ME 333 – Manufacturing Processes II

Chapter 4

Welding and Joining Processes

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- Manufacturing processes are operations for producing a single part (i.e. a part made from single piece of metal). However, in real life, very few parts consist of a single component.
- A product can be **an assembly** (a composition of single parts) or **a subassembly** (groups of single parts combined to serve certain purpose and forming part of a larger assembly).
- For instance, a simple ballpoint pen is an assembly that is composed of three single parts: a plastic tube and two caps, and one subassembly (a cartridge, which can be considered as an assembly of few more single parts).

- The processes for joining and assembling can be divided into two major classes:

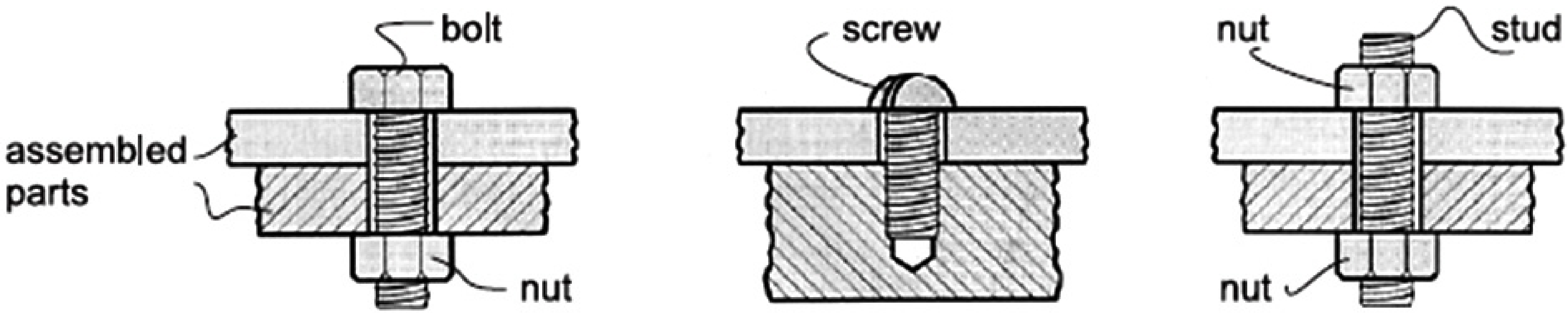
1. Non-permanent combining (multiple assembly/disassembly of single parts are allowed)
2. Permanent combining of single parts and/or subassemblies (eventual disassembling would result in severe damage to components in the assembly)

- Further classification is possible with respect to the operational methods used as follows:

1. **Mechanical Assembly:** involves use of various fastening methods to mechanically attach parts by permanent assembly (***riveting***, ***press fitting***, ***shrink fitting***) or non-permanent assembly (*assembly with threaded fasteners such as* ***screws***, ***bolts***, ***studs***, ***nuts***).
2. **Joining Processes:** parts are joined together to form a permanent assembly (***welding***, ***adhesive bonding***, ***brazing*** *and* ***soldering***).

Threaded Fasteners (non-permanent assembly)

- They are components that have external or internal threads for assembly of parts:
- **Bolt:** an externally threaded fastener that is inserted through holes in the parts and screwed into a nut on the opposite side.
- **Screw:** an externally threaded fastener that is usually assembled into a blind threaded hole and no nut is required.
- **Stud:** an externally threaded fastener without the bolt head. Studs can also be used to assemble two parts using a nut. They are available with threads on one end or both.
- **Nut:** an internally threaded fastener having standard threads.



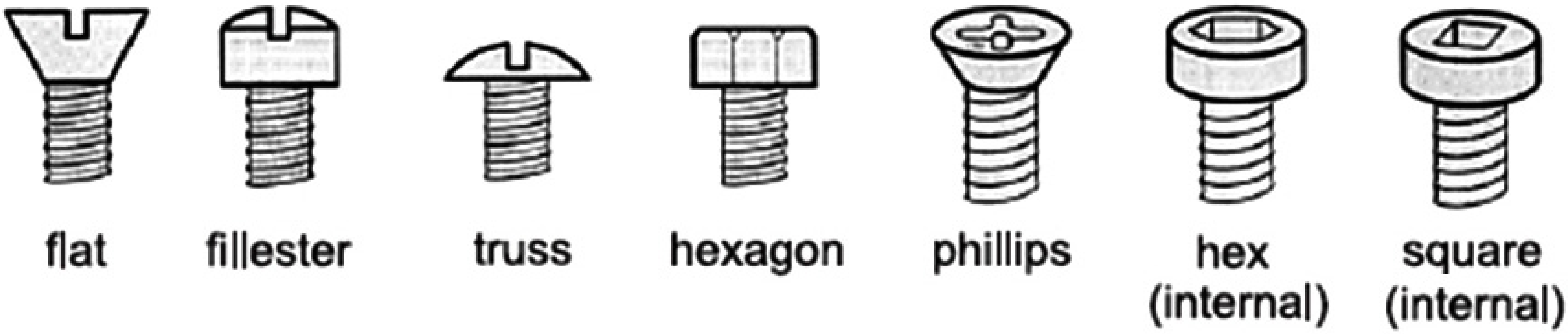
(a) bolt & nut (b) screw (c) stud & nut

Head styles in threaded fasteners

- Threaded fasteners come in a variety of sizes, threads, and shapes. Also, numerous head styles are available on bolts and screws, some of which are illustrated in the figure.

- The geometries of these heads, as well as the variety of sizes available, require different hand tools for the operator.

- In addition to these, other types of threaded fasteners and related hardware are available. They include *screw thread inserts*, *captive threaded fasteners*, and *washers*.

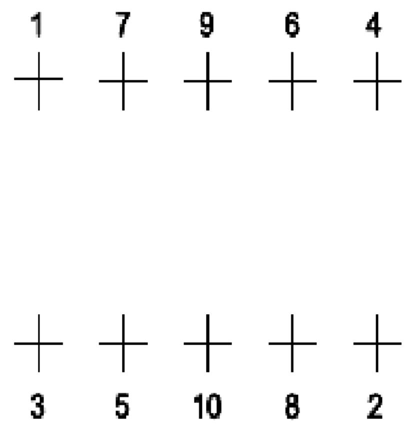


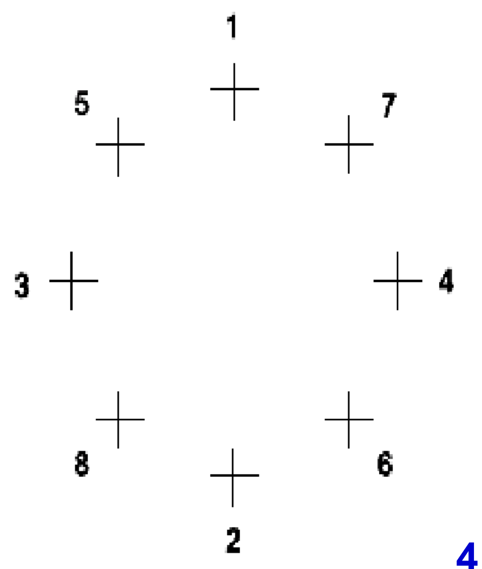
Tightening of threaded fasteners

- For threaded fasteners, **amount of torque** for tightening is significant. Once the fastener is rotated until it is seated against the part surface, additional tightening increases amount of tension in the fastener (and also amount of compression in the parts being held together).

- Various methods are employed to apply the required torque:
  – operator feel (not very accurate, but adequate for most assemblies)
  – torque wrenches (more powerful for easier tightening)
  – powered wrenches (designed to stall when the required torque is reached)
  – torque-turn tightening (initially tightening to low torque, then to specified additional amount)

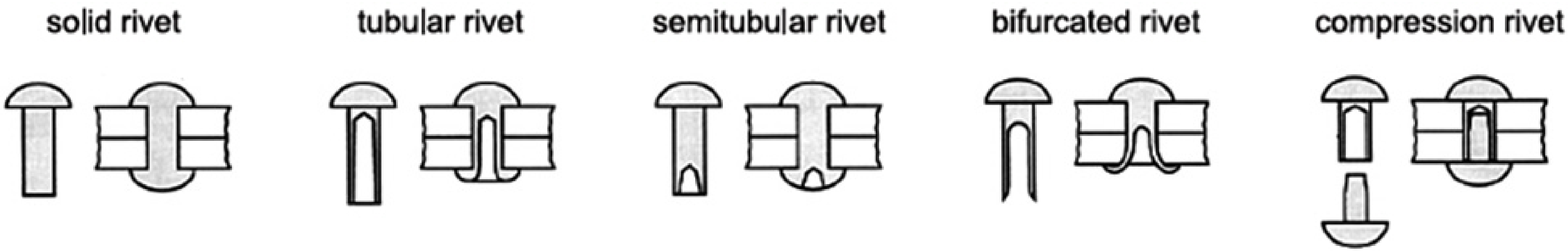
- An important issue in case of tightening multiple threaded joints is to select the proper sequence of tightening. In the figure shown, tightening is typically done in three steps:
  – *first, initial tightening with 1/3 torque*
  – *then, more tightening to 2/3 of the max. torque*
  – *finally, tightening to the full amount of torque*





Riveting (permanent assembly)

- **A rivet** is an unthreaded, headed pin used to join parts by passing the pin through holes in the parts and then forming (upsetting) the second head in the pin on the opposite side.
- Deforming operation can be performed hot or cold and by hammering or steady pressing. Once the rivet was deformed, it cannot be removed except by breaking one of the heads.
- Five basic geometries that affect how the rivet will be upset to form the second head:



- Riveting offers high production rates, simplicity, and low cost. Despite these, its applications have declined recently in favor of threaded fasteners, welding, and adhesive bonding.
- Riveting is used as one of the primary fastening processes in **aircraft and aerospace industries** for joining skins to channels and other structural members.
- Much of the equipment is portable and manually operated. Automatic drilling and riveting machines are available for drilling the holes and then inserting and upsetting the rivets.

Press Fits and Shrink/Expansion Fits (permanent assembly)

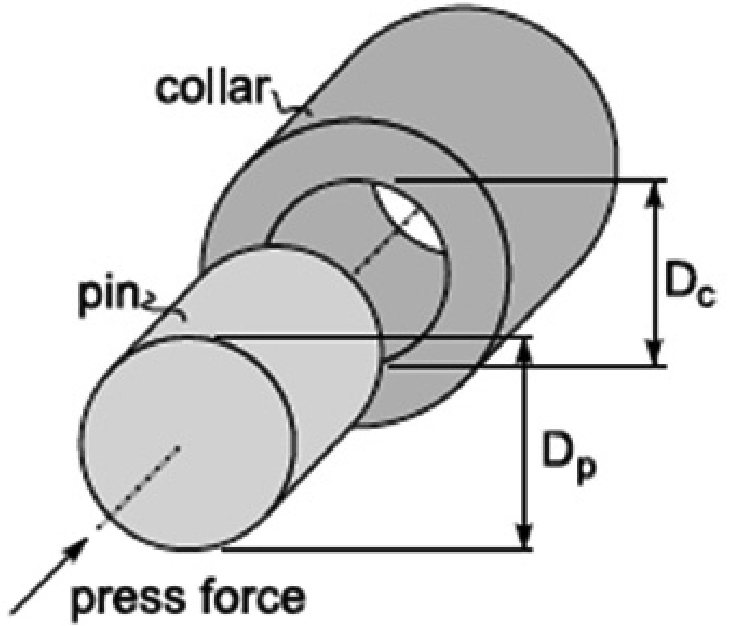
- Assembly methods based on mechanical interference between mating parts being joined.

Press Fitting

- In press fit assembly, two components have **an interference fit** between them. The typical case is when a pin with diameter **Dp** is pressed into a hole (collar) of a slightly smaller diameter **Dc** (*as given in figure*).

