WELDING PROCESSES

Resistance welding, Laser welding, Electron Beam welding

Resistance Welding

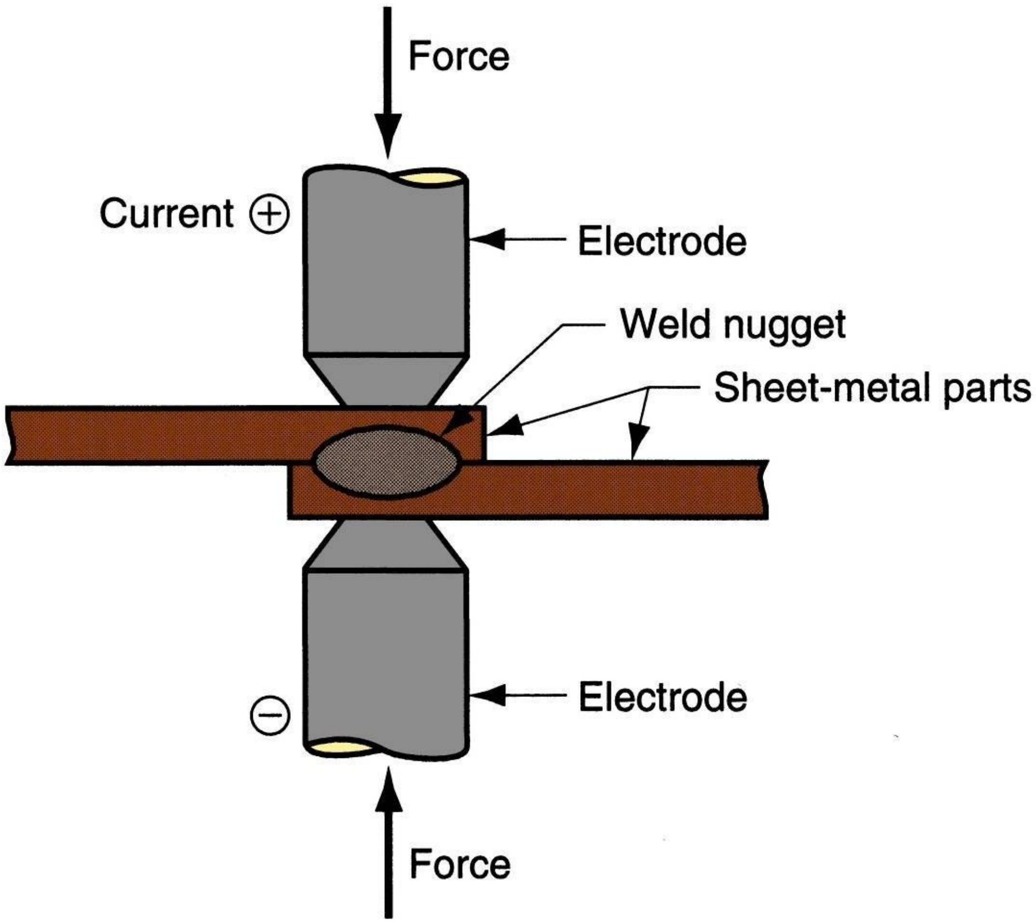


Figure Resistance welding, showing the components in spot welding, the main process in the RW group.

