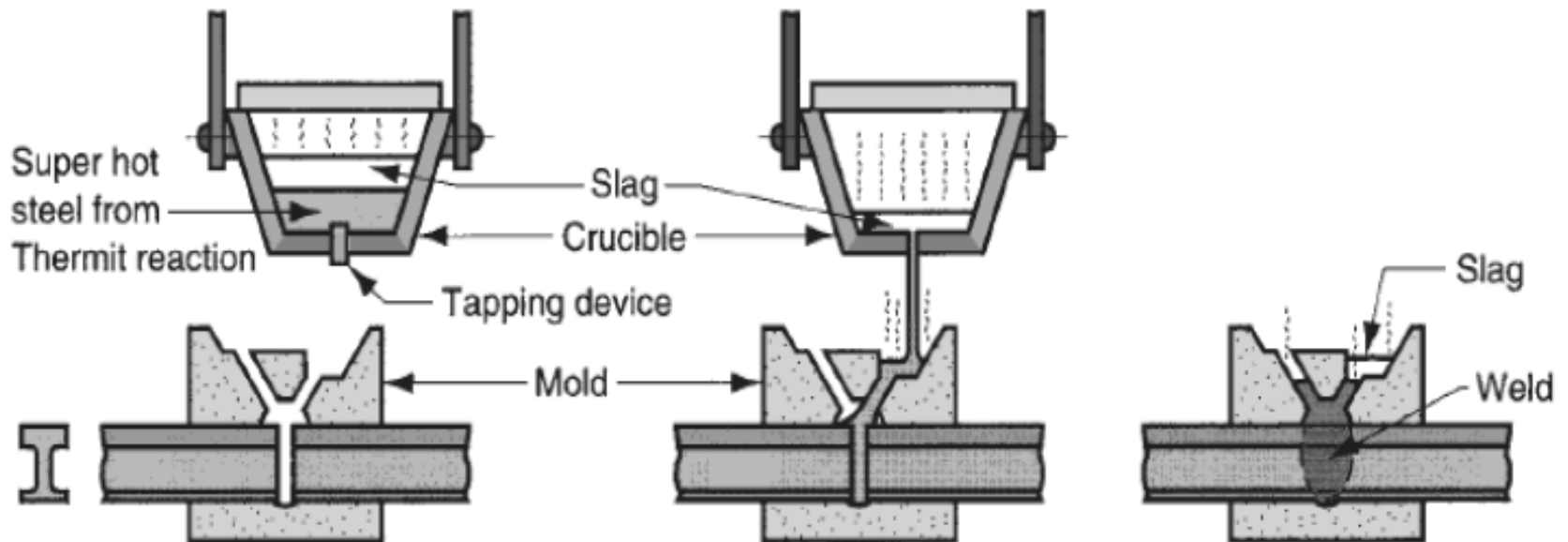
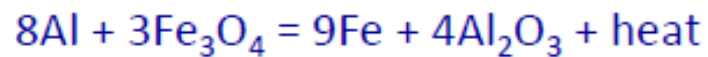
- Joining of railroad rails
- Repair of cracks in large steel castings and forgings
- Weld surface is often smooth enough that no finishing is required

Thermit welding

Thermit (thermit): a mixture of aluminum powder and iron oxide that produces an exothermic reaction when ignited.

In thermit welding, the heat for coalescence/joining is produced by superheated molten metal formed from the chemical reaction of thermit.

The following chemical reaction is seen when a thermit mixture is ignited at 1300°C. The temperature of the reaction is 2500°C.



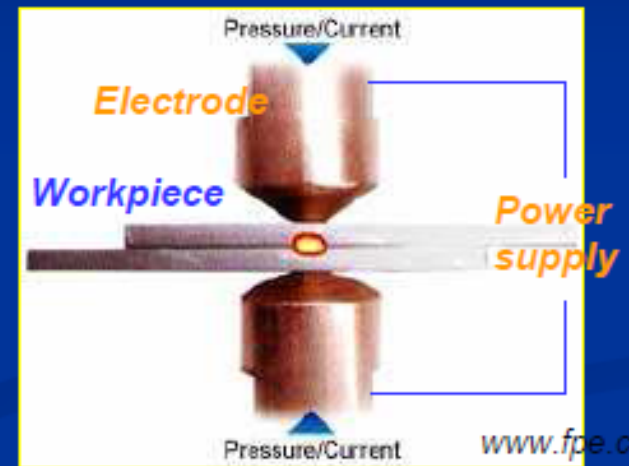
- At this temperature, superheated molten iron plus aluminum oxide is made that floats on the top as a slag and protects the iron from the atmosphere.
- **Applications of TW:**
- Joining of railway lines, repair of cracks in large steel castings and forgings like ingot molds, large diameter shafts, frames for machinery etc.
- This process can be used to weld heavy parts on site.
- It is useful for welding heavy sections.

Resistance welding

Resistance welding is used to join two or more metal parts together in a localised area by the **application of heat and pressure**. The heat is produced by the resistance of the material to carry a high amperage current.

There are at least **seven different types** of resistance welding:

- **Flash welding**
- **High-frequency resistance welding**
- **Percussion welding**
- **Projection welding**
- **Resistance seam welding**
- **Resistance spot welding**
- **Upset welding**



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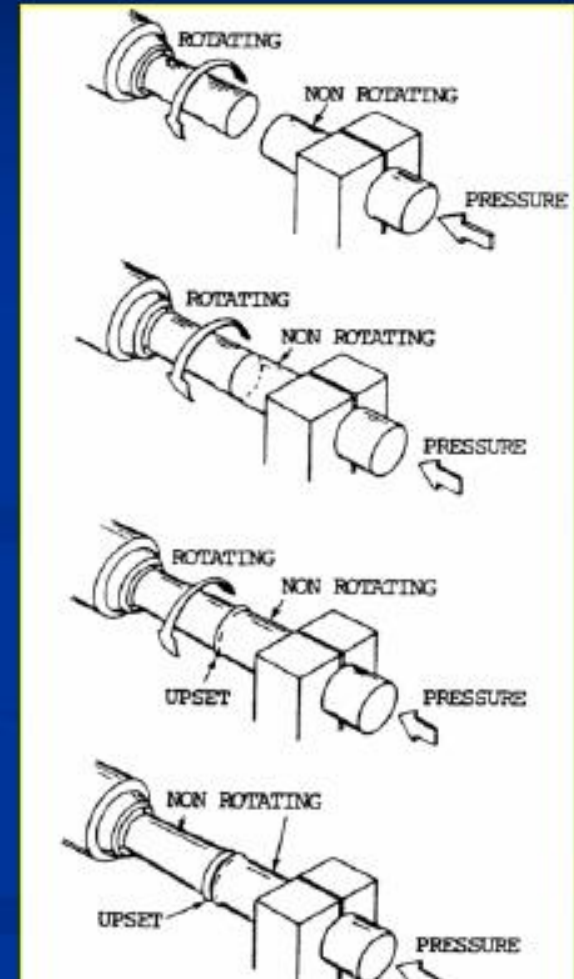
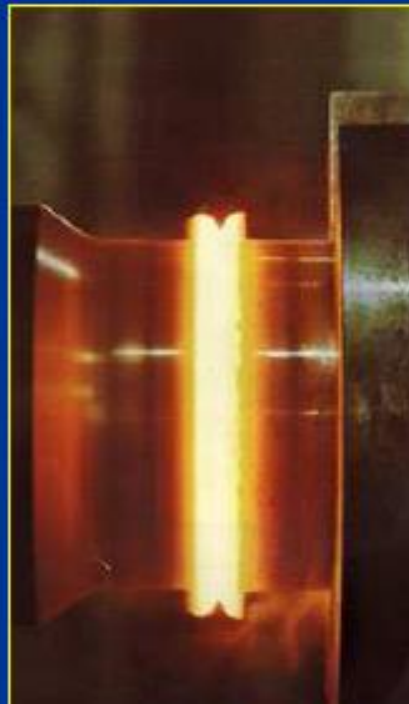
Projection welding



Friction welding

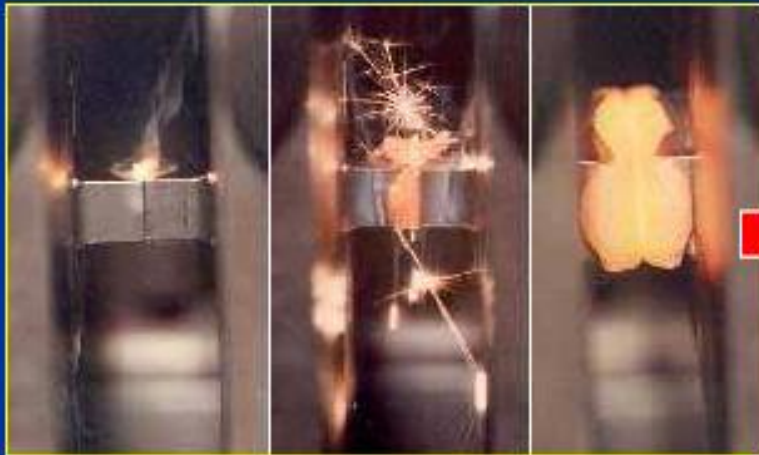
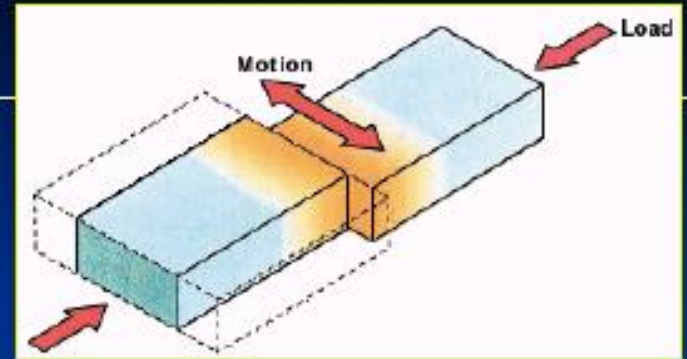
Friction welding is a **mechanical solid-phase welding process** in which heat generated by friction is used to create high-integrity joint between similar or dissimilar metals.

Can be used for **round** and **rectangular sections**.



Friction welding

Friction welding for rectangular sections



Friction welding process.

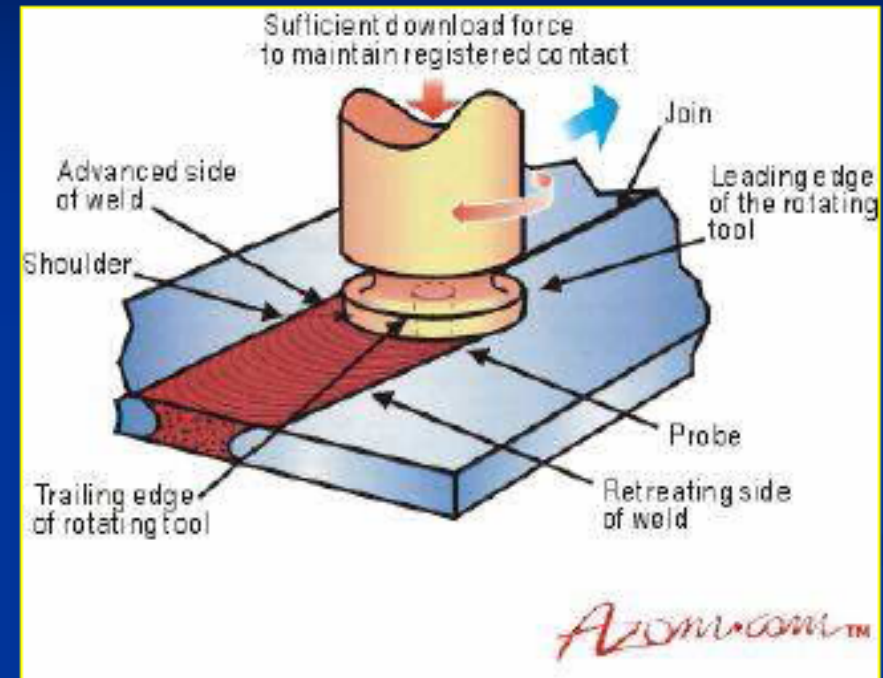


Weld structure obtained from friction welding.

- The heat generated due to frictional motions of the two workpieces, creating a **columnar microstructure** as shown in figure.

Friction stir welding

- **Friction stir welding** is a solid phase bonding process used mostly in welding aluminium.
- A cylindrical, shouldered tool with a **profiled probe** is rotated and slowly plunged into the joint line between two pieces of sheet or plate material, which are butted together.
- **Frictional heat** ($<T_m$) is generated between the wear resistant welding tool and the material of the workpieces.



Friction stir welding

- *High cost of welding machines.*
- *Can use to join dissimilar metals.*
- *Very small distortion.*



Chapter 6 , Chapter 7 . 1 and 7.2 are intentionally being left so that you would never forget to read text book.

Weldability

Definition

The capability of a material to be welded under the imposed fabrication conditions into a specific, suitably designed structure and to perform satisfactorily in the intended service.



- Weldability depends on various factors such as, nature of metals, weld designs, welding techniques, skills, etc.
- It has been stated that **all metals are weldable** but some are more difficult than another.
- **Steel** is readily weldable (in many ways) than **aluminium and copper**.
- **Copper** is not easily welded due to its high thermal conductivity which makes it difficult to raise the parent metal to its melting point. → require preheating ~300-400°C.
- Some **aluminium based die casting alloys** give weld pool too large to control, and aluminium welds normally have oxide inclusions and porosity.

Weldability

Steels

- **Weldability** of steels is inversely proportional to its **hardenability**, due to ***martensite formation*** during heat treatment

Carbon content



Hardenability



Weldability



- There is **a trade-off** between materials strength and weldability.
- **Austenitic stainless steels** tend to be the most weldable but suffer from distortion due to high thermal expansion. → Cracking and reduced corrosion resistance.
- **Ferritic and martensitic stainless steels** are not easily welded, often to be preheated and use special electrodes.
- **Ferritic steels** is susceptible to hot cracking if the ferrite amount is not controlled.

Weldability

Aluminium and its alloys

- **Weldability** of aluminium depends on chemical composition of the alloy.
- Aluminium alloys are susceptible to hot cracking, oxide inclusions, dross, porosity (hydrogen).
- Most of wrought series, **1xxx, 3xxx, 5xxx, 6xxx, and medium strength 7xxx** can be fusion welded by TIG, MIG while **2xxx and high strength 7xxx** are not readily welded due to liquation and solidification cracking.

Weldability

Copper and copper alloys

- **Weldability** of copper depends on chemical composition of the alloy.

Copper

- High thermal conductivity → required preheating to counteract heat sink effect.
- Can be TIG or MIG welded.

Brasses

- Volatilization (toxic) of zinc is the main problem, reducing weldability.
- Low zinc content brass can be TIG or MIG welded.

Bronzes

- Most are weldable, except gun metal or phosphor bronzes.
- Require careful cleaning and deoxidization to avoid porosity.

- **Silicon** improves weldability due to its deoxidizing and fluxing actions.
- **Oxygen** causes porosity and reduce strength of welds.
- **Tin** increases hot-cracked susceptibility during welding.
- ***Precipitation hardened alloys*** should be welded in the annealed condition, and then precipitation hardening treatment.

Welding defects:-

Defects in Weldments (unit formed by welding together an assembly of pieces)

- Defects occur in weldments due to improper welding procedures or due to random causes. With proper care these defects can be prevented.
- The defects commonly occurring can be classified into 3 main categories:
 1. Dimensional defects.
 2. Structural discontinuities.
 3. Inadequate properties.
- 1. **Dimensional defects:** Warpage, incorrect joint preparation, incorrect weld size and incorrect profile of the weld.
- 2. **Structural discontinuities:** Porosities, inclusion, incomplete fusion, under welding, inadequate penetration, cracks and other surface defects.
- 3. **Inadequate properties:** Low tensile strength, low yield strength, low ductility, inadequate hardness, impact failure, incorrect composition, and improper corrosion resistance.
- These effects may be further classified into **external** and **internal** defects.

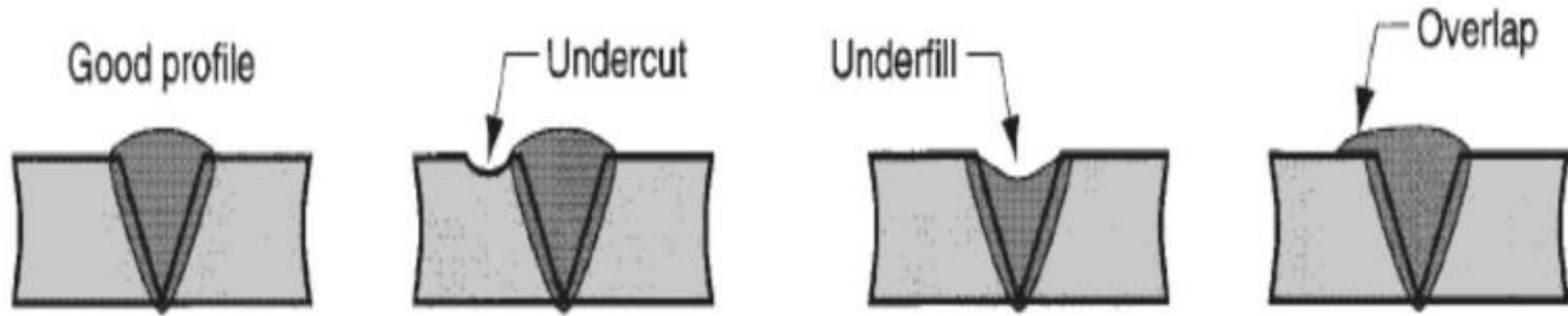
- Defects such as incorrect profile, crater, melted edge, surface porosity are visible on the surface and are called **surface** or **external defects**.
- **Internal defects** or **cracks** are not visible on the surface.
- These include blow holes, deep cracks, inclusions and incomplete penetration.
- The following defects are commonly found in weldments:

1. Undercut.	2. Incomplete fusion.
3. Porosity.	4. Slag inclusion.
5. Weld cracking.	6. Voids and Craters
7. Distortion.	8. Corrosion.
- **Undercut:** Undercut is a small notch at the weld interface. It is caused by too high welding current and improper welding technique. It is more likely in horizontal and vertical welding.
- **Incomplete Fusion:** This is caused by insufficient penetration of the joint, incorrect welding technique, wrong design of the joint, or poor selection of welding parameters and improper cleaning of the joint.

