GOVT. POLYTECHNIC,SECTOR-26 PANCHKULA

DEPARTMENT OF MECHANICAL ENGG.

Semester : 3rd

Subject : **Workshop Technology-I**

DETAILED CONTENTS

WELDING

FOUNDRY TECHNIQUES

METAL FORMING PROCESSES

PLASTIC PROCESSING

Unit I-Welding

1.1-WELDING PROCESSES

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

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

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

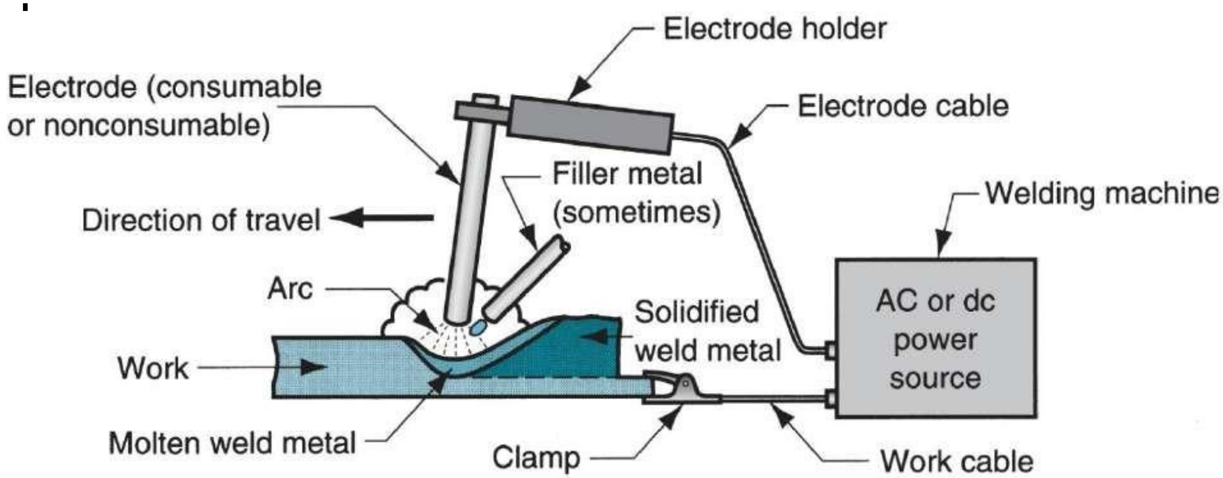
What is an Electric Arc?

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

Arc Welding

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



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%

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 if it is added

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 the arc and added to weld joint as filler metal

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

Arc Shielding

- At high temperatures in AW, metals are chemically reactive to oxygen, nitrogen, and hydrogen in air
  - Mechanical properties of joint can be 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

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

Various Flux Application Methods

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

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

Consumable Electrode AW Processes

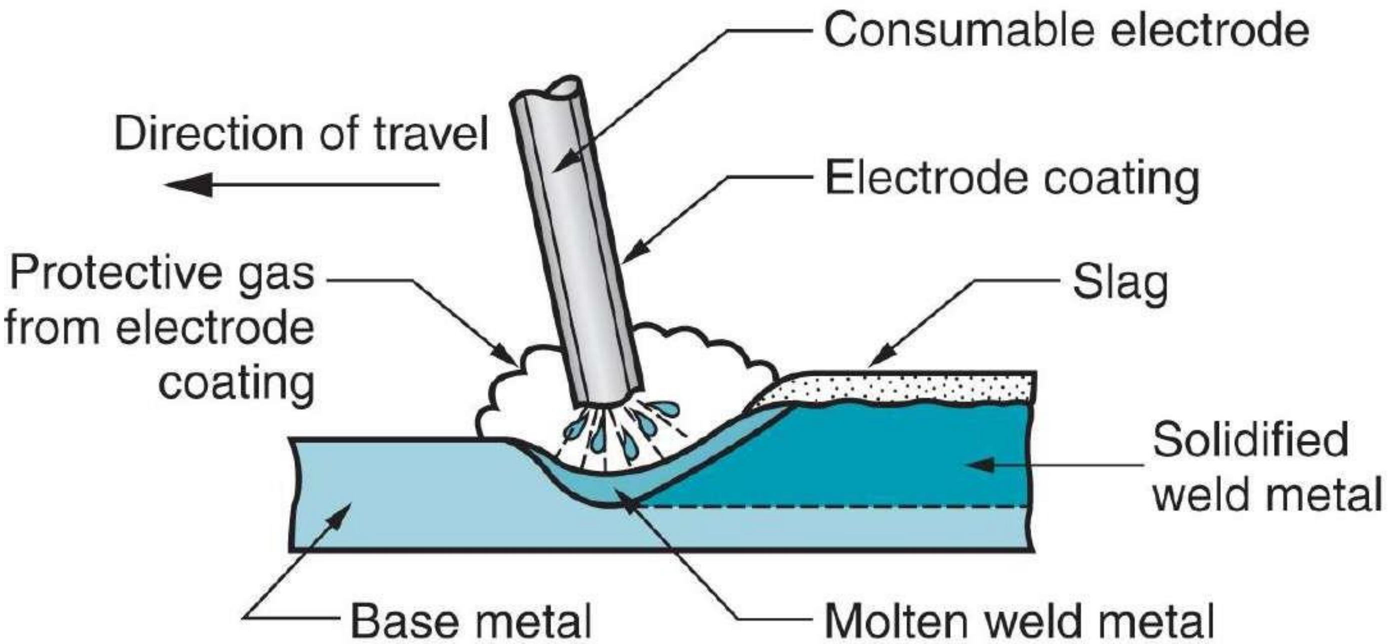
- Shielded Metal Arc Welding
- Gas Metal Arc Welding
- Flux-Cored Arc Welding
- Electrogas Welding
- Submerged Arc Welding

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

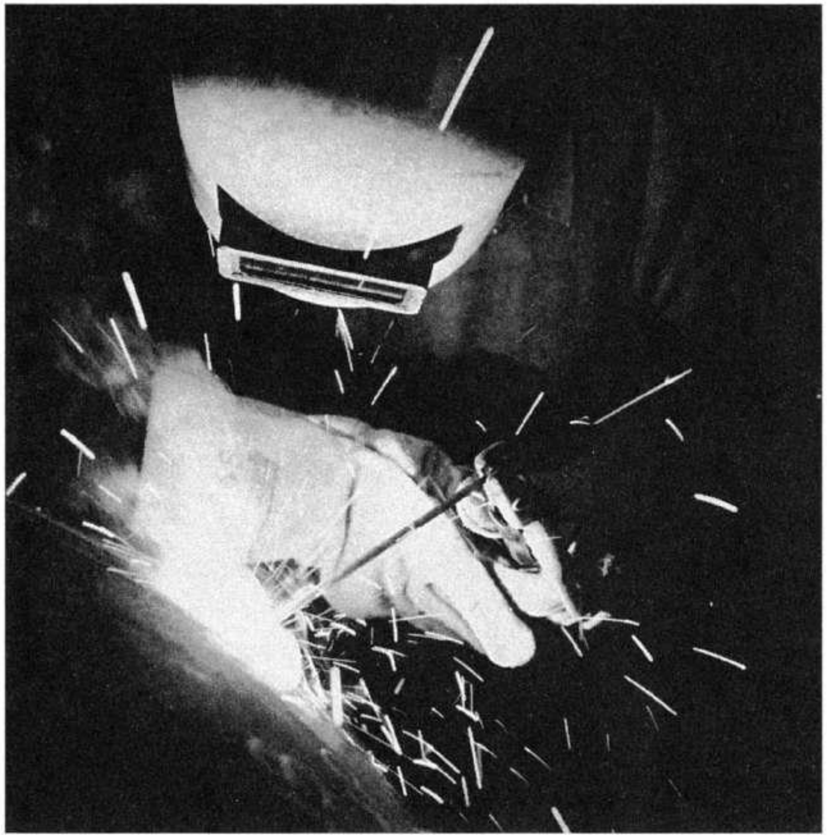
Shielded Metal Arc Welding (SMAW)



Welding Stick in SMAW

- Composition of filler metal usually close to base metal
- Coating: powdered cellulose mixed with oxides and carbonates, and 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

Shielded Metal Arc Welding



- Shielded metal arc welding (stick welding) performed by a human welder (photo courtesy of Hobart Brothers Co.)

SMAW Applications

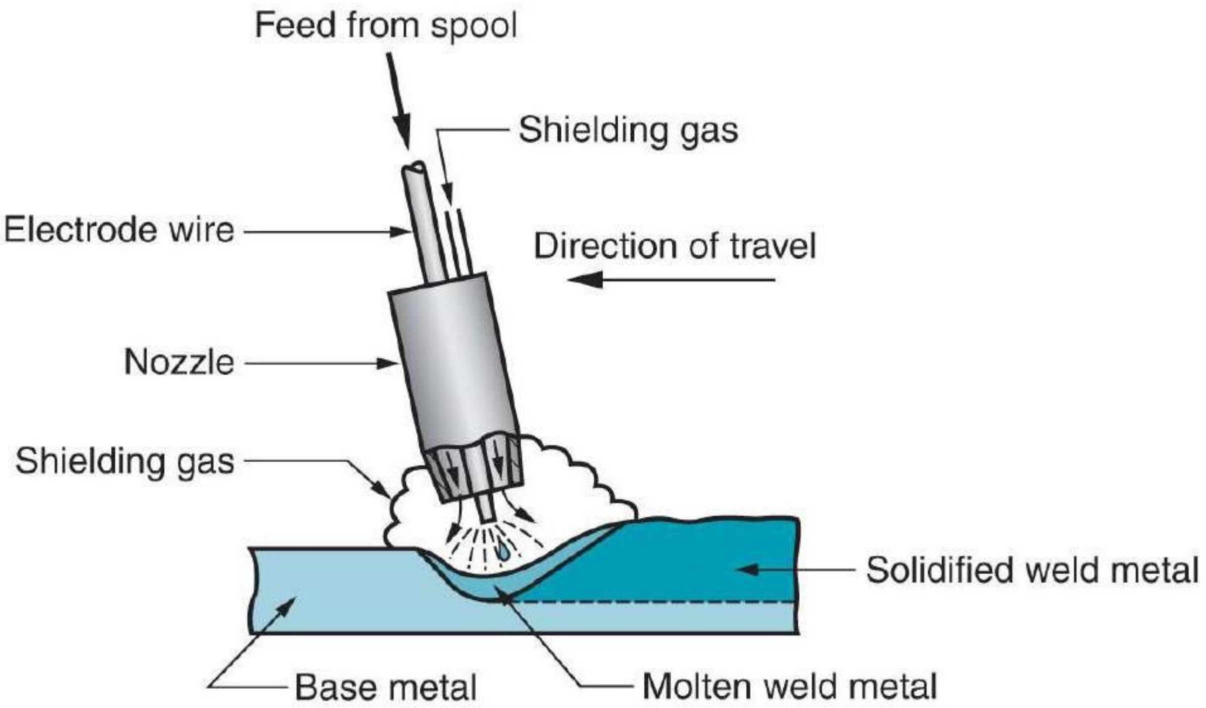
- Used for steels, stainless steels, cast irons, and certain nonferrous alloys
- Not used or rarely used for aluminum and its alloys, copper alloys, and titanium

Gas Metal Arc Welding (GMAW)

Uses a consumable bare metal wire as electrode with shielding by flooding arc with a gas

- Wire is fed continuously and automatically from a spool through the welding gun
- Shielding gases include argon and helium for aluminum welding, and 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

Gas Metal Arc Welding



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

Flux-Cored Arc Welding (FCAW)

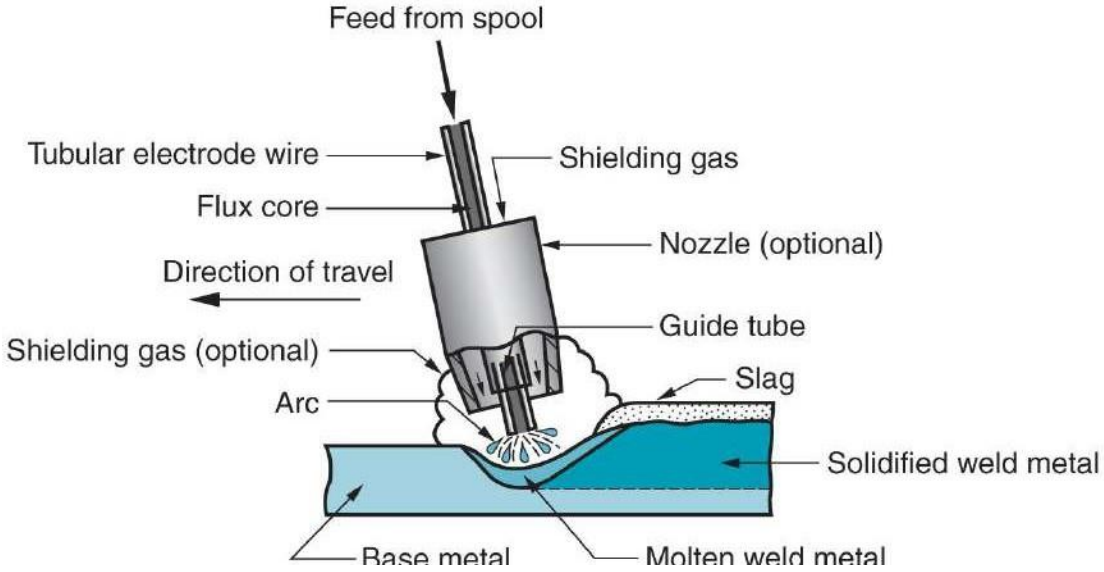
Adaptation of shielded metal arc welding, to overcome limitations of stick electrodes - two versions

- Self-shielded FCAW - core includes compounds that produce shielding gases
- Gas-shielded FCAW - uses externally applied shielding gases

- Electrode is a continuous consumable tubing (in coils) containing flux and other ingredients (e.g., alloying elements) in its core

Flux-Cored Arc Welding

Presence or absence of externally supplied shielding gas distinguishes: (1) self-shielded - core provides ingredients for shielding, (2) gas-shielded - uses external shielding gases



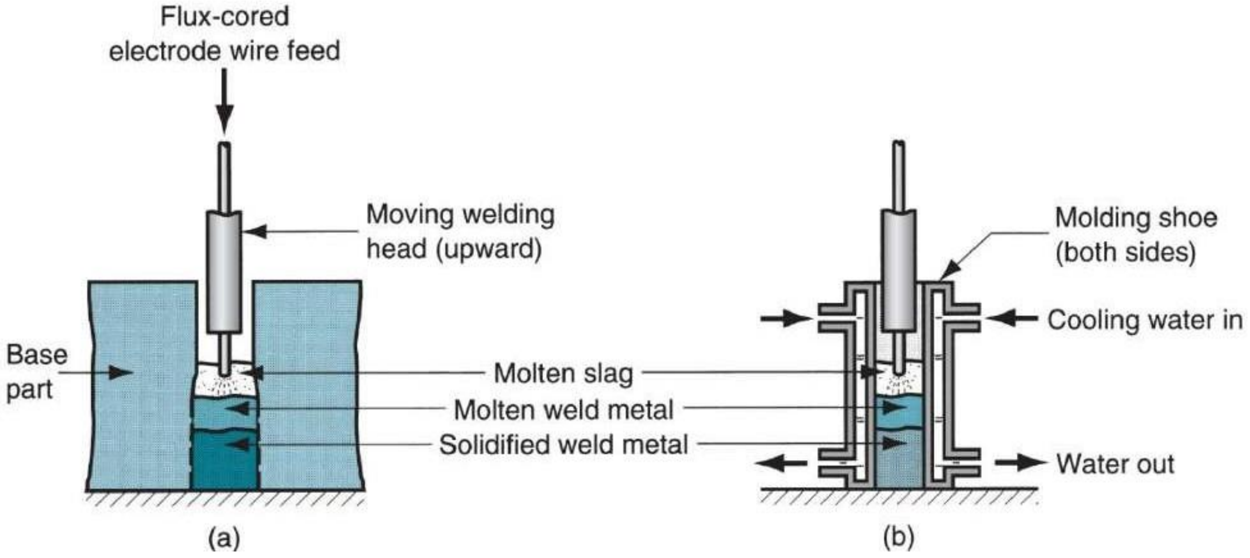
Electrogas Welding (EGW)

Uses a continuous consumable electrode, flux-cored wire or bare wire with externally supplied shielding gases, and molding shoes to contain molten metal

- When flux-cored electrode wire is used and no external gases are supplied, then special case of self-shielded FCAW
- When a bare electrode wire used with shielding gases from external source, then special case of GMAW

Electrogas Welding

- Electrogas welding using flux-cored electrode wire: (a) front view with molding shoe removed for clarity, and (b) side view showing molding shoes on both sides

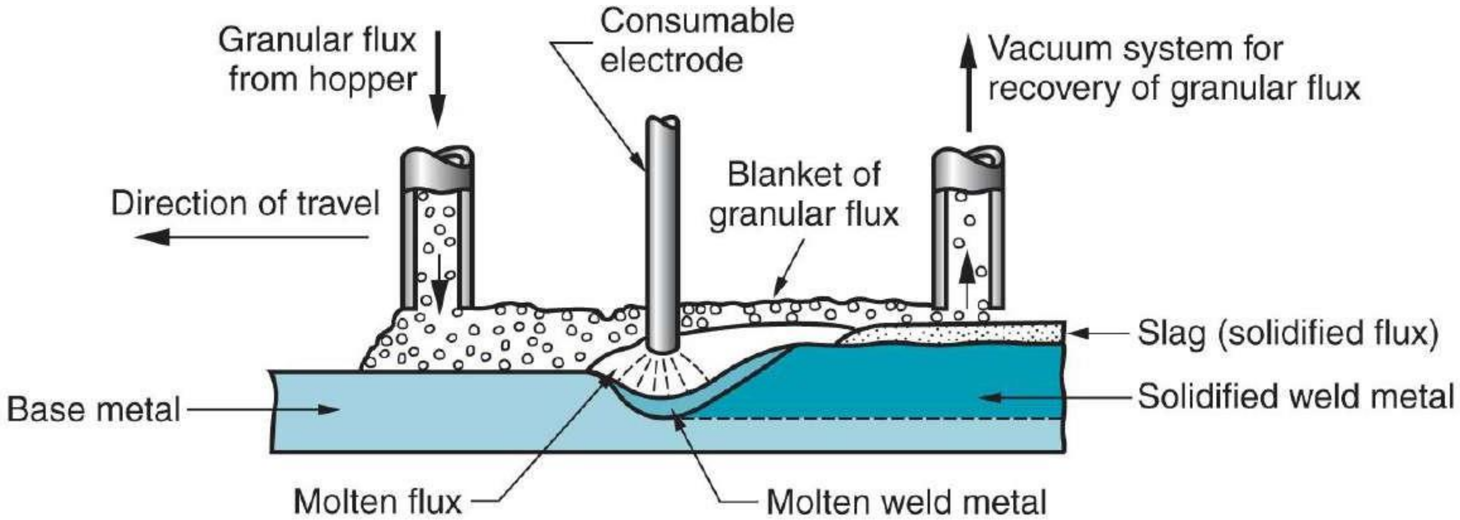


Submerged Arc Welding (SAW)

Uses a continuous, consumable bare wire electrode, with arc shielding 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

