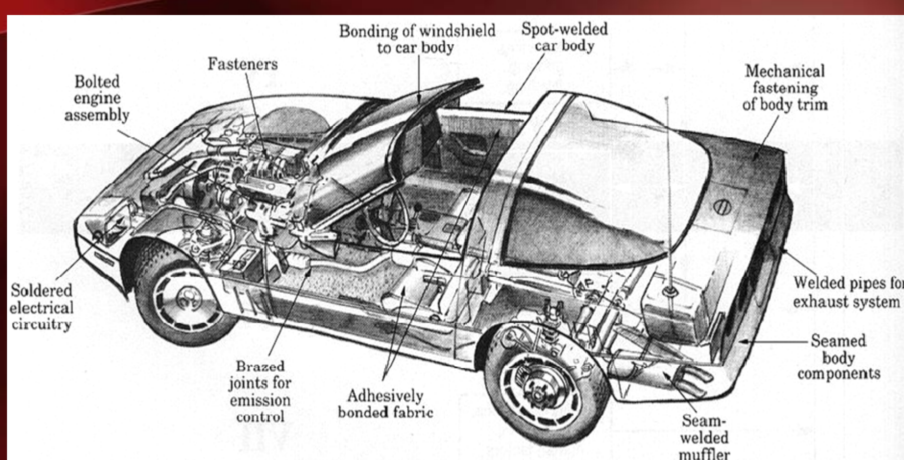
PROSES-PROSES PENYAMBUNGAN - 2

SME 2713
Manufacturing Processes

Assoc Prof Zainal Abidin Ahmad



Outlines

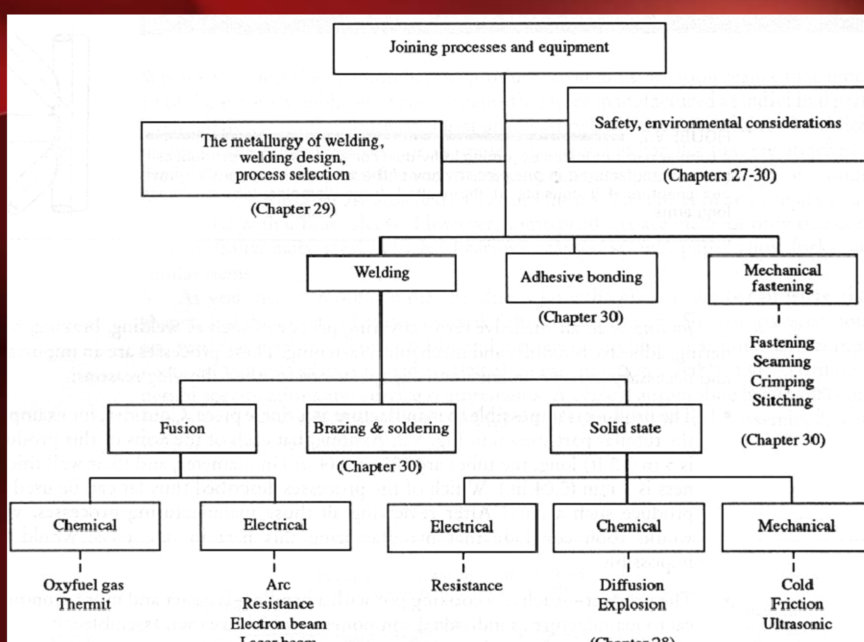
1. Introduction
2. Brazing
3. Soldering
4. ***Welding***
5. Mechanical fasteners
6. Adhesives

4. WELDING PROCESSES

1. Gas Welding
2. Arc Welding
3. Other Fusion Welding Processes
4. Solid State Welding
5. Weld Quality
6. Weldability
7. Design Considerations in Welding

4. Welding

- Joining process in which two (or more) parts are coalesced at their contacting surfaces by application of heat and/or pressure
  - Many welding processes are accomplished by heat alone, with no pressure applied
  - Others by a combination of heat and pressure
  - Still others by pressure alone with no external heat
  - In some welding processes a *filler* material is added to facilitate coalescence



Diversity of welding processes

WELDING

- **Solid state welding**
  - Cold welding
  - Friction welding
  - Diffusion welding
  - Flash welding
  - Ultrasonic welding
  - Explosion welding
- **Fusion welding**
  - Electrical energy
    - Consumable electrode
      - Gas metal arc welding
      - Shielded metal arc welding
      - Submerged arc welding
      - Flux cored arc welding
      - Electrogas welding
      - Electroslag welding
    - Non consumable electrode
      - Gas tungsten arc welding
      - Atomic hydrogen welding
      - Plasma arc welding
    - Other processes
      - Resistance welding
      - Laser beam welding
      - Thermit welding
      - Electron beam welding
  - Chemical energy
    - Oxyacetylene welding
    - Oxyfuel gas welding
- **Soldering and brazing**
  - Soldering
  - Brazing

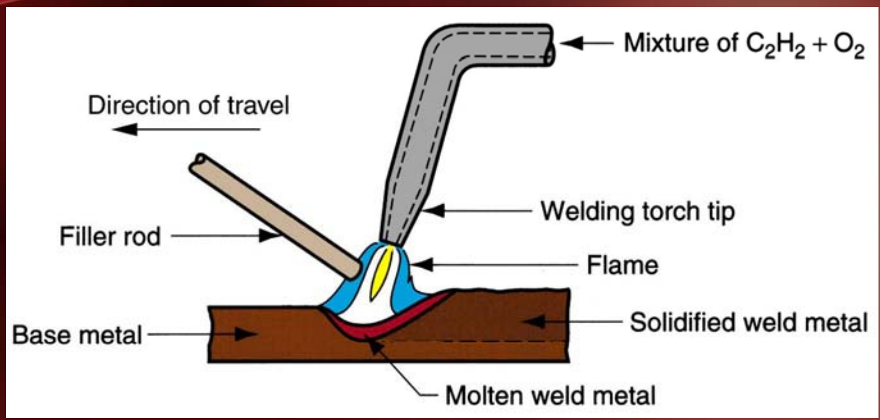
4.1 Oxyfuel Gas Welding (OFW)

- Group of fusion welding operations that burn various fuels mixed with oxygen
- OFW employs several types of gases
  - Methylacetylene-Propadiene (MAPP)
  - Hydrogen
  - Propylene
  - Propane
  - Natural Gas
- Oxyfuel gas is also used in flame cutting torches to cut and separate metal plates and other parts
- Most important OFW process is oxyacetylene welding

4.1 Oxyacetylene Welding (OAW)

- Fusion welding performed by a high temperature flame from combustion of acetylene and oxygen
- Flame is directed by a welding torch
- Filler metal is sometimes added
  - Composition must be similar to base metal
  - Filler rod often coated with *flux* to clean surfaces and prevent oxidation

4.1 Oxyacetylene Welding



A typical oxyacetylene welding operation (OAW).

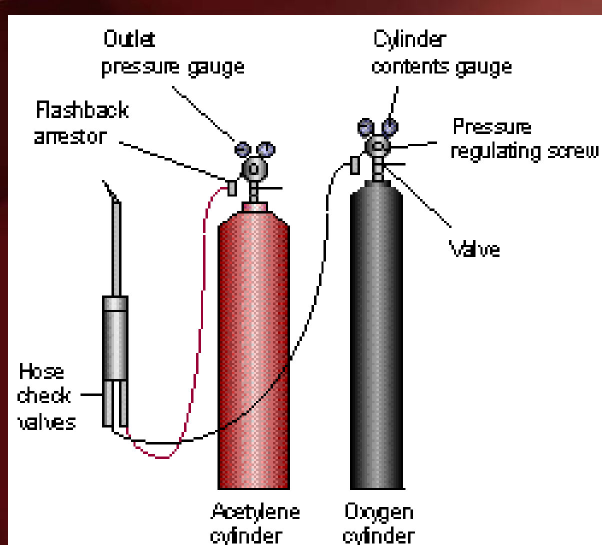
4.1 Acetylene (C_2H_2)

- Most popular fuel among OFW group because it is capable of higher temperatures than any other - up to 3480°C (6300°F)
- Two stage chemical reaction of acetylene and oxygen:
  - First stage reaction (inner cone of flame):

