Lecture #32

ERDM

Prof. John W. Sutherland

April 3, 2002
Joining Operations

- Generally involve placement of components in intimate contact, and then securing their relative positions

- Types of Joining (D.O. Anderson -- La Tech)
  - Chemical
  - Mechanical
  - Thermal

- Remember -- think about the environmental issues....
Joining Types
(D.O. Anderson -- La Tech)

- Chemical Joining
  - Adhesive Bonding (not externally heated)
  - Solvent Bonding

- Mechanical Joining
  - Explosive Welding
  - Friction (inertial) Welding
    # Ultrasonic Welding
- Laminating
  # Bulk Laminating
    ^ Spray Lay-up
    ^ Hand Lay-up
  # Filament Winding
  # Pultrusion
  # Sheet Laminating
    ^ Layered Object Manufacturing (LOM)
- Mechanical Fastening
  # by Bolt
  # by Latch
  # by Rivet
  # by Screw
- Pressure (Cold) Welding
- **Thermal Joining**
  - Brazing/Soldering (hot metallic adhesive)
    # Dip Brazing/Soldering
    # Furnace Brazing/Soldering
    # Induction Brazing/Soldering
    # Infrared Brazing/Soldering
    # Iron Soldering
    # Resistance Brazing/Soldering
    # Torch Brazing/Soldering
    # Wave Soldering

- **Hot Nonmetallic Adhesive**
  # hot glue (melt a solid adhesive and let it resolidify)
- Thermal Welding
  # Diffusion Bonding
  # Electric Resistance Welding
    ^ Butt Welding
    ^ Electroslag Welding
    ^ Percussion Welding
    ^ Projection Welding
    ^ Seam Welding
    ^ Spot Welding
  # Electric Arc Welding
    ^ Carbon Arc Welding
    ^ Metal Inert Gas (MIG) Welding
    ^ Shielded Metal Arc Welding (Arc Welding)
    ^ Submerged Arc Welding
    ^ Tungsten Inert Gas (TIG) Welding
# Gas/Chemical Welding
- Atomic Hydrogen Welding
- Combustible Gas Welding (i.e. Oxy-Acetylene)
- Thermite Welding

# High Energy Beam Welding
- Electron Beam Welding
- Laser Beam Welding
- Plasma Arc (Ion Beam) Welding

- Other classifications focus on Permanent vs. Non-permanent, mechanical/chemical/thermal, & state (solid-solid, solid-liquid, etc.)
General Joining Comments

• Addition of an adhesive/filler material or through the application of heat to promote diffusive bonding. Produce a variety of wastes and consume considerable amounts of energy.

• Adhesive bonding: epoxy resins used to join metallic or non-metallic materials. Some adhesives generate VOCs and other airborne contaminants. Components often require some surface preparation (e.g., cleaning and degreasing).
More General Thoughts

- Soldering and brazing: molten filler material added to gap between components. Alternative solder materials

- Mechanical joining uses physical means to hold components together: screws, snaps, rivets, and bolts. Environmental effects largely associated with the energy required to perform the operation and the manufacture of the fasteners. Reversible.

- Welding operations: HAPs, used materials, waste, heat, and EMR (retinal damage?).
Want More Concerns?

- Most popular welding operation is arc welding.
- NIOSH (1988) reports a number of health-related concerns associated with this process.
- Fumes/particulates -- condensation of vapors from metals, coatings, and fluxes.
- NIOSH [1990] reports that welders have an additional 40 percent risk of getting lung cancer.
- The American Conference of Government Industrial Hygienists has assigned welding fumes a threshold limit value (TLV) of 5 mg/m³ [ACGIH, 1988].
Adhesive Bonding
(Loctite)

- Acrylic Adhesives
- Cyanoacrylate Adhesives
- Epoxy & Urethane Adhesives
- Fiber Optics
- Hot Melt Adhesives
- Light Cure Adhesives

- Response to Environmental Concerns
  - Reduce/eliminate VOCs
  - Move toward aqueous-based systems
  - Less hazardous solvents
## Adhesive Comparisons

