WELDING, BRAZING, SOLDERING

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: 430^0 C – 800^0 C

Soldering – same as brazing; temperature range: 100^0 C – 450^0 C

Strength of joint determined by the adhesive quality of the filler

Welding – original materials are melted and joined → solidified

Mainly from Chapter 39:

Arranged according to the subject flow.

Joinability/Weldability

- Wettability: Hydrophobic or Hydrophilic
- Fluidity: Gap, Surface tension, material.
- Cleanliness: Oxide removal, etc.
- Prevention from further oxidation/Contamination

TABLE 37-3. Some Common Solders and Their Properties

Composition (wt %)	Freezing Temperature (°F) Liquidus	Solidus	Range	Applications
Lead–tin solders				
98 Pb–2 Sn	611	601	10	Side seams in three-piece can
90 Pb–10 Sn	576	514	62	Coating and joining metals
80 Pb–20 Sn	531	361	170	Filling and seaming auto bodies
70 Pb–30 Sn	491	361	130	Torch soldering
60 Pb–40 Sn	460	361	99	Wiping solder, radiator cores, heater units
50 Pb–50 Sn	421	361	60	General purpose
40 Pb–60 Sn	374	361	13	Electronic (low temperature)
Silver solders				
97.5 Pb–1 Sn–1.5 Ag	588	588	0	Higher-temperature service
36 Pb–62 Sn–2 Ag	372	354	18	Electrical
96 Sn–4 Ag	430	430	0	Electrical
Other alloys				
45 Pb–55 Bi	255	255	0	Low temperature
43 Sn–57 Bi	281	281	0	Low temperature
95 Sn–5 Sb	464	450	14	Electrical
50 Sn–50 In	257	243	14	Metal-to-glass
37.5 Pb–25 In–37.5 Sn	280	280	0	Low temperature

TABLE 39-4. Some Common Solders and Their Properties

Composition (wt %)	Freezing Temperature (°C) Liquidus	Solidus	Range	Applications
Lead–tin solders				
98 Pb–2 Sn	322	316	6	Side seams in three-piece can
90 Pb–10 Sn	302	268	34	Coating and joining metals
80 Pb–20 Sn	277	183	94	Filling and seaming auto bodies
70 Pb–30 Sn	255	183	72	Torch soldering
60 Pb–40 Sn	238	183	55	Wiping solder, radiator cores, heater units
50 Pb–50 Sn	216	183	33	General purpose
40 Pb–60 Sn	190	183	7	Electronic (low temperature)
Silver solders				
97.5 Pb–1 Sn–1.5 Ag	308	308	0	Higher-temperature service
36 Pb–62 Sn–2 Ag	189	179	10	Electrical
96 Sn–4 Ag	221	221	0	Electrical
Other alloys				
45 Pb–55 Bi	124	124	0	Low temperature
43 Sn–57 Bi	138	138	0	Low temperature
95 Sn–5 Sb	240	234	6	Electrical
50 Sn–50 In	125	117	8	Metal-to-glass
37.5 Pb–25 In–37.5 Sn	138	138	0	Low temperature
95.5 Sn–3.9 Ag–0.6 CO	217	217	0	Electrical

Soldering joints : soft → types:

1. Tin & Lead (60:40, 50:50, 40:60) – $t_f \cong 240^0$ C
2. Lead & Silver (97:3) → $t_f \cong 310^0$ C

For filling → 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.

Heating:- required to melt the filler (by any method: furnaces, torch, electrical resistance)

•Typical, the use of soldering iron heat is applied from the iron and solder is melted and it adheres to the surface of the joint (usually, as a wire)

•The joined parts should be also heated to improve the joining process

•Ultrasonic soldering →the soldering iron is actuated with 20KHz

SOLDERING JOINTS:

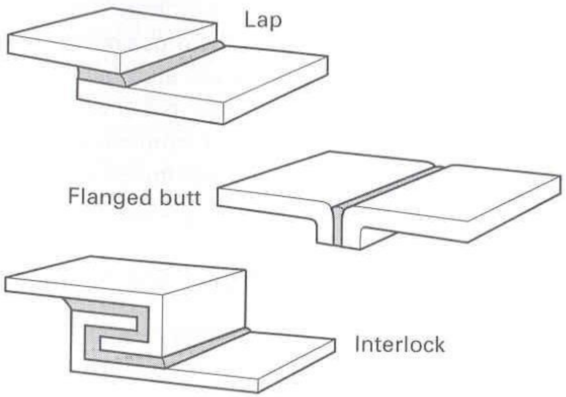


FIGURE 37-8 Some common designs for soldered joints. *(Courtesy of Lead Industries Association.)*

BRAZING: Similar to soldering but at temp > 450^0 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

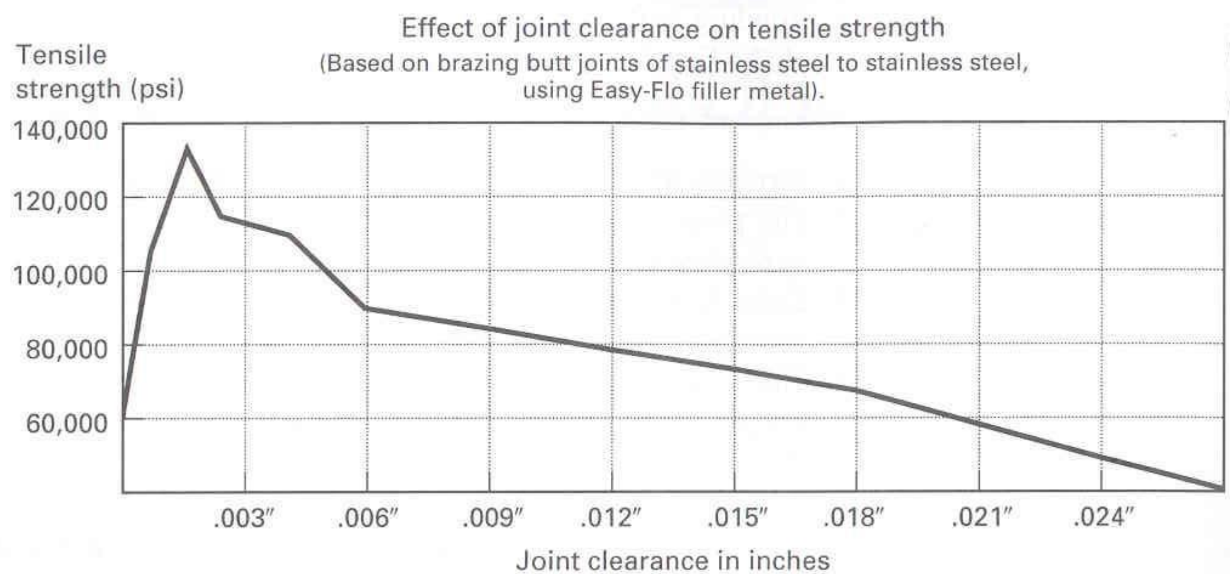
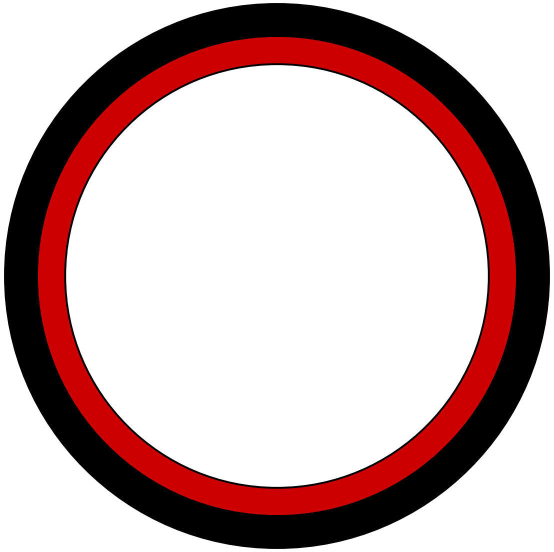


FIGURE 37-1 Typical variation of tensile strength with different joint clearances in a butt joint design. *(Courtesy of Handy & Harman).*

- The clearances are estimated at the brazing temperature.
- Estimate the initial dimensions based on the expansion coefficient→ gap or interference



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

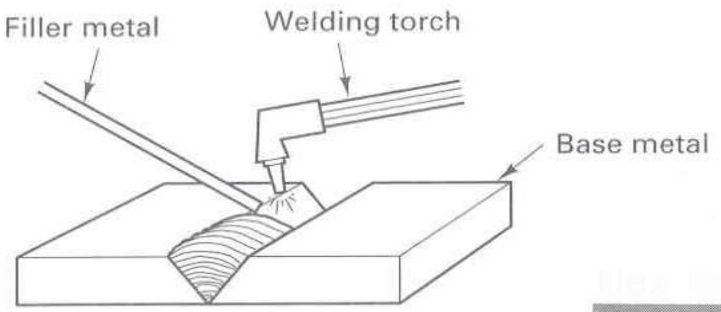


FIGURE 37-7 Schematic of the braze welding process.

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:

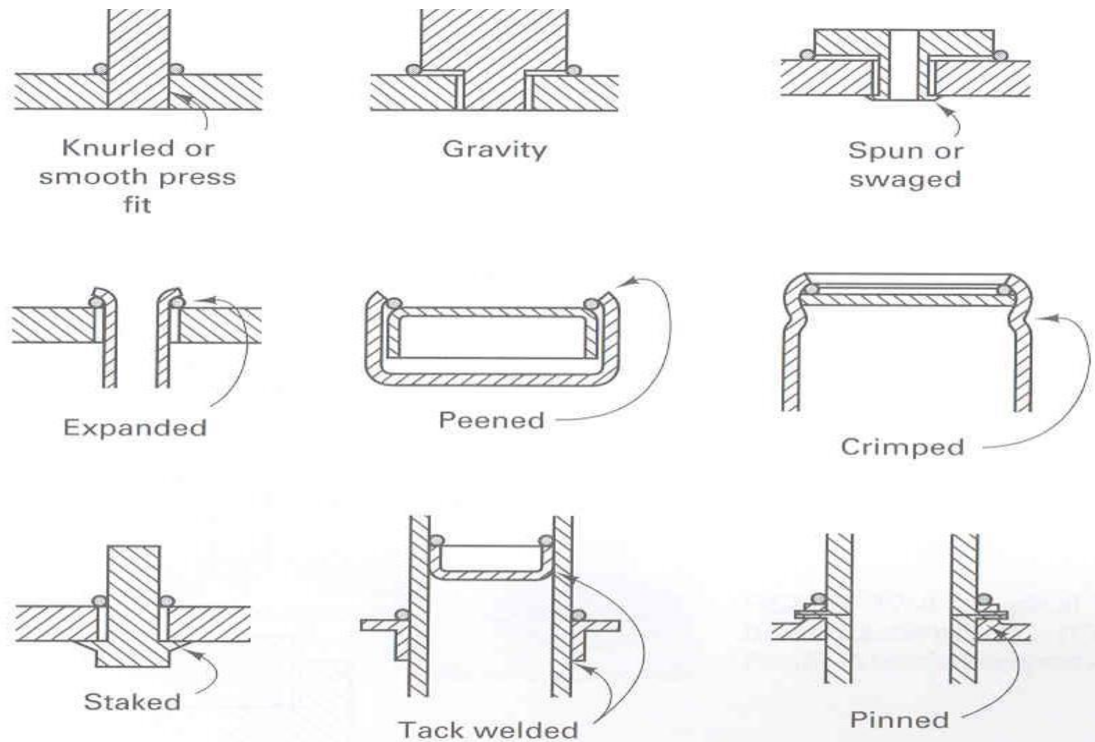


FIGURE 37-2 Methods of applying braze metal and positioning or fixturing various joints.

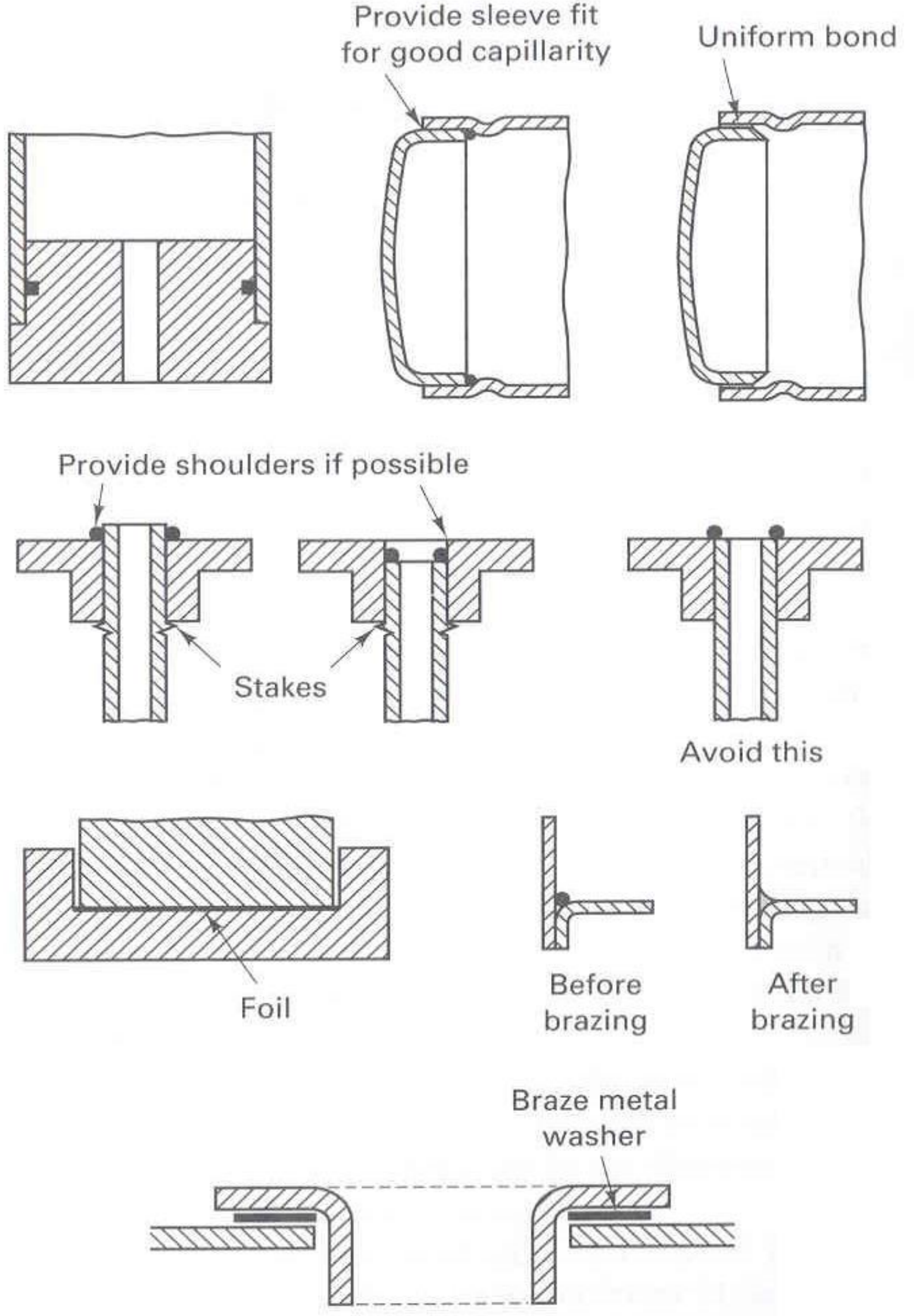


FIGURE 37-3 Techniques to apply brazing wire, foil, or sheet to assure proper flow into the joint.

