Fundamentals of Adhesives Used in Assembly

Part I:

General Overview and U.S. Industry Market Statistics

Originally presented at:
Assembly Tech Expo
September 2004
Assembly Adhesives: Selecting the Right Product

Definition of Assembly:
- The fitting together of parts to make a whole

Methods of Assembly:
- Mechanical (bolts, screws, tabs, rivets, crimps, pegs, nails)
- Heat (weld, braze, solder)
- Joint Design (dove tail, mortise, tenon)
- Adhere (adhesive, tape)

Assembly may involve combinations of the above
Conventional Mechanical Fasteners

Bolts, screws, rivets, staples, tabs, posts, and nuts, attach/join component. Device inserted to hold material or substrate in place.

**Advantages:**
• Fairly easy application, low capital for equipment needed to apply, nominal labor and provides good product aesthetics.

**Disadvantages:**
• Higher component costs: ↑ pre-fabricated fasteners inventory

• Smaller contact limits bond to materials: ↓ load performance

• Prone to loosening, weakening, rusting: ↑ noise source
Global Assembly Fastening Market

- **Bolts & Nuts**: 20%
- **Screws/Nails**: 7%
- **Weld/Braze**: 28%
- **Crimps**: 10%
- **Tapes**: 3%
- **Rivets**: 20%
- **Tabs**: 6%
- **Adhesives**: 6%

**Global Fastening Market**: US $356 billion ◇ AGR 4%-5%

*Total does not include sealants, plywood binder, rug backing and corrugation

Source: DPNA International Inc.
Why Choose An Adhesive?

- Permits joining of materials with dissimilar coefficients of expansion and contraction
- Allows components to be designed with an “invisible” means of attachment
**Joining Methods**

**Mechanical Engineering Solutions**
- Fasteners - nuts, bolts, nails, staples, screws, tap, posts
- Rivets
- Weld/Solder

**Chemical Engineering Solutions**
- Hot Melt Adhesives
- Spray Adhesives
- Liquid Adhesives
- Pressure-sensitive adhesives (PSAs)
Joining Method Considerations

Quality

Production Time  Investment
Adhesive Selection Process

1. Identify the substrates
2. Specify the service requirements
3. Determine the assembly process
4. Review the adhesive options available
5. Select the adhesive
6. Test the bond
Substrates

May include, but are not limited to...

- Paper
- Glass
- Textile
- Ceramic
- Plastic
- Leather
- Metal
- Wood
- Rubber
- Concrete
Adhesive Strengths

- Distributes joint stress
- Permits use of different materials
- Isolates two dissimilar metals
- Can be made electrically conductive or non-conductive
- Absorbs vibration
- Provides design flexibility
- Reduces weight of assembly
- Fills voids
- Invisible
Adhesive Weaknesses

- Complicates quality control of bond
- May not withstand high or low temperatures
- Poor joint design = failure
- Some require mixing 2 or more components
- Requires careful surface preparation
- Parts need to be held in place (fixtured) during bond formation
Key Performance Factors

• **Adhesion**: Measure of bond strength between an adhesive and a substrate.

• **Tack**: The initial attraction or grab of an adhesive to a substrate.

• **Shear**: The internal or cohesive strength of an adhesive film.

**A universal all-purpose adhesive does not exist!**
Assembly Adhesive Industry

• Water borne and solvent contact adhesives represent more than half of assembly adhesives sold

• Making up the majority of the remaining assembly adhesives are epoxies, urethanes, cyanoacrylates, modified acrylics and hot melts
Adhesives in Assembly:
Hot Melts

Ethylene vinyl acetate (EVA)-based materials, applied as a molten substance and forms a bond when cooled. Bond achieved by applying adhesive in beads or swirls on substrate.

Advantages:
• Inexpensive low raw material costs

Disadvantages:
• Constant inspection by user to ensure quality -- ↑ labor
• Equipment to melt & deliver adhesive is needed, difficult to apply adhesive to very edge of parts -- ↑ higher capital/maintenance
• Performance may be adversely affected by time between application of adhesive on one substrate until contact to second substrate
Adhesives in Assembly: Liquid & Spray

Solvent based, emulsion, epoxies or acrylates applied via air pressure mist or dispensing applicator, a brush, or roller coating. Additional equipment may be required to activate curing to set and establish the bond. May or may not be tacky to the touch after drying. Upon application of adhesive, second substrate can be bonded.