- Applications of press fitting include locating and locking the components such as *assembly of collars, gears, pulleys, and similar components onto shafts*.

- The major limitations are the necessity of a substantial press force and possible damage to the surfaces of components during press fitting. *These limitations are eliminated in the process of shrink fitting.*



Shrink Fitting & Expansion Fitting

- In **shrink fitting**, external part is heated to enlarge by thermal expansion while internal part either remains at room temperature or cooled to contract its size. The parts are then assembled and brought back to room temperature so that the external part shrinks and the internal part (if previously cooled) expands to form a strong interference fit.

- A modification of the shrink fitting method is so called **expansion fitting** that occurs when only the internal part is cooled to contract it for assembly. Once inserted into the mating component, it warms to room temperature, expanding to create the interference assembly.

- Various methods are used to accomplish **heating and/or cooling of the workparts**. Heating equipment includes *torches*, *furnaces*, *electric resistance heaters*, and *electric induction heaters*. Cooling methods include *conventional refrigeration*, *packing in dry ice*, and *immersion in cold liquids (including liquid nitrogen)*.

- **The change in diameter** resulting from heating/cooling depends upon the coefficient of thermal expansion and the temperature difference that is applied to the parts.

- These methods are used to *fit gears, pulleys, sleeves and other components onto solid and hollow shafts*. However, the most popular application is *to fit bearing onto shafts*.

- Welding is a permanent joining process where **coalescence** (unite of microstucture) is obtained **by heat and/or pressure**. It also refers to **metallurgical bonding** due to attracting the forces between atoms. Assemblage of parts is called **weldment**.

- Many welding processes were developed, which differ in manner of applying heat/pressure and equipment used. They are classified according to the state of base material during welding:
  - **Liquid-state (fusion) welding (F):** Coalescence is done **by melting** the surfaces to be joined (in some cases, filler metal is added to joint).
  - **Solid-state welding (S):** Coalescence is achieved by heat/ pressure, but **no melting** of base metal occurs and no filler metal is added.

- Coalescence is improved by **cleanliness of surfaces** to be welded.
- **Surface oxides** must be removed as they are entrapped in solidifying metal. **Fluxes** are used to remove oxides in **fusible slag** protecting weld surface from atmospheric contamination.
- Arc welding uses coated electrodes. In gas/forge welding, a powder form is used, e.g. *borax* or *NH_4Cl (ammonium chloride - nışadır)*.

Common welding processes:

- Soldering & Brazing (F)
- Forge welding (S)
- Oxyfuel gas welding (F)
- Resistance welding (F)
  - Spot welding
  - Seam welding
  - Butt welding
  - Projection welding
  - Induction welding
- Arc welding (F)
  - Carbon & metal electrodes
  - Gas metal arc welding
  - Submerged arc welding
  - Plasma arc welding
- Friction welding (S)
- Cold roll welding (S)
- Diffusion welding (S)
- Explosion welding (S)

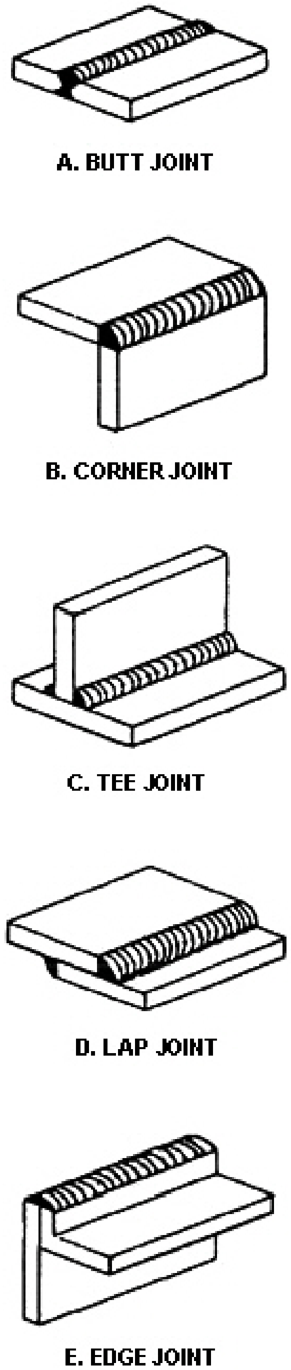
Types of Joints & Welds

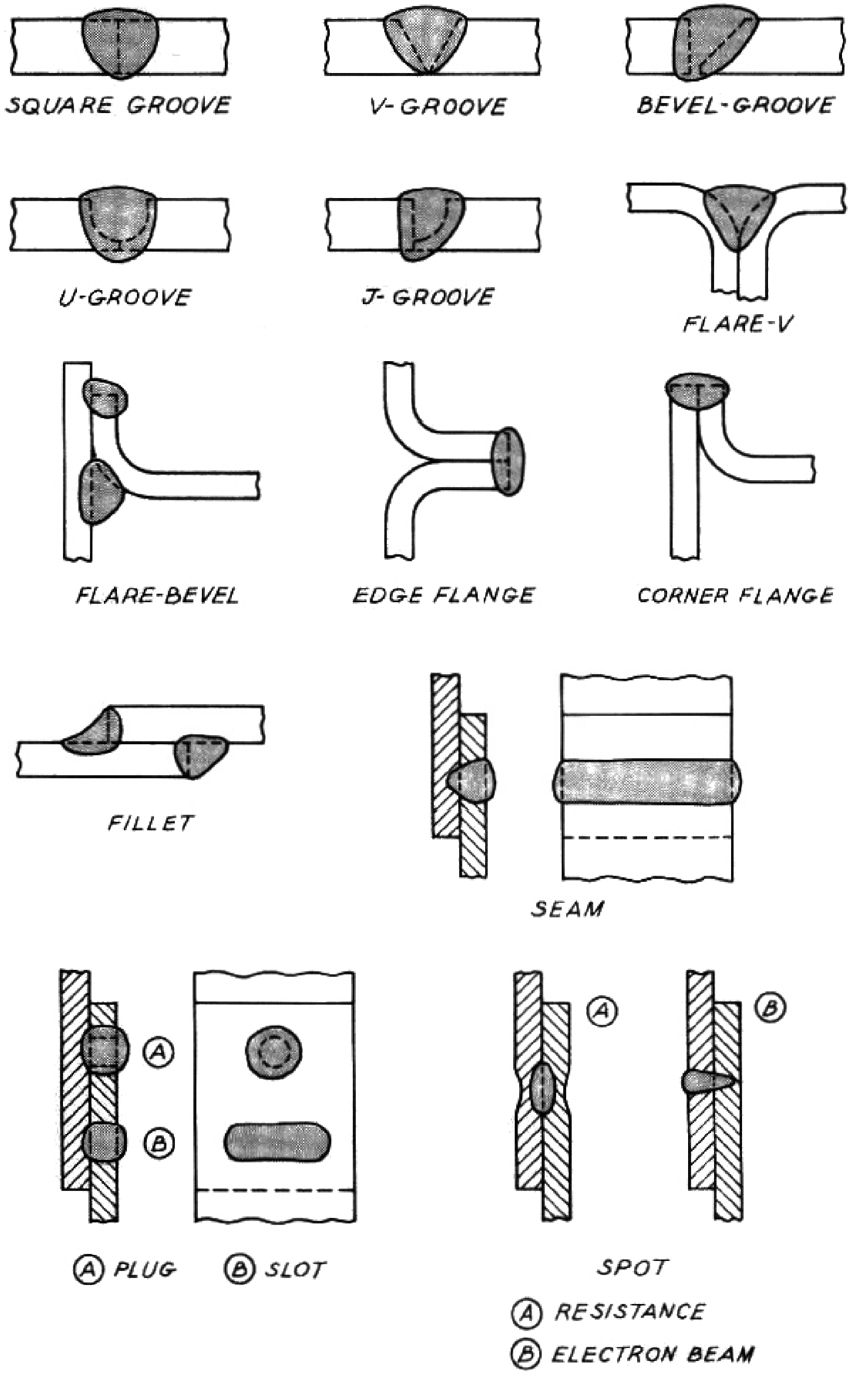
Types of Joints:

1. Butt joint
2. Corner joint
3. Lap joint
4. Tee joint
5. Edge joint

Types of Welds:

1. Fillet weld
2. Groove weld
3. Plug and Slot weld
4. Spot and Seam weld
5. Flange weld
6. Surface weld

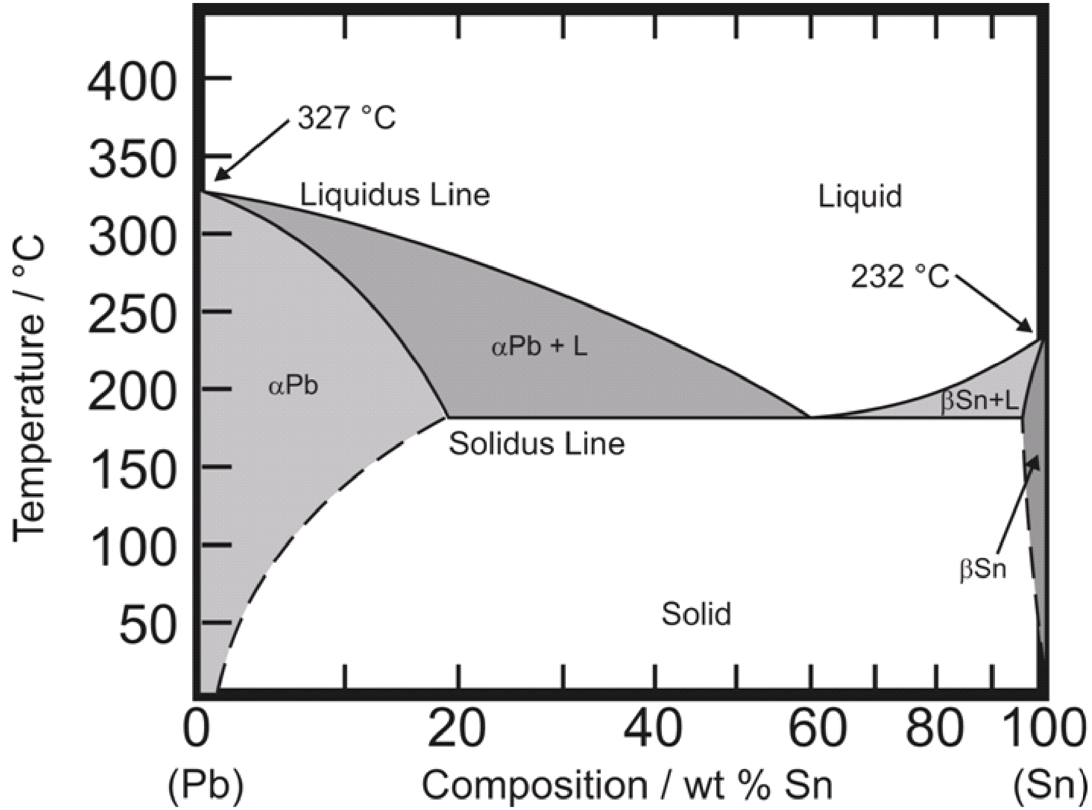




- **Soldering (*yumuşak lehim*)** and **brazing (*sert lehim*)** are processes that unite metals with a third joining metal (***filler metal***) which is introduced into the joint in a liquid state and allowed to solidify. These processes have *wide commercial use in the uniting of small assemblies, in repair work and electrical parts*.

Soldering

- Lead and tin alloys (with melting range of 180-370 °C) are mainly used in soldering.
- Commonly used composition is **50% Pb & 50% Sn** that melts **at 220 °C**. In order to lower price or increase properties, *alloying elements (Cd, Ag, Cu, Zn)* can be added.
- Although any heating method can be used (dipping, torch, electrical resistance), it is usually done with **soldering iron**.
- **Strength is low.** Thus, commonly used in electronic industry.



