Using Structural Adhesives to Make Permanent Bonds to Plastics
Outline

Adhesion Basics
• Adhesion
• Surface energy
• Classification of plastics

Surface Preparation
• Common techniques

Structural Adhesives
• Descriptions; features
• Comparison to other attachment methods
• Adhesive types; application examples; lead products

Adhesive Selection Process
Adhesion

There are several possible surface interactions that can create adhesion between a liquid structural adhesive and a solid plastic surface:

**Mechanical Lock**
- Adhesive flows into surface texture
- Adhesive swells and diffuses into substrate

**Chemical Bonds**
- Covalent
- Ionic
- Hydrogen

These bonds are strong, but not common
Adhesion

By far, the most common surface interactions that create adhesion:

**Dispersive Forces**

- van der Waals forces
- Permanent dipoles
- Induced dipoles

Dispersive forces require super close contact between the adhesive and substrate to occur → why surface energy is so important
Surface Energy

• For optimum adhesion to most plastics, the structural adhesive must thoroughly flow or “wet out” the bonding surface, which provides close contact and maximizes the attractive forces between adhesive and substrate.

• The amount of close contact depends greatly on the surface energy of the substrate – a measure of how much a solid substrate likes a liquid adhesive making contact with its surface.

- High surface energy
- Low surface energy

• The extent of wet-out also depends on several other factors:
  - Adhesive work life
  - Adhesive viscosity

A lower viscosity adhesive making contact for a longer period of time aids wet-out.
### Surface Energy

<table>
<thead>
<tr>
<th>Plastic</th>
<th>Surface Energy (dyne/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyethersulfone (PES)</td>
<td>48</td>
</tr>
<tr>
<td>Polyphenylene oxide (PPO)</td>
<td>47</td>
</tr>
<tr>
<td>Polyhexamethylene adipamide</td>
<td>46</td>
</tr>
<tr>
<td>Polycarbonate (PC)</td>
<td>46</td>
</tr>
<tr>
<td>Polycaprolactam</td>
<td>42</td>
</tr>
<tr>
<td>Polyethylene terephthalate (PET)</td>
<td>42</td>
</tr>
<tr>
<td>Acrylonitrile butadiene styrene (ABS)</td>
<td>42</td>
</tr>
<tr>
<td>Polysulfone</td>
<td>41</td>
</tr>
<tr>
<td>Polymethylmethacrylate (PMMA)</td>
<td>41</td>
</tr>
<tr>
<td>Styrene acrylonitrile (SAN)</td>
<td>40</td>
</tr>
<tr>
<td>Polymide</td>
<td>40</td>
</tr>
<tr>
<td>Polyvinyl chloride (rigid) (PVC)</td>
<td>39</td>
</tr>
<tr>
<td>Polyphenylene sulfide (PPS)</td>
<td>38</td>
</tr>
<tr>
<td>Polyurethane (PU)</td>
<td>38</td>
</tr>
<tr>
<td>Acetal</td>
<td>36</td>
</tr>
<tr>
<td>Polyvinyl chloride (flexible) (PVC)</td>
<td>35</td>
</tr>
<tr>
<td>Polystyrene (PS)</td>
<td>34</td>
</tr>
<tr>
<td>Polybutylene terephthalate (PBT)</td>
<td>32</td>
</tr>
<tr>
<td>Polypropylene (PP)</td>
<td>30</td>
</tr>
<tr>
<td>Polyethylene (PE)</td>
<td>30</td>
</tr>
<tr>
<td>Polyvinyl fluoride (PVF)</td>
<td>28</td>
</tr>
<tr>
<td>Polymidilene fluoride (PVDF)</td>
<td>25</td>
</tr>
<tr>
<td>Polydimethyl siloxane (PDMS)</td>
<td>23</td>
</tr>
<tr>
<td>Polytetrafluoroethylene (PTFE)</td>
<td>19</td>
</tr>
</tbody>
</table>

- Most adhesives have a surface energy of about 36-38 dyne/cm
Surface Energy

High surface energy

• Metals

• Glass

Medium surface energy

• ABS, acrylic (PMMA), ASA, phenolic, polycarbonate, polyester (PET), polyimide, polyurethane, PVC, SAN, vinyl ester

