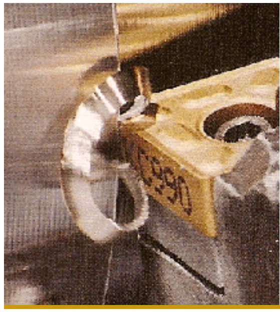
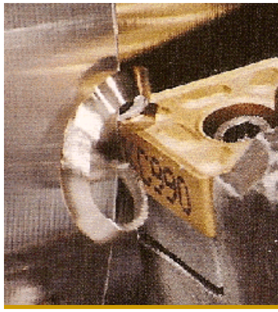


FUNDAMENTALS OF WELDING

1. Overview of Welding Technology
2. The Weld Joint
3. Physics of Welding
4. Features of a Fusion Welded Joint

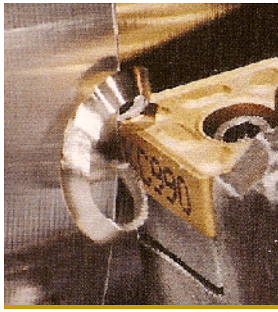


Joining and Assembly Distinguished

- Joining - welding, brazing, soldering, and adhesive bonding
  - These processes form a permanent joint between parts
- Assembly - mechanical methods (usually) of fastening parts together
  - Some of these methods allow for easy disassembly, while others do not

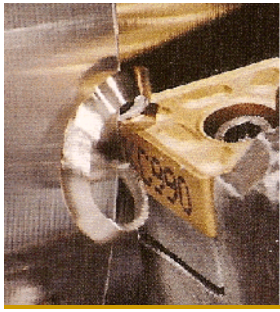
Welding Defined

- 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



Why Welding is Important

- Provides a permanent joint
  - Welded components become a single entity
- Usually the most economical way to join parts in terms of material usage and fabrication costs
  - Mechanical fastening usually requires additional hardware (e.g., screws) and geometric alterations of the assembled parts (e.g., holes)
- Not restricted to a factory environment
  - Welding can be accomplished "in the field"



Limitations and Drawbacks of Welding

- Most welding operations are performed manually and are expensive in terms of labor cost
- Most welding processes utilize high energy and are inherently dangerous
- Welded joints do not allow for convenient disassembly
- Welded joints can have quality defects that are difficult to detect

Faying Surfaces in Welding

- The part surfaces in contact or close proximity that are being joined
- Welding involves localized coalescence of the two metallic parts at their faying surfaces
- Welding is usually performed on parts made of the same metal
  - However, some welding operations can be used to join dissimilar metals

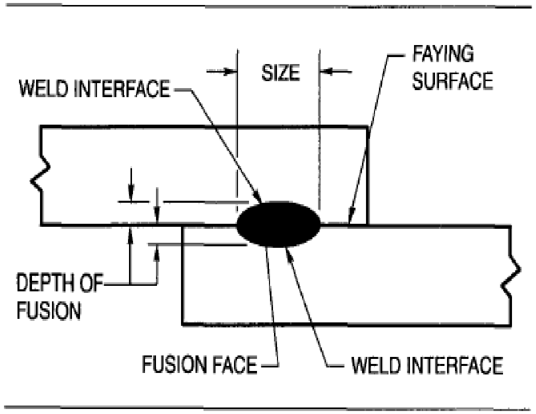
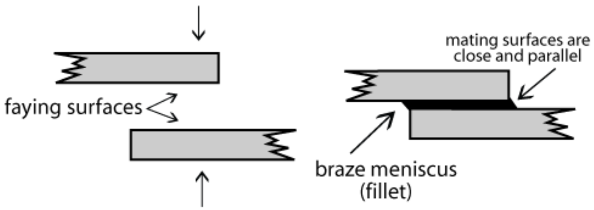


Figure R-6—Resistance Spot Weld

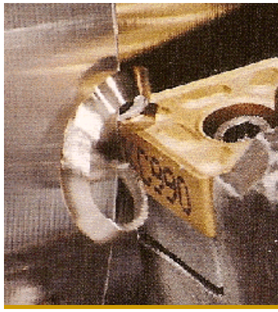


Types of Welding Processes

- Some 50 different types of welding processes have been catalogued by the American Welding Society (AWS)
- Welding processes can be divided into two major categories:
  - Fusion welding
  - Solid state welding

Fusion Welding

- Joining processes that melt the base metals
  - In many fusion welding operations, a filler metal is added to the molten pool to facilitate the process and provide bulk and added strength to the welded joint
  - A fusion welding operation in which no filler metal is added is called an *autogenous* weld

