Lecture #32

ERDM

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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 metalic adhesive)**
    - **Dip Brazing/Soldering**
    - **Furnace Brazing/Soldering**
    - **Induction Brazing/Soldering**
    - **Infrared Brazing/Soldering**
    - **Iron Soldering**
    - **Resistance Brazing/Soldering**
    - **Torch Brazing/Soldering**
    - **Wave Soldering**

  - **Hot Nonmetalic 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. Evironmental 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/m^3 [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

PERFORMANCE CONSIDERATIONS	ADHESIVE CATEGORY					
	Acrylics	Cyanoacrylates	Epoxies	Hot Melts	Silicones	Urethanes
Benefits	Good impact resistance/ flexibility	Excellent adhesion to rubber or plastics	Wide range of formulations	Fast, large gap filling	Excellent temperature resistance	Excellent toughness/ flexibility
Limitations	Primer required	Low solvent resistance	Mixing required	Low heat resistance	Low strength	Sensitive to moisture
Temperature Resistance						
Typical for the category (°F)	-65 to +300	-65 to +180	-65 to +180	-65 to +250	-65 to +400	-65 to +250
Highest Rated Product (°F)	400	250	275	330	600	300
Environmental Resistance						
Polar Solvents *(ex, H20, Ethylene Glycol, IPA, Acetone)*	Good	Poor[1]	Very good	Good	Good	Good
Non-Polar Solvents *(ex, Motor Oil, Toluene, Gasoline, ATF)*	Very good	Good	Excellent	Good	Poor	Good
Adhesion to Substrates						
Metals	Excellent	Very good	Excellent	Good	Good	Good
Plastics[2]	Fair	Excellent	Fair	Very good	Fair	Very good
Glass	Excellent	Poor	Excellent	Good	Very good	Good
Rubber	Poor	Very good	Fair	Fair	Good	Good
Wood	Good	Good	Very Good	Excellent	Fair	Fair
Overlapping Shear Strength	High	High	High	Low	Low	Medium
Peel Strength	Medium	Low	Medium	Medium	Medium	Medium
Tensile Strength	High	High	High	Low	Low	Medium
Elongation/Flexibility	Medium	Low	Low	High	Very High	High
Hardness	Semi-Rigid	Rigid	Rigid	Semi-Soft	Soft	Soft

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)

Advantages	Limitations
no HAPS or VOCs no explosion risk	lower peel strength lower shear strength lower humidity resistance less flexible may need an oven, so energy costs may increase

- 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-styreneopolymers**
  - **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)

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

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.**
- **Soft soldering -- common metals -- solder melts at a temperature below that of base metal (always < 800°F). Sn-Pb alloy most common. Others: tin-antimony-lead, tin-lead-silver, tin-zinc, cadmium-silver, cadmium-zinc, zinc-aluminum, bismuth, and indium.**

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.

