Fusion Welding Processes

**Welding Processes**

**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
Welding Processes

SMAW – Shielded Metal Arc Welding

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

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

Power... Current I (50 - 300 amps)  
Voltage V (15 - 45 volts)  
Power = VI ≈ 10 kW
Welding Processes

Electric Arc Welding -- Polarity

SMAW - DC Polarity

Straight Polarity
- Shallow penetration
  - (thin metal)
- Reverse Polarity
- Deeper weld penetration
- AC - Gives pulsing arc
  - used for welding thick sections
GMAW – Gas Metal Arc Welding (MIG)

- 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

SAW – Submerged Arc Welding

- 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

http://www.twi.co.uk
GTAW – Gas Tungsten Arc Welding (TIG)

- 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

- Power $\approx 8-20$ kW

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

- 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
Solid State Welding Processes

- Friction Welding
- Diffusion Welding
- Ultrasonic Welding
- Resistance Welding
Welding Processes

Friction Welding (Inertia 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
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 ($Q = I^2 R t$)
- 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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  - Seam welding
• 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

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

- Soldering Iron & Solder Wire

- Heating lead & placing solder

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

- Trim excess lead

PTH - Pin-Through-Hole connectors
Automated Reflow Soldering

• 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.

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

Printed solder paste on a printed circuit board (PCB)
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
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**Brazing**

**Figuring length of lap for flat joints.**

\[ X = \text{Length of lap} \]
\[ T = \text{Tensile strength of weakest member} \]
\[ W = \text{Thickness of weakest member} \]
\[ C = \text{Joint integrity factor of .8} \]
\[ L = \text{Shear strength of brazed filler metal} \]

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

**Solution:**

\[ C = .8 \times T = 70,000 \text{ psi (annealed Monel sheet)} \]
\[ W = .050" \]
\[ L = 25,000 \text{ psi (Typical shear strength for silver brazing filler metals)} \]

\[ X = (70,000 \times .050) / (.8 \times 25,000) = .18" \text{ lap length} \]
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?

Solution:  
L = Shear strength of brazed filler metal
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)