Submerged Arc Welding



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

Nonconsumable Electrode Processes

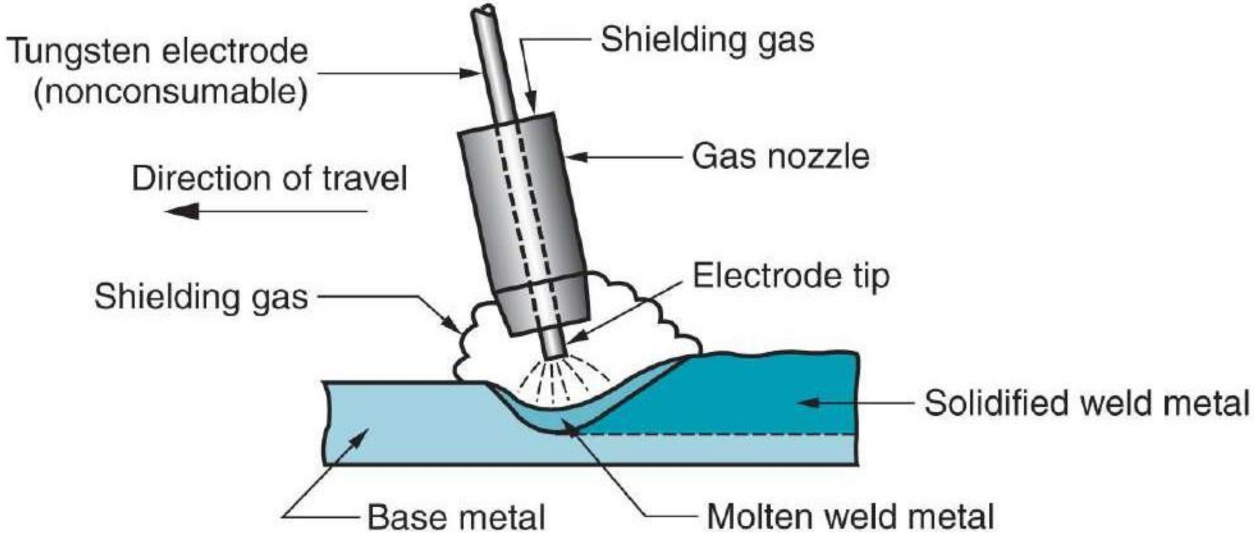
- Gas Tungsten Arc Welding
- Plasma Arc Welding
- Carbon Arc Welding
- Stud Welding

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 mostly

Gas Tungsten Arc Welding



Advantages and 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:

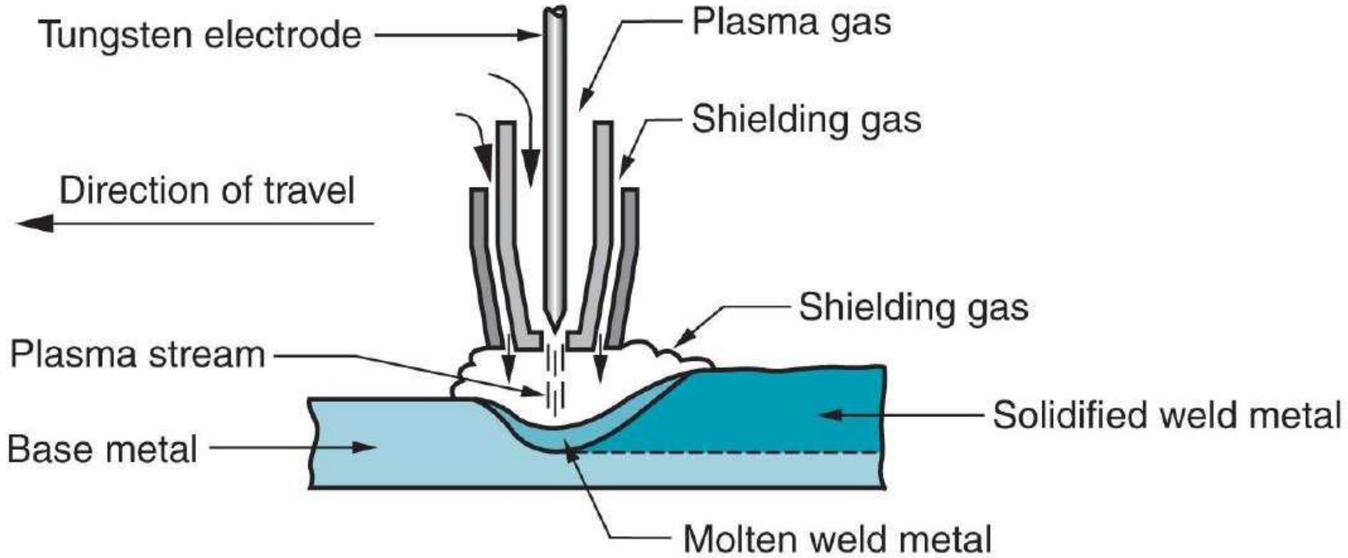
- Generally slower and more costly than consumable electrode AW processes

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

Plasma Arc Welding



Advantages and Disadvantages of PAW

Advantages:

- Good arc stability and excellent weld quality
- Better penetration control than other AW processes
- High travel speeds
- Can be used to weld almost any metals

Disadvantages:

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

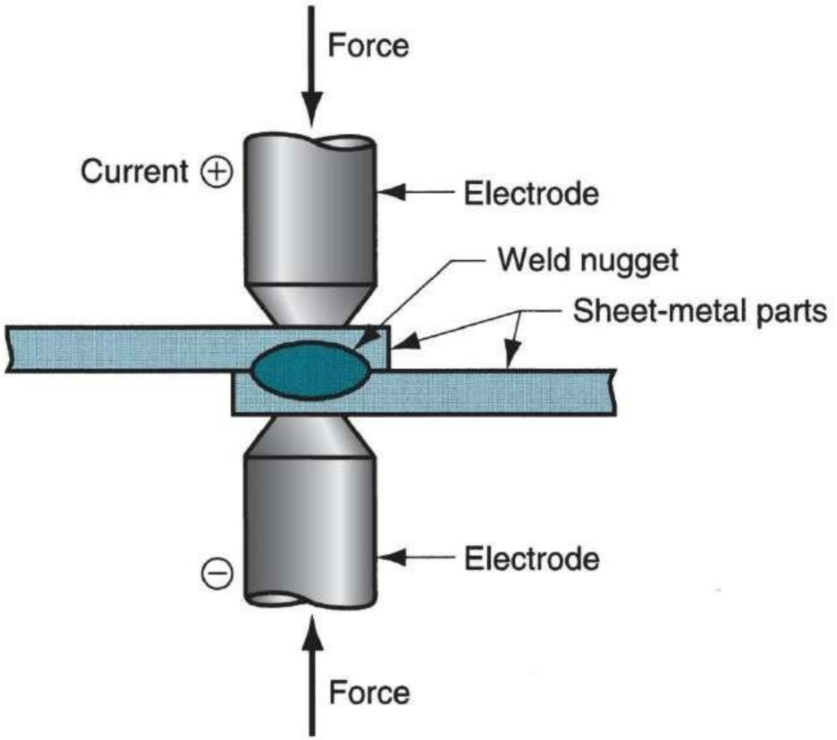
Resistance Welding (RW)

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)

Resistance Welding

- Resistance welding, showing 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 and Drawbacks of Resistance Welding

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

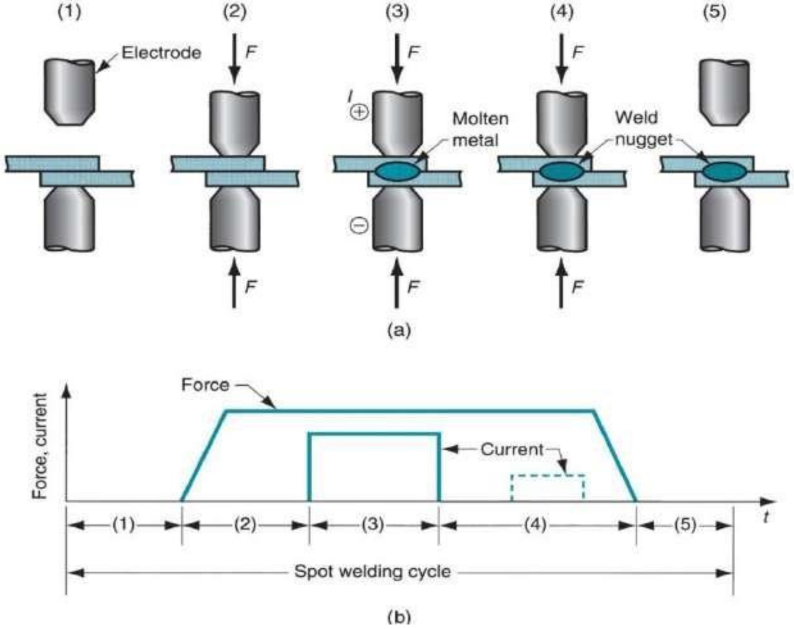
Resistance Spot Welding (RSW)

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
- Widely used in mass production of automobiles, metal furniture, appliances, and other sheet metal products
  - 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

- (a) Spot welding cycle
- (b) Plot of force and current
- Cycle: (1) parts inserted between electrodes, (2) electrodes close, (3) current on, (4) current off, (5) electrodes opened

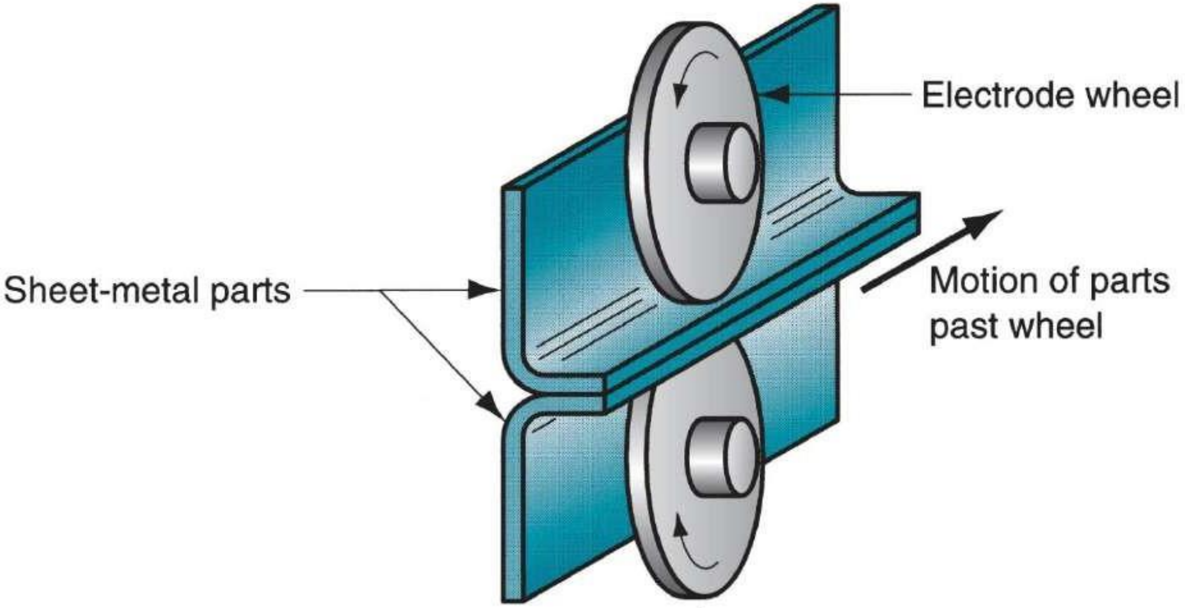


Resistance Seam Welding (RSEW)

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 sheet metal containers

Resistance Seam Welding



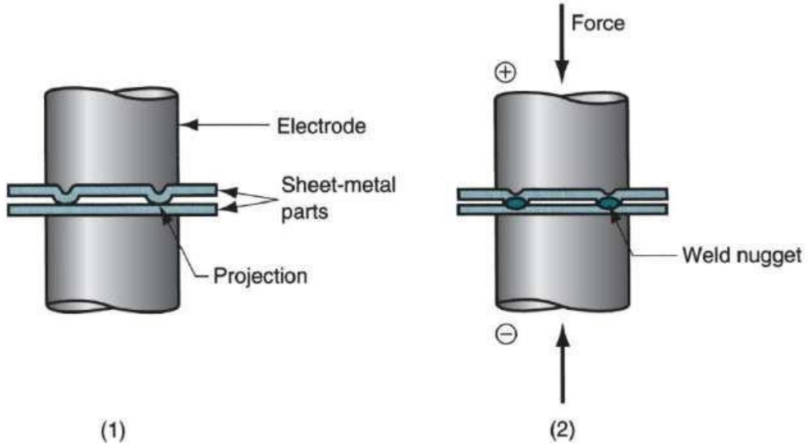
Resistance Projection Welding (RPW)

A resistance welding process in which coalescence occurs at one or more small contact points on the parts

- Contact points determined by design of parts to be joined
  - May consist of projections, embossments, or localized intersections of parts

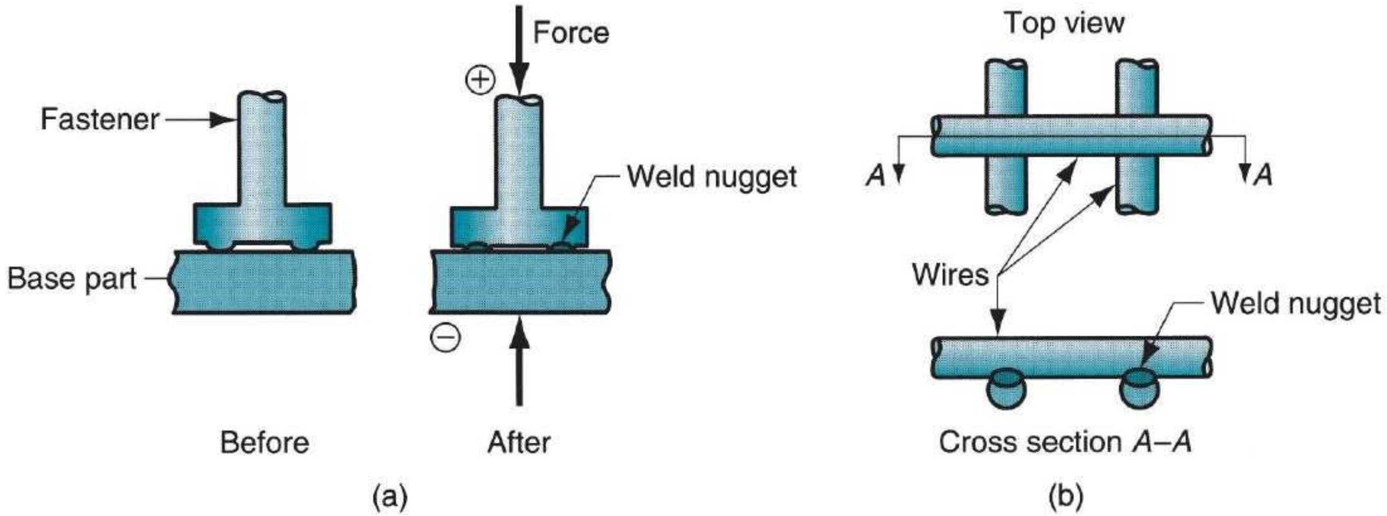
Resistance Projection Welding

- (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



Other Resistance Projection Welding Operations

- (a) Welding of fastener on Sheetmetal and (b) cross-wire welding



Oxyfuel Gas Welding (OFW)

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

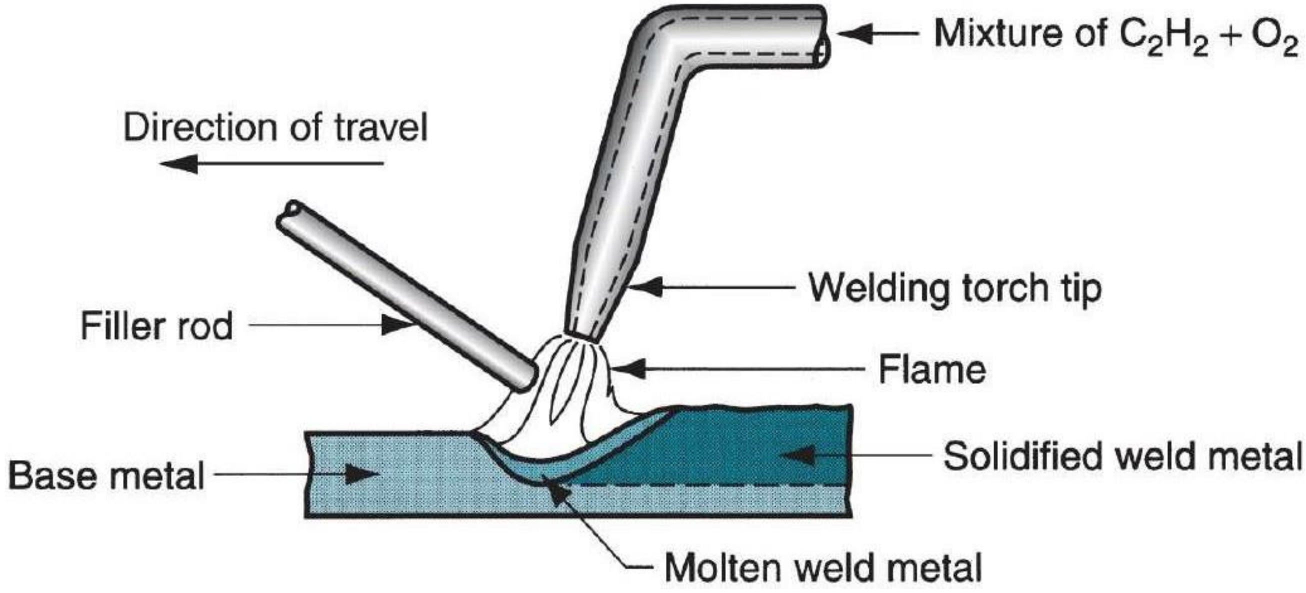
- OFW employs several types of gases, which is the primary distinction among the members of this group
- Oxyfuel gas is also used in flame cutting torches to cut and separate metal plates and other parts
- Most important OFW process is oxyacetylene welding

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



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 reaction of acetylene and oxygen:
  - First stage reaction (inner cone of flame)

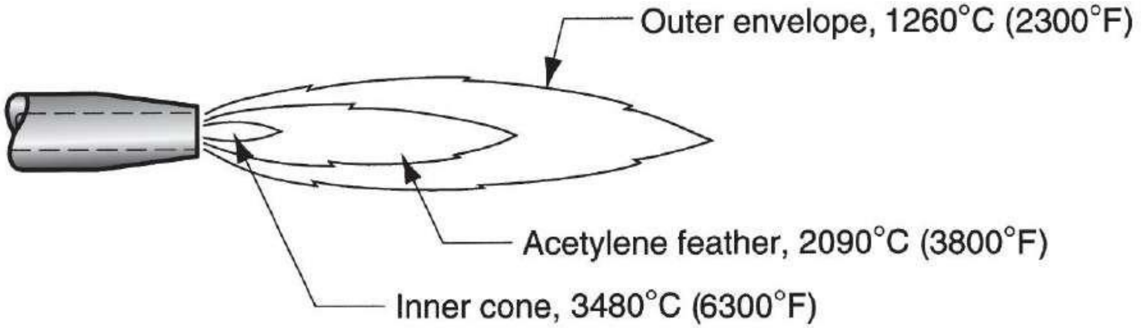
$$C_2H_2 + O_2 \rightarrow 2CO + H_2 + \text{heat}$$

  - 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 surface from atmosphere
- Shown below is neutral flame of oxyacetylene torch indicating temperatures achieved



Safety Issue in OAW

- Together, acetylene and oxygen are highly flammable
- C_2H_2 is colorless and odorless
  - It is therefore processed to have characteristic garlic odor