Brazing

- This is similar to soldering, but temperature is **above 430 °C** (should be lower than melting points of parent metals). Non-ferrous filling metal is distributed by capillary attraction.

- Brazing metals and alloys are as follows:
  - **Copper:** melting point of 1083 °C
  - **Copper alloys:** brass and bronze (melting point from 870 °C to 1100 °C)
  - **Silver alloys:** melting points from 630 °C to 845 °C
  - **Aluminum alloys:** melting point from 570 °C to 640 °C

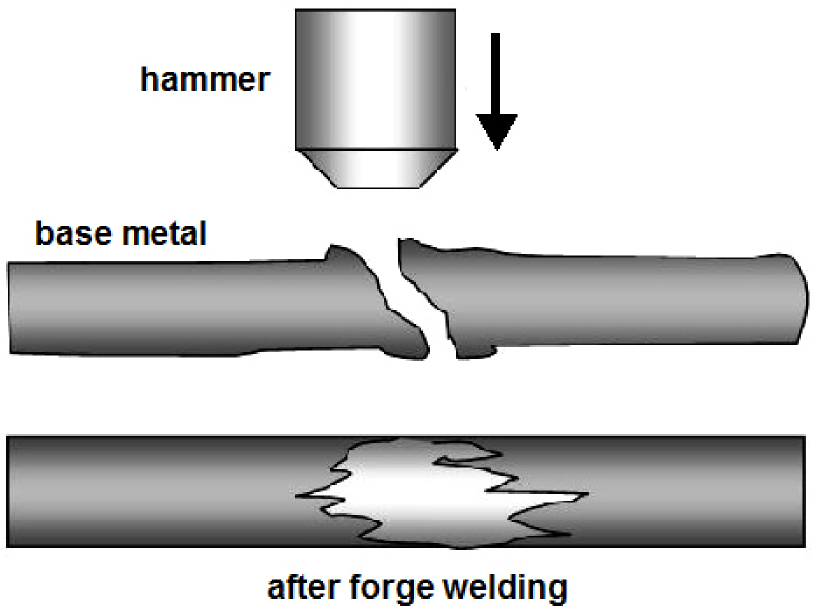
- In addition to dipping, furnace, electric; **oxyacetylene torch** provides an excellent source of heat for many applications. **Borax** is the commonly used salt as flux.

- Brazing is used for *the assembly of pipes to fittings, cemented carbide cutting tips to holders, radiators, electrical parts, etc*. **It is quite strong as compared to soldering.**

Brazing and Braze Welding

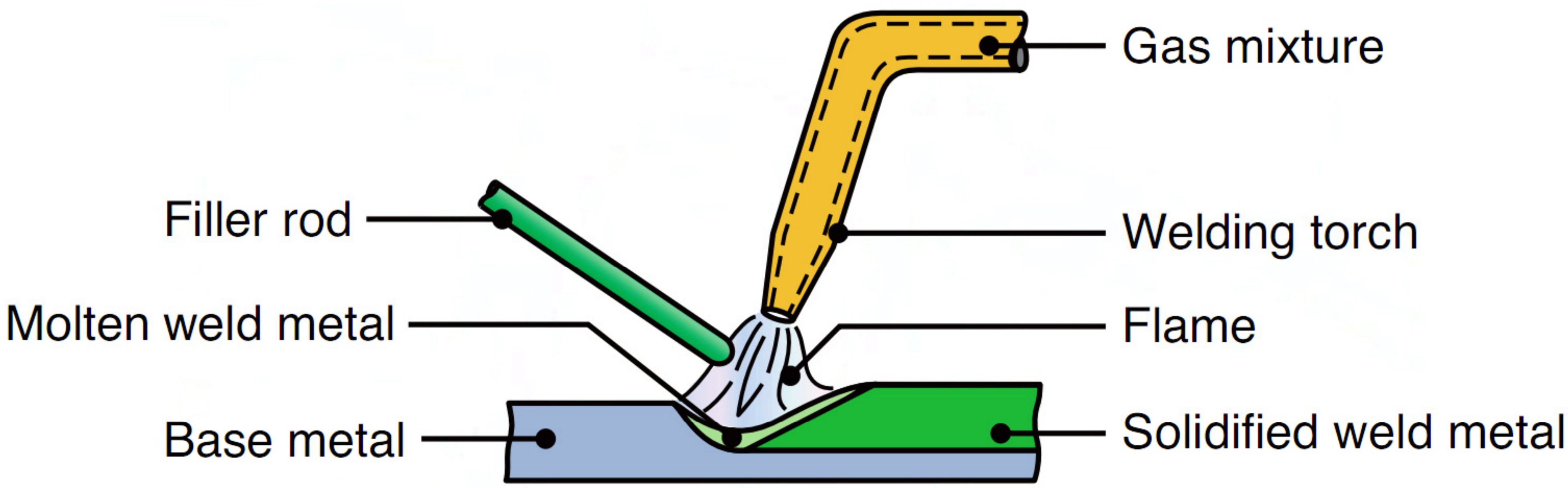
- **Dipping**: Metal, Chemical
- **Furnace**: Gas, Electric
- **Torch**: Oxyacetylene, Oxyhydrogen
- **Electric**: Resistance, Induction
- **Welding**: Torch, Arc

- It is **the oldest welding process**, usually done in coal or coke-fired forge.
- The pieces are formed to correct shape before heating. Borax alone or in combination with NH_4Cl is commonly used as flux.
- Generally **low carbon steels or wrought irons** are welded by this technique. Heated pieces are **hammered to form weld**.
- Process is rather slow, and there is considerable danger of an oxide scale forming on the surface.
- Considerable skill is required by the craftsmen who practices it to achieve a good weld. The process has historical role in development of welding technology. However, it is of minor commercial importance.



- **Oxyfuel gas welding** is the group of fusion operations that burn various fuels mixed with oxygen *to perform welding or cutting*.

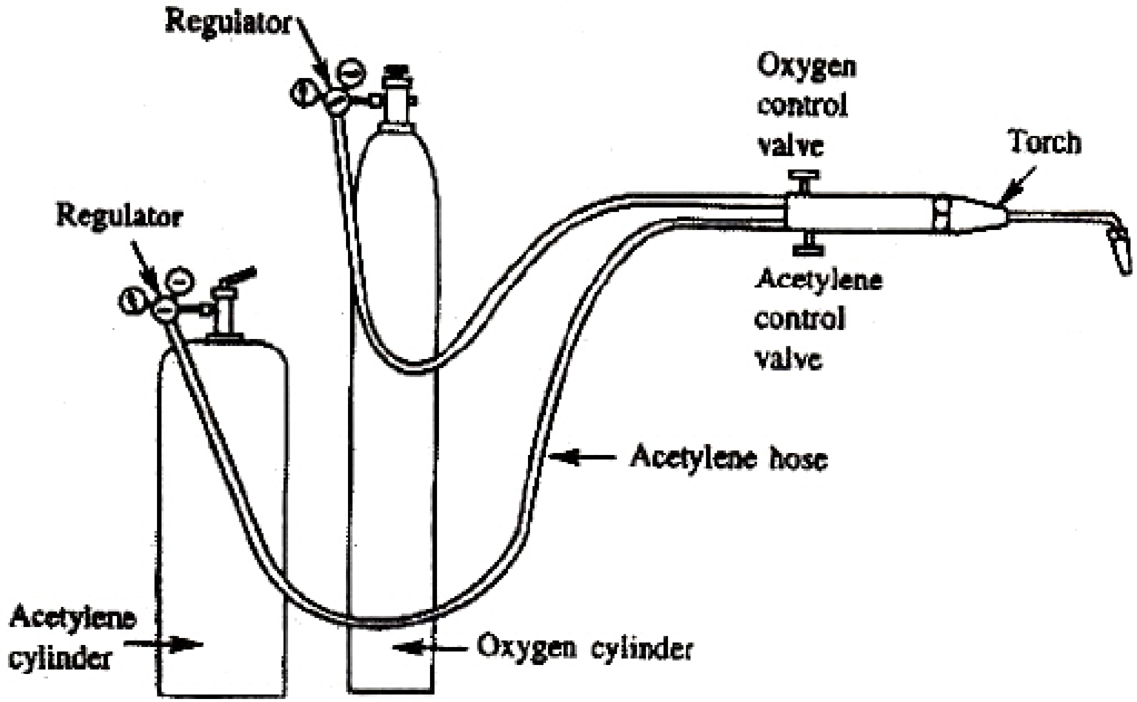
- **Oxyacetylene Welding (OAW)** is **a fusion welding process** performed by use of high-temperature flame from combustion of acetylene and oxygen.
- The flame is directed by a welding torch while a filler metal is added.
- Composition of filler material must be similar to that of the base metal.



- **Oxygen** is obtained by liquefying air and separating oxygen from nitrogen.
- **Acetylene gas** is obtained by dropping lumps of calcium carbide in water.

$$\underbrace{CaC_2}_{\text{calcium carbide (karpit)}} + \underbrace{2H_2O}_{\text{water}} \Rightarrow \underbrace{Ca(OH)_2}_{\text{slaked lime (sönmüş kireç)}} + \underbrace{C_2H_2}_{\text{acetylene gas}}$$

- OAW equipment is relatively inexpensive and portable. It is economical, versatile process that is well suited to low-quantity production and repair jobs.
- Although OAW can be mechanized, it is usually performed manually. Thus, it is highly dependent on the skill of welder to produce a high-quality weld joint.



➤ **The proportion of gases** is of extreme importance for the characteristics of flame:

1. **Neutral flame:** the widest application in welding and cutting operations. Bright core requires **one-to-one mixture**. Oxygen for the other envelope comes from atmosphere. The maximum temperature obtained is from 3300 °C to 3500 °C.

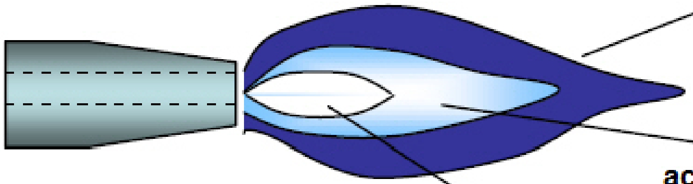
2. **Reducing (carburizing) flame:** If **excess acetylene** is used, the flame is longer than neutral flame. Too much acetylene causes sootiness (*is, kurum*). It is used in *welding of monel metal, nickel, certain alloy steels, hard-surfacing materials*.

3. **Oxidizing flame:** If the torch is adjusted to give **excessive oxygen**, a flame similar in appearance to the neutral flame is obtained, but bright cone is much shorter. This flame is *generally used in flame cutting*.


Neutral flame


Carburising flame


Oxidising flame

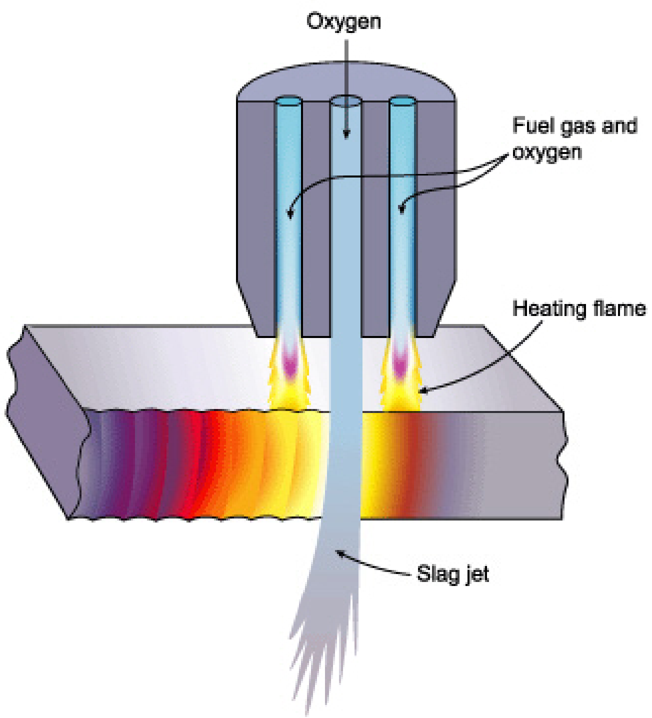


- **Cutting torch** differs from welding torch in such a way that it has several small holes for preheating the flames surrounding a central hole through which **pure oxygen** passes.