• Most paints, coatings, and composite materials

Borderline surface energy

• Acetal, nylon, polyester (PBT), polystyrene

Low surface energy

• Polyolefins (polypropylene, polyethylene, TPO), PTFE

• Some paints, coatings (PVDF) and composite materials (polyolefins)
Surface Energy

• Plastic parts can be manufactured from a huge variety of resins, fillers, additives (all of which can possibly affect adhesion)
  → Increasing number of copolymers and blends are made to tailor plastic properties for a specific application

• Important to identify actual substrate surface, which may be different from bulk material

• Existing information on basic types of plastics can be used to select candidate structural adhesives for evaluation, but adequate adhesion should always be checked with tests to actual substrates
Medium Surface Energy Plastics

- With light abrasion and solvent clean for surface preparation, most adhesives bond well to **medium surface energy** plastics

- Top adhesive families:
  - Flexible epoxy
  - MMA acrylic
  - Low odor acrylic
  - Flexible urethane
  - Instant adhesives

- General surface preparation:
  - IPA clean (to remove mold release agents) +
  - Light abrasion (Scotch-Brite™ or fine grit sandpaper) +
  - IPA clean (to remove debris)

**Flexible** adhesives nearly always provide better adhesion to plastics than **rigid** adhesives
Many adhesive options for bonding medium surface energy plastics, especially acrylic and flexible epoxy structural adhesives.
Borderline Surface Energy Plastics

- Adhesion to **borderline surface energy** plastics can depend greatly on the specific resin type and surface preparation used
- Top adhesives:
  - Flexible epoxy
  - LSE acrylic
  - Instant adhesives
- General surface preparation:
  - IPA clean (to remove mold release agents) +
  - Light abrasion (Scotch-Brite™ or fine grit sandpaper) +
  - IPA clean (to remove debris)

Consider plasma treatment for a surface preparation method for these plastics
Flexible epoxy adhesives (with plasma treatment) or LSE acrylic adhesives (with light abrasion) often provide best adhesion to borderline surface energy plastics.
Low Surface Energy Plastics

• Adhesion to low surface energy plastics requires special adhesives or more involved surface preparation methods

• Top adhesives:
  - LSE acrylic adhesives

• General surface preparation (polyolefins):
  - IPA clean (to remove contaminants)
    * Do not abrade polyolefins (mechanical abrasion causes damage to plastic itself which lowers overall bond strength)

• General surface preparation (PTFE):
  - IPA clean (to remove mold release agents) +
  - Light abrasion (Scotch-Brite™ or fine grit sandpaper) +
  - IPA clean (to remove debris)
Low Surface Energy Plastics

Standard structural adhesives (even with plasma treatment) could not match the performance of LSE acrylic adhesive (with just IPA wipe) to HDPE.

HDPE
Overlap shear; 0.5 in/min pull rate; 72°F test temperature

Overlap Shear (psi)

<table>
<thead>
<tr>
<th>Material</th>
<th>Color</th>
<th>Overlap Shear (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DP125</td>
<td>Gray</td>
<td>400</td>
</tr>
<tr>
<td>DP420</td>
<td>Off-White</td>
<td>800</td>
</tr>
<tr>
<td>DP8410NS</td>
<td>Green</td>
<td>1,200</td>
</tr>
<tr>
<td>DP8810NS</td>
<td>Green</td>
<td>1,600</td>
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<tr>
<td>DP620NS</td>
<td>Black</td>
<td>0</td>
</tr>
<tr>
<td>DP640</td>
<td>Brown</td>
<td>0</td>
</tr>
<tr>
<td>DP8010</td>
<td>Blue</td>
<td>0</td>
</tr>
</tbody>
</table>

Plasma Treat IPA Clean
Surface Preparation
Despite their clean appearance, plastic surfaces may not be ready for adhesive bonding:

- Mold release materials (silicones, waxes)
- Flow agents, plasticizers, other additives
- Fingerprints, oils, dust
- Moisture, condensation
- Abrasion debris

Adhesive wets out surface

**Good Bond**

Adhesive does not contact surface

**Poor Bond**
Surface Preparation

Optimal surface conditions for structural adhesive bonds:

- Clean
- Rough
- Dry

Typical surface preparation of plastics for structural adhesive bonds:

- Solvent wipe
- Light abrasion
- Solvent wipe

Acrylic adhesives may require less surface preparation than epoxy or urethane adhesives
Solvent Wipe

