Department of Mechanical Engineering
GENERAL SIR JOHN KOTELAWALA DEFENCE UNIVERSITY

WORKSHOP TECHNOLOGY

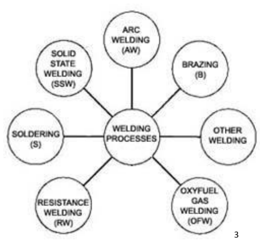
METAL JOINING

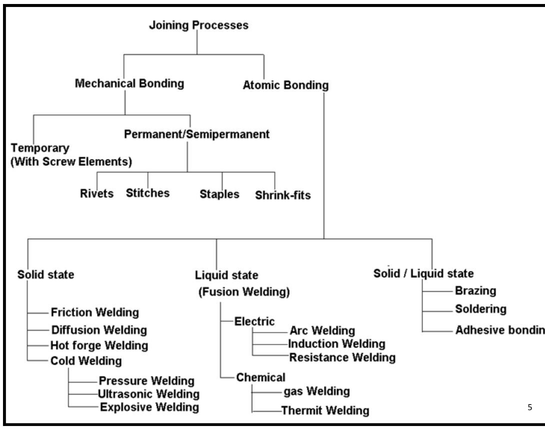
Welding is a materials joining process which produces coalescence of materials by heating them to suitable temperatures with or without the application of pressure or by the application of pressure alone, and with or without the use of filler material.

The American Welding Society

Groups of welding processes:

- Arc welding
- Brazing
- Oxyfuel Gas Welding
- Resistance Welding
- Solid State Welding
- Soldering
- Other





Liquid state (Fusion) Process

- Usually involves fusion resulting due to melting of metal particles – Filler metals
- E.g. Oxy-Fuel Welding, laser welding, chemical, electrical, optical

Solid State process

- Ultrasound, friction, explosion
- No filler metal is used here
- Joining occurs due to external pressure and heat source.

Liquid – Solid State process

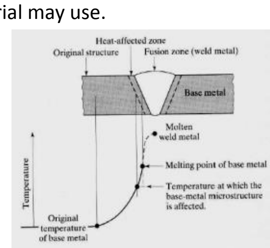
- Braze metal, Soldering, Adhesive bonding
- Liquid metal applied to solid base metals to join parts

Mechanical means

- Fasteners, bolts, nuts screws, seaming etc
- Easy to dissemble.

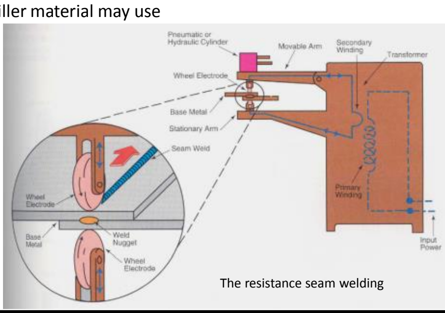
Fusion welding

- This process involves the partial melting of the two members to be welded in the joint region.
- The thermal energy required for this fusion is usually supplied by chemical or electrical means.
- Filler material may use.



Solid state welding

There is no fusion of the workpiece
No liquid phase in the joint
Filler material may use



The resistance seam welding

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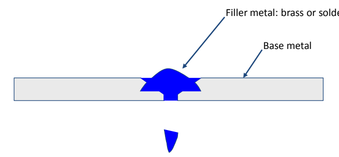
Soldering or brazing

Only the filler metals are melted and not the base metal.
The braze metals have higher melting temperatures than the solder metals.



Characteristics of a brazed or soldered joint

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Introduction

- Definition : Fusion Welding is defined as melting together and coalescing materials by means of heat.
- Energy is supplied by thermal or electrical means.
- May or may not use filler metal.
- Fusion welds made without filler metals are known as autogenous welds.

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1. Oxyacetylene Welding (OAW)

- The oxyacetylene welding process uses a combination of oxygen and acetylene (as a fuel) gas to provide a high temperature flame.
- This flame heat melts the metals at the joint.

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Oxyacetylene Welding (OAW)

- OAW is a manual process in which the welder must personally control the torch movement and applying of filler rod.
- Cylinders contain oxygen and acetylene gas at extremely high pressure.

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Oxy-fuel Gas Welding

Primary combustion process

$C_2H_2 + O_2 \qquad 2CO + H_2 + heat$

- This reaction dissociates into carbon monoxide and hydrogen.