OAW Safety Issue

- C_2H_2 is physically unstable at pressures much above 15 lb./in^2 (about 1 atm)
  - Storage cylinders are packed with porous filler material saturated with acetone (CH_3COCH_3)
  - Acetone dissolves about 25 times its own volume of acetylene
- Different screw threads are standard on C_2H_2 and O_2 cylinders and hoses to avoid accidental connection of wrong gases

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 Vacuum Chamber

- When first developed, EBW had to be carried out in a vacuum chamber to minimize disruption of electron beam by air molecules
  - Serious inconvenience in production
    - Pumpdown time can take as long as an hour

Three Vacuum Levels in EBW

1. High-vacuum welding – welding in same vacuum chamber as beam generation to produce highest quality weld
2. Medium-vacuum welding – welding in separate chamber but partial vacuum reduces pump-down time
3. Non-vacuum welding – welding done at or near atmospheric pressure, with work positioned close to electron beam generator - requires vacuum divider to separate work from beam generator

EBW Advantages and Disadvantages of EBW

Advantages:

- High-quality welds, deep and narrow profiles
- Limited heat affected zone, low thermal distortion
- 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

- 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)

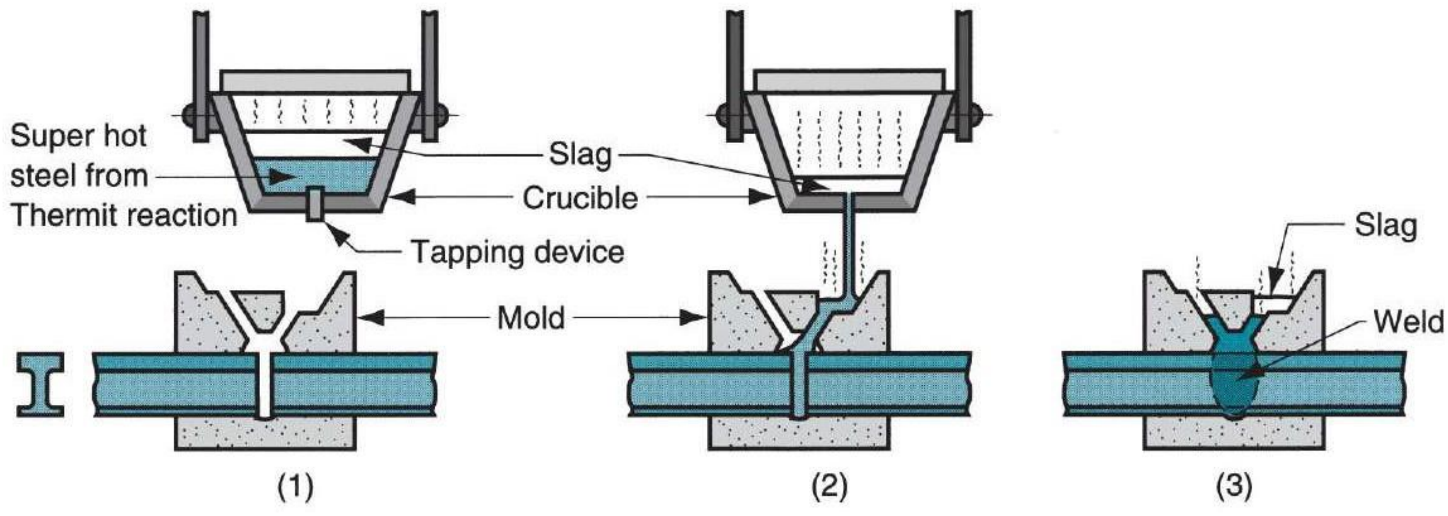
Thermit Welding (TW)

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

- (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

Cold Welding (CW)

SSW process done by applying high pressure between clean contacting surfaces at room temperature

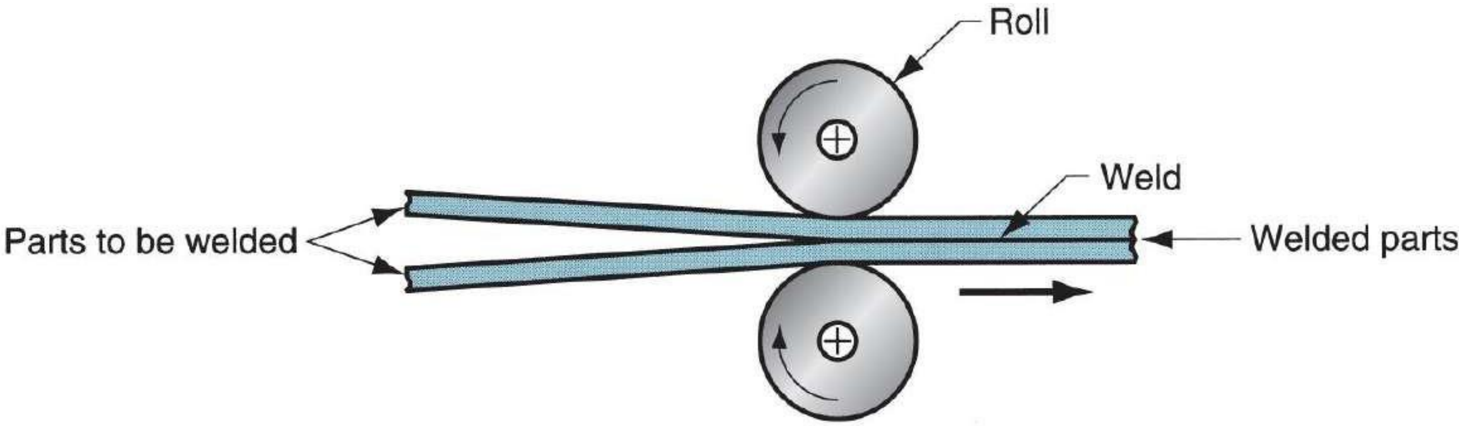
- Cleaning usually done by degreasing and wire brushing immediately before joining
- No heat is applied, but deformation raises work temperature
- At least one of the metals, preferably both, must be very ductile
    - Soft aluminum and copper suited to CW
- Applications: making electrical connections

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



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

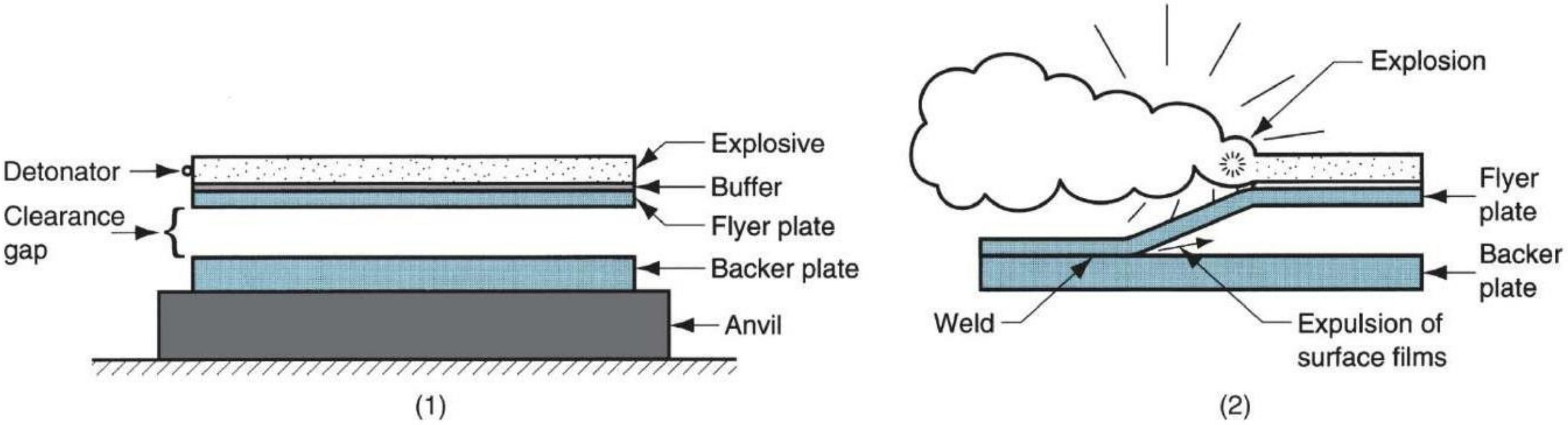
- No filler metal used
- No external heat applied
- No diffusion occurs - time is too short
- Bonding is metallurgical, combined with mechanical interlocking that results from a rippled or wavy interface between the metals

Explosive Welding

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

Explosive Welding

- Commonly used to bond two dissimilar metals, e.g., to clad one metal on top of a base metal over large areas
- (1) Setup in parallel configuration, and (2) during detonation of the explosive charge



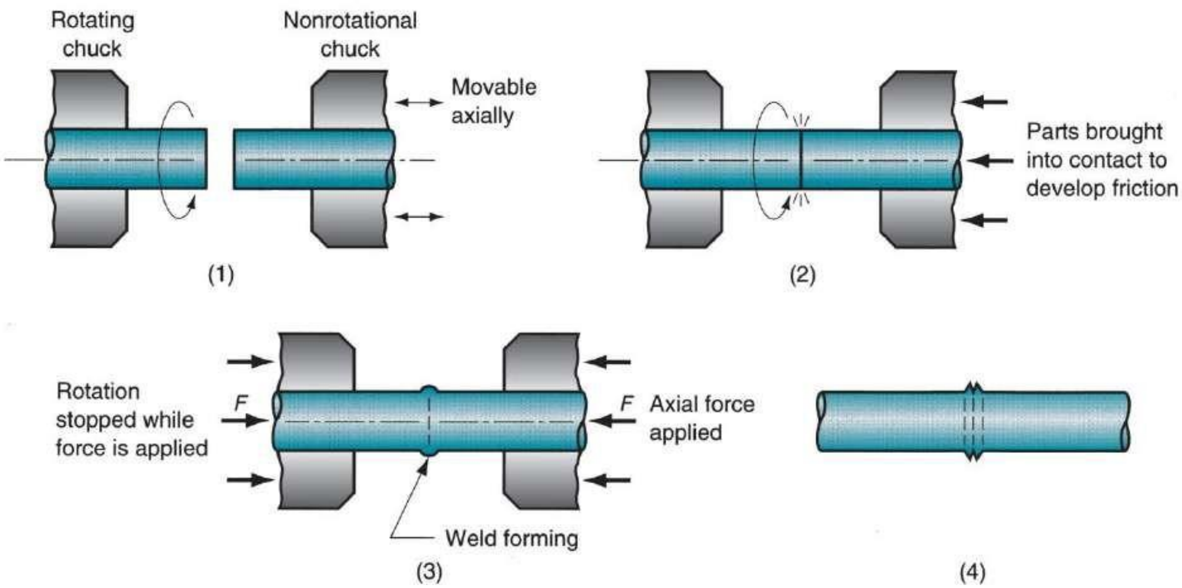
Friction Welding (FRW)

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

- (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 and Limitations of Friction Welding

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 (extra operation)
- Upsetting reduces the part lengths (which must be taken into consideration in product design)

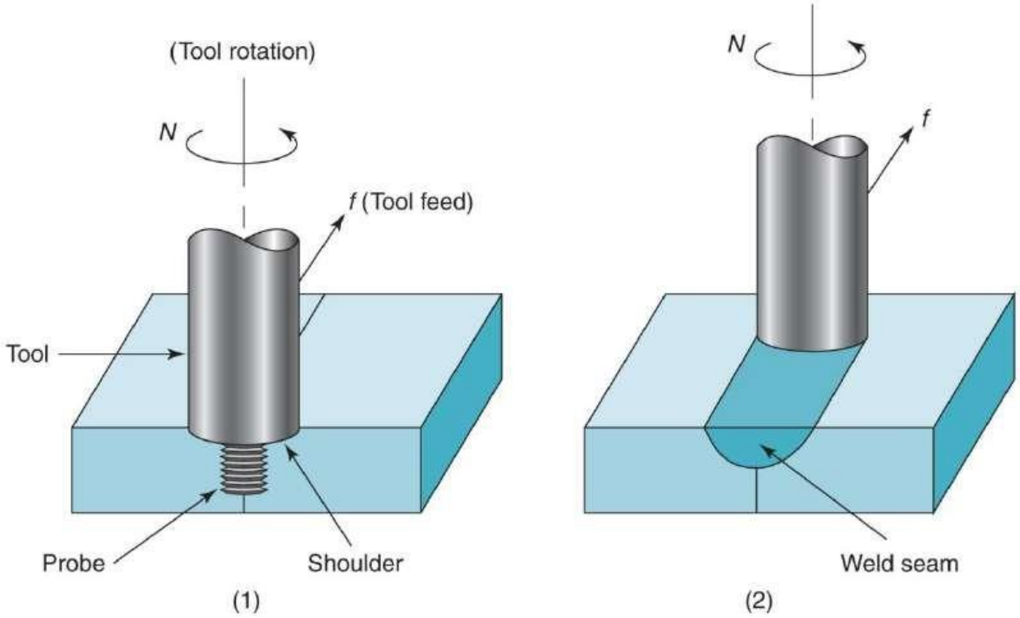
Friction Stir Welding (FSW)

SSW process in which a rotating tool is fed along a joint line between two workpieces, generating friction heat and mechanically stirring the metal to form the weld seam

- Distinguished from FRW because heat is generated by a separate wear-resistant tool rather than the parts
- Applications: butt joints in large aluminum parts in aerospace, automotive, and shipbuilding

Friction Stir Welding

- (1) Rotating tool just before entering work, and (2) partially completed weld seam



Advantages and Disadvantages of Friction Stir Welding

- Advantages
  - Good mechanical properties of weld joint
  - Avoids toxic fumes, warping, and shielding issues
  - Little distortion or shrinkage
  - Good weld appearance
- Disadvantages
  - An exit hole is produce when tool is withdrawn
  - Heavy duty clamping of parts is required

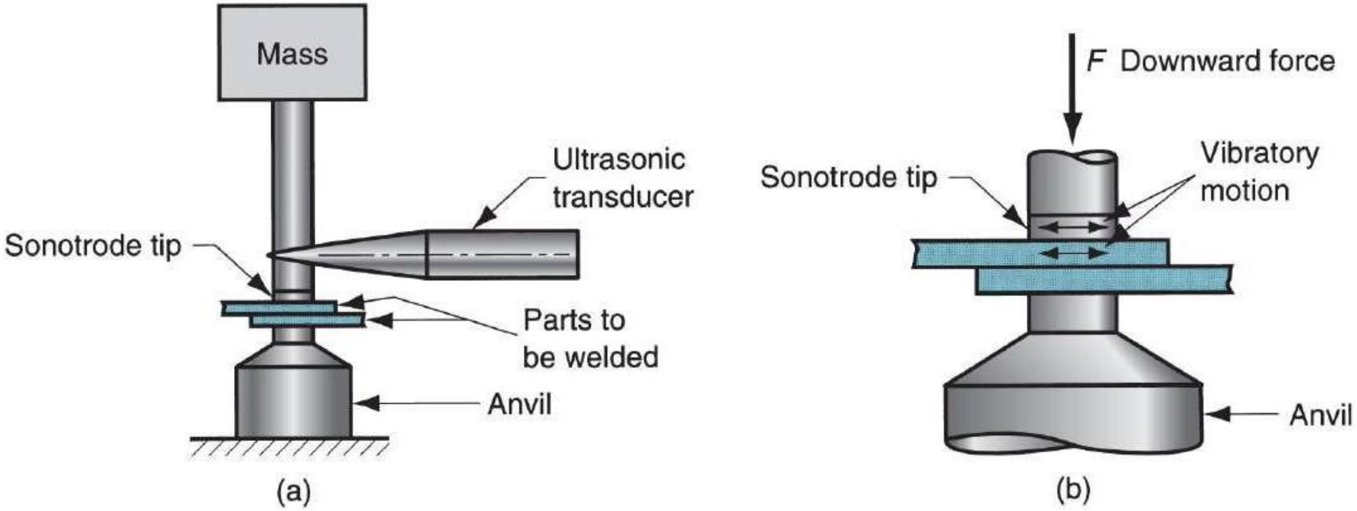
Ultrasonic Welding (USW)

Two components are held together, and 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
- Temperatures are well below T_m
- No filler metals, fluxes, or shielding gases
- Generally limited to lap joints on soft materials

Ultrasonic Welding

- (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

Weld Quality

Concerned with obtaining an acceptable weld joint that is strong and absent of defects

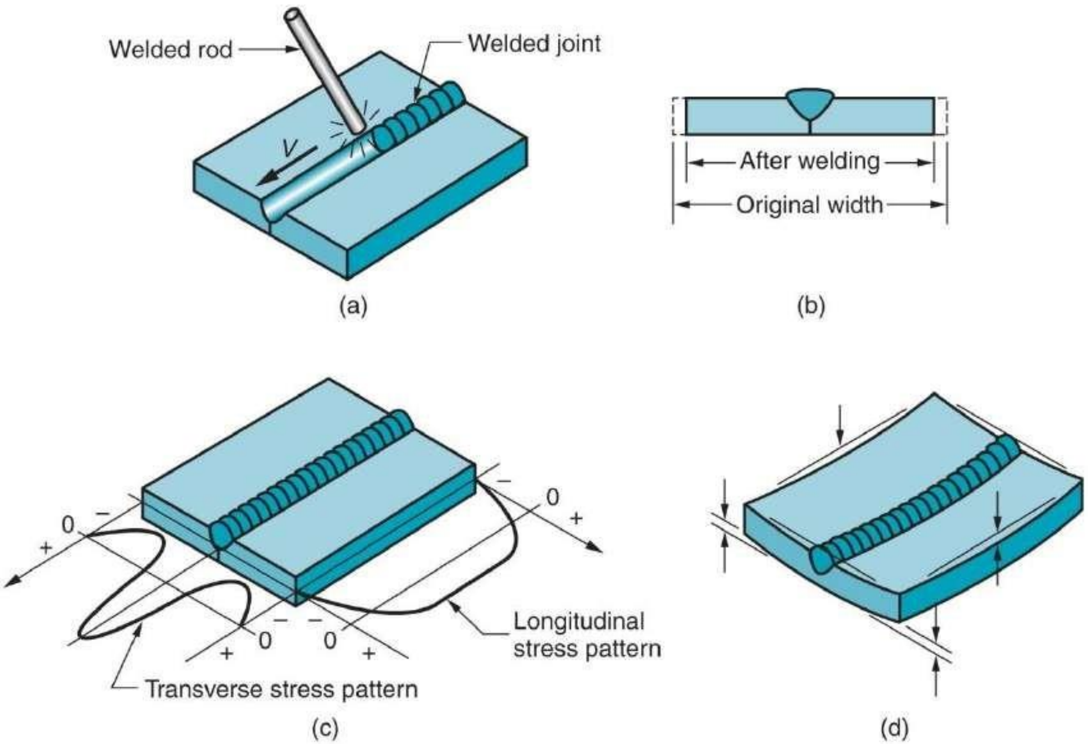
- Also concerned with the methods of inspecting and testing the joint to assure its quality
- Topics:
  - Residual stresses and distortion
  - Welding defects
  - Inspection and testing methods

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)

Residual Stresses and Distortion

- (a) Butt welding two plates
- (b) Shrinkage
- (c) Residual stress patterns
- (d) Likely warping of weldment