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

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

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

Spot Welding Cycle

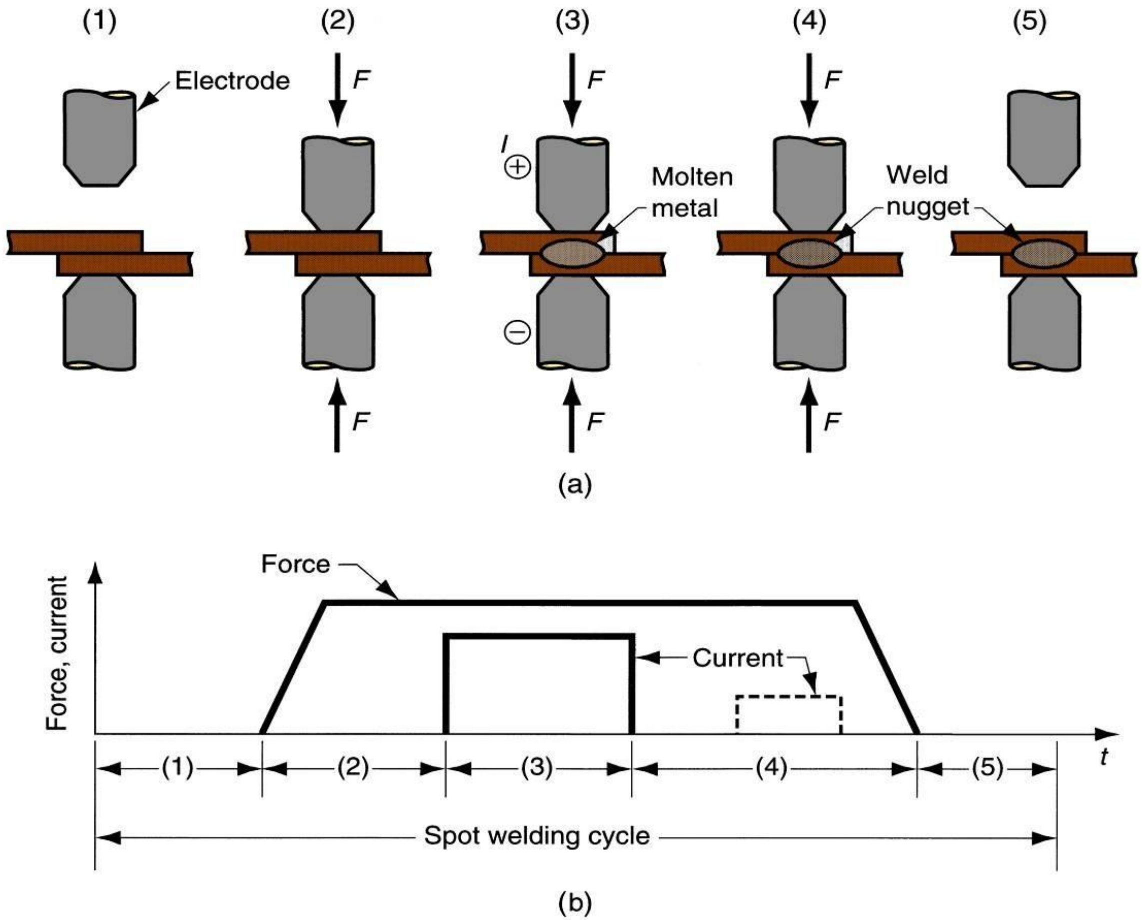


Figure (a) Spot welding cycle, (b) plot of squeezing force & current in cycle (1) parts inserted between electrodes, (2) electrodes close, force applied, (3) current on, (4) current off, (5) electrodes opened.

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

Resistance Seam Welding

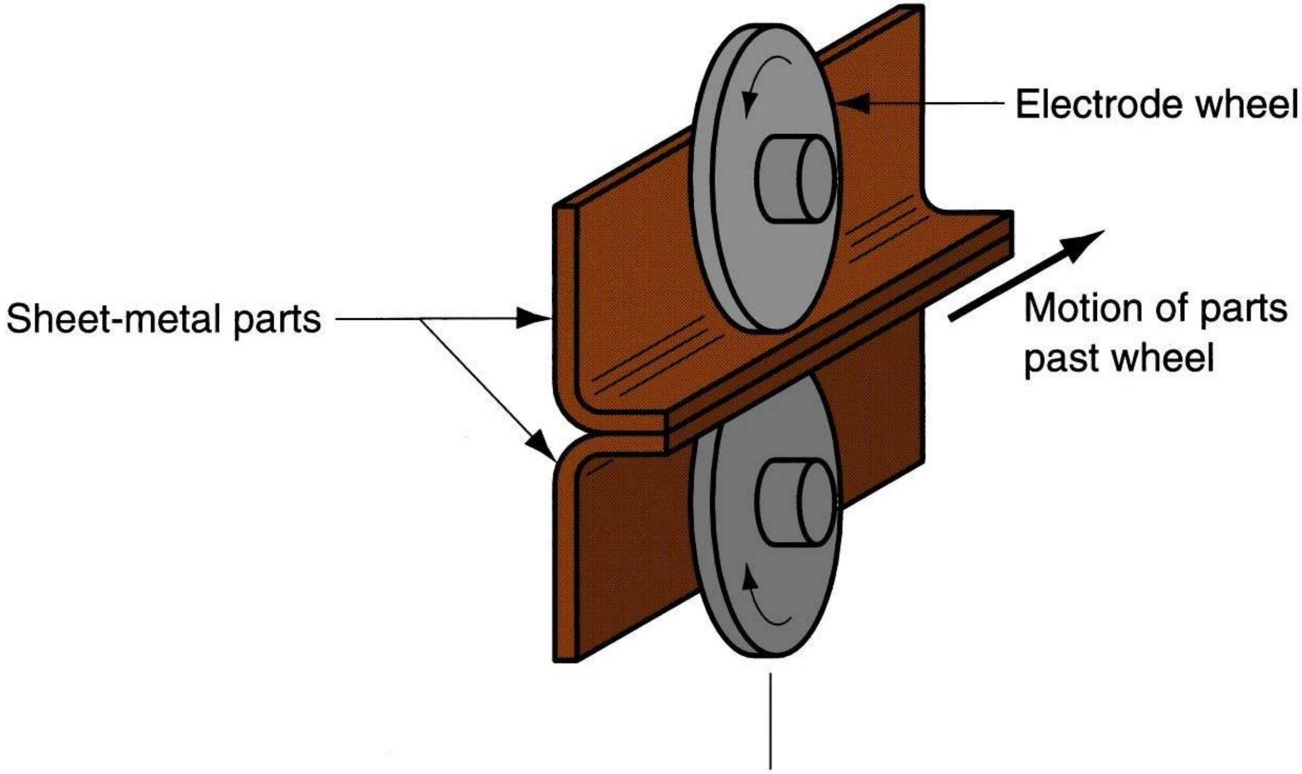


Figure Resistance seam welding (RSEW).