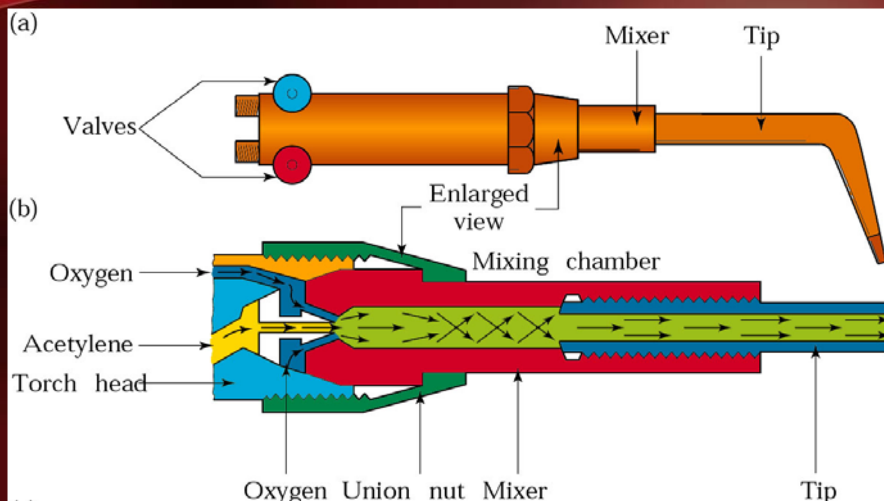
    $C_2H_2 + O_2 \rightarrow 2CO + H_2 + \text{heat}$
  - Second stage reaction (outer envelope):

    $2CO + H_2 + 1.5O_2 \rightarrow 2CO_2 + H_2O + \text{heat}$

4.1 Acetylene (C_2H_2)

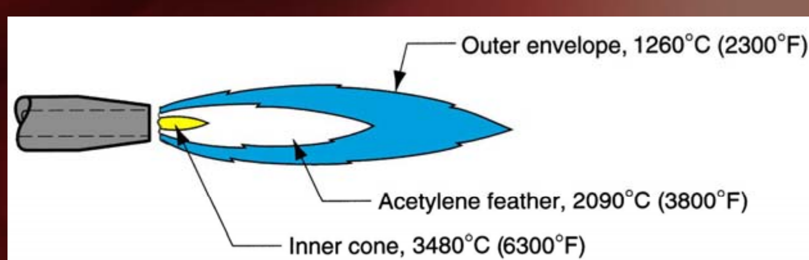


4.1 Acetylene (C_2H_2)



4.1 Oxyacetylene Torch

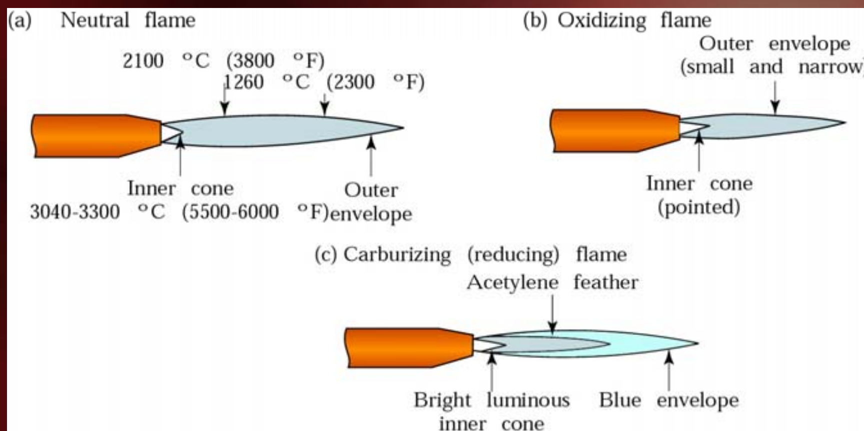
- Maximum temperature reached at tip of inner cone, while outer envelope spreads out and shields work surfaces from atmosphere



The neutral flame from an oxyacetylene torch indicating temperatures achieved.

4.1 Oxyacetylene Torch

- Oxy-acetylene flames



4.1 Oxyacetylene Welding (OAW)

4.2 Arc Welding

4.2 Two Categories of Welding Processes

- Fusion welding - coalescence is accomplished by melting the two parts to be joined, in some cases adding filler metal to the joint
  - Examples: arc welding, resistance spot welding, oxyfuel gas welding
- Solid state welding - heat and/or pressure are used to achieve coalescence, but no melting of base metals occurs and no filler metal is added
  - Examples: forge welding, diffusion welding, friction welding

4.2 Arc Welding (AW)

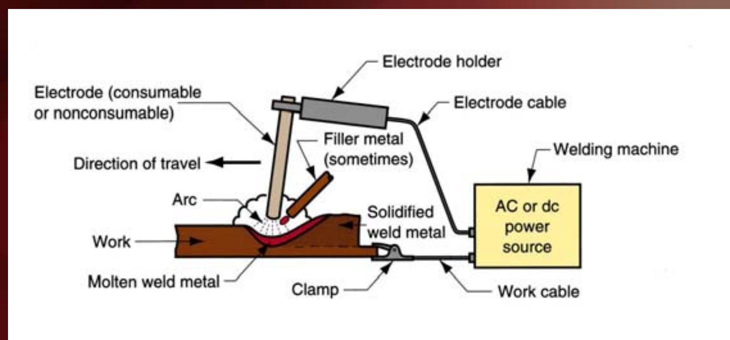
- A fusion welding process in which coalescence of the metals is achieved by the heat from an electric arc between an electrode and the work
- Electric energy from the arc produces temperatures ~ 10,000 F (5500 C), hot enough to melt any metal
- Most AW processes add filler metal to increase volume and strength of weld joint

4.2 What is an Electric Arc?

- An electric arc is a discharge of electric current across a gap in a circuit
- It is sustained by an ionized column of gas (*plasma*) through which the current flows
- To initiate the arc in AW, electrode is brought into contact with work and then quickly separated from it by a short distance

4.2 Arc Welding

A pool of molten metal is formed near electrode tip, and as electrode is moved along joint, molten weld pool solidifies



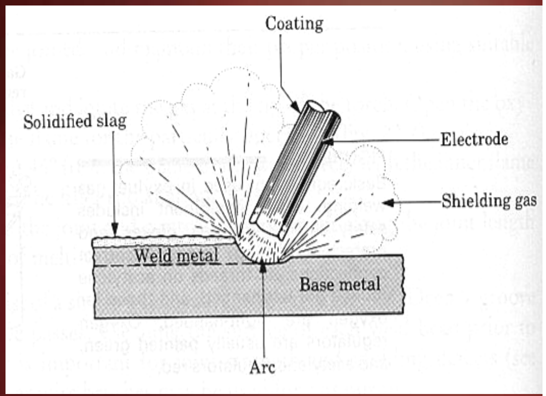
Basic configuration of an arc welding process.

4.2 Manual Arc Welding and Arc Time

- Problems with manual welding:
  - –Weld joint quality
  - –Productivity
- Arc Time = (time arc is on) divided by (hours worked)
  - –Also called “arc-on time”
  - –Manual welding arc time = 20%
  - –Machine welding arc time ~ 50%

4.2 Two Basic Types of AW Electrodes

- Consumable – consumed during welding process
  - –Source of filler metal in arc welding
- Nonconsumable – not consumed during welding process
  - –Filler metal must be added separately



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4.2 Consumable Electrodes

- Forms of consumable electrodes
  - Welding rods (a.k.a. sticks) are 9 to 18 inches and 3/8 inch or less in diameter and must be changed frequently
  - Weld wire can be continuously fed from spools with long lengths of wire, avoiding frequent interruptions
- In both rod and wire forms, electrode is consumed by arc and added to weld joint as filler metal

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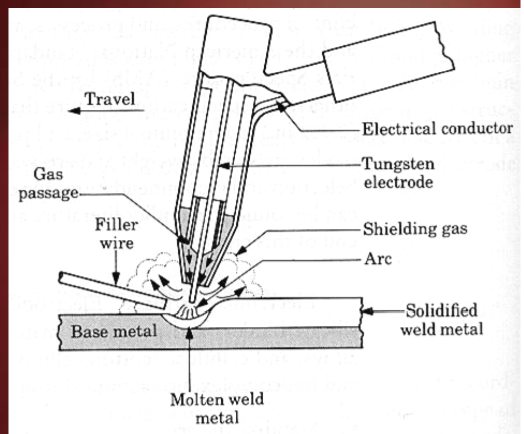
4.2 Nonconsumable Electrodes

- Made of tungsten which resists melting
- Gradually depleted during welding (vaporization is principal mechanism)
- Any filler metal must be supplied by a separate wire fed into weld pool



4.2 Arc Shielding

- At high temperatures in AW, metals are chemically reactive to oxygen, nitrogen, and hydrogen in air
  - Mechanical properties of joint can be seriously degraded by these reactions
  - To protect operation, arc must be shielded from surrounding air in AW processes
- Arc shielding is accomplished by:
  - Shielding gases, e.g., argon, helium, CO_2
  - Flux

4.2 Flux

- A substance that prevents formation of oxides and other contaminants in welding, or dissolves them and facilitates removal
- Provides protective atmosphere for welding
- Stabilizes arc
- Reduces spattering