Secondary combustion process

$2CO + H_2 + 1.5\ O_2 \qquad 2CO_2 + H_2O + heat$

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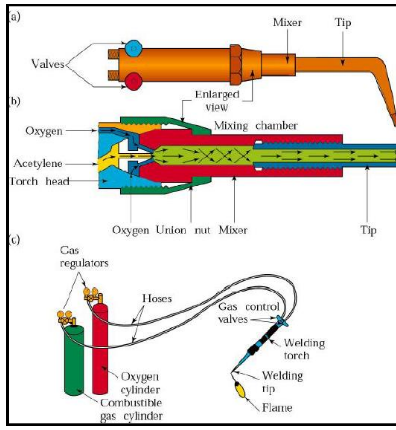
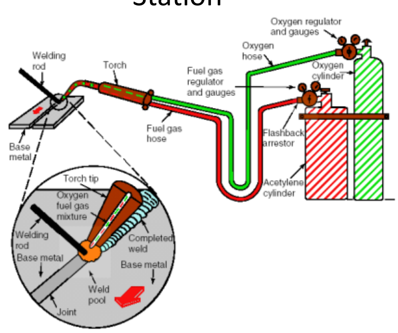
Filler Metals

- Additional material to weld the weld zone
- Available as rod or wire
- They can be used bare or coated with flux



Torch used in Oxyacetylene Welding

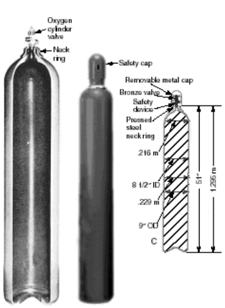
Typical Oxyacetylene Welding (OAW) Station



Oxygen Cylinders

- Oxygen is stored within cylinders of various sizes and pressures ranging from 2000 - 2640 PSI. (Pounds Per square inch)
- Oxygen cylinders are forged from solid armor plate steel. No part of the cylinder may be less than 1/4" thick.
- Cylinders are then tested to over 3,300 PSI using a hydrostatic pressure test.

Oxygen Cylinders



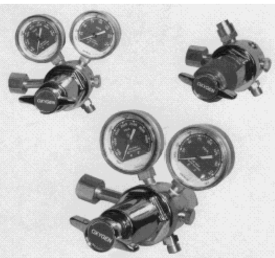
244ft³ (6909L) Capacity Oxygen Cylinder

- Cylinders are regularly re-tested using NDT while in service.
- Cylinders are regularly chemically cleaned and annealed to relieve "jobsite" stresses created by handling.

Cylinder Transportation

- Never transport cylinders without the safety caps in place.
- Never transport with the regulators in place.
- Never allow bottles to stand freely. Always chain them to a secure cart or some other object that cannot be toppled easily.

Pressure Regulators for Cylinders



- Reduce high storage cylinder pressure to lower working pressure.
- Most regulators have a gauge for cylinder pressure and working pressure.

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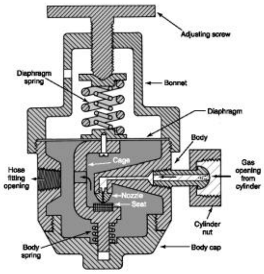
Pressure Regulators for Cylinders



- Regulators are shut off when the adjusting screw is turn out completely.
- Regulators maintain a constant torch pressure although cylinder pressure may vary.
- Regulator diaphragms are made of stainless steel.

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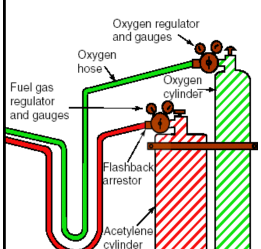
Regulator Hoses



- Hoses are fabricated from rubber & nylon.
- Oxygen hoses are green in color and have right hand thread.
- Acetylene hoses are red in color with left hand thread.
- Left hand threads can be identified by a grove in the body of the nut and it may have "ACET" stamped on it.

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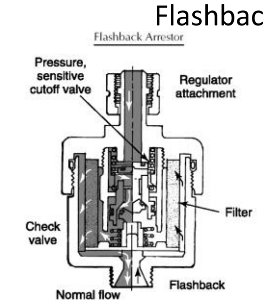
Check Valves & Flashback Arrestors



- Check valves allow gas flow in one direction only.
- Flashback arrestors are designed to eliminate the possibility of an explosion at the cylinder.
- Combination Check/ Flashback Valves can be placed at the torch or regulator.

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Acetylene Gas

- Virtually all the acetylene distributed for welding and cutting use is created by allowing calcium carbide (a man made product) to react with water.
- Calcium carbide method of producing acetylene can be done on almost any scale desired. Placed in tightly-sealed cans, calcium carbide keeps indefinitely. For years, miners' lamps produced acetylene by adding water, a drop at a time, to lumps of carbide.
- Before acetylene in cylinders became available in almost every community, appreciable amount of gas was produced from calcium carbide.

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Acetylene Cylinders

- Acetylene is stored in cylinders specially designed for this purpose only.
- Acetylene is extremely unstable in its pure form at pressure above 15 PSI.

