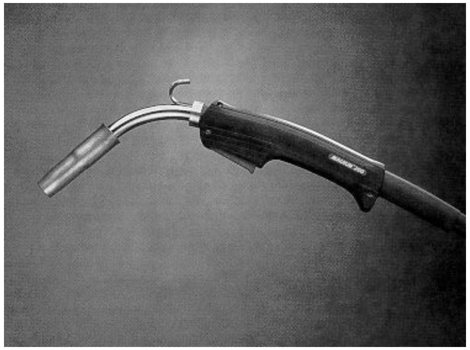
Consumable Electrode

SMAW – Shielded Metal Arc Welding

GMAW – Gas Metal Arc Welding

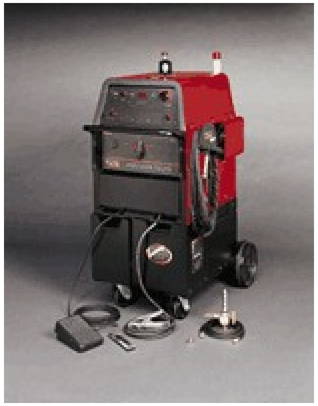
SAW – Submerged Arc Welding



Non-Consumable Electrode

GTAW – Gas Tungsten Arc Welding

PAW – Plasma Arc Welding



High Energy Beam

Electron Beam Welding

Laser Beam Welding

- Consumable electrode
- Flux coated rod
- Flux produces protective gas around weld pool
- Slag keeps oxygen off weld bead during cooling

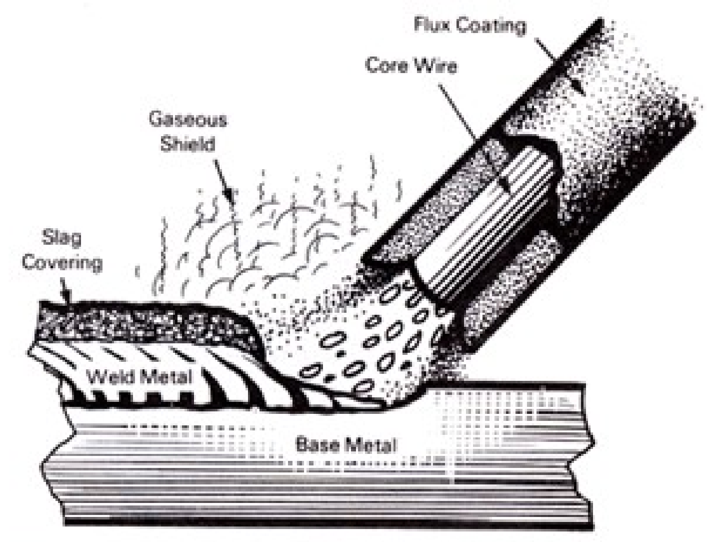


Fig. 6

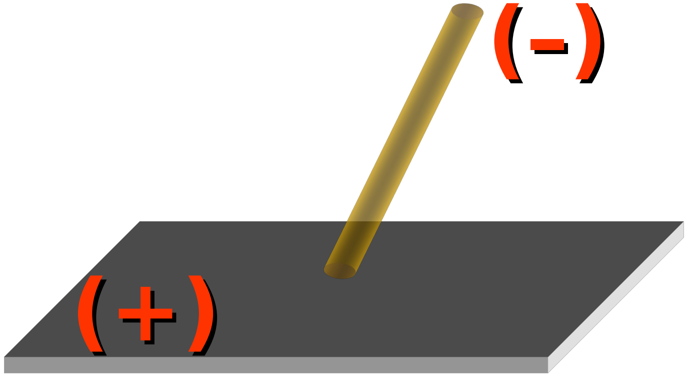
- General purpose welding—widely used
- Thicknesses 1/8” – 3/4”
- Portable

Power... Current I (50 - 300 amps)
Voltage V (15 - 45 volts)

Power = VI $\approx$ 10 kW

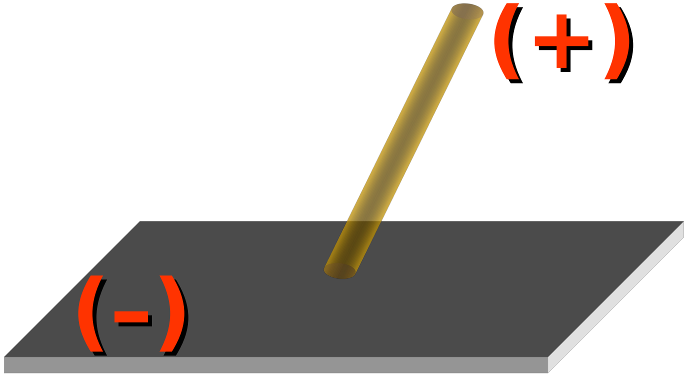
SMAW - DC Polarity

Straight Polarity



Shallow penetration
(thin metal)