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

Resistance Projection Welding

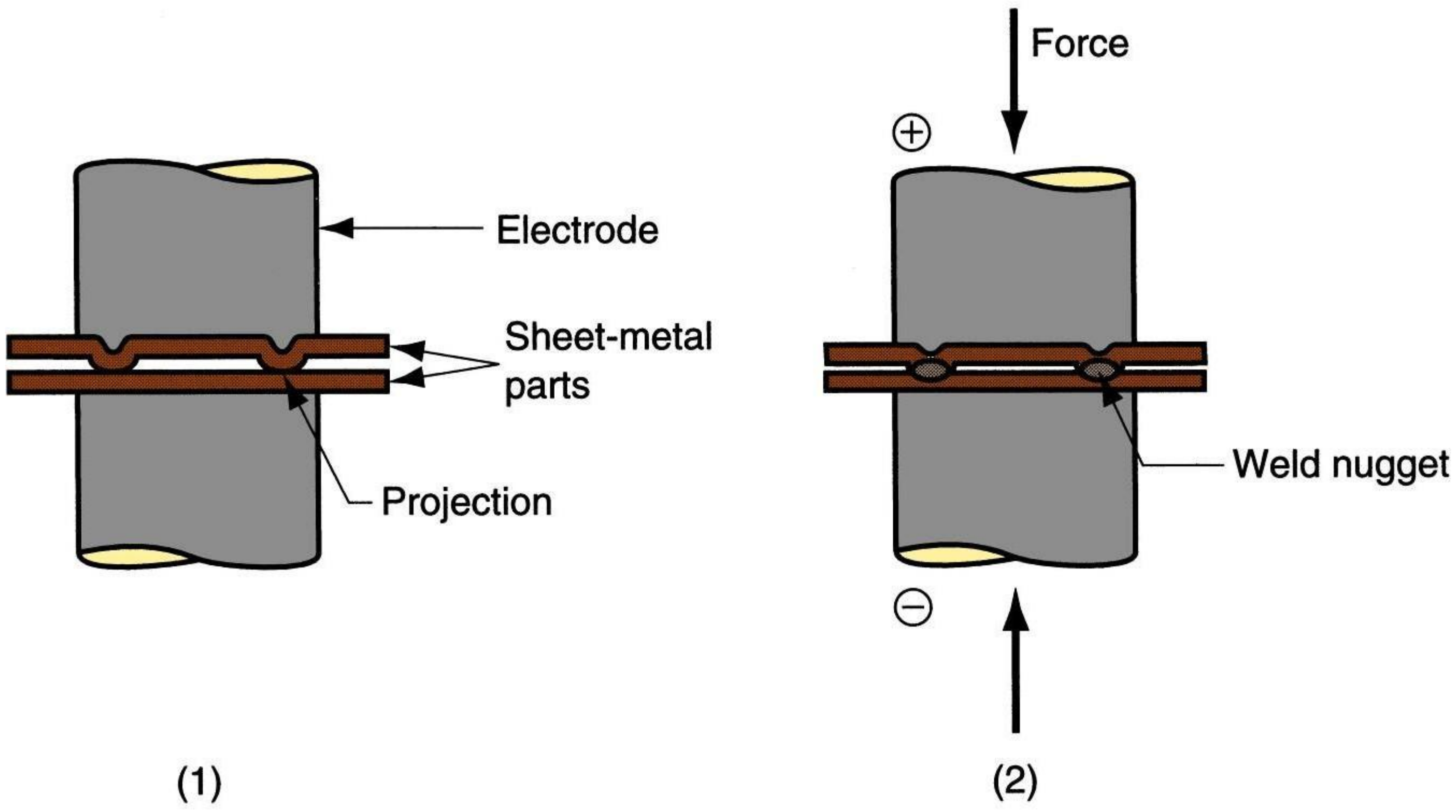


Figure Resistance projection welding (RPW): (1) start of operation, contact between parts is at projections; (2) when current is applied, weld nuggets similar to spot welding are formed at the projections.