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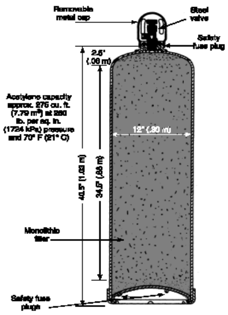
Acetylene Cylinders



- Cylinders are filled with a very porous substance "monolithic filler" to help prevent large pockets of pure acetylene forming.
- Cylinders have safety (Fuse) plugs in the top and bottom designed to melt at 212° F (100 °C).

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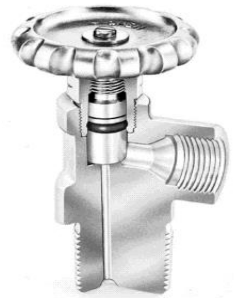
Acetylene Valves



- Acetylene cylinder shut off valves should only be opened 1/4 to 1/2 turn.
- This will allow the cylinder to be closed quickly in case of fire.
- Cylinder valve wrenches should be left in place on cylinders that do not have a hand wheel.

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Oxygen and Acetylene Regulator Pressure Settings

- Regulator pressure may vary with different torch styles and tip sizes.
- PSI (pounds per square inch) is sometimes shown as PSIG. (pounds per square inch -gauge)
- Common gauge settings for cutting
  - 1/4" material Oxy 30-35psi Acet 3-9 psi
  - 1/2" material Oxy 55-85psi Acet 6-12 psi
  - 1" material Oxy 110-160psi Acet 7-15 psi
- Check the torch manufactures data for optimum pressure settings.

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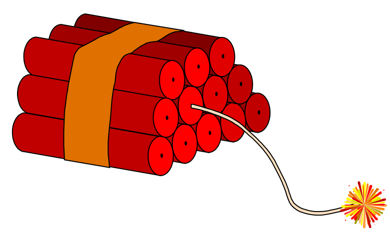
Regulator Pressure Settings

- The maximum safe working pressure for acetylene is 15 PSI.



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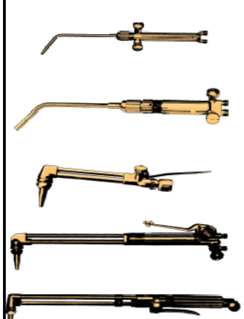
Typical torch styles



- A small welding torch, with throttle valves located at the front end of the handle. Ideally suited to sheet metal welding.
- It can be fitted with cutting attachment in place of the welding head shown.
- Welding torches of this general design are the most widely used types. They will handle any oxyacetylene welding job.
- Further it can be fitted with multi-flame (Rosebud) heads for heating applications, and accommodate cutting attachments to cut steel 6 in. thick.
- A full-size oxygen cutting torch which has all valves located in its rear body. Another style of cutting torch, with oxygen valves located at the front end of its handle.

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Typical startup procedures

- Prepare the edges to be joined and maintain the proper position.
- Verify that equipment visually appears safe i.e: Hose condition, visibility of gauges.
- Clean torch orifices with a "tip cleaners" (a small wire gauge file set used to clean slag and dirt form the torch tip)
- Open cylinder valves slightly allowing pressure to enter the regulators slowly
  - Opening the cylinder valve quickly will crash the regulator and will cause failure.
  - Never stand directly in the path of a regulator when opening the cylinder.

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Typical startup procedures

- Check for leaks using by listening for "Hissing" or by using a soapy "Bubble" solution.
- Adjust the regulators to the correct operating pressure.
- Slightly open and close the Oxygen and Acetylene valves at the torch head to purge any atmosphere from the system.
- Hold the torch at about 45deg to the work piece plane.
- Inner flame near the work piece and filler rod at about 30 – 40 deg.
- Touch filler rod at the joint and control the movement according to the flow of the material.

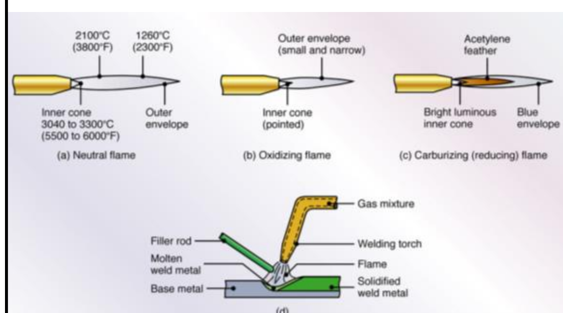
Typical startup procedures

- Always use a flint and steel spark lighter to light the oxygen acetylene flame.
- Never use a butane lighter to light the flame

Flame Settings

- There are three distinct types of oxy-acetylene flames, usually termed:
  - Neutral
  - Carburizing (or "excess acetylene")
  - Oxidizing (or "excess oxygen")
- The type of flame produced depends upon the ratio of oxygen to acetylene in the gas mixture which leaves the torch tip.

Oxyacetylene Flame Types



Acetylene Burning in Atmosphere
Open fuel gas valve until smoke clears from flame.

Carburizing Flame
(Excess acetylene with oxygen.) Used for hard-facing and welding white metal.