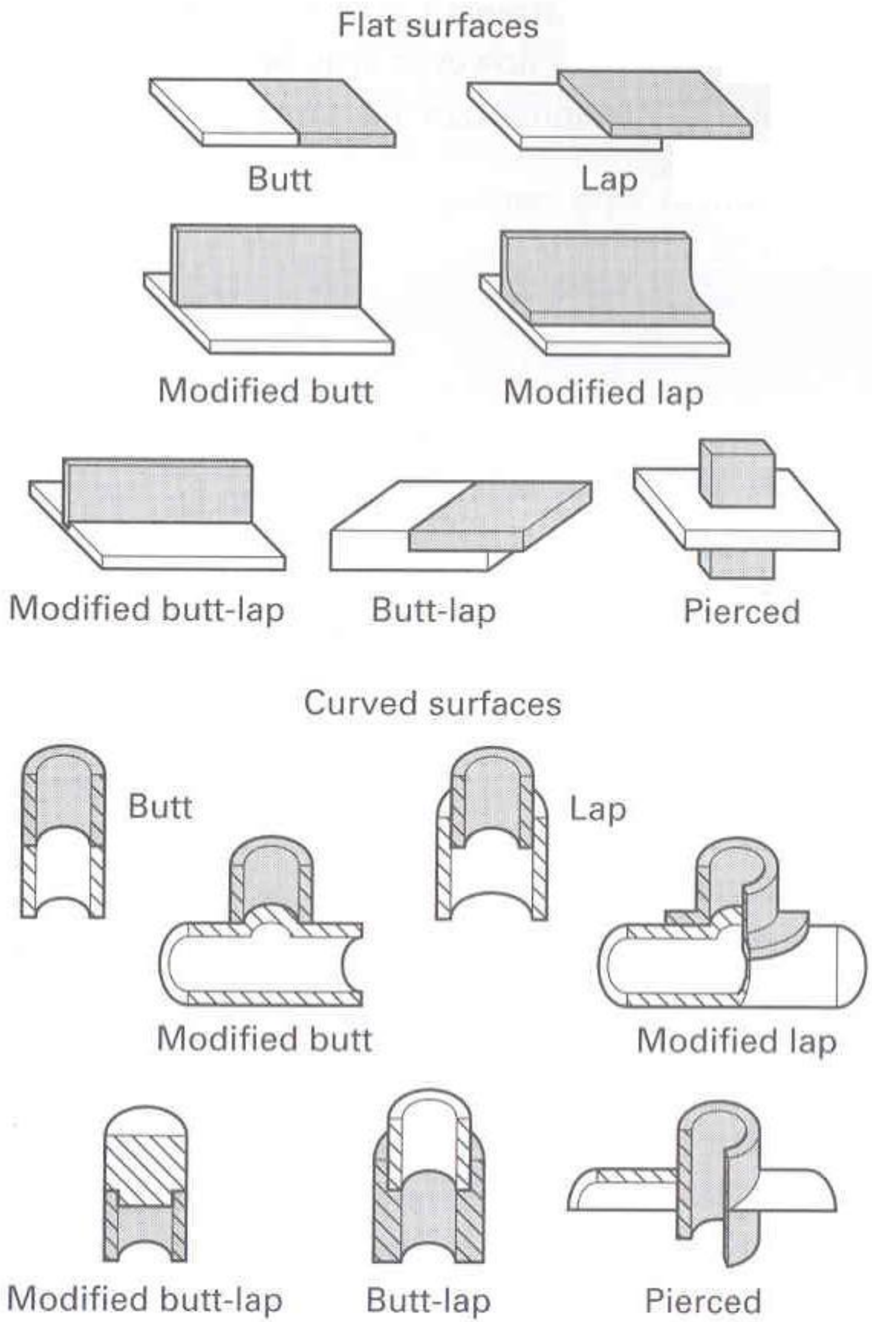


FIGURE 37-5 Some common designs of brazed joints for flat and curved surfaces. *(Adapted from* The Brazing Book, *Handy & Harman).*

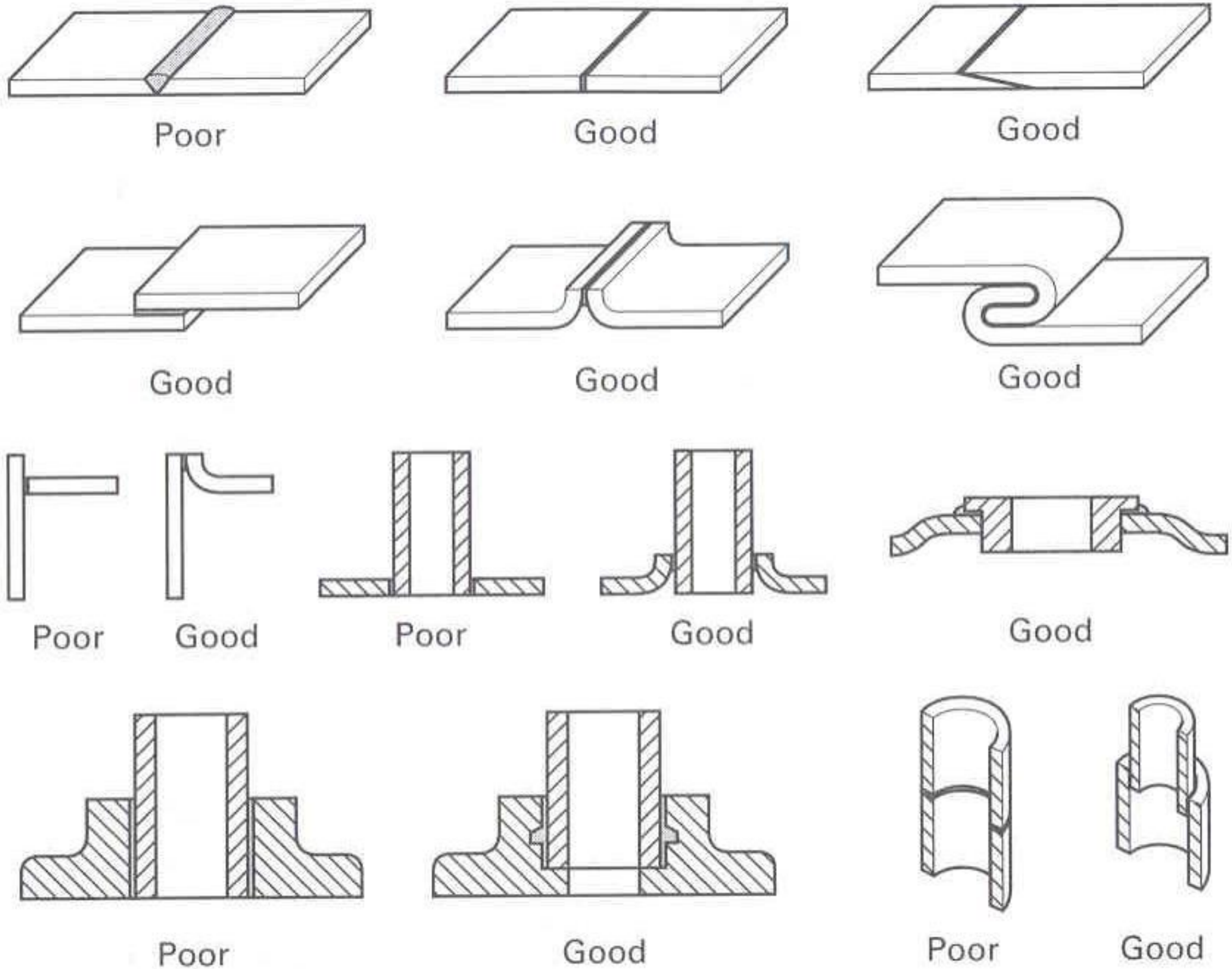


FIGURE 37-6 Examples of good and bad joint design for brazing.

Quality of joints:

Rule of thumb: stronger joints for larger contact area
stronger joints for optimal clearance
stronger joints for appropriate brazing material

Brazing of pipes – in hydraulic works, can be performed in different ways →
Induction brazing (brazing process named by the method that is used to heat assembly), furnace, dipping, torch, electric

The brazing operation must be preceded by cleaning and setting of the proper gap [jigs are used to hold the parts at their position during brazing]

Typical Process Assembly of pipes, carbide tips, radiators, heat exchangers, repair of casting

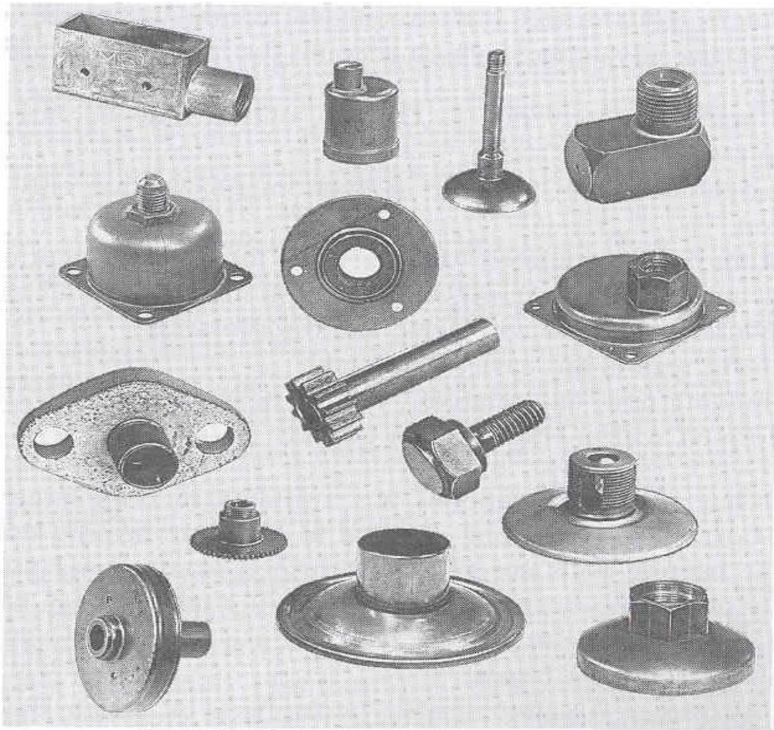


FIGURE 37-4 Typical furnace-brazed assemblies. *(Courtesy of Pacific Metals Company.)*

Chapter 35

WELDING

Metal joining process – without different metal added between.

Coalescence– can be obtained by heat and/or pressure, metallurgical conditions

BY HEAT → hot welding (melted partly at the joint)

BY PRESSURE →metallurgical process at the level of the intermolecular forces
→ cold welding (attraction forces between atoms at the contact surface)

PROBLEMS:

•Keeping weld clean – coalescence is improved by cleanliness of surface to be welded

•Surface oxides –removed before welding → fluxes are used during the welding, the fluxes burn and produce *slag* → because they float as slag on the molten metal and protect it from atmospheric contamination (made of SiO_2 + additives).

•In gas welding, the filler metal rod is often coated with flux

•In electrical arc – welding – the electrode is coated with flux or the flux is added as powder over the welding seem

•A non – oxidising atmosphere is created and the welding is shielded against oxygen (oxidation)

•Inert gasses used to protect the weld created from oxygen

CLASSIFICATION

FIGURE 33-1 Classification of common welding processes along with their AWS (American Welding Society) designations.

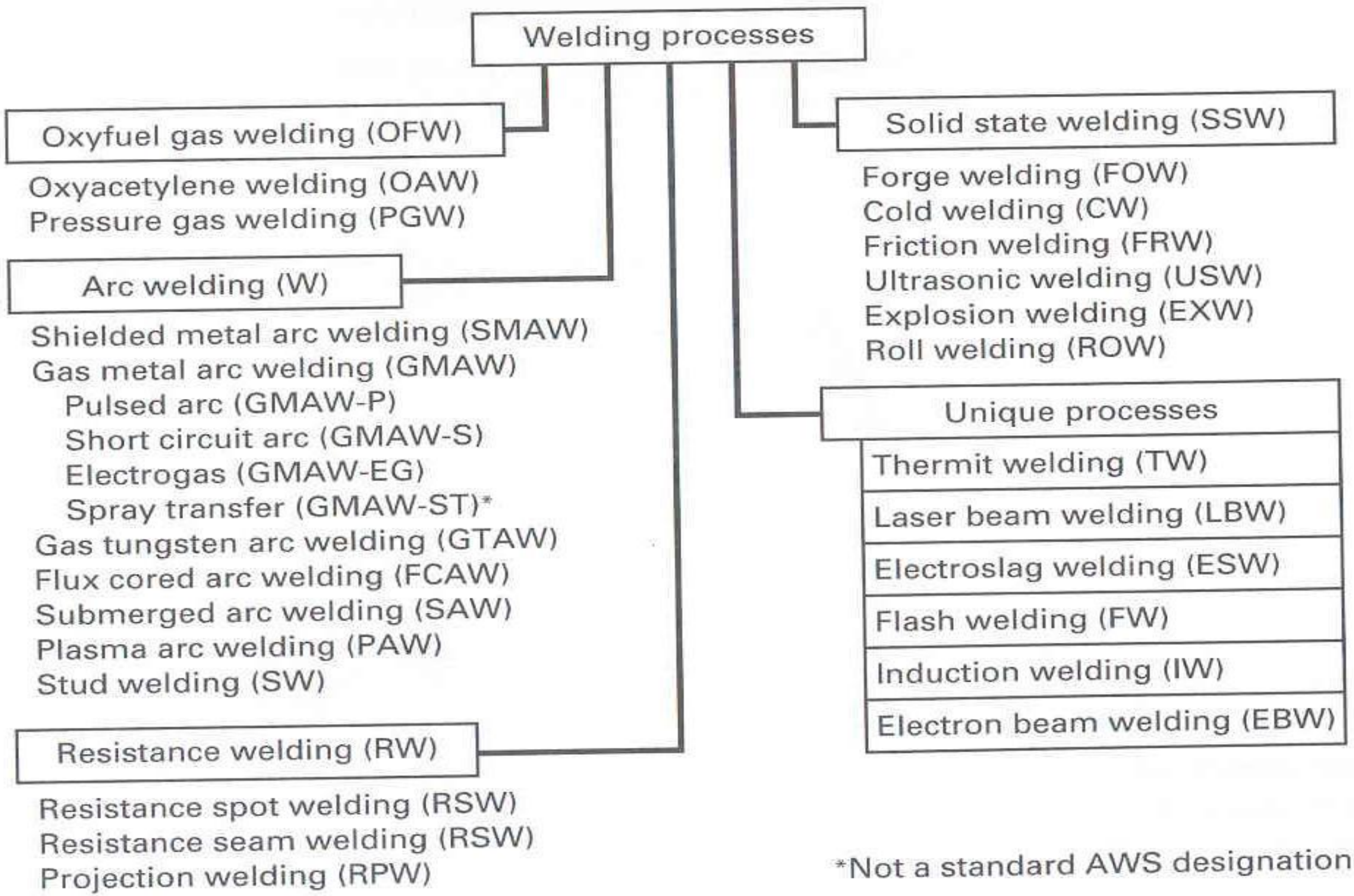
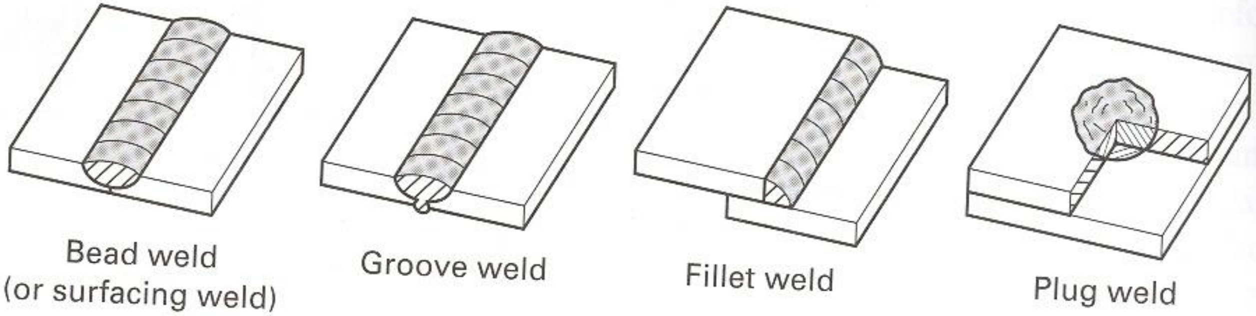


FIGURE 35-3 Four basic types of fusion welds.



...solidified from the molten state.

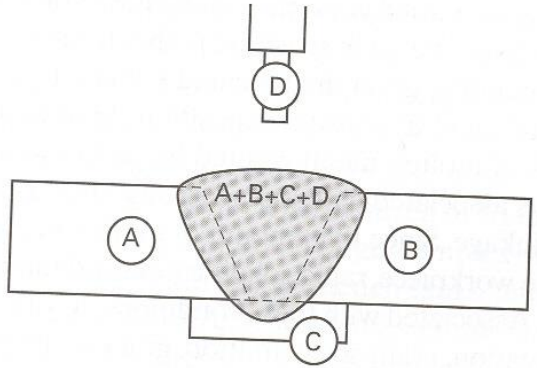
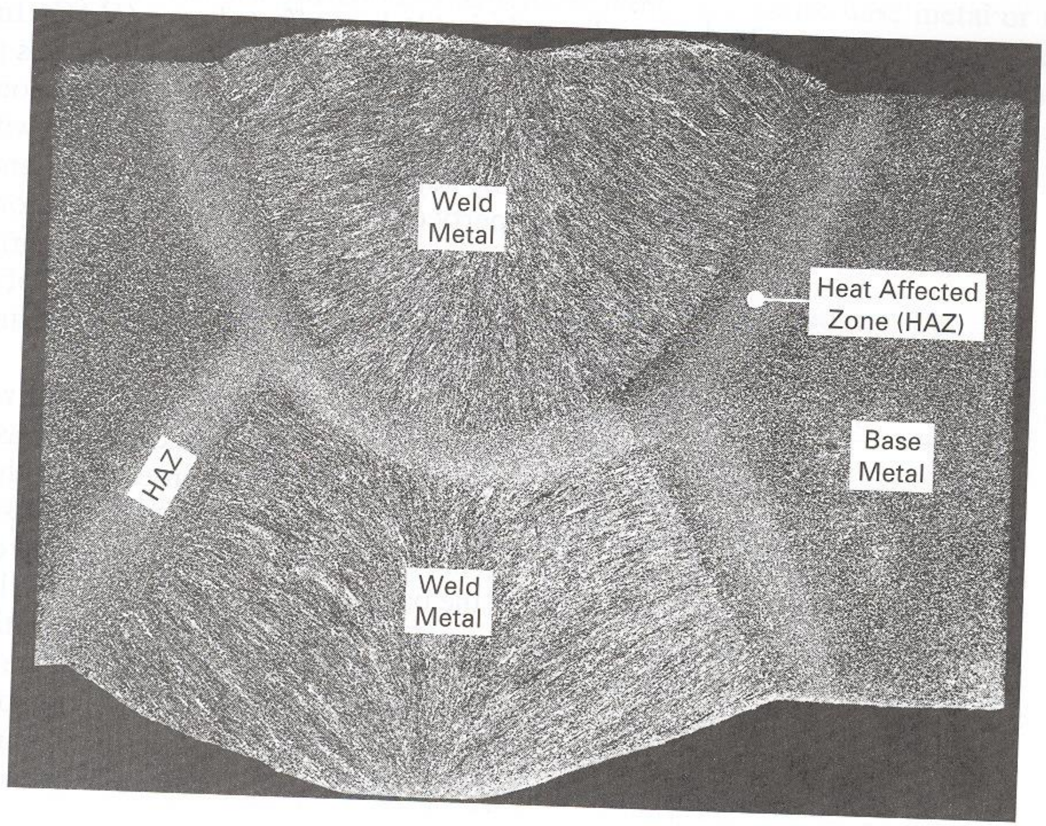


FIGURE 35-9 Schematic of a butt weld between a plate of metal A and a plate of metal B, with a backing plate of metal C and filler of metal D. The resulting weld nugget becomes a complex alloy of all four metals.

...GURE 35-10 Grain structure ...d various zones in a fusion ...eld.