Oxyfuel Gas Welding (OFW)

Group of fusion welding operations that burn various fuels mixed with oxygen

- OFW employs several types of gases, which is the primary distinction among the members of this group
- 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

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

Oxyacetylene Welding

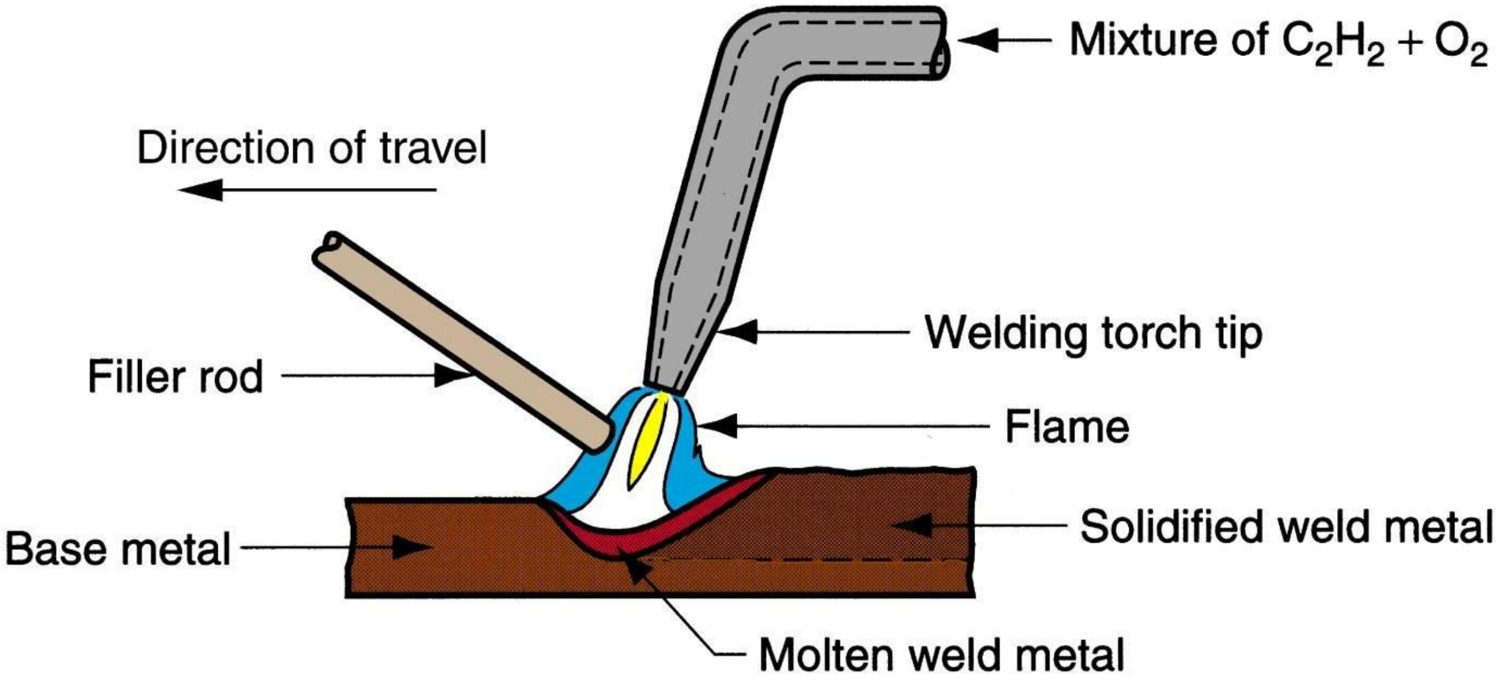


Figure A typical oxyacetylene welding operation (OAW).

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):

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

Oxyacetylene Torch

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

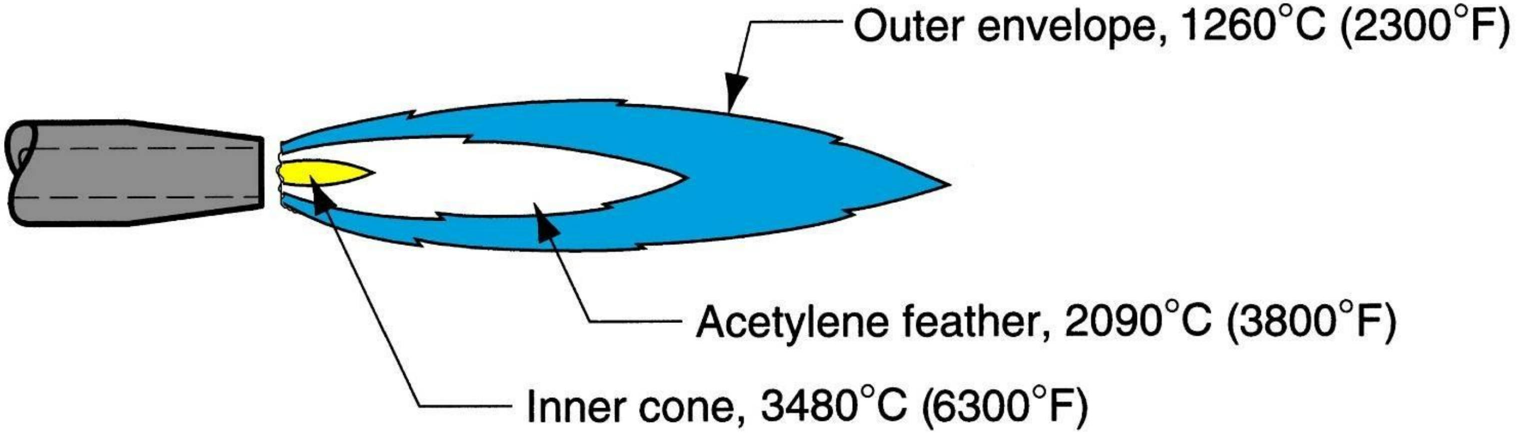


Figure The neutral flame from an oxyacetylene torch indicating temperatures achieved.