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

Welding Defects

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

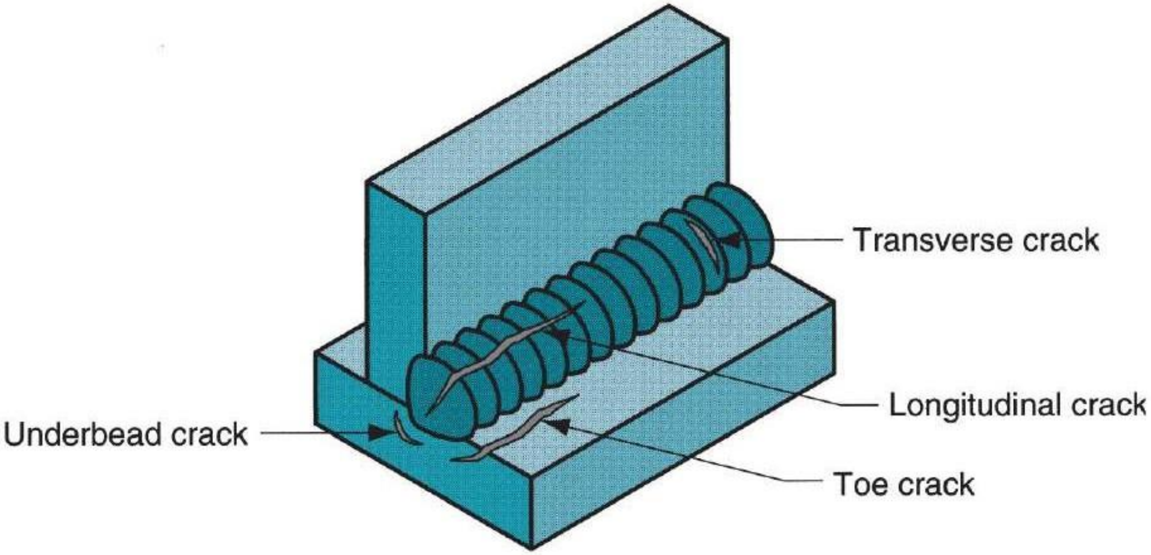
Welding Cracks

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

Welding Cracks

- Various forms of welding cracks



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

Solid Inclusions

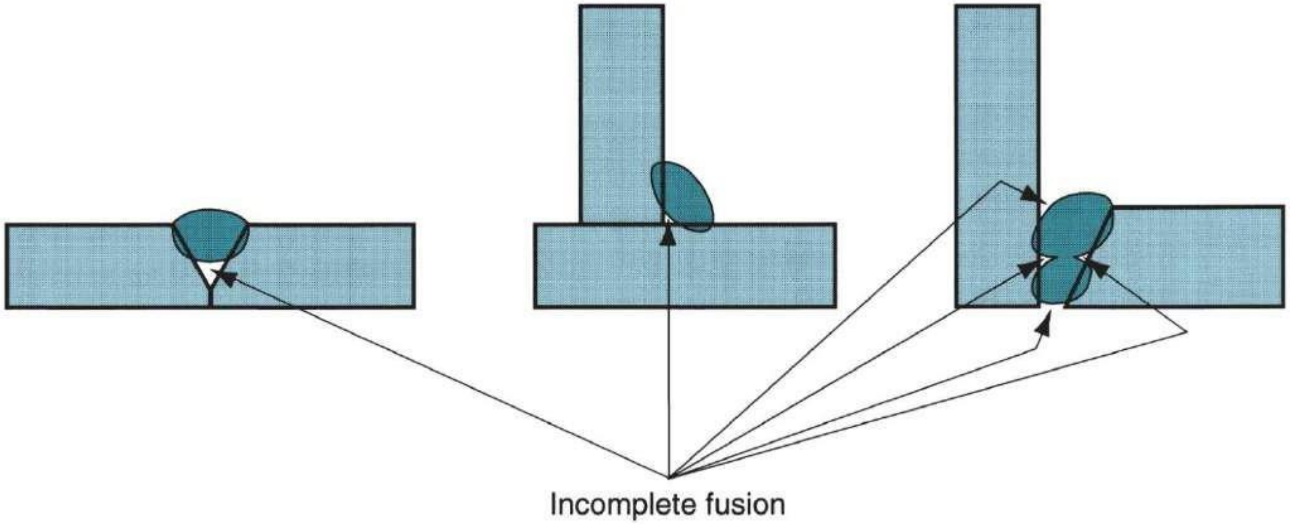
Nonmetallic material entrapped in weld metal

- 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
- Other forms: metallic oxides that form during welding of certain metals such as aluminum, which normally has a surface coating of Al_2O_3

Incomplete Fusion

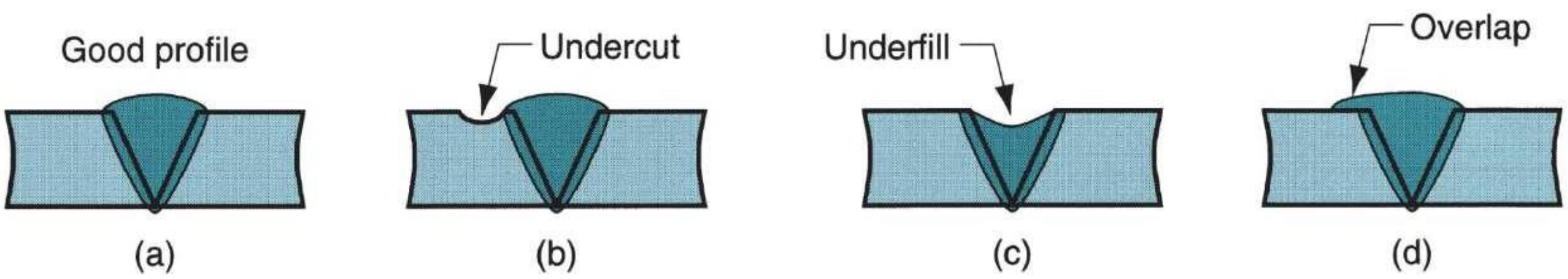
A weld bead in which fusion has not occurred throughout entire cross section of joint

- Several forms of incomplete fusion are shown below



Weld Profile in AW

- (a) Desired profile for single V-groove weld joint, (b) undercut - portion of base metal melted away, (c) underfill - depression in weld below adjacent base metal surface, and (d) overlap - weld metal spills beyond joint onto part surface but no fusion occurs



Inspection and Testing Methods

- Visual inspection
- Nondestructive evaluation
- Destructive testing

Visual Inspection

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

Nondestructive Evaluation (NDE) Tests

- Ultrasonic testing - high frequency sound waves through specimen to detect cracks and inclusions
- Radiographic testing - x-rays or gamma radiation provide photograph of internal flaws
- Dye-penetrant and fluorescent-penetrant tests - to detect small cracks and cavities at part surface
- Magnetic particle testing – iron filings sprinkled on surface reveal subsurface defects by distorting magnetic field in part

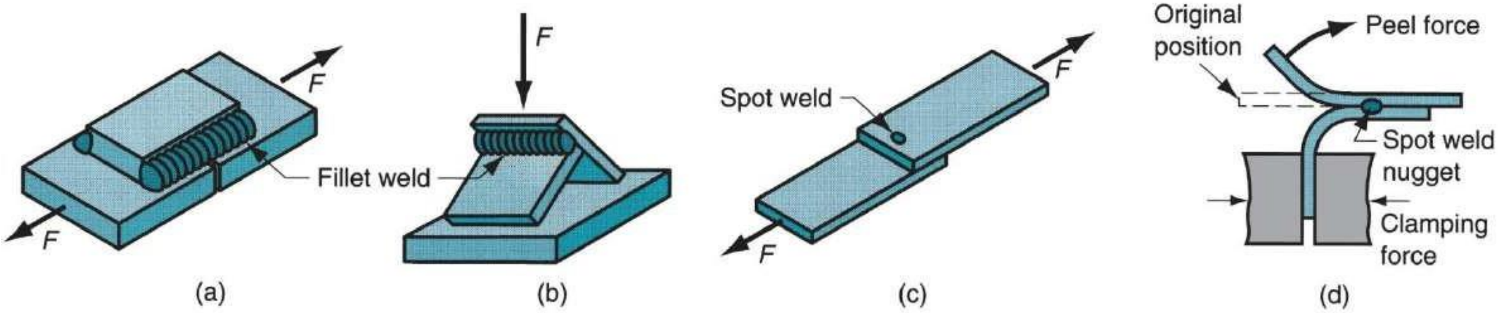
Destructive Testing

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

Mechanical Tests in Welding

- (a) Tension-shear test, (b) fillet break test, (c) tension-shear of spot weld, and (d) peel test for spot weld



Weldability

Capacity of a metal or combination of metals to be welded into a suitable 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 is accomplished
  - Absence of weld defects
  - Strength, ductility, and toughness in welded joint

Weldability Factors – Welding Process

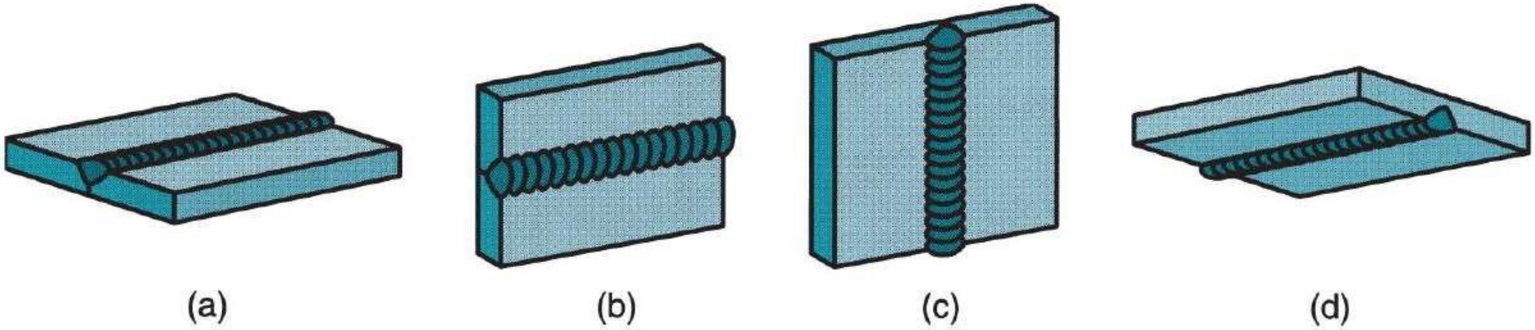
- Some metals or metal combinations can be readily welded by one process but are difficult to weld by others
  - Example: stainless steel readily welded by most AW and RW processes, but difficult to weld by OFW

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

Arc Welding Positions

- Welding positions defined here for groove welds: (a) flat, (b) horizontal, (c) vertical, and (d) overhead



Design Guidelines - RSW

- Low-carbon sheet steel up to 0.125 (3.2 mm) is ideal metal for RSW
- How additional strength and stiffness can be obtained in large flat sheet metal components
  - Spot welding reinforcing parts into them
  - Forming flanges and embossments
- Spot welded assembly must provide access for electrodes to reach welding area
- Sufficient overlap of sheet metal parts required for electrode tip to make proper contact

METAL CASTING PROCESSES

1. Sand Casting
2. Other Expendable Mold Casting Processes
3. Permanent Mold Casting Processes
4. Foundry Practice
5. Casting Quality
6. Metals for Casting
7. Product Design Considerations

Two Categories of Casting Processes

1. Expendable mold processes - mold is sacrificed to remove part
    - Advantage: more complex shapes possible
    - Disadvantage: production rates often limited by the time to make mold rather than casting itself
2. Permanent mold processes - mold is made of metal and can be used to make many castings
    - Advantage: higher production rates
    - Disadvantage: geometries limited by need to open mold

- Sand casting weighing over 680 kg (1500 lb) for an air compressor frame (photo courtesy of Elkhart Foundry).

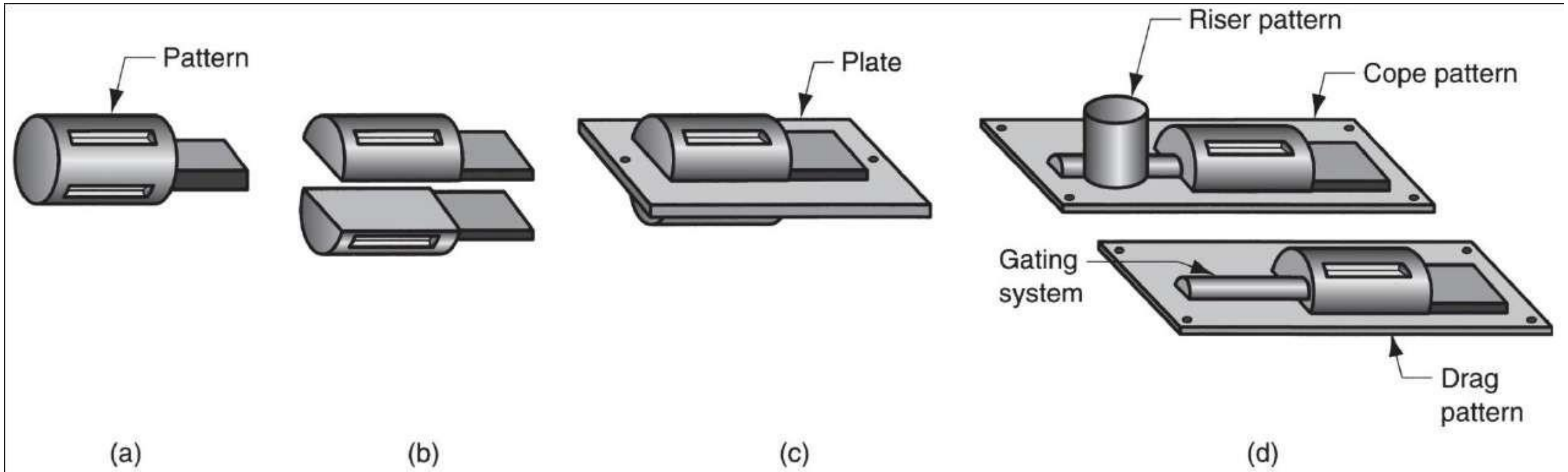
The Pattern

Full-sized model of part, slightly enlarged to account for shrinkage and machining allowances in the casting

- Pattern materials:
  - Wood - common material because it is easy to work, but it warps
  - Metal - more expensive to fabricate, but lasts longer
  - Plastic - compromise between wood and metal

Types of Patterns

- Types of patterns used in sand casting: (a) solid pattern, (b) split pattern, (c) match-plate pattern, (d) cope and drag pattern



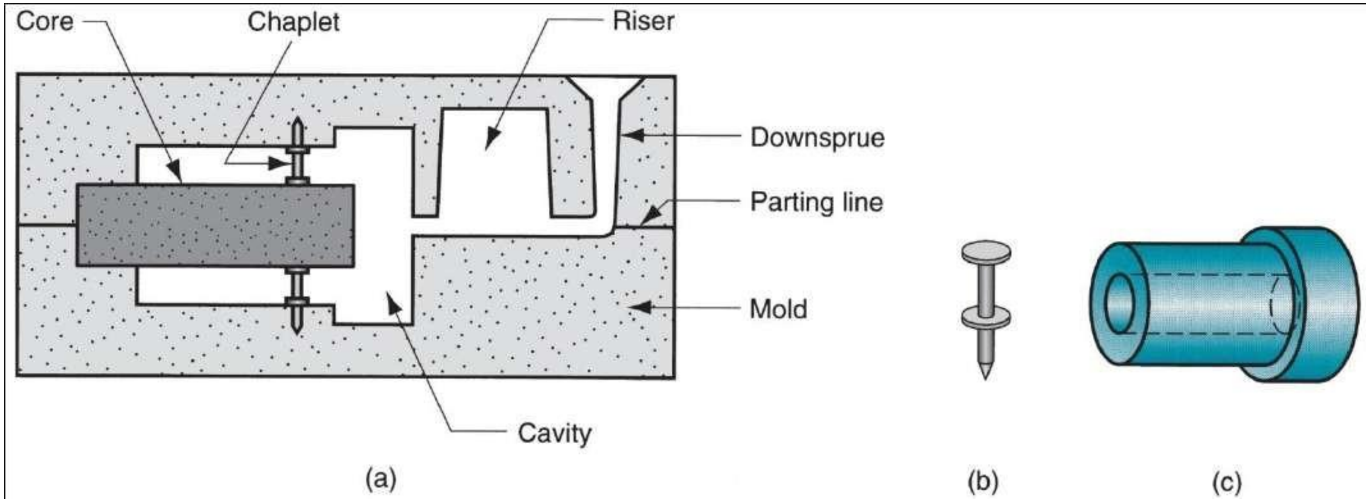
Core

Full-scale model of interior surfaces of part

- Inserted into mold cavity prior to pouring
- The molten metal flows and solidifies between the mold cavity and the core to form the casting's external and internal surfaces
- May require supports to hold it in position in the mold cavity during pouring, called *chaplets*

Core in Mold

- (a) Core held in place in the mold cavity by chaplets, (b) possible chaplet design, (c) casting



Foundry Sand

Silica (SiO_2) or silica mixed with other minerals

- Good refractory properties - for high temperatures
- Small grain size for better surface finish on cast part
- Large grain size is more permeable, allowing gases to escape during pouring
- Irregular grain shapes strengthen molds due to interlocking, compared to round grains
  - Disadvantage: interlocking reduces permeability

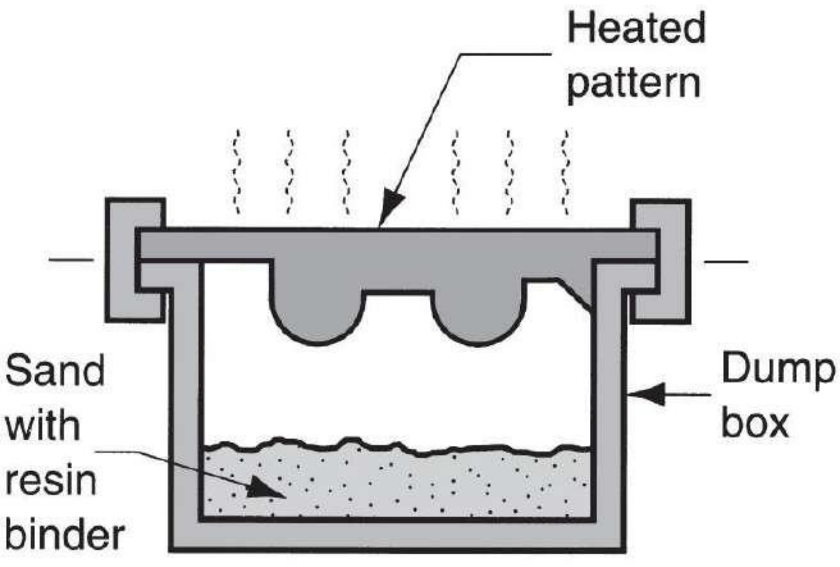
Other Expendable Mold Processes

- Shell Molding
- Vacuum Molding
- Expanded Polystyrene Process
- Investment Casting
- Plaster Mold and Ceramic Mold Casting

Shell Molding

Casting process in which the mold is a thin shell of sand held together by thermosetting resin binder

- Steps: (1) A metal pattern is heated and placed over a box containing sand mixed with thermosetting resin



(1)

Vacuum Molding

Uses sand mold held together by vacuum pressure rather than by a chemical binder

- The term "vacuum" refers to mold making rather than casting operation itself
- Developed in Japan around 1970

Investment Casting: Advantages and Disadvantages

- Advantages:
  - Parts of great complexity and intricacy can be cast
  - Close dimensional control and good surface finish
  - Wax can usually be recovered for reuse
  - This is a net shape process
    - Additional machining is not normally required
- Disadvantages:
  - Many processing steps are required
  - Relatively expensive process

Permanent Mold Casting Processes

- Economic disadvantage of expendable mold casting:
  - A new mold is required for every casting
- In permanent mold casting, the mold is reused many times
- The processes include:
  - Basic permanent mold casting
  - Die casting
  - Centrifugal casting