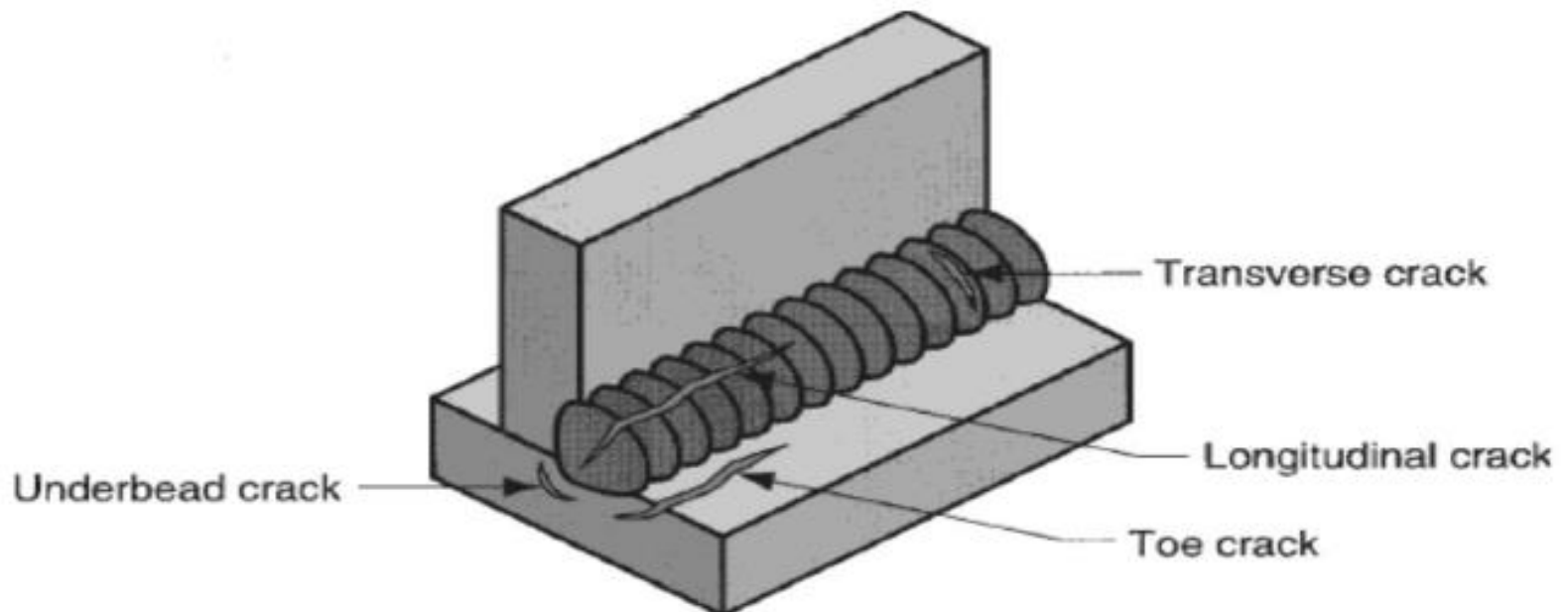
- **Porosity:** Porosity is caused by entrapment of gases during the solidification process. The gases mostly consists of hydrogen, oxygen, nitrogen of which hydrogen is most prominent for causing porosity. Gases like argon, helium or carbon dioxide do not cause porosity because they are insoluble.
- **Slag Inclusion:** Slag is formed by the reaction of fluxes and is expected to float out at the top of molten metal and be removed after solidification. Slag may also be present in multi-pass welds.
- **Weld cracking:** Weld cracking may be hot cracking or cold cracking. Hot cracking occurs during the root pass if the mass of the base metal is very large compared to the weld metal deposited. It can be controlled by preheating the base metal, by changing the contour, composition of weld bead.
- **Voids and Craters:** It has been shown that voids upto 7% of the cross section have not much effect on the tensile or impact strength or the ductility of the weld. If the size of voids are larger presence of foreign matters cause a large reduction in the strength of the weld leading to opening of cracks.

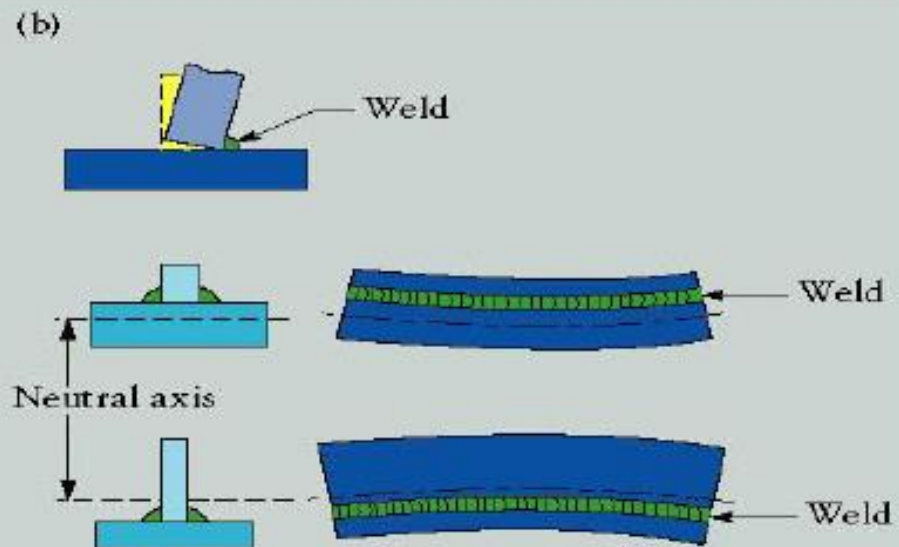
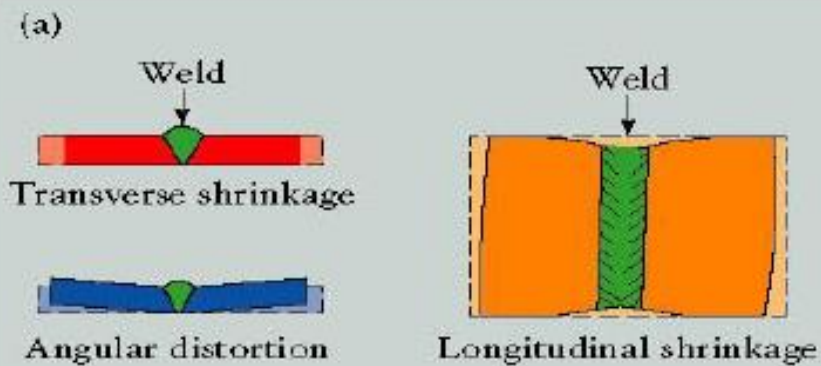
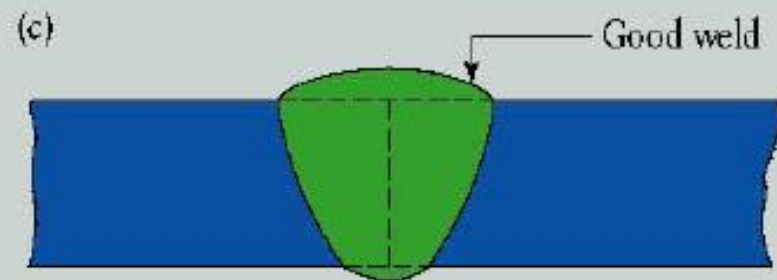
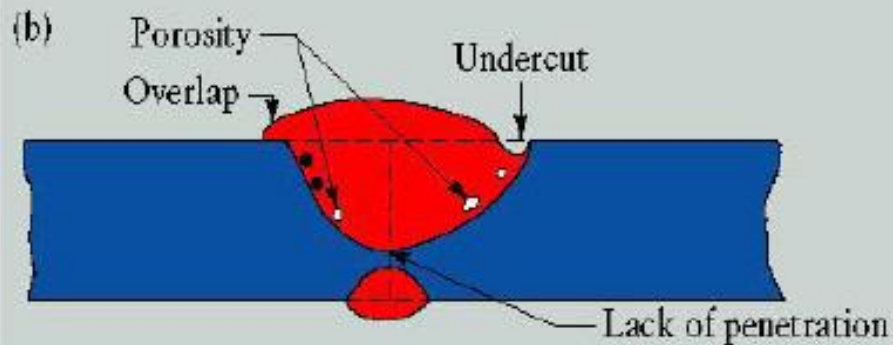
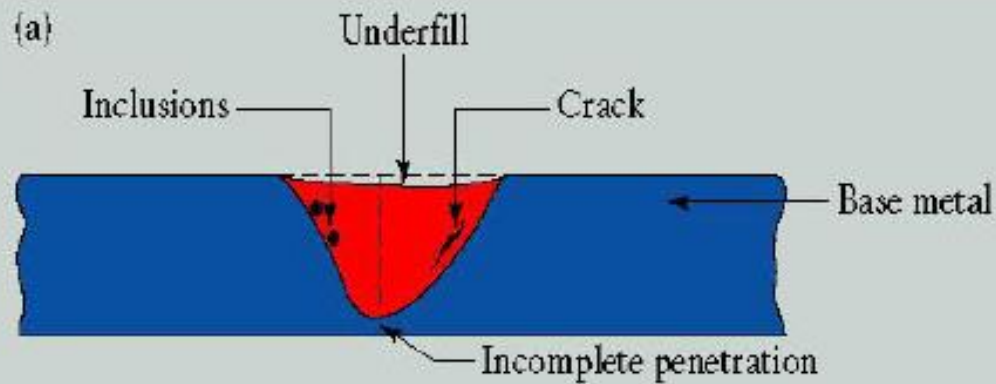
- **Distortion:** Distortion is one of the major problems found in weldments. It is caused mainly by shrinkage. 3 types of distortion are possible in weldments:
 1. Longitudinal Shrinkage: This occurs parallel to the weld line and is so small that it can be ignored.
 2. Transverse shrinkage: This occurs perpendicular to the weld line. It is result of contraction of base metal which had expanded during welding.
 3. Angular change or orientation about the weld line: The weld distortions occur because of the shrinkage that takes place in weldments. It cannot be completely eliminated but can be reduced by restraining the pieces being joined so that the distortions cannot take place.
- **Corrosion:** Welding makes metals more susceptible to corrosion in a number of ways. The intense heat of welding removes protective coatings from metal surfaces and also changes some metals to make them more susceptible to corrosion. For ex: welding can make stainless steel lose its corrosion resistance.

Improper weld profile:



Weld cracks:





Weld cracking

There are various types of weld cracking

- **Solidification cracking (hot cracking)**
- **Hydrogen cracking (cold cracking)**
- **Liquation cracking**
- **Lamellar Tearing**

Weld assessments

Appropriate
welding method



Reliable products



Specifications
Quality control method

• Destructive testing

- Mechanical testing, i.e., tensile, fracture toughness, impact, fatigue tests.
- Expensive, require specimen preparation under standard specifications.

• Non destructive testing

- Weldments are not destroyed.
- Many NDT techniques are expensive and have their own limitations.
- Inspection should be carefully planned to make sure the technique used is capable of detecting the concerned defects.

Non-destructive testing

• We must remember that **NDT result** itself cannot guarantee whether the weld is acceptable, but can only report what **types of defects we discover**.

There are a range of NDT techniques available;

- Visual inspection
- Liquid penetrant inspection
- Magnetic-particle inspection
- Radiography
- Ultrasonic inspection

Note: At least one of the **NDT methods** should be taken for weld inspections.

Visual inspection

- Weld defects can often be discovered by naked eyes and can be repaired at this stage:



- *Weld dimensions*
- *Joint penetration*
- *Surface defects*

Liquid-penetrant inspection

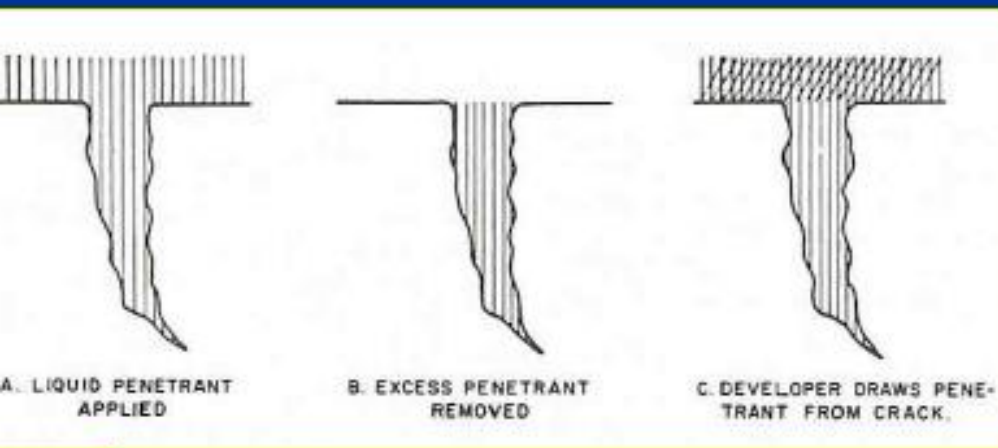
- Used to detect minute discontinuities such as cracks, pores, which are open to the surface.
- Can be applied to ferrous & non ferrous metals, glass and plastics.
- The *surface must be clean*.

Properties

- Low surface tension
- Low viscosity
- Can be dye or fluorescence



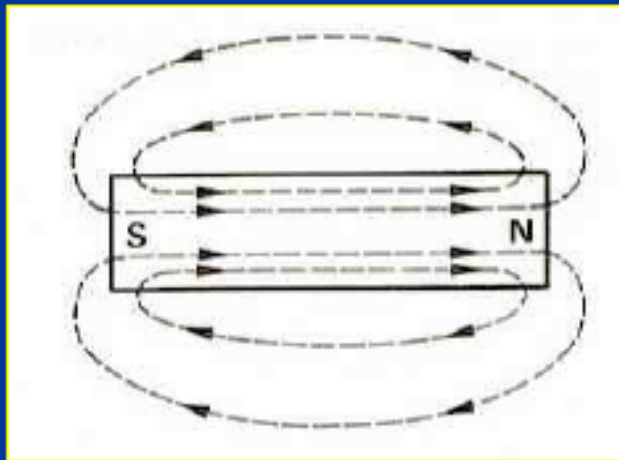
Liquid panetrant



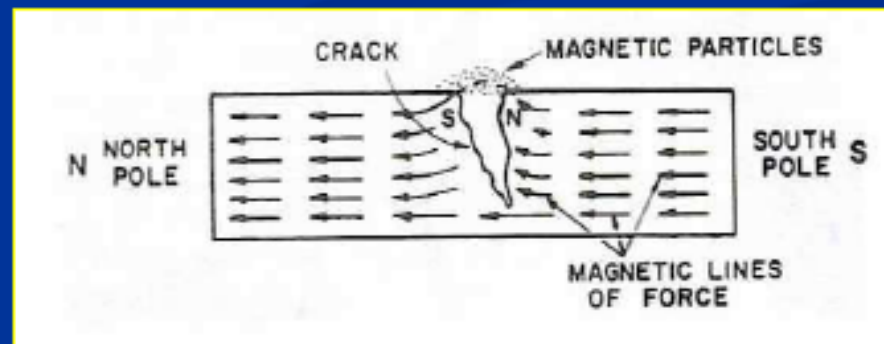
- Liquid penetrant inspection is **portable** and very easy to **use on site**.
- Required **appropriate protections** because the liquid used **might be toxic**.
- Limited on **surface inspection** and should be used in combination of other NDT techniques.

Magnetic particle inspection

- **Magnetic particle inspection** is used to detect cracks porosity, seams, inclusions lack of fusion and other discontinuities in **ferromagnetic materials**.
- Used on the **surface and shallow subsurface**.
- The lines of force within the magnet run smoothly from **S to N**.
- When a crack is present, **N and S poles** are set up at the edges of the crack.
- The **magnetic particles** will be attracted to the crack (poles).