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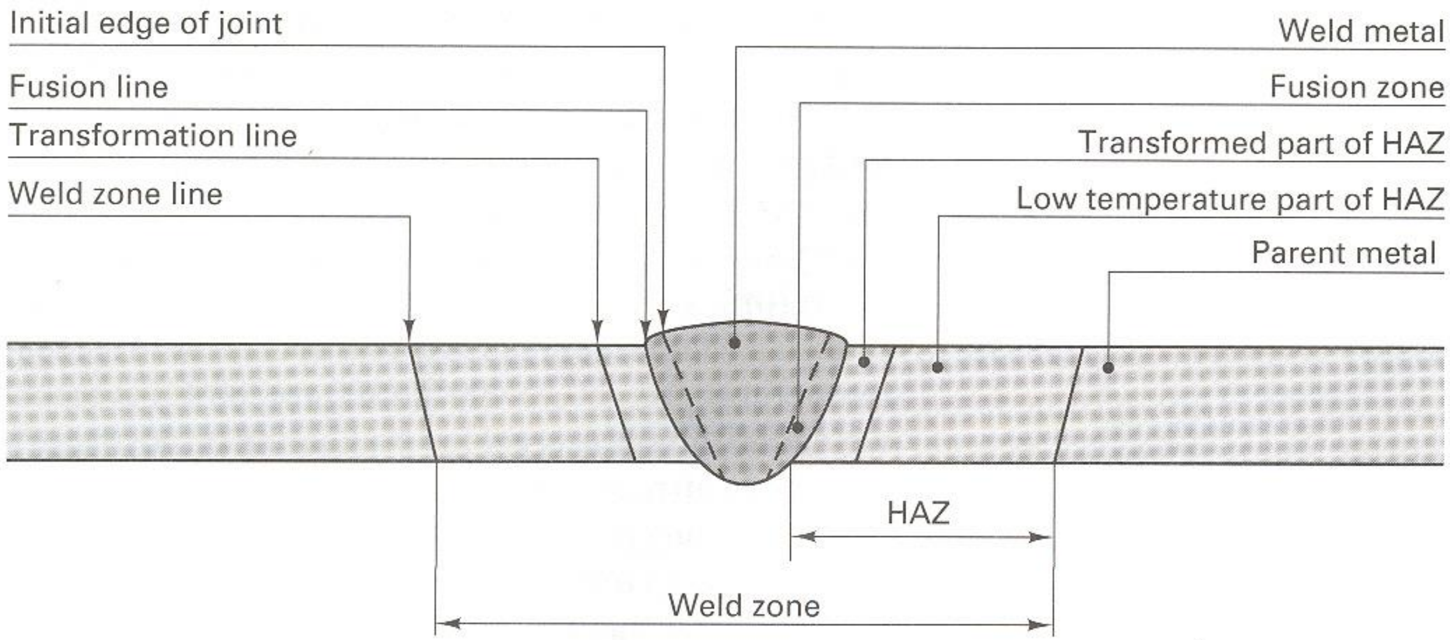


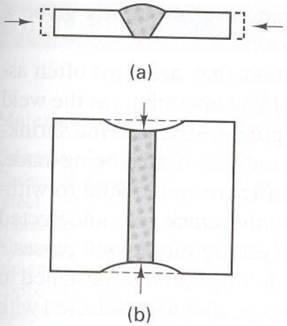


FIGURE 35-14 Shrinkage of a typical butt weld in the transverse (a) and longitudinal (b) directions as the material responds to the induced stresses. Note that restricting transverse motion will place the entire weld in transverse tension.

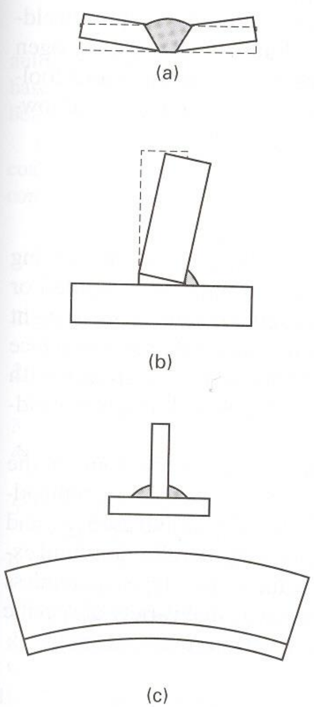


FIGURE 35-15 Distortions or warpage that may occur as a

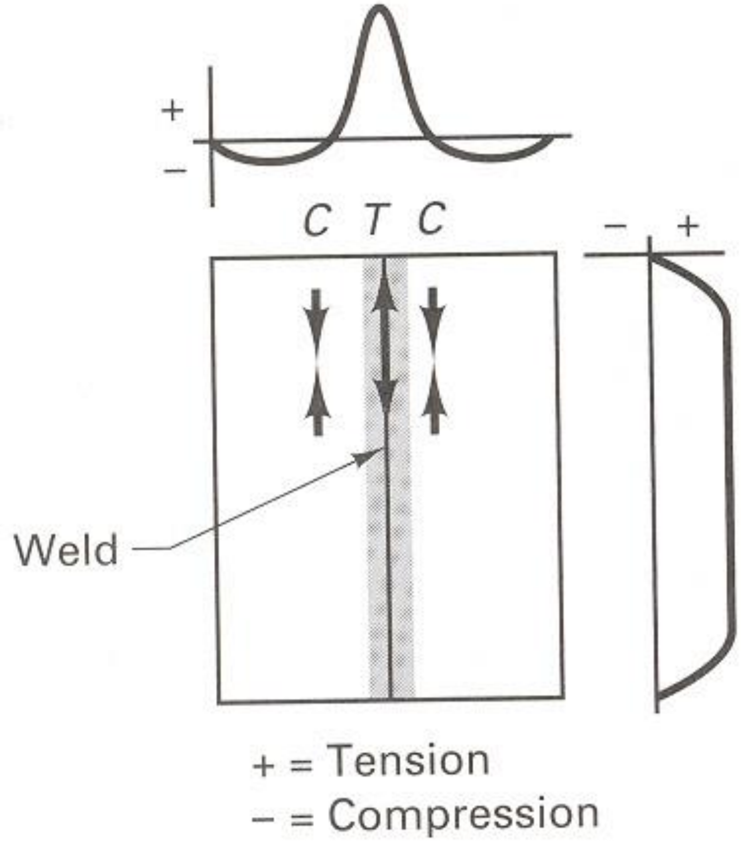


FIGURE 35-13 Schematic of the longitudinal residual stresses in a fusion-welded butt joint.

TABLE 35-2. Weldability or Joinability of Various Engineering Materials[a]

Material	Arc Welding	Oxyacetylene Welding	Electron Beam Welding	Resistance Welding	Brazing	Soldering	Adhesive Bonding
Cast iron	C	R	N	S	D	N	C
Carbon and low-alloy steel	R	R	C	R	R	D	C
Stainless steel	R	C	C	R	R	C	C
Aluminum and magnesium	C	C	C	C	C	S	R
Copper and copper alloys	C	C	C	C	R	R	C
Nickel and nickel alloys	R	C	C	R	R	C	C
Titanium	C	N	C	C	D	S	C
Lead and zinc	C	C	N	D	N	R	R
Thermoplastics	Heated tool R	Hot gas R	N	Induction C	N	N	C
Thermosets	N	N	N	N	N	N	C
Elastomers	N	N	N	N	N	N	R
Ceramics	N	S	C	N	N	N	R
Dissimilar metals	D	D	C	D	D/C	R	R

[a]C, commonly performed; R, recommended (easily performed with excellent results); D, difficult; N, not used; S, seldom used.

Chapters 36, 37 and 38

WELDING PROCESSES

1. FORGE WELDING (FOW)

- Welding with use of pressure & heat – not much in use today
- Hot metal are hammered together until welded (but not melted)

2 COLD WELDING (CW) – no heat is used → coalescence through rapid application of pressure

- Surface must be very clean, flat in order to bring the atoms of metal very close
- Done by a punch-press or hammer – a kind of cold working process

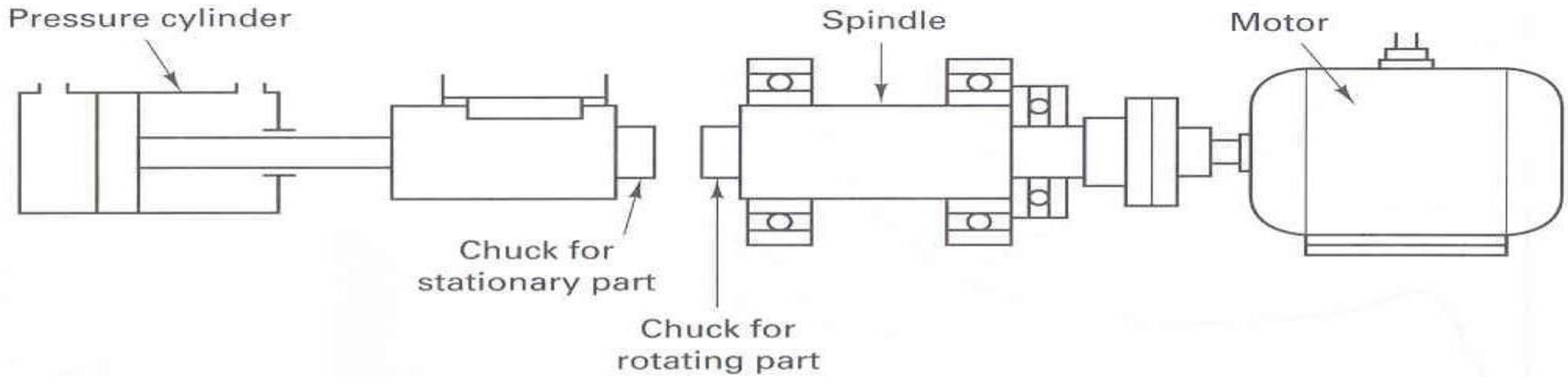


FIGURE 36-3 Schematic diagram of the equipment used for friction welding. *(Courtesy of Materials Engineering.)*

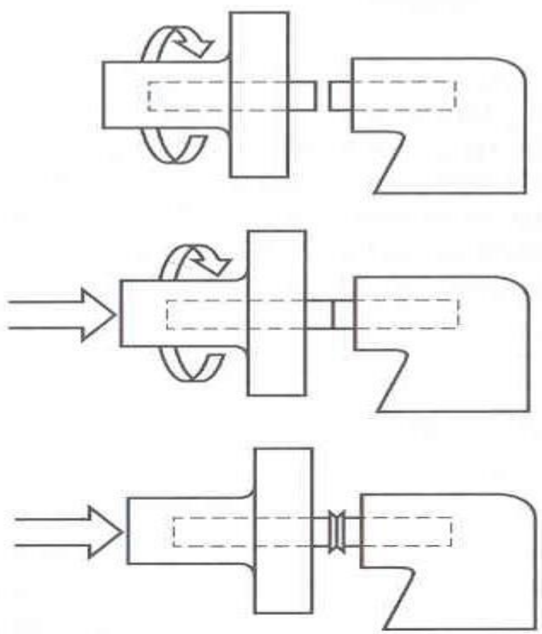
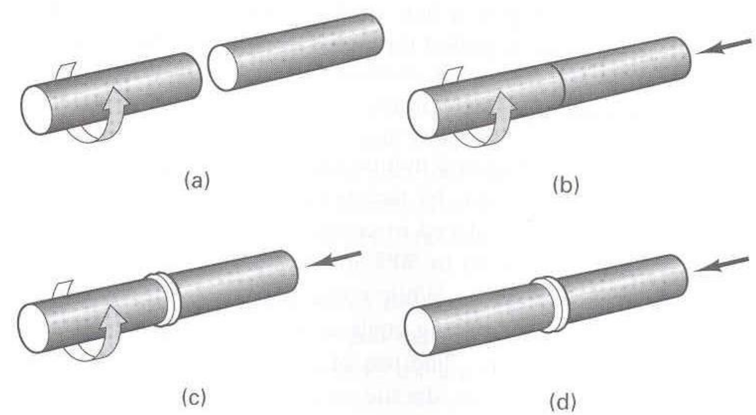


FIGURE 36-4 Schematic representation of the three steps in inertia welding.

FIGURE 36-2 Sequence for making a friction weld. (a) Components with square surfaces are inserted into a machine where one part is rotated and the other is held stationary. (b) The components are pushed together with a low axial pressure to clean and prepare the surfaces. (c) The pressure is increased, causing an increase in temperature, softening, and possibly some melting. (d) Rotation is stopped and the pressure is increased rapidly, creating a forged joint with external flash.



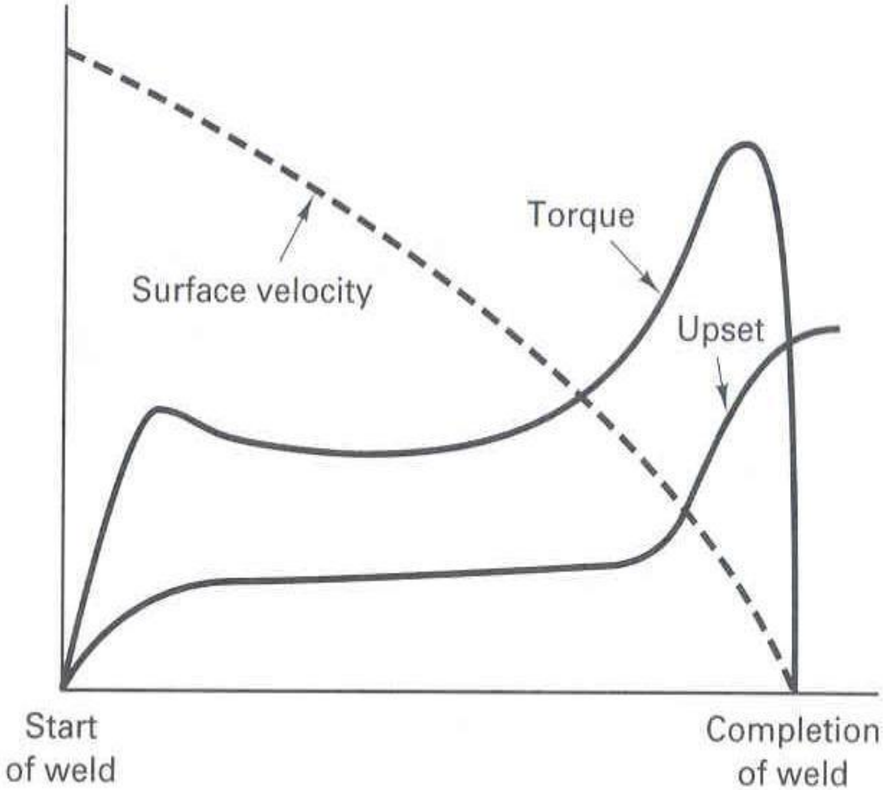


FIGURE 36-5 Relationship between surface velocity (speed), torque, and upset throughout the inertia welding process.

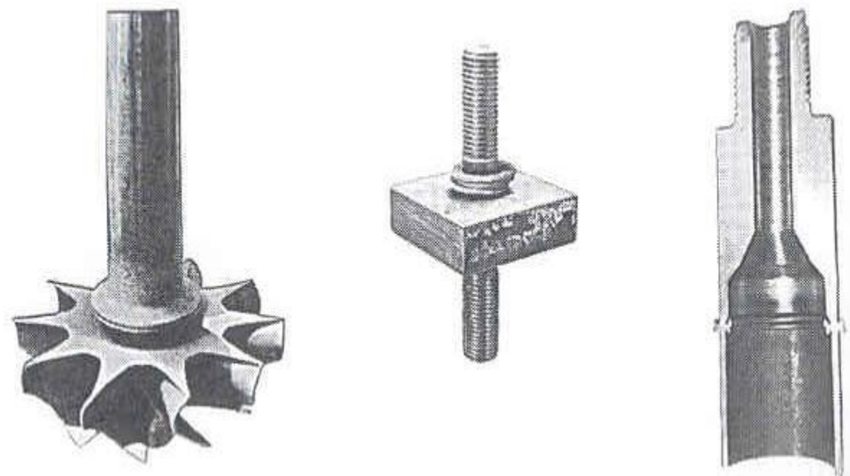


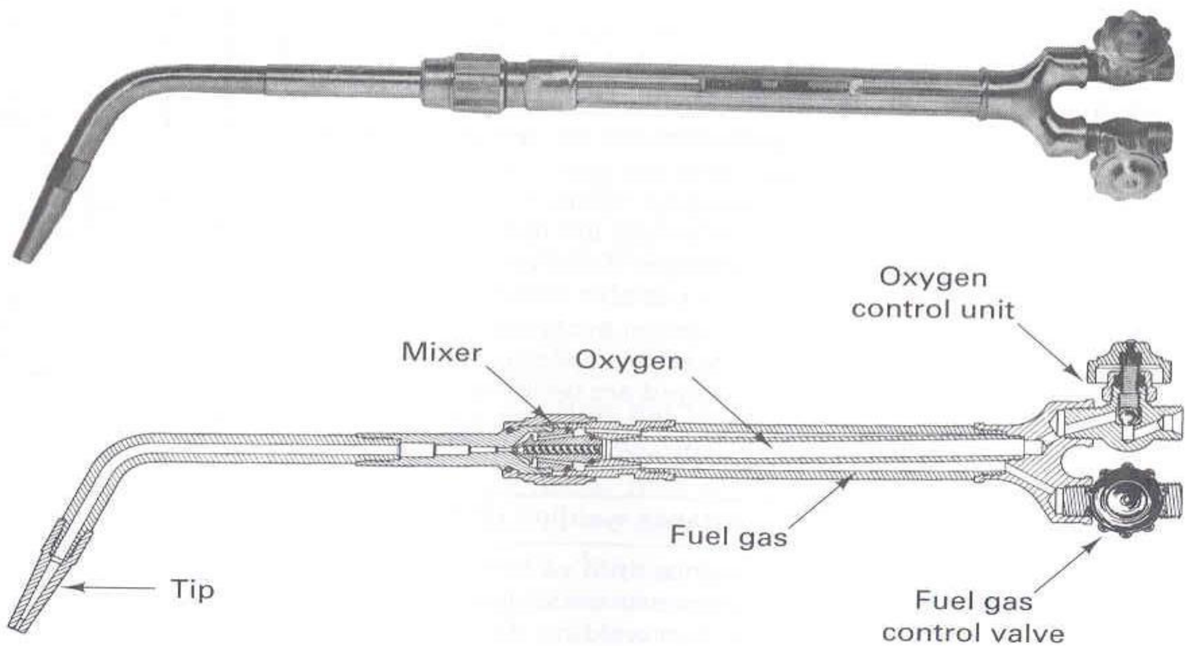
FIGURE 36-6 Some typical friction-welded parts. (*Left*) Impeller made by joining a chrome–moly steel shaft to a nickel–steel casting. (*Center*) Stud plate with two mild steel studs joined to a square plate. (*Right*) Tube component where a turned segment is joined to medium-carbon steel tubing. *(Courtesy of Newcor Bay City, Div. of Newcor, Inc.)*