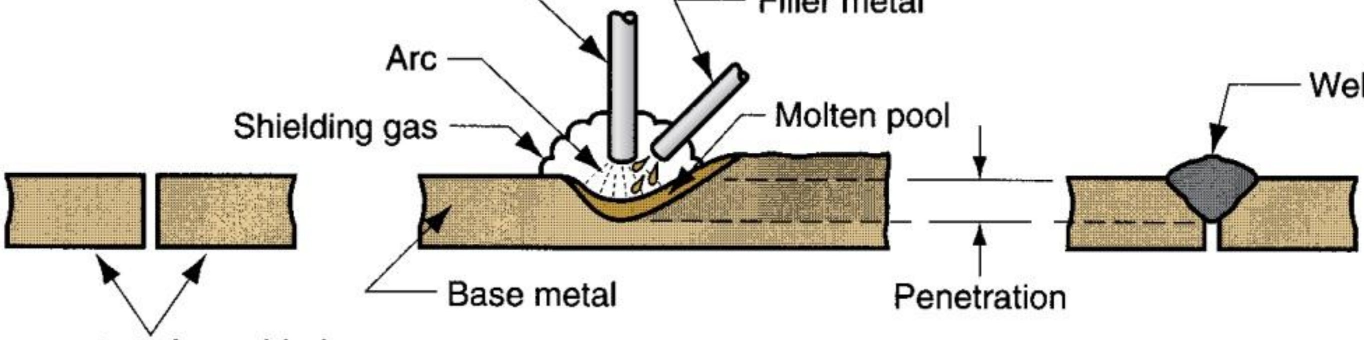


Some Fusion Welding Processes

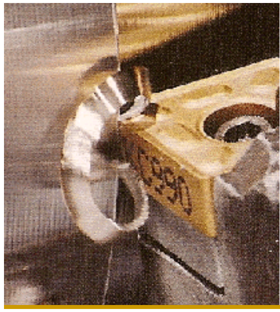
- Arc welding (AW) – melting of the metals is accomplished by an electric arc
- Resistance welding (RW) - melting is accomplished by heat from resistance to an electrical current between faying surfaces held together under pressure
- Oxyfuel gas welding (OFW) - melting is accomplished by an oxyfuel gas such as acetylene

Arc Welding

- Basics of arc welding: (1) before the weld; (2) during the weld, the base metal is melted and filler metal is added to molten pool; and (3) the completed weldment



(1) End view (before)
(2) Cross-sectional (side) view (during welding)
(3) End view (after)



Solid State Welding

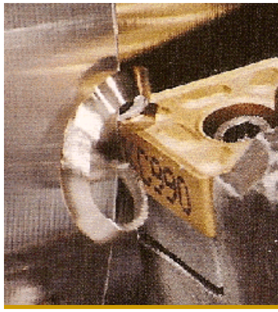
- Joining processes in which coalescence results from application of pressure alone or a combination of heat and pressure
  - If heat is used, temperature is below melting point of metals being welded
  - No filler metal is added in solid state welding

Some Solid State Welding Processes

- Diffusion welding (DFW) –coalescence is by solid state fusion between two surfaces held together under pressure at elevated temperature
- Friction welding (FRW) - coalescence by heat of friction between two surfaces
- Ultrasonic welding (USW) - coalescence by ultrasonic oscillating motion in a direction parallel to contacting surfaces of two parts held together under pressure

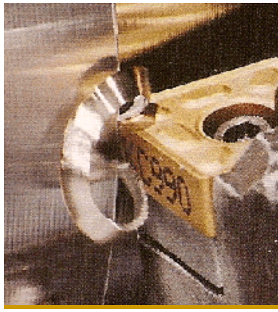
Principal Applications of Welding

- Construction - buildings and bridges
- Piping, pressure vessels, boilers, and storage tanks
- Shipbuilding
- Aircraft and aerospace
- Automotive
- Railroad



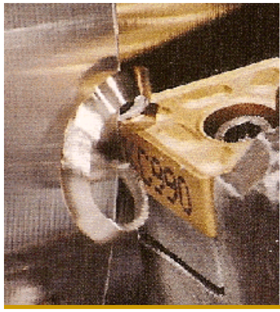
Welder and Fitter

- The welder manually controls the path or placement of welding gun
- Often assisted by second worker, called a *fitter*, who arranges the parts prior to welding
  - Welding fixtures and positioners are used to assist in this function



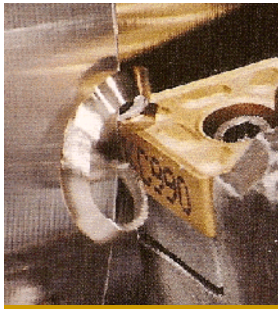
The Safety Issue

- Welding is inherently dangerous to human workers
  - High temperatures of molten metals
  - In gas welding, fuels (e.g., acetylene) are a fire hazard
  - Many welding processes use electrical power, so electrical shock is a hazard



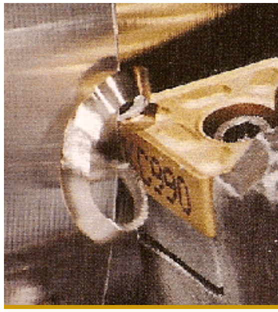
Special Hazards in Arc Welding

- Ultraviolet radiation emitted in arc welding is injurious to human vision
  - Welder must wear special helmet with dark viewing window
    - Filters out dangerous radiation but welder is blind except when arc is struck
- Sparks, spatters of molten metal, smoke, and fumes
  - Ventilation needed to exhaust dangerous fumes from fluxes and molten metals