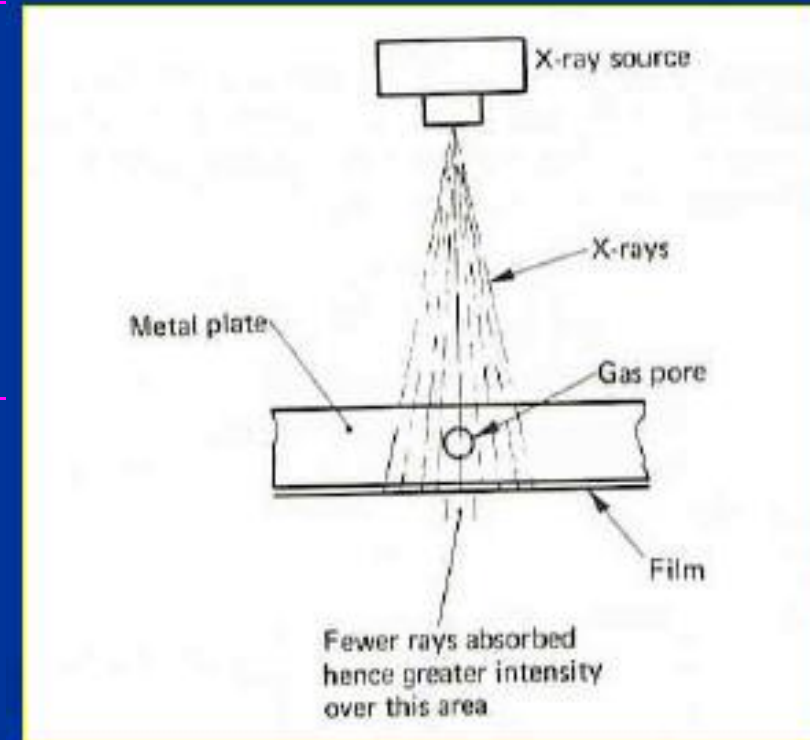
Magnetic fields around bar magnet and a crack



Accumulation of magnetic particles on defects

Radiographic examination

- **Interior defects** (porosity, cracks, voids) can be examined by using **X-ray or gamma ray**, which can penetrate through materials and **its intensity depends on materials thickness and density**.
 - Provide a **permanent film record** which is easy to interpret.
 - Slow and expensive, however this method is positive to determine **defect size**.
-
- **X-ray** is generated by electron bombardment on tungsten.
 - **Gamma ray** is emitted by radioactive elements.
-
- **X-ray or gamma ray** is absorbed during transmission through the materials.
 - **Pores or defects** absorb less energy than uniform areas → giving **a variation of intensity of the beam** generated on the film placed underneath the materials.



Principal of radiography

Ultrasonic inspection

- A *beam of ultrasonic vibration* produced by quartz crystal is directed into the specimen to detect defects or discontinuities.
- Sound area gives small loss of signal, except when the ultrasonic is intercepted and reflected by defects.

WELDING, BRAZING, SOLDERING

Welding:-

Metal joining process that uses melted metal as joints

Brazing & soldering: joining two different/similar metals using a third filler material into the joint in liquid state & allowed to solidify

Brazing differs from soldering → in the melting temp. of the filler

Brazing - only the filler is melted → wets the materials to be joined
- temperature: 430°C – 800°C

Soldering – same as brazing; temperature range: 100°C – 450°C

Strength of joint determined by the adhesive quality of the filler

Welding – original materials are melted and joined → solidified

Soldering joints : soft \rightarrow types:

1. Tin & Lead (60:40, 50:50, 40:60) – $t_f \approx 240^\circ \text{C}$
2. Lead & Silver (97:3) $\rightarrow t_f \approx 310^\circ \text{C}$

For filling \rightarrow 20/30 % tin – lead composition – cheaper

Cleanliness – Critical to the strength of the joint

Oxide have to be removed from the surfaces before joining

Cleaning methods

1. Using fluxes (chemical action)
2. Abrasive removal (mechanical action)
3. Ultrasonic cleaning (acoustic action)

Fluxless Soldering: Gold coated, Ultrasonic, Inert atmosphere.

BRAZING: Similar to soldering but at **temp > 450° C**, still lower than melting temperature of the brazed metal parts.

Here, the capillary attraction is driving the filler metal into the joint (clearance is very small)

For different fillers → different recommended clearances to improve the strength of the joint

- Copper → no clearance
- silver alloy → 0.04 – 0.05 mm
- brass → 0.5 – 0.75 mm

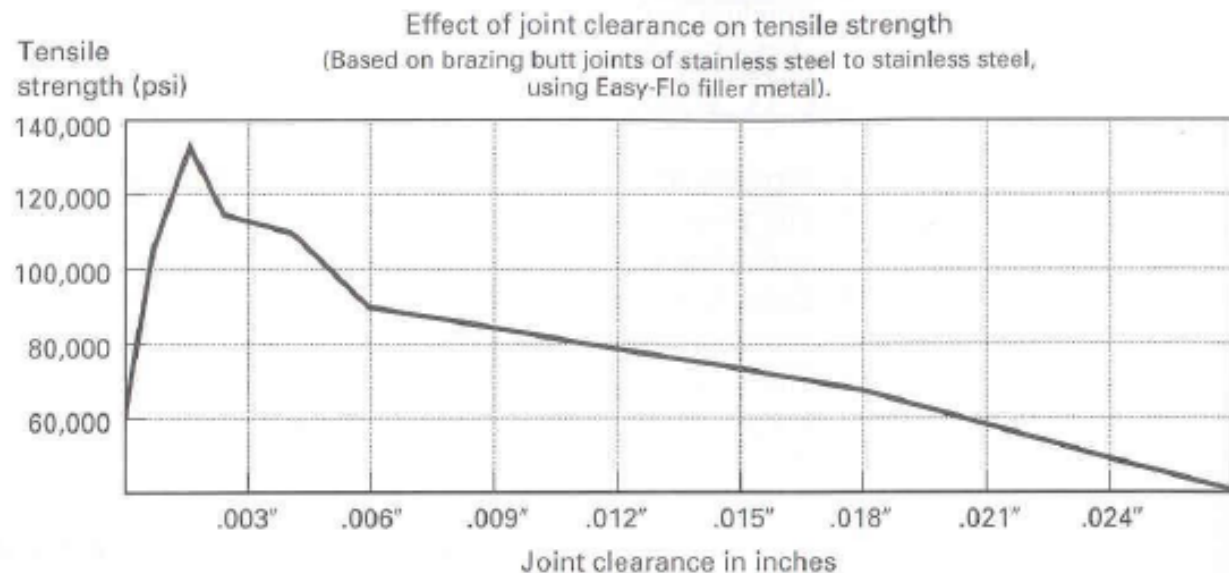


FIGURE 37-1 Typical variation of tensile strength with different joint clearances in

BRAZE WELDING → a joining process where the capillary attraction is not used to distribute the filler metal. The molten filler is deposited before brazing is done.

→ special fluxes are used (Borax) to: remove the oxide

improve the fluidity of the fillers
wet the joint surfaces

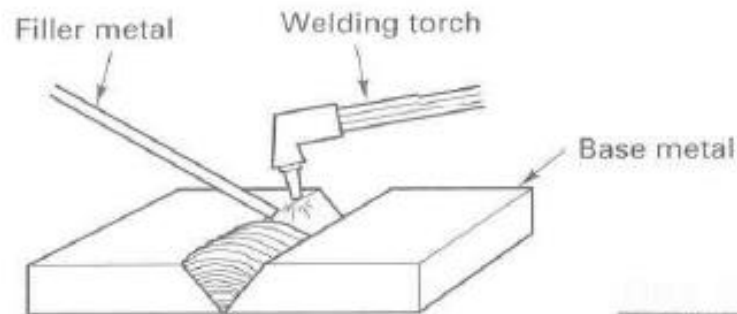


FIGURE 37-7 Schematic of the braze welding process.

TABLE 37-2. Engineering Materials and Their Compatibility with Brazing

Material	Brazing Recommendation
Cast iron	Somewhat difficult
Carbon and low-alloy steels	Recommended for low- and medium-carbon materials; difficult for high-carbon materials; seldom used for heat-treated alloy steels
Stainless steel	Recommended; Silver and nickel brazing alloys are preferred
Aluminum and magnesium	Common for aluminum alloys and some alloys of magnesium
Copper and copper alloys	Recommended for copper and high-copper brasses; somewhat variable with bronzes
Nickel and nickel alloys	Recommended
Titanium	Difficult, not recommended
Lead and zinc	Not recommended
Thermoplastics, thermosets, and elastomers	Not recommended
Ceramics and glass	Not recommended
Dissimilar metals	Recommended, but may be difficult, depending on degree of dissimilarity
Metals to nonmetals	Not recommended
Dissimilar nonmetals	Not recommended

TABLE 39-2. Some Common Braze Metal Families, Metals They Are Used to Join, and Typical Brazing Temperatures

Braze Metal Family	Materials Commonly Joined	Typical Brazing Temperature (°C)
Aluminum-silicon	Aluminum alloys	565–620
Copper and copper alloys	Various ferrous metals as well as copper and nickel alloys and stainless steel	925–1150
Copper-phosphorus	Copper and copper alloys	700–925
Silver alloys	Ferrous and nonferrous metals, except aluminum and magnesium	620–980
Precious metals (gold-based)	Iron, nickel, and cobalt alloys	900–1100
Magnesium	Magnesium alloys	595–620
Nickel alloys	Stainless steel, nickel, and cobalt alloys	925–1200

Brazing Materials:
copper alloys
silver alloys
aluminium alloys

Basic joint types in brazing:

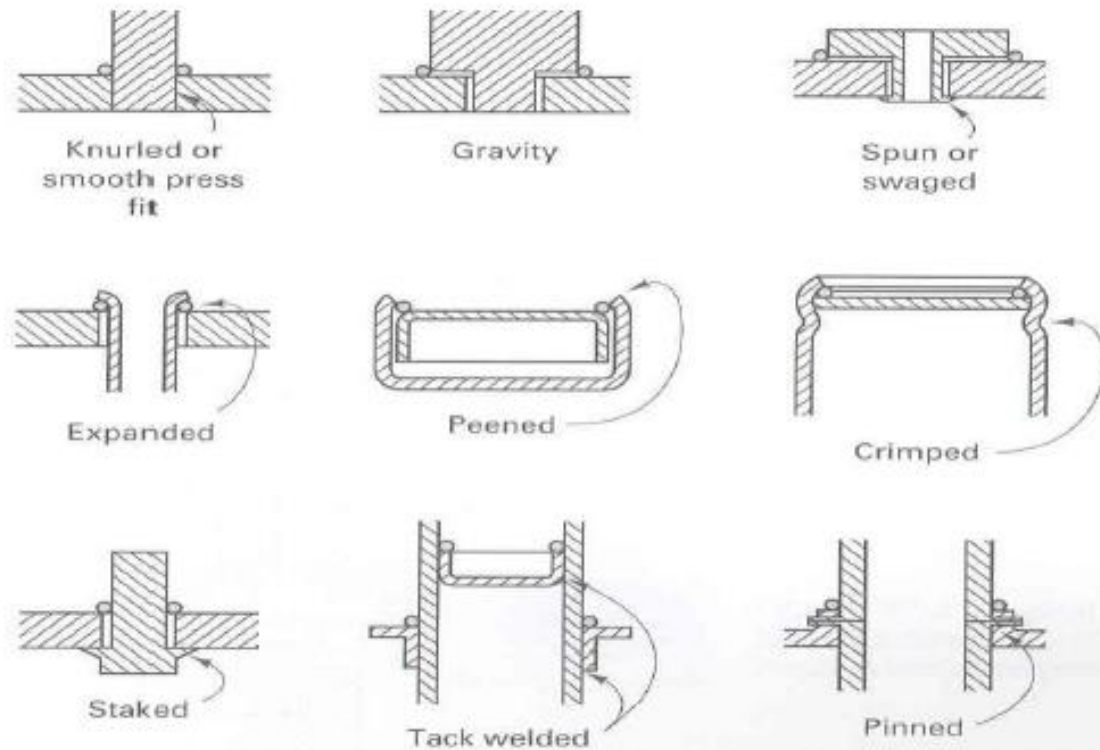
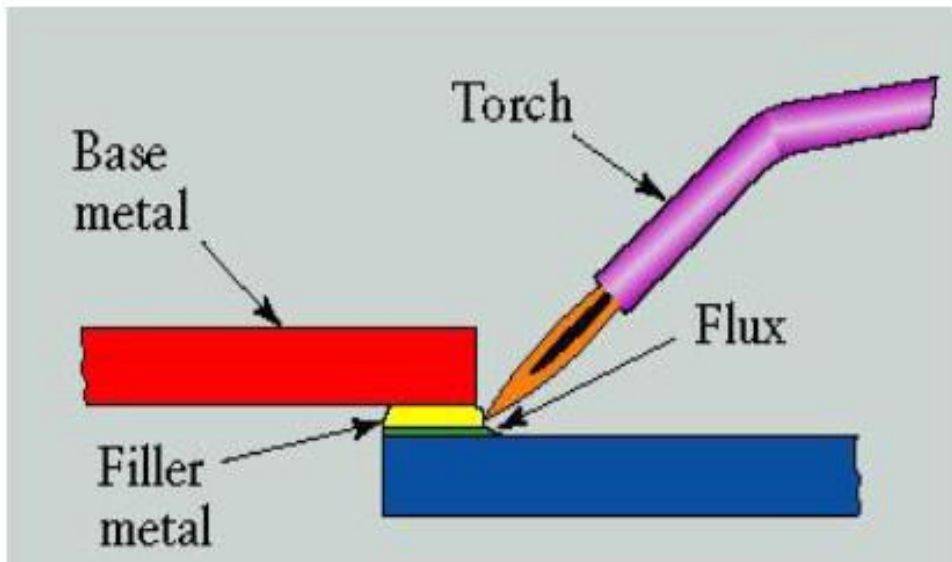


FIGURE 37-2 Methods of applying braze metal and positioning or fixturing various joints.

Brazing

- It is a joining process in which a filler metal is melted and distributed by capillary action between the faying (contact) surfaces of the metal parts being joined.
- In brazing, the filler metal has a melting temperature above 450°C , but below the melting point of base metals to be joined.
- Join produced by this welding is stronger than soldering.
- This process offers better corrosion resistance.
- Filler used in brazing include Cu and Cu alloys, silver alloys and Al alloys.
- In this process heating is done by torch, furnace, induction, resistance, bath dipping infrared techniques.



Advantages of brazing

- Brazing can be used to join a large variety of dissimilar metals.
- Pieces of different thickness can be easily joined by brazing
- Thin-walled tubes & light gauge sheet metal assemblies not joinable by welding can be joined by brazing.
- Complex & multi-component assemblies can be economically fabricated with the help of brazing.
- Inaccessible joint areas which could not be welded by gas metal or gas tungsten arc spot or seam welding can be formed by brazing.

- **Applications:**

- 1) Automobile – Joining Tubes
- 2) Pipe/Tubing joining (HVAC)
- 3) Electrical equipment - joining wires
- 4) Jewelry Making

SOLDERING

- Soldering is similar to brazing and can be defined as a joining process in which a filler metal with melting point not exceeding 450°C is melted and distributed by capillary action between the faying surfaces of the metal parts being joined.
- As in brazing, no melting of the base metals occurs, but the filler metal wets and combines with the base metal to form a metallurgical bond.
- Filler metal, called **Solder**, is added to the joint, which distributes itself between the closely fitting parts.
- Strength of the joint is weak
- Corrosion resistance is less

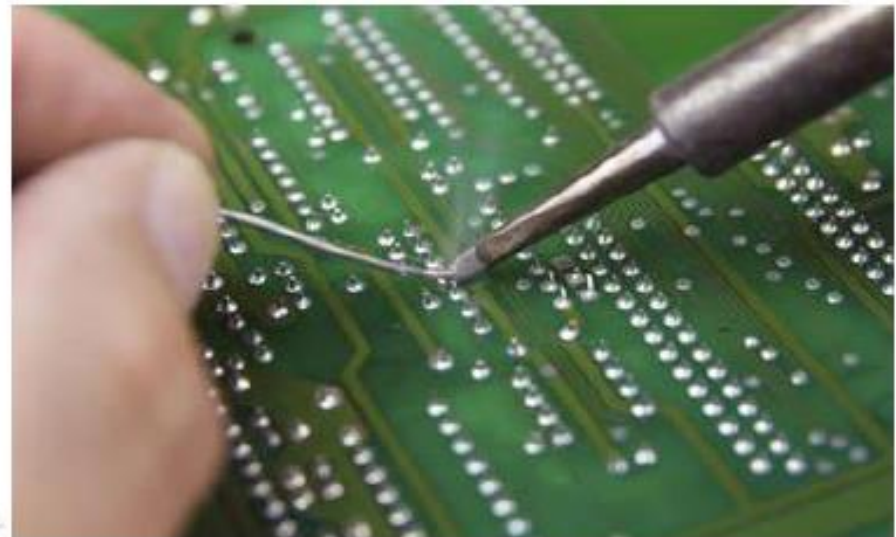
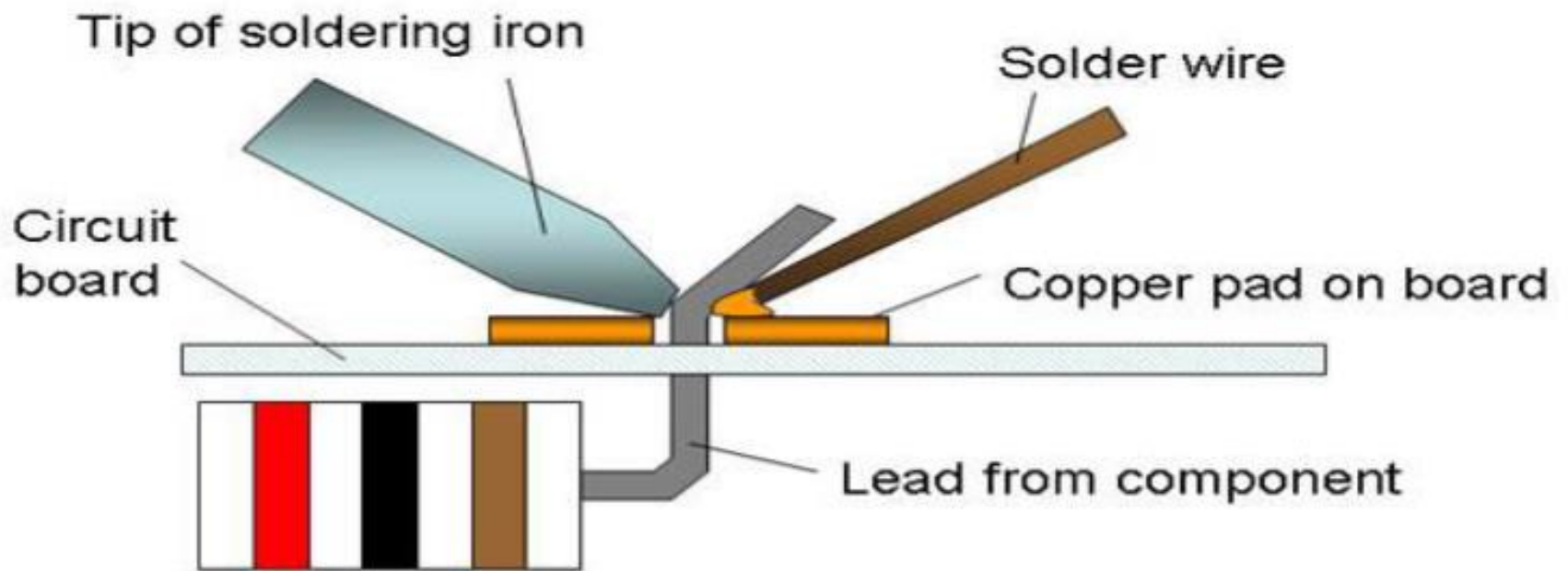
SOLDER: Alloys of Tin and Lead. Tin is chemically active at soldering temperatures and promotes the wetting action required for successful joining.