Advantages:
• Inexpensive, low material costs, can achieve 100% coverage

Disadvantages:
• Overspraying, difficult to limit to specific areas
• High capital for application equipment, maintenance, labor intensive in use
• Environmental and regulatory process implications for solvent-based products
• May be subject to labor intensive clean up
Adhesives in Assembly: Pressure-Sensitive

A term designating a distinct category of adhesives which in dry form are aggressive and permanently tacky at room temperature. Supplied on a webstock, pressure sensitive adhesives (PSAs) cover a wide range of performance characteristics & properties for specific applications. Options include single-coated tape, double-coated, transfer adhesive, adhesive sandwich.

• Will adhere to a variety of substrates when applied with pressure, including difficult-to-adhere low surface energy plastics
• Do not require activation by water, solvent or heat
• Have sufficient cohesive strength so they can be handled with the fingers
Pressure-Sensitive Adhesives

**Advantages:**
- Minimal capital costs to apply on substrates
- Provides 100% coverage for optimal adhesion to bonding area
- Can improve aesthetics by eliminating visible mechanical fasteners
- Provides structural strength that can replace bolts, rivets, welds and other mechanical fasteners
- Permits use of lighter, thinner materials
- Bond dissimilar materials without incompatibility concerns
- Acts as moisture seal/environmental barrier
- Provides uniform thickness, gap-filling properties
- Shortens assembly time and boosts productivity (eliminates the need for bonding “both” substrates together at the same time and location providing optimum manufacturing flexibility)
- Eliminates need for surface refinishing to remove weld distortions, etc.
- Provides properties and functionalities beyond joining: sound/vibration damping, thermal conductivity, anti-friction/abrasion resistance, flame retardancy

**Disadvantages:**
- PSAs range from $1.00/MSI (thousand square inch) to $25/MSI (often higher than competitive fasteners)
Adhesive Product Trends

• New thermoset hot melts
• Multiple step cure
• Introduction of inorganic polymer adhesives
• Multi-purpose adhesives
• Structural tapes (*refer to Part III of this presentation*)
# Joining Technologies Comparison

<table>
<thead>
<tr>
<th></th>
<th>Radial/Orbital Riveting</th>
<th>Clinching</th>
<th>Self Piercing Riveting</th>
<th>Screws Bolts – Fasteners</th>
<th>Spot Welding</th>
<th>Adhesive Bonding</th>
<th>PSA Bonding</th>
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<tbody>
<tr>
<td>Corrosion</td>
<td>Little</td>
<td>Little</td>
<td>Little</td>
<td>Little</td>
<td>High</td>
<td>None</td>
<td>None</td>
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<td>Joining Point Alteration</td>
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<td>None</td>
<td>None</td>
<td>None</td>
<td>Yes</td>
<td>None</td>
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<td>Dynamic Load</td>
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<td>Very Good</td>
<td>Less Good</td>
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<td>Very Good</td>
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<td>Crush Load</td>
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<td>Very Good</td>
<td>Very Good</td>
<td>Very Good</td>
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<td>Edges-Burring-Splinters</td>
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<td>None</td>
<td>Yes</td>
<td>None</td>
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<td>Consumable</td>
<td>Rivet</td>
<td>None</td>
<td>Punch Rivet</td>
<td>Nuts, bolts, tap</td>
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<td>Adhesive</td>
<td>PSA</td>
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<tr>
<td>Energy</td>
<td>Little</td>
<td>Little</td>
<td>Little</td>
<td>Little</td>
<td>Very High</td>
<td>Varies</td>
<td>Little</td>
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</table>

- **PSA Bonding**: None
- **Adhesive Bonding**: None
## Joining Technologies Comparison (cont’d)