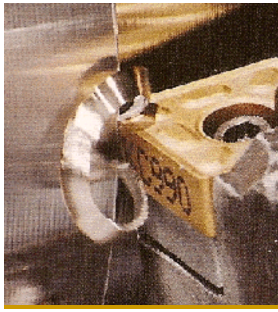
Automation in Welding

- Because of the hazards of manual welding, and to increase productivity and improve quality, various forms of mechanization and automation are used
  - Machine welding – mechanized welding under supervision and control of human operator
  - Automatic welding – equipment performs welding without operator control
  - Robotic welding - automatic welding implemented by industrial robot



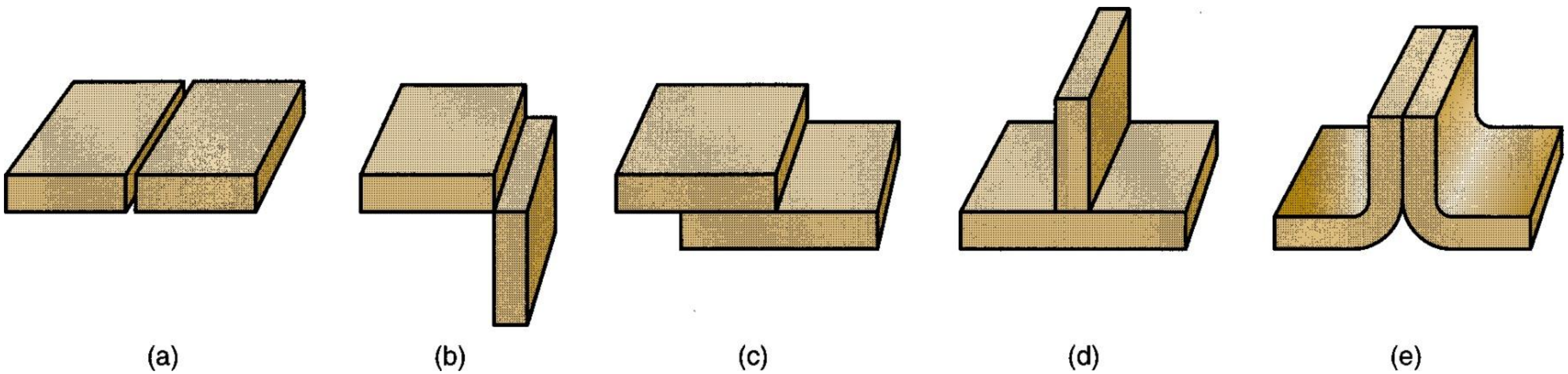
The Weld Joint

- The junction of the edges or surfaces of parts that have been joined by welding
  - Two issues about weld joints:
    - Types of joints
    - Types of welds used to join the pieces that form the joints



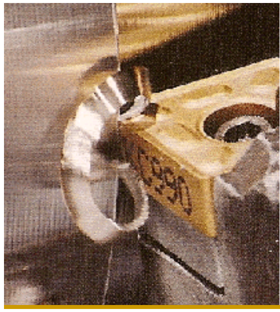
Five Types of Joints

- (a) Butt joint, (b) corner joint, (c) lap joint, (d) tee joint, and (e) edge joint



Types of Welds

- Each of the preceding joints can be made by welding
- Other joining processes can also be used for some of the joint types
- There is a difference between joint type and the way it is welded - the weld type

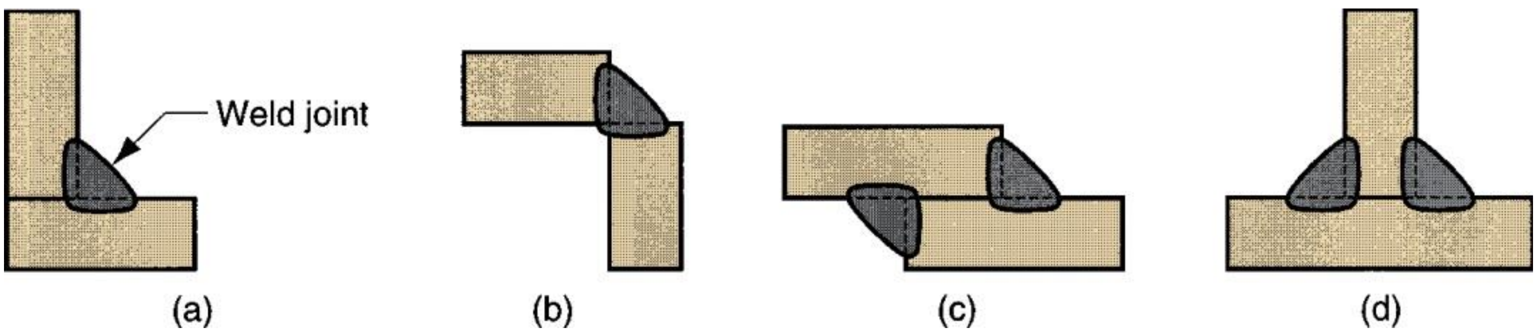


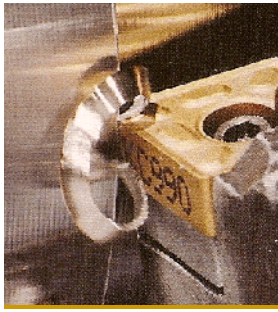
Fillet Weld

- Used to fill in the edges of plates created by corner, lap, and tee joints
- Filler metal used to provide cross section in approximate shape of a right triangle
- Most common weld type in arc and oxyfuel welding
- Requires minimum edge preparation