Applications:

- 1) Printed Circuit Board (PCB) manufacture
- 2) Pipe joining (copper pipe)

Easy to solder: copper, silver, gold

Difficult to solder: aluminum, stainless steels



Comparison between Welding,soldering and brazing

Sl. No.	Welding	Soldering	Brazing
1.	These are the strongest joints used to bear the load. Strength of a welded joint may be more than the strength of base metal.	These are weakest joint out of three. Not meant to bear the load. Use to make electrical contacts generally.	These are stronger than soldering but weaker than welding. These can be used to bear the load upto some extent.
2.	Temperature required is upto 3800°C of welding zone.	Temperature requirement is upto 450°C.	It may go to 600°C in brazing.
3.	Workpiece to be joined need to be heated till their melting point.	No need to heat the workpieces.	Workpieces are heated but below their melting point.

4.	Mechanical properties of base metal may change at the joint due to heating and cooling.	No change in mechanical properties after joining.	May change in mechanical properties of joint but it is almost negligible.
5.	Heat cost is involved and high skill level is required.	Cost involved and skill requirements are very low.	Cost involved and skill required are in between others two.
6.	Heat treatment is generally required to eliminate undesirable effects of welding.	No heat treatment is required.	No heat treatment is required after brazing.
7.	No preheating of workpiece is required before welding as it is carried out at high temperature.	Preheating of workpieces before soldering is good for making good quality joint.	Preheating is desirable to make strong joint as brazing is carried out at relatively low temperature.

Definition of Powder Metallurgy

- ▶ Powder metallurgy may defined as, “the art and science of producing metal powders and utilizing them to make serviceable objects.”

OR

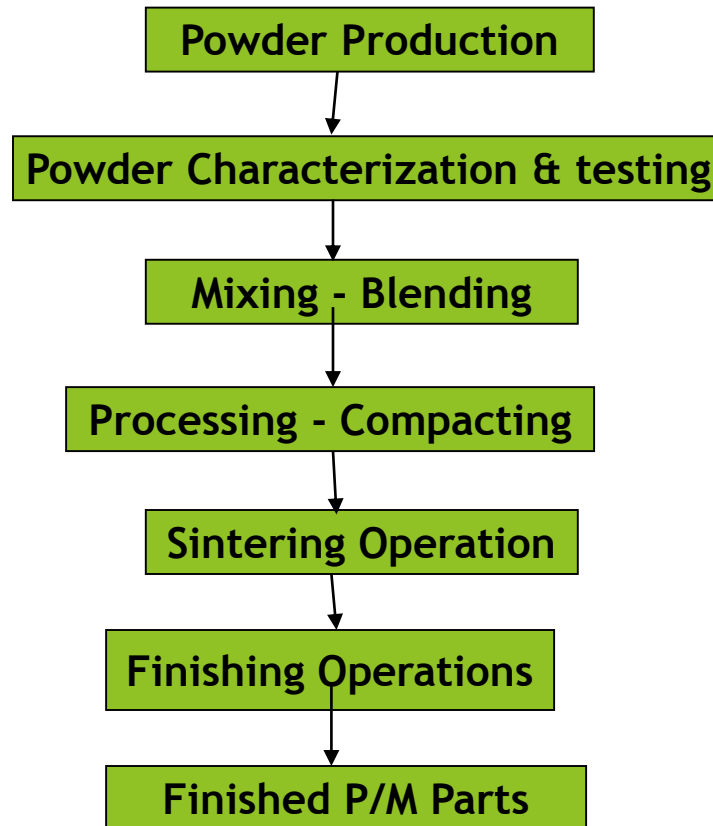
- ▶ It may also be defined as “material processing technique used to consolidate particulate matter i.e. powders both metal and/or non-metals.”

POWDER METALLURGY:

- ▶ Powder metallurgy is a forming and fabrication technique consisting of three major processing stages.
- ▶ First, the primary material is physically powdered, divided into many small individual particles.
- ▶ Next, the powder is injected into a mold or passed through a die to produce a weakly cohesive structure (via cold welding) very near the dimensions of the object ultimately to be manufactured.
- ▶ Finally, the end part is formed by applying pressure, high temperature, long setting times during which self-welding occurs.

Process of Powder Metallurgy:

The process of P/M in general consists of a series of steps/stages to form a final shape. These stages are shown by a simple flow sheet diagram.



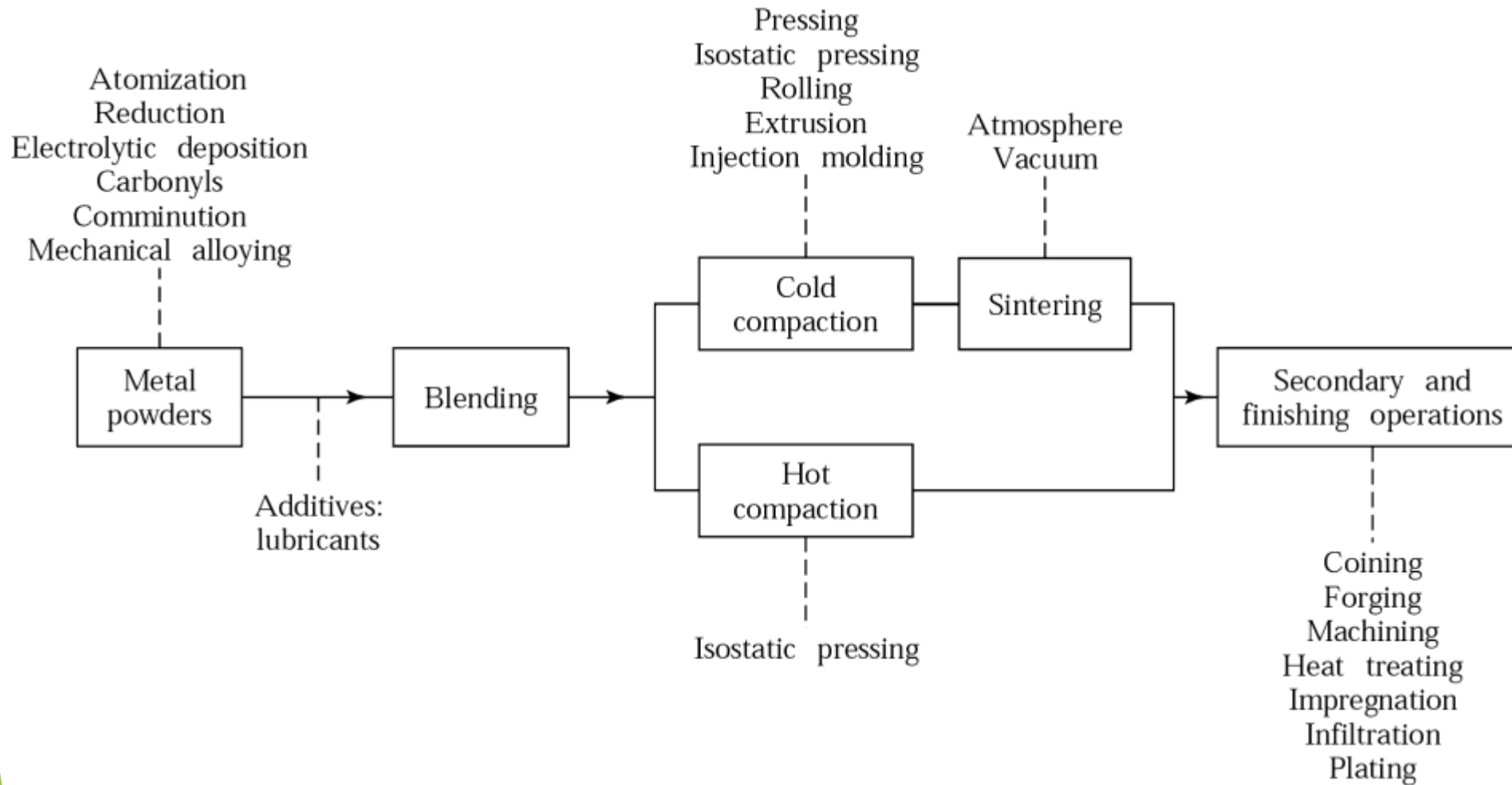
- ▶ Powder Metallurgy (P/M) is an improved alternative method as compared to Industrial Metallurgy (I/M) being more economical for large production series with precision of design and savings of energy, material and labor. Further it is a unique method for producing cement , cutting tools, nuclear fuel elements, self-lubricating bearing, copper-graphite brushes etc.

Importance of P/M:

- ▶ The methods of powder metallurgy have permitted the attainment of compositions and properties not possible by the conventional methods of melting and casting.
- ▶ Powder metallurgy is an alternative, economically viable mass production method for structural components to very close tolerance.
- ▶ Powder metallurgy techniques produce some parts which can't be made by any other method.

Processing of Metal Powders

- ▶ Powder Metallurgy Process (P/M process)
 - ▶ The process where metal powders are compacted into desired and often complex shapes and sintered to form a solid piece
- ▶ Process was first used five thousand years ago by Egyptians to make iron tools



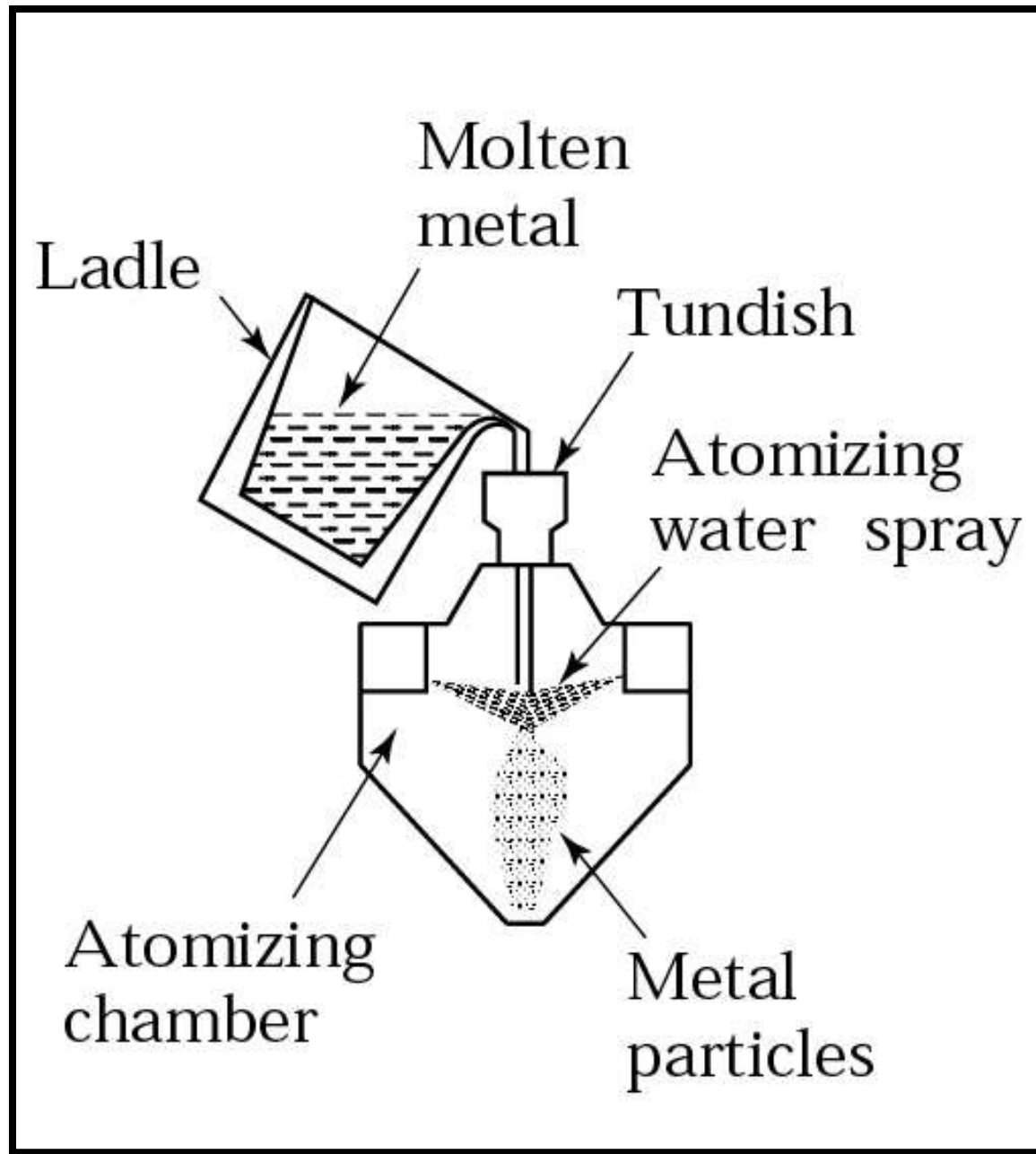
Powder Production

- ▶ First step in P/M process
- ▶ Methods
 - ▶ Atomization
 - ▶ Reduction
 - ▶ Electrolytic deposition
 - ▶ Carbonyls
 - ▶ Commination
 - ▶ Mechanical alloying
 - ▶ Miscellaneous methods



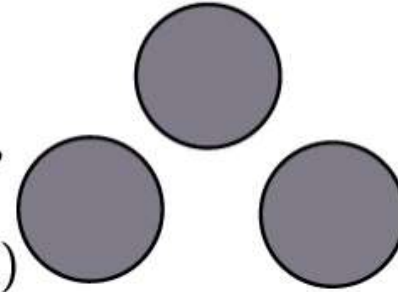
Atomization

- ▶ Produces a liquid-metal stream by injecting molten metal through a small orifice
- ▶ The stream is broken up by jets of inert gas or air



- ▶ The size and shape of the particles from atomization depend on the temperature, flow rate, size of nozzle, and the jet characteristics
- ▶ When water is used it creates a slurry metal powder and leaves a liquid at the bottom of the atomization chamber
- ▶ The water cools the metal faster for a higher production rates

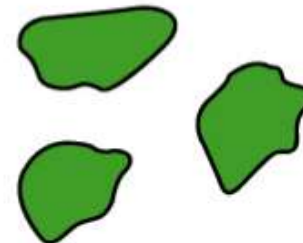
Spherical
(atomization,
carbonyl (Fe),
precipitation
from a liquid)

