MSE 440/540: Processing of Metallic Materials

Instructors: Yuntian Zhu
Office: 308 RBII
Ph: 513-0559
ytzhu@ncsu.edu

Lecture 7: Joining Methods
Joining and Assembly

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
Types of Welding Processes

Welding processes can be divided into two major categories:

Fusion welding
- Arc welding (AW)
- Resistance welding (RW)
- Oxyfuel gas welding (OFW)

Solid state welding: Joining processes using 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
Five Types of Joints

(a) Butt joint, (b) corner joint, (c) lap joint, (d) tee joint, and (e) edge joint
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)
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)
Plug Weld and Slot Weld

- (a) Plug weld and (b) slot 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
Typical Fusion Welded Joint

- Fusion zone
- Heat-affected zone (HAZ)
- Unaffected base metal zone
- Columnar grains in fusion zone
- Coarse grains in HAZ near weld interface
- Finer grains in HAZ away from weld interface
- Original cold-worked grains

Weld interface
Arc Welding: The most common fusion welding

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

http://www.youtube.com/watch?v=TeBX6cKKHWY
Two Basic Types of Arc Welding Electrodes

- Consumable – consumed during welding process
  - Source of filler metal in arc welding
- Nonconsumable – not consumed during welding process (e.g. Tungsten)
  - Filler metal must be added separately if it is added
Arc Shielding

- At high temperatures in arc welding, metals are chemically reactive to O₂, N₂ and H₂ 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, CO₂
  - 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 spatter

Flux Application

- 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
Consumable Electrode Arc Welding 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.
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
- Disadvantages of stick welding:
  - Sticks must be periodically changed
  - High current levels may melt coating prematurely
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

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

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

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

http://www.youtube.com/watch?v=66-RK0DPXfU
Resistance Seam Welding
Roll Welding

Parts to be welded → Roll → Weld → Welded parts

Surface treatment → Degreasing & Wire brushing → Stacking → Roll-bonding → Cutting
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

http://www.youtube.com/watch?v=HvJee_1w4tA
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

http://www.youtube.com/watch?v=5JbnDXw-0pM
Friction Stir Welding

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

http://www.youtube.com/watch?v=_qAOKR6mdTI
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
Brazing

Joining process in which a filler metal is melted and distributed by capillary action between faying surfaces of metal parts being joined

- No melting of base metals occurs
  - Only the filler melts

- Filler metal $T_m$ is greater than 450°C (840°F)
  - But less than $T_m$ of base metal(s) to be joined
Brazing Compared to Welding

- Any metals can be joined, including dissimilar metals
- Can be performed quickly and consistently, permitting high production rates
- Multiple joints can be brazed simultaneously
- Less heat and power required than FW
- Problems with HAZ in base metal are reduced
- Joint areas that are inaccessible by many welding processes can be brazed
  - Capillary action draws molten filler metal into joint
Disadvantages and Limitations of Brazing

• Joint strength is generally less than a welded joint
• Joint strength is likely to be less than the strength of the base metals
• High service temperatures may weaken a brazed joint
• Color of brazing metal may not match color of base metal parts
  – A possible aesthetic disadvantage
Brazing Applications

- Automotive (e.g., joining tubes and pipes)
- Electrical equipment (e.g., joining wires and cables)
- Cutting tools (e.g., brazing cemented carbide inserts to shanks)
- Jewelry
- Chemical process industry
- Plumbing and heating contractors join metal pipes and tubes by brazing
- Repair and maintenance work
Soldering

Joining process in which a filler metal with $T_m$ less than or equal to 450C (840F) is melted and distributed by capillary action between faying surfaces of metal parts being joined

- No melting of base metals, but filler metal wets and combines with base metal to form metallurgical bond
- Filler metal called *solder*
- Closely associated with electrical assembly
Soldering Advantages and Disadvantages

Advantages:
• Lower energy than brazing or fusion welding
• Variety of heating methods available
• Good electrical and thermal conductivity in joint
• Easy repair and rework

Disadvantages:
• Low joint strength unless reinforced mechanically
• Joint weakens or melts at elevated temperatures
Solders

Traditionally alloys of tin and lead (both have low $T_m$)

- Lead is poisonous and its percentage is minimized in most solders
- Tin is chemically active at soldering temperatures and promotes wetting action for successful joining
  - In soldering copper, copper and tin form intermetallic compounds that strengthen bond
- Silver and antimony also used in soldering alloys
Soldering Fluxes: Functions

- Be molten at soldering temperatures
- Remove oxide films and tarnish from base part surfaces
- Prevent oxidation during heating
- Promote wetting of surfaces
- Be readily displaced by molten solder during process
- Leave residue that is non-corrosive and nonconductive
Soldering Methods

• Many soldering methods same as for brazing, except less heat and lower temperatures are required

• Additional methods:
  – Hand soldering – manually operated soldering gun
  – Wave soldering – soldering of multiple lead wires in printed circuit cards
  – Reflow soldering – used for surface mount components on printed circuit cards
HW assignment

• Reading assignment: Chapters 12, 13