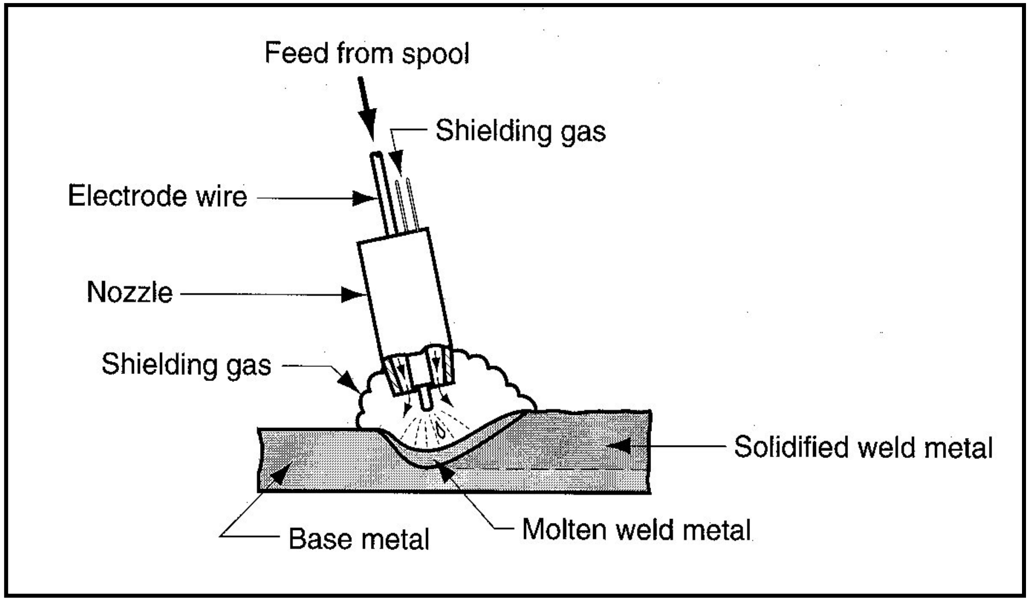
Reverse Polarity



Deeper weld penetration

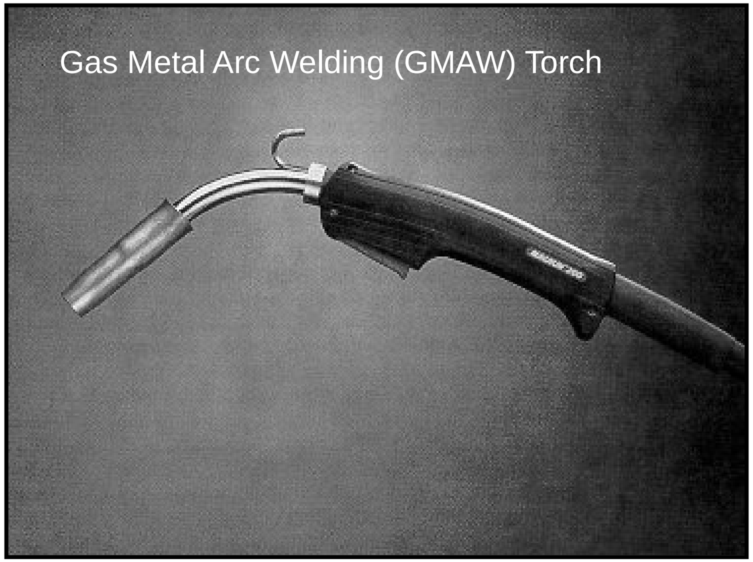
AC - Gives pulsing arc

- used for welding thick sections



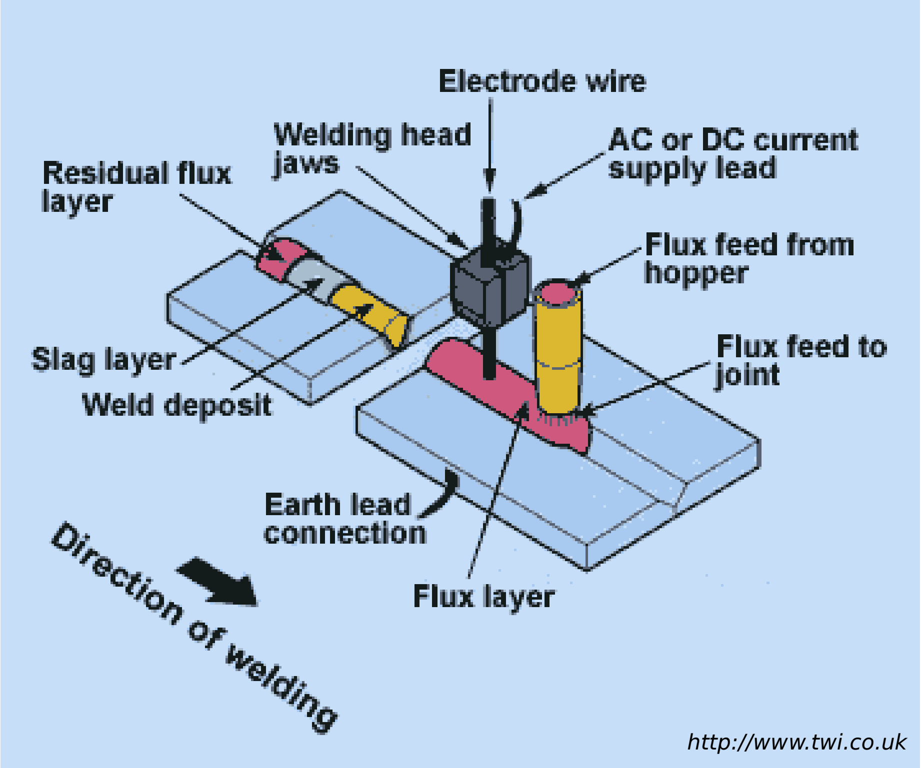
- DC reverse polarity - hottest arc
- AC - unstable arc

- MIG - Metal Inert Gas
- Consumable wire electrode
- Shielding provided by gas
- Double productivity of SMAW