- The principle on which flame cutting operates is that ***oxygen has an affinity for iron and steel***. At high temperatures, this action is much more rapid. Oxidation is instantaneous and steel is actually burn into iron oxide.

- About 2.25 m^3 of oxygen is required to burn 1000 cm^3 of iron. Low carbon and low alloy steels (up to 760 mm thick) can be cut by this process. However, *cast iron, nonferrous alloys and high mangenese alloys are not readily cut by this process*.

- **Underwater cutting torches** are provided with an extra pressurized air hose that provides bubble around the tip of the torch to displace water. There are automatically operating machines to cut parts from steel straps of varying thickness.



- In this process, a heavy electric current is passed through the metals causing local heating at the joint, and the weld is completed by pressure.

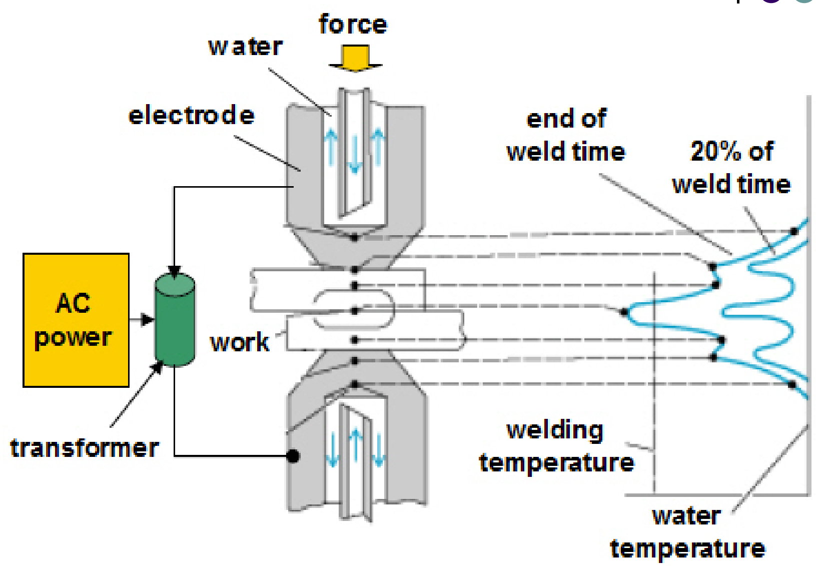
- A transformer reduces the alternating current voltage **from 220 V to around 4-12 V**, and raises the amperage to heat the sample. Heating takes place at the point of great resistance in the path. The amount of current necessary is **50-60 MVA/m^2** of the area to be welded for **10 s**. The necessary pressure will vary **from 30 to 60 MPa**.

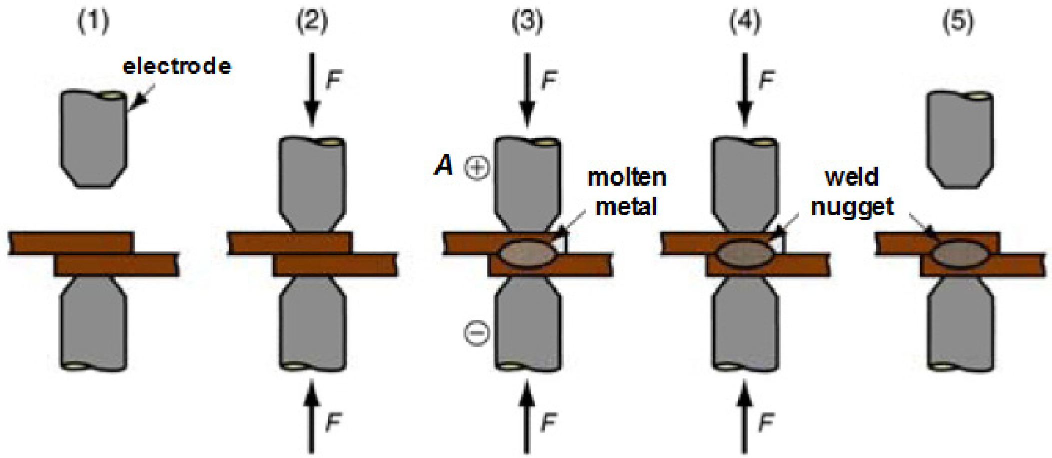
- Typical resistance welding processes are:
  - **Spot welding**
  - **Projection welding**
  - **Seam welding**
  - **Butt welding**
  - **Induction welding**

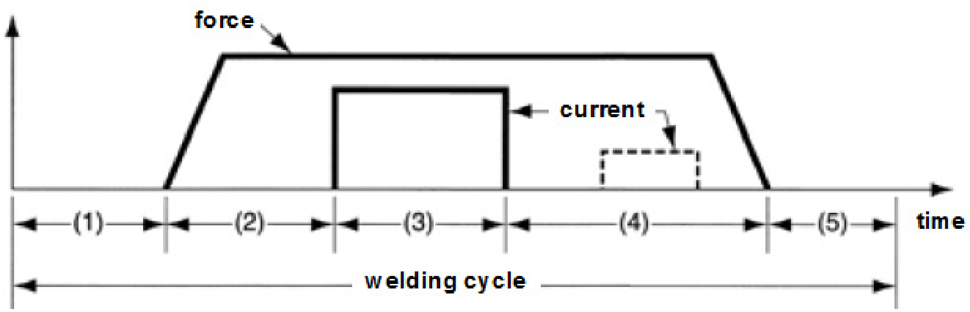
➤ Two or more sheets of metal can be welded:

1. Sheets are positioned between electrodes.
2. Electrodes contact the sheets under pressure before current is applied **(squeeze time)**.
3. Low-voltage current of sufficient amperage is passed through the joint, which heats metals to welding temperature **(heat time)**.
4. Pressure between electrodes squeeze sheets together and completes the weld **(weld time)**.
5. While pressure is still on, current is shut off for a period **(hold time)** during which metal regains some strength.

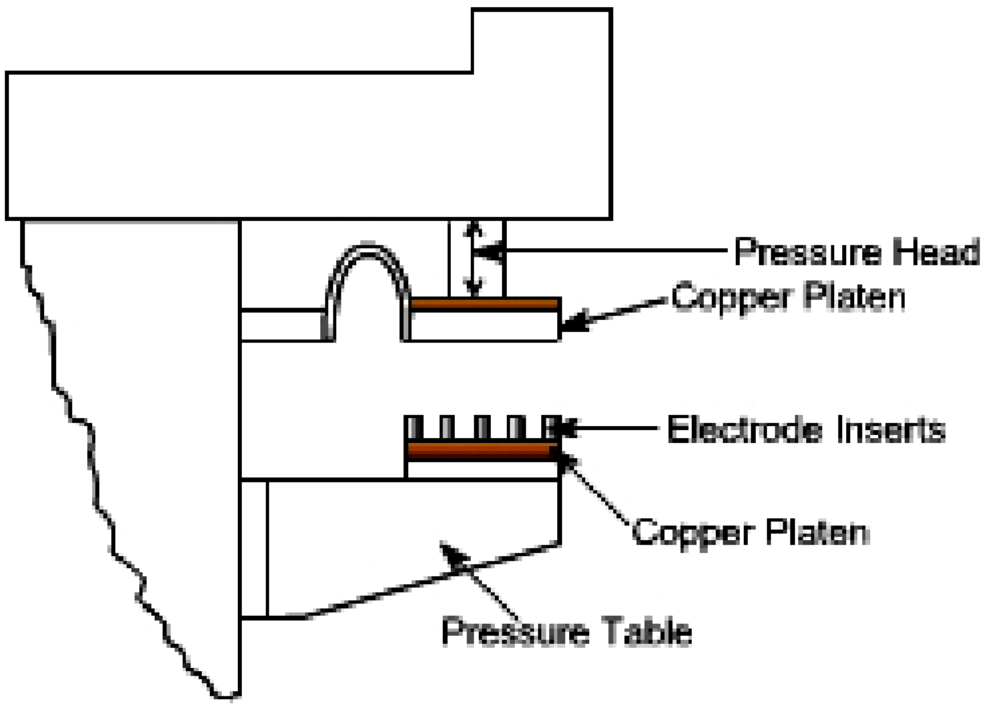
➤ For welding sheets with different thicknesses, different electrode size or conductivity may be used to obtain the weld nugget at the center.