3. OXYFUEL GAS WELDING (OFW):old method → metals are heated with a flame produced from reaction of oxygen with acetylene

+ use of a filler – metal to fill the gap (the same metal)

- to a state of fusion → no pressure is used
- Oxygen → from air → stored in steel cylinders at a pressure of 2000 psi (140 bar)
- acetylene gas (C_2H_2)- obtained from reaction between calcium carbide + water (or in bottles (cylinders) – 250 psi /17 bar)
- mixing & burning of acetylene + oxygen → torch (the flow controlled by valves)

FIGURE 33-2 Typical oxyacetylene welding torch and cross-sectional schematic. *(Courtesy of Victor Equipment Company.)*



• **pure oxygen provides a flame with temperature much higher than using air (up to 3500^0 C)**

Combustion reactions:

Primary: 3500°C 1. $C_2H_2 + O_2 = 2CO + H_2$ -> very high temp. @ cone of flame

Secondary: 2. $2CO + O_2 = 2CO_2$ -> outside the cone

2'. $H_2 + 1/2\ O_2 = H_2O$ -> from atmosphere

- **Control of the flow rates of oxygen and acetylene – very important.** **This affects the characteristic of the flame which depends on O_2/C_2H_2 ratio**

- **Three types of flame can be obtained: REDUCING, NEUTRAL & OXIDIZING**

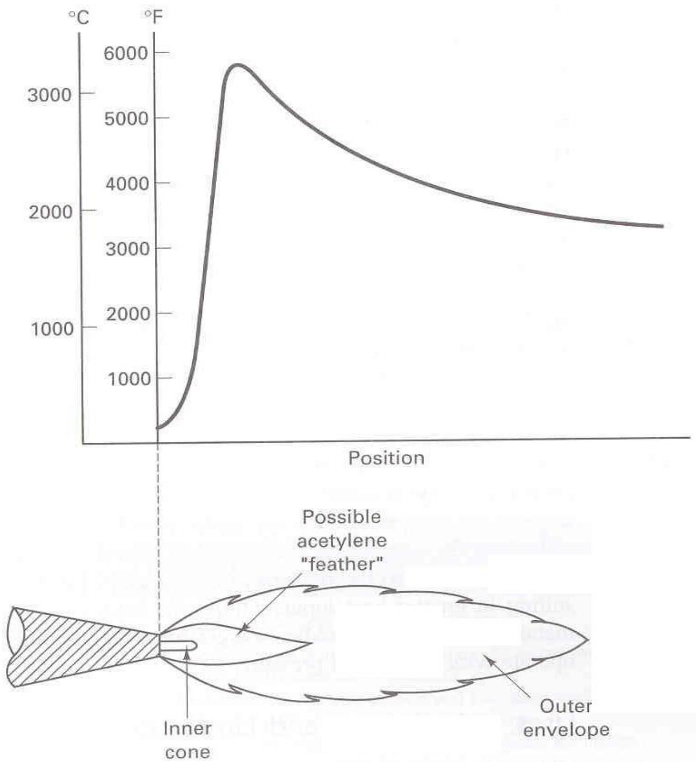


FIGURE 33-3 Typical oxyacetylene flame and the associated temperature distribution.

NEUTRAL flame → the widest application : the inner luminous cone has 1:1 ratio (stochiometric) of O_2 and C_2H_2

- First part of reaction ($C_2H_2 + O_2 = 2CO + H_2$) occurs near the torch tip

- SAFETY – a real problem: eye protection from the radiation + explosion
  Ex: C_2H_2 fitting has left hand valve and O_2 right hand thread, to avoid mistakes.

- Utilisation: gas –flame welding largely replaced by arc or resistance welding except for repair work, field welding or some special applications (thin metal sheet welding, artistic welding)

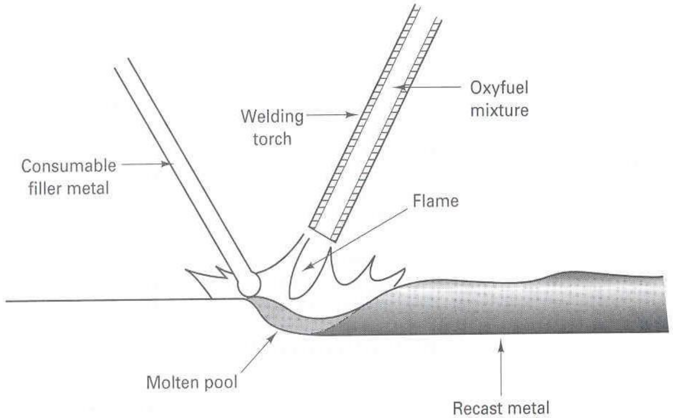


FIGURE 33-4 Schematic of oxyfuel gas welding with a consumable welding rod.

ADVANTAGES:

by gas welding even with thin materials, temperatures can be easily controlled

DISADVANTAGES:

exposure of heated metal to various gases from the atmosphere,
without shielding →contamination;

distortion of thin metal parts (non uniform heating)

more expensive→replaced by shielded metal arc welding & inert gas metal welding

TABLE 33-1. Engineering Materials and Their Compatibility with Oxyfuel Welding

Material	Oxyfuel Welding Recommendation
Cast iron	Recommended with cast iron filler rods; braze welding recommended if there are no corrosion objections
Carbon and low-alloy steels	Recommended for low-carbon and low-alloy steels, using rods of the same material; more difficult for higher carbon
Stainless steel	Common for thinner material; more difficult for thicker
Aluminum and magnesium	Common for aluminum thinner than 1 in.; difficult for magnesium alloys
Copper and copper alloys	Common for most alloys; more difficult for some types of bronzes
Nickel and nickel alloys	Common for nickel, Monels, and Inconels
Titanium	Not recommended
Lead and zinc	Recommended
Thermoplastics, thermosets, and elastomers	Hot-gas welding used for thermoplastics, not used with thermosets and elastomers
Ceramics and glass	Seldom used with ceramics, but common with glass
Dissimilar metals	Difficult; best if melting points are within 50°F; concern for galvanic corrosion
Metals to nonmetals	Not recommended
Dissimilar nonmetals	Difficult

4. Pressure – Gas Welding. (PGW) – To make butt joints between bars or ends heated with gas flame but below the melting point temperature, and then forced to join together under pressure

- **Can be considered as solid phase weld → this method requires special equipment**

5. Arc Welding – in general

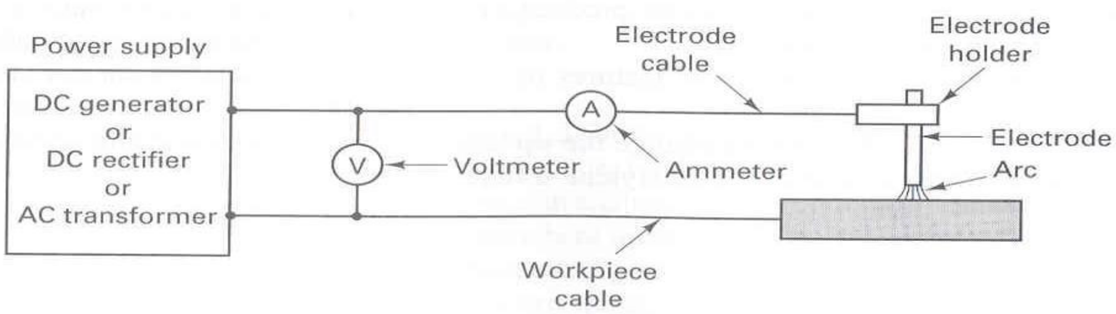
Process in which coalescence is obtained by heat produced from an electric arc created between the work piece and an electrode. – no pressure applied;

The electrode or filler metal is also heated to a liquid state and deposited into the joint to make the weld.

The two electrodes: 1. Workpiece and 2. Electrode → an electric circuit is created

- **By closing the electrodes, the arc is formed at low voltage (28V), high current (few hundreds of A)**
- **the electric energy is converted into an arc with intense heat release which creates high temperature, around 3900^0 C**
- **difficult to control the temperature → by on –off method only**
- **there is no possibility to control the temp. as in gas welding**
- **Traditionally, DC was used with heavy and expensive rectifiers**

FIGURE 34-1 Basic circuit for arc welding.



Two procedures:

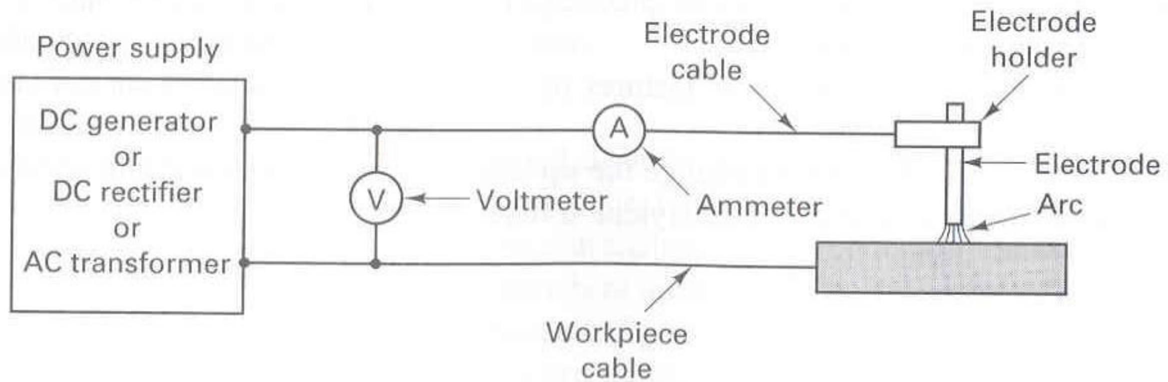
- **1. Straight polarity → electrode –**

  (e⁻ pulled to job, Heavy ions to electrode, more heat at electrode → more melting and filling of electrode → but shallow weld penetration in job.

- **2. Reversed polarity → electrode +**

  The reverse happens, more heat at the job → more melting of job → heavier ions result in deeper weld penetration.

FIGURE 34-1 Basic circuit for arc welding.



- Now: AC → more spread because of the simplicity of the equipment (no rectifiers but just an inexpensive transformer)
- the electrode used usually melts at temp. below the temp. of the arc
  → electrodes consume in the welding process
  → this electrode is moved towards the workpiece when consumed.
- also, not consumable electrode, made of tungsten are used.
- The method needs to feed the weld filler.

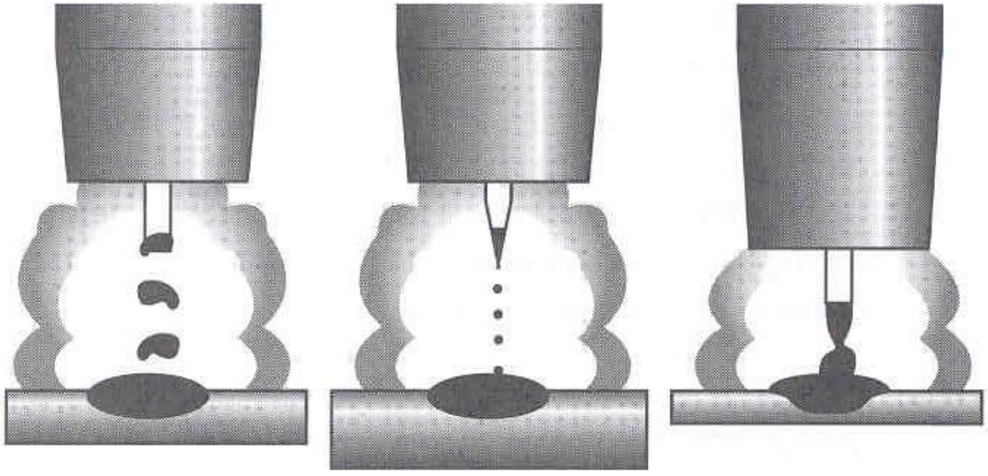


FIGURE 34-2 Three modes of metal transfer during arc welding. *(Courtesy of Republic Steel Corporation.)*

TYPES OF ELECTRODES

1. **Bare electrodes:** **limited use for iron and mild steel → low quality materials**

2. **Fluxed electrodes:** **with light coat of flux →eliminate undesirable oxides and prevent their formation**

3. **Heavy coated electrode:** very used presently for shielded metal arc welding (95%) →a gas shield is provided around the arc to eliminate the undesirable oxides and nitrides to be formed in weld metal. It also provides the weld metal with a protective slag coating, which prevents oxidation of the surface metal during cooling

*** the type of coating of the flux is considered in terms of the type of welding and the materials that must be welded: flux compounds Coating consists of slag forming compounds**

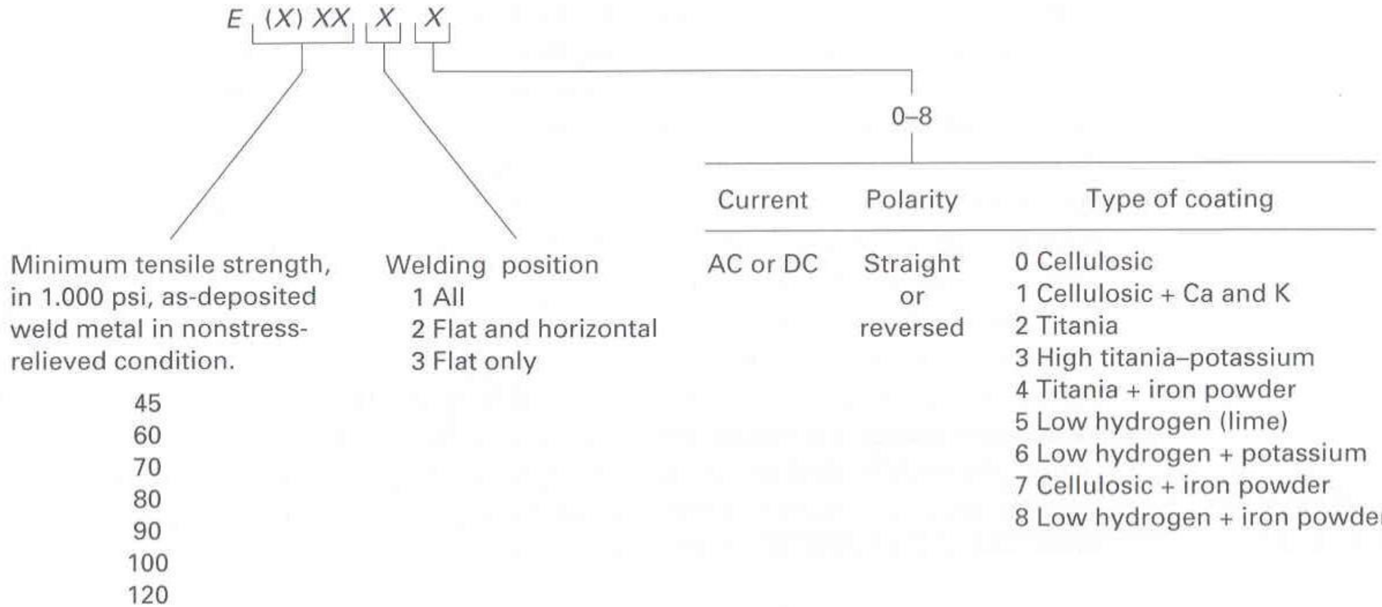


FIGURE 34-3 Designation system for arc-welding electrodes.

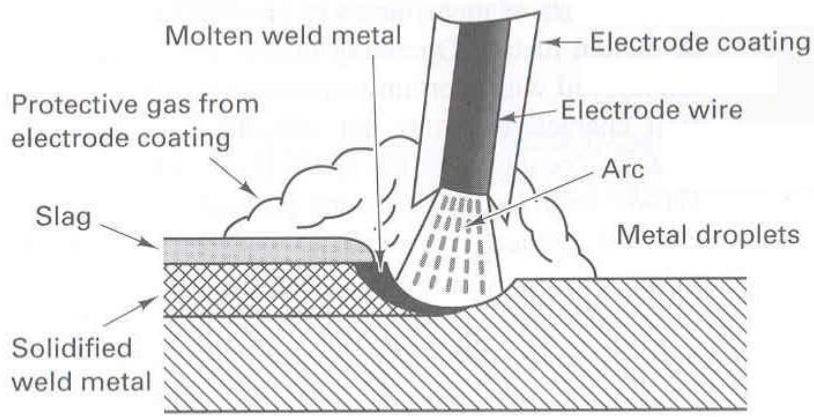


FIGURE 34-4 Schematic diagram of shielded metal arc welding (SMAW). *(Courtesy of American Iron and Steel Institute, Washington, D.C.)*

TYPES OF ARC WELDING PROCESS

5a. Shield Metal Arc Welding – (SMAW) – uses heavy –coated electrodes

5b. Gas Tungsten Arc Welding – (GTAW)

Special purpose such as stainless steel welding → to prevent oxidation

- **The inert gas substitutes for the shielded electrodes (Ar, He)**
- **Electrode – non consumable – by tungsten → NO SLAG**
- **Filler metal must be provided**