Fillet Welds

- (a) Inside single fillet corner joint; (b) outside single fillet corner joint; (c) double fillet lap joint; (d) double fillet tee joint (dashed lines show the original part edges)



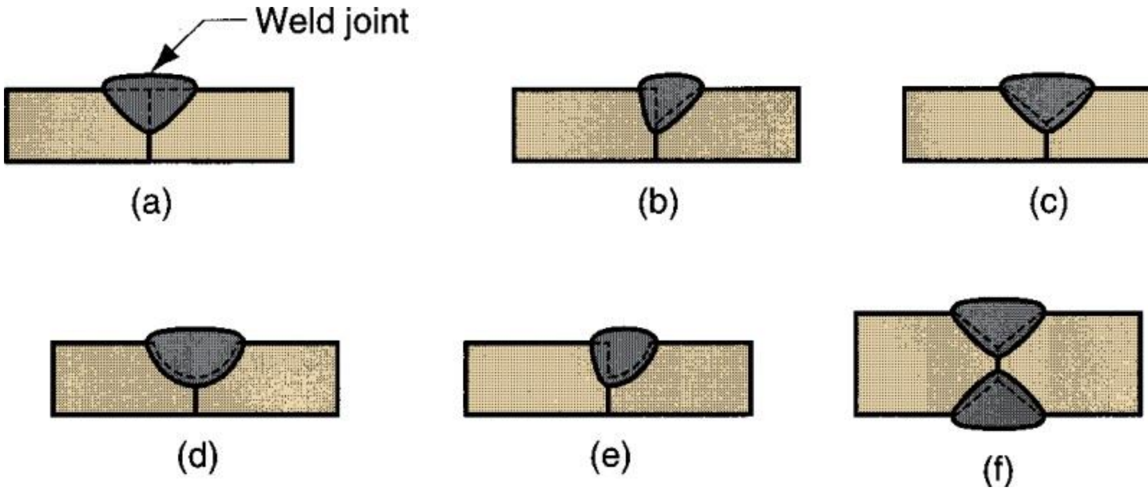


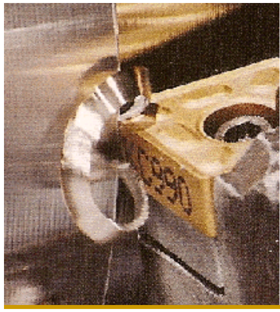
Groove Welds

- Usually requires part edges to be shaped into a groove to facilitate weld penetration
- Edge preparation increases cost of parts fabrication
- Grooved shapes include square, bevel, V, U, and J, in single or double sides
- Most closely associated with butt joints

Groove Welds

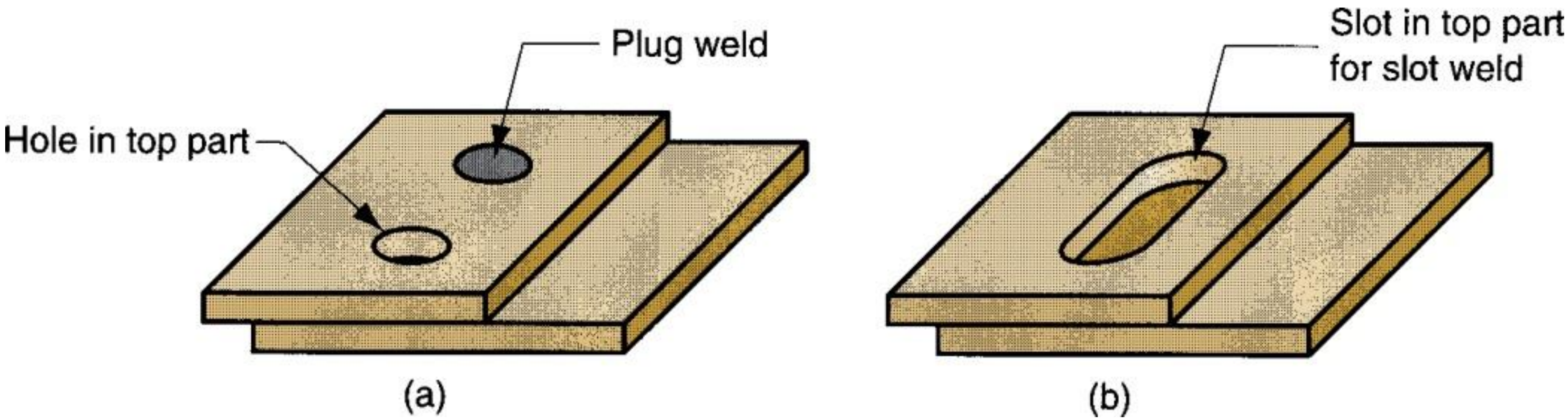
- (a) Square groove weld, one side; (b) single bevel groove weld; (c) single V-groove weld; (d) single U-groove weld; (e) single J-groove weld; (f) double V-groove weld for thicker sections (dashed lines show original part edges)