<table>
<thead>
<tr>
<th>PERFORMANCE CONSIDERATIONS</th>
<th>ADHESIVE CATEGORY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acrylics</td>
</tr>
<tr>
<td>Benefits</td>
<td>Good impact resistance/ flexibility</td>
</tr>
<tr>
<td>Limitations</td>
<td>Primer required</td>
</tr>
<tr>
<td>Temperature Resistance</td>
<td>-65 to +300 400</td>
</tr>
<tr>
<td>Environmental Resistance</td>
<td>Good</td>
</tr>
<tr>
<td>Polar Solvents</td>
<td>Acetone, Ethylene Glycol, IPA</td>
</tr>
<tr>
<td>Non-Polar Solvents</td>
<td>Gasoline, ATF</td>
</tr>
<tr>
<td>Adhesion to Substrates</td>
<td>Excellent</td>
</tr>
<tr>
<td>Metals</td>
<td>Excellent</td>
</tr>
<tr>
<td>Plastics</td>
<td>Excellent</td>
</tr>
<tr>
<td>Glass</td>
<td>Excellent</td>
</tr>
<tr>
<td>Rubber</td>
<td>Poor</td>
</tr>
<tr>
<td>Wood</td>
<td>Good</td>
</tr>
<tr>
<td>Overlapping Shear Strength</td>
<td>High</td>
</tr>
<tr>
<td>Peel Strength</td>
<td>Medium</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>High</td>
</tr>
<tr>
<td>Elongation/Flexibility</td>
<td>Medium</td>
</tr>
<tr>
<td>Hardness</td>
<td>Semi-Rigid</td>
</tr>
</tbody>
</table>

© John W. Sutherland

Environmentally Responsible Design & Manufacturing (MEEM 4685/5685)
Dept. of Mechanical Engineering - Engineering Mechanics
Michigan Technological University
Theories of Adhesive Bonding

- Each theory inadequate to describe complete process of bonding by itself.
- Mechanical Bonding: adhesive fills valleys/asperities of each adherend (body to be bonded). Adhesion is the mechanical interlocking of the adhesive and the adherend together.
- Adsorption Mechanism Theory: Intermolecular attraction (van der Waals bonding or permanent dipole, for example) -- wetting -- surface energy
- Electrostatic Theory: Electrostatic forces.
- Weak-Boundary Layer Theory: Explains curious behavior - adhesive bonds break not at the adhesion interface, but slightly within the adherend. Boundary layer of weak material formed around interface -- impurities or adverse chemical reactions.
Greening Adhesive Joining
(from Northeast Waste Management Officials Association)

- Reducing the amount of solvents used in adhesive joining represents one of the greatest opportunities for pollution prevention. Solvent-free alternatives include water-based, hot melt, and radiation-cured adhesives.

- Water-based Adhesives: Formulated from rubber components with water as the carrier fluid. Curing may be performed in ovens or under ambient conditions. Water-based adhesives may sometimes be applied using existing equipment.
Water-based Adhesives (PPRC 1998a)

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>no HAPS or VOCs</td>
<td>lower peel strength</td>
</tr>
<tr>
<td>no explosion risk</td>
<td>lower shear strength</td>
</tr>
<tr>
<td></td>
<td>lower humidity resistance</td>
</tr>
<tr>
<td></td>
<td>less flexible</td>
</tr>
<tr>
<td></td>
<td>may need an oven, so energy costs may increase</td>
</tr>
</tbody>
</table>

- Purchase costs of water-based adhesives are 15 to 20 percent lower & overall costs are 33 percent lower than solvent-based. systems. (PPRC 1998a).
Hot Melt Adhesives

- Hot melt adhesives are solvent-free -- solid at temperatures below 180°F. Eliminate VOCs since the solvent is the volatile portion of the adhesive formula. Examples:
  - ethylene vinyl acetate (EVA) copolymers
  - styrene-isopropene-styrene copolymers
  - styrene-butadiene-styrene (SBS) copolymers
  - ethylene ethyl acrylate (EEA) copolymers
  - polyurethane reactive (PUR)

- May replace mechanical fasteners in some applications (PPRC 1998b).
## Hot Melt Adhesives (PPRC 1998b)

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>form a strong bond quickly</td>
<td>cannot be used with heat sensitive substrates</td>
</tr>
<tr>
<td>compatible with most materials</td>
<td>lose strength at high temperatures</td>
</tr>
<tr>
<td>easy to handle</td>
<td>chemical resistance may be lacking</td>
</tr>
<tr>
<td>less water sensitive than other thermoplastic polymers</td>
<td>exposure to high temperatures can cause adhesive to melt</td>
</tr>
<tr>
<td>once applied, unaffected by water, moisture, or humidity</td>
<td>applied at temperatures above 300°F</td>
</tr>
<tr>
<td>100 percent solids; no VOCs, no HAPs</td>
<td>clean-up must be done immediately</td>
</tr>
<tr>
<td>rapid set-up</td>
<td></td>
</tr>
<tr>
<td>less expensive than solvent-based adhesives, pound for pound dry solids</td>
<td></td>
</tr>
<tr>
<td>weight</td>
<td></td>
</tr>
</tbody>
</table>
Soldering

- Soldering: process of using fusible alloys for joining metals -- solder type depends on metals being joined.

