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

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
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
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 differ from spot welding?

- Seam welding is the same as spot welding. The difference is that in the case of seam welding, the rotating wheel is used, and it is a faster process than spot welding.

- Spot welding is mainly used for joining car bodies, while seam welding is used for making fuel tanks and other components.
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, $W/\text{mm}^2$ (Btu/sec-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

<table>
<thead>
<tr>
<th>Welding process</th>
<th>W/mm$^2$</th>
<th>(Btu/sec-in$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxyfuel</td>
<td>10</td>
<td>(6)</td>
</tr>
<tr>
<td>Arc</td>
<td>50</td>
<td>(30)</td>
</tr>
<tr>
<td>Resistance</td>
<td>1,000</td>
<td>(600)</td>
</tr>
<tr>
<td>Laser beam</td>
<td>9,000</td>
<td>(5,000)</td>
</tr>
<tr>
<td>Electron beam</td>
<td>10,000</td>
<td>(6,000)</td>
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</tbody>
</table>
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 source for welding
  - (1-\(f_1\)) Heat losses
  - \(f_1\) Heat transferred to work surface
  - Work surface
  - \(f_2\) Heat used for melting
  - (1-\(f_2\)) Heat dissipated into work

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\(^3\))
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