Flame profiles

Neutral Flame
(Acetylene and oxygen.) Temperature 5589°F (3087°C). For fusion welding of steel and cast iron.

Oxidizing Flame
(Acetylene and excess oxygen.) For braze welding with bronze rod.

Flame definition

- The **neutral** flame is produced when the ratio of oxygen to acetylene, in the mixture leaving the torch, is almost exactly one-to-one. It's termed "neutral" because it will usually have no chemical effect on the metal being welded. It will not oxidize the weld metal; it will not cause an increase in the carbon content of the weld metal.
- The **excess acetylene** flame, as its name implies, is created when the proportion of acetylene in the mixture is higher than that required to produce the neutral flame. Used on steel, it will cause an increase in the carbon content of the weld metal.
- The **oxidizing flame,** results from burning a mixture which contains more oxygen than required for a neutral flame. It will oxidize or "burn" some of the metal being welded.

Process Capabilities

- Low cost of Equipment
- Manual operation
- Slow
- Use for fabrication and repair work
- Economical for simple & low quantity work
- Required Well trained and skilled operator

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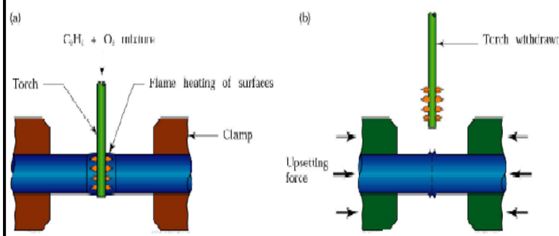
Pressure-Gas Welding Process



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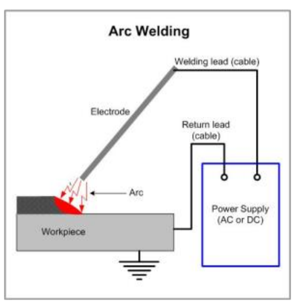
Arc Welding

- Fusion process for joining metals
- An electric arc from a AC or DC power source supplies intense heat to join the base material and an electrode



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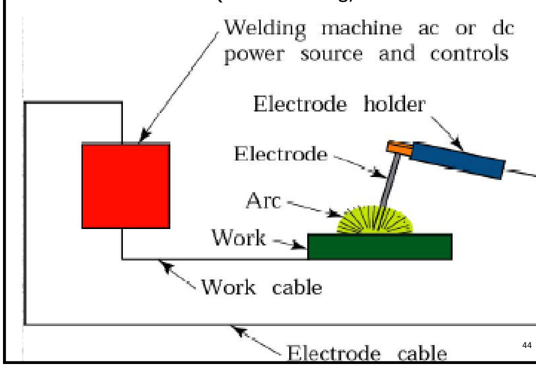
Shielded Metal Arc Welding (SMAW)
(Stick Welding)



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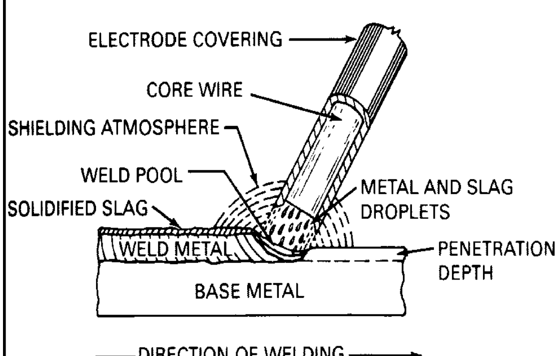

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Arc welding process

1. Oldest, simple & versatile
2. Process goes with the consumable electrode or non consumable electrode
3. Arc produced between the tip of the electrode & work piece
4. The arc is moved over the work at the appropriate arc length and travel speed, melting and fusing a portion of the base metal and continuously adding filler metal.
5. Arc temperature about 3000 degrees.
6. 50 % of industry uses this process.
7. Heat generated, heats the electrode & immediate area of the base projected by arc.

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Arc welding process

8. Weld forms when molten metal (mixture of base metal, electrode metal and substance from the coating on the electrode) solidifies.
9. Electrodes are in the shape of thin, long stick, so the process is known as stick welding.
10. Electrode types and sizes, (with predetermined coating compositions) are selected, correspond to
    - the required strength levels of base metal
    - the types of welding power supplies utilized
    - depth of penetration
    - amount of weld metal fill required.