4.2 Various Flux Application Methods

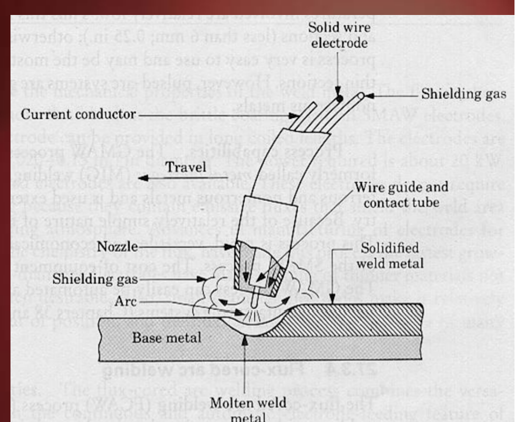
- Pouring granular flux onto welding operation (SAW)
- Stick electrode coated with flux material that melts during welding to cover operation (MMA)
- Tubular electrodes in which flux is contained in the core and released as electrode is consumed (FCAW)

4.2 Power Source in Arc Welding

- Direct current (DC) vs. Alternating current (AC)
  - AC machines less expensive to purchase and operate, but generally restricted to ferrous metals
  - DC equipment can be used on all metals and is generally noted for better arc control

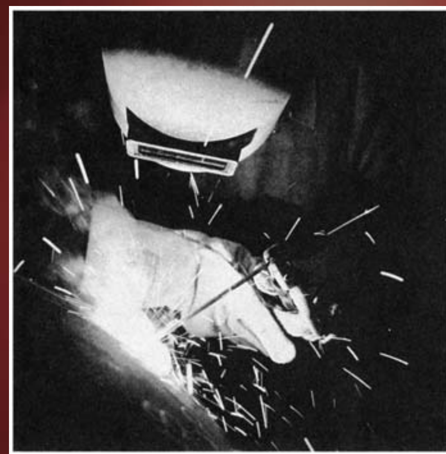
4.2 Consumable Electrode AW Processes

- Shielded Metal Arc Welding
- Gas Metal Arc Welding
- Flux-Cored Arc Welding
- Electrogas Welding
- Submerged Arc Welding

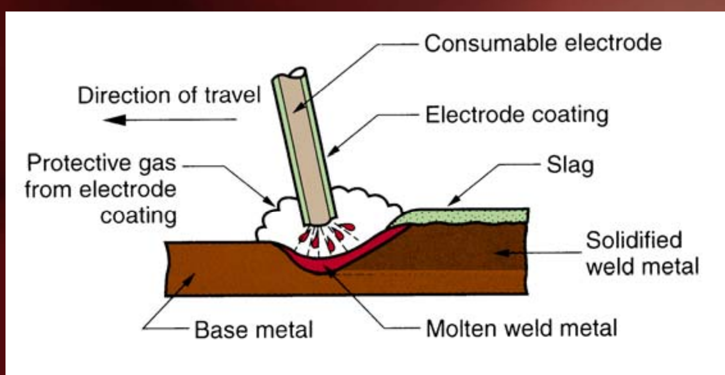


4.2 Shielded Metal Arc Welding (SMAW)

- Uses a consumable electrode consisting of a filler metal rod coated with chemicals that provide flux and shielding
- Sometimes called "stick welding"
- Power supply, connecting cables, and electrode holder available for a few thousand dollars



4.2 Shielded Metal Arc Welding

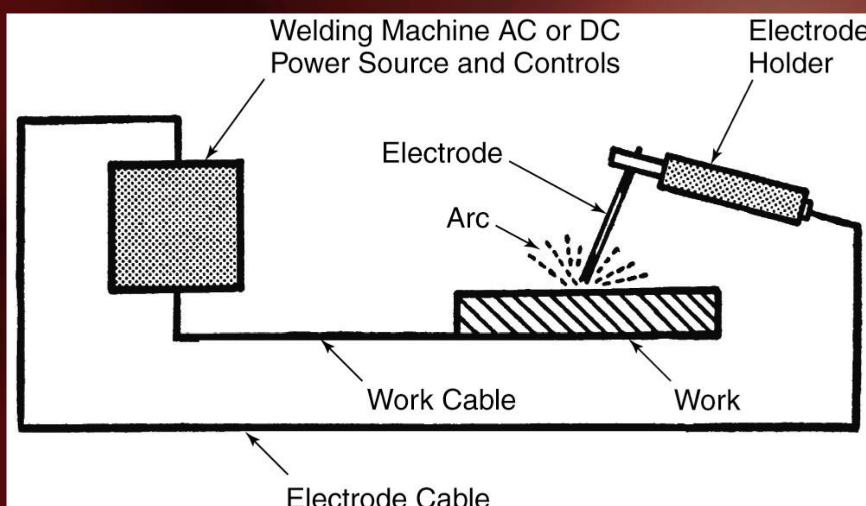


Shielded metal arc welding (SMAW).

4.2 Welding Stick in SMAW

- Composition of filler metal usually close to base metal
- Coating: powdered cellulose mixed with oxides, carbonates, and other ingredients, held together by a silicate binder
- Welding stick is clamped in electrode holder connected to power source
- Disadvantages of stick welding:
  - Sticks must be periodically changed
  - High current levels may melt coating prematurely

SMAW Operating Principle



4.2 SMAW Applications

- Used for steels, stainless steels, cast irons, and certain nonferrous alloys
- Not used or rarely used for aluminum and its alloys, copper alloys, and titanium

Designations for Mild Steel Coated Electrodes

TABLE 27.2

The prefix "E" designates arc welding electrode.
The first two digits of four-digit numbers and the first three digits of five-digit numbers indicate minimum tensile strength:

E60XX 60,000	psi minimum tensile strength
E70XX 70,000	psi minimum tensile strength
E110XX 110,000	psi minimum tensile strength

The next-to-last digit indicates position:

EXX1X	All positions
EXX2X	Flat position and horizontal fillets

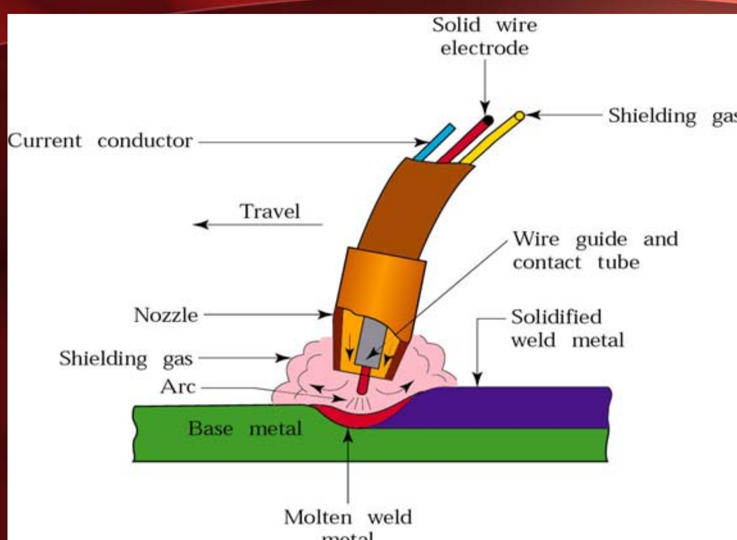
The last two digits together indicate the type of covering and the current to be used.
The suffix (Example: EXXXX-A1) indicates the approximate alloy in the weld deposit:

—A1	0.5% Mo
—B1	0.5% Cr, 0.5% Mo
—B2	1.25% Cr, 0.5% Mo
—B3	2.25% Cr, 1% Mo
—B4	2% Cr, 0.5% Mo
—B5	0.5% Cr, 1% Mo
—C1	2.5% Ni
—C2	3.25% Ni
—C3	1% Ni, 0.35% Mo, 0.15% Cr
—D1 and D2	0.25–0.45% Mo, 1.75% Mn
—G	0.5% min. Ni, 0.3% min. Cr, 0.2% min. Mo, 0.1%min. V, 1% min. Mn (only one element required)

4.2 Gas Metal Arc Welding (GMAW)

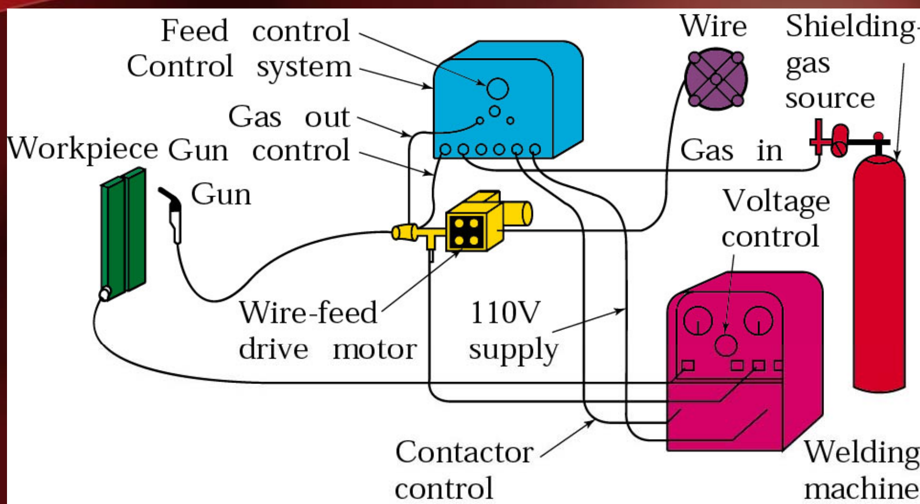
- Uses a consumable bare metal wire as electrode and shielding accomplished by flooding arc with a gas
- Wire is fed continuously and automatically from a spool through the welding gun
- Shielding gases include inert gases such as argon and helium for aluminum welding, and active gases such as CO_2 for steel welding
- Bare electrode wire plus shielding gases eliminate slag on weld bead - no need for manual grinding and cleaning of slag