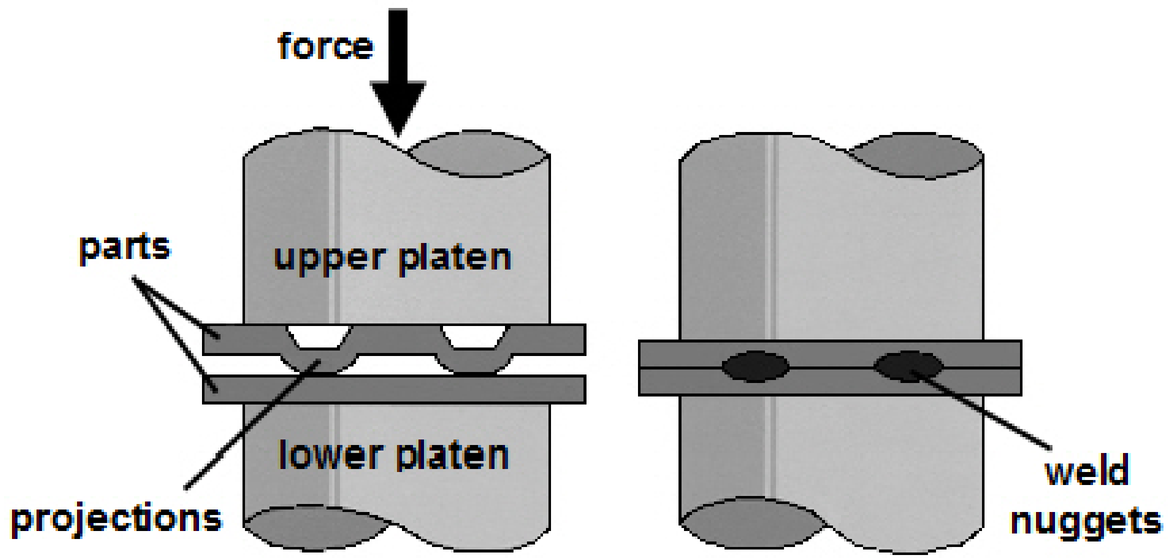




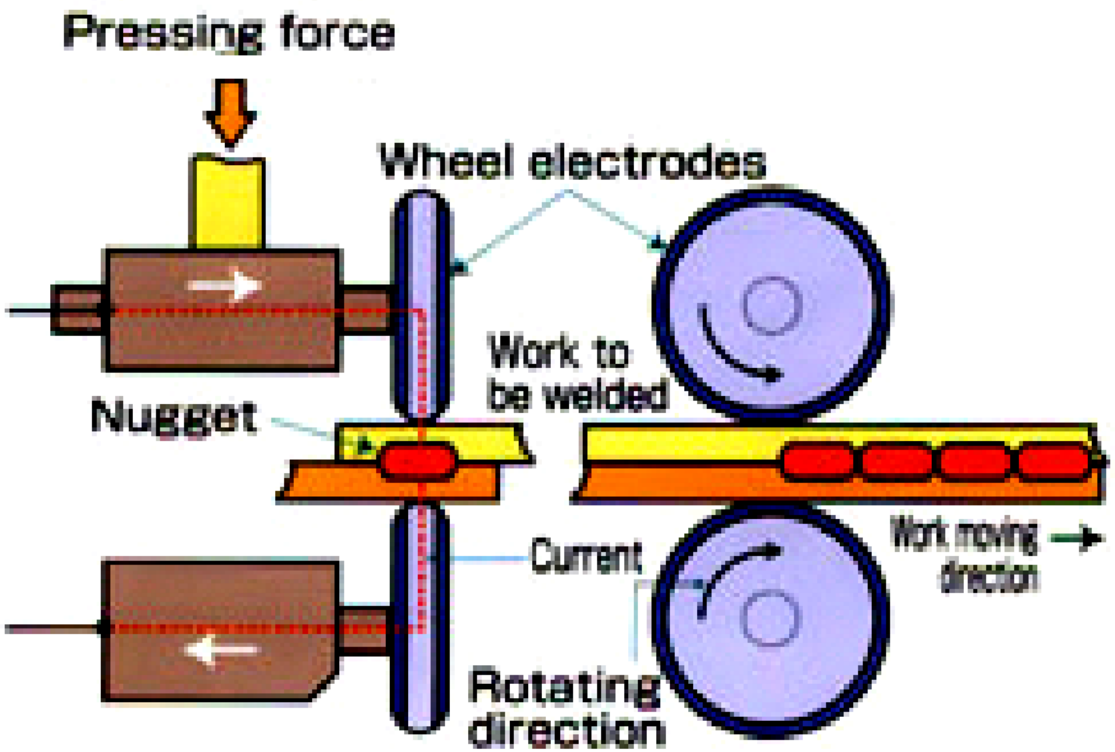


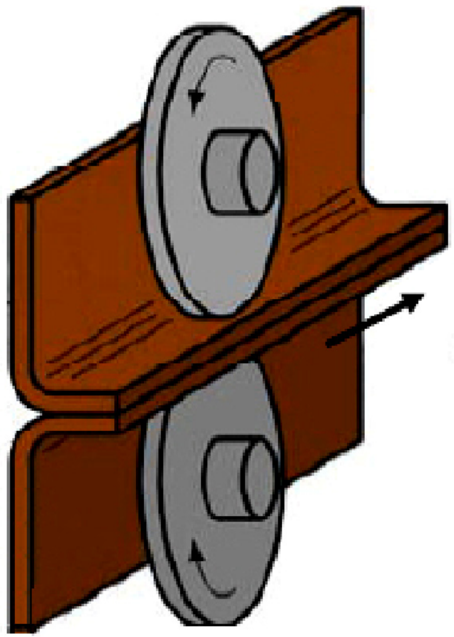
- It is a process similar to spot welding.
- Projection welds (weld nuggets) are produced at localized points in **embossed workpieces** that are held under pressure between suitable electrodes.
- Electrode lives are long since flat surfaces are used.

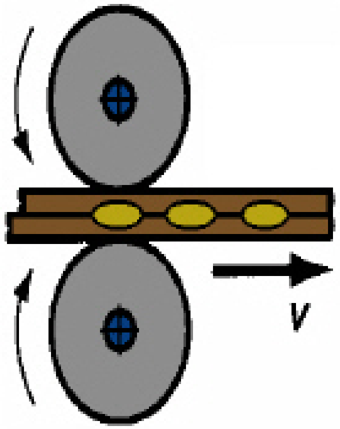




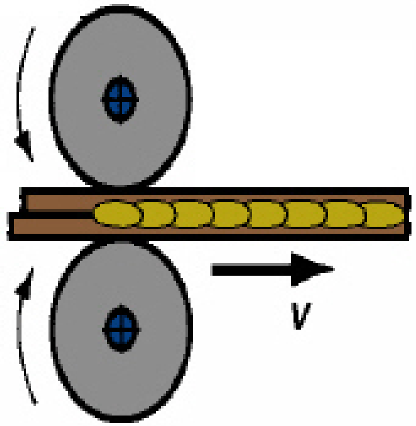
- Seam welding is the continuous version of spot welding.
- **Electrodes are rotating**, and the current is regulated by a timer.
- Depending on speed of feeding, various layouts of weld nuggets (i.e. **individual**, **overlapping**, **continuous**) are obtained.