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SMAW Advantages

- Easily implemented
- Inexpensive
- Flexible
- Not as sensitive to part fit-up variances
- Equipment relatively easy to use, inexpensive, portable
- Filler metal and means for protecting the weld puddle are provided by the covered electrode
- Less sensitive to drafts, dirty parts, poor fit-up
- Can be used on carbon steels, low alloy steels, stainless steels, cast irons, copper, nickel

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Quality Issues

- Discontinuities associated with manual welding process that utilize flux for pool shielding
  - Slag inclusions
  - Lack of fusion
- Other possible effects on quality are porosity, and cracking
- Dependence on operator technique & Skills
- Changing Electrodes after consumed
- Require cleaning the weld
- Low Deposition Rates
- Low Productivity

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Welding Flux

- Three forms
  - Granular
  - Electrode wire coating
  - Electrode core
- Produce a Shielding gas to protect the weld area
- Fluxes melt to form a protective *slag* over the weld pool
- Other purposes
  - Contain scavenger elements to purify weld metal
  - Contain metal powder added to increase deposition rate
  - Add alloy elements to weld metal
  - Decompose to form a shielding gas

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Shielding Gas

- Shielding gas forms a protective atmosphere over the molten weld pool to prevent contamination
  - *Inert* shielding gases, argon often used in the flat and horizontal position, since it is heavier than air or helium can be used in the overhead position, since it is lighter than air, keep out oxygen, nitrogen, and other gases
- *Active* gases, such as oxygen and carbon dioxide, are sometimes added to improve variables such as arc stability and spatter reduction

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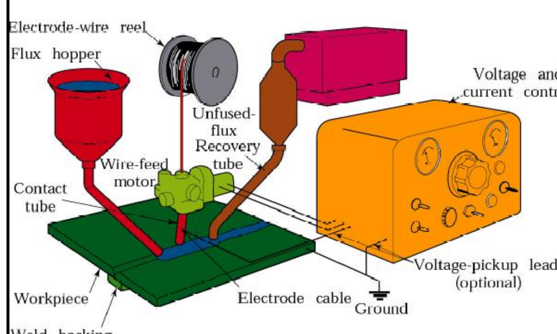
Submerged Arc Welding



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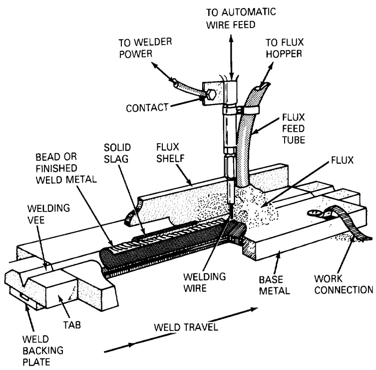

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Submerged Arc Welding (SAW)

- Weld arc is shielded by a granular flux, consisting of silica, lime, manganese oxide, calcium fluoride and other compounds.
- Flux is fed into the weld zone by gravity flow through nozzle.
- Thick layer of flux covers molten metal.
- Flux acts as a thermal insulator ,promoting deep penetration of heat into the work piece.
- Consumable electrode is a coil of bare round wire fed automatically through a tube.
- Power is supplied by 3-phase or 2-phase power lines.

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Advantages

High deposition rates

No arc flash or glare

Minimal smoke and fumes

Flux and wire added separately - extra dimension of control

Easily automated

Joints can be prepared with narrow grooves

Can be used to weld carbon steels, low alloy steels, stainless steels, chromium-molybdenum steels, nickel base alloys

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Limitations

Flux obstructs view of joint during welding

Flux is subject to contamination – porosity

Normally not suitable for thin material

Restricted to the flat position for grooves - flat and horizontal for fillets

Slag removal required

Flux handling equipment

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Gas Metal Arc Welding (GMAW)

- GMAW is a metal inert gas welding (MIG)
- Weld area shielded by an effectively inert atmosphere of argon, helium, carbon dioxide, various other gas mixtures

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Process capabilities

- GMAW process is suitable for welding a variety of ferrous and non-ferrous metals
- Process is versatile, rapid, economical, welding productivity is double that of SMAW

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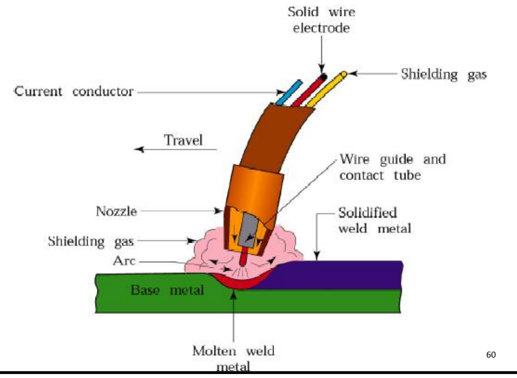
Gas Metal Arc Welding (GMAW/MIG)



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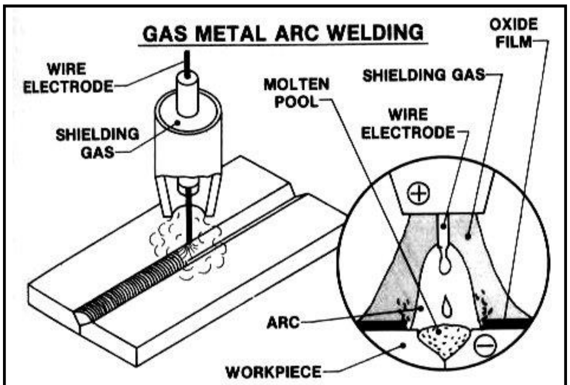