4.2 Gas Metal Arc Welding

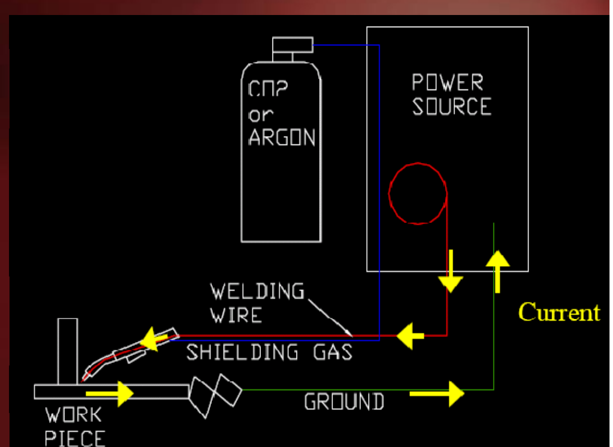


Gas metal arc welding (GMAW).

4.2 Gas Metal Arc Welding



4.2 Gas Metal Arc Welding



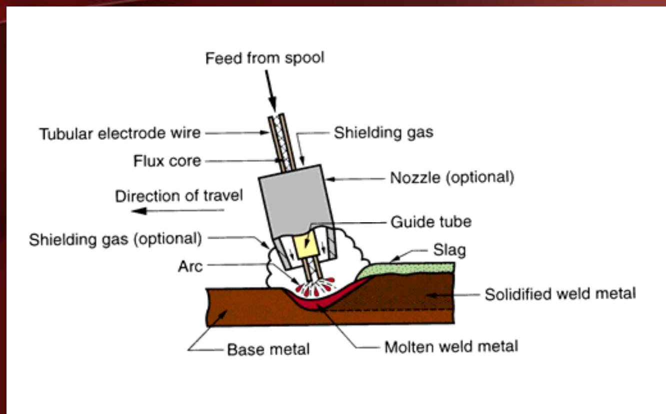
4.2 GMAW Advantages over SMAW

- Better arc time because of continuous wire electrode
  - – Sticks must be periodically changed in SMAW
- Better use of electrode filler metal than SMAW
  - – End of stick cannot be used in SMAW
- Higher deposition rates
- Eliminates problem of slag removal
- Can be readily automated

4.2 Flux-Cored Arc Welding (FCAW)

- Adaptation of shielded metal arc welding, to overcome limitations of stick electrodes
- Electrode is a continuous consumable tubing (in coils) containing flux and other ingredients (e.g., alloying elements) in its core
- Two versions:
  - – Self-shielded FCAW - core includes compounds that produce shielding gases
  - – Gas-shielded FCAW - uses externally applied shielding gases

4.2 Flux-Cored Arc Welding

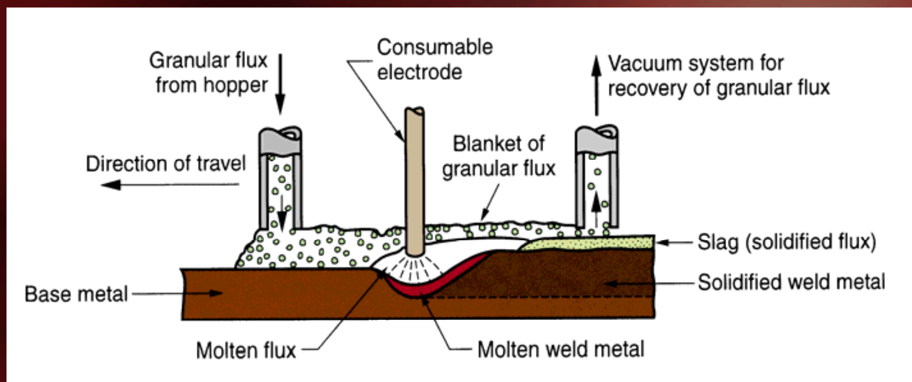


Flux-cored arc welding. Presence or absence of externally supplied shielding gas distinguishes the two types: (1) self-shielded, in which core provides ingredients for shielding, and (2) gas-shielded, which uses external shielding gases.

4.2 Submerged Arc Welding (SAW)

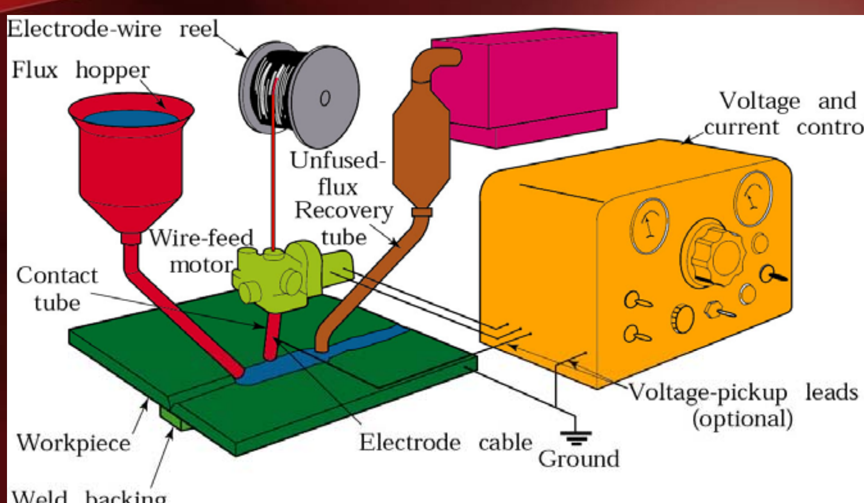
- Uses a continuous, consumable bare wire electrode, with arc shielding provided by a cover of granular flux
- Electrode wire is fed automatically from a coil
- Flux introduced into joint slightly ahead of arc by gravity from a hopper
  - Completely submerges operation, preventing sparks, spatter, and radiation

4.2 Submerged Arc Welding



Submerged arc welding.

4.2 Submerged Arc Welding



4.2 SAW Applications and Products

- Steel fabrication of structural shapes (e.g., I-beams)
- Seams for large diameter pipes, tanks, and pressure vessels
- Welded components for heavy machinery
- Most steels (except hi C steel)
- Not good for nonferrous metals

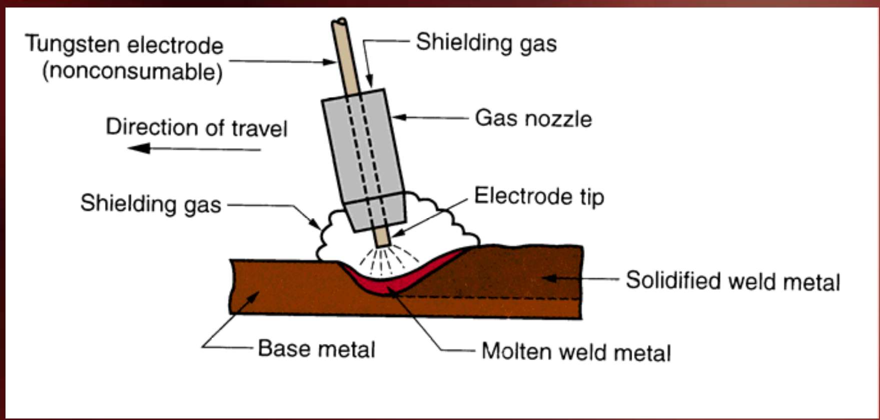
4.2 Nonconsumable Electrode Processes

- Gas Tungsten Arc Welding
- Plasma Arc Welding
- Carbon Arc Welding
- Stud Welding