Alternative Gases for OFW

- Methylacetylene-Propadiene (MAPP)
- Hydrogen
- Propylene
- Propane
- Natural Gas

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

Electron Beam Welding (EBW)

Fusion welding process in which heat for welding is provided by a highly-focused, high-intensity stream of electrons striking work surface

- Electron beam gun operates at:
  - High voltage (e.g., 10 to 150 kV typical) to accelerate electrons
  - Beam currents are low (measured in milliamps)
- Power in EBW not exceptional, but power density is

EBW Advantages / Disadvantages

Advantages:

- High-quality welds, deep and narrow profiles
- Limited heat affected zone, low thermal distortion
- High welding speeds
- No flux or shielding gases needed

Disadvantages:

- High equipment cost
- Precise joint preparation & alignment required
- Vacuum chamber required
- Safety concern: EBW generates x-rays

Laser Beam Welding (LBW)

Fusion welding process in which coalescence is achieved by energy of a highly concentrated, coherent light beam focused on joint

- Laser = "light amplification by stimulated emission of radiation"
- LBW normally performed with shielding gases to prevent oxidation
- Filler metal not usually added
- High power density in small area, so LBW often used for small parts

Comparison: LBW vs. EBW

- No vacuum chamber required for LBW
- No x-rays emitted in LBW
- Laser beams can be focused and directed by optical lenses and mirrors
- LBW not capable of the deep welds and high depth-to-width ratios of EBW
  - Maximum LBW depth = ~ 19 mm (3/4 in), whereas EBW depths = 50 mm (2 in)

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

Thermit Welding

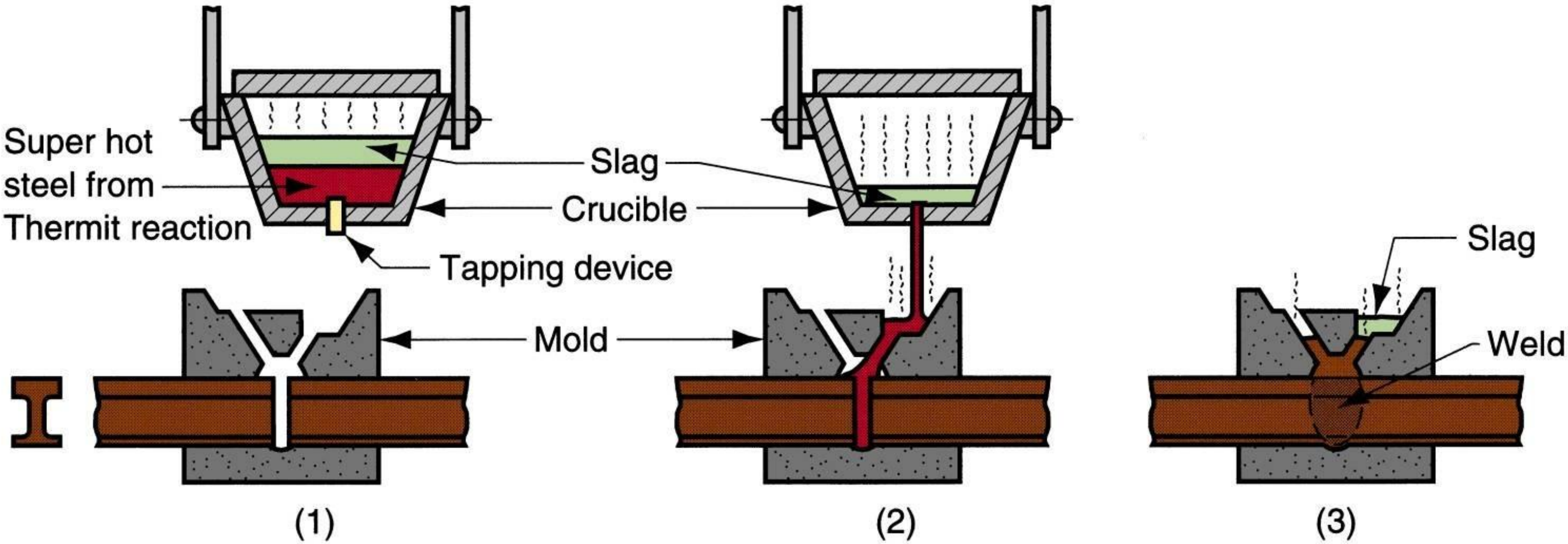


Figure Thermit welding: (1) Thermit ignited; (2) crucible tapped, superheated metal flows into mold; (3) metal solidifies to produce weld joint.