<table>
<thead>
<tr>
<th>Environmental Friendliness</th>
<th>Radial/Orbital Riveting</th>
<th>Clinching</th>
<th>Self Piercing Riveting</th>
<th>Screws Bolts – Fastener</th>
<th>Spot Welding</th>
<th>Adhesive Bonding</th>
<th>PSA Bonding</th>
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<tr>
<td>Good</td>
<td>Good</td>
<td>Good</td>
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<td>Poor</td>
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<th>Handling</th>
<th>Simple</th>
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<th>Simple</th>
<th>Simple</th>
<th>Varies</th>
<th>Simple</th>
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<tr>
<td>Good</td>
<td>Simple</td>
<td>Simple</td>
<td>Simple</td>
<td>Simple</td>
<td>Simple</td>
<td>Varies</td>
<td>Simple</td>
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<table>
<thead>
<tr>
<th>Reproducibility</th>
<th>Very Good</th>
<th>Very Good</th>
<th>Very Good</th>
<th>Good</th>
<th>Satisfactory</th>
<th>Good</th>
<th>Very Good</th>
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</thead>
<tbody>
<tr>
<td>Very Good</td>
<td>Very Good</td>
<td>Very Good</td>
<td>Good</td>
<td>Satisfactory</td>
<td>Good</td>
<td>Very Good</td>
<td>Very Good</td>
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<table>
<thead>
<tr>
<th>Dependence of Joint Result &amp; Surface Quality</th>
<th>None</th>
<th>Little</th>
<th>None</th>
<th>Little</th>
<th>High</th>
<th>Very High</th>
<th>Very High</th>
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<table>
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<tr>
<th>Pre-Processing</th>
<th>Drilling</th>
<th>None</th>
<th>None</th>
<th>Drilling</th>
<th>Washing, etching</th>
<th>Washing, Etching</th>
<th>Cleaning, Washing</th>
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<tbody>
<tr>
<td>Joining Different Materials</td>
<td>Very Good</td>
<td>Poor</td>
<td>Poor</td>
<td>Very Good</td>
<td>None</td>
<td>Very Good</td>
<td>Very Good</td>
</tr>
<tr>
<td>Joining Fragile Components</td>
<td>Very Good</td>
<td>None</td>
<td>None</td>
<td>Good</td>
<td>None</td>
<td>Very Good</td>
<td>Good</td>
</tr>
<tr>
<td>Investments</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
<td>Varies</td>
<td>Low</td>
</tr>
<tr>
<td>Assembly Flexibility</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Varies</td>
<td>Very High</td>
</tr>
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</table>
Part II:

Adhesive Design Considerations
Adhesives and Adhesion

An **adhesive** is a substance capable of holding materials together by surface attachment.

- **Adhesion** – force between dissimilar materials at the bond line between adhesive & substrate
- **Cohesion** - internal strength of the adhesive itself
Surface Considerations

- Surface Energy
- Surface Roughness
- Glossy Surfaces
- Weak Boundary Layers
- Surface Modification Techniques
## Surface Energy

### High Surface Energy
- Metals
- Polymide
- Polyester
- Acrylic
- Rigid Polyurethane
- ABS
- Polycarbonate
- PVC (rigid)

- Affects how the adhesive wets out the surface

### Low Surface Energy
- Polystyrene
- Acetal
- EVA
- Polyurethane elastomer
- Polyethylene
- Polypropylene
- PVF
- PTFE
- EPDM (Prime)

- Most common for adhesion to be directly dependent on surface energy
Adhesive Wetting

- **Good Wetting**
- **Some Wetting**
- **Poor Wetting**
Surface Energy Of Substrates

- **VHSE (very high surface energy) Substrates (>200 dynes/cm)**
  - Metals, Glass
- **HSE (high surface energy) Plastics (> 37 dynes/cm)**
  - Kapton, Nylon, polyester, epoxy paint, ABS, polycarbonate, rigid PVC, acrylic
- **MSE (medium surface energy) Plastics (31-36 dynes/cm)**
  - PVA, polystyrene
- **LSE (low surface energy) Plastics (< 31 dynes/cm)**
  - Polyethylene, polypropylene, Teflon
Surface Energy

Typical Cost to Form Bond

$ $

$ $$$

Increased Surface Energy

Generalization

Metals, Glass

HSE Plastics

MSE Plastics

LSE Plastics
Rough Surfaces

- Abrade to make smoother
- Use thicker bond line (also good for varying bond gaps)
- Avoid air entrapment in the bond line
Glossy Surfaces