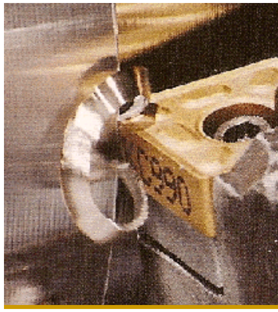




Plug Weld and Slot Weld

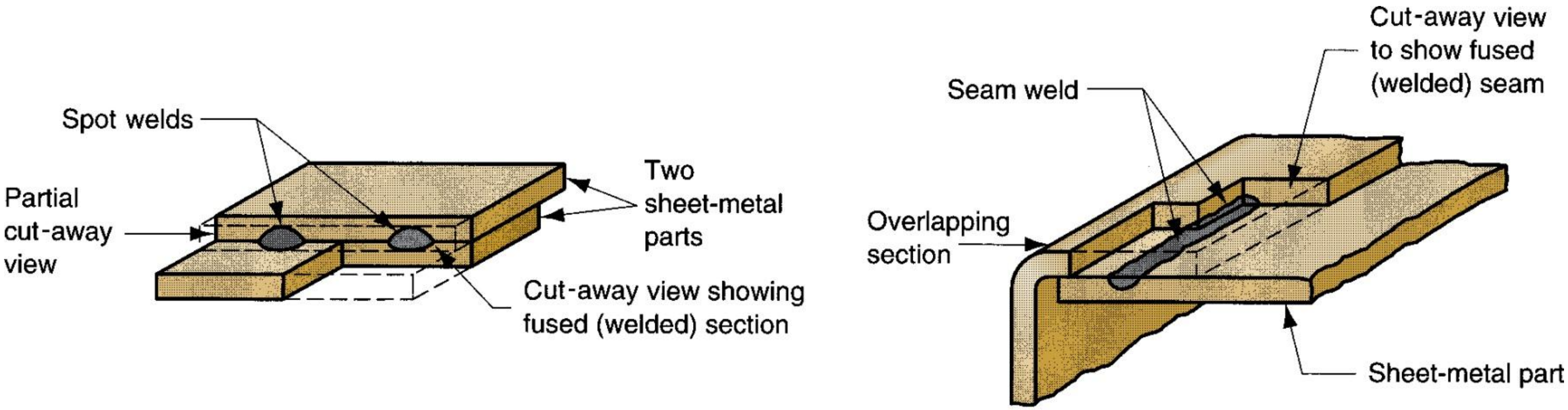
- (a) Plug weld and (b) slot weld



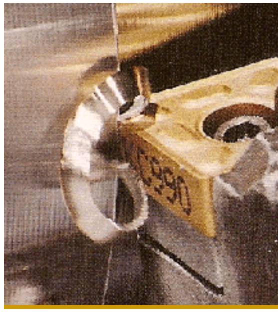


Spot Weld and Seam Weld

- Fused section between surfaces of two sheets or plates: (a) spot weld and (b) seam weld
  - Used for lap joints
  - Closely associated with resistance welding

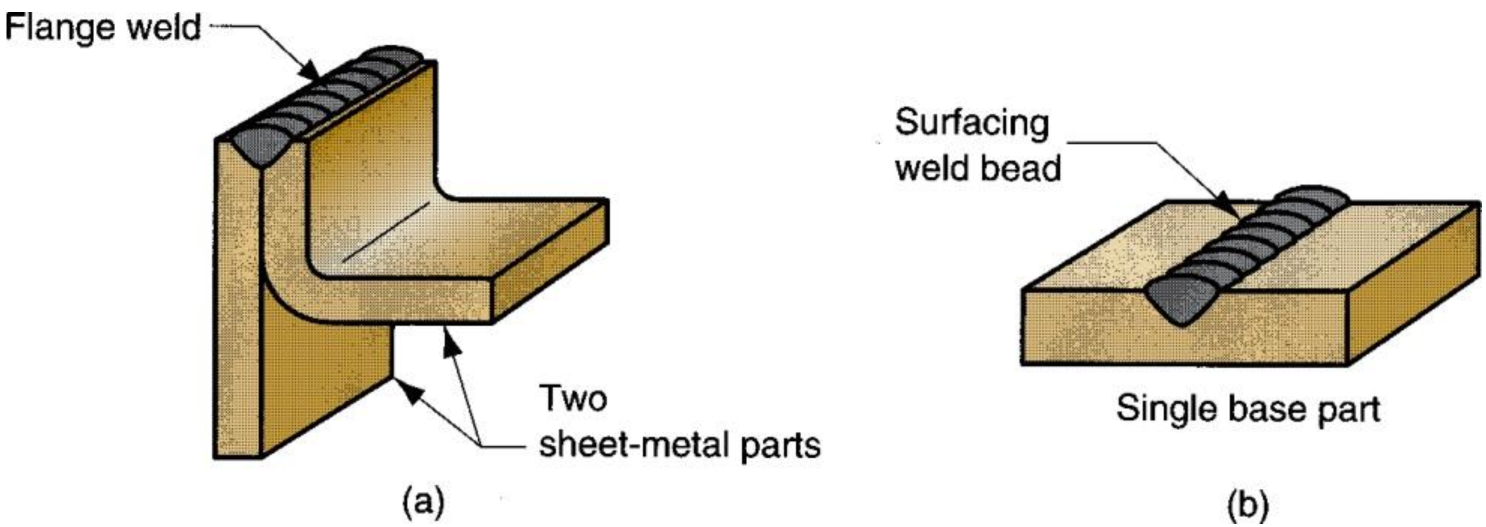


(a) (b)