The Basic Permanent Mold Process

Uses a metal mold constructed of two sections designed for easy, precise opening and closing

- Molds used for casting lower melting point alloys are commonly made of steel or cast iron
- Molds used for casting steel must be made of refractory material, due to the very high pouring temperatures

Die Casting

A permanent mold casting process in which molten metal is injected into mold cavity under high pressure

- Pressure is maintained during solidification, then mold is opened and part is removed
- Molds in this casting operation are called *dies*; hence the name die casting
- Use of high pressure to force metal into die cavity is what distinguishes this from other permanent mold processes

Die Casting Machines

- Designed to hold and accurately close two mold halves and keep them closed while liquid metal is forced into cavity
- Two main types:
  1. Hot-chamber machine
  2. Cold-chamber machine

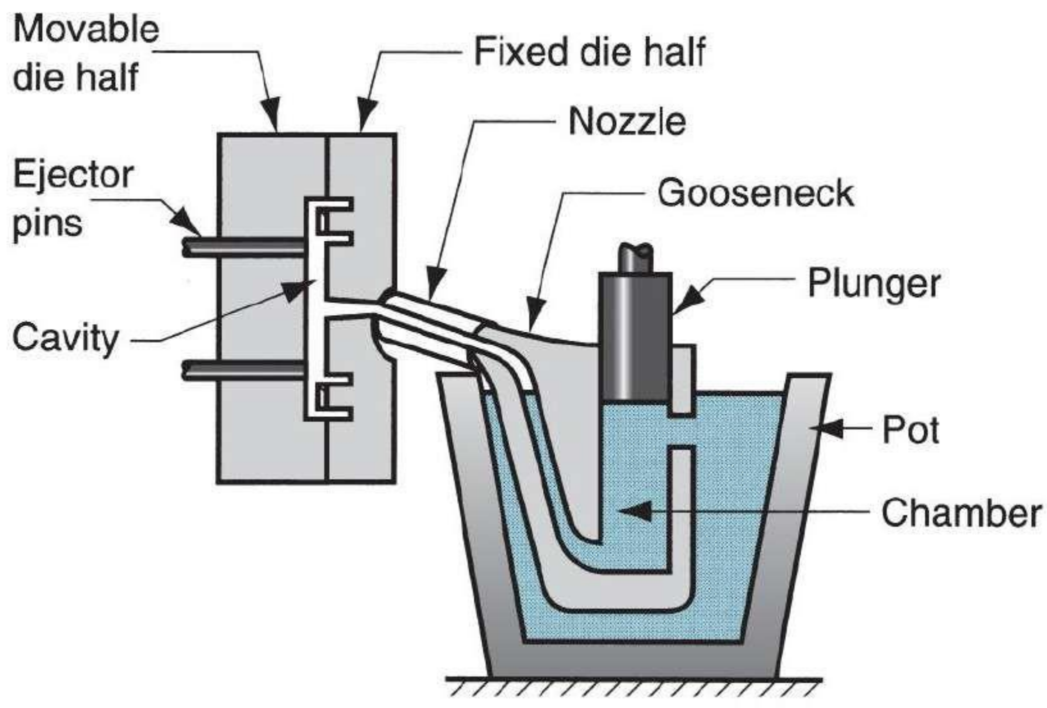
Hot-Chamber Die Casting

Metal is melted in a container, and a piston injects liquid metal under high pressure into the die

- High production rates
  - 500 parts per hour not uncommon
- Applications limited to low melting-point metals that do not chemically attack plunger and other mechanical components
- Casting metals: zinc, tin, lead, and magnesium

Hot-Chamber Die Casting

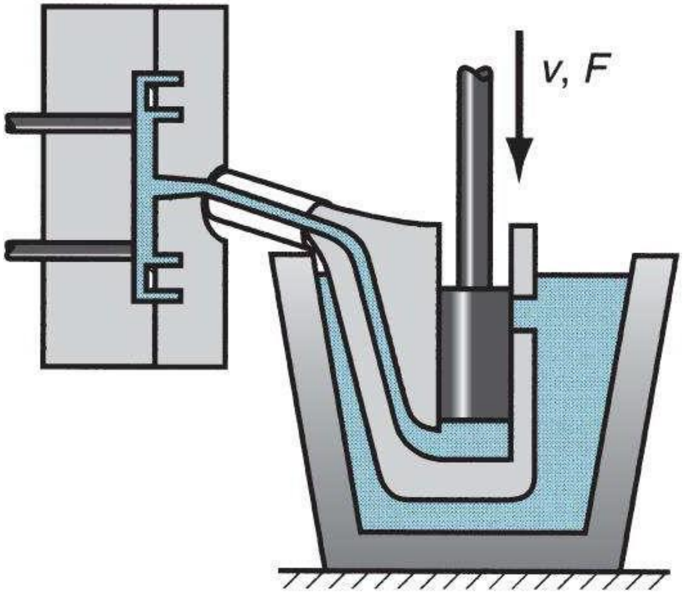
- Hot-chamber die casting cycle: (1) with die closed and plunger withdrawn, molten metal flows into the chamber



(1)

Hot-Chamber Die Casting

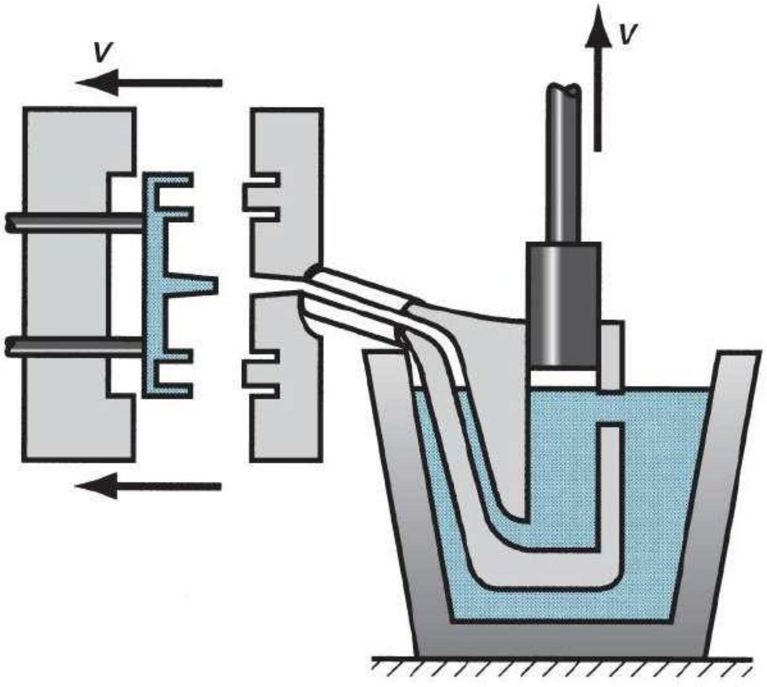
- (2) plunger forces metal in chamber to flow into die, maintaining pressure during cooling and solidification.



(2)

Hot-Chamber Die Casting

- (3) Plunger is withdrawn, die is opened, and casting is ejected



(3)

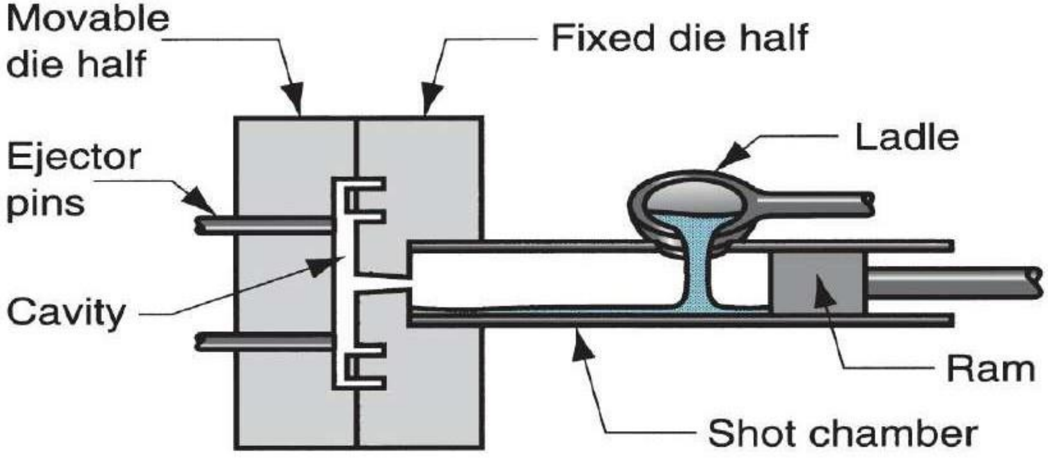
Cold-Chamber Die Casting Machine

Molten metal is poured into unheated chamber from external melting container, and a piston injects metal under high pressure into die cavity

- High production but not usually as fast as hot-chamber machines because of pouring step
- Casting metals: aluminum, brass, and magnesium alloys
- Advantages of hot-chamber process favor its use on low melting-point alloys (zinc, tin, lead)

Cold-Chamber Die Casting Cycle

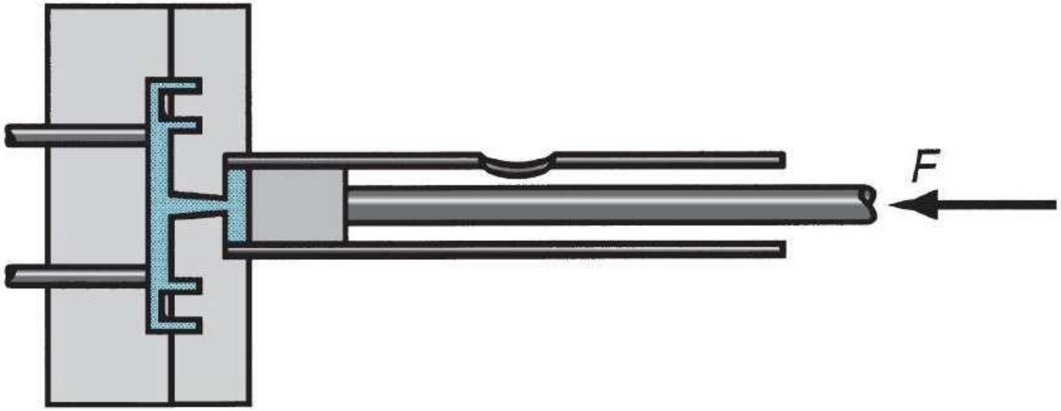
- (1) With die closed and ram withdrawn, molten metal is poured into the chamber



(1)

Cold-Chamber Die Casting Cycle

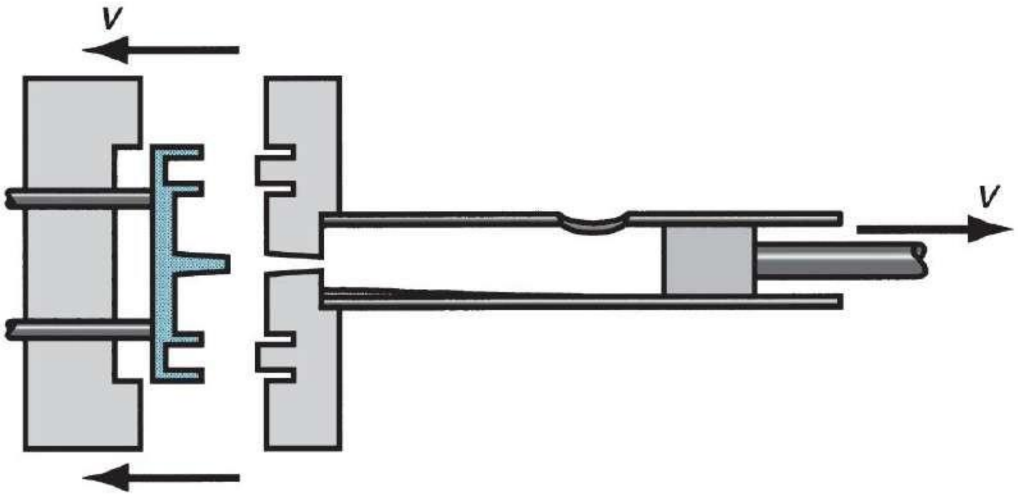
- (2) Ram forces metal to flow into die, maintaining pressure during cooling and solidification



(2)

Cold-Chamber Die Casting Cycle

- (3) Ram is withdrawn, die is opened, and part is ejected



(3)

Molds for Die Casting

- Usually made of tool steel, mold steel, or maraging steel
- Tungsten and molybdenum (good refractory qualities) used to die cast steel and cast iron
- Ejector pins required to remove part from die when it opens
- Lubricants must be sprayed onto cavity surfaces to prevent sticking

Die Casting:
Advantages and Limitations

- Advantages:
  - Economical for large production quantities
  - Good accuracy and surface finish
  - Thin sections possible
  - Rapid cooling means small grain size and good strength in casting
- Disadvantages:
  - Generally limited to metals with low metal points
  - Part geometry must allow removal from die

Squeeze Casting

Combination of casting and forging in which a molten metal is poured into a preheated lower die, and the upper die is closed to create the mold cavity after solidification begins

- Differs from usual closed-mold casting processes in which die halves are closed before introduction of the molten metal
- Compared to conventional forging, pressures are less and finer surface details can be achieved

Semi-Solid Metal Casting

Family of net-shape and near net-shape processes performed on metal alloys at temperatures between liquidus and solidus

- Thus, the alloy is a mixture of solid and molten metals during casting (mushy state)
  - To flow properly, the mixture must consist of solid metal globules in a liquid
    - Achieved by stirring the mixture to prevent dendrite formation

Semi-Solid Metal Casting: Advantages

- Complex part geometries
- Thin part walls possible
- Close tolerances
- Zero or low porosity, resulting in high strength of the casting

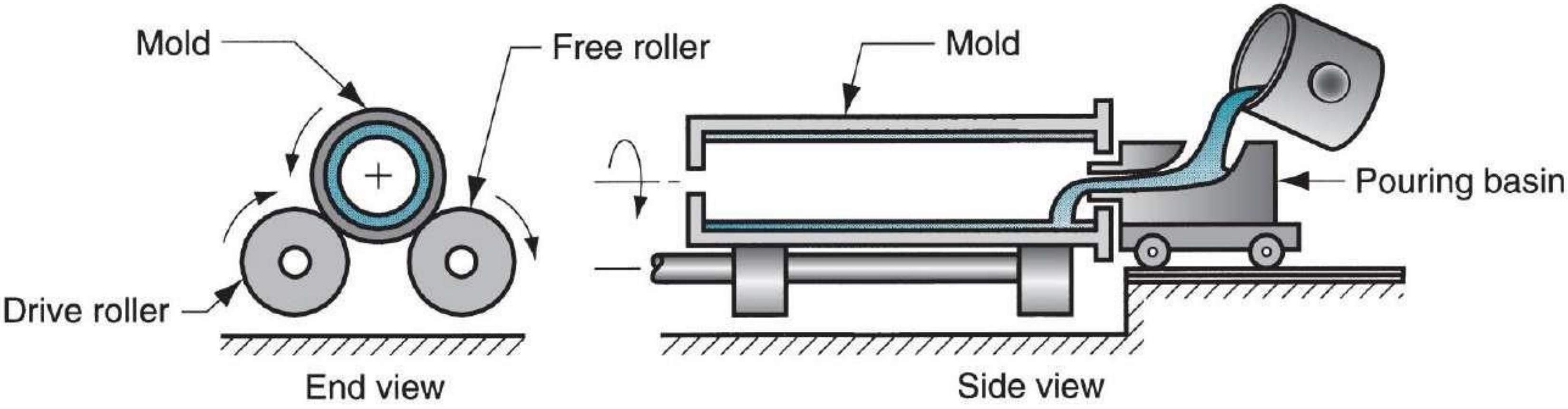
Centrifugal Casting

A family of casting processes in which the mold is rotated at high speed so centrifugal force distributes molten metal to outer regions of die cavity

- The group includes:
  - True centrifugal casting
  - Semicentrifugal casting
  - Centrifuge casting

True Centrifugal Casting

- Setup for true centrifugal casting

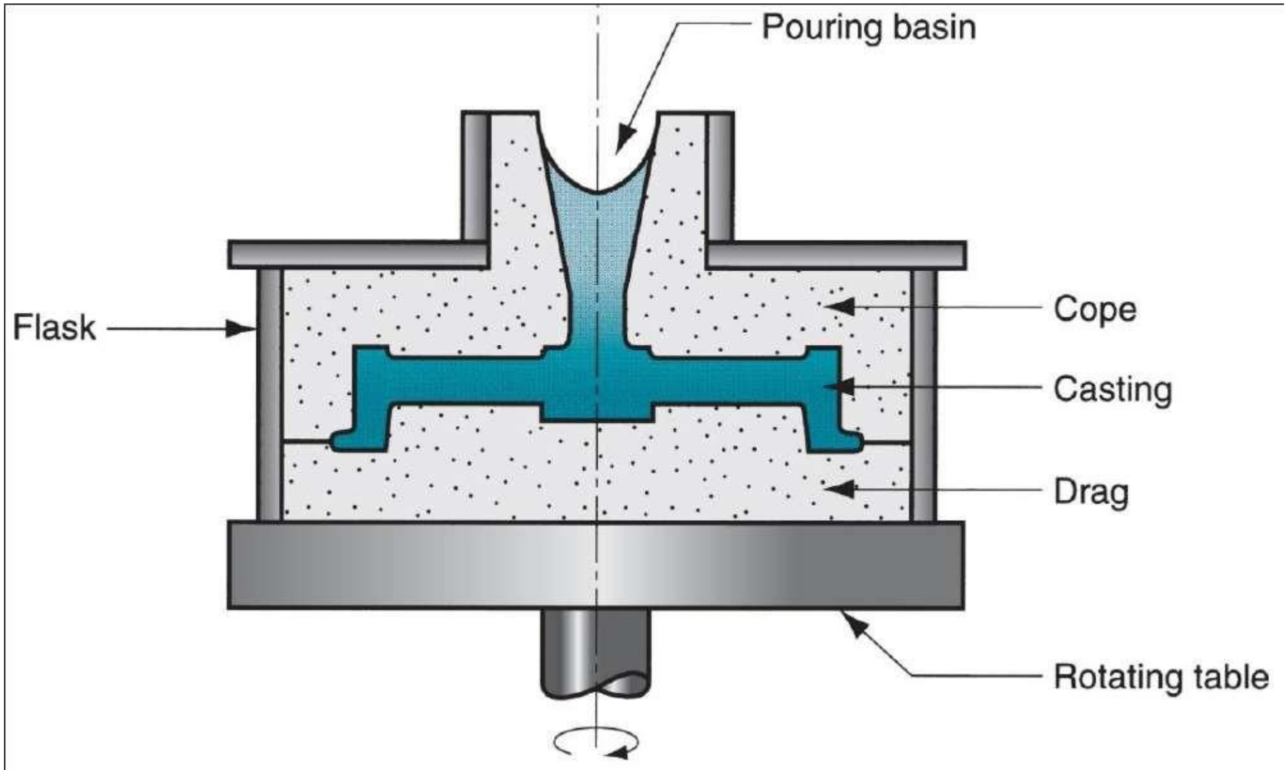


Semicentrifugal Casting

Centrifugal force is used to produce solid castings rather than tubular parts

- Molds use risers at center to supply feed metal
- Density of metal in final casting is greater in outer sections than at center of rotation
- Often used on parts in which center of casting is machined away, thus eliminating the portion where quality is lowest
  - Examples: wheels and pulleys