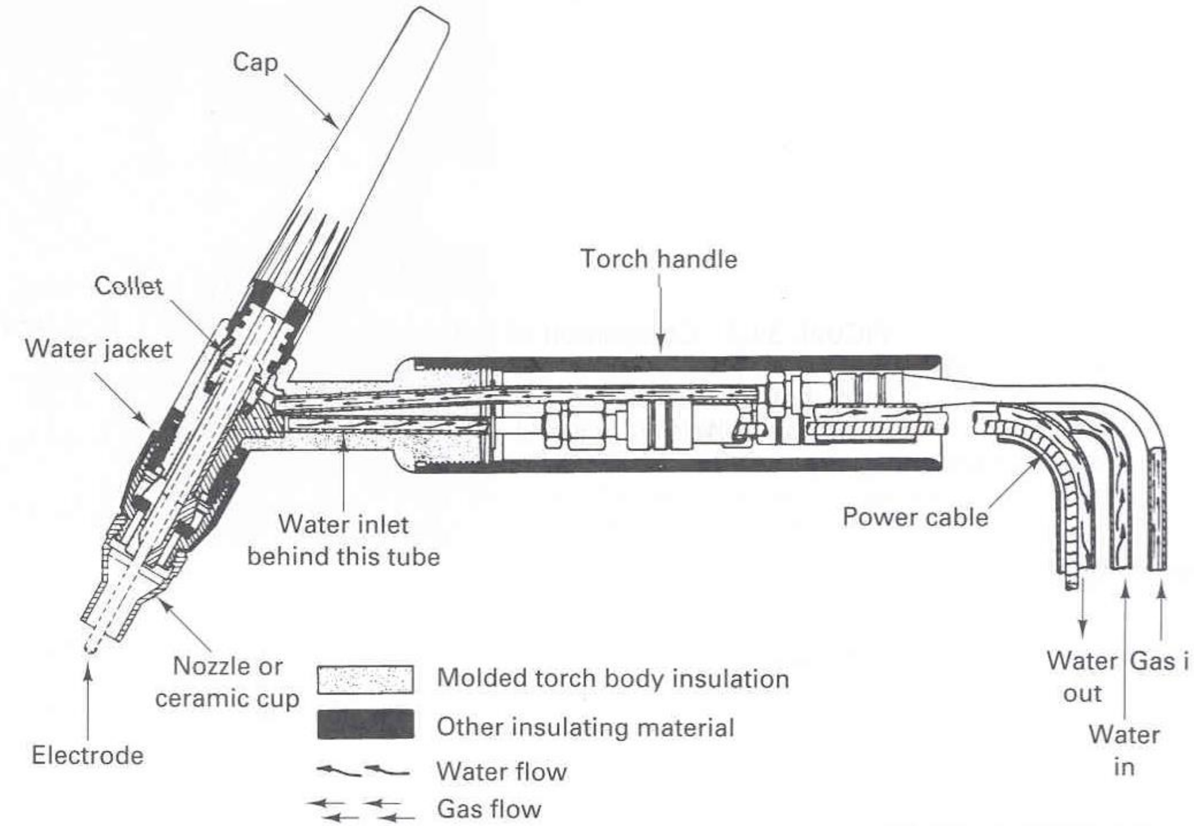


FIGURE 34-5 Welding torch used in nonconsumable-electrode, gas tungsten arc welding (GTAW), showing feed lines for power, cooling water, and inert gas flow. *(Courtesy of Linde Division, Union Carbide Corporation.)*

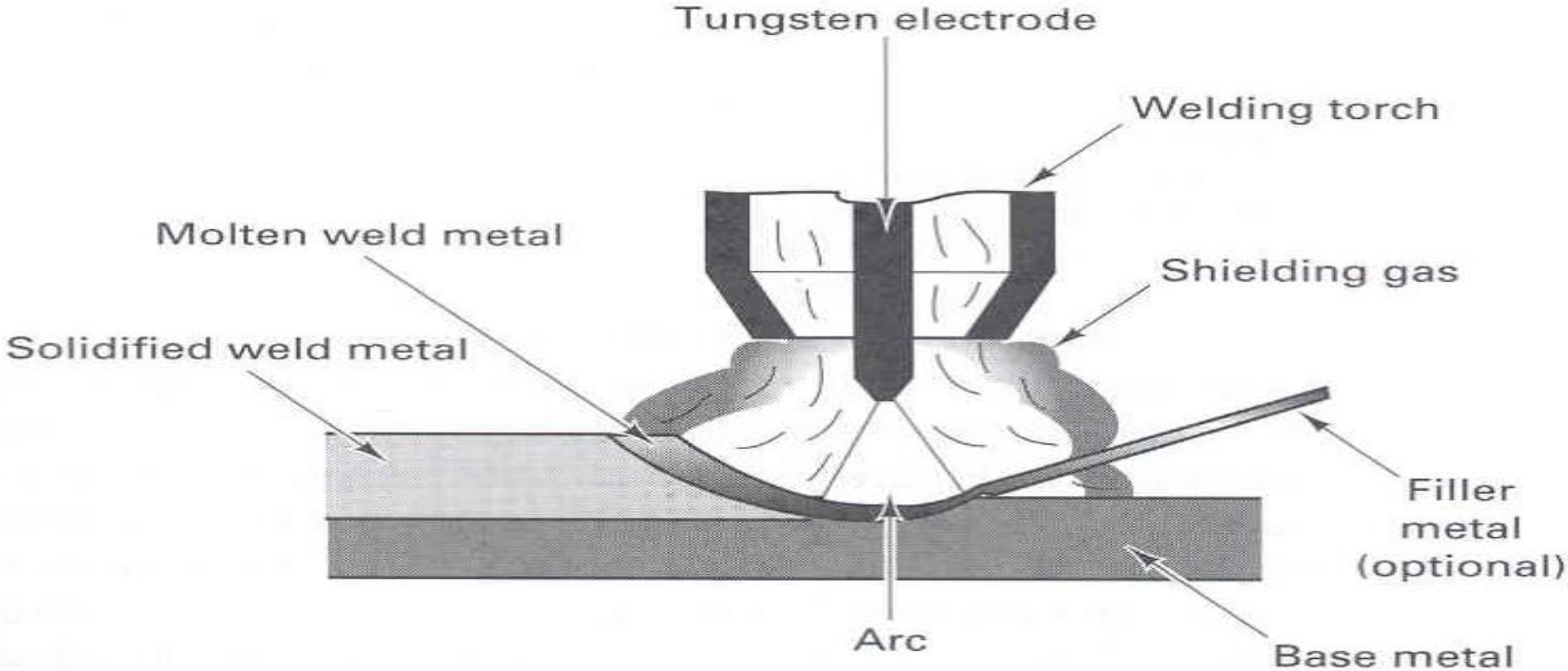


FIGURE 34-6 Schematic diagram of gas tungsten arc welding (GTAW). *(Courtesy of American Iron and Steel Institute, Washington, D.C.)*

5c. Gas Metal Arc Welding →

inert gas used for shielding against atmosphere (CO_2, N_2 - inexpressive)

- **consumable bare electrode are used**
- **for non – ferrous metals –(aluminium)**

→ NO SLAG

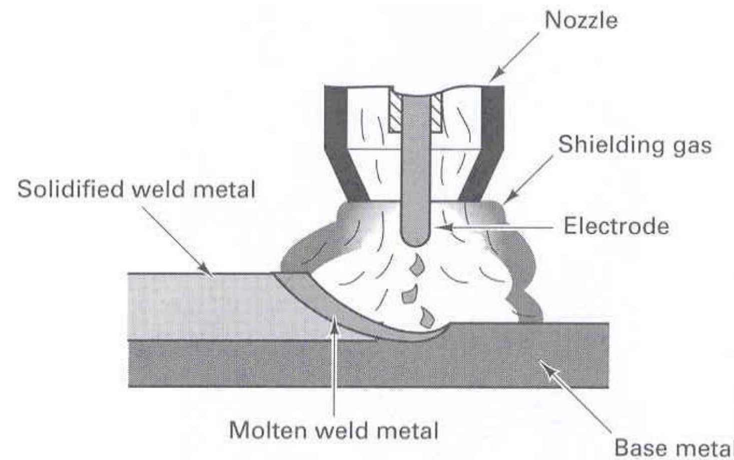


FIGURE 34-10 Schematic diagram of gas metal arc welding (GMAW). *(Courtesy of American Iron and Steel Institute, Washington, D.C.)*

5d. Flux Cored Arc Welding (FCAW)

- **Flux core – inside the electrode**
- **SLAG coats the hot weld**
- **gas produced from flux burning protects the weld**

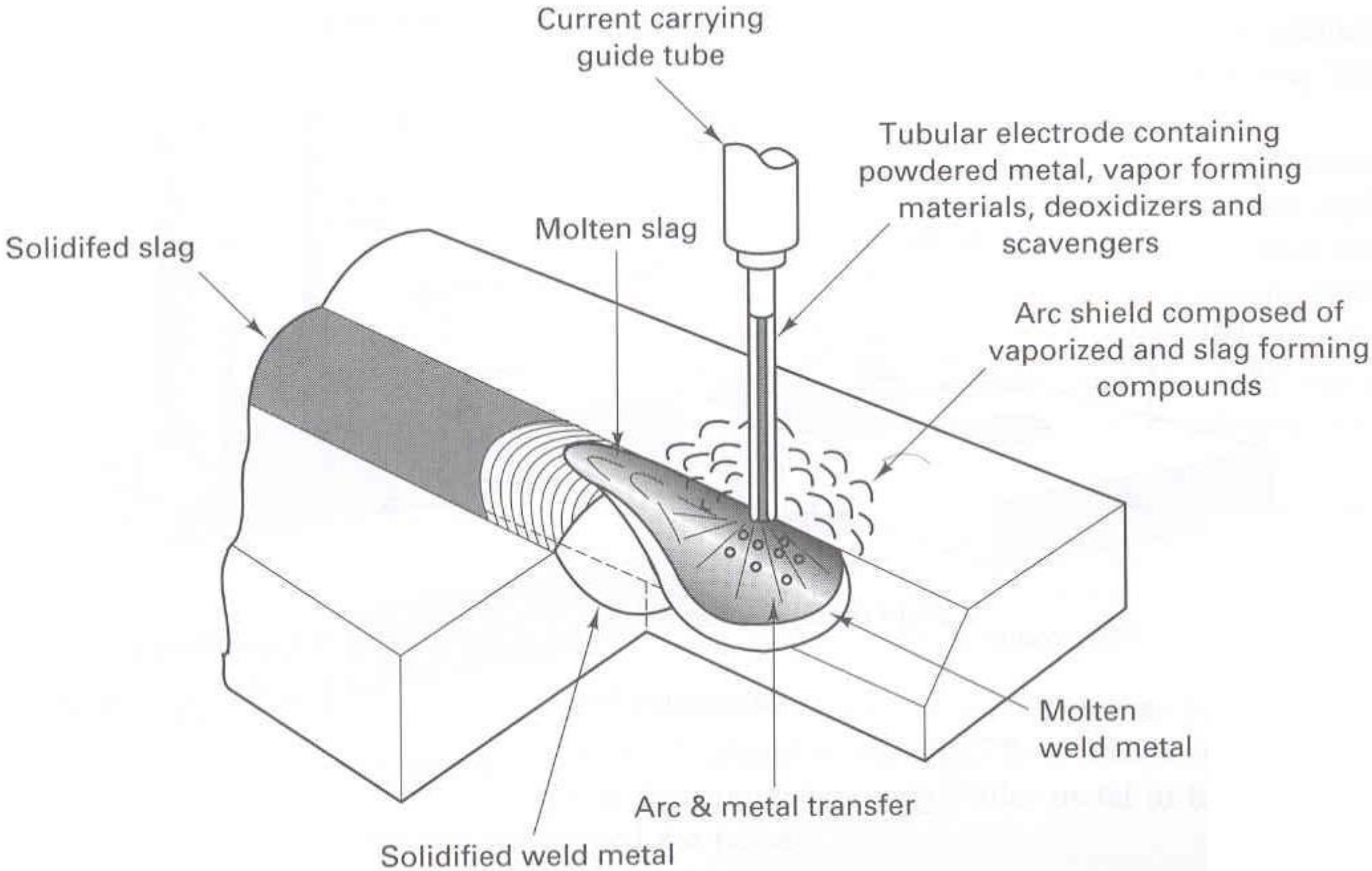


FIGURE 34-11 Schematic representation of the flux-cored arc welding process (FCAW). *(Courtesy of The American Welding Society, New York.)*

5e. Submerged – Arc welding (SAW)

- **Suitable for automation →(automation process)**
- **Arc is shielded by a blanket of granular flux fed from a hopper during welding**
- **Bare electrode is fed into the granular flux which laid down along the seam to be welded**
- **Welding action takes place beneath the flux which laid down along the seam to be welded**
- **Welding action takes place beneath the flux cover**
- **Intense heat of the arc produces a pad of molten metal in the joint →the same time, a portion of the granular flux which will float on top of the molten metal will burn and produce slag → will protect the melted metal from the oxidation**
- **After cooling, the fused slag solidifies → is removed easily**
- **flux can be required**

Ex: vessel welding →

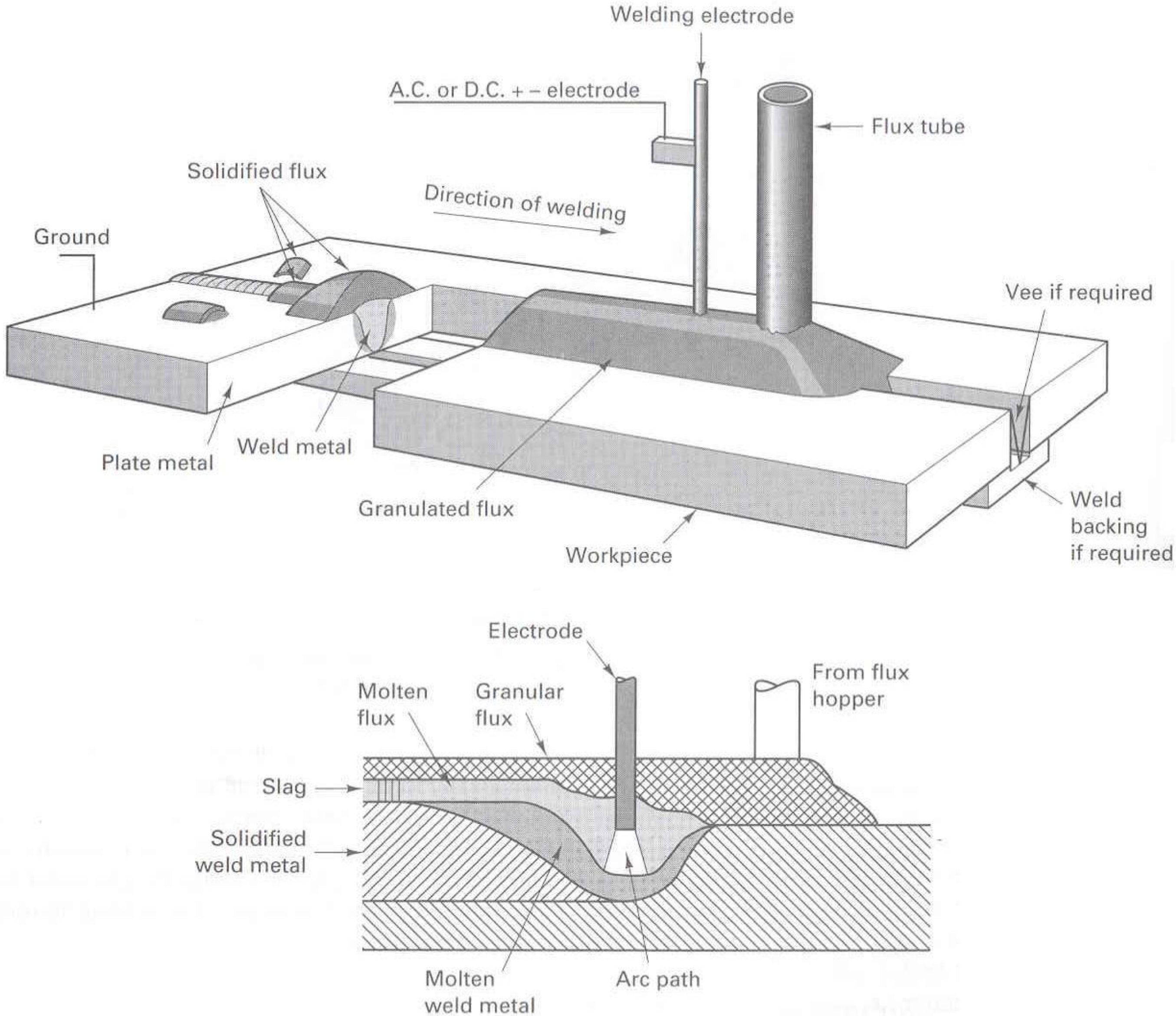


FIGURE 34-12 (*Top*) Basic features of the submerged arc welding process (SAW). *(Courtesy of Linde Division, Union Carbide Corporation.)* (*Bottom*) Cutaway schematic of submerged arc welding. *(Courtesy of American Iron and Steel Institute, Washington, D.C.)*

- **Only flat surface or surfaces with large aperture can be welded**
- **high welding rate can be obtained with mechanised process**
- **good weld control obtained**
- **thick metal plates can be welded**

5f. Stud Welding –(S.W) – arc welding process to end –weld metal studs to flat surfaces

- **Special welding gun is used to hold the stud**
- **when the trigger is pressed, the stud is lifted to create an arc, and then, forced against molten pool by backing springs**
- **the operation – automatically controlled – no skill required**
- **frequency 60 operations/min**

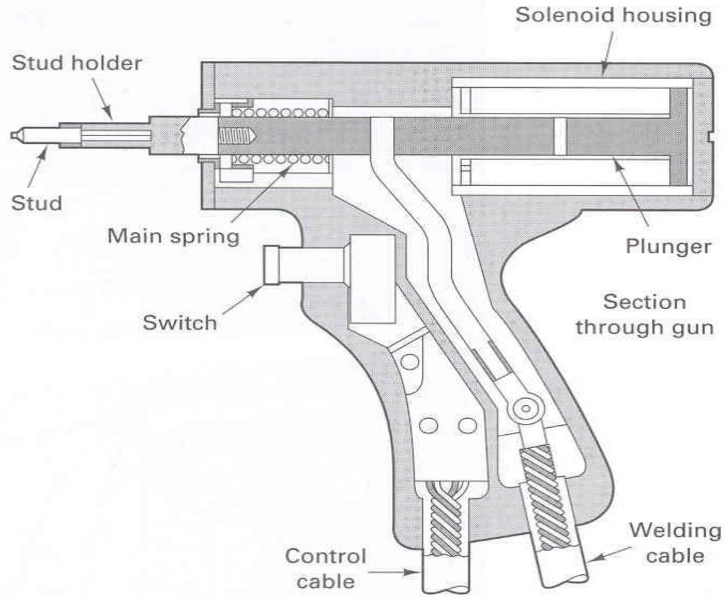


FIGURE 34-14 Schematic diagram of a stud welding gun. *(Courtesy of American Machinist.)*