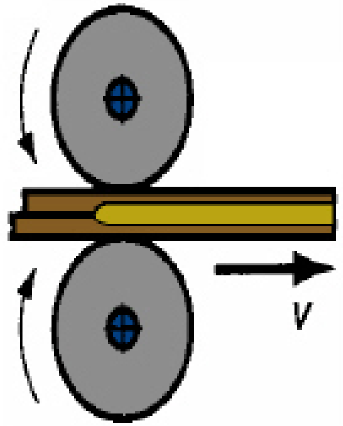




individual

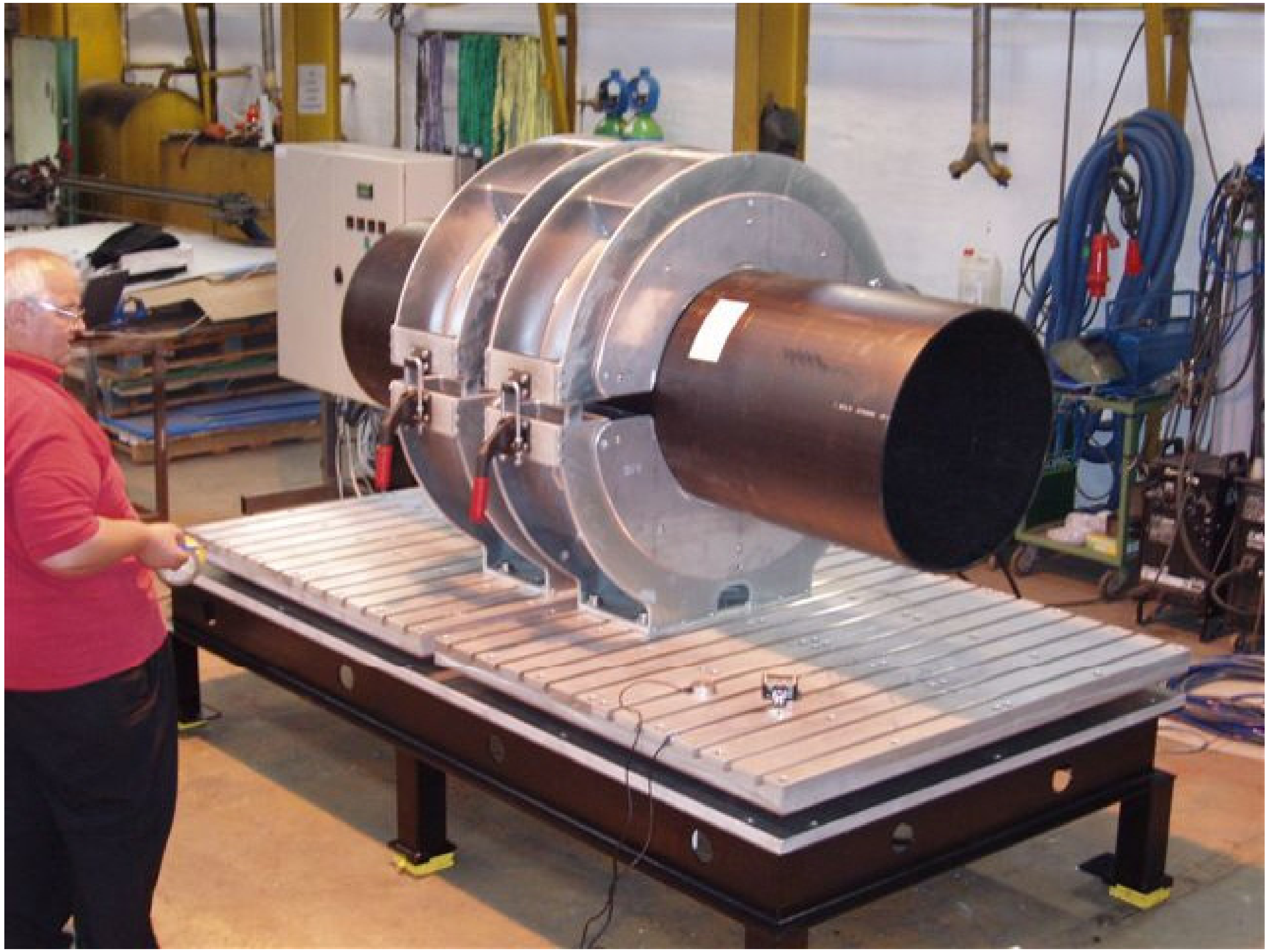


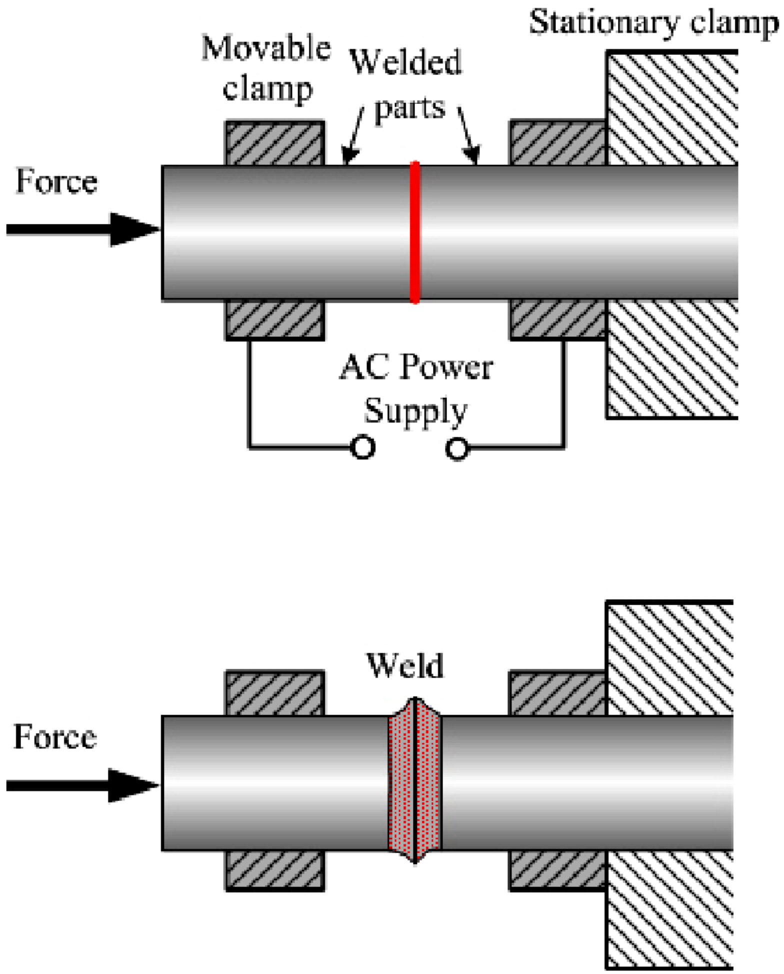
overlapping



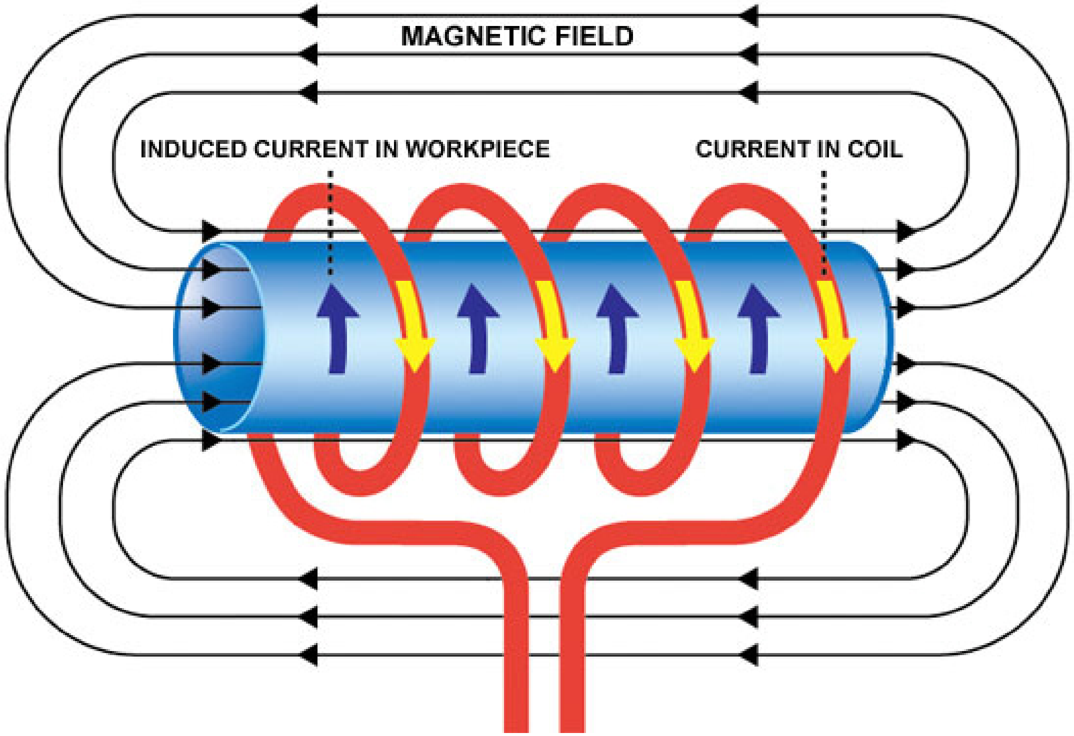
continuous

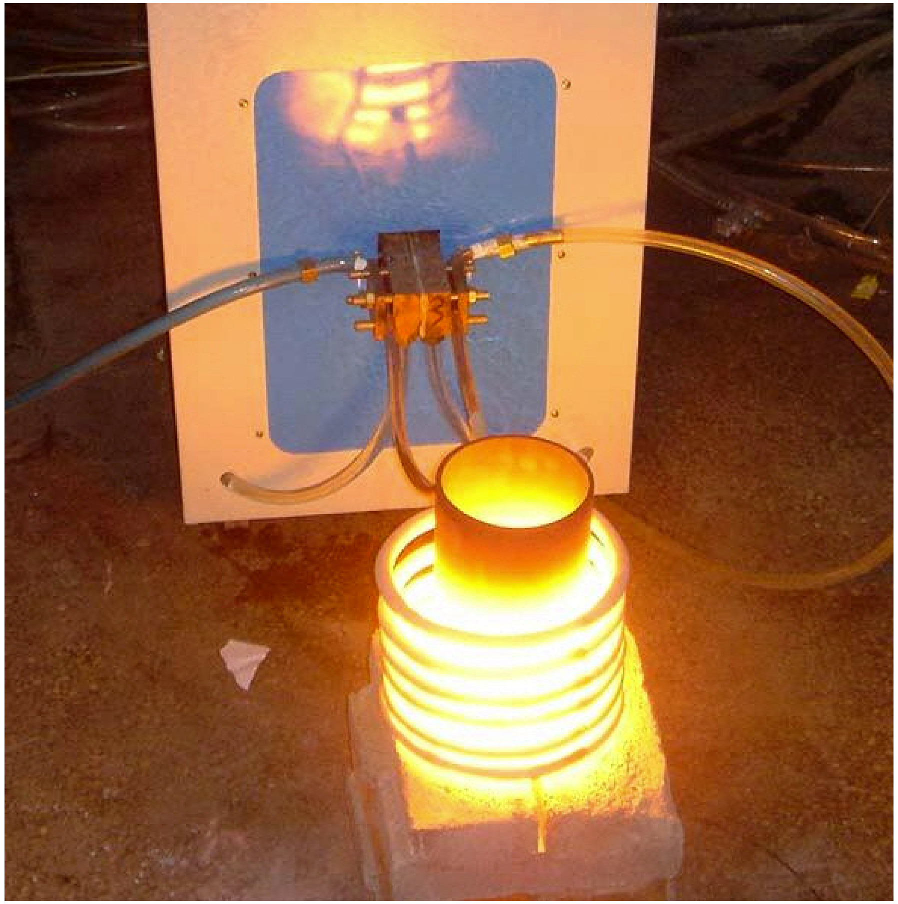
- Welding is done by gripping together of two parts with the same cross-section (e.g. tubes).
- Heat is generated along the contact surface by electrical resistance through applied power. Pressure **(about 15-55 MPa)** is also applied.





- Heat is generated from resistance of weldment to the flow of an induced electrical current.
- Pressure is frequently used to complete the weld. The inductor coil is not in contact with the weldment. Frequencies **(ranging from 200 to 500 kHz)** are used.



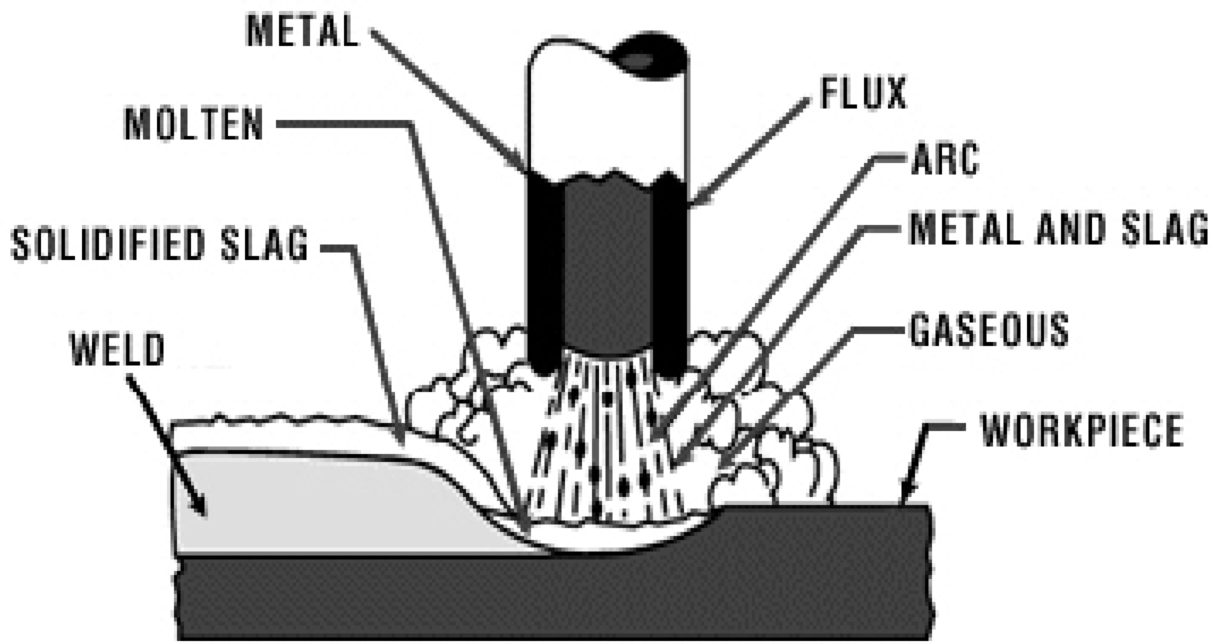


- Heat is generated from **an electric arc** between the work and an electrode. Contact is first made between electrode and work to create an electric circuit. After that, by separating conductors, an arc is formed. Temperatures of **up to 5500 °C** are possible.

- A pool of molten metal, consisting of base metal(s) and filler metal (can be more than one), is formed near the tip of the electrode. In most arc welding processes, filler metal is added during the operation to increase volume and strength of the weld joint.

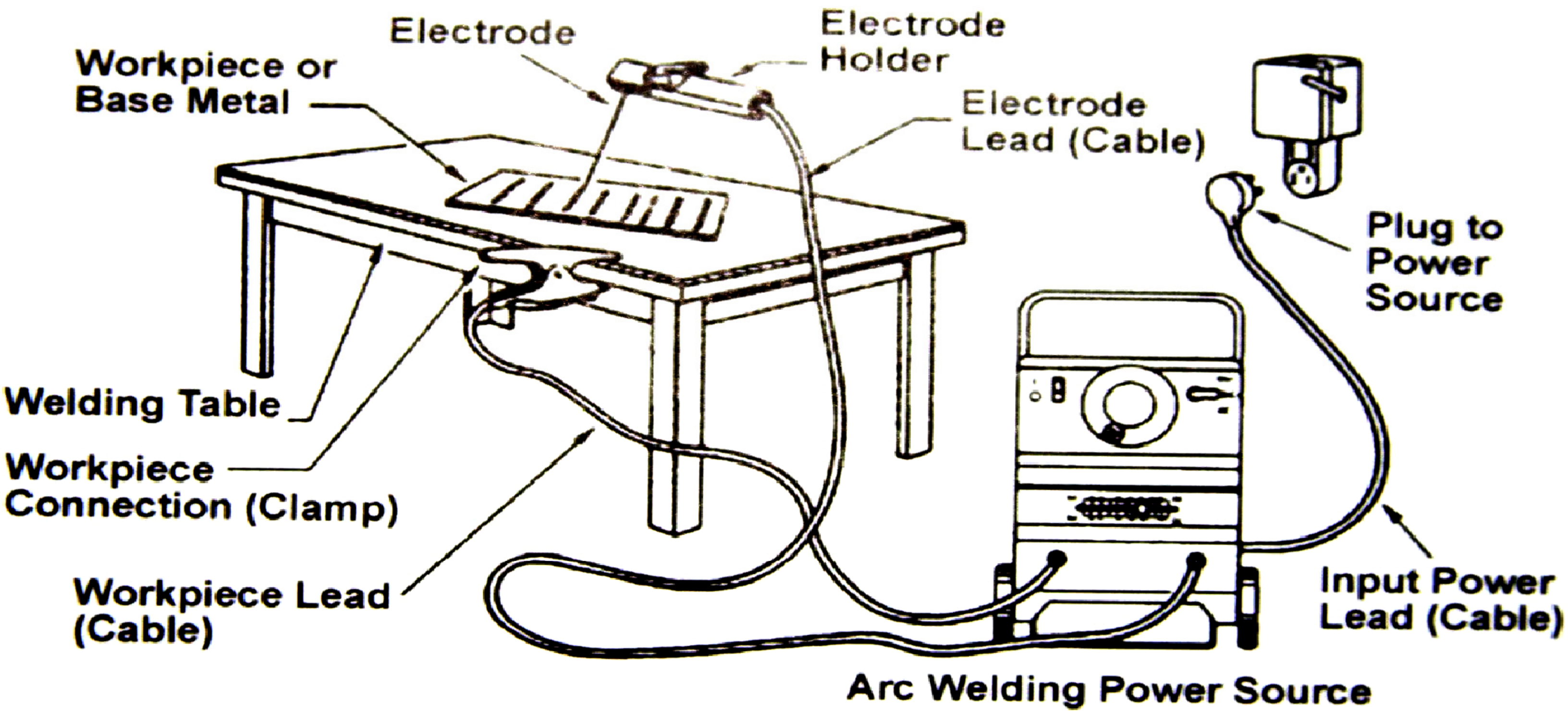
- Electrode movement relative to work is accomplished either **by a human** (manual welding) or **by mechanical means** (machine welding, automatic welding, or robotic welding).