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

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

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

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

Solid State Welding Processes

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

Forge Welding

Welding process in which components to be joined are heated to hot working temperature range and then forged together by hammering or similar means

- Historic significance in development of manufacturing technology
  - Process dates from about 1000 B.C., when blacksmiths learned to weld two pieces of metal
- Of minor commercial importance today except for its variants

Roll Welding (ROW)

SSW process in which pressure sufficient to cause coalescence is applied by means of rolls, either with or without external heat

- Variation of either forge welding or cold welding, depending on whether heating of workparts is done prior to process
  - If no external heat, called cold roll welding
  - If heat is supplied, hot roll welding

Roll Welding

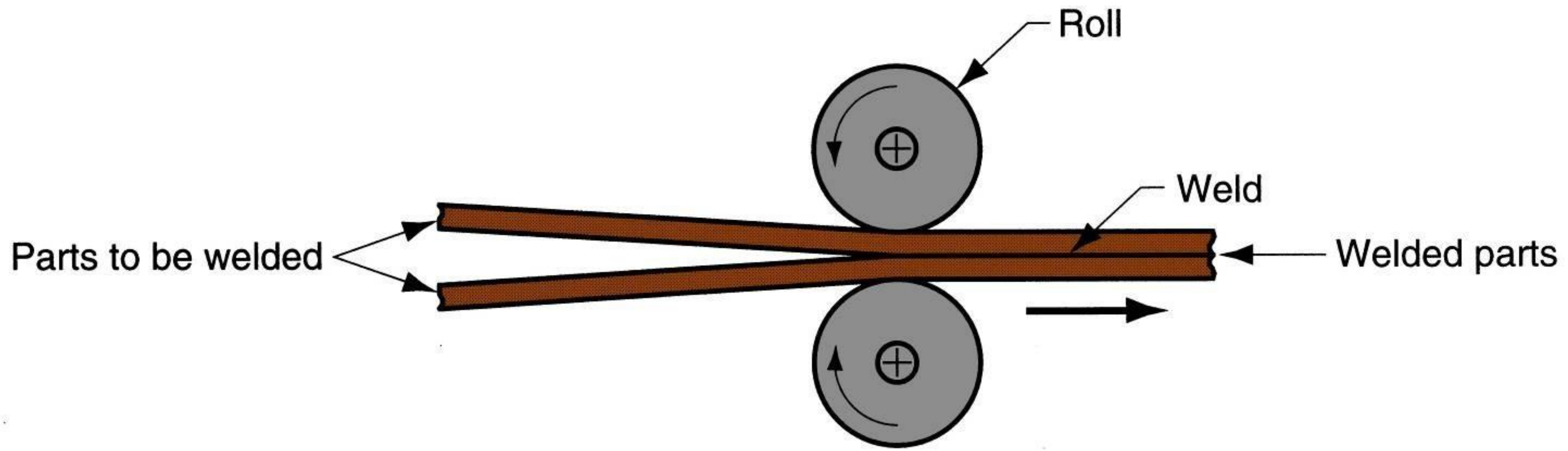


Figure Roll welding (ROW).

Roll Welding Applications

- Cladding stainless steel to mild or low alloy steel for corrosion resistance
- Bimetallic strips for measuring temperature
- "Sandwich" coins for U.S mint

Diffusion Welding (DFW)

SSW process uses heat and pressure, usually in a controlled atmosphere, with sufficient time for diffusion and coalescence to occur

- Temperatures $\leq 0.5\ T_m$
- Plastic deformation at surfaces is minimal
- Primary coalescence mechanism is solid state diffusion
- Limitation: time required for diffusion can range from seconds to hours

DFW Applications

- Joining of high-strength and refractory metals in aerospace and nuclear industries
- Can be used to join either similar and dissimilar metals
- For joining dissimilar metals, a filler layer of different metal is often sandwiched between base metals to promote diffusion

Explosion Welding (EXW)