- Easily automated

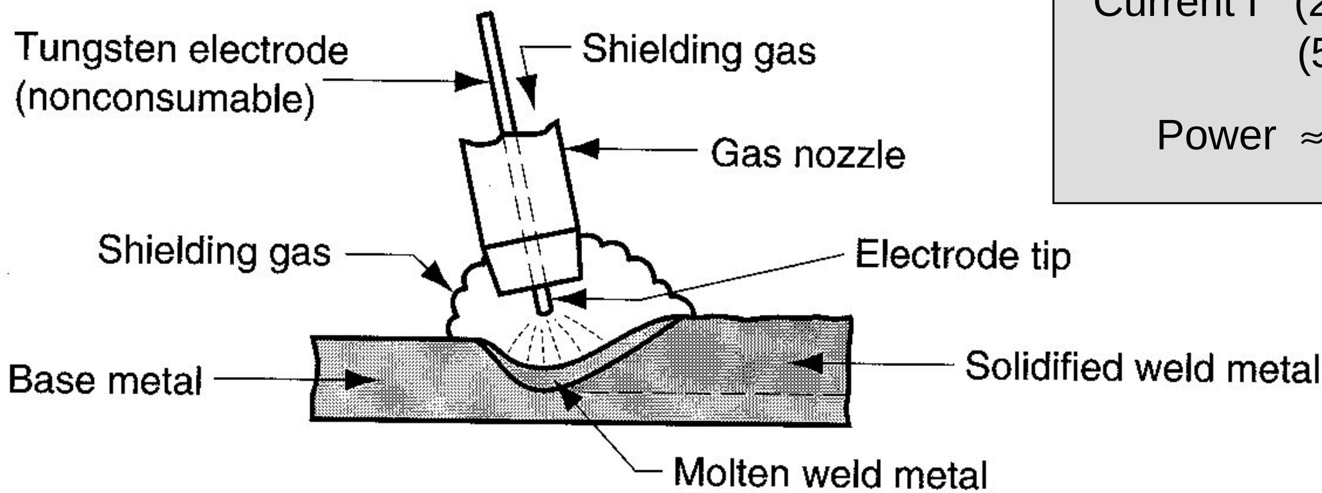


Groover, M., *Fundamentals of Modern Manufacturing*,, p. 734, 1996

• 300 – 2000 amps (440 V)



- Consumable wire electrode
- Shielding provided by flux granules
- Low UV radiation & fumes
- Flux acts as thermal insulator
- Automated process (limited to flats)
- High speed & quality (4 – 10x SMAW)
- Suitable for thick plates