- In manual welding, quality of weld joint is very dependent on skill and experience of the welder. The weld quality is much better in machine, automatic, and robotic welding.



- **AC or DC current** can be used for arc welding. AC welders are simple, and their efficiencies are high. AC welding is **generally above 200 A**. DC welding is used when polarity of the electrode is important.

- *For welding of non-ferrous metals, carbon electrode is connected to negative terminal* ***(straight polarity)****.*



- There are two types of electrodes used in arc welding:

1. **Carbon Electrodes:** Only used as a heat source *(as in the case of oxyacetylene welding)*. Filler metal rods are also used if additional metal is necessary.

2. **Metal Electrodes:** Produces arc and supplies filler metal as well. There are three types:
   - **Bare:** *Used for mild iron and wrought iron.* Straight polarity is used.
   - **Fluxed:** Fluxing materials remove any present oxide on metal and prevent their formation.
   - **Heavy Coated:** Over 95% of the electrodes used are coated. Electrode provides a gas shield around the arc to eliminate oxidation, and also it forms a slag layer on top of the weld to prevent oxidation during cooling.

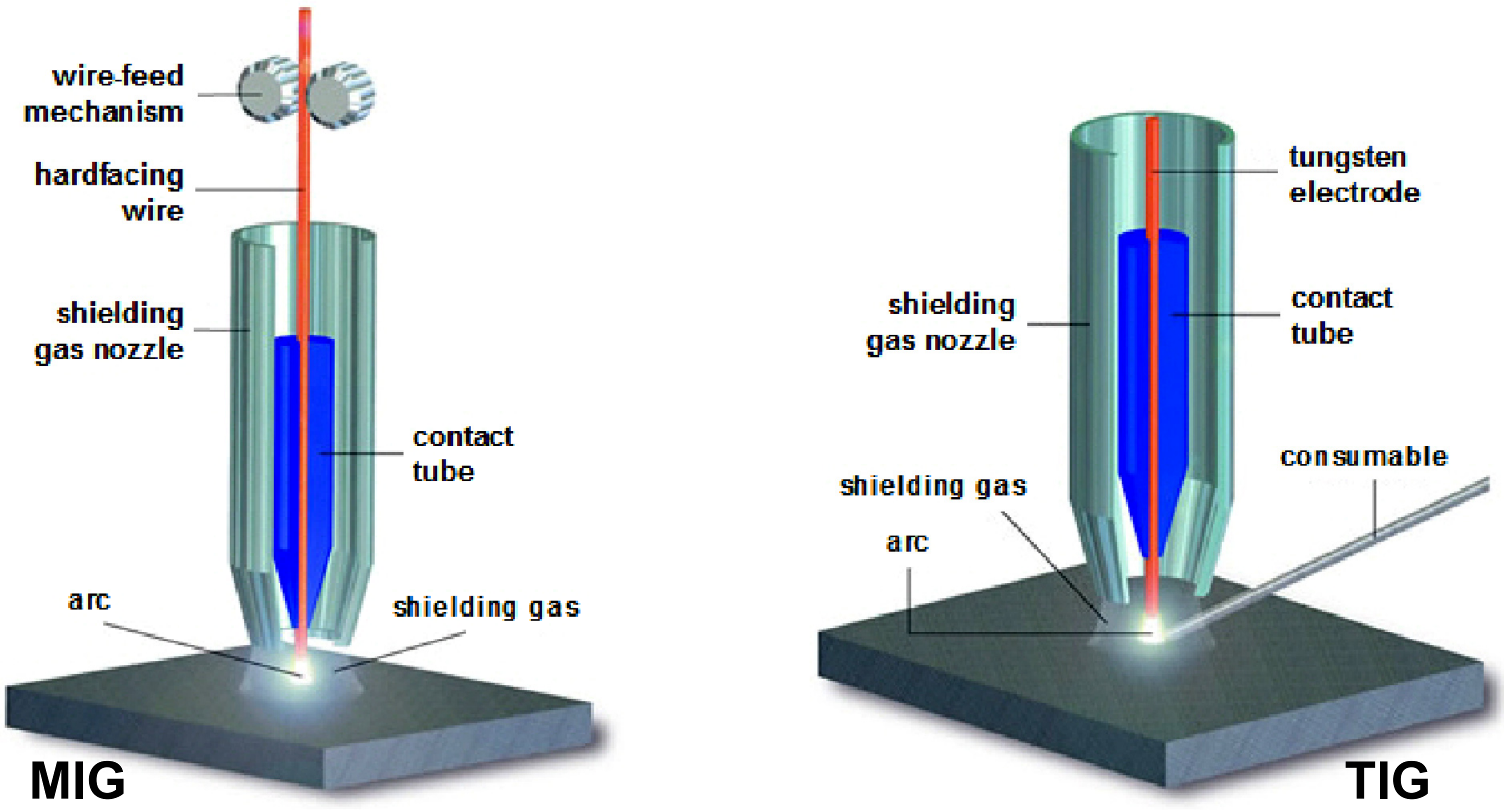
Electrode Coatings:

1. Slag-forming constituents: SiO_2, MnO_2 and FeO
2. Constituents to improve arc: Na_4O, CaO, MgO and TiO_2
3. Deoxidizing constituents: Graphite, Al, and wood flour
4. Binding material: Sodium silicate, potassium silicate, asbestos
5. Alloying constituents to improve strength: V, Co, Mo, Al, Cr, Ni, Mn, W.

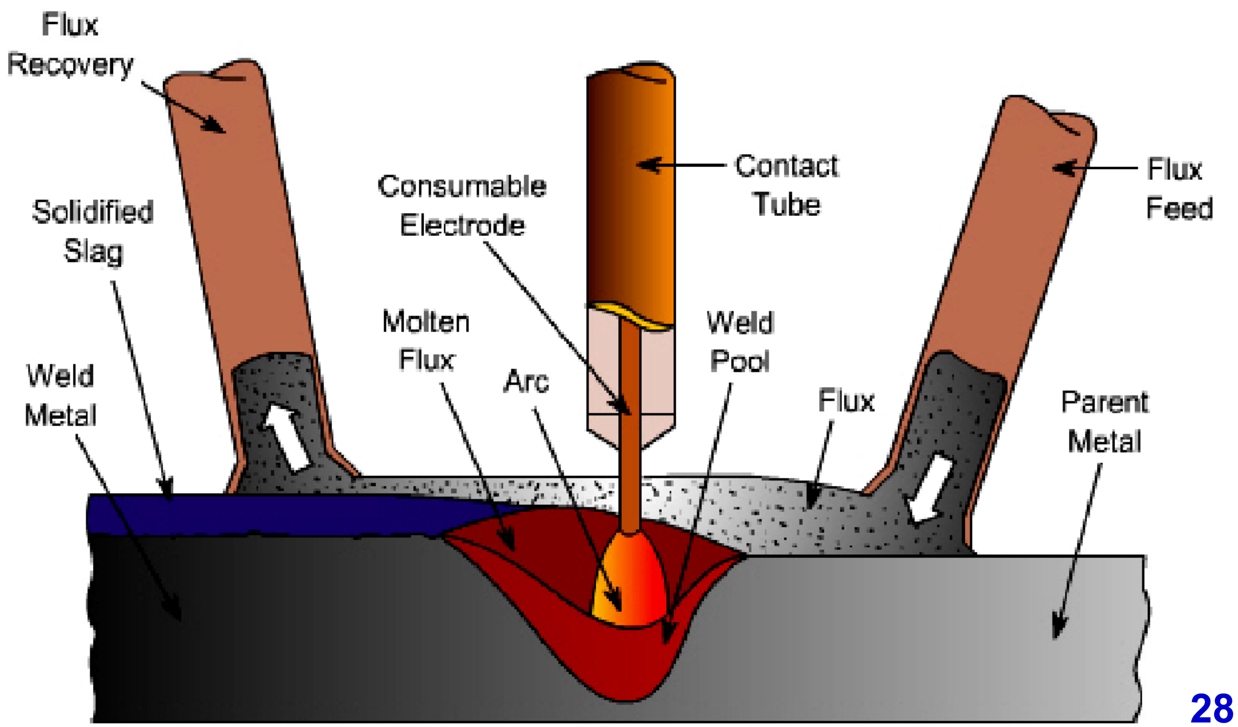
Useful Functions of Electrode Coatings:

1. Provide a protective atmosphere
2. Provide slag to protect the molten metal
3. Stabilize the arc
4. Add alloying elements to the weld
5. Slow down cooling rate of the weld

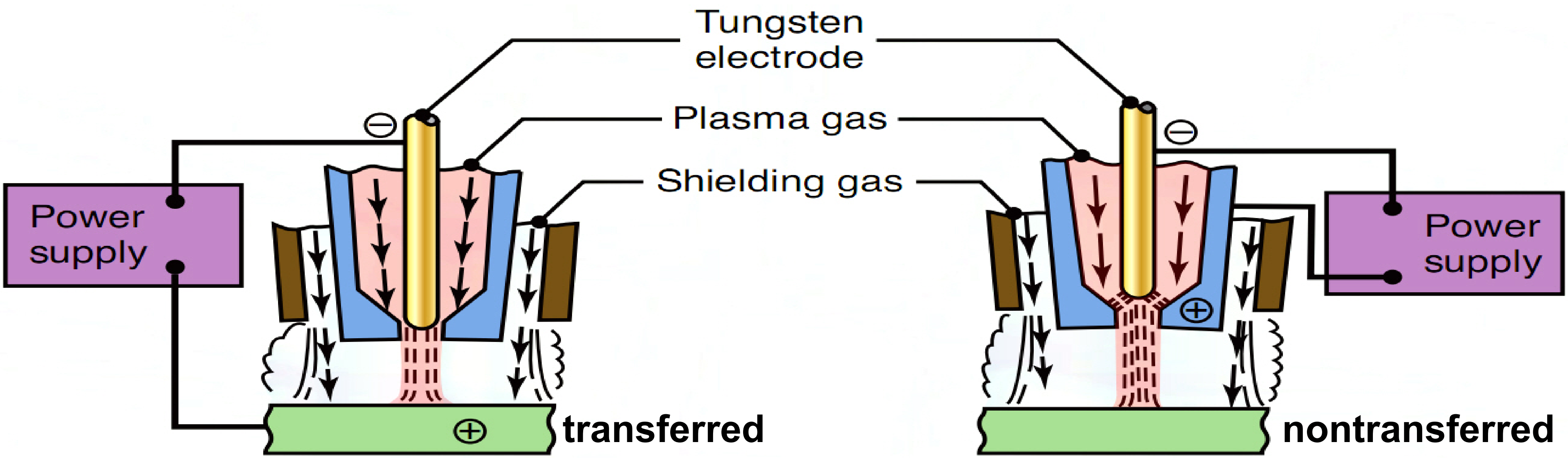
- There are two types: **Metal Inert Gas (MIG) Welding** & **Tungsten Inert Gas (TIG) Welding**
- In these processes, heat is produced from the arc between electrode and work. Atmosphere is shielded by the supply of **an inert gas** (e.g. **Ar**, **He**, **CO_2**).
- In MIG welding, **a consumable metal wire electrode** is used. In TIG welding, electrode is **tungsten (non-consumable)** and a filler rod is used as supply material.
- There is *no flux or coating on the electrodes*. Either AC or DC can be used.