4.2 Gas Tungsten Arc Welding (GTAW)

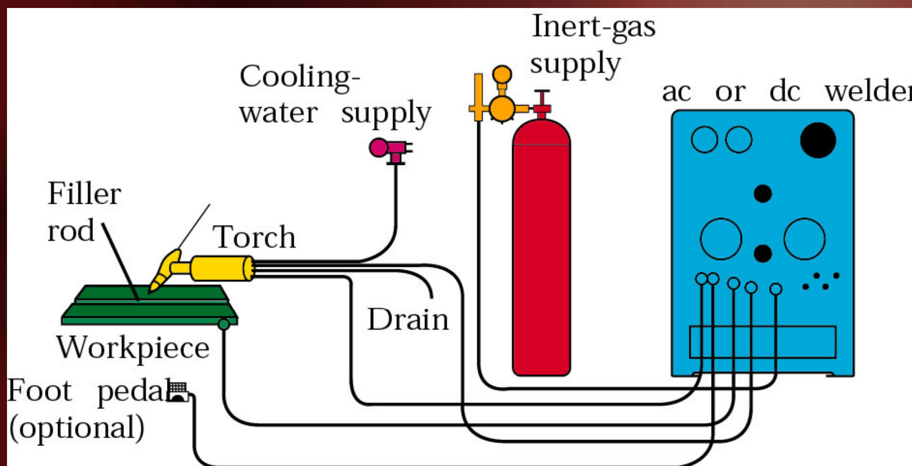
- Uses a nonconsumable tungsten electrode and an inert gas for arc shielding
- Melting point of tungsten = 3410°C (6170°F)
- A.k.a. Tungsten Inert Gas (TIG) welding
  - In Europe, called "WIG welding"
- Used with or without a filler metal
  - When filler metal used, it is added to weld pool from separate rod or wire
- Applications: aluminum and stainless steel most common

4.2 Gas Tungsten Arc Welding



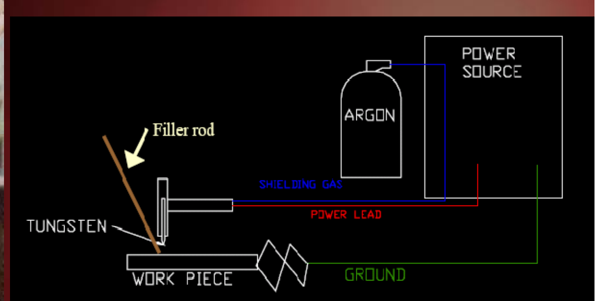
Gas tungsten arc welding.

4.2 Gas Tungsten Arc Welding



4.2 Gas Tungsten Arc Welding

TIG welding a Nascar chassis together.



4.2 Advantages / Disadvantages of GTAW

Advantages:

- High quality welds for suitable applications
- No spatter because no filler metal through arc
- Little or no post-weld cleaning because no flux

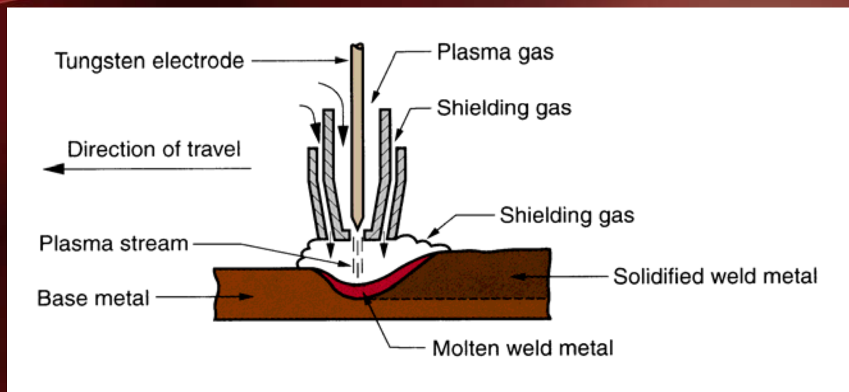
Disadvantages:

- Generally slower and more costly than consumable electrode AW processes

4.2 Plasma Arc Welding (PAW)

- Special form of GTAW in which a constricted plasma arc is directed at weld area
- Tungsten electrode is contained in a nozzle that focuses a high velocity stream of inert gas (argon) into arc region to form a high velocity, intensely hot plasma arc stream
- Temperatures in PAW reach 28,000°C (50,000°F), due to constriction of arc, producing a plasma jet of small diameter and very high energy density

4.2 Plasma Arc Welding



Plasma arc welding (PAW).

4.2 Advantages / Disadvantages of PAW

Advantages:
- Good arc stability
- Better penetration control than other AW
- High travel speeds
- Excellent weld quality
- Can be used to weld almost any metals

Disadvantages:
- High equipment cost
- Larger torch size than other AW
  – Tends to restrict access in some joints

GENERAL CHARACTERISTICS OF JOINING PROCESSES

Process	Operation	Advantage	Skill Level Required	Welding Position	Current Type	Distortion*	Cost of Equipment
SMAW	Manual	Portable and flexible	High	All	ac, dc	1 to 2	Low
SAW	Automatic	High deposition	Low to medium	Flat and horizontal	ac, dc	1 to 2	Medium
GMAW	Semiautomatic or automatic	Most metals	Low to high	All	dc	2 to 3	Medium to high
GTAW	Manual or automatic	Most metals	Low to high	All	ac, dc	2 to 3	Medium
FCAW	Semiautomatic or automatic	High deposition	Low to high	All	dc	1 to 3	Medium
OFW	Manual	Portable and flexible	High	All	—	2 to 4	Low
EBW, LBW	Semiautomatic or automatic	Most metals	Medium to high	All	—	3 to 5	High

* 1, highest; 5, lowest.

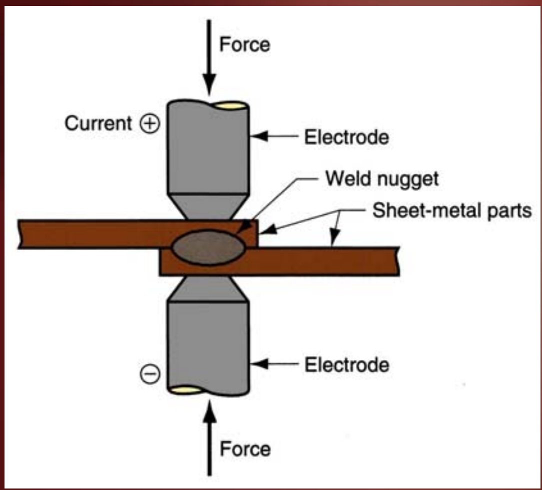
Comparison of Electric Arc Welding Processes

Welding Process	SMAW	MIG	TIG	SAW
Configuration	AC, DC	DCRP	AC, DCRP	AC, DC
Current (amps)	10-500	500	200-500	450-1600
Voltage (volts)	17-45	16-30	55	20-50
Travel Speed (IPM)	4-45	13-24	10-18	20-120
Deposition Rate (lb/Min)	3-17	4-16	3-18	14-30
Penetration	20%-70%	Deep	Deep	60%-80%
Electrode	Consumable	Consumable	Non-consumable	Consumable
Quality	Good	High	High	Excellent
Cost	Low	Fair	Fair	High
Shielding Gas	---	CO_2, Ar, He	Ar, He	Ar, He
Application	Wide	Wide	Wide	Ship, railroad, car, pipe
Spatter	Yes	No	No	No
Distortion	Big	Less	Less	Less

4.2 Resistance Welding (RW)

- A group of fusion welding processes that use a combination of heat and pressure to accomplish coalescence
- Heat generated by electrical resistance to current flow at junction to be welded
- Principal RW process is resistance spot welding (RSW)

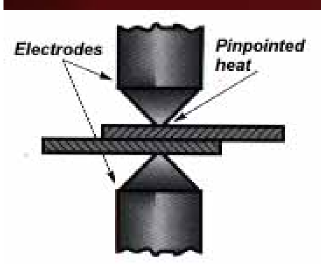
4.2 Resistance Welding

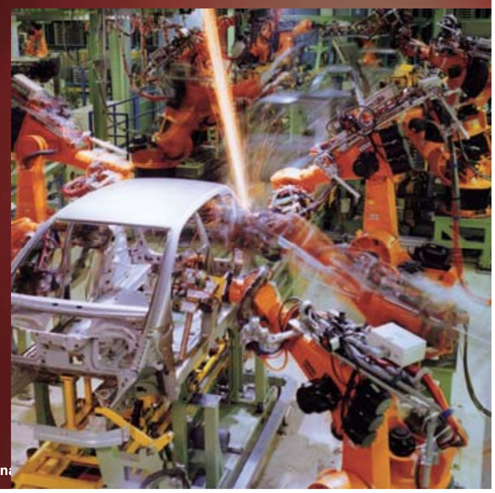


Resistance welding, showing the components in spot welding, the main process in the RW group.

3.3. Resistance Welding (spot welding)

An electrical pules combined with a moderate pressure is applied at a small area, causing intensive local heating and inter-fusion of overlying metals. This technique is suitable for spot welding of thin sheets and is widely used in automobile manufacturing.