Current I (200 A DC)
(500 A AC)

Power ≈ 8-20 kW

- a.k.a. TIG - Tungsten Inert Gas
- Non-consumable electrode
- With or without filler metal
- Shield gas usually argon
- Used for thin sections of Al, Mg, Ti.
- Most expensive, highest quality

- Laser beam produced by a CO2 or YAG Laser
- High penetration, high-speed process
- Concentrated heat = low distortion
- Laser can be shaped/focused & pulsed on/off
- Typically automated & high speed (up to 250 fpm)
- Workpieces up to 1” thick

Typical laser welding applications :

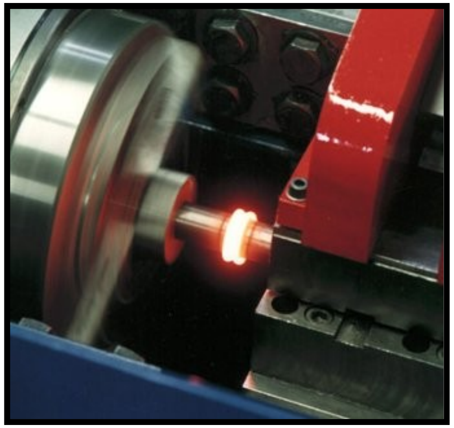
- Catheters & Other Medical Devices
- Small Parts and Components
- Fine Wires
- Jewelry
- Small Sensors
- Thin Sheet Materials Down To 0.001" Thick