Semicentrifugal Casting

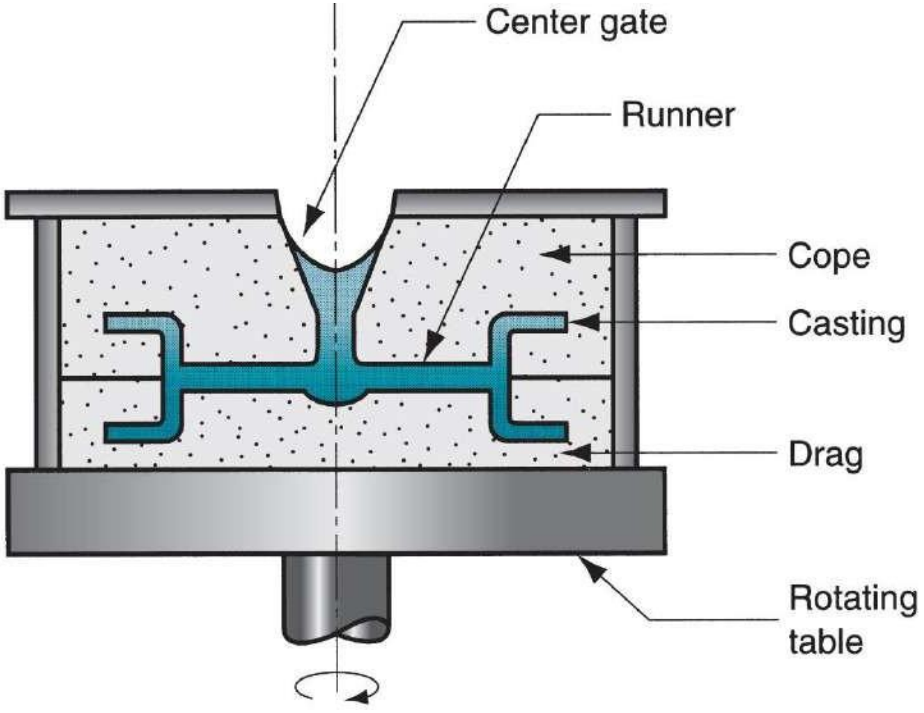


Centrifuge Casting

Mold is designed with part cavities located away from axis of rotation, so molten metal poured into mold is distributed to these cavities by centrifugal force

- Used for smaller parts
- Radial symmetry of part is not required as in other centrifugal casting methods

Centrifuge Casting



Furnaces for Casting Processes

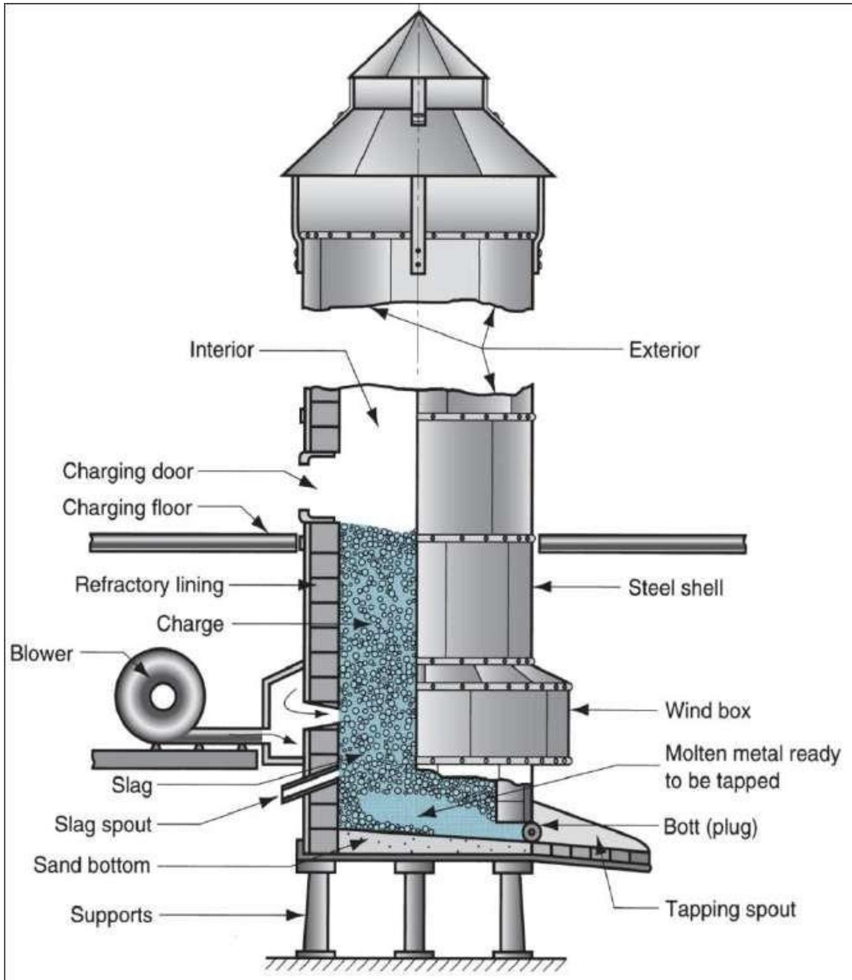
- Furnaces most commonly used in foundries:
  - Cupolas
  - Direct fuel-fired furnaces
  - Crucible furnaces
  - Electric-arc furnaces
  - Induction furnaces

Cupolas

Vertical cylindrical furnace equipped with tapping spout near base

- Used only for cast irons
  - Although other furnaces are also used, the largest tonnage of cast iron is melted in cupolas
- The "charge," consisting of iron, coke, flux, and any alloying elements, is loaded through a charging door located less than halfway up height of cupola

- Cupola for melting cast iron



Direct Fuel-Fired Furnaces

Small open-hearth in which charge is heated by natural gas fuel burners located on side of furnace

- Furnace roof assists heating action by reflecting flame down against charge
- At bottom of hearth is a tap hole to release molten metal
- Generally used for nonferrous metals such as copper-base alloys and aluminum

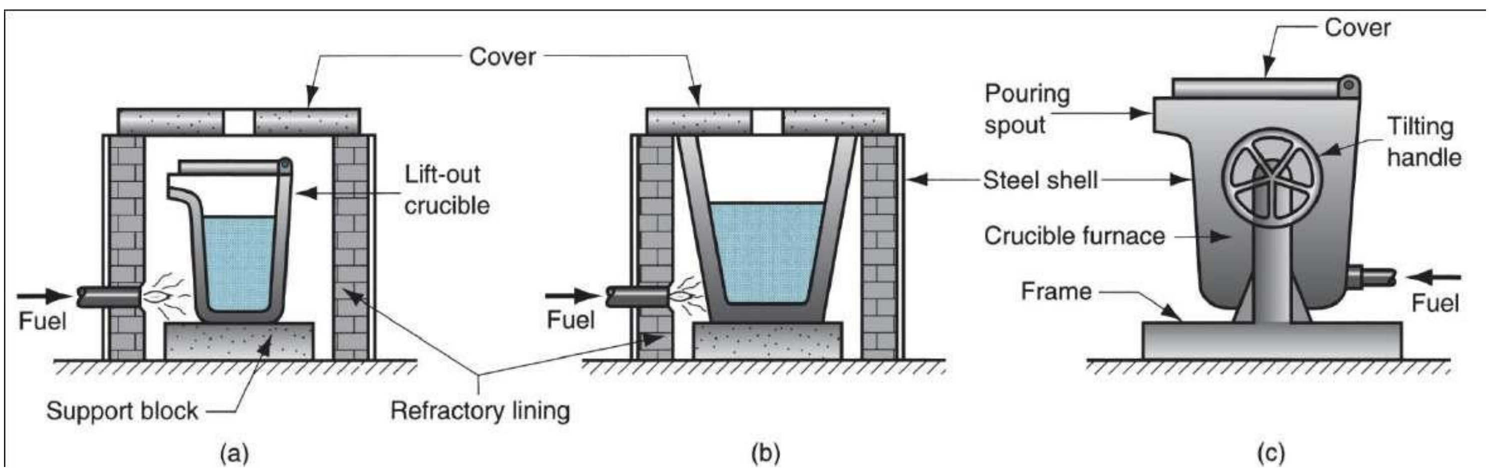
Crucible Furnaces

Metal is melted without direct contact with burning fuel mixture

- Sometimes called *indirect fuel-fired furnaces*
- Container (crucible) is made of refractory material or high-temperature steel alloy
- Used for nonferrous metals such as bronze, brass, and alloys of zinc and aluminum
- Three types used in foundries: (a) lift-out type, (b) stationary, (c) tilting

Three Types of Crucible Furnaces

- (a) Lift-out crucible, (b) stationary pot - molten metal must be ladled, and (c) tilting-pot furnace



Electric-Arc Furnaces

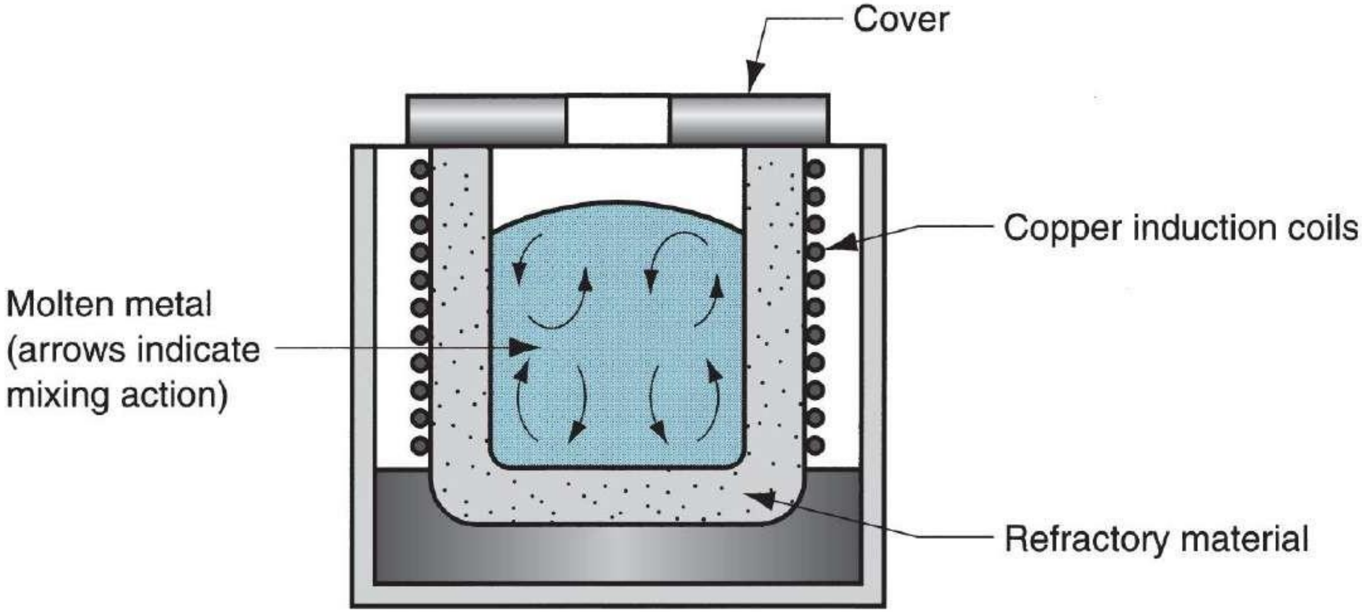
Charge is melted by heat generated from an electric arc

- High power consumption
  - But electric-arc furnaces can be designed for high melting capacity
- Used primarily for melting steel

Induction Furnaces

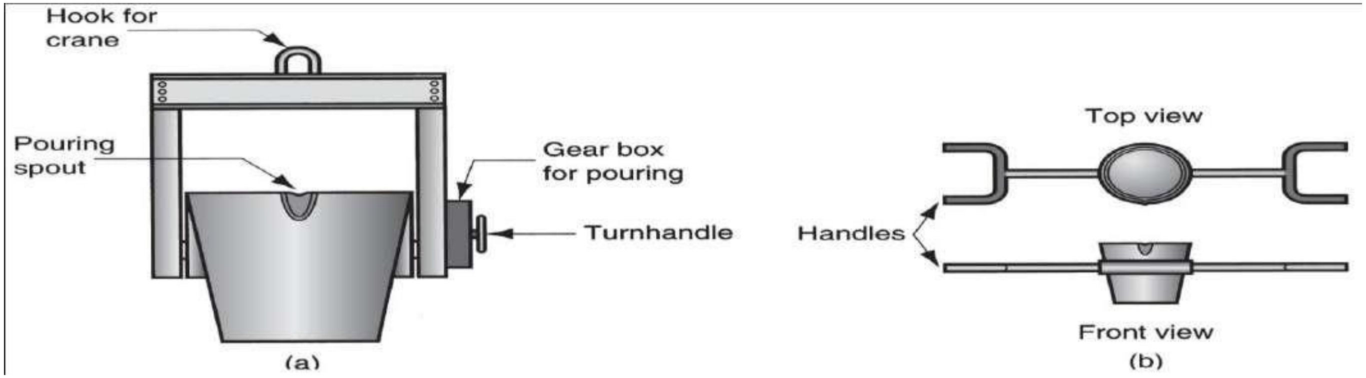
- Uses alternating current passing through a coil to develop magnetic field in metal
  - Induced current causes rapid heating and melting
  - Electromagnetic force field also causes mixing action
- Since metal does not contact heating elements, environment can be closely controlled to produce molten metals of high quality and purity
- Common alloys: steel, cast iron, and aluminum

Induction Furnace



Ladles

- Two common types of ladles to transfer molten metals to molds: (a) crane ladle, and (b) two-man ladle



Additional Steps After Solidification

- Trimming
- Removing the core
- Surface cleaning
- Inspection
- Repair, if required
- Heat treatment

Trimming

Removal of sprues, runners, risers, parting-line flash, fins, chaplets, and any other excess metal from the cast part

- For brittle casting alloys and when cross sections are relatively small, appendages can be broken off
- Otherwise, hammering, shearing, hack-sawing, band-sawing, abrasive wheel cutting, or various torch cutting methods are used

Removing the Core

- If cores have been used, they must be removed
  - Most cores are bonded, and they often fall out of casting as the binder deteriorates
  - In some cases, they are removed by shaking the casting, either manually or mechanically
  - In rare cases, cores are removed by chemically dissolving bonding agent
  - Solid cores must be hammered or pressed out

Surface Cleaning and Inspection

Removal of sand from casting surface and otherwise enhancing appearance of surface

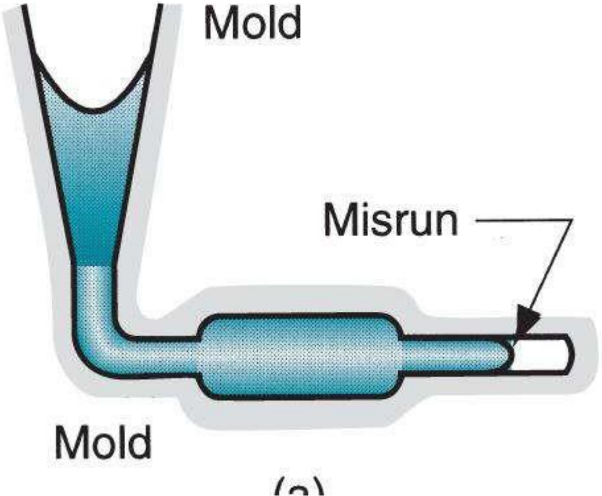
- Cleaning methods: tumbling, air-blasting with coarse sand grit or metal shot, wire brushing, buffing, and chemical pickling
- Surface cleaning is most important for sand casting
  - In many permanent mold processes, this step can be avoided
- Defects are possible in casting, and inspection is needed to detect their presence

Heat Treatment

- Castings are often heat treated to enhance properties
- Reasons for heat treating a casting:
  - For subsequent processing operations such as machining
  - To bring out the desired properties for the application of the part in service

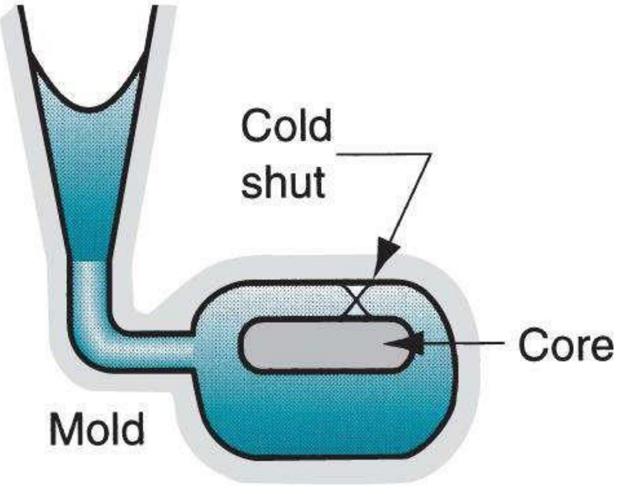
General Defects: Misrun

- A casting that has solidified before completely filling mold cavity



General Defects: Cold Shut

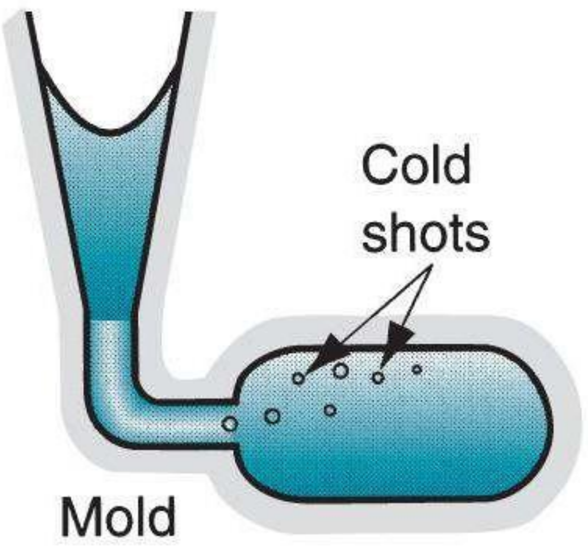
- Two portions of metal flow together but there is a lack of fusion due to premature freezing



(b)

General Defects: Cold Shot

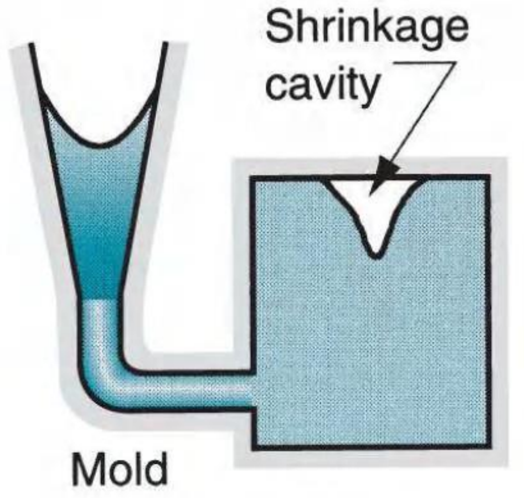
- Metal splatters during pouring and solid globules form and become entrapped in casting



(c)

General Defects: Shrinkage Cavity

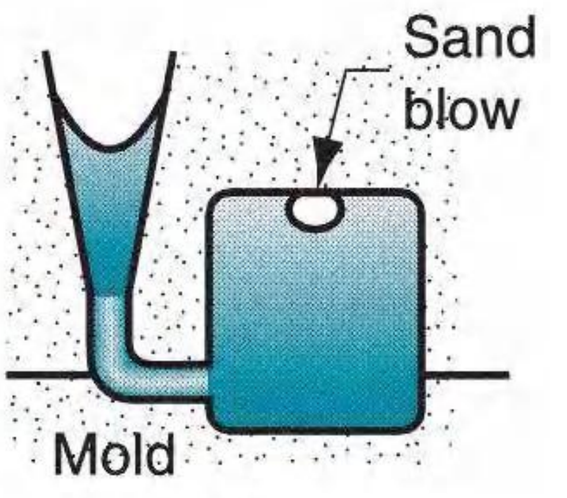
- Depression in surface or internal void caused by solidification shrinkage that restricts amount of molten metal available in last region to freeze