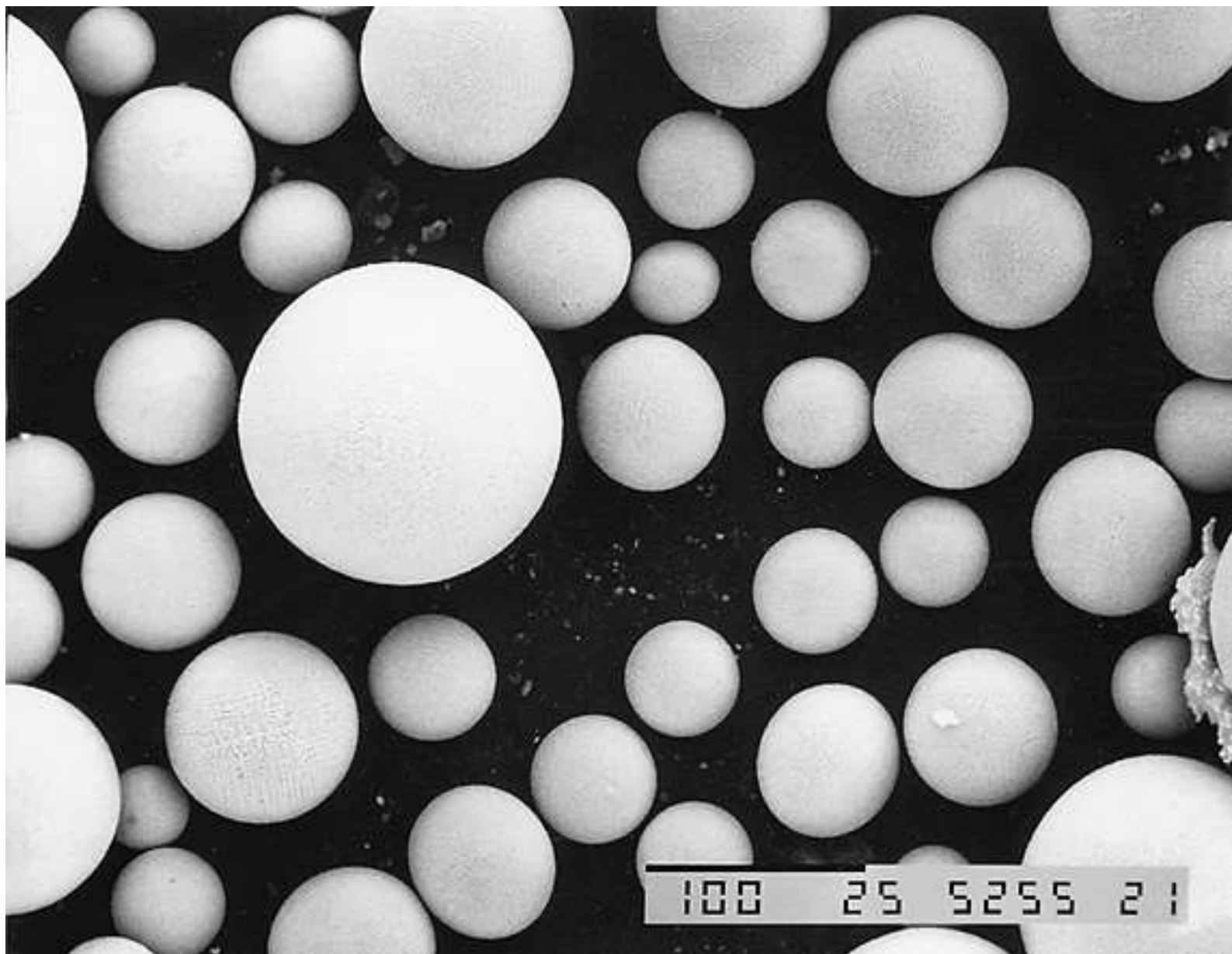


Irregular rodlike
(chemical
decomposition,
mechanical
comminution)



Rounded
(atomization,
chemical
decomposition)

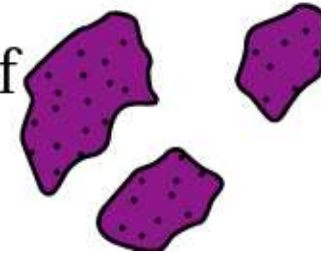




Reduction of Metal Oxides

- ▶ A process that uses gases as a reducing agent
- ▶ Hydrogen and carbon monoxide
- ▶ Also known as the removal of oxygen
- ▶ Very fine metallic oxides are reduced to the metallic state
- ▶ Spongy and porous powders are produced

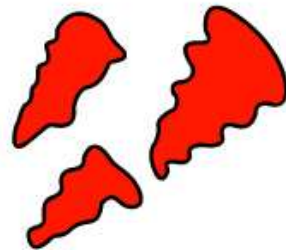
Porous
(reduction of
oxides)



Electrolytic Deposition and Carbonyls

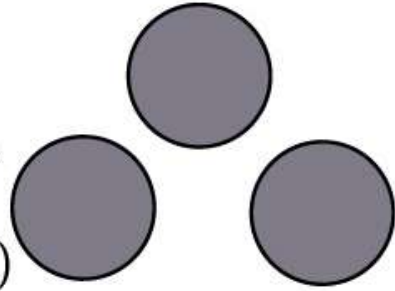
- ▶ Electrolytic Deposition utilizes either aqueous solutions or fused salts
- ▶ Makes the purest powders that are available

Dendritic
(electrolytic)

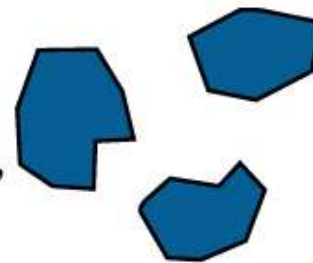


- ▶ Metal carbonyls are formed by letting iron or nickel react with carbon monoxide
- ▶ Reaction product is decomposed to iron and nickel
- ▶ Forms small, dense, uniform spherical particles

Spherical
(atomization,
carbonyl (Fe),
precipitation
from a liquid)

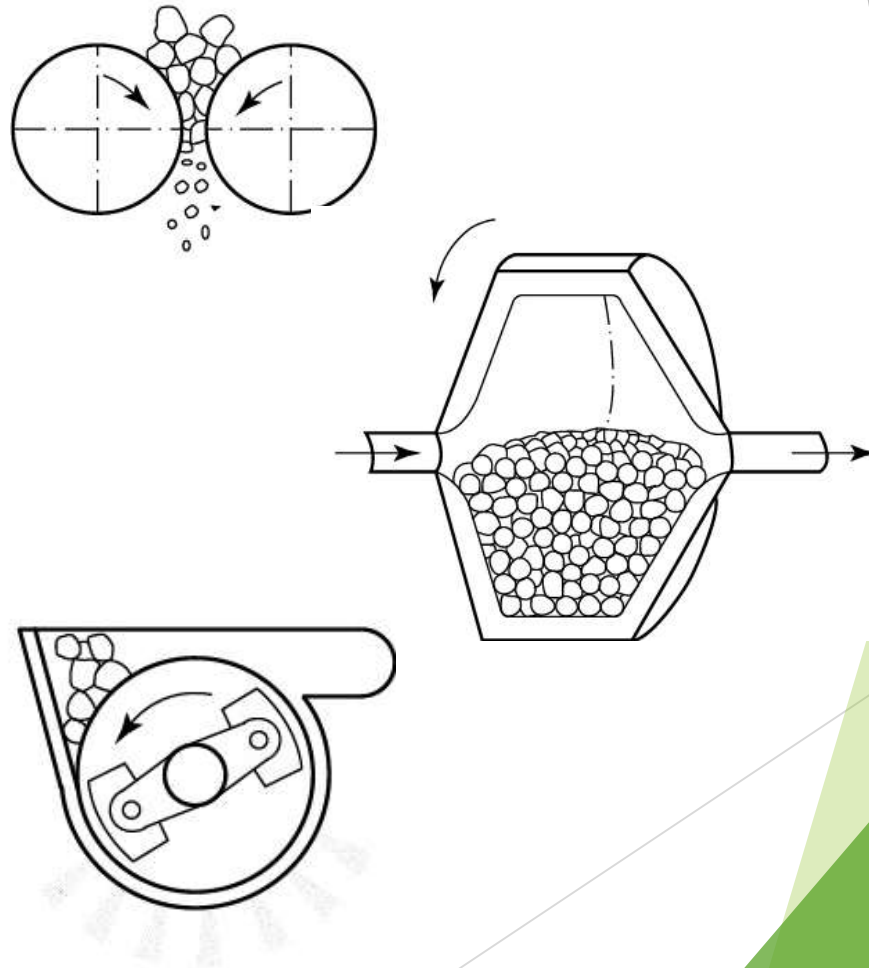


Angular
(mechanical disintegration,
carbonyl (Ni))

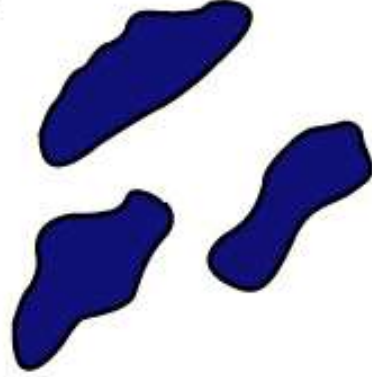


Mechanical Commination

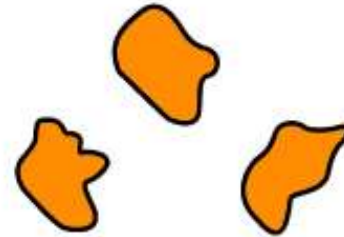
- ▶ Also known as pulverization
- ▶ Involves roll crushing, milling in a ball mill, or grinding of brittle or less ductile metals into small particles
- ▶ Brittle materials have angular shapes
- ▶ Ductile metals are flaky and not particularly suitable for P/M



Irregular rodlike
(chemical
decomposition,
mechanical
comminution)



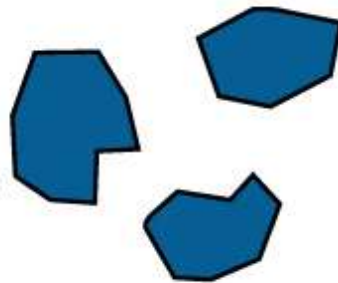
Flake
(mechanical
comminution)



Mechanical Alloying

- ▶ Powders of two or more pure metals are mixed in a ball mill
- ▶ Under the impact of the hard balls the powders fracture and bond together by diffusion, forming alloy powders
- ▶ The dispersed phase can result in strengthening of the particles or can impart special electrical or magnetic properties

Angular
(mechanical disintegration,
carbonyl (Ni))



Miscellaneous Methods

- ▶ Precipitation from a chemical solution
- ▶ Production of fine metal chips by machining
- ▶ Vapor condensation

Types of Powders

▶ Nano powders

- ▶ Consist of mostly copper, aluminum, iron, titanium
- ▶ Are pyrophoric (ignite spontaneously)
- ▶ Contaminated when exposed to air
- ▶ The particle size is reduced and becomes porous free when subjected to large plastic deformation by compression and shear stress
- ▶ Posses enhanced properties

▶ Microencapsulated powders

- ▶ Coated completely with a binder
- ▶ The binder acts as an insulator for electrical applications preventing electricity from flowing between particles
- ▶ Compacted by warm pressing
- ▶ The binder is still in place when used

Particle Size, Shape, and Distribution

- ▶ Particle size is measured by a process called screening
- ▶ Screening is the passing of metal powder through screens of various mesh sizes
- ▶ The main process of screening is Screen Analysis
- ▶ Screen analysis uses a vertical stack of screens with mesh size becoming finer as the powder flows down through screens

Particle Shape and Shape Factor

- ▶ Major influence on processing characteristics
- ▶ Usually described by aspect ratio and shape factor
- ▶ Aspect ratio is the ratio of the largest dimension to the smallest dimension
- ▶ Ratio ranges from unity (spherical) to 10 (flake-like, needle-like)
- ▶ Shape factor (SF) is also called the shape index
- ▶ Is a measure of the ratio of the surface area to its volume
- ▶ The volume is normalized by a spherical particle of equivalent volume
- ▶ The shape factor for a flake is higher than it is for a sphere

Size Distribution and Other Properties

- ▶ Size distribution is important because it affects the processing characteristics of the powder
- ▶ Flow properties, compressibility and density are other properties that have an affect on metal powders behavior in processing them
- ▶ Flow
 - ▶ When metal powders are being filled into dies
- ▶ Compressibility
 - ▶ When metal powders are being compressed
- ▶ Density
 - ▶ Theoretical density, apparent density, and the density when the powder is shaken or tapped in the die cavity

Basic Steps In Powder Metallurgy (P/M)

- ▶ Powder Production
- ▶ Blending or Mixing
- ▶ Compaction
- ▶ Sintering
- ▶ Finishing



Blending Metal Powders

- ▶ Blending (mixing) is the next step in P/M process
- ▶ Must be carried out under controlled conditions to avoid contamination or deterioration
- ▶ Deterioration is caused by excessive mixing and causes the shape to be altered or the particles harden causing the compaction process to be difficult
- ▶ Is done for several significant reasons

Reasons for Blending

- ▶ To impart special physical and mechanical properties and characteristics
- ▶ Proper mixing is essential to ensure the uniformity of mechanical properties throughout the part
- ▶ Even one metal can have powder vary in size and shape
- ▶ The ideal mix is one in which all of the particles of each material are distributed uniformly
- ▶ Lubricants can be mixed with the powders to improve flow of metal powder into dies, reduce friction between metal particles, and improve the die life
- ▶ Binders are used to develop sufficient green strength
- ▶ Other additives can be used to facilitate sintering

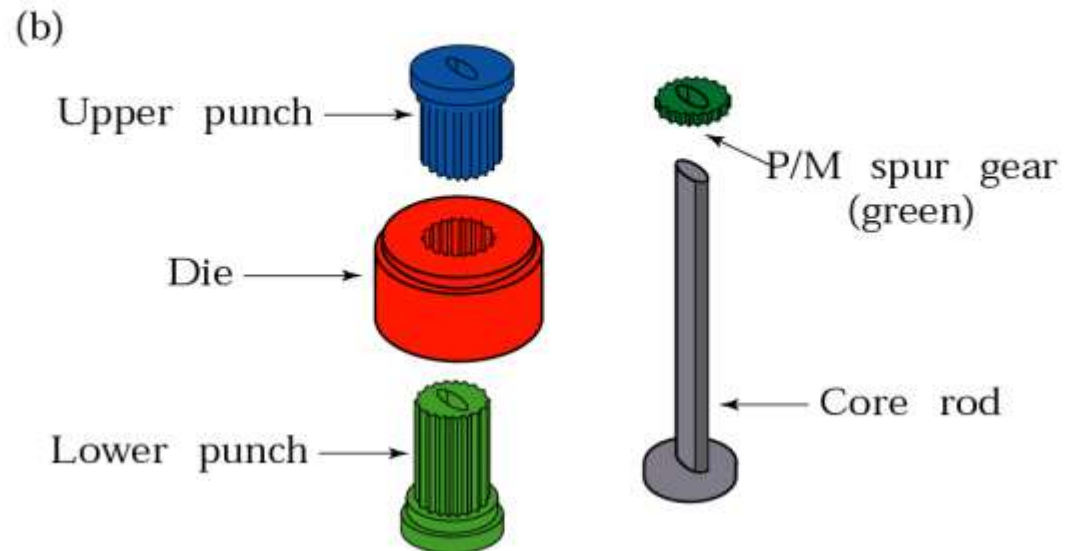
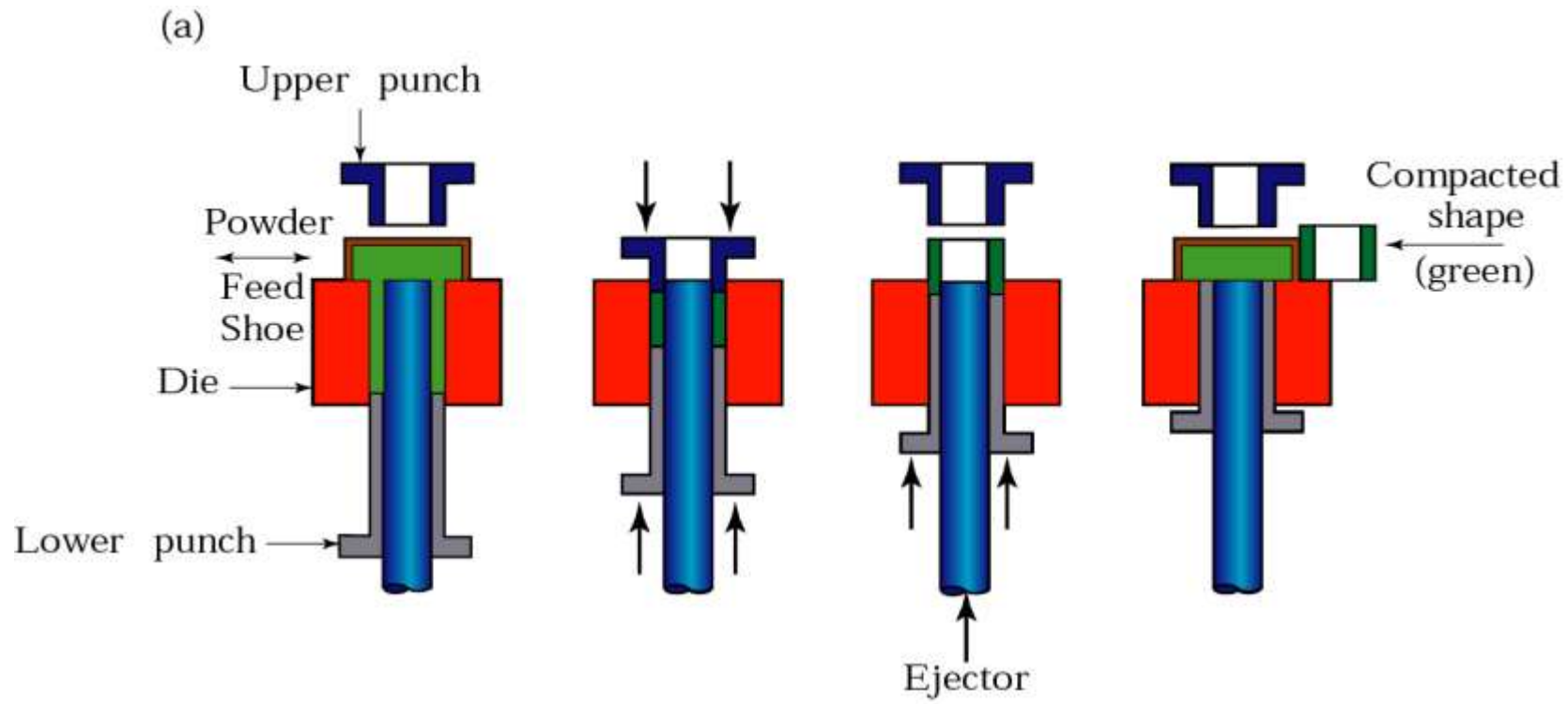