- Hard solders: spelter -- hard soldering is called silver solder brazing.

Brazing

- Brazing: similar to soldering in that a filler rod with a melting point lower than that of the base metal, but above 800°F is used.

- Groove, fillet, plug, or slot weld is made -- filler metal distributed by capillary action.

- Filler metal depends on the types of metals to be joined. Examples: Cu-Si (silicon-bronze) for brazing copper alloys. Cu-Sn (phosphor-bronze) for brazing similar copper alloys & steel / cast iron.

- Flux may be used to prevent oxidation -- chemically active and fluid at the brazing temperature.
Greening Soldering and Brazing

- Wastes resulting from soldering and brazing operations include excess fluxes, solders, and filler metals, spent cleaner baths, and VOC emissions from fluxes.

- Changing the materials or more strictly controlling the operating parameters may reduce or eliminate waste generation.

- Strategies for Improvement
• Alternative Fluxes and Solders
  Avoid cadmium-bearing solders, lead-bearing solders, and low-VOC solder and brazing fluxes.

• Elimination of Post-cleaning -- excess flux often removed with alcohol, chlorinated hydrocarbon solvents, alkaline cleaners, or dilute acids. Try to avoid post cleaning then alkaline cleaners preferable.

• Optimize Flux Delivery -- Deliver only as much flux, solder, or filler metal as needed to form joint.

• Optimize Heating of Filler Metal

• Dross Removal -- manually skimming of bath
Welding Basics
Types of Joints

Welding Electrodes

- **Covered Electrodes** -- slag cover protects weld metal from atmosphere. Source of cover: electrode coating.

- **Coatings**: Cellulose-sodium, Cellulose-potassium, Rutile-sodium, Rutile-potassium, Rutile-iron powder, low hydrogen-sodium, low hydrogen-potassium, etc.

- **Shielded Arc or Heavy Coated Electrodes**: Cellulose coatings, mineral coatings, & combination of mineral and cellulose. Cellulose: soluble cotton (cellulose) + potassium, sodium, or titanium. Mineral: sodium silicate, metallic oxides, clay, & other inorganics.
Welding Fumes

- Fume constituents may include: arsenic, nickel, iron, copper, tin, lead, beryllium, silicon, cadmium, cobalt, manganese, magnesium, molybdenum, chromium, vanadium, and zinc [NIOSH, 1988; AWS, 1987].

- Gas phase: carbon dioxide, carbon monoxide, nitrogen oxides, and ozone [Welding Institute, 1976].

- Fume formation rates for SMAW range from 8.0 to 81.6 g fumes/ kg of electrode consumed [EPA, 1991].

- Stern [1977]: mass median diameter 0.3-0.5 μm

- Fume emissions depend on process variables.
## MTU Tests

<table>
<thead>
<tr>
<th>Composition</th>
<th>E7014</th>
<th>E6013</th>
<th>E316-16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium, Ca</td>
<td>19.38</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Potassium, K</td>
<td>0.00</td>
<td>0.00</td>
<td>40.25</td>
</tr>
<tr>
<td>Silicon, Si</td>
<td>78.88</td>
<td>94.34</td>
<td>51.54</td>
</tr>
<tr>
<td>Iron, Fe</td>
<td>1.23</td>
<td>5.66</td>
<td>4.88</td>
</tr>
<tr>
<td>Manganese, Mn</td>
<td>0.37</td>
<td>0.00</td>
<td>0.89</td>
</tr>
<tr>
<td>Chromium, Cr</td>
<td>0.00</td>
<td>0.00</td>
<td>2.44</td>
</tr>
<tr>
<td>Zinc, Zn</td>
<td>0.13</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>
Mass Concentration Behavior

![Graph showing mass concentration behavior over time for MG 500 and E316-16.]