(d)

Sand Casting Defects: Sand Blow

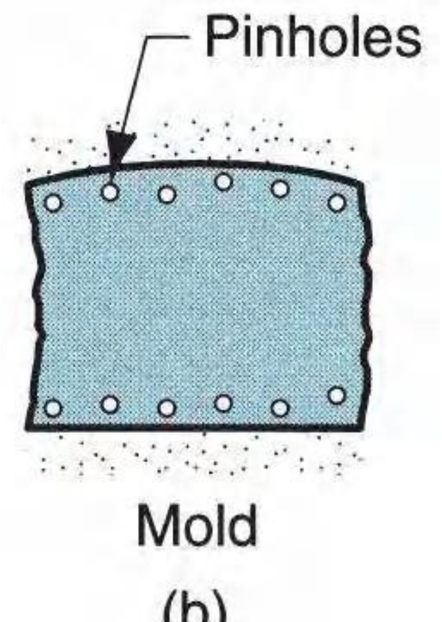
- Balloon-shaped gas cavity caused by release of mold gases during pouring



(a)

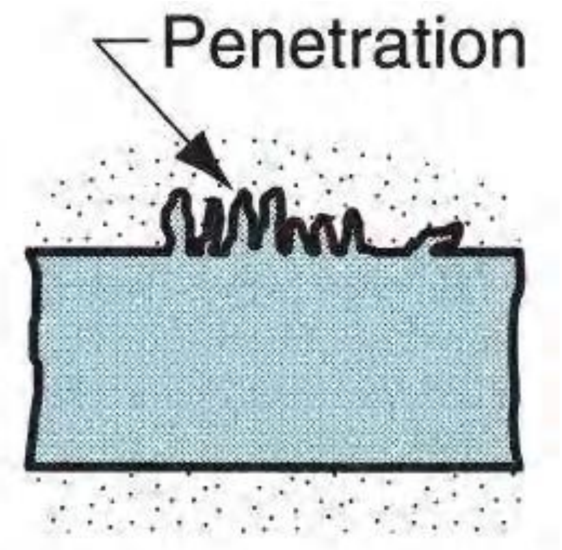
Sand Casting Defects: Pin Holes

- Formation of many small gas cavities at or slightly below surface of casting



Sand Casting Defects: Penetration

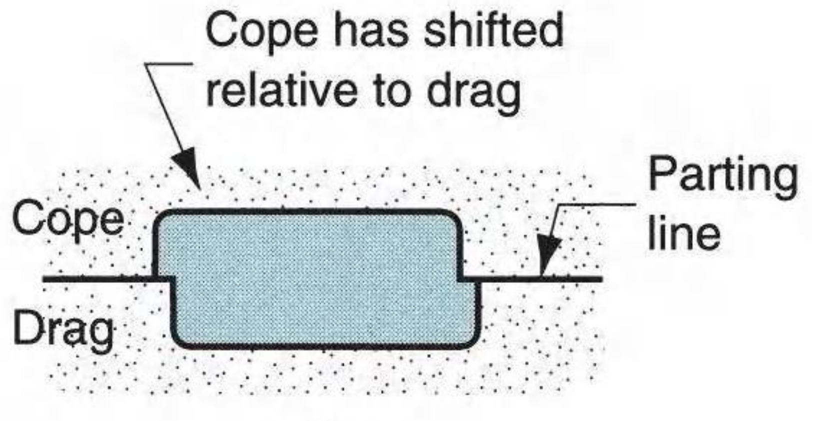
- When fluidity of liquid metal is high, it may penetrate into sand mold or core, causing casting surface to consist of a mixture of sand grains and metal



(e)

Sand Casting Defects: Mold Shift

- A step in the cast product at parting line caused by sidewise relative displacement of cope and drag



(f)

Metals for Casting

- Most commercial castings are made of alloys rather than pure metals
  - Alloys are generally easier to cast, and properties of product are better
- Casting alloys can be classified as:
  - Ferrous
  - Nonferrous

Ferrous Casting Alloys: Cast Iron

- Most important of all casting alloys
- Tonnage of cast iron castings is several times that of all other metals combined
- Several types: (1) gray cast iron, (2) nodular iron, (3) white cast iron, (4) malleable iron, and (5) alloy cast irons
- Typical pouring temperatures ~ 1400°C (2500°F), depending on composition

Ferrous Casting Alloys: Steel

- The mechanical properties of steel make it an attractive engineering material
- The capability to create complex geometries makes casting an attractive shaping process
- Difficulties when casting steel:
  - Pouring temperature is high $\sim$ 1650°C (3000°F)
    - At such temperatures, steel readily oxidizes, so molten metal must be isolated from air
  - Molten steel has relatively poor fluidity

Nonferrous Casting Alloys: Copper Alloys

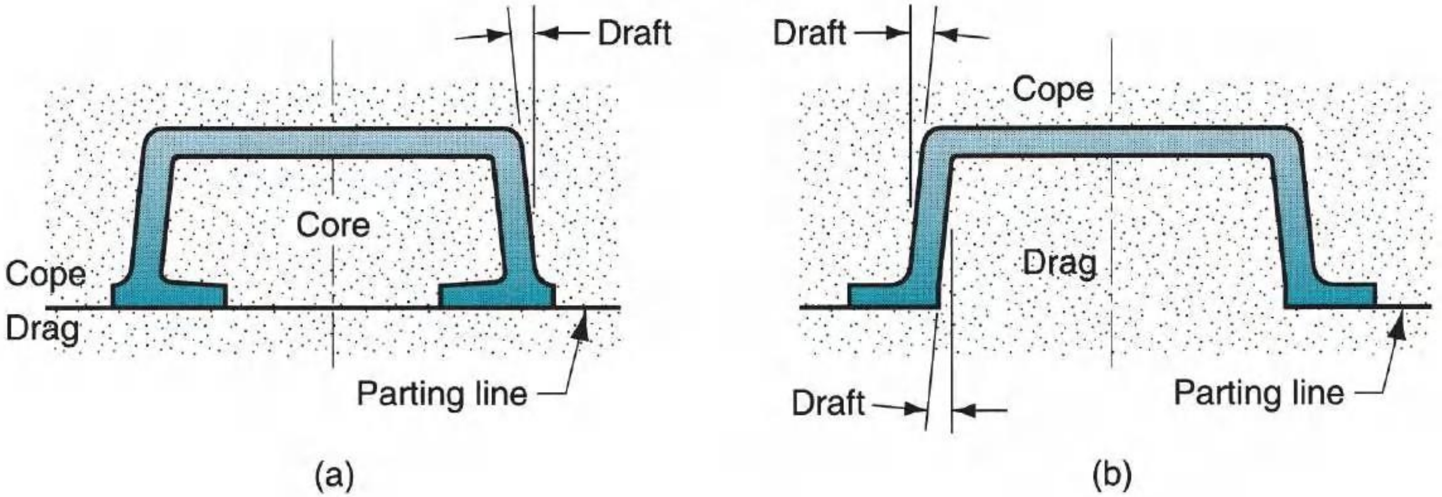
- Includes bronze, brass, and aluminum bronze
- Properties:
  - Corrosion resistance
  - Attractive appearance
  - Good bearing qualities
- Limitation: high cost of copper
- Applications: pipe fittings, marine propeller blades, pump components, ornamental jewelry

Nonferrous Casting Alloys: Zinc Alloys

- Very castable, commonly used in die casting
- Low pouring temperatures due to low melting temperature
  - Pure zinc T_m = 419°C (786°F)
- Good fluidity for ease of casting
- Properties:
  - Low creep strength, so castings cannot be subjected to prolonged high stresses

Draft

- Design change to eliminate need for using a core: (a) original design, and (b) redesign



Metal Forming

Large group of manufacturing processes in which plastic deformation is used to change the shape of metal workpieces

- The tool, usually called a ***die***, applies stresses that exceed the yield strength of the metal
- The metal takes a shape determined by the geometry of the die

Stresses in Metal Forming

- Stresses to plastically deform the metal are usually compressive
  - Examples: rolling, forging, extrusion
- However, some forming processes
  - Stretch the metal (tensile stresses)
  - Others bend the metal (tensile and compressive)
  - Still others apply shear stresses (shear spinning)

Material Properties in Metal Forming

- Desirable material properties:
  - **Low yield strength**
  - **High ductility**
- These properties are affected by **temperature**:
  - Ductility increases and yield strength decreases when work temperature is raised
- Other factors:
  - Strain rate and friction

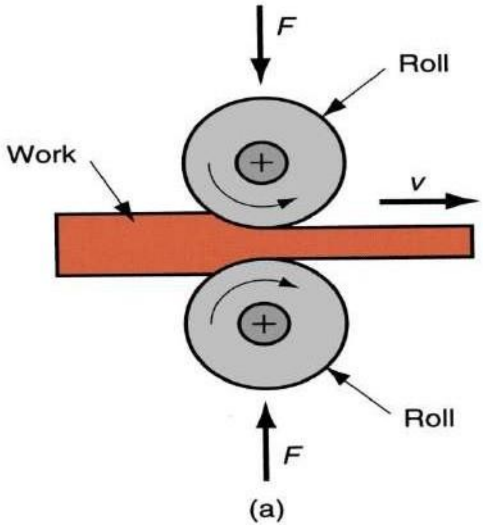
Basic Types of Deformation Processes

1. Bulk deformation
   - Rolling
   - Forging
   - Extrusion
   - Wire and bar drawing
2. Sheet metalworking
   - Bending
   - Deep drawing
   - Cutting

Bulk Deformation Processes

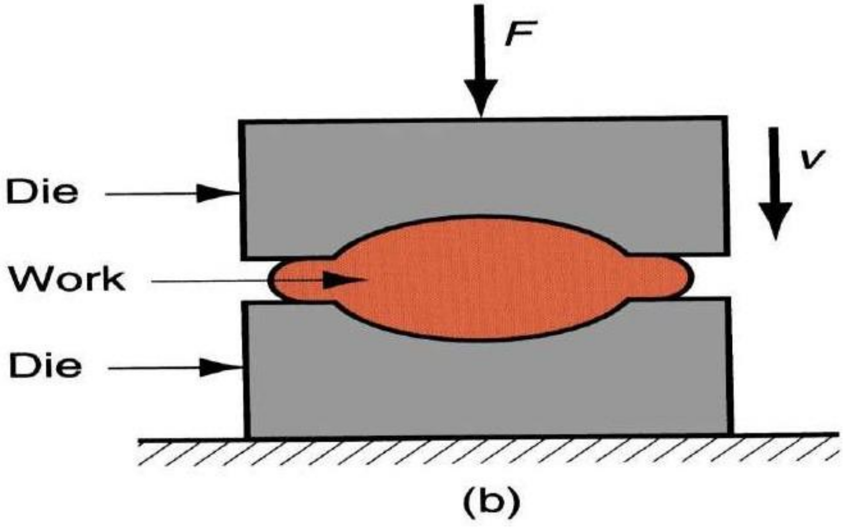
- Characterized by significant deformations and massive shape changes
- "Bulk" refers to workparts with relatively low surface area-to-volume ratios
- Starting work shapes include cylindrical billets and rectangular bars

Rolling



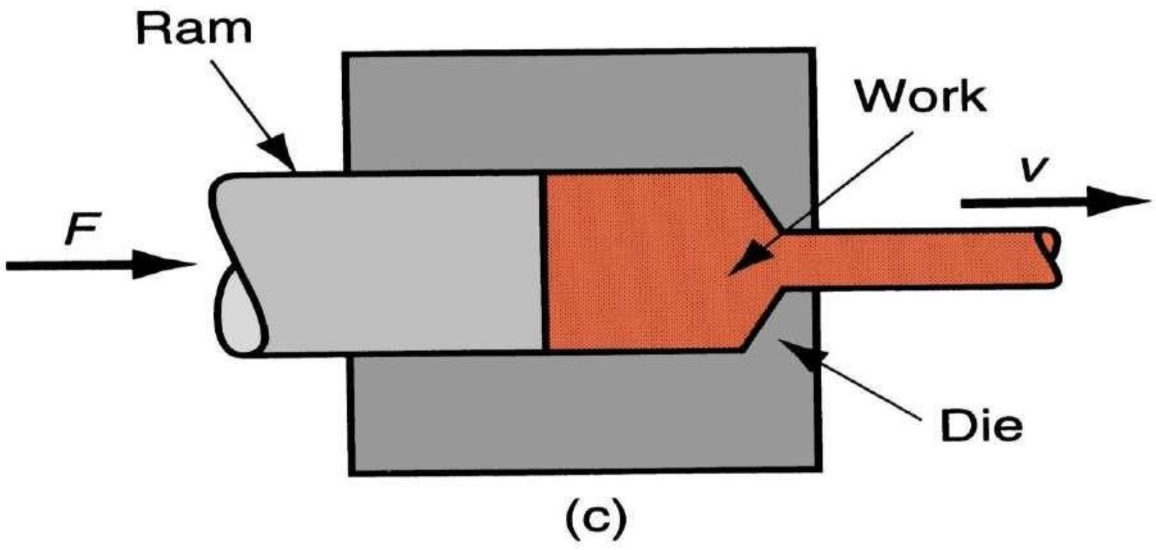
Basic bulk deformation processes: rolling

Forging



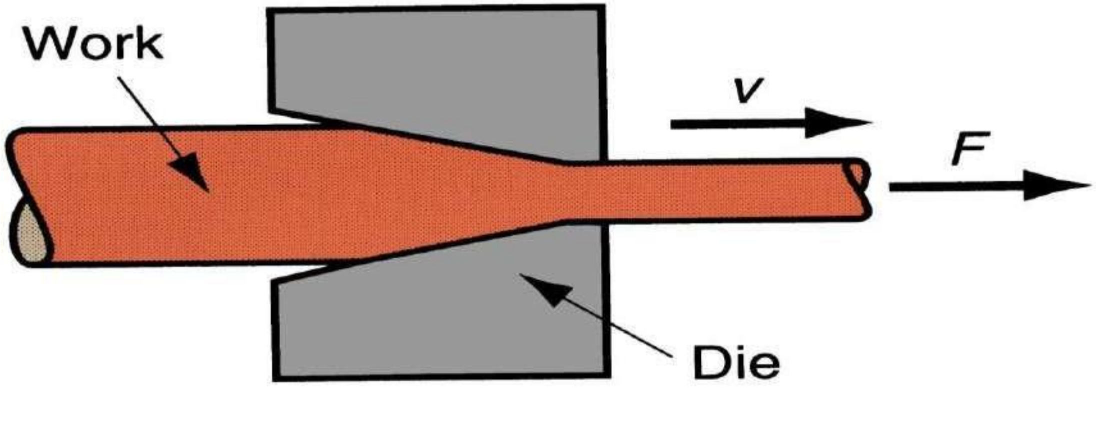
Basic bulk deformation processes: forging

Extrusion



Basic bulk deformation processes: (c) extrusion

Wire and Bar Drawing

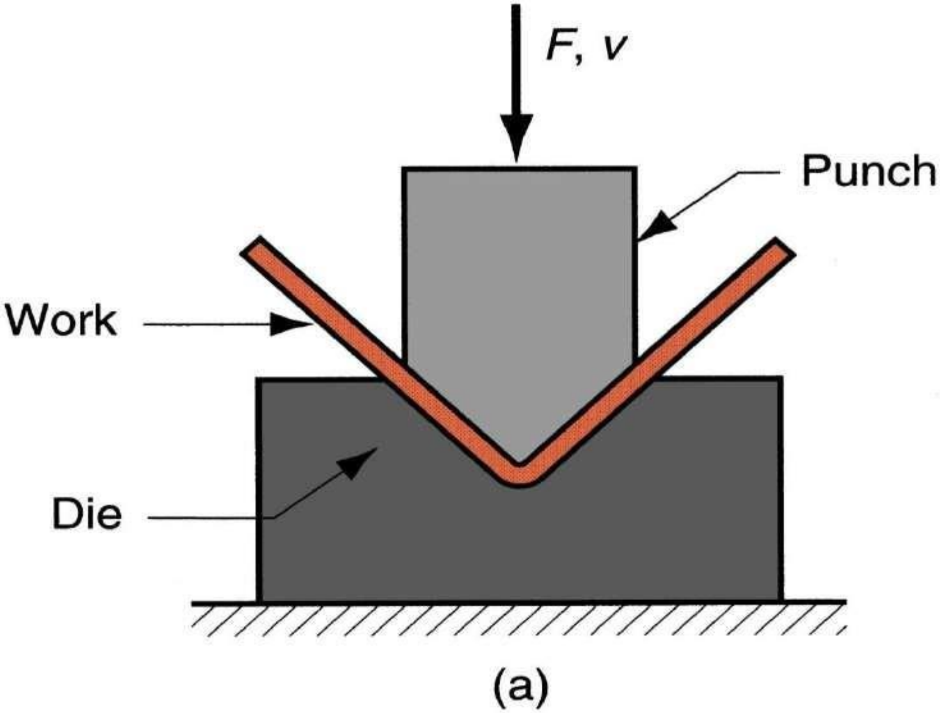


Basic bulk deformation processes: (d) drawing

Sheet Metalworking

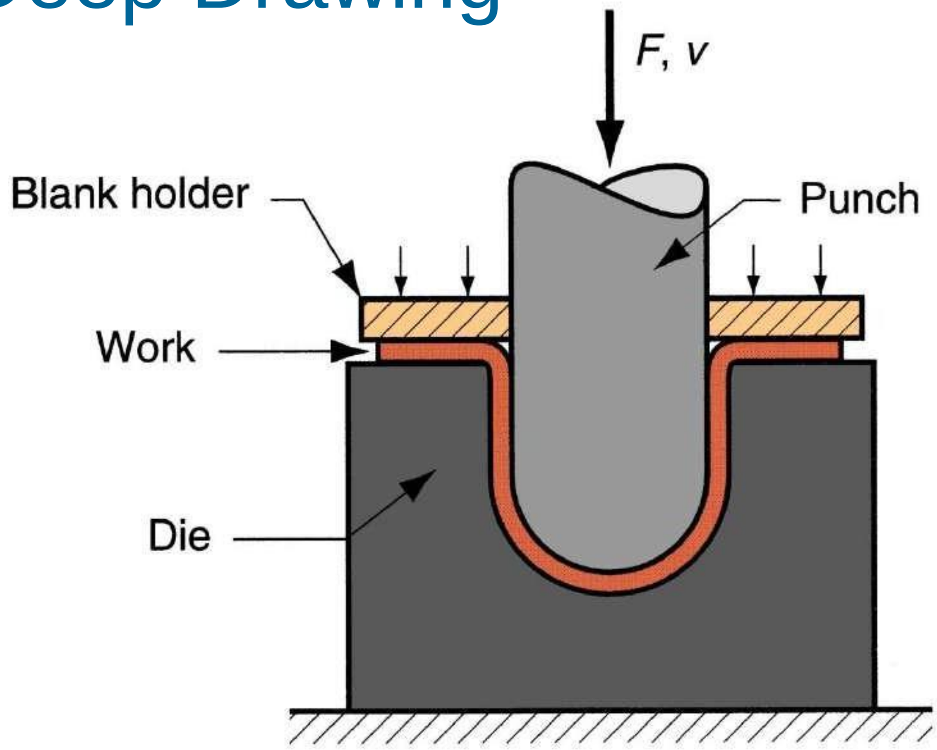
- Forming and related operations performed on metal sheets, strips, and coils
- High surface area-to-volume ratio of starting metal, which distinguishes these from bulk deformation
- Often called *pressworking* because presses perform these operations
  - Parts are called *stampings*
  - Usual tooling: *punch* and *die*