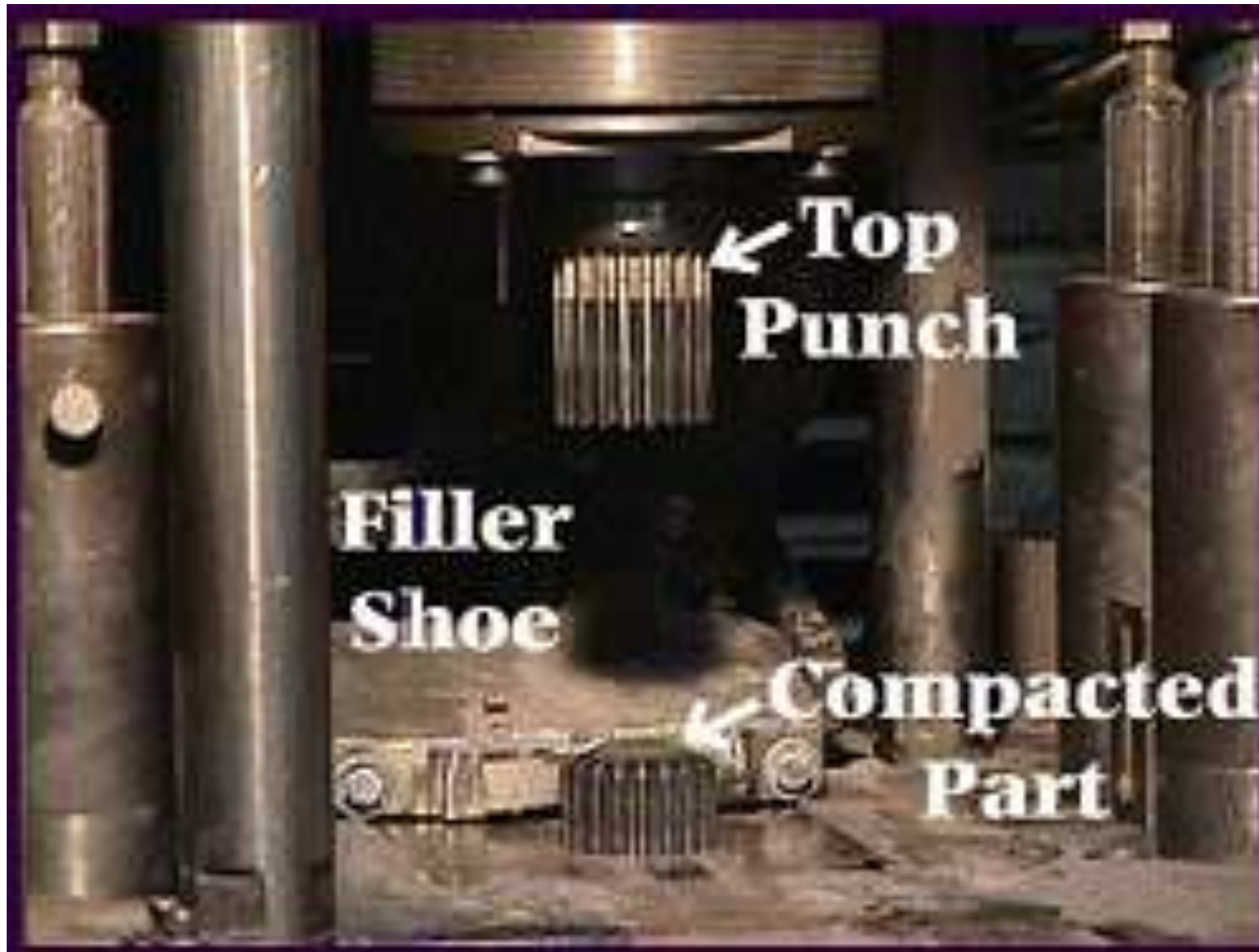
Hazards of Blending

- ▶ Metal powders are explosive because of the high surface area-to-volume ratio (mostly aluminum, magnesium, titanium, zirconium, and thorium)
- ▶ Most be blended, stored, handled with great care
- ▶ Precautions
 - ▶ Grounding equipment
 - ▶ Preventing sparks
 - ▶ Avoiding friction as a source of heat
 - ▶ Avoiding dust clouds
 - ▶ Avoiding open flames
 - ▶ Avoiding chemical reactions

Compaction of Metal Powders

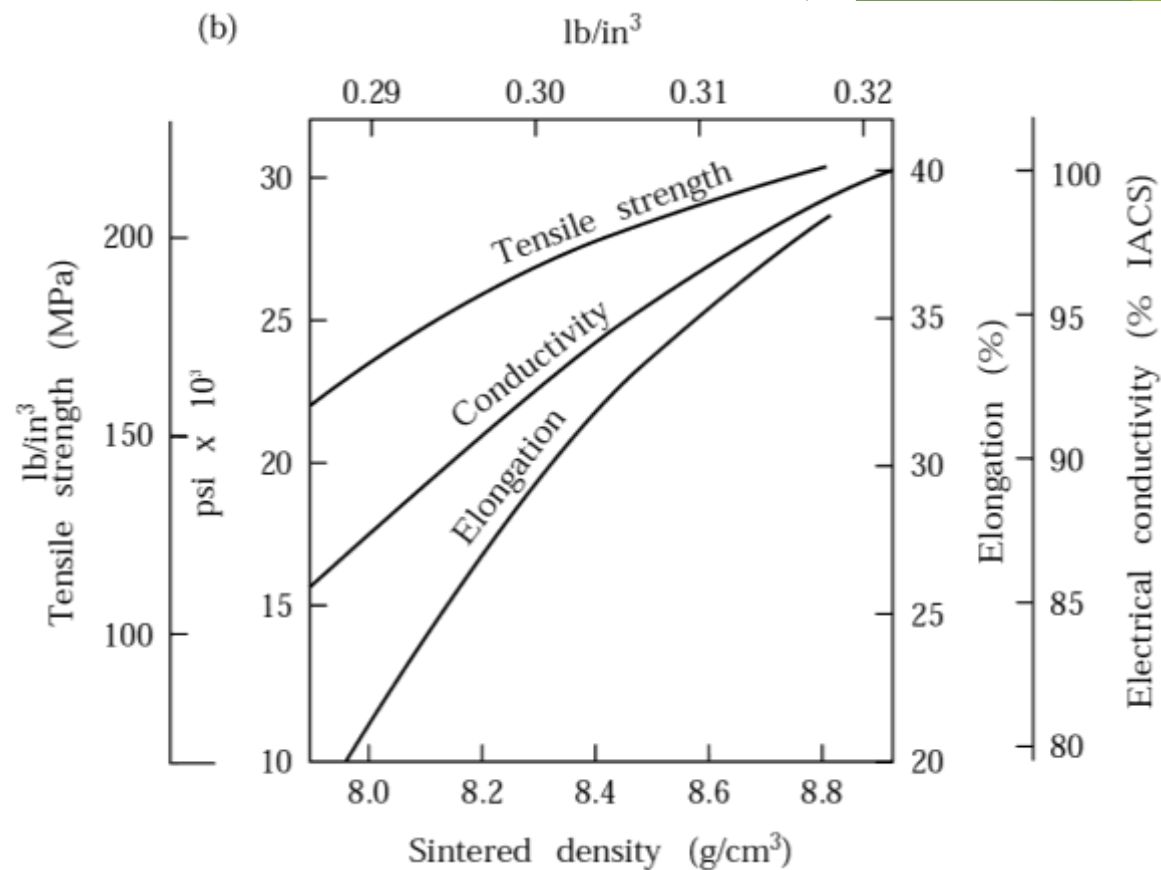
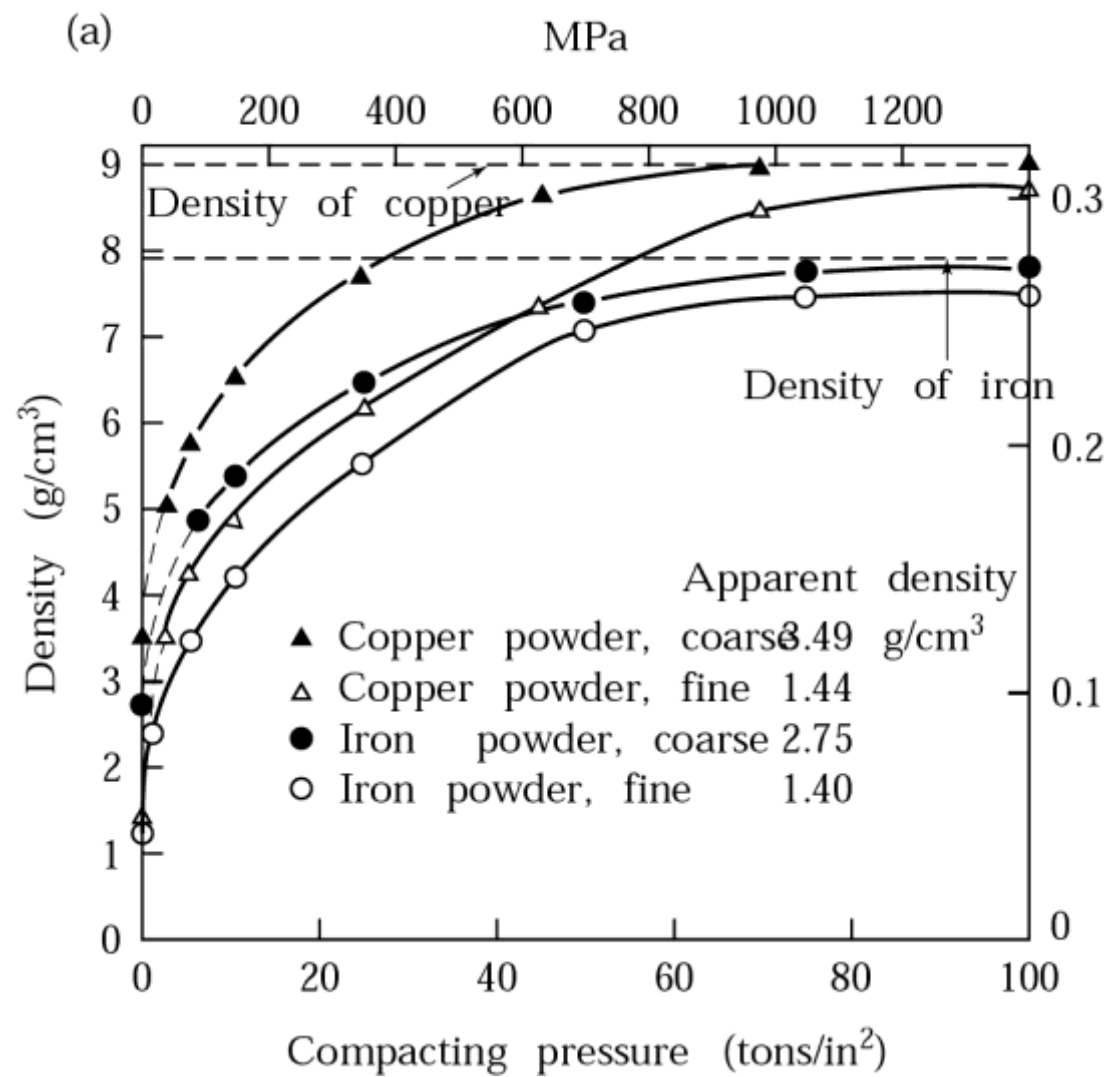
- ▶ The third step in the P/M process which the blended powders are pressed into various shapes in dies
- ▶ The purpose of compaction is to obtain the required shape, density, and particle-to-particle contact and to make the part sufficiently strong for further processing
- ▶ Green compact is known as pressed powder and is very fragile and can be crumbled like chalk





- ▶ The density of a green compact depends on the pressure applied
- ▶ Important factor in density is the size distribution of the particles
- ▶ If all particles are the same size then there will always be porosity (ex. box filled tennis balls will always have space in between them)

- ▶ The higher the density, the higher the strength and elastic modulus
- ▶ The higher the density, the higher the amount of solid metal in the same volume and then the higher the strength



COMPACTION

- To achieve greater densities requires an external pressure.

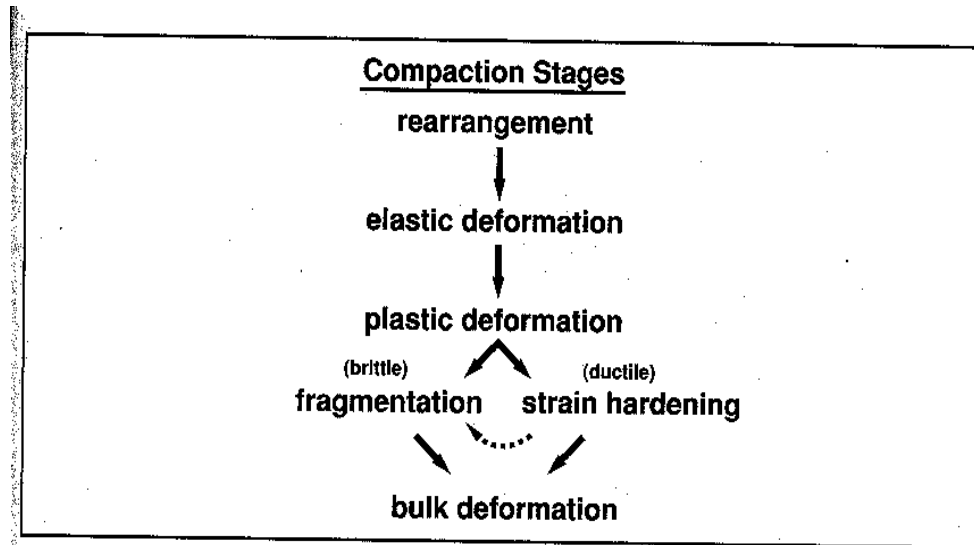


Figure 6.19. A flow chart of the compaction process, giving the key differences in the behavior of ductile and brittle powders.

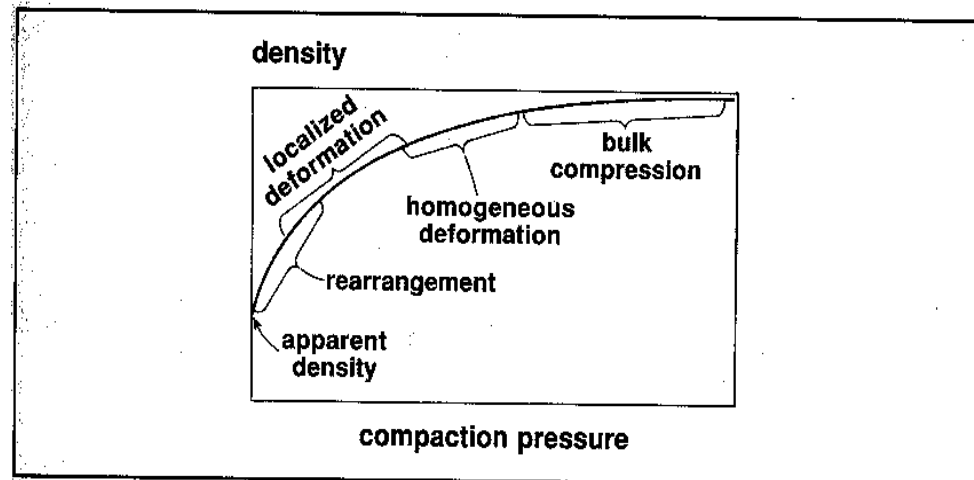


Figure 6.16. A sketch of the density versus compaction pressure during metal powder compaction, showing key stages and declining compressibility as the density increases.

Stages of Compaction

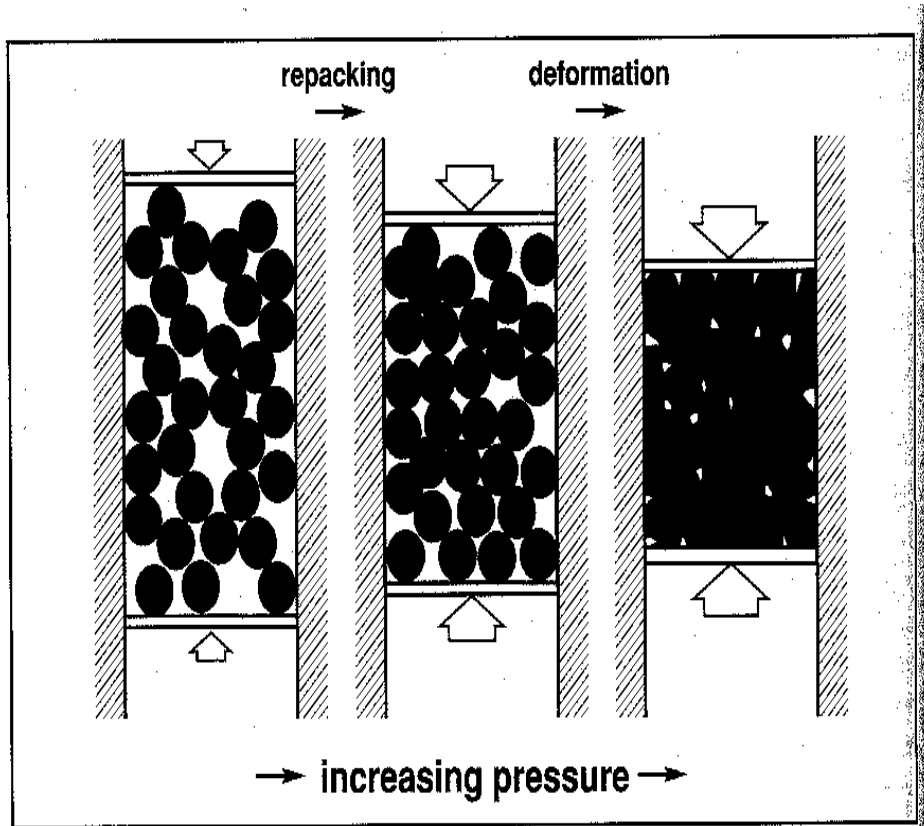


Figure 6.17. A simplified view of the stages of metal powder compaction. Initially repacking occurs with the elimination of particle bridges. With higher compaction pressures, particle deformation is the dominant mode of densification.