Flange Weld and Surfacing Weld

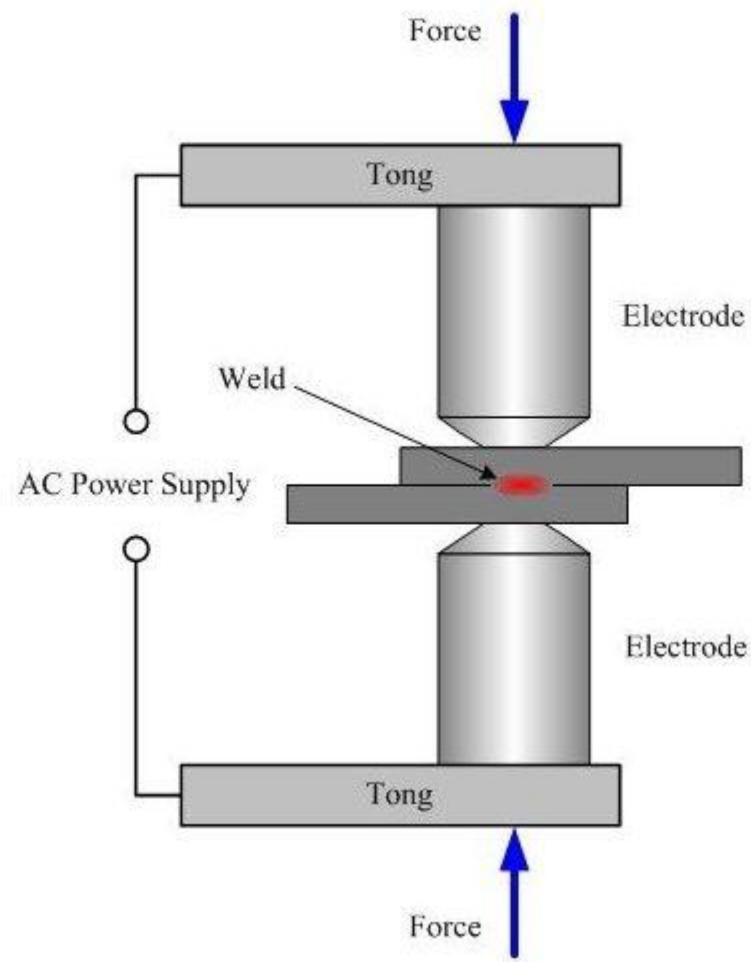
- (a) Flange weld and (b) surfacing weld used not to join parts but to deposit filler metal onto surface of a base part



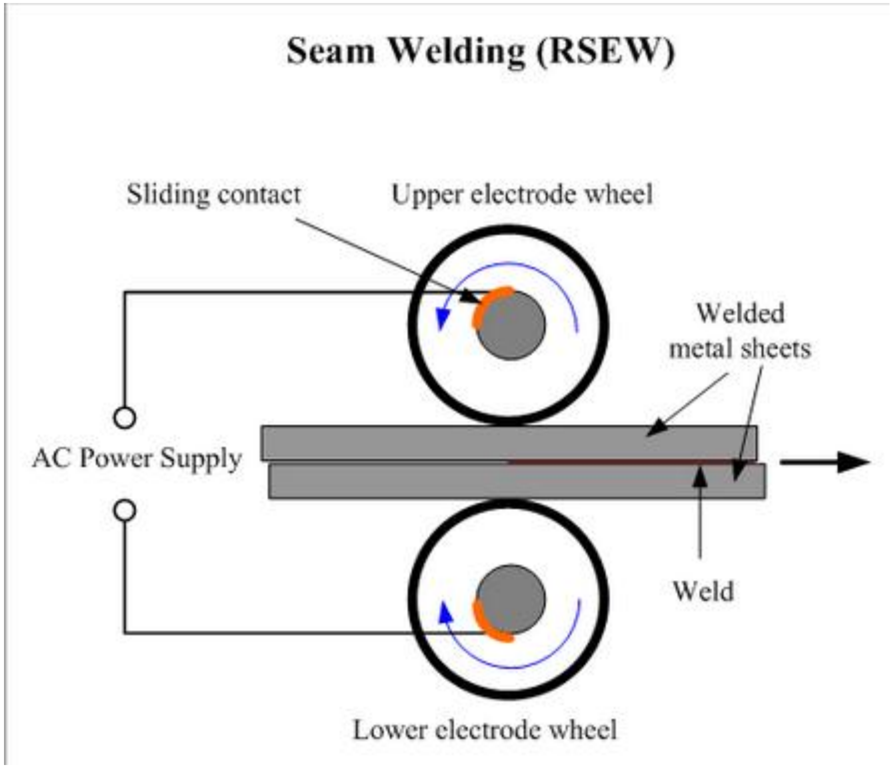
How does seam welding is differ from spot welding?