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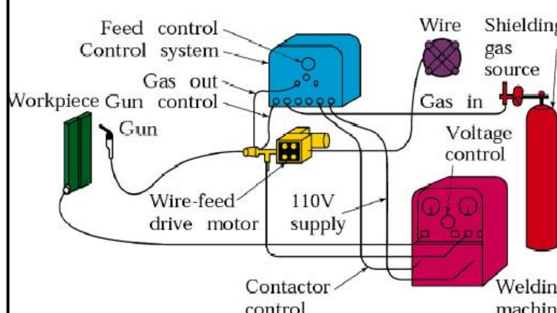
Equipment used in Gas Metal-Arc Welding Operations



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GMAW Advantages

- Deposition rates higher than SMAW due to the continuously fed wire electrode
- No time lost in order to change electrodes
- Productivity higher than SMAW with no slag removal and continuous welding
- Easily automated

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Quality

- Spatter
  - Droplets of electrode material that land outside the weld fusion area and may or may not fuse to the base material
- Porosity
  - Small volumes of entrapped gas in solidifying weld metal

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Limitations

- Equipment is more expensive and complex than SMAW
- Process variants/metal transfer mechanisms make the process more complex and the process window more difficult to control
- Restricted access
  - GMAW gun is larger than SMAW holder

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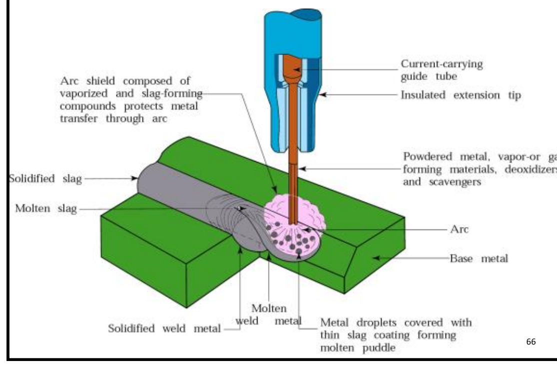
Flux Cored Arc Welding



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Flux Cored Arc Welding

- Flux cored arc welding is similar to a gas metal arc welding
- Electrode is tubular in shape and is filled with flux
- Cored electrodes produce more stable arc improve weld contour and produce better mechanical properties
- Flux is more flexible than others

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Advantages

- High deposition rates
- Deeper penetration than SMAW
- High-quality
- Less pre-cleaning than GMAW
- Can developed Specific weld – metal chemistries (Alloy)

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Limitations

- Slag must be removed
- Possible slag inclusion discontinuities
- More smoke and fumes than GMAW and SAW
- Spatter
- FCAW wire is more expensive
- Equipment is more expensive and complex than for SMAW

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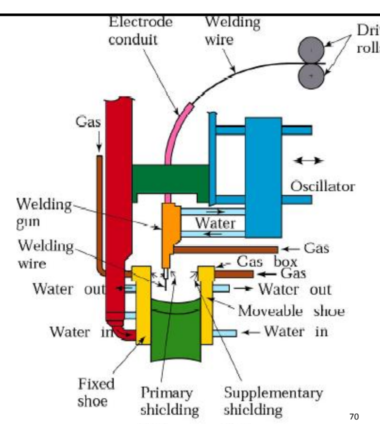
Electrogas Welding



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Electro gas Welding

- EGW is welding the edges of sections vertically in one pass with the pieces placed edge to edge
- Weld metal is deposited into weld cavity between the two pieces to be joined
- Mechanical drives moves shoes upwards
- Single and multiple electrodes are fed through a conduit and a continuous arc is maintained using flux-cored electrodes at up to 750 A

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Electro gas Welding :

Process capabilities :

- Weld thickness ranges from 12mm to 75mm
- Metals can be welded steel, titanium, aluminum alloys
- Applications are construction of bridges, pressure vessels, thick walled and large diameter pipes, storage tanks and ships.