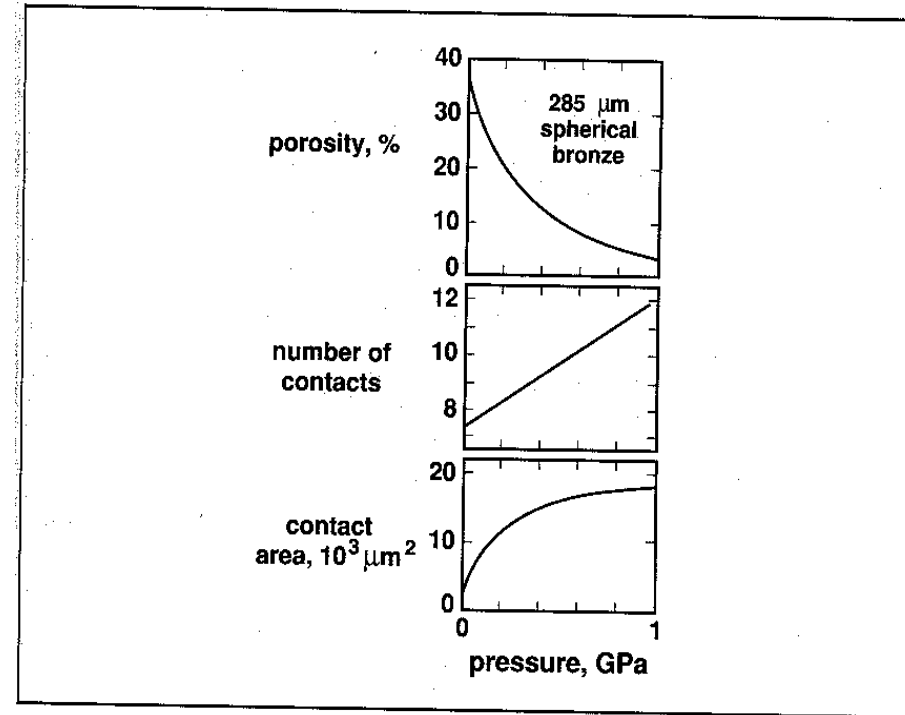


Figure 6.18. Data for the die compaction of a spherical bronze powder. The upper plot shows the porosity decrease with pressurization, the middle plot shows the average number of contacts per particle (repacking), and the lower plot gives the contact area (deformation). Compaction involves both particle repacking and deformation mechanisms.

Conventional Compaction

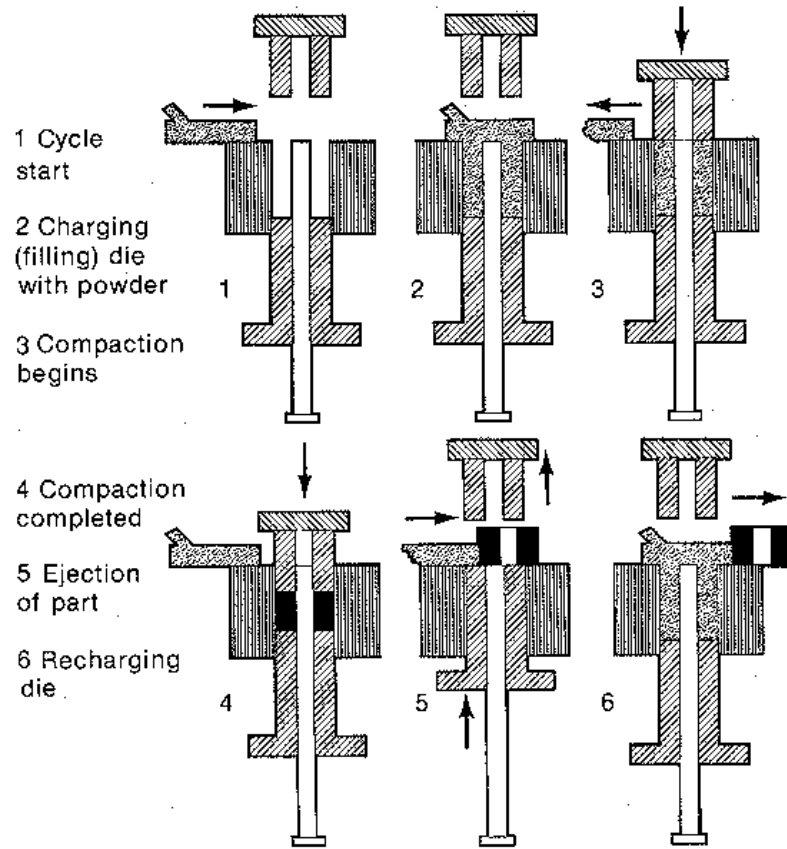


Figure 3 Pressing Cycle For A Single Level Part

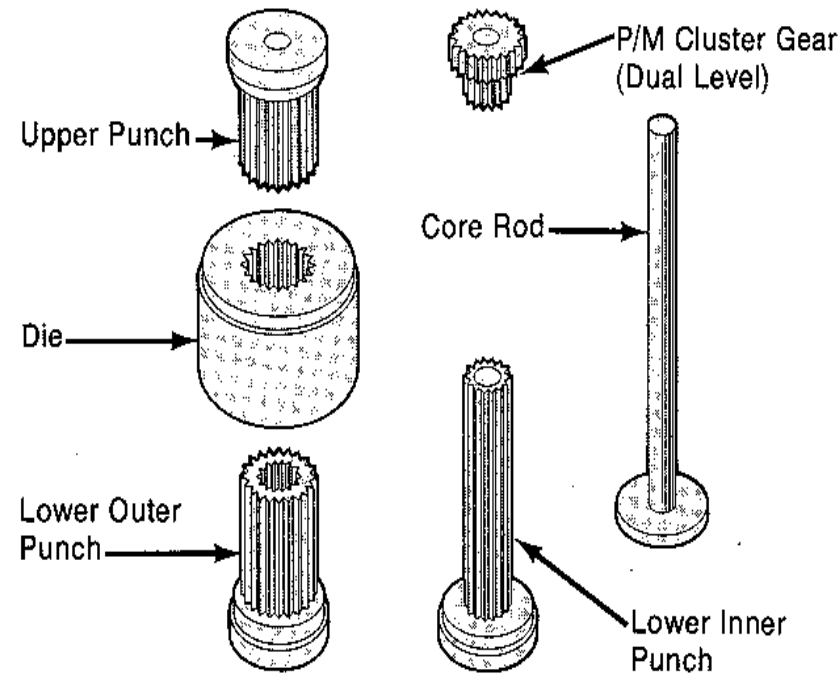
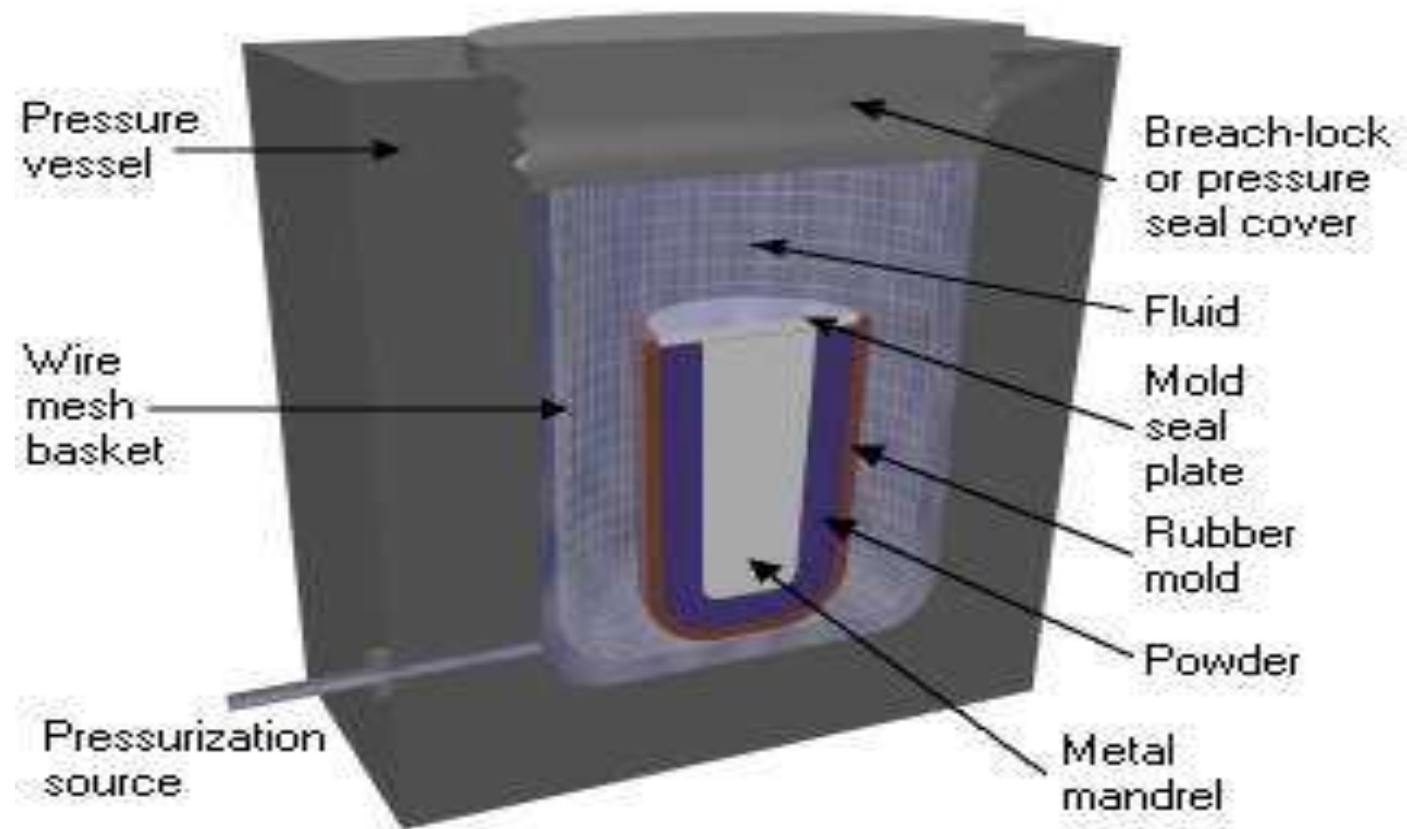
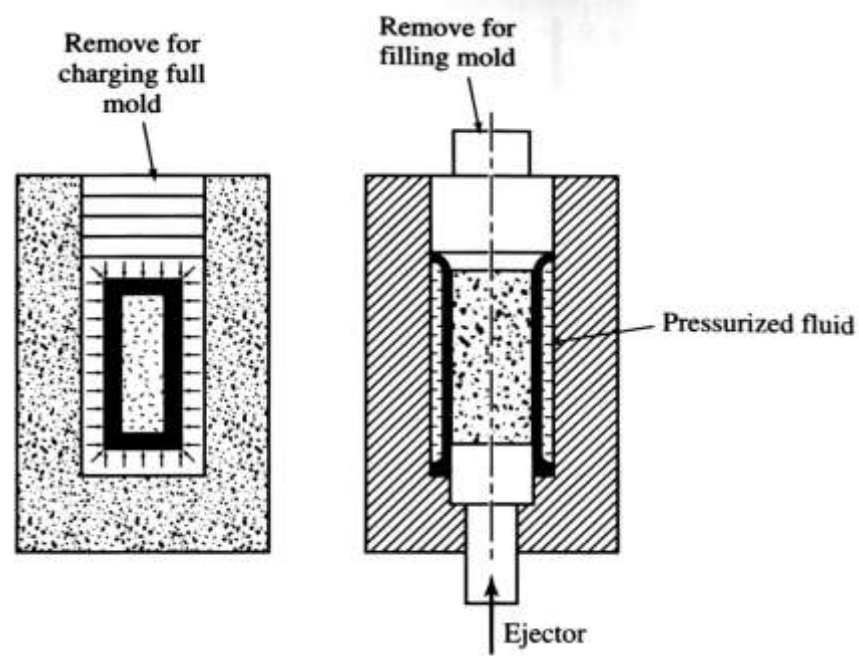


Figure 4 P/M Tooling For A Two-Level Part

Isostatic Pressing



Isostatic Pressing



- Because of friction between particles
 - Apply pressure uniformly from all directions (in theory)
- Wet bag (left)
- Dry bag (right)

Powder-injection molding (PIM)

- ▶ Metals melting above 1000°C (1830°F)
(carbon, stainless steels, copper, bronze, titanium)
- ▶ Ex. Watches, parts for guns, door hinges surgical knives
- ▶ **Advantages**
 - ▶ Complex shapes
 - ▶ Dimensional tolerances good
 - ▶ High production rates

Disadvantage: high cost and limited availability of fine metal powders

Powder-injection molding (PIM)

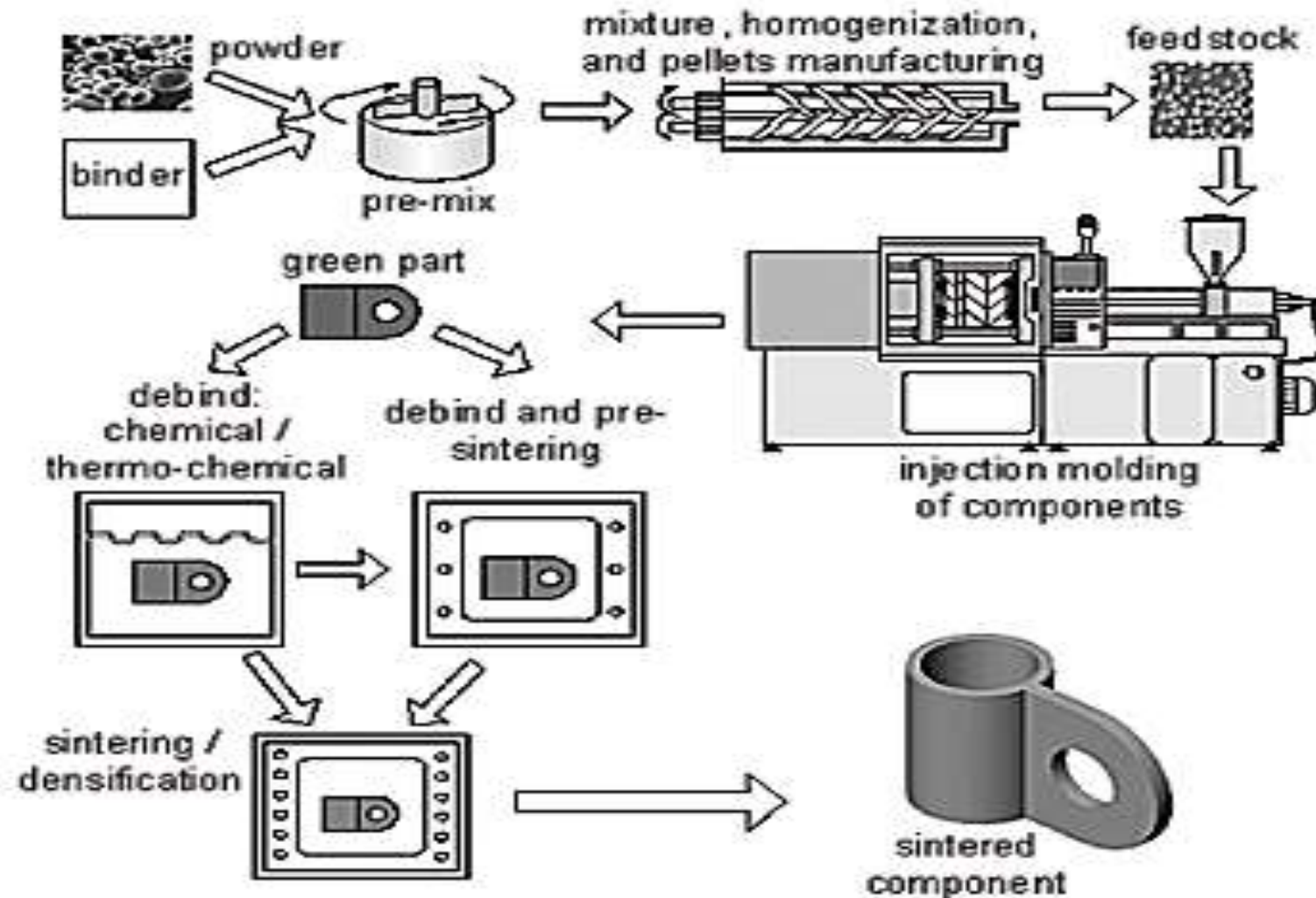
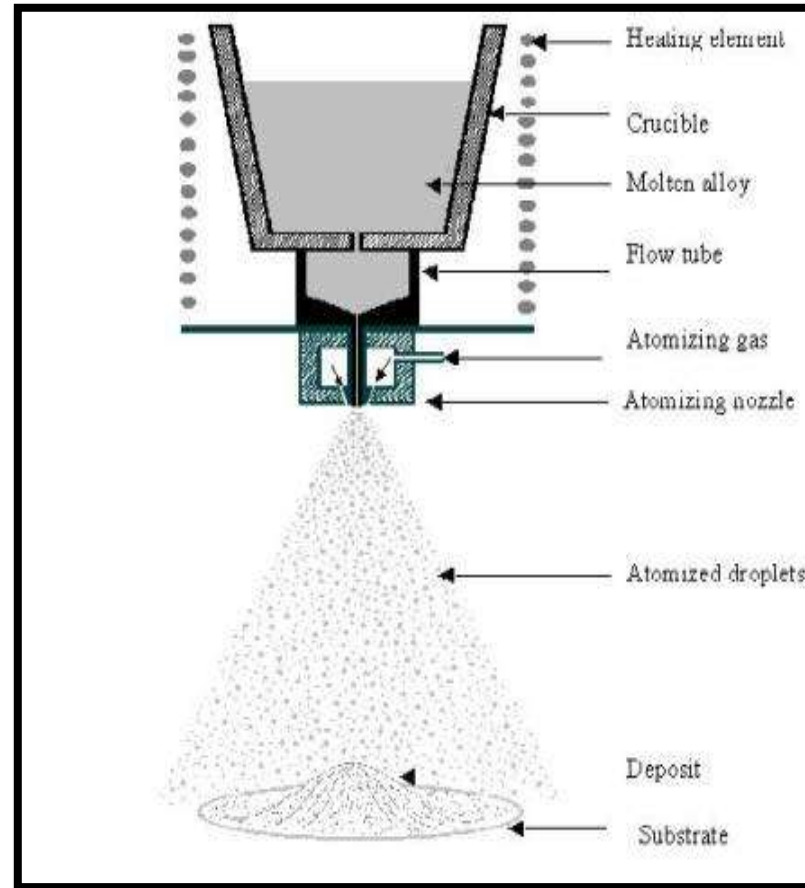