• Glossy is good for wetting if adhesive is lower surface energy than substrate
• Light abrasion to increase contact area
• Surface energy is largest factor to consider in assessing how adhesive will perform over time
Weak Boundary Layers

- Chemical additives that bloom to the surface
  - Clean with solvent
  - Abrade off the surface and clean
- Surface oxidation (e.g. rust)
  - Abrade off the surface and clean
Surface Modification
Cleaning – Abrading – Priming

- **Cleaning**
  - Make sure surface is clean from dirt and oils
  - Clean with a solvent or grease cutter

- **Abrading**
  - Usually a light abrasion works well
  - Creates more surface area
  - Creates higher surface energy

- **Priming**
  - Consider...
    - Primer classes
    - Application methods
    - Pre-abrasion helps
Other Surface Modifications

- Flame treatment
- Flame treatment with primer*

*exercise caution…this can be dangerous
Tactics for Low Surface Energy Substrates

• Cleaning
• Abrasion
• Priming/surface modification
• Novel adhesive chemistry
  – e.g. Acrylic Adhesives designed to “bite into” polyolefins - acrylates
Type of Forces

- Tensile/Compression, Shear: *Better for Design*
- Cleavage, Peel: *More Problems for Design*
Stress Distribution: Shear Forces

Bonded tensile lap-shear specimens

- Undeformed state
- Uniform shear deformation of the adhesive
- Differential straining of the adherends
- Adherend bonding (exaggerated to show effect)
Stress Distribution: Shear Forces

Stress is higher at each end, but is still spread across the entire bond area (length and width)
Stress Distribution:
Peel and Cleavage Forces

Stress is concentrated at one end of the bond width (length of overlap doesn’t matter)
General Joint Design

• Most desirable to design the joint which minimizes peel or cleavage stresses and maximizes tensile, shear or compressive stresses

Improving joint design to accommodate applied stress
Joint Area - Width vs. Overlap

Equivalent Bond Area = 2 sq in, subjected to the same Shear Force. Which joint can handle the higher load?
What Have We Learned?

• Joint Overlap
  – Wider is Better

In the previous slide, the 4” wide X 0.5” overlap assembly is stronger than the 1” wide X 2” overlap!
Joint Design

Effect of Gap / Thickness

- Bond Strength
  - Small Gap: Increase
  - Large Gap: Decrease

- Fixture Time
  - Small Gap: Decrease
  - Large Gap: Increase

- Durability
  - Small Gap: Increase
  - Large Gap: Increase
What Have We Learned?

• Gap
  – Smaller is better

Smaller GAPS exhibit HIGHER strength and FASTER fixture. Smaller Gaps are also more DURABLE for long term performance.

However, thicker gaps (that offer some degree of flexibility) are sometimes required to compensate for dimensional changes and exerted STRESSES due to thermal expansion, impact or vibration, etc.
Summary of Joint Design Guidelines

- Maximize These Forces
  - Shear, Tension and/or Compression
- Minimize These Forces
  - Peel, Cleavage
- Increase Bond Area
  - Wider is better (than Overlap)
- Minimize Thickness (Gap)
# Adhesive Selection
*(Typical Choices based on Substrate Type)*

<table>
<thead>
<tr>
<th>Metals (1)</th>
<th>Plastics (2, 3)</th>
<th>Rubber</th>
<th>Wood</th>
<th>Glass (3)</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy</td>
<td>Cyano-acrylate</td>
<td>Contact Cement</td>
<td>Yellow Glue</td>
<td>Acrylic</td>
<td>Contact Cement</td>
</tr>
<tr>
<td>Urethane</td>
<td>Urethane</td>
<td>Epoxy (may result in reduced elasticity of rubber)</td>
<td>White Glue</td>
<td>Epoxy</td>
<td>Hot Melt</td>
</tr>
<tr>
<td>Modified Acrylic</td>
<td>Epoxy (low strength only)</td>
<td>Urethane</td>
<td>Urethane</td>
<td>White Glue</td>
<td></td>
</tr>
<tr>
<td>Hybrids</td>
<td>Modified Acrylic</td>
<td>Cyano-acrylate</td>
<td>Hot Melt</td>
<td></td>
<td>Film</td>
</tr>
<tr>
<td>Others</td>
<td>Others</td>
<td>Others</td>
<td>Others</td>
<td>Others</td>
<td>Others</td>
</tr>
</tbody>
</table>