- Seam welding is same as of Spot welding. Difference is that in case of seam welding the rotating wheel is used and it is the fast process than spot welding.

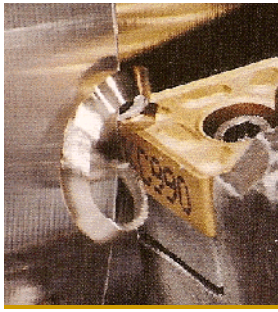
- Spot welding is mainly using for joining of the car body and Seam welding is using for making of fuel tank and all.



Spot welding



Seam welding



Physics of Welding

- Fusion is most common means of achieving coalescence in welding
- To accomplish fusion, a source of high density heat energy must be supplied to the faying surfaces
  - Resulting temperatures cause localized melting of base metals (and filler metal, if used)
- For metallurgical reasons, it is desirable to melt the metal with minimum energy but high heat densities

Power Density

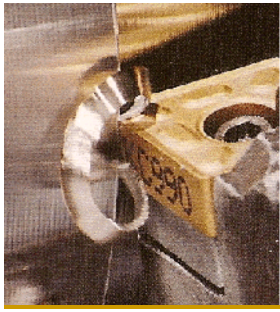
- Power transferred to work per unit surface area, W/mm^2 ($Btu/sec\text{-}in^2$)
  - If power density is too low, heat is conducted into work, so melting never occurs
  - If power density too high, localized temperatures vaporize metal in affected region
  - There is a practical range of values for heat density within which welding can be performed

Comparisons Among Welding Processes

- Oxyfuel gas welding (OFW) develops large amounts of heat, but heat density is relatively low because heat is spread over a large area
  - Oxyacetylene gas, the hottest OFW fuel, burns at a top temperature of around 3500°C (6300°F)
- Arc welding produces high energy over a smaller area, resulting in local temperatures of 5500° to 6600°C (10,000° to 12,000°F)

Power Densities for Welding Processes

Welding process	W/mm^2	(Btu/sec-in^2)
Oxyfuel	10	(6)
Arc	50	(30)
Resistance	1,000	(600)
Laser beam	9,000	(5,000)
Electron beam	10,000	(6,000)



Power Density

- Power entering surface divided by corresponding surface area:

$$PD = \frac{P}{A}$$

where PD = power density, W/mm^2 (Btu/sec-in^2); P = power entering surface, W (Btu/sec); and A = surface area over which energy is entering, mm^2 (in^2)

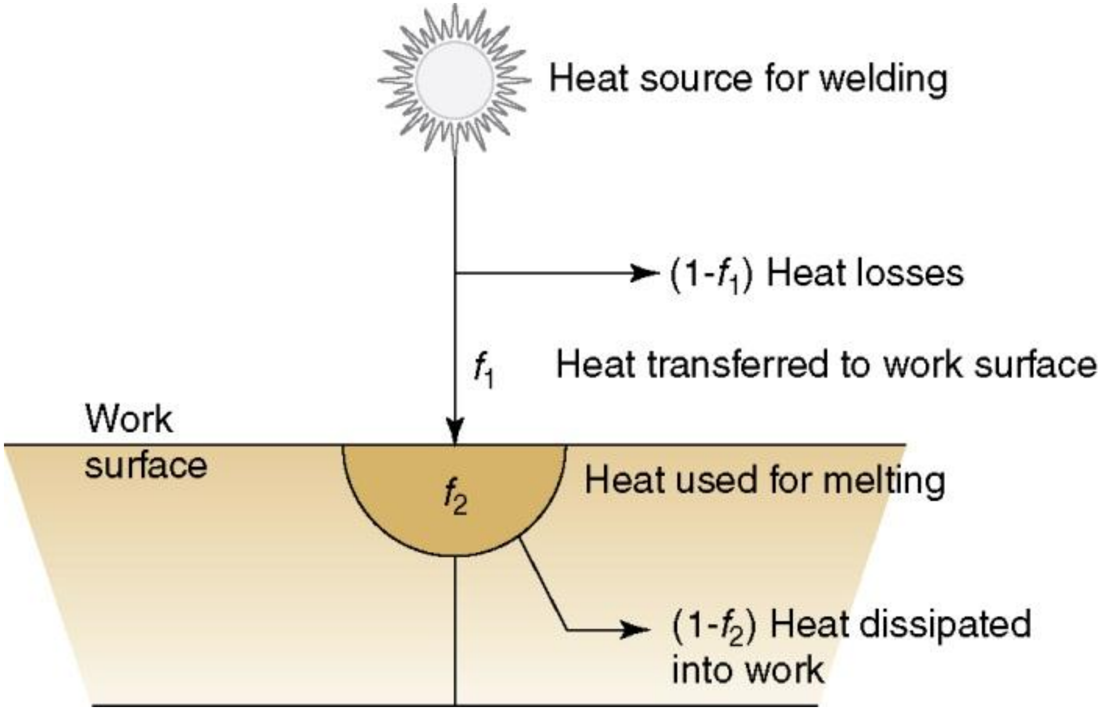
Unit Energy for Melting

- Quantity of heat required to melt a unit volume of metal
- Unit energy U_m is the sum of:
  - Heat to raise temperature of solid metal to melting point
    - Depends on metal's volumetric specific heat
  - Heat to transform metal from solid to liquid phase at melting point
    - Depends on metal's heat of fusion