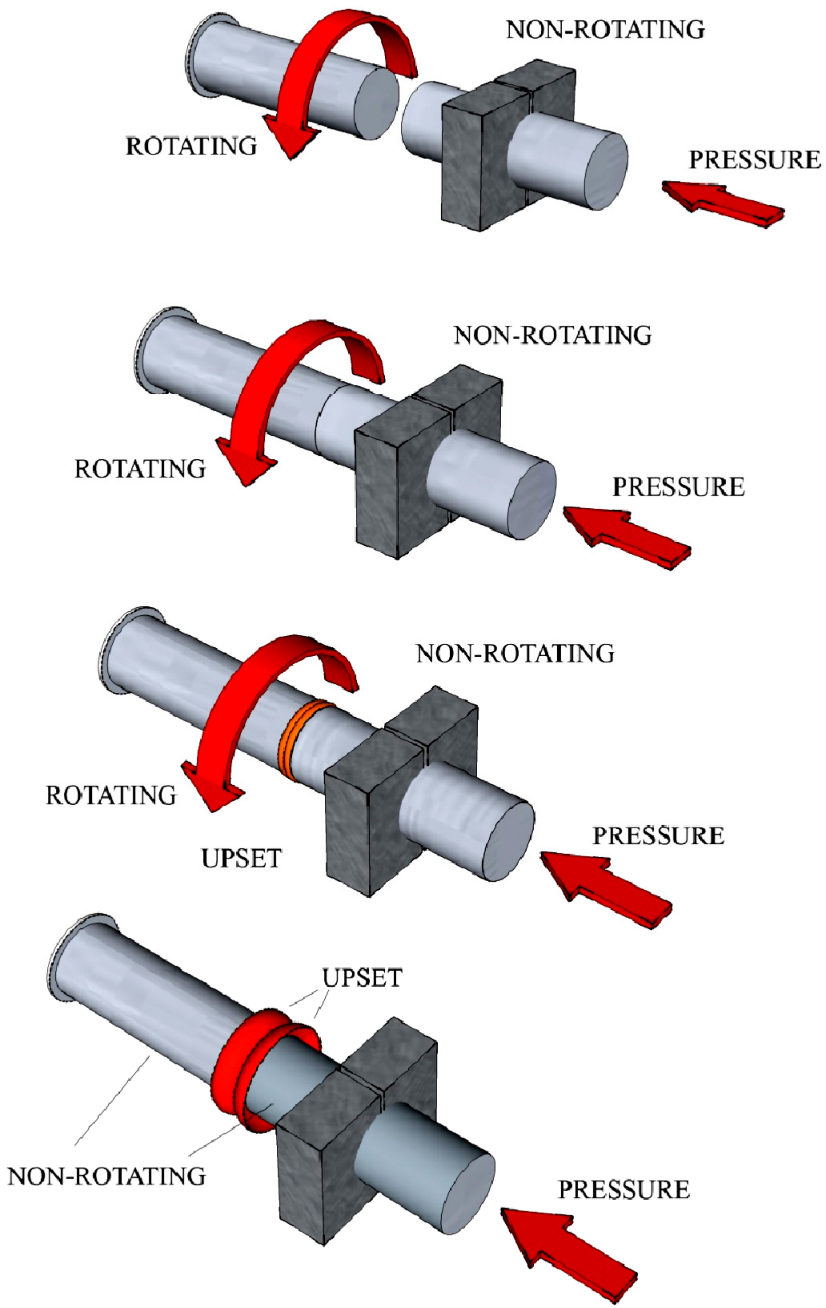
- This process uses a continuous, consumable bare wire electrode. Arc shielding is provided by a cover of granular flux. The electrode wire is fed automatically from a coil into the arc. The flux is introduced into the joint slightly ahead of the weld arc by gravity from a hopper.
- The blanket of granular flux prevents sparks, spatter and radiation. The portion of flux closest to the arc is melted, mixing with molten weld metal to remove impurities, and then solidifying on top of the weld joint to form a glasslike slag. It provides good protection from atmosphere and good thermal insulation for weld area. This results in slow cooling and a high-quality weld joint. The infused flux remaining after welding is recovered and reused.
- Submerged arc welding is widely used for **automated welding** of *structural shapes, longitudinal and circumferential seams for large-dia. pipes, tanks, and pressure vessels*. Due to gravity feed of the granular flux, the parts **must always be in horizontal orientation**.



- This is a special form of TIG welding, in which **a plasma arc is directed at the weld area**.
- Tungsten electrode in a nozzle gives **a high-velocity stream of inert gas** (Ar, Ar-H mixture, or helium) into arc zone to produce **a high-velocity plasma jet** of small diameter with very high-energy density.
- Temperatures are **up to 30,000 °C** or greater, which is hot enough to melt any known metal.
- Arc is obtained by the electrode and either workpiece **(transferred arc process)** or water-cooled constricting nozzle **(nontransferred arc process)**. The latter can be used for cutting electrically conductive metals (including tunsgten) at quick cutting rates, resulting in good surface quality.
- As a substitute for TIG welding, it is used in applications such as *in automobile subassemblies, metal cabinets, door and window frames, and home appliances*.



- Coalescence is achieved by heat of friction generated by rotating one piece against other under axial pressure.
- Two mating surfaces are heated to melting temperature, and the adjacent material becomes plastic. The relative motion is stopped, and a forging pressure is applied which upsets the joint slightly.
- **1500 rpm** and **10 MPa** are needed for **25 mm steel bar**.
- Machines used for friction welding have the appearance of an engine lathe. They require a powered spindle to turn one part at high speed and a means of applying an axial force between rotating part and non-rotating part.
- With its short cycle times, the process is suitable for **mass production**. It is applied in *the welding of various shafts and tubular parts of similar or dissimilar metals*. One typical application is *to weld medium-carbon steel shanks to carbide tips in producing twist drills*.



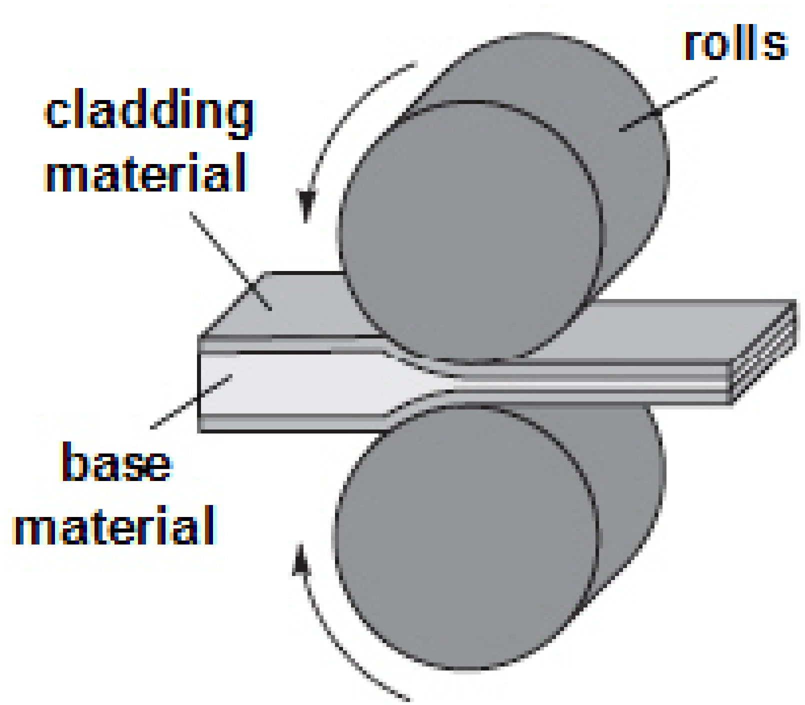
Cold Roll Welding (Cladding)

- This is a solid-state welding process accomplished by applying high pressure by means of rolls between clean contacting surfaces at room temperature.

- Metals to be welded must be very ductile and free of work hardening. Contact surfaces must be exceptionally clean.

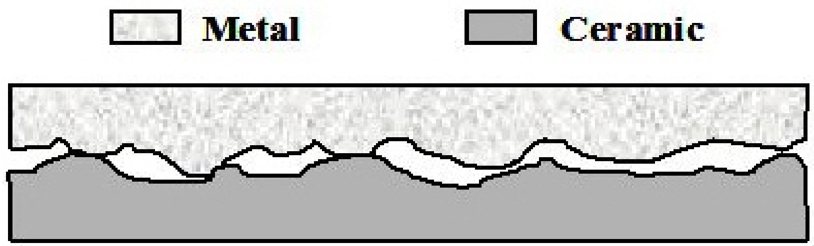
- Metals such as *soft aluminum, copper, gold and silver* can be readily cold-welded. For small parts, the forces may be applied by simple hand operated tools. For heavier work, powered presses are required to exert the necessary force.

- Applications include *cladding stainless steel to mild steel* for improving its corrosion resistance, *making bimetallic strips* for measuring their temperature, and *producing sandwich strips* for coins.

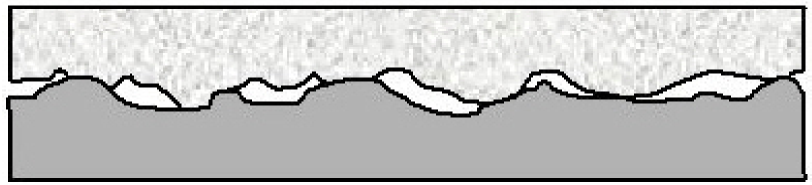


Diffusion Welding

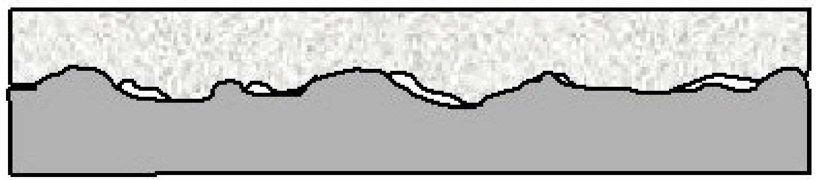
- It is a solid-state welding process resulting from application of heat and pressure, in a controlled atmosphere, with sufficient time allowed for solid-state diffusion and coalescence to occur.
- Temperatures are well below the melting points of metals, and the plastic deformation at the surfaces is only minimal.
- **Similar and dissimilar metals can be joined**. In latter case, a layer of different metal (filler) is sandwiched between base metals to promote diffusion.
- The process is used for *joining of high-strength and refractory metals in aerospace and nuclear industries*.
- A limitation of the process can be the time required for diffusion to occur between the faying surfaces, which may range from seconds to hours.



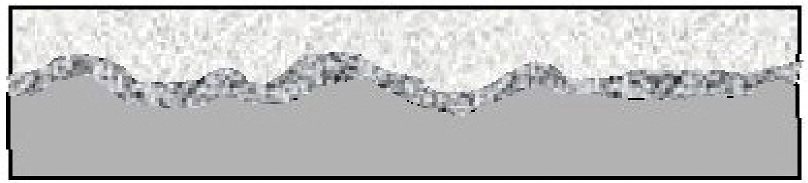
(a) Hard ceramic and ductile metal surfaces come into contact at asperity tips.



(b) Ceramic asperities indent the metal surface that yields plastically under large local stress.



(c) Deformation continues primarily in the metal, leading to a filling of interfacial voids.



(d) Finally, the bond is formed ideally as a perfect interface boundry.

- This is a solid-state welding process in which rapid coalescence of two metallic surfaces is caused by the energy of a detonated explosive.
- Two plates in a parallel configuration, separated by a gap, with the explosive charge above the upper plate (*flyer plate*). A buffer layer (e.g. rubber or plastic) is used between explosive and flyer plate to protect its surface. The lower plate (*backer metal*) rests on an anvil for support. When detonation is initiated, the explosive charge propagates along the flyer plate. The resulting high-pressure zone propels the flyer plate to collide with the backer metal progressively at high velocity, so it takes on an angular shape as the explosion advances.
- It is commonly used to **bond two dissimilar metals**, in particular to clad one metal on top of a base metal over large areas. Applications include *production of corrosion-resistant sheet and plate stock for making processing equipment in the chemical and petroleum industries*.
- The term **explosion cladding** is also used in this context. **No filler metal** is used in explosion welding, and **no external heat** is applied.