Figure 3. Sketch of the PIM process (adapted from German & Bose, 1997).

Spray Deposition

- Shape-generation process
- Used to produce seamless tubing and piping
- Produces 99% solid metal density
- *Osprey Process*



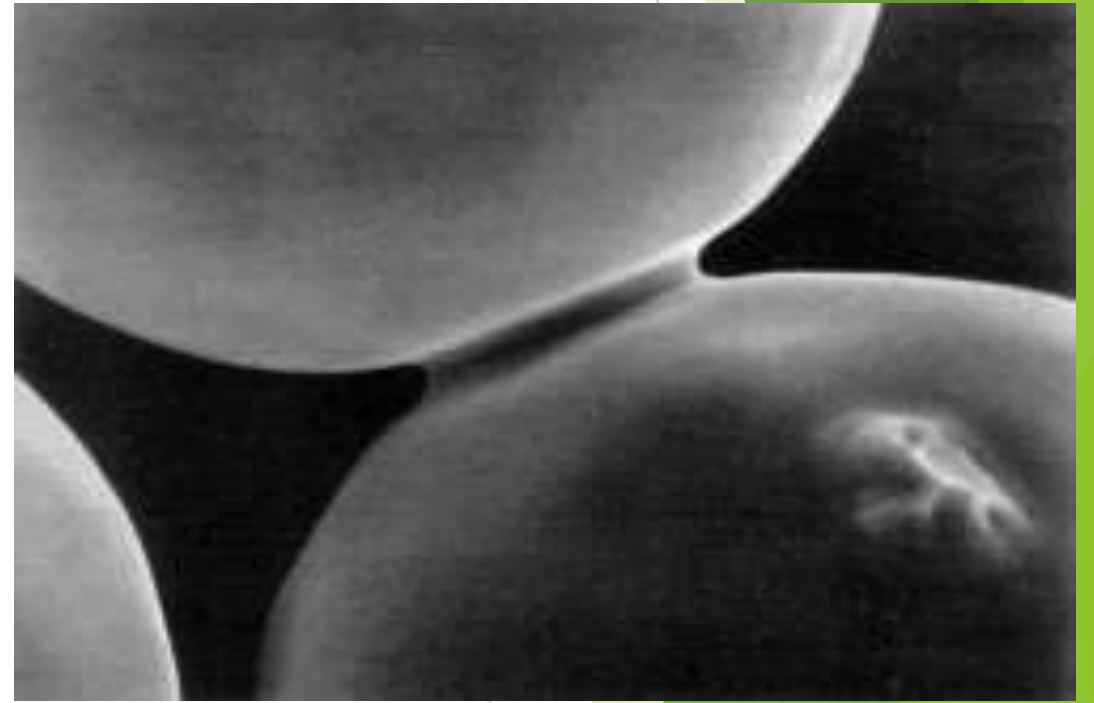
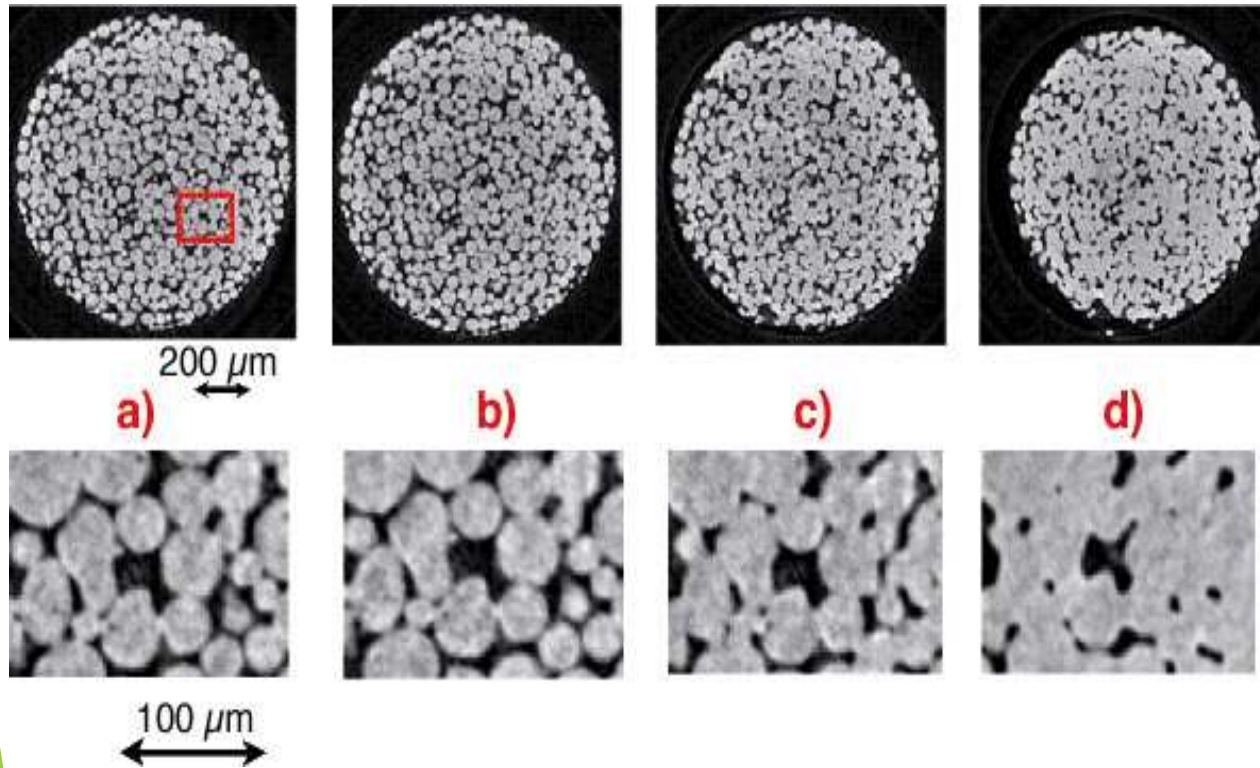
Other Compacting and shaping processes

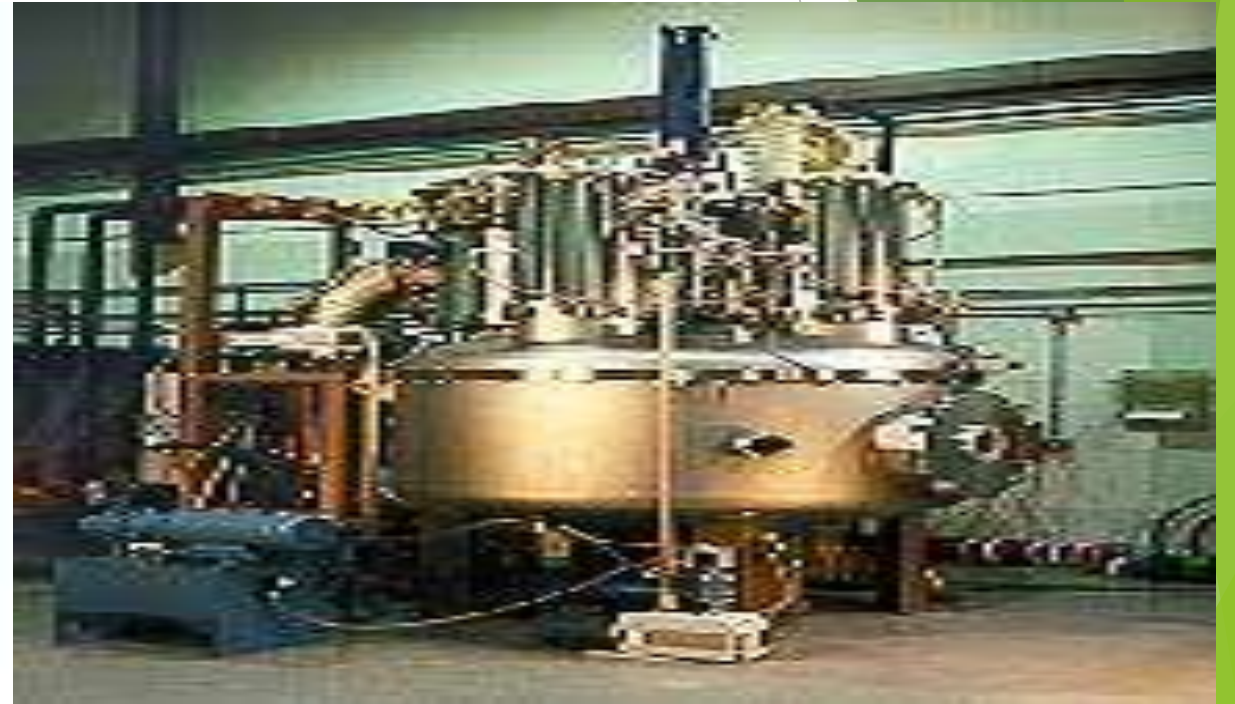
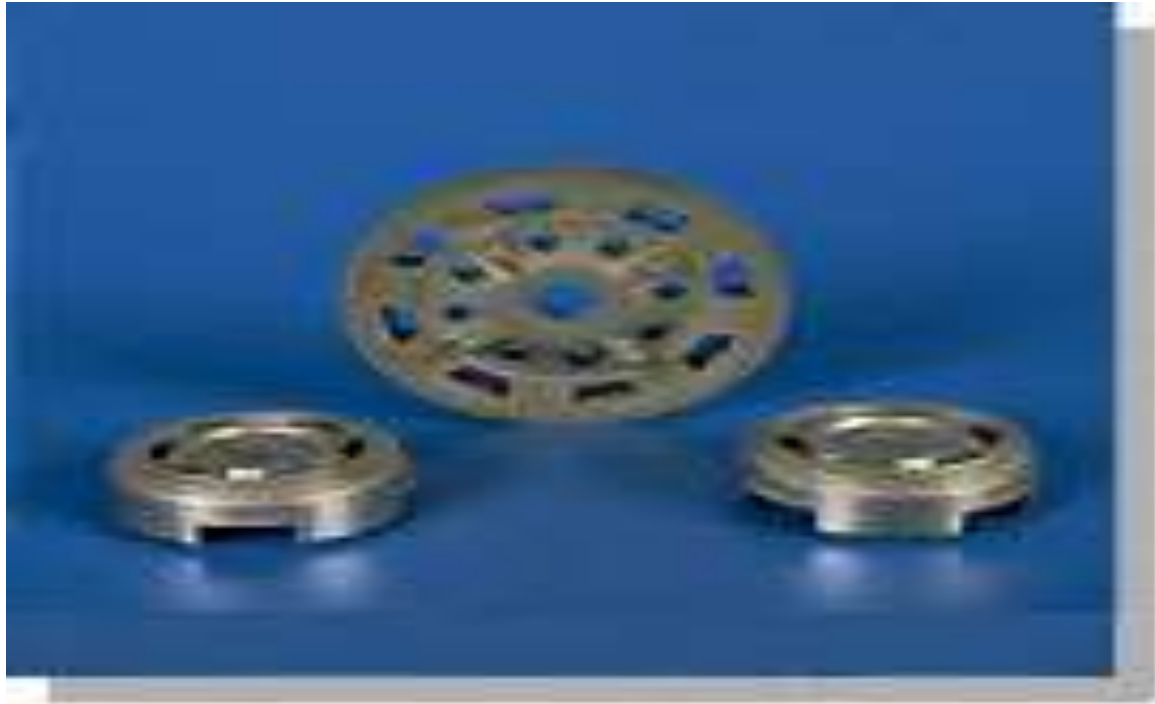
- ▶ Powder rolling (roll compaction)
- ▶ Extrusion
- ▶ Pressureless compaction
- ▶ Ceramic molds

Sintering

- ▶ Green compacts
- ▶ Temperature within 70-90% of melting point
- ▶ Sintering time from 10 minutes to 8 hours
- ▶ Furnace atmosphere (hydrogen, burned ammonia, partially combusted hydrocarbon gases, nitrogen)
- ▶ Diffusion mechanism
- ▶ Vapor-phase transport
- ▶ Liquid-phase sintering
- ▶ Spark sintering

Sintering metal powders, sintering products, sintering furnace





SINTERING



Secondary and finishing operations

- ▶ Coining and sizing
- ▶ Impact forging
- ▶ Machining
- ▶ Grinding
- ▶ Plating
- ▶ Heat treating
- ▶ Impregnating
- ▶ Infiltration

Die Design for P/M

- ▶ Thin walls and projections create fragile tooling.
- ▶ Holes in pressing direction can be round, square, D-shaped, keyed, splined or any straight-through shape.
- ▶ Draft is generally not required.
- ▶ Generous radii and fillets are desirable to extend tool life.
- ▶ Chamfers, rather the radii, are necessary on part edges to prevent burring.
- ▶ Flats are necessary on chamfers to eliminate feather-edges on tools, which break easily.

Advantages of P/M for Structural Components:

These may be classified into two main headings;

- (a) Cost advantages, and
- (b) Advantages due to particular properties of sintered components.

Cost Advantages:

- (i) Zero or minimal scrap;
- (ii) Avoiding high machining cost in mass production as irregularly shaped holes, flats, counter bores, involute gear teeth, key-ways can be molded into the components;
- (iii) Extremely good surface finish at very low additional cost after sizing and coining;
- (iv) very close tolerance without a machining operation;
- (v) Assembly of two or more parts (by I/M) can be made in one piece;
- (vi) Separate parts can be combined before sintering.
- (vii) High production rates

Advantages of P/M for Structural Components:

- (i) Improved surface finish with close control of mass, volume and density;
- (ii) Components are malleable and can be bent without cracking.

- ❖ P/M makes possible the production of hard tools like diamond impregnated tools for cutting porcelain, glass and tungsten carbides.

- ❖ Reactive and non-reactive metals (both having high m.p & low m.p) can be processed.

Limitations of P/M Process

There are numbers of limitations of Powder Metallurgy process as given below:

- (i) In general, the principal limitations of the process are those imposed by the size and shape of the part, the compacting pressure required and the material used.
- (ii) The process is capital intensive and initial high costs mean that the production ranges in excess of 10,000 are necessary for economic viability (cost of dies is very high).
- (iii) The configuration of the component should be such that it can be easily formed and ejected from a die, undercuts and re-entrant angles can not be molded (when using conventional pressing and sintering) and have to be machined subsequently.

- (iv) The capacity and stroke of the compacting press and the compacting pressure required limit the cross-sectional area and length of the component.
- (v) Spheres cannot be molded and hence a central cylindrical portion is required.
- (vi) Sintering of low melting point powders like lead, zinc, tin etc., offer serious difficulties.

Disadvantages of P/M

- ▶ Limited in size capability due to large forces
- ▶ Specialty machines
- ▶ Need to control the environment - corrosion concern
- ▶ Will not typically produce part as strong as wrought product. (Can repress items to overcome that)
- ▶ Cost of die - typical to that of forging, except that design can be more - specialty
- ▶ Less well known process