Heat Transfer Mechanisms in Welding

- Not all of the input energy is used to melt the weld metal
  1. Heat transfer efficiency f_1 - actual heat received by workpiece divided by total heat generated at source
  2. Melting efficiency f_2 - proportion of heat received at work surface used for melting
     - The rest is conducted into work metal

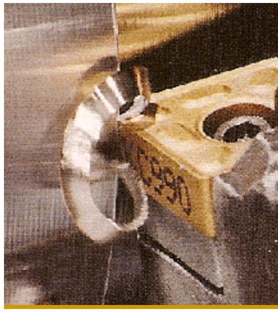
Heat Transfer Mechanisms in Welding



Heat Available for Welding

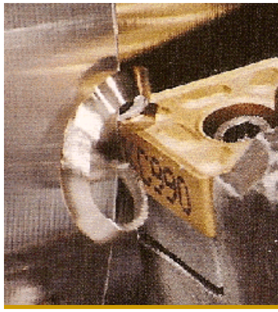
$$H_w = f_1 \, f_2 \, H$$

where H_w = net heat available for welding; f_1 = heat transfer efficiency; f_2 = melting efficiency; and H = total heat generated by welding process



Heat Transfer Efficiency f_1

- Proportion of heat received at work surface relative to total heat generated at source
  - Depends on welding process and capacity to convert power source (e.g., electrical energy) into usable heat at work surface
    - Oxyfuel gas welding processes are relatively inefficient
    - Arc welding processes are relatively efficient



Melting Efficiency f_2

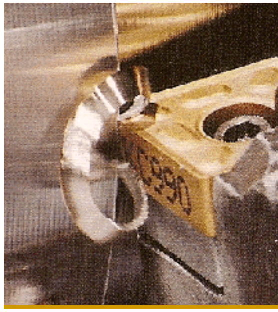
- Proportion of heat received at work surface used for melting; the rest is conducted into the work
  - Depends on welding process but also thermal properties of metal, joint shape, and work thickness
    - Metals with high thermal conductivity, such as aluminum and copper, present a problem in welding because of the rapid dissipation of heat away from the heat contact area

Energy Balance Equation

- Net heat energy into welding operation equals heat energy required to melt the volume of metal welded

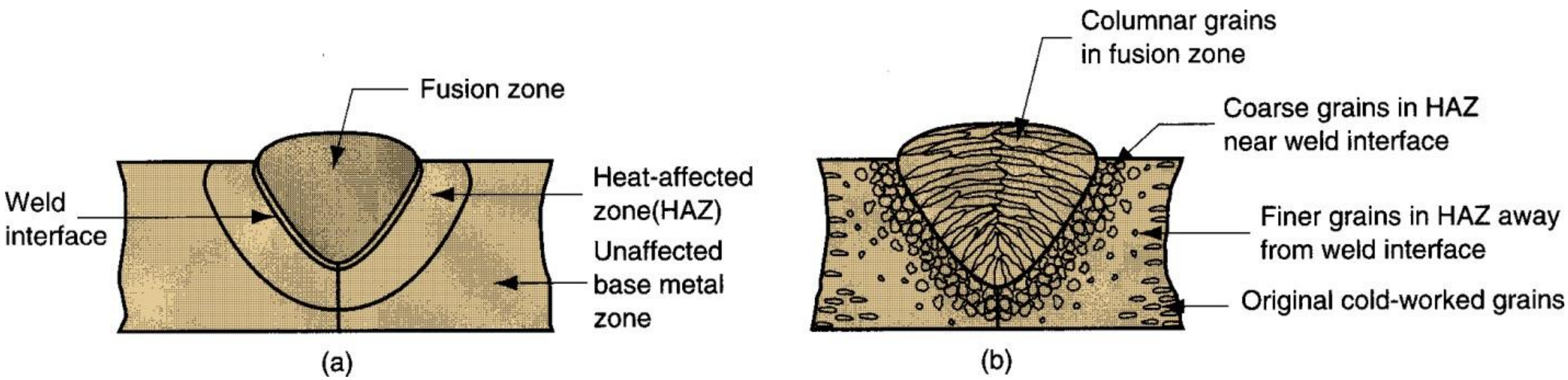
$$H_w = U_m V$$

where H_w = net heat energy delivered to operation, J (Btu); U_m = unit energy required to melt the metal, J/mm^3 (Btu/in^3); and V = volume of metal melted, mm^3 (in^3)



Typical Fusion Welded Joint

- Cross section of a typical fusion welded joint: (a) principal zones in the joint, and (b) typical grain structure



Features of Fusion Welded Joint

- Typical fusion weld joint in which filler metal has been added consists of:
  - Fusion zone
  - Weld interface
  - Heat affected zone (HAZ)
  - Unaffected base metal zone

Heat Affected Zone

- Metal has experienced temperatures below melting point, but high enough to cause microstructural changes in the solid metal
  - Chemical composition same as base metal, but this region has been heat treated so that its properties and structure have been altered
    - Effect on mechanical properties in HAZ is usually negative
    - It is here that welding failures often occur