4.2 Components in Resistance Spot Welding

- Parts to be welded (usually sheet metal)
- Two opposing electrodes
- Means of applying pressure to squeeze parts between electrodes
- Power supply from which a controlled current can be applied for a specified time duration

4.2 Advantages / Drawbacks of RW

Advantages:

- No filler metal required
- High production rates possible
- Lends itself to mechanization and automation
- Lower operator skill level than for arc welding
- Good repeatability and reliability

Disadvantages:

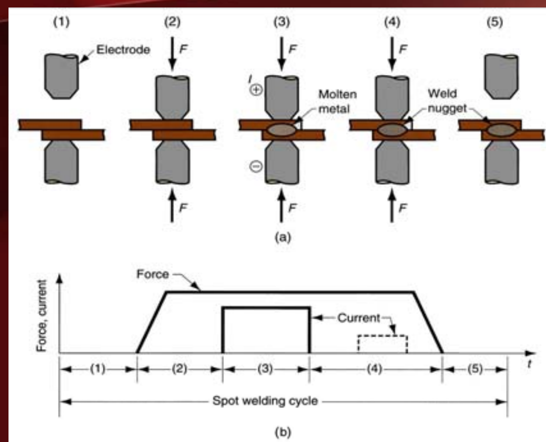
- High initial equipment cost
- Limited to lap joints for most RW processes

4.2 Resistance Spot Welding (RSW)

Resistance welding process in which fusion of faying surfaces of a lap joint is achieved at one location by opposing electrodes

- Used to join sheet metal parts using a series of spot welds
- Widely used in mass production of automobiles, appliances, metal furniture, and other products made of sheet metal
  - Typical car body has ~ 10,000 spot welds
  - Annual production of automobiles in the world is measured in tens of millions of units

4.2 Spot Welding Cycle



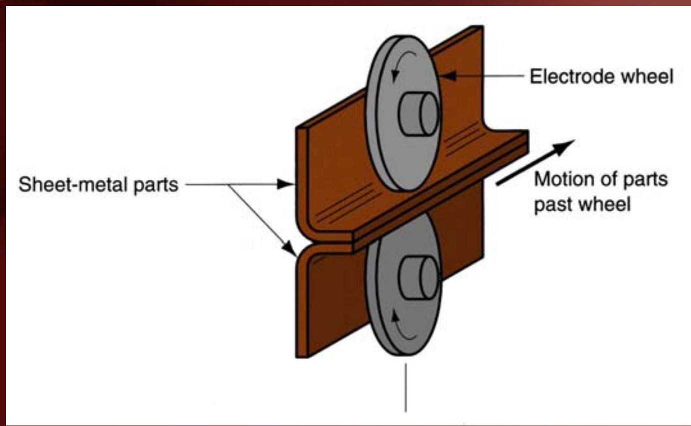
(a) Spot welding cycle, (b) plot of squeezing force & current in cycle (1) parts inserted between electrodes, (2) electrodes close, force applied, (3) current on, (4) current off, (5) electrodes opened.

4.2 Resistance Seam Welding (RSEW)

Uses rotating wheel electrodes to produce a series of overlapping spot welds along lap joint

- Can produce air-tight joints
- Applications:
  - Gasoline tanks
  - Automobile mufflers
  - Various other sheet metal containers

4.2 Resistance Seam Welding

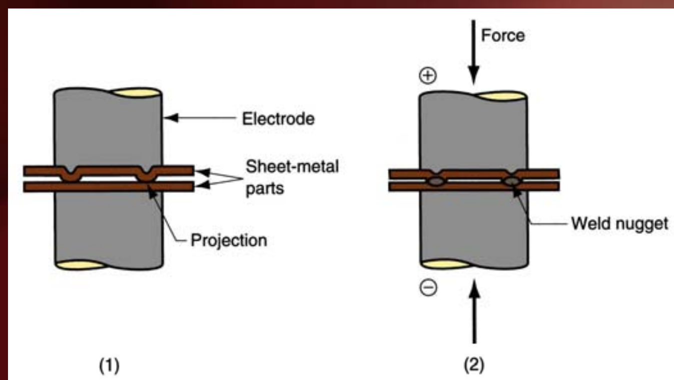


Resistance seam welding (RSEW).

4.2 Resistance Projection Welding (RPW)

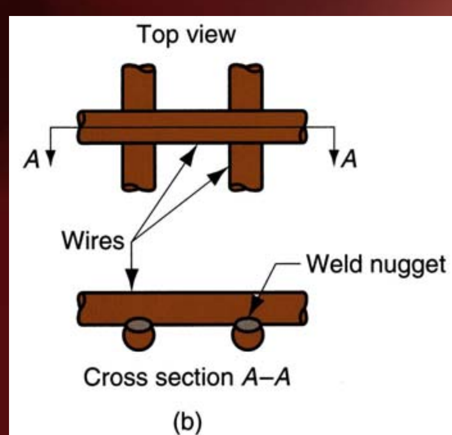
- A resistance welding process in which coalescence occurs at one or more small contact points on parts
- Contact points determined by design of parts to be joined
  - May consist of projections, embossments, or localized intersections of parts

4.2 Resistance Projection Welding



Resistance projection welding (RPW): (1) start of operation, contact between parts is at projections; (2) when current is applied, weld nuggets similar to spot welding are formed at the projections.

4.2 Cross-Wire Welding



(b) cross-wire welding.

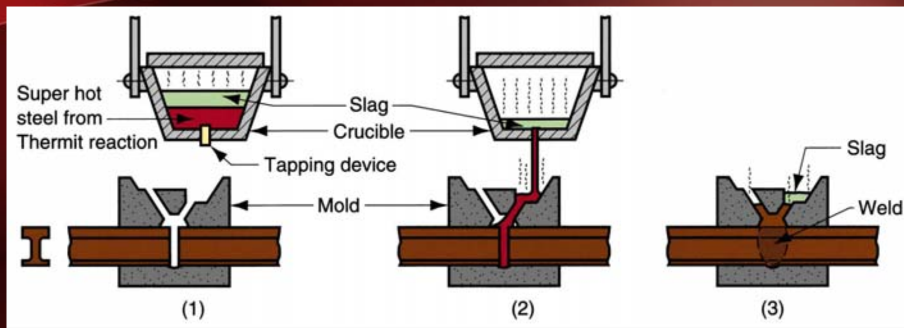
4.3 Other Fusion Welding Processes

- FW processes that cannot be classified as arc, resistance, or oxyfuel welding
- Use unique technologies to develop heat for melting
- Applications are typically unique
- Processes include:
  - Electron beam welding
  - Laser beam welding
  - Electroslag welding
  - Thermit welding

4.3 Thermit Welding (TW)

- FW process in which heat for coalescence is produced by superheated molten metal from the chemical reaction of thermite
- *Thermite* = mixture of Al and Fe_3O_4 fine powders that produce an exothermic reaction when ignited
- Also used for incendiary bombs
- Filler metal obtained from liquid metal
- Process used for joining, but has more in common with casting than welding

4.3 Thermit Welding



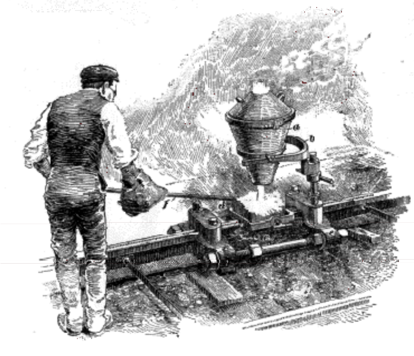
Thermit welding: (1) Thermit ignited; (2) crucible tapped, superheated metal flows into mold; (3) metal solidifies to produce weld joint.

4.3 TW Applications

- Joining of railroad rails
- Repair of cracks in large steel castings and forgings
- Weld surface is often smooth enough that no finishing is required

Thermit Welding

Take a mixture of powdered Al or Mg and iron oxide, ignite it, and stand back! Within seconds the mixture flames to twice the temperature of molten steel, and from the bottom of the crucible comes molten iron. Invented a century ago, Thermit is a cheap and simple way to weld railway tracks.



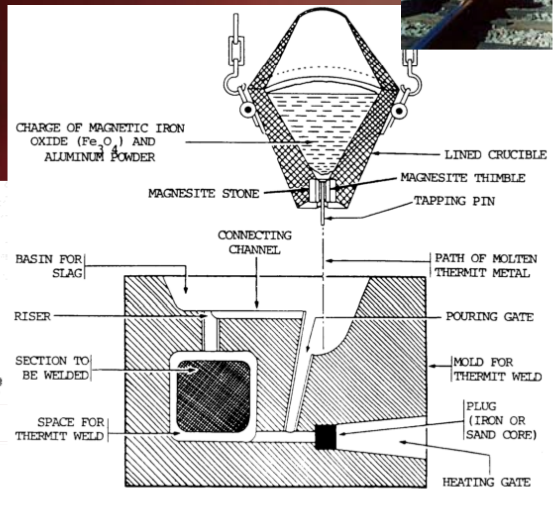


Figure 5-41. Thermit welding crucible and mold.