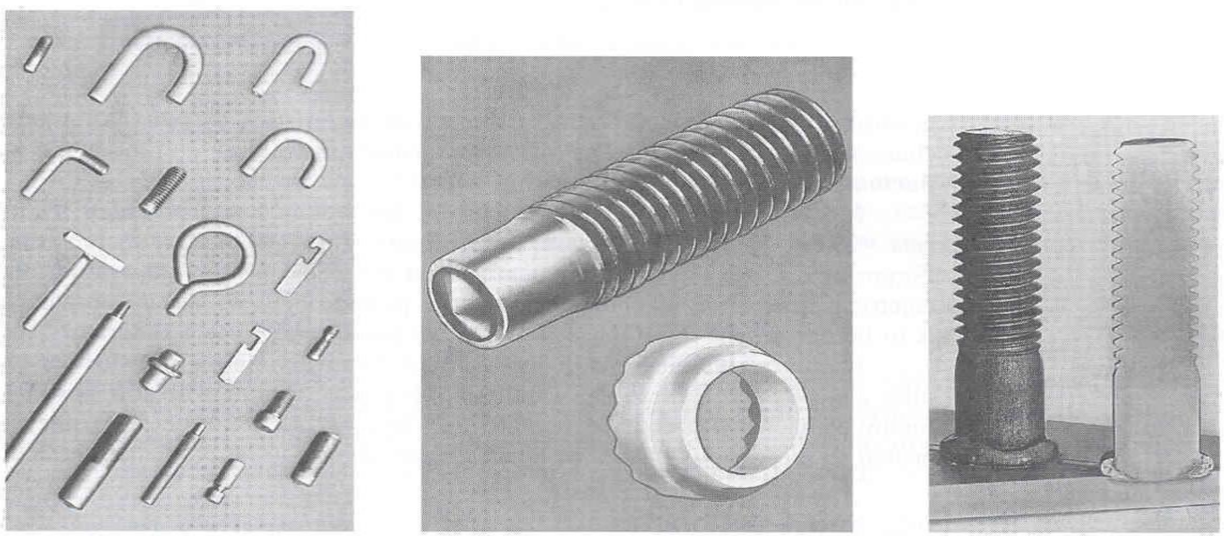


FIGURE 34-15 (*Left*) Types of studs used for stud welding. (*Center*) Stud and ceramic ferrule. (*Right*) Stud after welding and a section through a welded stud. *(Courtesy of Nelson Stud Welding Co.)*

6. Resistance Welding-

Phenomenon when high current is passed through a joint and heat is released

Joule's effect → $E = I^2Rt$

- **Heat and pressure are used to join parts: suitable for automation →robots perform this job.**
- **For plates and sheets => heavy current is passed through both parts causing local heating at the joint (the highest resistance)**
- **Welding is completed by application of pressure**
- **low voltages ~ 4-12 V at high flow (current) from transformers**
- **When the current passes through metal, most heat →at the joint point → greatest resistance (in the electrical path, which is at the interface of the sheets)**

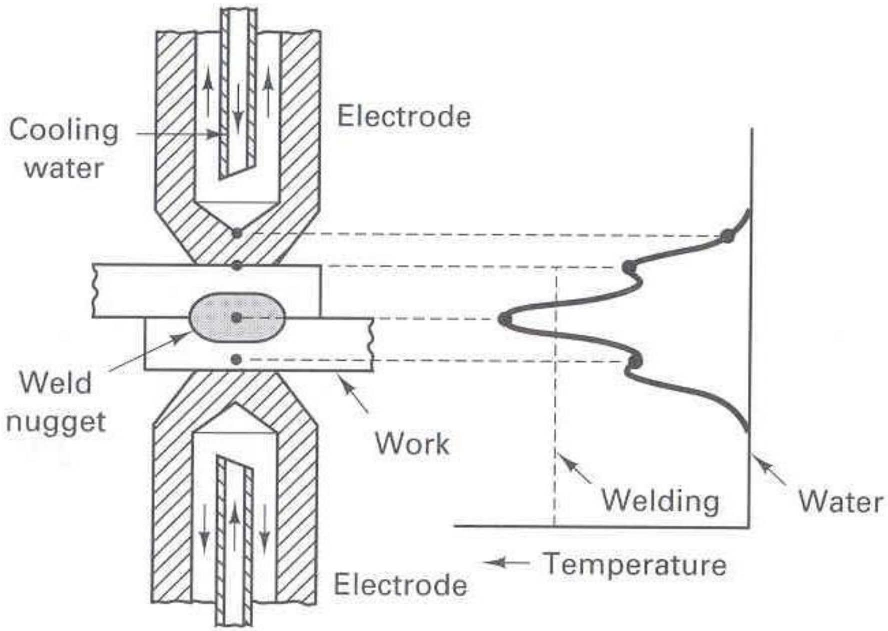


FIGURE 35-2 The desi
temperature distributio
the electrodes and the
workpieces in lap resist
welding.

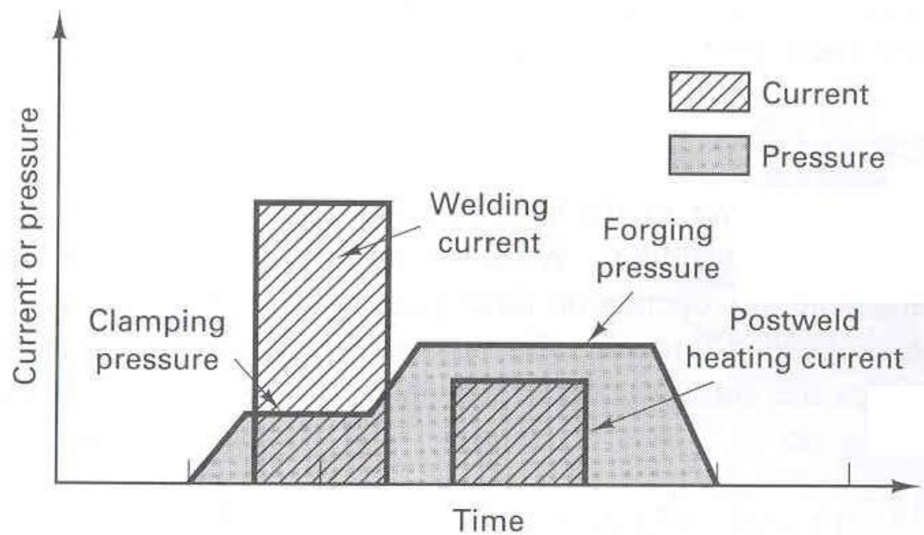


FIGURE 35-3 Typical current and pressure cycle for resistance welding. The cycle includes forging and postheating operations.

- Power flow 30-40 KVA/ in max. 10 sec. Time
- Pressure to complete the weld is 4000-8000 psi (28-55 MPa)
- Resistance of the workpiece is determined by the type of the metal and its thickness →it is usually small
- Electrodes – high conductivity → copper, do not melt, has cooling circuit
- Resistance between the surface depends on:
  - the finish of the surface
  - the contamination of surface
  - the pressure applied
  - the contact area of surface

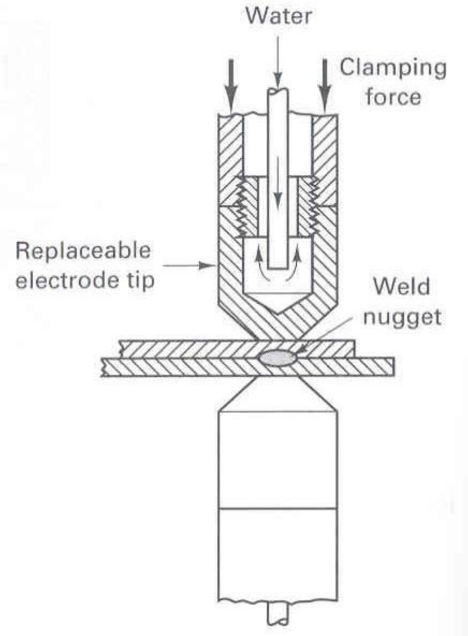


FIGURE 35-4 The arrangement of the electrodes and the work in spot welding, showing design for replaceable electrode tips.

6a. Resistance spot welding (RSW): **two or more sheets of metal are hold between metal electrodes.**

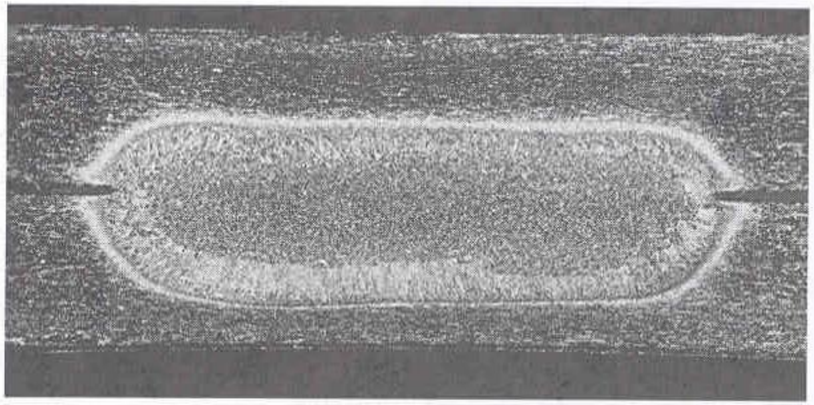


FIGURE 35-5 A spot-weld nugget between two sheets of 0.05-in. (1.3-mm) aluminum alloy. The nugget is not symmetrical because the radius of the upper electrode was greater than that of the lower electrode. *(Courtesy Locheed Aircraft Corporation.)*

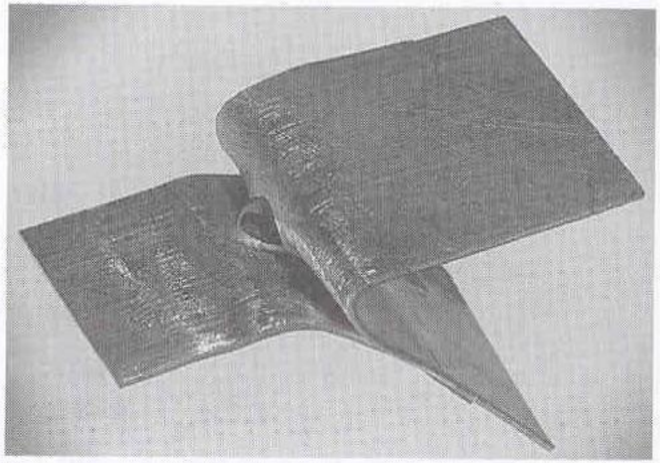


FIGURE 35-6 Tear test of a satisfactory spot weld, showing how failure occurs outside of the weld.

Welding cycle: **electrodes contact the metal (pressure is applied)**

⇒Known as squeeze time

- **Current is passed between electrodes →the temperature increases at the contact point → the metals melt → the electrodes squeeze the material → weld time**
- **Current is shut – down →pressure increased → hold time**

pressure is released →off time
weld nugget is formed

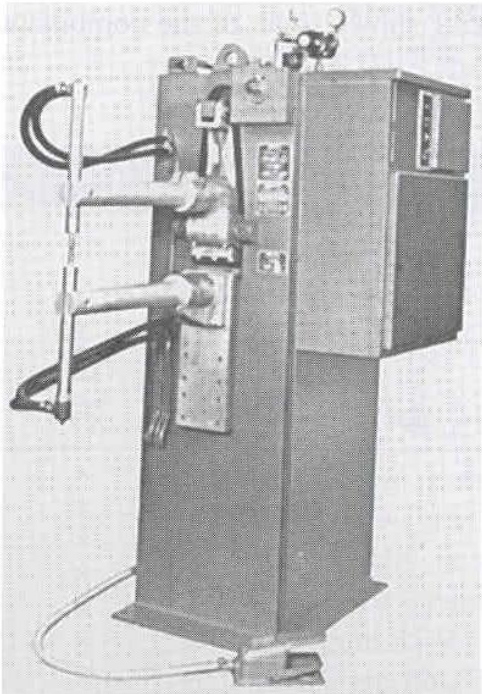


FIGURE 35-7 Foot-operated rocker-arm, spot-welding machine. *(Courtesy Sciaky Bros., Inc.)*

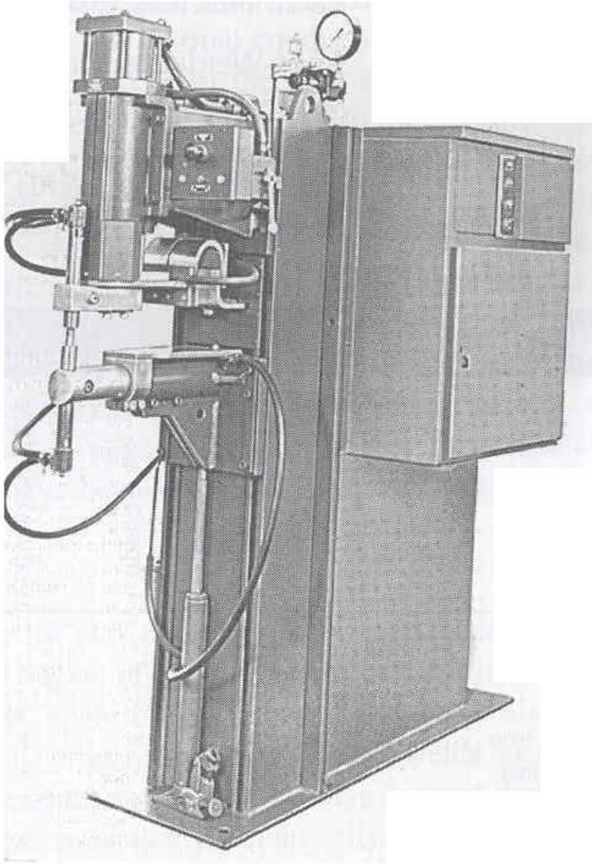


FIGURE 35-8 Single-phase, air-operated, press-type resistance welder with microprocessor control. *(Courtesy Sciaky Bros., Inc.)*

6b. Resistance Seam Welding (RSEW)

- Continuous weld on two overlapping pieces of sheet metal – can be leak proof (tanks, reservoirs)
- It is like frequency spot welding process, with the current applied periodically.
- Typical welding speed (~ 60 in/min)

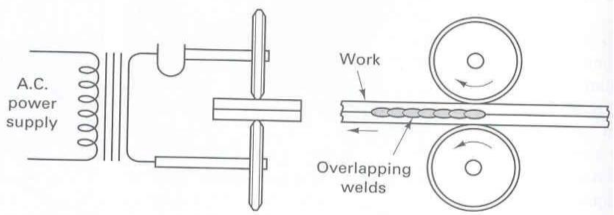


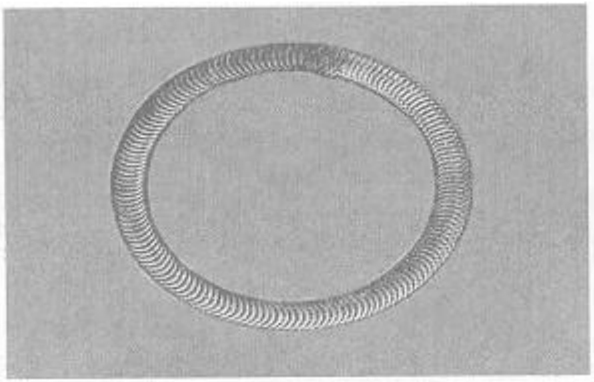
FIGURE 35-10 Schematic representation of seam welding.

Types of seam

- lap seam weld
- finish seam weld – only one side of the joint is visible

Water cooling of electrodes is needed

Seam welding used in manufacturing of metal containers, automobile parts, tanks, pipes.



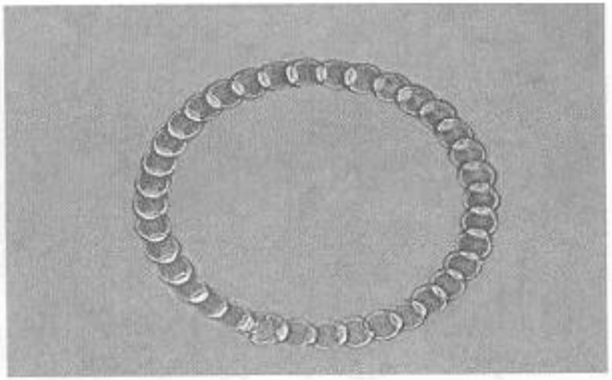


FIGURE 35-9 Seam welds made with overlapping spots of varied spacing.