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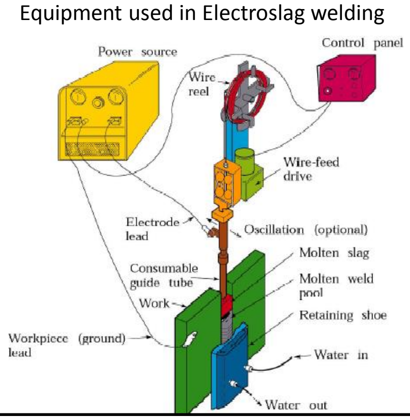
Equipment used in Electroslag welding



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Electroslag Welding

- Similar to Electro gas welding
- Difference is Arc is started between electrode tip and bottom part of the part to be welded
- Flux added first and then melted by the heat on the arc
- Molten slag reaches the tip of the electrode and the arc is extinguished
- Heat is then continuously produced by electrical resistance of the molten slag
- Single or multiple solid as well as flux-cored electrodes may be used

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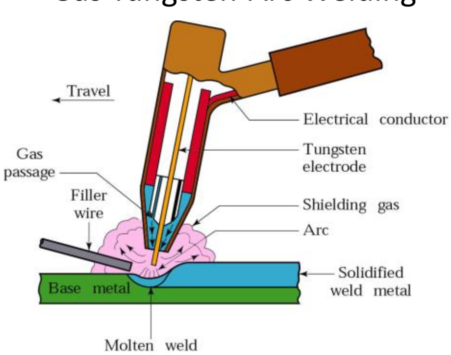
Gas Tungsten-Arc Welding



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Gas Tungsten-Arc Welding

- Non-consumable Tungsten or Tungsten alloy electrode.
- Filler metal is added by hand or by a cold wire feeder.
- Inert shielding gas protects the weld and electrode.

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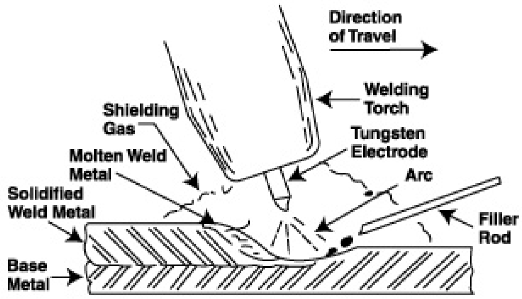
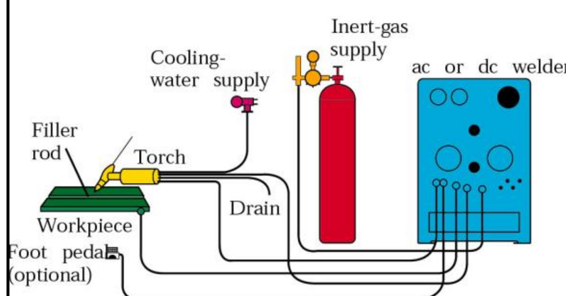


Advantages

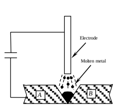
- Constant and stable gap can be maintain with a constant current
- High quality and precision with better control
- Non consumable tungsten electrode
- No flux or slag
- Shielding gas – Argon, Helium (no smoke or fumes)
- AC or DC
- Welds more metals and alloys than any other process

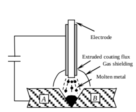
Limitations

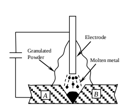
- Contamination on electrode
- Slower travel speeds
- Low deposition rates
- Expensive than SMAW
- Suitable for thin metal
- Hand-eye coordination is a required skill

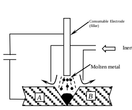


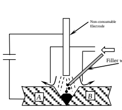
Summary

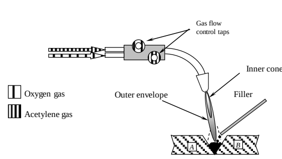

Metal-Arc Welding


Shielded Metal-Arc Welding


Submerged Arc Welding

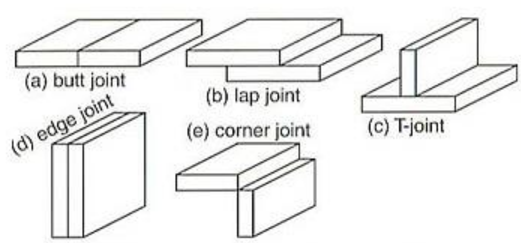

Gas Metal Arc Welding (GMAW/MIG)


Gas Tungsten Arc Welding (GTAW/TIG)

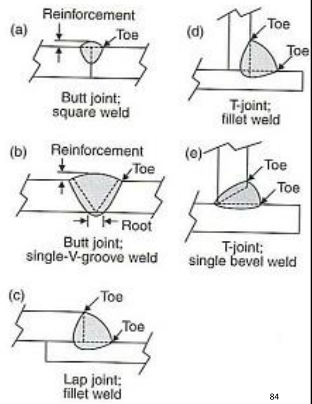


Gas welding using Oxyacetylene torch.

Five basic types of weld joint designs.