4.4 Solid State Welding (SSW)

- Coalescence of part surfaces is achieved by:
  - Pressure alone, or
  - Heat and pressure
    - If both heat and pressure are used, heat is not enough to melt work surfaces
  - For some SSW processes, time is also a factor
- No filler metal is added
- Each SSW process has its own way of creating a bond at the faying surfaces

4.4 Success Factors in SSW

- Essential factors for a successful solid state weld are that the two faying surfaces must be:
  - Very clean
  - In very close physical contact with each other to permit atomic bonding

4.4 SSW Advantages over FW Processes

- If no melting, then no heat affected zone, so metal around joint retains original properties
- Many SSW processes produce welded joints that bond the entire contact interface between two parts rather than at distinct spots or seams
- Some SSW processes can be used to bond dissimilar metals, without concerns about relative melting points, thermal expansions, and other problems that arise in FW

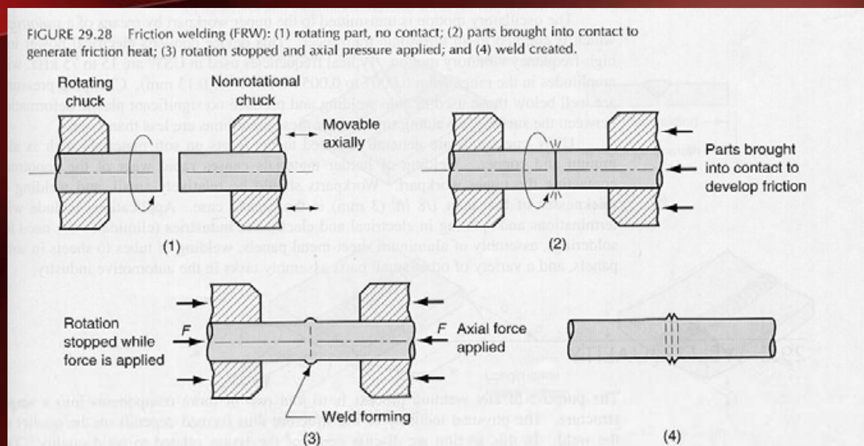
4.4 Solid State Welding Processes

- Forge welding
- Cold welding
- Roll welding
- Hot pressure welding
- Diffusion welding
- Explosion welding
- Friction welding
- Ultrasonic welding

4.4 Friction Welding (FRW)

- SSW process in which coalescence is achieved by frictional heat combined with pressure
- When properly carried out, no melting occurs at faying surfaces
- No filler metal, flux, or shielding gases normally used
- Process yields a narrow HAZ
- Can be used to join dissimilar metals
- Widely used commercial process, amenable to automation and mass production

4.4 Friction Welding



Friction welding (FRW): (1) rotating part, no contact; (2) parts brought into contact to generate friction heat; (3) rotation stopped and axial pressure applied; and (4) weld created.

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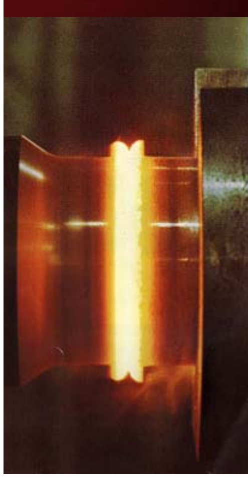
3.4. Friction Welding



Friction welding is a process by which two metal butt surfaces are slide (mostly in rotational motion) against each other rapidly under pressure to generate intensive heat at the interface. The action is then stopped to allow inter-fusion to happen to form the weld. This method is particularly useful for joining immiscible metals that are difficult to mix in fusion, such as stainless steel with Al.

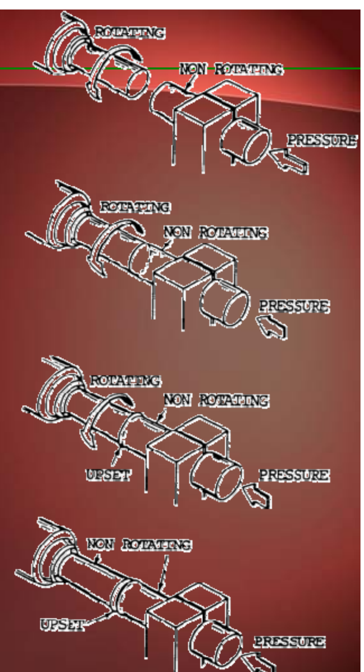


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Figure 10-79. Friction welding process.

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4.4 Two Types of Friction Welding

1. Continuous-drive friction welding
   – One part is driven at constant rpm against stationary part to cause friction heat at interface
   – At proper temperature, rotation is stopped and parts are forced together
2. Inertia friction welding
   – Rotating part is connected to flywheel, which is brought up to required speed
   – Flywheel is disengaged from drive, and parts are forced together

4.4 Applications / Limitations of FRW

Applications:

- Shafts and tubular parts
- Industries: automotive, aircraft, farm equipment, petroleum and natural gas

Limitations:

- At least one of the parts must be rotational
- Flash must usually be removed
- Upsetting reduces the part lengths (which must be taken into consideration in product design)

4.5 Weld Quality

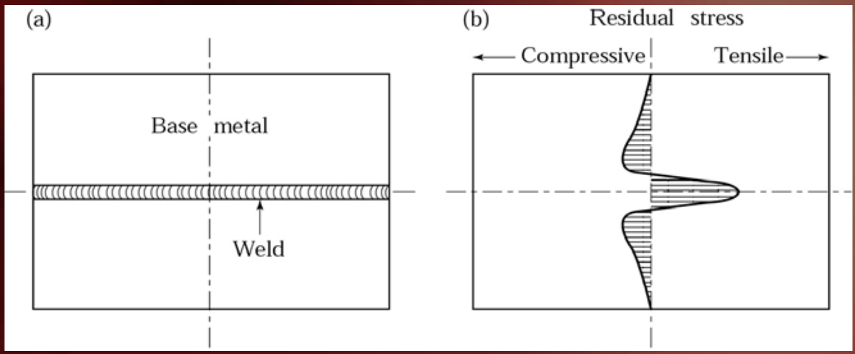
Concerned with obtaining an acceptable weld joint that is strong and absent of defects, and the methods of inspecting and testing the joint to assure its quality

- Topics:
  - Residual stresses and distortion
  - Welding defects
  - Inspection and testing methods

4.5 Residual Stresses and Distortion

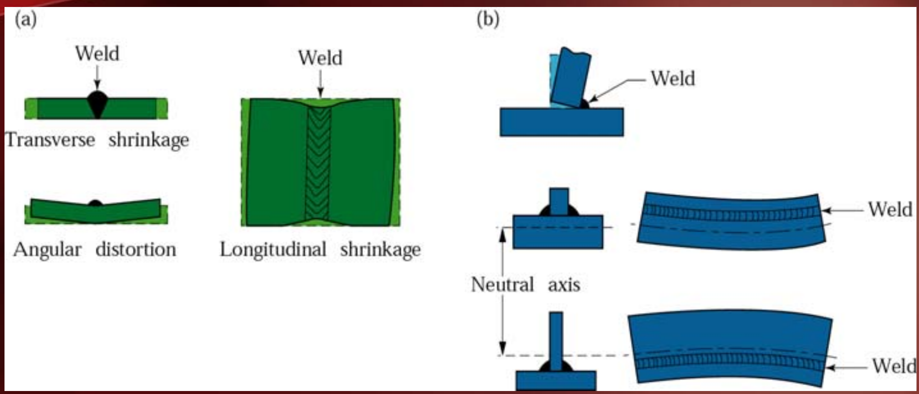
- Rapid heating and cooling in localized regions during FW result in thermal expansion and contraction that cause residual stresses
- These stresses, in turn, cause distortion and warpage
- Situation in welding is complicated because:
  - Heating is very localized
  - Melting of base metals in these regions
  - Location of heating and melting is in motion (at least in AW)

4.5 Residual Stresses Developed During Welding



Residual stresses developed during welding of a butt joint.
***Source*: American Welding Society.**

4.5 Distortion After Welding



Distortion of parts after welding: (a) butt joints; (b) fillet welds. Distortion is caused by differential thermal expansion and contraction of different parts of the welded assembly.