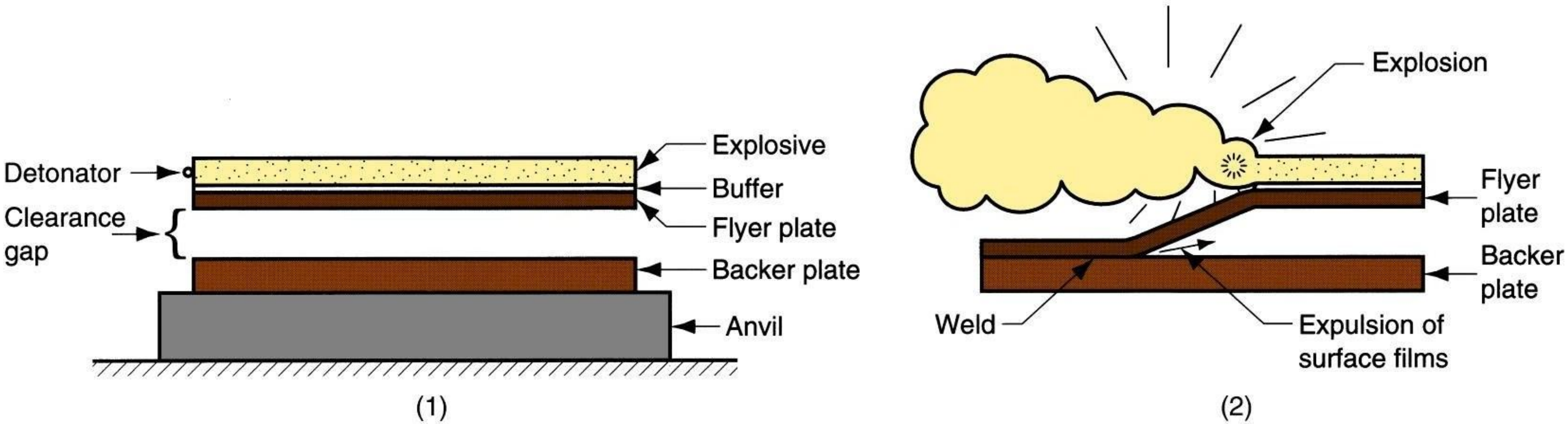
SSW process in which rapid coalescence of two metallic surfaces is caused by the energy of a detonated explosive

- No filler metal used
- No external heat applied
- No diffusion occurs - time is too short
- Bonding is metallurgical, combined with mechanical interlocking that results from a rippled or wavy interface between the metals

Explosive Welding

Commonly used to bond two dissimilar metals, in particular to clad one metal on top of a base metal over large areas

Figure 31.27 Explosive welding (EXW): (1) setup in the parallel configuration, and (2) during detonation of the explosive charge.