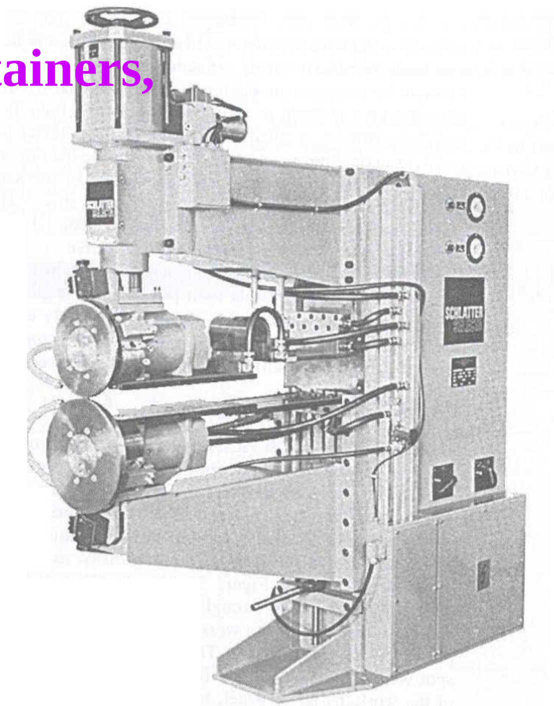


FIGURE 35-11 Typical commercial seam welder. *(Courtesy H. A. Schlatter AG.)*

6c. Butt welding → a sort of resistance welding → to weld two identical parts by pressure and heat generation just on the surface using high frequency current

6d. Pipe Welding → most of seam welding →
welding, in (shaping or forming)
Sides of the strips brought together and current is passed through
→ RESISTANCE BUTT WELDING

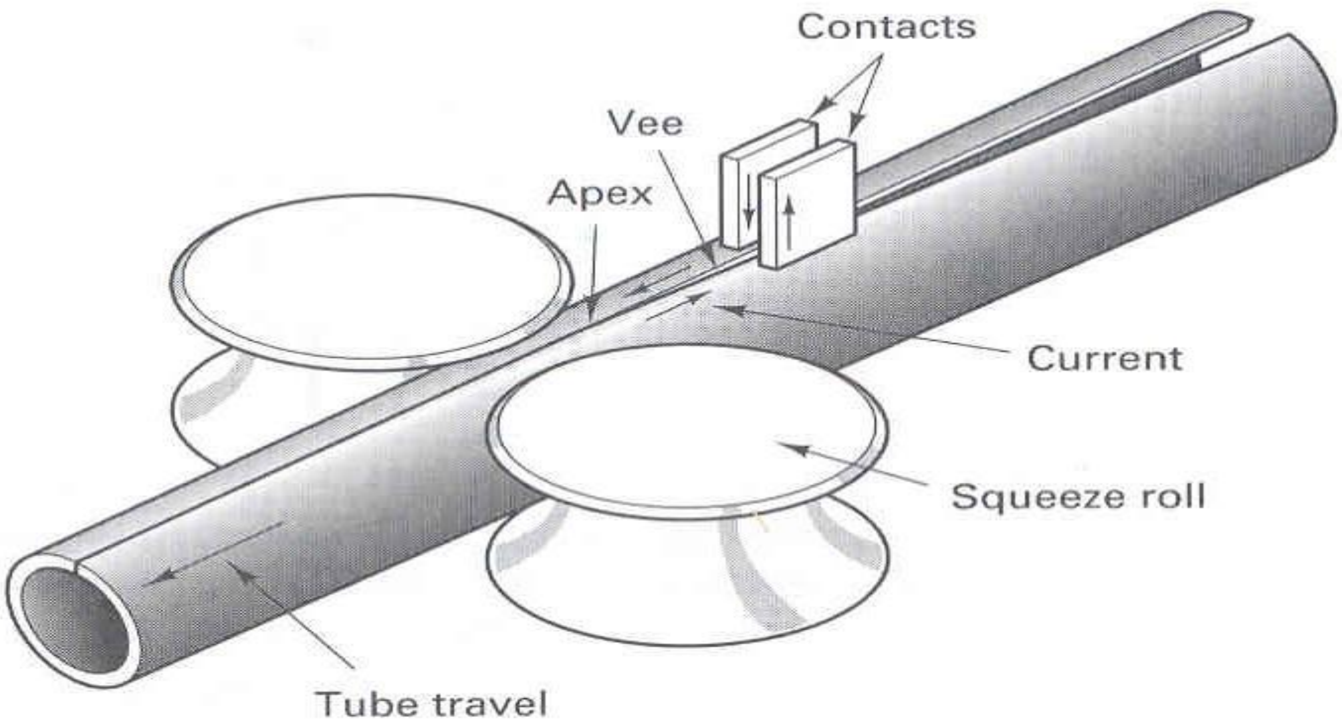


FIGURE 35-12 Using high-frequency ac current to produce a resistance seam weld in butt-welded tubing. Arrows from the contacts indicate the path of the high-frequency current.

Another method : high frequency induction heating of the surface before the material is squeezed together →

HIGH FREQUENCY WELDING OF PIPES

MACHINES FOR RESISTANCE WELDING

- stationary single spot machine
- portable single spot machine
- multiple spot machine
- robots

PORTABLE SPOT WELDING MACHINES

- Different metals can be spot – welded together
- sheets can be welded to rolled shapes and castings
- practically →size limitation of 1/8 inch (~ 3 mm) for a sheet to be spot welded

6e Resistance Projection Welding (RPW) →similar to spot welding

- One of metal sheets to be welded, has to be put through a punch press which makes small projection or buttons in the metal sheet

- Projection welds are produced at localised points in work pieces help under pressure between suitable electrodes.

- Welds are made simultaneously

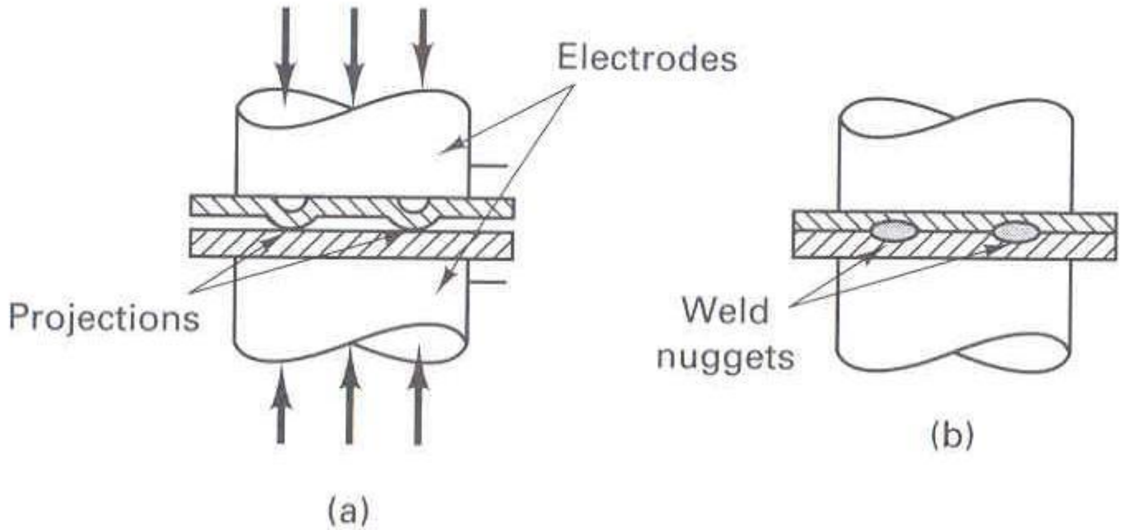


FIGURE 35-13 Principle of projection welding: prior to application of current and pressure (a) and after formation of the welds (b).

COMPARISON: Oxy-fuel, Arc, Resistance

Gas welding:

- **Functionally competitive to arc welding – but not as convenient from the equipment point of view (requires gases in bottles and expensive)**

Arc Welding:

- **Requires high skill operator**
- **Convenient supply of electric power**
- **New techniques of shielding, metal welding and submerged welding**

Resistance Welding:

- **High production process,**
- **Easy to automate**
- **Dependent on the skills of the operator**

QUALITY CONTROL OF WELDS

Cracks occurring in welds

hot cracks → in weld and fusion zone

cold cracks → in the heat affected zone

Due to the heating, the grain size of the weld is changing and so is the hardness → where hardness is the smallest, cracks can occur

WELD INSPECTION:

Visual

FPI

MPI

(cracks or internal defects → distorted magnetic fields. Current is passed through the weld seam →magnetic particles will gather at the crack)

X-ray (for safety reasons)

(not ultrasonic, which needs a flat datum)

NEW WELDING PROCESS

1. Electron Beam welding (EBW)

New technology for "clean welds"

- principles: high velocity e^- are emitted & directed towards the metal from, a tungsten that is heated to 2200^0 C → e^- pass through a magnetic field → centered by the anode and deflecting coils.
- The e^- beam is produced in vacuum. high purity of the weld. (also, fusion temperature is lower for the metal/ for all materials)
- High penetration of e-beam.
- Depth to width ratio of weld is 25:1 and the beam is 0.8 –3.2 mm DIA. (could be made much smaller).
- Low heat input, low distortion, narrow heat affected zone → high purity of weld is assured.

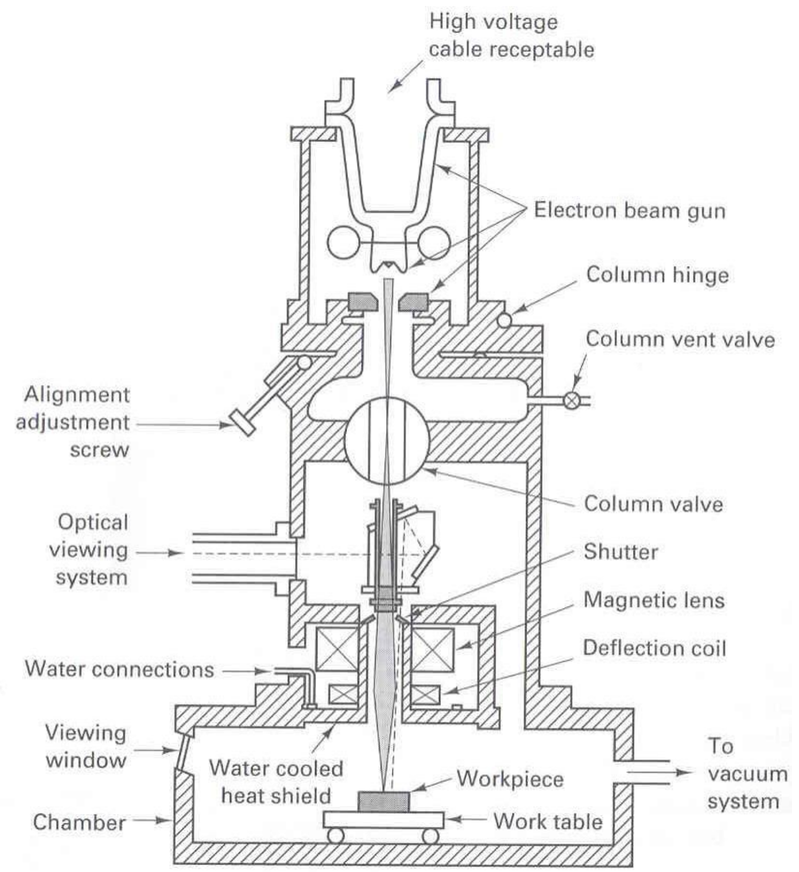


FIGURE 36-10 Schematic diagram of the electron beam welding process. *(Courtesy of American Machinist.)*

2. Laser Beam Welding (LBW)

- Focused laser beam is used for metal vaporisation
- Vaporised metal heats the surrounded metal
- Depth to width ratio > 4:1
- Laser beam welding has some advantages over e beam
    - vacuum is not required
    - can weld inside the transparent containers (eye surgery)

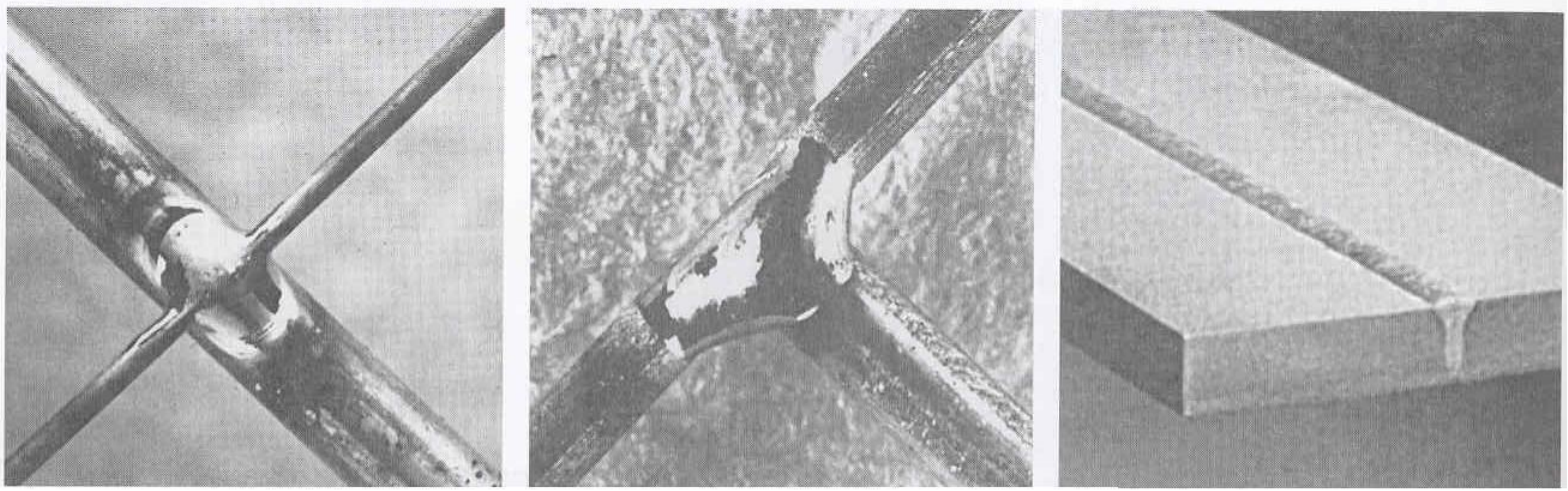


FIGURE 36-12 (*Left*) Small electronic welds made by laser welding. *(Courtesy of Linde Division, Union Carbide Corporation.)*, (*Right*) Laser butt weld of 0.125-in. (3-mm) stainless steel, made at 60 in./min (1.5 m/min) with a 1250-W laser. *(Courtesy of Coherent, Inc.)*

3. Ultrasonic Welding (USW)

- Coalesence is obtained by high shear vibration + pressure localised on the welded pieces
- Used in electronic industry for special precision welding without temperature impact
- Frequency → 10 – 200kHz mechanical vibrations
- Welding depends on right combination of time, pressure and energy output

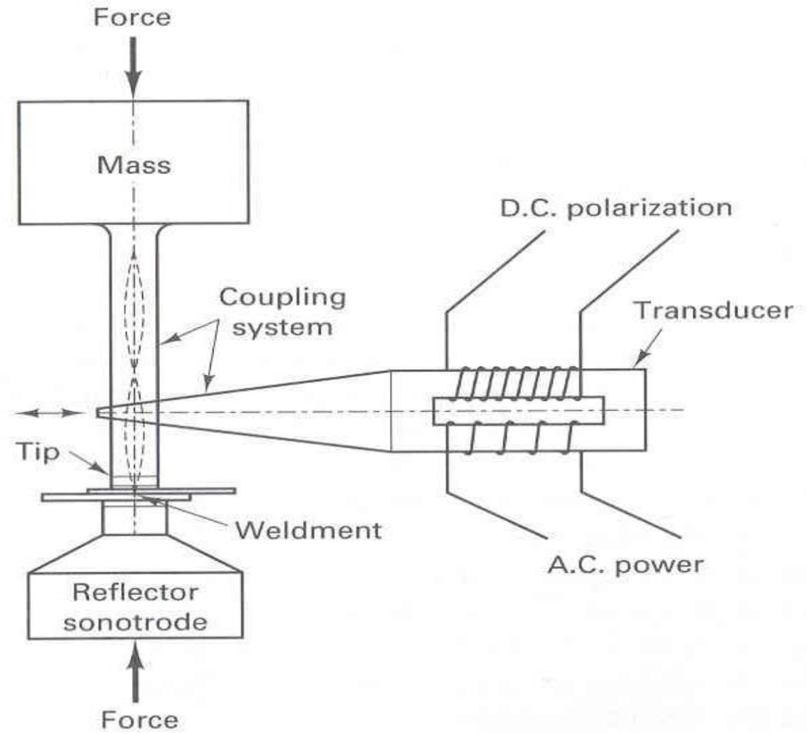


FIGURE 36-7 Schematic diagram of the equipment used in ultrasonic welding.

METALLIZING – metal spraying

- By gas flame, electric arc, plasma
- plasma spray process → highest temperatures (up to 16000^0 C)
- can spray materials with melting point temperature up to 3300^0 C
- For ceramics: conductive or protective surface coating → to protect against built – up surfaces

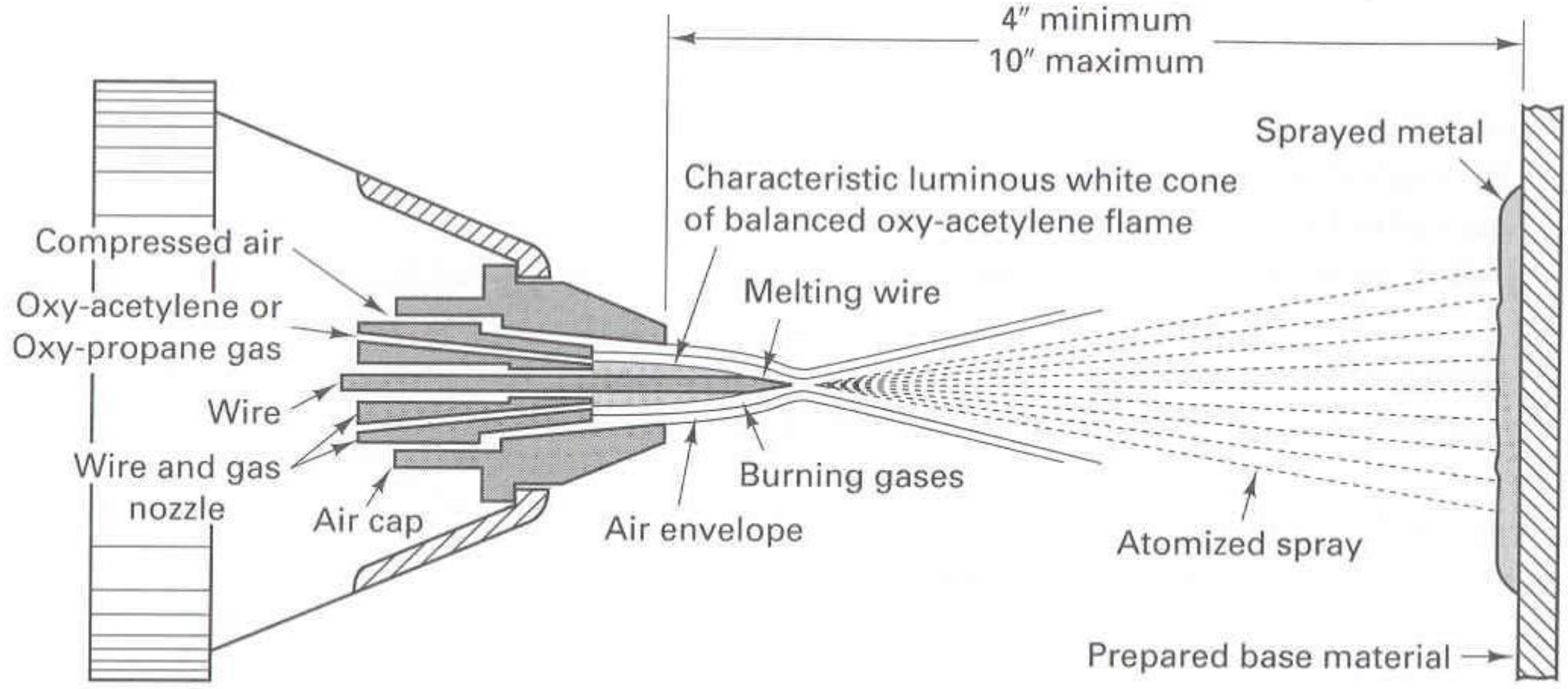


FIGURE 36-17 Schematic diagram of an oxyacetylene metal-spraying gun. *(Courtesy of METCO, Inc.)*

WELDING OF PLASTICS

- Thermoplastic materials only → torch flame temp ~ 300^0 C
- vibration or friction welding (low frequency – 100-240 Hz)

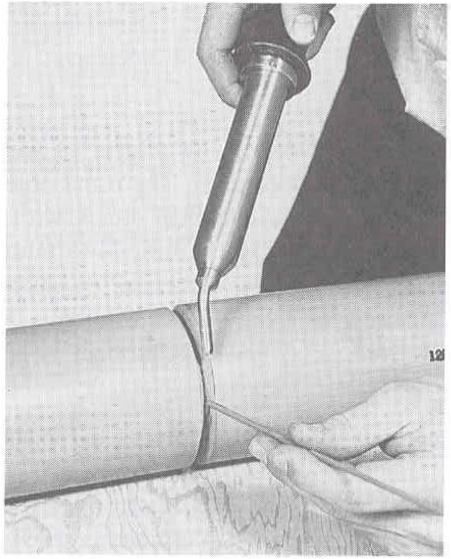


FIGURE 36-16 Using a hot-gas torch to make a weld in plastic pipe.