4.5 Techniques to Minimize Warpage

- Welding fixtures to physically restrain parts
- Heat sinks to rapidly remove heat
- Tack welding at multiple points along joint to create a rigid structure prior to seam welding
- Selection of welding conditions (speed, amount of filler metal used, etc.) to reduce warpage
- Preheating base parts
- Stress relief heat treatment of welded assembly
- Proper design of weldment

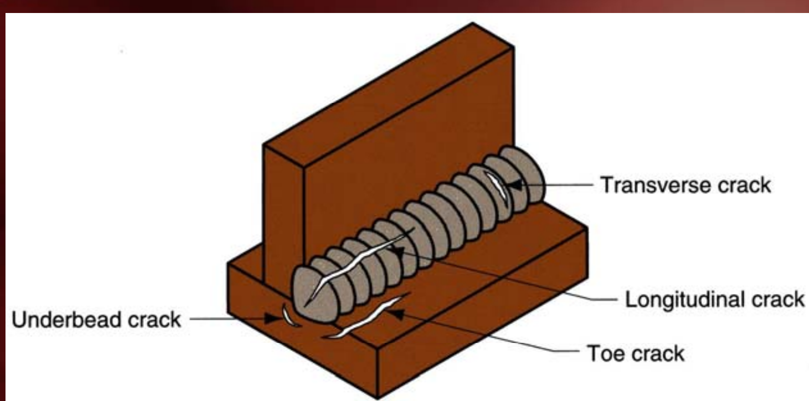
4.5 Welding Defects

- Cracks
- Cavities
- Solid inclusions
- Imperfect shape or unacceptable contour
- Incomplete fusion
- Miscellaneous defects

4.5 Welding Cracks

- Fracture-type interruptions either in weld or in base metal adjacent to weld
- Serious defect because it is a discontinuity in the metal that significantly reduces strength
- Caused by embrittlement or low ductility of weld and/or base metal combined with high restraint during contraction
- In general, this defect must be repaired

4.5 Welding Cracks



Various forms of welding cracks.

4.5 Cavities

Two defect types, similar to defects found in castings:

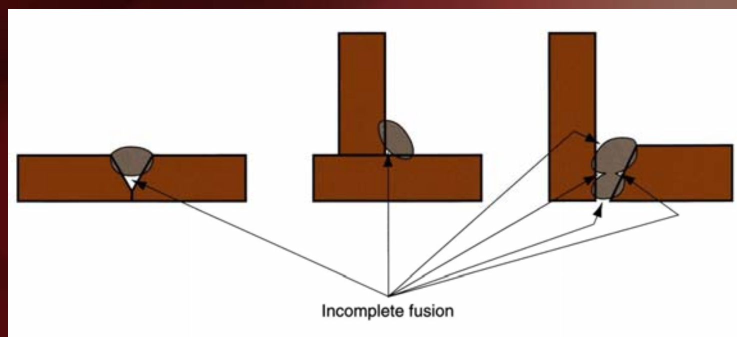
1. Porosity - small voids in weld metal formed by gases entrapped during solidification
   - Caused by inclusion of atmospheric gases, sulfur in weld metal, or surface contaminants
2. Shrinkage voids - cavities formed by shrinkage during solidification

4.5 Solid Inclusions

- Solid inclusions - nonmetallic material entrapped in weld metal
- Most common form is slag inclusions generated during AW processes that use flux
  - Instead of floating to top of weld pool, globules of slag become encased during solidification
- Metallic oxides that form during welding of certain metals such as aluminum, which normally has a surface coating of Al_2O_3

4.5 Incomplete Fusion

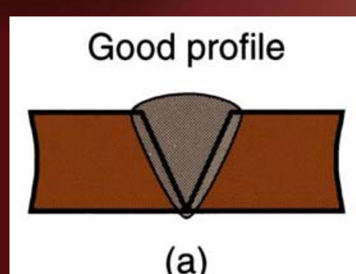
Also known as *lack of fusion*, it is simply a weld bead in which fusion has not occurred throughout entire cross section of joint



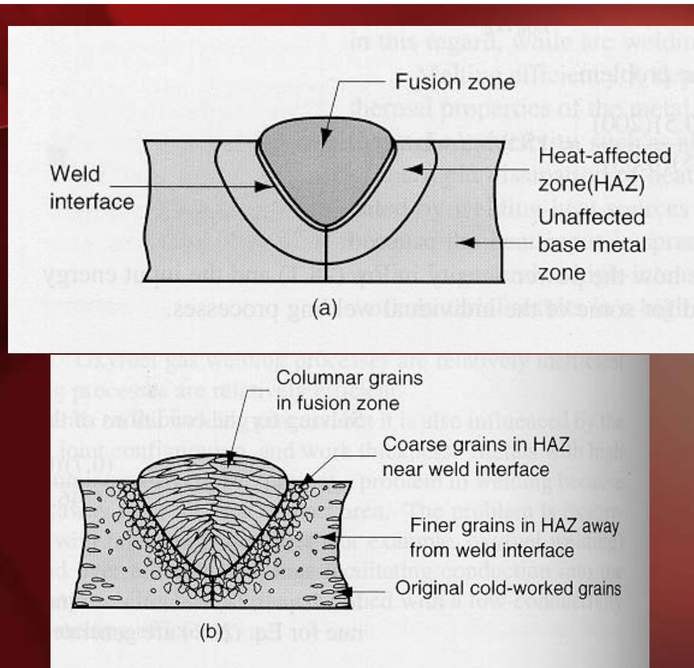
Several forms of incomplete fusion.

4.5 Weld Profile in AW

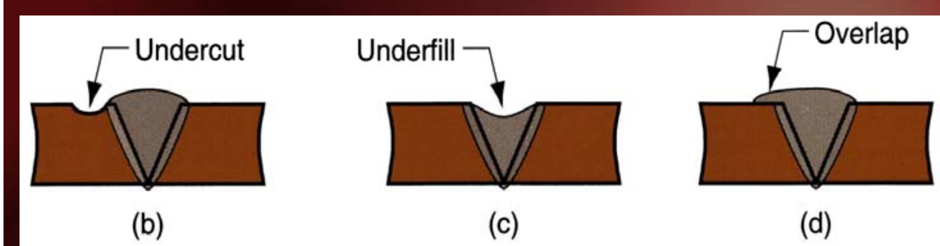
- Weld joint should have a certain desired profile to maximize strength and avoid incomplete fusion and lack of penetration



(a) Desired weld profile for single V-groove weld joint.



4.5 Weld Defects in AW



Same joint but with several weld defects: (b) *undercut*, in which a portion of the base metal part is melted away; (c) *underfill*, a depression in the weld below the level of the adjacent base metal surface; and (d) *overlap*, in which the weld metal spills beyond the joint onto the surface of the base part but no fusion occurs.

4.5 Inspection and Testing Methods

- Visual inspection
- Nondestructive evaluation
- Destructive testing

4.5 Visual Inspection

- Most widely used welding inspection method
- Human inspector visually examines for:
  - Conformance to dimensions
  - Warpage
  - Cracks, cavities, incomplete fusion, and other surface defects
- Limitations:
  - Only surface defects are detectable
  - Welding inspector must also determine if additional tests are warranted

4.5 Nondestructive Evaluation (NDE) Tests

- Ultrasonic testing - high frequency sound waves directed through specimen - cracks, inclusions are detected by loss in sound transmission
- Radiographic testing - x-rays or gamma radiation provide photograph of internal flaws
- Dye-penetrant and fluorescent-penetrant tests - methods for detecting small cracks and cavities that are open at surface
- Magnetic particle testing – iron filings sprinkled on surface reveal subsurface defects by distorting magnetic field in part

4.5 Destructive Testing

- Tests in which weld is destroyed either during testing or to prepare test specimen
- Mechanical tests - purpose is similar to conventional testing methods such as tensile tests, shear tests, etc
- Metallurgical tests - preparation of metallurgical specimens (e.g., photomicrographs) of weldment to examine metallic structure, defects, extent and condition of heat affected zone, and similar phenomena

4.6 Weldability

- Capacity of a metal or combination of metals to be welded into a suitably designed structure, and for the resulting weld joint(s) to possess the required metallurgical properties to perform satisfactorily in intended service
- Good weldability characterized by:
  - Ease with which welding process is accomplished
  - Absence of weld defects
  - Acceptable strength, ductility, and toughness in welded joint

4.6 Weldability Factors – Welding Process

- Some metals or metal combinations can be readily welded by one process but are difficult to weld by others
  - Example: stainless steel readily welded by most AW and RW processes, but difficult to weld by OFW

4.6 Weldability Factors – Base Metal

- Some metals melt too easily; e.g., aluminum
- Metals with high thermal conductivity transfer heat away from weld, which causes problems; e.g., copper
- High thermal expansion and contraction in metal causes distortion problems
- Dissimilar metals pose problems in welding when their physical and/or mechanical properties are substantially different

4.6 Other Factors Affecting Weldability

- Filler metal
  - Must be compatible with base metal(s)
  - In general, elements mixed in liquid state that form a solid solution upon solidification will not cause a problem
- Surface conditions
  - Moisture can result in porosity in fusion zone
  - Oxides and other films on metal surfaces can prevent adequate contact and fusion

4.6 Weldability of various materials

TABLE 39-2. Weldability and Joinability of Various 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.