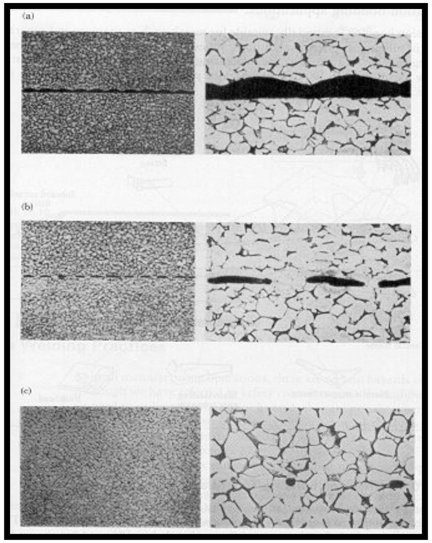
Friction Welding

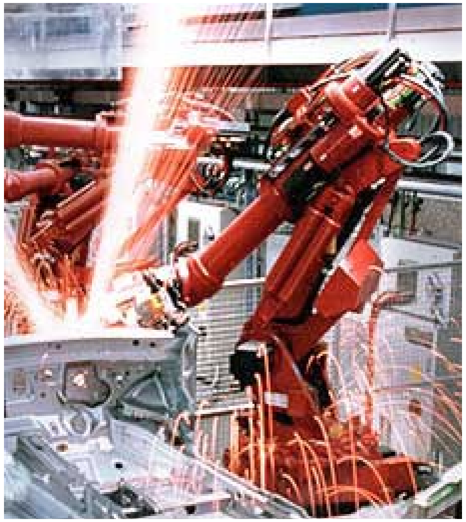
Diffusion Welding

Ultrasonic Welding

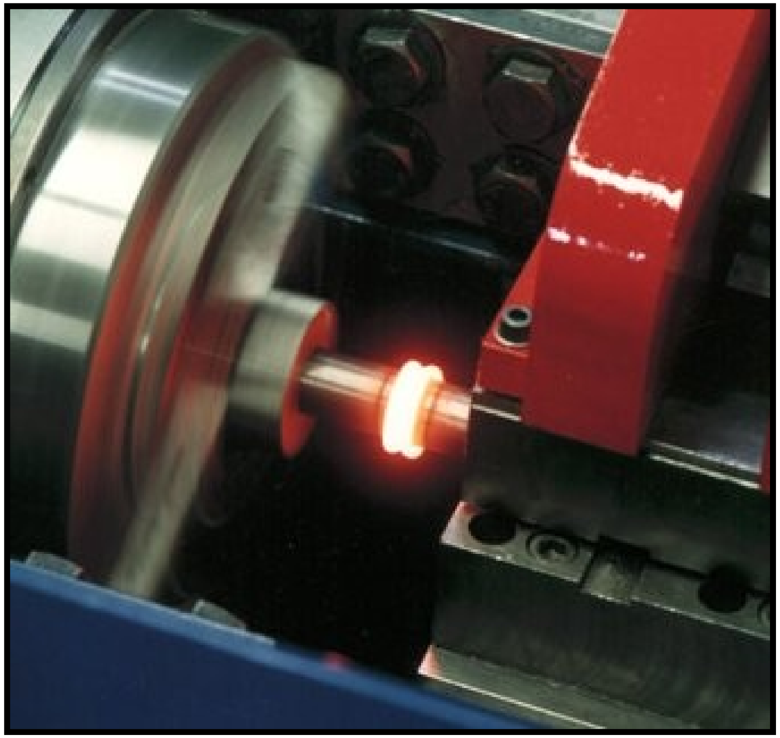
Resistance Welding







- One part rotated, one stationary
- Stationary part forced against rotating part
- Friction converts kinetic energy to thermal energy
- Metal at interface melts and is joined
- When sufficiently hot, rotation is stopped & axial force increased

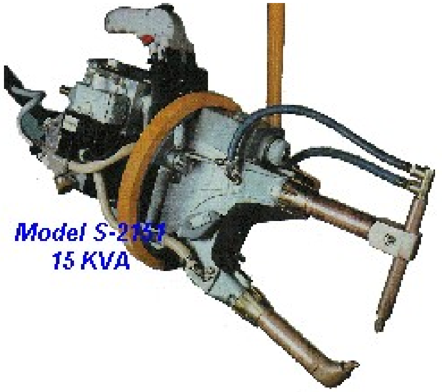


RWMA®

Resistance Welder Manufacturers' Association

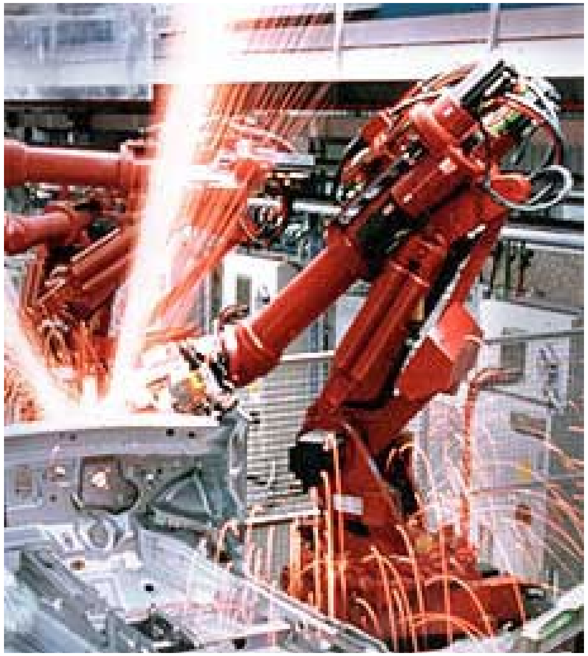
Joining Together to Promote Resistance Welding Excellence

Resistance Welding is the coordinated application of electric current and mechanical pressure in the proper magnitudes and for a precise period of time to create a coalescent bond between two base metals.



- Heat provided by resistance to electrical current ($Q=I^2Rt$)
- Typical 0.5 – 10 V but up to 100,000 amps!
- Force applied by pneumatic cylinder
- Often fully or partially automated

    - Spot welding
    - Seam welding



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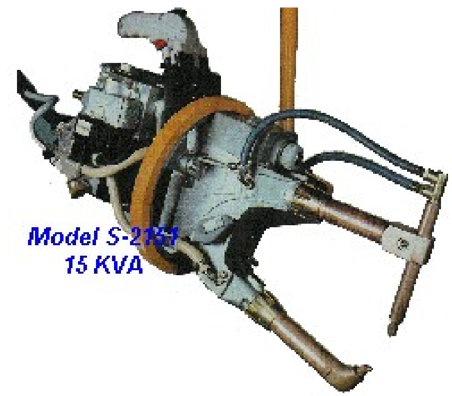