Weld joint variations



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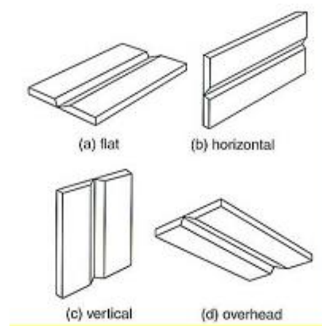
Welding position



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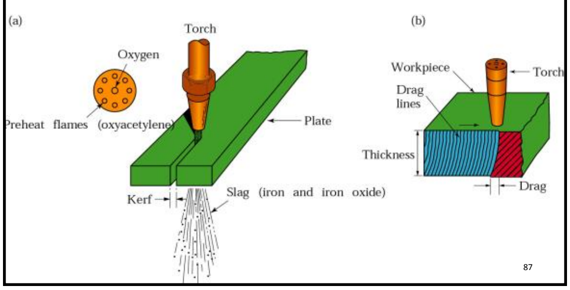

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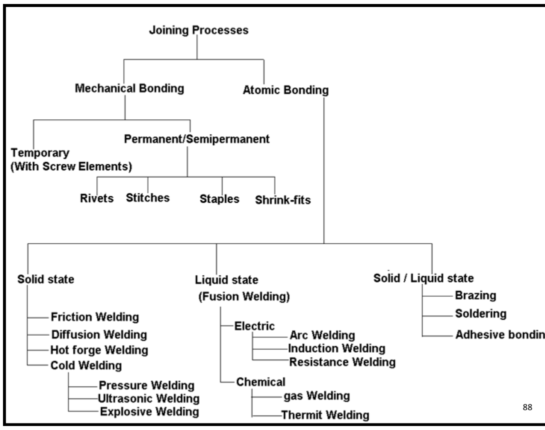

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Soldering

- A joining method using a low melting point lead-tin alloy (solder) to fill in a small gap between sheets.
- The solder wets the metal and produce an intermetallic bond.
- T ~ 183–275 C depending on compositions.

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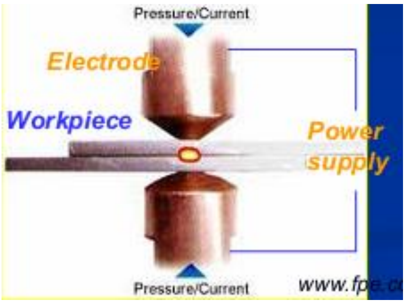
Resistance welding



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Brazing

- Brazing is similar to soldering but uses fillers of higher Tm (450-800 C).
- Give better strength than soldering but might get oxidation problems or discolouration.
- Heating methods such as gas torch & furnace.

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Fusion Welding Processes

TABLE 30.1

General Characteristics of Fusion Welding Processes

Joining process	Operation	Advantage	Skill level required	Welding position	Current type	Distortion*	Typical cost of equipment ($)
Shielded metal arc	Manual	Portable and flexible	High	All	AC, DC	1 to 2	Low (1500+)
Submerged arc	Automatic	High deposition	Low to medium	Flat and horizontal	AC, DC	1 to 2	Medium (5000+)
Gas metal arc	Semiautomatic or automatic	Works with most metals	Low to high	All	DC	2 to 3	Medium (3000+)
Gas tungsten arc	Manual or automatic	Works with most metals	Low to high	All	AC, DC	2 to 3	Medium (5000+)
Fluxed-cored arc	Semiautomatic or automatic	High deposition	Low to high	All	DC	1 to 3	Medium (2000+)
Oxyfuel	Manual	Portable and flexible	High	All	-	2 to 4	Low (500+)
Electron beam, laser beam	Semiautomatic or automatic	Works with most metals	Medium to high	All	-	3 to 5	High (100,000-1 million)

*1=highest; 5=lowest.

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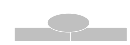
Weld Defects

- Undercuts/ Overlaps



  - Excessive current
  - Not deposit enough filler metal along the edges of the weld
  - Using an incorrect filler metal
- Grain Growth
  - A wide ΔT will exist between base metal and welded area. Preheating and cooling methods will affect the brittleness of the metal in this region
- Blowholes
  - Air cavities caused by gas entrapment during the solidification of the weld puddle. Prevented by proper weld technique (even temperature and speed)

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Weld Defects

- Inclusions
  - Impurities or foreign substances which are forced into the weld puddle during the welding process. Has the same effect as a crack. Prevented by proper technique/cleanliness.
- Segregation
  - Condition where some regions of the metal are enriched with an alloy ingredient and others aren't. Can be prevented by proper heat treatment and cooling.
- Porosity
  - The formation of tiny pinholes generated by atmospheric contamination. Prevented by keeping a protective shield over the molten weld puddle.

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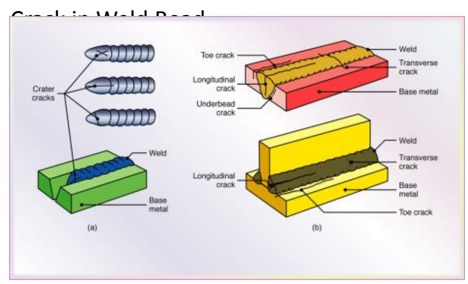
- Crack in Weld Bead
-



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