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

Friction Welding

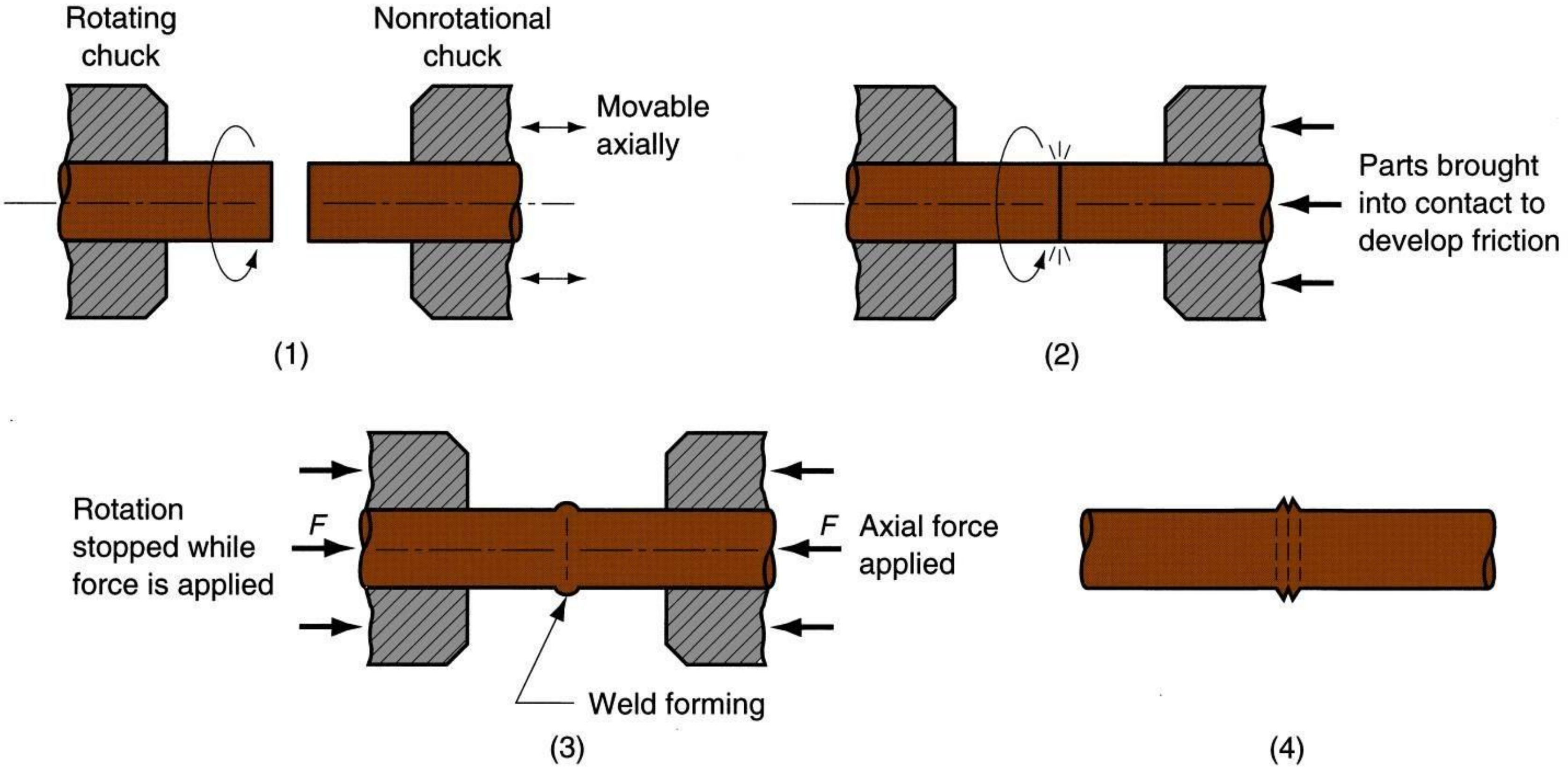


Figure Friction welding (FRW): (1) rotating part, no contact; (2) parts brought into contact to generate friction heat; (3) rotation stopped and axial pressure applied; and (4) weld created.

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)

Ultrasonic Welding (USW)

Two components are held together, oscillatory shear stresses of ultrasonic frequency are applied to interface to cause coalescence

- Oscillatory motion breaks down any surface films to allow intimate contact and strong metallurgical bonding between surfaces
- Although heating of surfaces occurs, temperatures are well below T_m
- No filler metals, fluxes, or shielding gases
- Generally limited to lap joints on soft materials such as aluminum and copper

Ultrasonic Welding

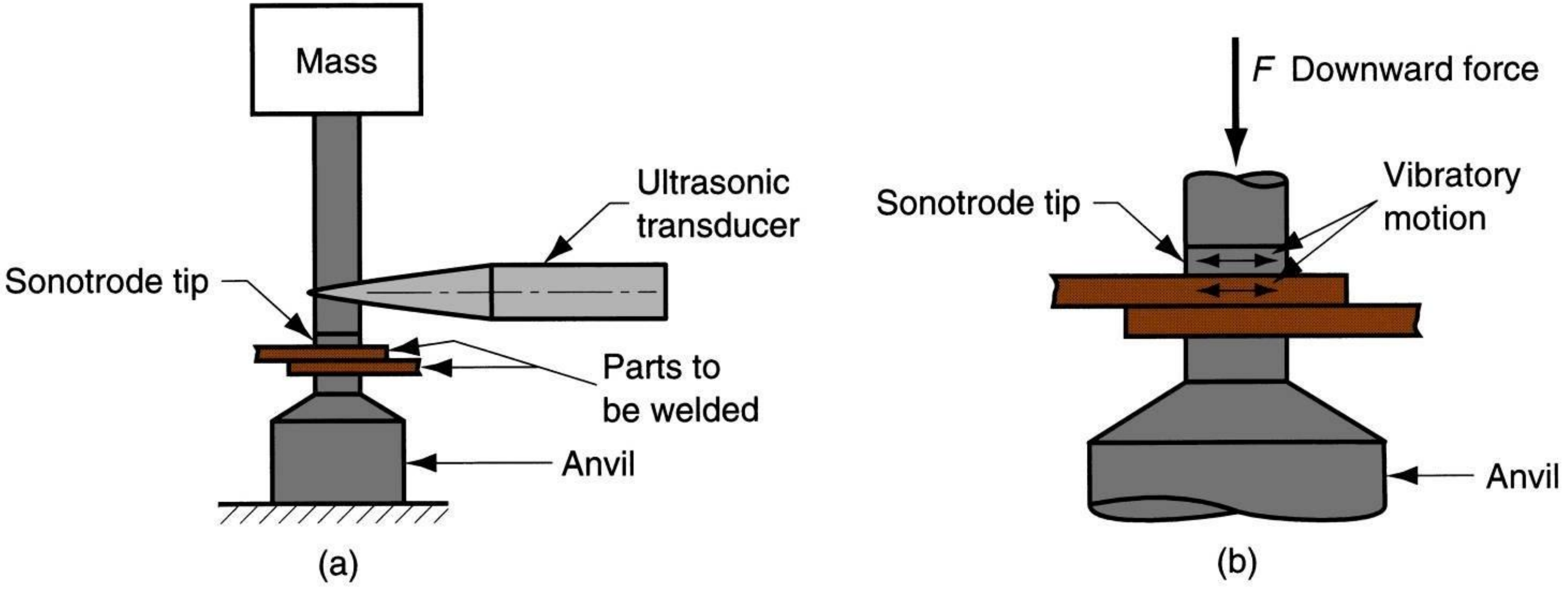


Figure Ultrasonic welding (USW): (a) general setup for a lap joint; and (b) close-up of weld area.

USW Applications

- Wire terminations and splicing in electrical and electronics industry
  - Eliminates need for soldering
- Assembly of aluminum sheet metal panels
- Welding of tubes to sheets in solar panels
- Assembly of small parts in automotive industry

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