**Notes:**

1. If at least one surface is non-metallic, avoid anaerobic adhesive
2. Avoid polyolefin plastics if possible – adhesive options are limited
3. Unless one surface is transparent, light cure adhesives will not work

CAVEAT: Please consult your adhesive supplier for additional information and limitations concerning your particular application.
Adhesive Selection
(Guidelines based on joint design)

- If it **will not** hold without an adhesive, then forget Anaerobics
- If need High Strength, avoid Hot Melts & Silicones
- If need High Durability, avoid Cyanoacrylates
- If need High Flexibility, use Hot Melts, Silicones, Urethanes, or 2 part Acrylics
- If only some Flexibility needed, try Epoxies and Acrylics
- Unless 1 surface is transparent, Light Cure will **not** work
Adhesive Selection
(Guidelines based on Service Environment)

- If Temp > 200°F, avoid Cyanoacrylates
- If Temp > 250°F, avoid Hot Melts & Urethanes
- If Temp > 300°F, avoid Epoxy & Acrylics
- If Temp > 400°F, try Silicones ONLY

REFER to your Supplier’s Technical Data Sheet.
There are always exceptions to these rules!
Part III:

Structural Adhesive Tapes

An Alternative to Liquid Adhesives
Market Applications
Structural Adhesive Tapes

- Automotive
- Aircraft
- Building/Construction
- HVAC
- General Industrial
- Electronics & Appliances
High Performance Bonding Tapes

- Acrylic Foam Technology
- Viscoelasticity

**ENERGY ABSORPTION**
Absorb and dissipate energy by the acrylic foam core

⇒ The **foam** provides the strength

**STRESS RELAXATION**
Reduce long term stress in bond line by dispersing into the acrylic foam

⇒ The **foam** protects the bond

- Durability
  All-acrylic construction
  100% Closed Cell
High Performance Bonding Tapes

Value Propositions

- Improved appearance
- Productivity
- Proven durability
- Bonds dissimilar materials
- Vibration & fatigue resistant
- Uniform stress distribution
- Weight reduction
- Seals and bonds
- Allows unique designs
High Performance Bonding Tapes

Surface Issues

- Abrade to make smoother
- Use thicker bond line (also good for varying bond gaps)
- Use softer tape (ie. foam tape vs solid adhesive) or lower viscosity adhesives.
- Avoid air entrapment in the bond line
Application Factors

PSA Selection

• The selection of the product for an application requires as much detail about the needs of both the converter and end user as possible.

• Satisfaction of end-use requirements without addressing concerns of how a material is processed does not insure successful use of the product.

• Identifying range of needs as early as possible improves ability to address requirements in the processing and application stages.

Application Factors which Should be Considered

• Price target
• Expected usage (Volume)
• Timing of project
• Materials to be joined
• How will the product be processed
• Migratory components of substrate

• Life expectancy of product
• Existing Specifications
• Previous problems encountered
• How the product is applied
• Condition of substrates
• What does the tape need to DO

There is NO substitution for actual testing of substrate materials to ensure success in an application
Choice in fastening/joining/attaching/method introduces set of cost factors.

Greater knowledge in the design phase prevents costly mistakes and improves profitability.

Selection of the most appropriate fastening system for your application must include an analysis of:

- **Capital costs**
- **Annual fixed costs**
- **Annual variable costs**
## Total Cost of Ownership

### Annual Fixed Costs
- Floor Space Cost for Equipment
- Opportunity Costs for Equipment Floor Space
- Annual Depreciation of Capital Equipment

Total Annual Fixed Costs

### Capital Costs
- Machine Costs
- Auxiliary Equipment/Accessories
- Installation
- Subtotal
  (Less Investment Tax Credits)

Total Capital Costs

### Annual Variable Costs
- Adhesive or Fastener Costs
- Floor Space Cost for Adhesive/Fastener Inventory
- Opportunity Costs for Adhesive/Fastener Inventory and Floor Space
- Labor
- Downtime
- Scrap
- Energy
- Maintenance

Total Annual Variable Costs
Fundamentals of Adhesives Used in Assembly

The Adhesive and Sealant Council acknowledges the generous support of its member companies in developing this presentation:

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