Sheet Metal Bending



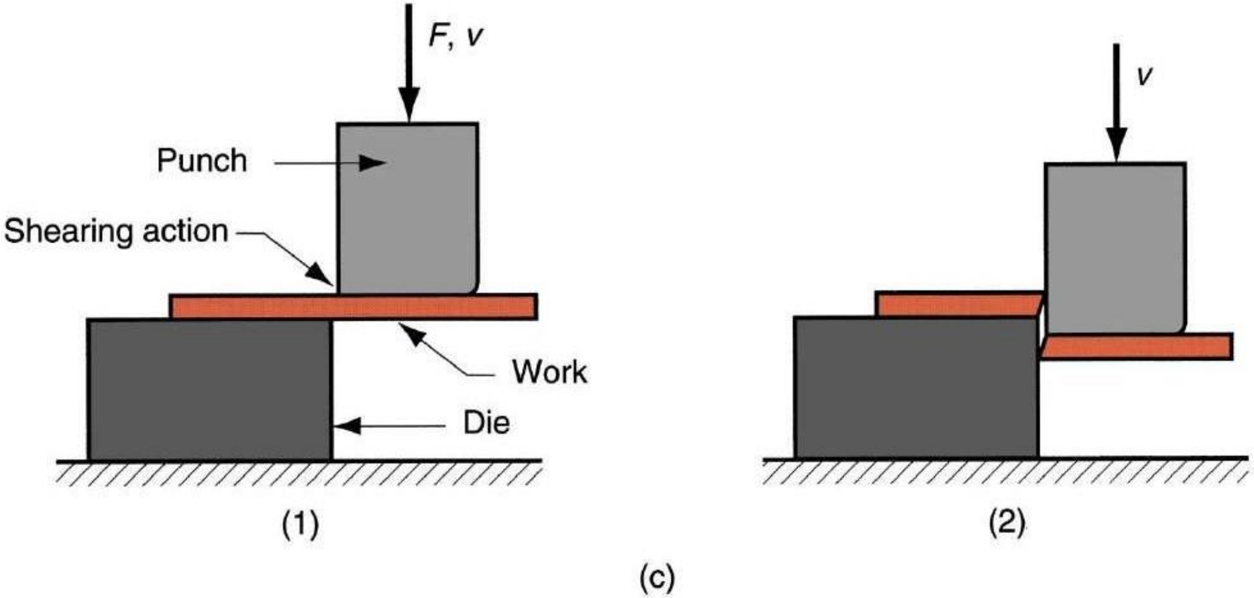
Basic sheet metalworking operations: bending

Deep Drawing



Basic sheet metalworking operations: drawing

Shearing of Sheet Metal



Basic sheet metalworking operations: shearing

Temperature in Metal Forming

- Any deformation operation can be accomplished with lower forces and power at elevated temperature
- Three temperature ranges in metal forming:
  - Cold working
  - Warm working
  - Hot working

Cold Working

- Performed at room temperature or slightly above
- Many cold forming processes are important mass production operations
- Minimum or no machining usually required

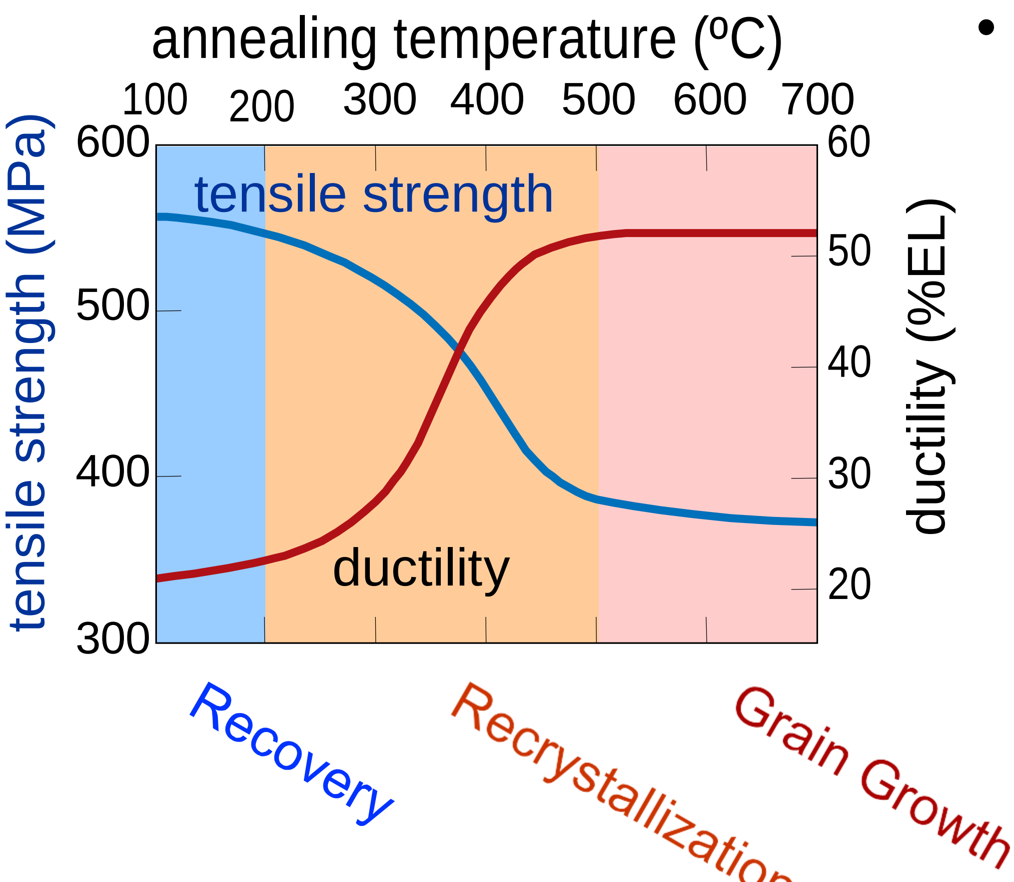
Advantages of Cold Forming

- Better accuracy, closer tolerances
- Better surface finish
- Strain hardening increases strength and hardness
- No heating of work required

Disadvantages of Cold Forming

- Higher forces and power required in the deformation operation
- Ductility and strain hardening limit the amount of forming that can be done
  - In some cases, metal must be annealed to allow further deformation
  - In other cases, metal is simply not ductile enough to be cold worked

Effect of Heat Treating After Cold Working



- Three Annealing stages:
  1. Recovery
  2. Recrystallization
  3. Grain Growth

Adapted from Fig. 8.22, *Callister & Rethwisch 4e.* (Fig. 8.22 is adapted from G. Sachs and K.R. van Horn, *Practical Metallurgy, Applied Metallurgy, and the Industrial Processing of Ferrous and Nonferrous Metals and Alloys*, American Society for Metals, 1940, p. 139.)

Recrystallization Temperature

T_R = recrystallization temperature = temperature at which recrystallization just reaches completion in 1 h.

$$0.3T_m < T_R < 0.6T_m$$

For a specific metal/alloy, T_R depends on:

- %CW -- T_R decreases with increasing %CW
- Purity of metal -- T_R decreases with increasing purity

Advantages of Warm Working

- Lower forces and power than in cold working
- More intricate work geometries possible
- Need for annealing may be reduced or eliminated
- Low spring back

Disadvantage:

1. Scaling of part surface

Hot Working

- Deformation at temperatures above the *recrystallization temperature*
- Recrystallization temperature = about one-half of melting point on absolute scale
  - In practice, hot working usually performed somewhat above $0.6T_m$
  - Metal continues to soften as temperature increases above $0.6T_m$, enhancing advantage of hot working above this level

Why Hot Working?

Capability for substantial plastic deformation of the metal - far more than possible with cold working or warm working

- Why?
  - Strength coefficient (***K***) is substantially less than at room temperature
  - Strain hardening exponent (*n*) is zero (theoretically)
  - Ductility is significantly increased

Advantages of Hot Working

- Work part shape can be significantly altered
- Lower forces and power required
- Metals that usually fracture in cold working can be hot formed
- Strength properties of product are generally isotropic
- No work hardening occurs during forming

Disadvantages of Hot Working

- Lower dimensional accuracy in case of bulk forming
- Higher total energy required (due to the thermal energy to heat the workpiece)
- Work surface oxidation (scale), poorer surface finish
- Shorter tool life

INTRODUCTION TO PLASTICS PROCESSING

INTRODUCTION

- Plastics – The unique class of wonder materials – came into existence by virtue of their superior performance and cost effectiveness over to conventional materials.

  - Over the years the applications spectrum of plastics have been widened with the advent of new generation Polymers, blend alloys and composites

- . Every day newer and newer application are being promoted in all the key sectors of Indian Economy viz, Automobiles, Agriculture, Aerospace. Building & Construction, Infrastructure, Telecommunication, IT, Medical & Bio Medical engineering, Packaging, etc.

- This inturn necessitates the need for different types processing methods and machinery to produce quality plastics products at affordable cost

- Today a host of processing methods and machinery are available to manufacture plastics products meeting stringent quality requirements and cost to performance balance.

DEFINITION:

Raw Materials (Powder/granules) → Processing → **Semi-finished or Finished Products**

Plastics Processing – in a simple layman's language – can be defined as the process of converting the plastic raw materials into Semi-finished or finished products.

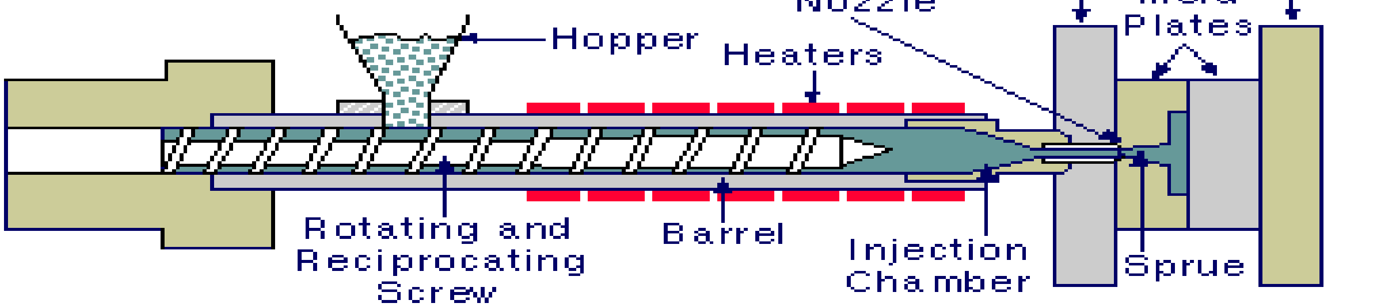
INJECTION MOULDING :

Very widely used. High automation of manufacturing is standard practice. Thermoplastic or thermoset is heated to plasticate in cylinder at controlled temperature, then forced under pressure through a nozzle into sprue, runners, gates, and cavities of mould. The resin undergoes solidification rapidly. The mould is opened, and the part ejected, Injection Moulding is growing in the making of glass-reinforced parts. High production runs, low labour costs, high reproducibility of complex details, and excellent surface finish are the merits.

Limitations:

High initial tool and die costs; not economically practical for small runs.

INJECTION MOULDING



Refrigerator cabinet in Lustran

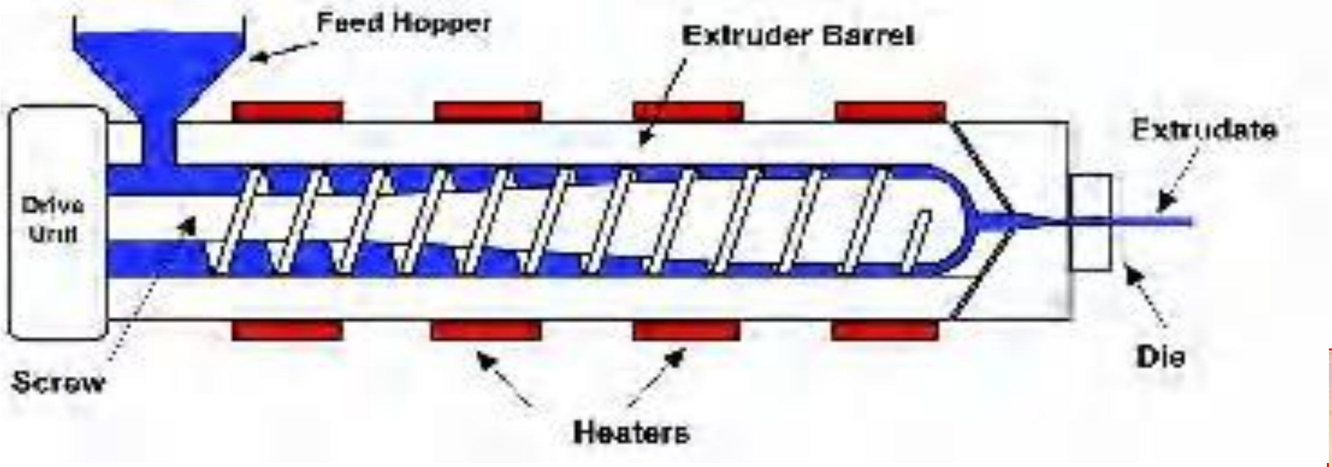
EXTRUSION :

Widely used for continuous production of film, sheet, tube, and other profiles; also used in conjunction with blow moulding. Thermoplastic moulding compound is fed from a hopper to a screw pump where it is heated to plasticate then pumped out through the shaping orifice (die) to achieve desired cross section. Production lines require input and takeoff equipment that can be complex. Low tool cost, numerous complex profile shapes possible, very rapid production rates, can apply coatings or jacketing to core materials (Such as wire).

Limitations:

Usually limited to sections of uniform cross section.

EXTRUSION


Feed Hopper
Extruder Barrel
Extrudate
Drive Unit
Screw
Heaters
Die

COMPRESSION MOULDING :

Thermoset compound, usually preformed, is positioned in a heated mould cavity; the mould is closed (heat and pressure are applied) and the material flows and fills the mould cavity. Heat completes polymerization and the part is ejected. The process is sometimes used for thermoplastics, e.g. Vinyl phonograph records. Little material waste is attainable; large, bulky parts can be moulded; process is adaptable to rapid automation.

Limitations:

Extremely intricate parts containing undercuts, side draws, small holes, delicate inserts, etc.; very close tolerances are difficult to produce. Time consuming process.

TRANSFER MOULDING

Widely used to produce Thermoset products with part complexity. Thermoset moulding compound is fed into transfer chamber where it is then heated to plasticate; it is then fed by a plunger through sprues, runners, and gates into a closed mould where it cures; mould is opened and part ejected. Good dimensional accuracy, rapid production rate, and very intricate parts can be produced.

Limitations:

High mould cost; high material loss in sprues and runners; size of parts is somewhat limited.

ROTATIONAL MOULDING

A predetermined amount of powdered thermoplastic material is poured into mould; mould is closed, heated, and rotated in the axis of two planes until contents have fused to the inner walls of mould; mould is then opened and part is removed. Low mould cost, large hollow parts in one piece can be produced, and moulded parts are essentially isotropic in nature.

Limitations:

Limited to hollow parts; production rates are usually slow.

ROTATIONAL MOULDING

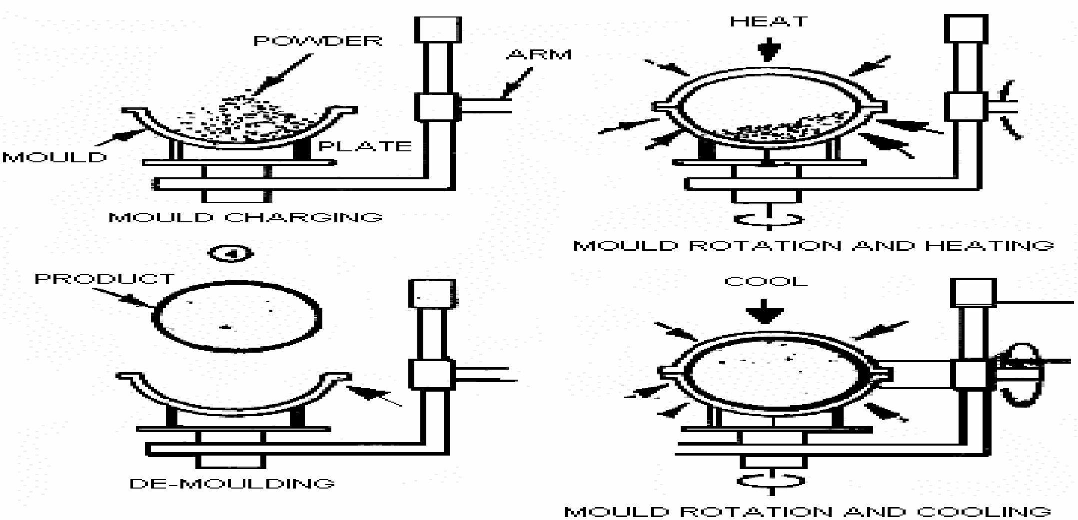


FIG-6.1 PRINCIPLE OF ROTATIONAL MOULDING

THERMOFORMING

Heat-softened thermoplastic sheet is positioned over male or female mould; air is evacuated between sheet and mould, forcing sheet to conform to contour of mould. Variations are vacuum snapback, plug assist, drape forming, etc. Tooling costs are generally low, large part production with thin sections possible, and often comes out economical for limited part production.

Limitations:

Limited to parts of simple configuration, high scrap, and limited number of materials from which to choose.

THERMOFORMING

CASTING

Liquid plastic which is generally thermoset except for acrylics is poured into a mould without pressure, cured, and taken from the mould. Cast thermoplastic films are produced via building up the material (either in solution or hot-melt form) against a highly polished supporting surface. Low mould cost, capability to form large parts with thick cross sections, good surface finish, and convenient for low-volume production.

Limitations:

Limited to relatively simple shapes. Most thermoplastics are not suitable for this method.

Except for cast films, method becomes uneconomical at high volume production rates.

CENTRIFUGAL CASTING:

Reinforcement is placed in mould and is rotated. Resin distributed through pipe; impregnates reinforcement through centrifugal action. Utilized for round objects, particularly pipe.

Limitations:

Limited to simple curvatures in single axis rotation. Low production rates.

COATING

Description :

Process methods vary. Both thermoplastics and thermosets widely used in coating of numerous materials. Roller coating similar to calendaring process. Spread coating employs blade in front of roller to position resin on material. Coatings also applied via brushings, spraying, and dipping.

MATCHED-DIE MOULDING :

A variation of the conventional compression moulding, this process employs two metal moulds possessing a close-fitting, telescoping area to seal in the plastic compound being moulded and to allow trim of the reinforcement. The mat or preform reinforcement is positioned in the mould and the mould is closed and heated under pressures of 150 – 400psi (1-3MPa). The mould is then opened and the part is removed after curing.

Prevalent high mould and equipment costs. Part often require expensive surface finishing.

SLUSH MOULDING :

Liquid thermoplastic material (Plastisol) is poured into a mould to capacity; mould is closed and heated for a predetermined time in order to achieve a specified buildup of partially fused material on mould walls; mould is opened and excess material is poured out; and semifused part is removed from mould and fully fused in oven. Low mould costs and economical for small production runs.

Limitations:

Limited to hollow parts; production rates are very slow; and limited choice of materials that can be processed.

Thank
You