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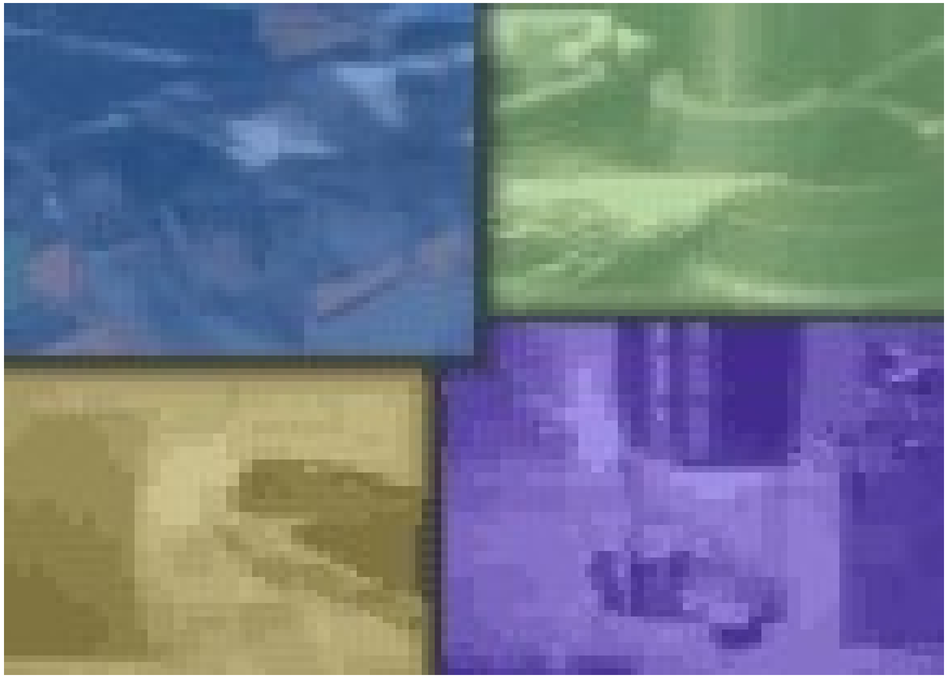
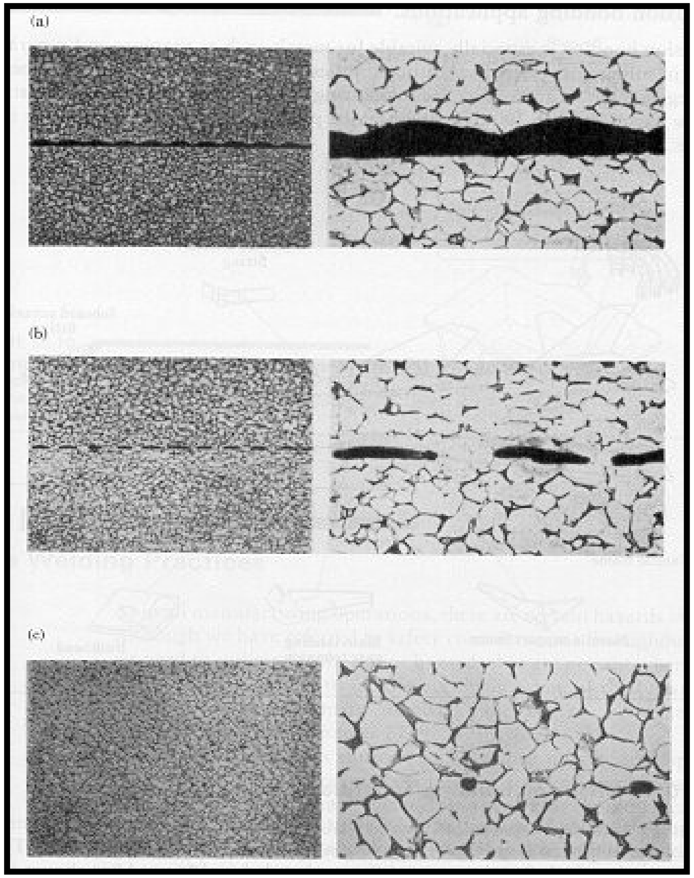
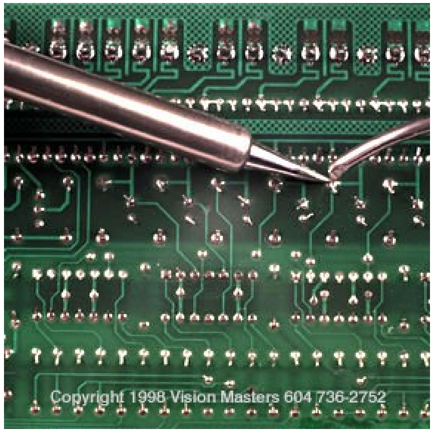


- Parts forced together at high temperature (< 0.5Tm absolute) and pressure
- Heated in furnace or by resistance heating
- Atoms diffuse across interface
- After sufficient time the interface disappears
- Good for dissimilar metals
- Bond can be weakened by surface impurities