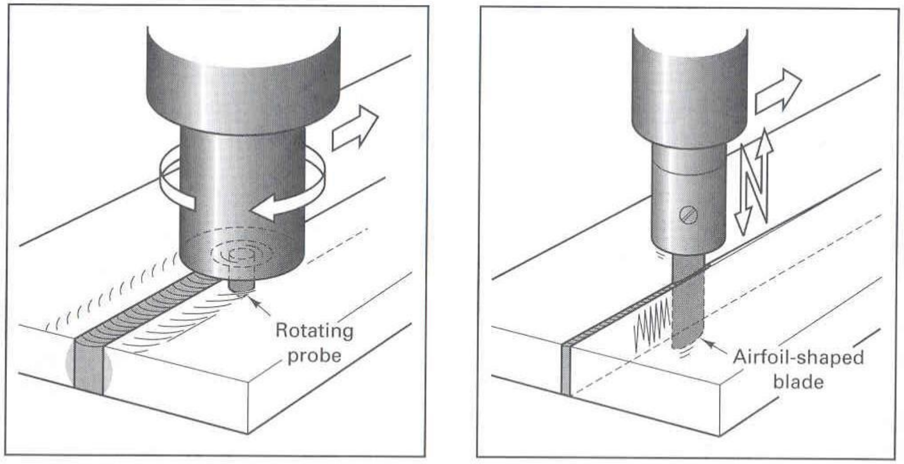


FIGURE 36-15 Friction stir welding using rotary and reciprocal motions to produce welds in plastics. The shoulder on the rotating probe provides additional friction heating to the top surface and prevents expulsion of the softened material from the joint. *(Courtesy of ASM International.)*

GAS & ELECTRIC ARC CUTTING

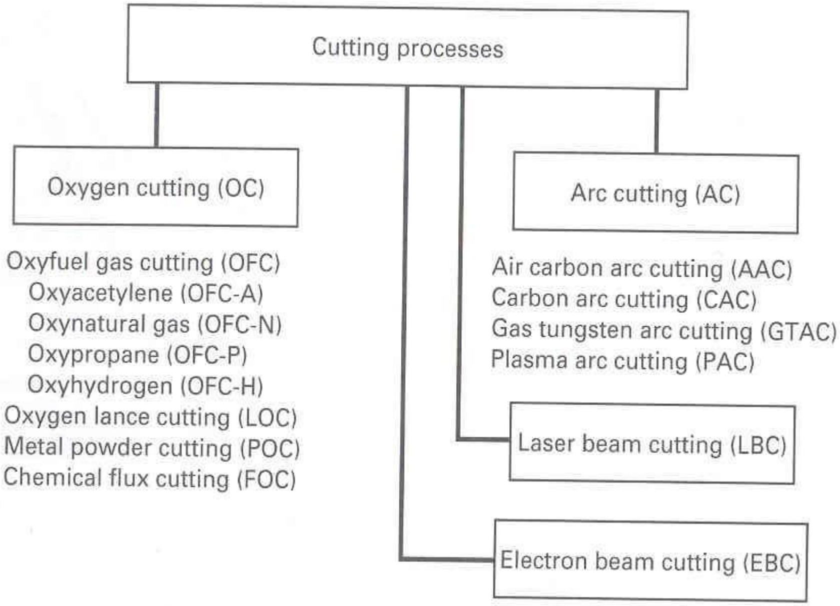


FIGURE 33-5 Classification of common cutting processes with their AWS (American Welding Society) designations.

Oxyacetylene torch cutting: important production processes

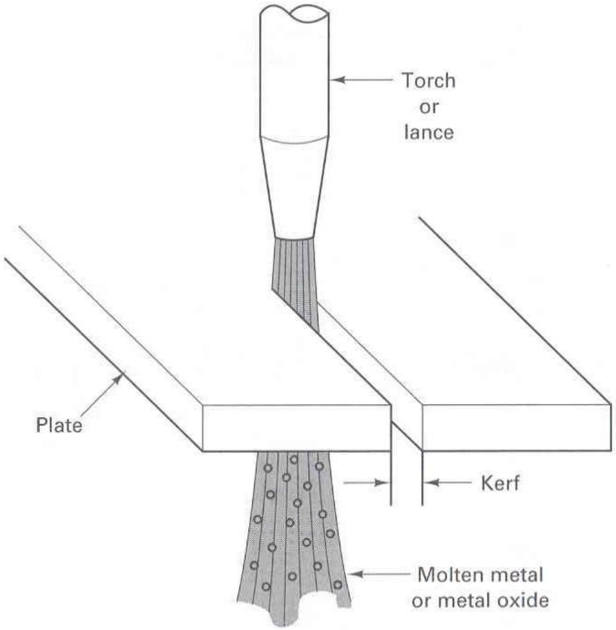


FIGURE 33-6 Flame cutting of a metal plate.

Torch made for cutting is different: It has several small holes surrounding a central hole through which pure oxygen passes → no premixing

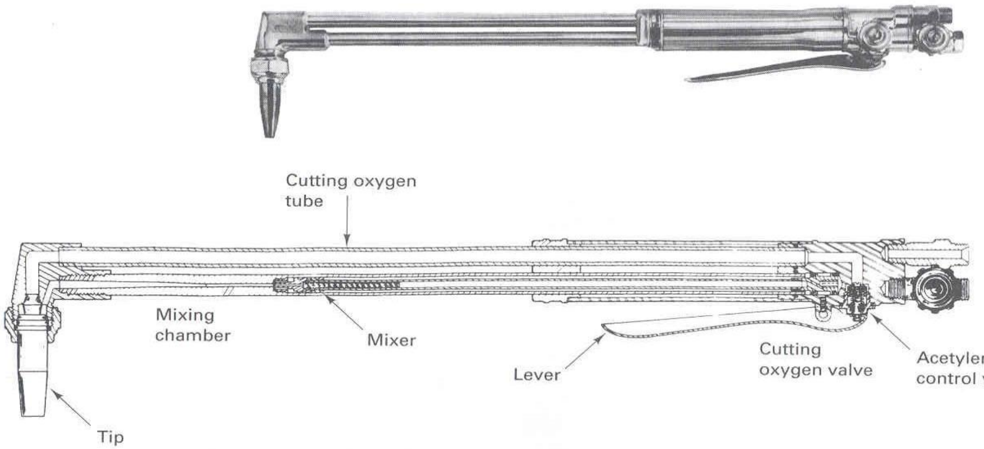


FIGURE 33-7 Typical oxyacetylene cutting torch and cross-sectional schematic. *(Courtesy of Victor Equipment Company.)*

Principle of cutting → oxygen has affinity for ferrous materials (and for Al)

- If steel is heated to the red temperature and a jet of pure O is blown on the surface, the steel is burned instantaneously → iron oxide

  $3Fe + 2O_2 = Fe_3O_4 + heat$

  Metal plates up to 30 in thick can be cut by this method

UNDERWATER CUTTING: Torches are provided with connections for three gases:

- Preheating gas (H_2)
- Oxygen
- Compressed air: Air bubbles around the tip of the torch to stabilise the flame and to displace the water from the tip area

- H2 – for preheating (C_2H_2 – not safe to operate under high pressure created by the water → it can explode)
- Cutting machine → with automatic control of the torch movement
- Usually → a copying system, numerically controlled torch cutting designed with control of speed, preheating, torch light, path, etc.
- Non ferrous metals, cost iron and high manganese alloys are difficult to cut with this method (except Al)

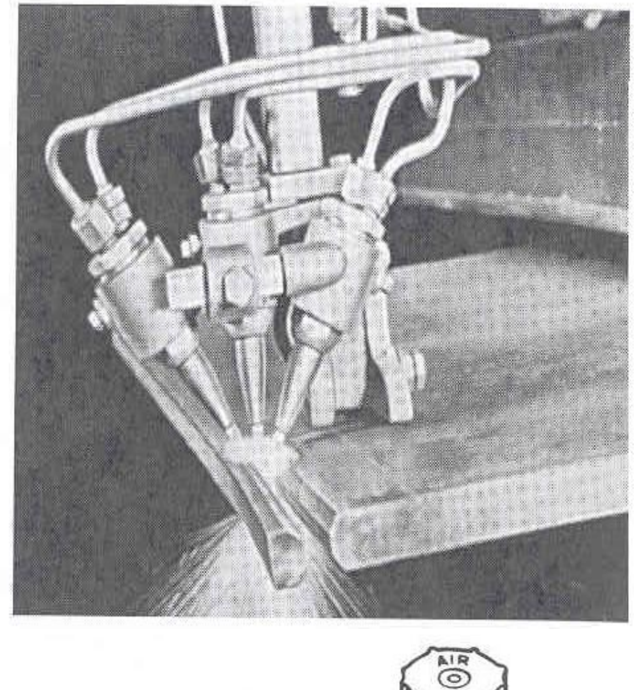


FIGURE 33-9 Plate edge being prepared for welding. The beveled shape is produced by three simultaneous oxyacetylene cuts. *(Courtesy of Linde Division, Union Carbide Corporation.)*

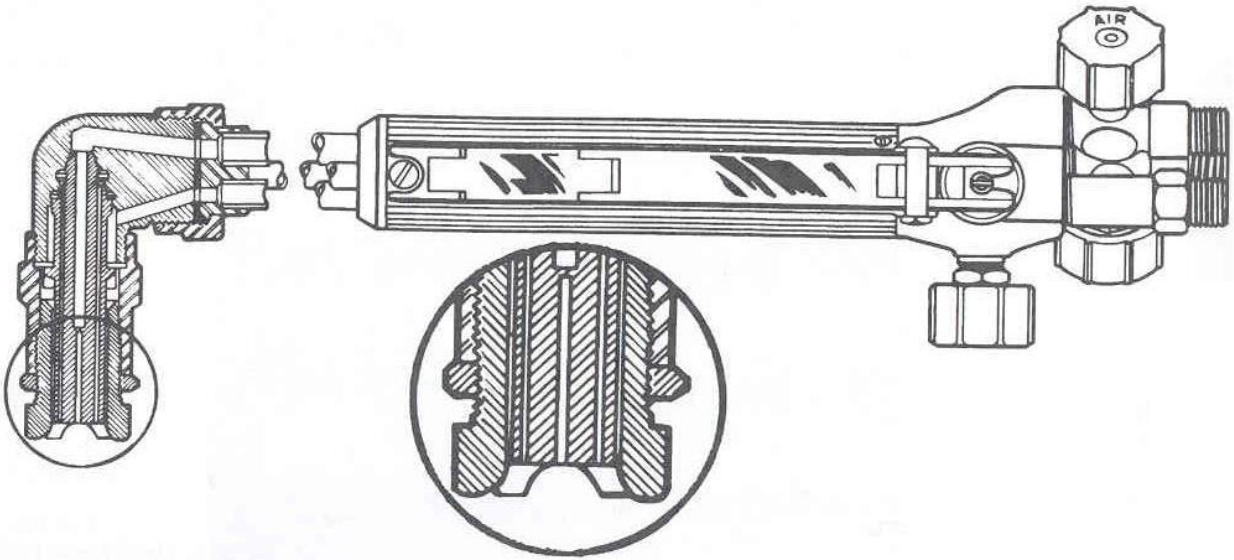


FIGURE 33-10 Underwater cutting torch. Note the extra set of gas openings in the nozzle to permit the flow of compressed air and the extra control valve. *(Courtesy of Bastian-Blessing Company.)*

ARC CUTTING PROCESS

- Melting metal to produce a kerf
- Carbon Arc Cutting (CAC)
- Carbon electrode produces arc
- Air is blowing the metal out from the cut – not oxidising (good for cast iron, which is difficult to cut with oxygen flame)

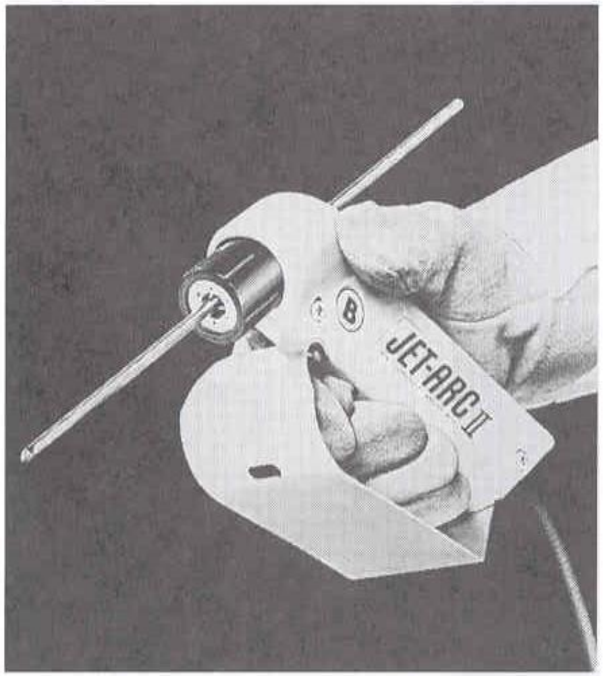


FIGURE 34-18 Gun used in the arc-air cutting process. Note the air holes surrounding the electrode in the holder. *(Courtesy of Jackson Products.)*

PLASMA ARC CUTTING

- Very high temperature – used for Stainless steel and non ferrous materials (carbon electrode cathode)
- inert gas flowing through the arc is forming plasm
- Two types of torch;
  non-transferred arc: ~ 16,000^0 C
  transferred arc (~ 30000^0 C) for non metals
- cutting speeds:
  2.5 m/min (steel)
  7.5 m/min Al – in thick plates

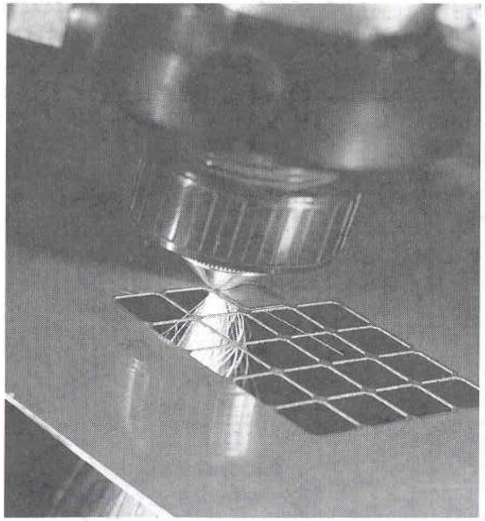


FIGURE 34-20 Cutting sheet metal with a plasma torch. *(Courtesy of GTE Sylvania.)*

LASER BEAM CUTTING (CO_2 lasers)

- Uses the heat of laser cutting to melt and evaporate metal
- any known material can be cut, $T>11000^0$ C, very accurate, poor surface finishing.

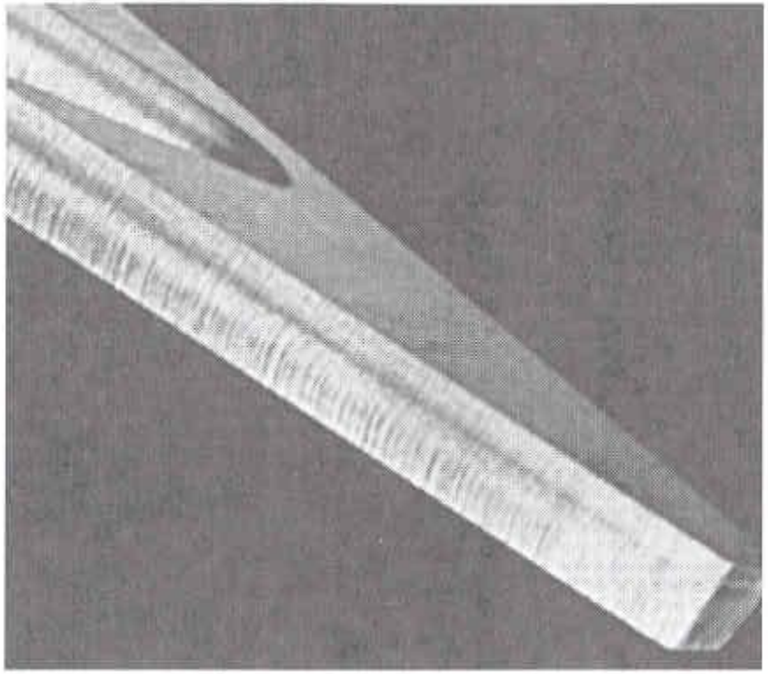


FIGURE 36-13 Surface of $\frac{1}{4}$-in. (6-mm)-thick carbon steel cut with a 1250-W laser at 70 in./min (1.8 m/min). *(Courtesy of Coherent, Inc.)*