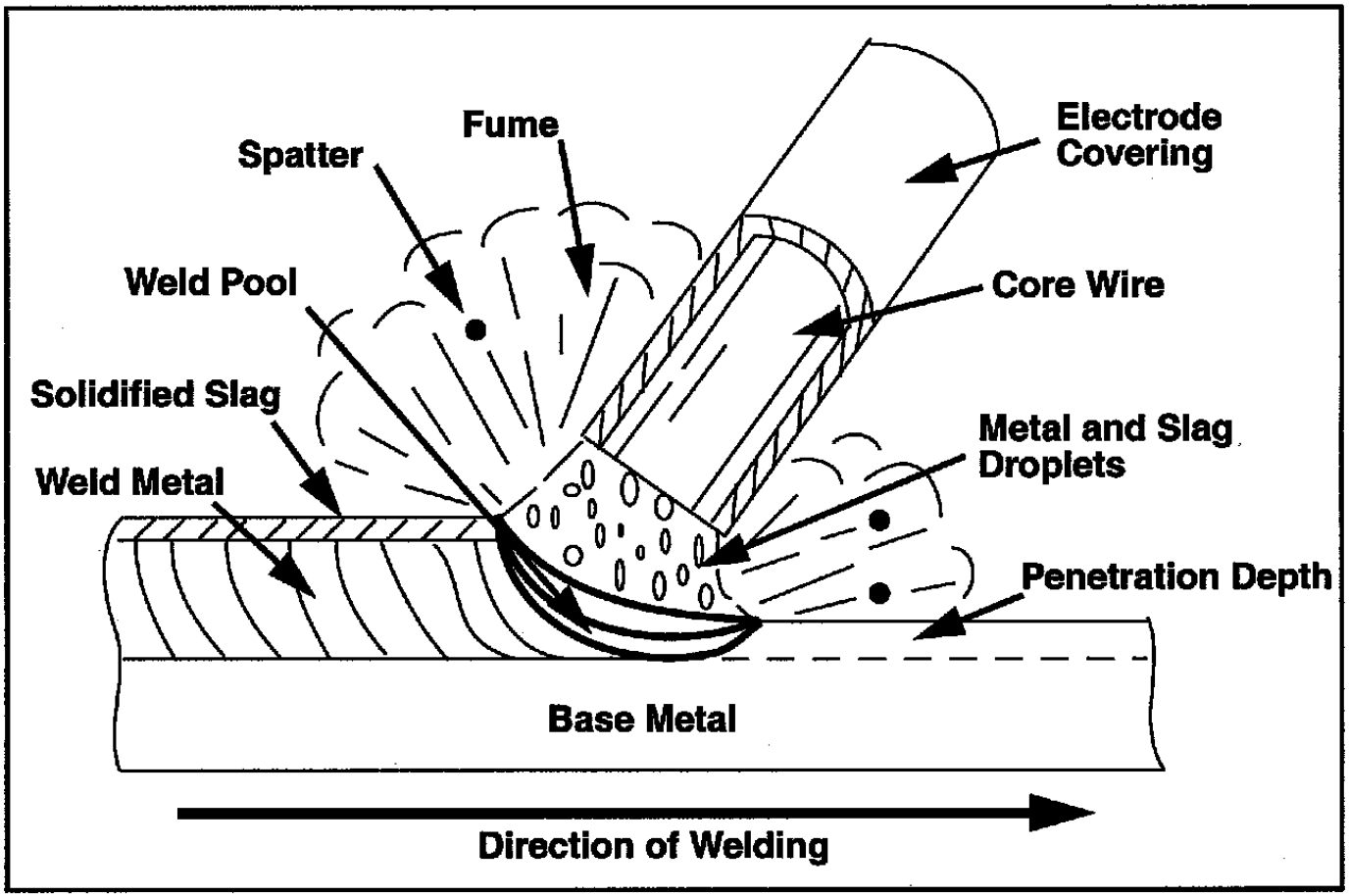
- **Elimination of Post-cleaning -- excess flux often removed with alcohol, chlorinated hydrocarbon solvents, alkaline cleaners, or dilute acids. Try to avoid post cleaning then alkaline cleaners preferable.**

- **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**

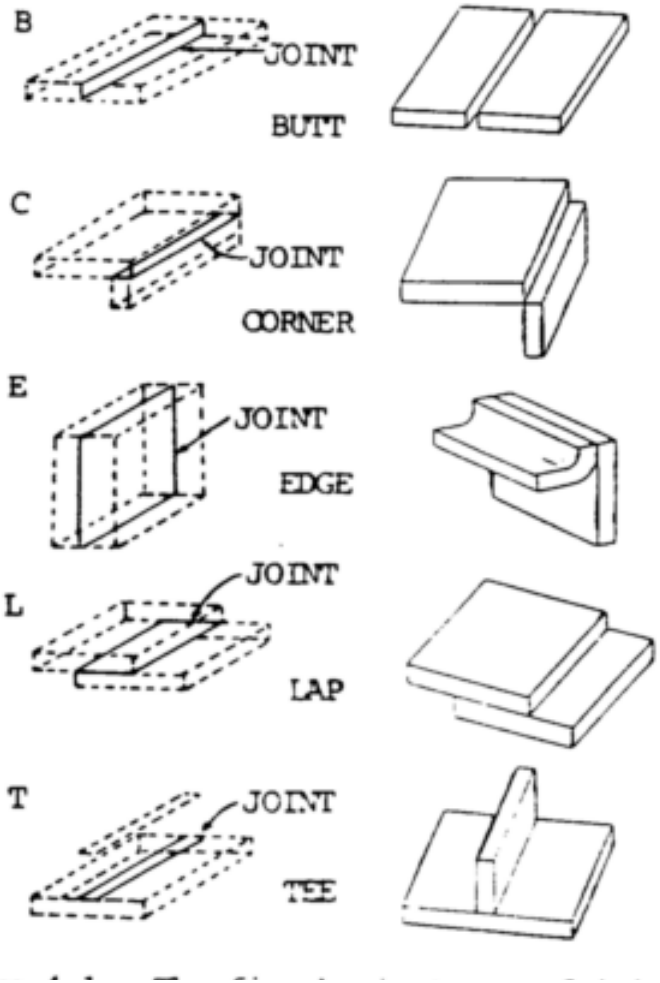
Welding Basics



V-C-O

Types of Joints

http://www.adtdl.army.mil/cgi-bin/atdl.dll/tc/9-237/toc.htm



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

Composition	E7014	E6013	E316-16
Calcium, Ca	19.38	0.00	0.00
Potassium, K	0.00	0.00	40.25
Silicon, Si	78.88	94.34	51.54
Iron, Fe	1.23	5.66	4.88
Manganese, Mn	0.37	0.00	0.89
Chromium, Cr	0.00	0.00	2.44
Zinc, Zn	0.13	0.00	0.00

Mass Concentration Behavior