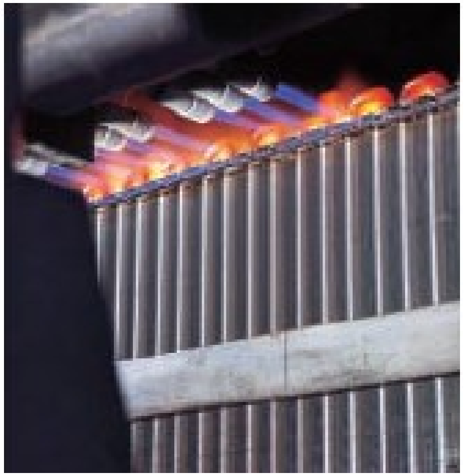


Kalpakjian, S., *Manufacturing Engineering & Technology*, p. 889, 1992



Soldering & Brazing

- Only filler metal is melted, not base metal
- Lower temperatures than welding
- Filler metal distributed by capillary action
- Metallurgical bond formed between filler & base metals
- Strength of joint typically
  - stronger than filler metal itself
  - weaker than base metal
  - gap at joint important (0.001 – 0.010”)

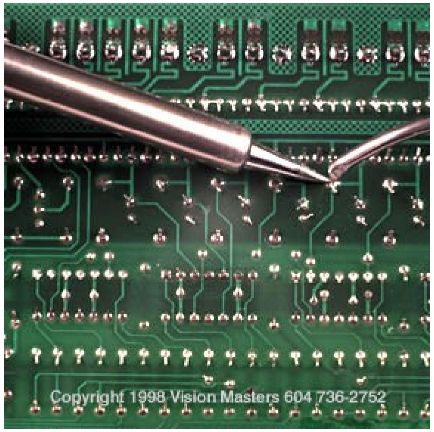


- Pros & Cons
  - Can join dissimilar metals
  - Less heat - can join thinner sections (relative to welding)
  - Excessive heat during service can weaken joint

Soldering

Solder = Filler metal

- Alloys of Tin (silver, bismuth, lead)
- Melt point typically below 840 F



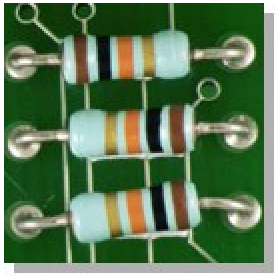
Flux used to clean joint & prevent oxidation

- separate or in core of wire (rosin-core)

Tinning = pre-coating with thin layer of solder

Applications:

- Printed Circuit Board (PCB) manufacture
- Pipe joining (copper pipe)
- Jewelry manufacture
- Typically non-load bearing



Easy to solder: copper, silver, gold

Difficult to solder: aluminum, stainless steels

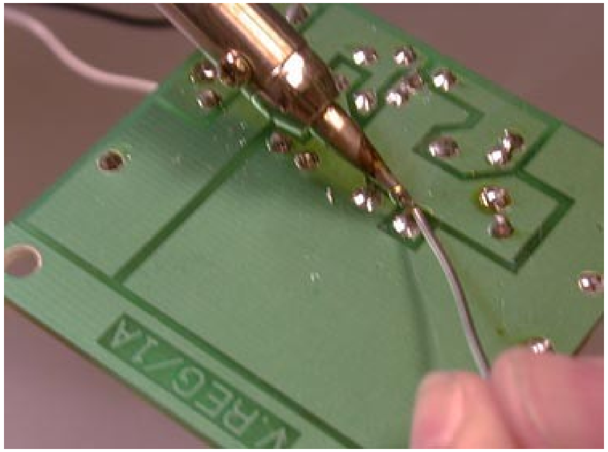
(can pre-plate difficult to solder metals to aid process)

Manual PCB Soldering

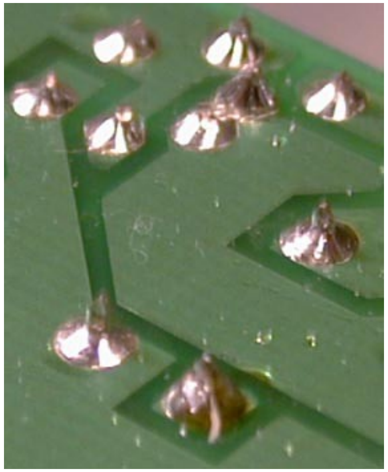
PTH - Pin-Through-Hole connectors

• Soldering Iron & Solder Wire

• Heating lead & placing solder



• Heat for 2-3 sec. & place wire opposite iron



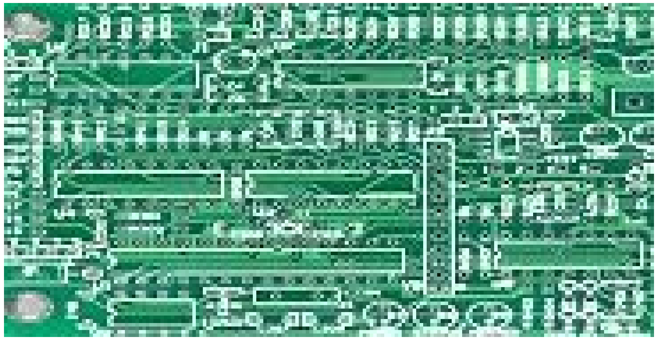
• Trim excess lead

Automated Reflow Soldering

SMT = Surface Mount Technology

- Solder/Flux paste mixture applied to PCB using screen print or similar transfer method

- Solder Paste serves the following functions:
  - supply solder material to the soldering spot,
  - hold the components in place prior to soldering,
  - clean the solder lands and component leads
  - prevent further oxidation of the solder lands.



Printed solder paste on a printed circuit board (PCB)

- PCB assembly then heated in “Reflow” oven to melt solder and secure connection

Brazing

Use of low melt point filler metal to fill thin gap between mating surfaces to be joined utilizing capillary action

- Filler metals include Al, Mg & Cu alloys (melt point typically above 840 F)
- Flux also used
- Types of brazing classified by heating method:
  - Torch, Furnace, Resistance

Applications:

- Automotive - joining tubes
- Pipe/Tubing joining (HVAC)
- Electrical equipment - joining wires
- Jewelry Making
- Joint can possess significant strength

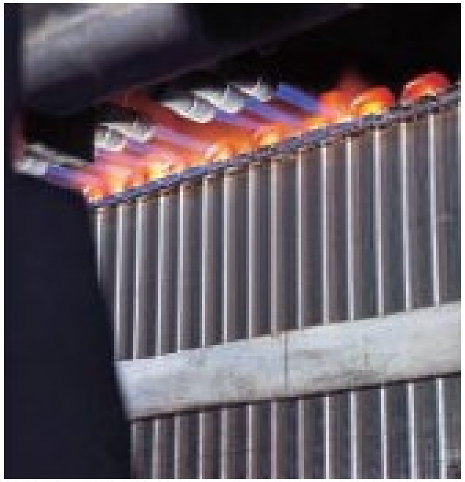


Figure 7. Typical brazed pipe/tube applications. (Photo courtesy of Handy & Harman)

Figure 11. Typical brazing filler metal preforms. (Photo courtesy of Handy & Harman)

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Figure 9. Typical carbide cutting tools brazed to metal in a brazing furnace. (Photo courtesy of Handy & Harman)

Brazing

Figuring length of lap for flat joints.

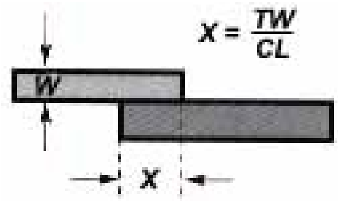
X = Length of lap

T = Tensile strength of weakest member

W = Thickness of weakest member

C = Joint integrity factor of .8

L = Shear strength of brazed filler metal



Let's see how this formula works, using an example.

Problem: *What length of lap do you need to join .050" annealed Monel sheet to a metal of equal or greater strength?*

Solution:

C = .8 T = 70,000 psi (annealed Monel sheet)

W = .050"

L **=** 25,000 psi (Typical shear strength for silver brazing filler metals)

X = (70,000 x .050) /(.8 x 25,000) = .18" lap length

Brazing

Figuring length of lap for tubular joints.

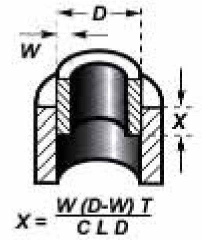
X = Length of lap area

W = Wall thickness of weakest member

D = Diameter of lap area

T = Tensile strength of weakest member

C = Joint integrity factor of .8



Again, an example will serve to illustrate the use of this formula. Problem: *What length of lap do you need to join 3/4" O.D. copper tubing (wall thickness .064") to 3/4" I.D. steel tubing?*

L = Shear strength of brazed filler metal

Solution:

W = .064"

D = .750"

C= .8

T = 33,000 psi (annealed copper)

L **=** 25,000 psi (a typical value)

X = (.064 x (.75 – .064) x 33,000)/(.8 x .75 x 25,000)

X = .097" (length of lap)