- Removes contaminants (dust, fingerprints, oils) from surface
  - Isopropyl alcohol (IPA) generally preferred for plastics (acetone for metals, glass, and some plastics)
  - Solvent must be pure or only mixed slightly with water to slow evaporation rate; use clean rag; be certain bonding surfaces are completely dry

Do not use rubbing alcohol, denatured alcohol, or any cleaner that can leave behind a film or residue on the surface
Common Surface Preparation Techniques

Abrasión

• Generates free radicals, creates sites for mechanical locks, and increases effective bond area

  - Sandpaper (80-180 grit), sandblasting, Scotch-Brite™ pads
  - Usually not recommended for polyolefins (abrasion can damage the internal strength of the plastic itself)
Common Surface Preparation Techniques

Flame / Corona / Plasma Treatment

- Removes contaminants from surface; creates reactive sites; increases surface energy
  - Works well on a wide variety of plastics including polyolefins
  - Solvent-free; works on three-dimensional parts; relatively fast
  - Effectiveness and duration of surface treatment depends on many factors (such as energy level, exposure time, time delay before applying adhesive)
Common Surface Preparation Techniques

Primer / Adhesion Promoter

- Reactive materials form chemical bridge between adhesive and substrate
  - Typically solvent-based; applied with brush or sprayed on, then allowed to dry

Chemical Etching

- Creates physical cavities for mechanical lock and reactive sites for chemical reactions
  - Several different chemicals and processes
  - Some EHS concerns
Structural Adhesives
Structural Adhesives

• “Structural” = overlap shear strength of at least 1,000 psi (7 MPa); withstands high load-bearing conditions; bonds often stronger than materials being joined

• Used where high strength required from small bond area (replace mechanical fasteners, ultrasonic welding, solvent cements)

• Excellent environmental resistance (UV, heat, humidity); high resistance to chemicals; good retention of properties at elevated temperatures

• 100% solids (solvent-free) and low VOC (most formulations)

• Thermosetting (most formulations)
Structural Adhesives

- Applications requiring **high strength** (especially static load holding power)

- Applications that need **high stiffness** (rigidity)
Structural Adhesives

• Applications with irregularly shaped or gapped bond lines (three-dimensional parts)

• Applications with extreme environmental conditions
Advantages of Structural Adhesives

... compared to other attachment methods for plastics:

**Mechanical Fasteners**

- Screws, nails, bolts, staples, rivets

**Ultrasonic Welding**

- High frequency vibrations cause frictional heat that melts the plastic components together

**Solvent Cements**

- Solvent penetrates and softens plastic parts which bond together under pressure when solvent dissipates
Advantages of Structural Adhesives

Uniform Stress Distribution

• Eliminate stress concentrations; reduce distortion and cracking

No Damage to Substrates

• Eliminate holes, prevent thermal damage, maintain protective coatings

Weight Reduction

• Allow thinner substrates

Less Labor

• No drilling holes

Lower Capital Equipment Cost
Advantages of Structural Adhesives

Bond and Seal Simultaneously
• Prevent water/moisture intrusion

Bond Dissimilar Materials
• Plastics to metals, glass, composites

Improved Appearance
• Allow unique designs

Some Sound Damping, Vibration Damping, and Thermal Expansion Capability

Solvent-Free
Disadvantages of Structural Adhesives

Many Adhesive Options

- Selecting best adhesive for particular application depends on factors including strength, materials being bonded, environmental conditions

Need to Pay Attention During Use

- Operators must use adhesives properly to achieve expected strength (such as performing surface preparation correctly and using adhesive within the work life)

Cure Time Required to Achieve Handling Strength

- Clamps/fixtures may be required to hold parts in place

Difficult Removal

- No easy disassembly (without destroying the bonded parts)
Structural Adhesives for Bonding Plastics

A broad range of products are available for bonding plastics.
Structural Adhesives for Bonding Plastics

Structural Adhesives (Epoxy, Acrylic, Urethane)

- Two component; cure at room temperature upon mixing
- High load holding power
- High creep and fatigue resistance
- Excellent durability
- Broad portfolio with various cure speeds, viscosities, colors
- Formulations that can bond nearly all materials

Applications

- Sporting goods, automotive tier components, electronics, appliances, furniture
Structural Adhesives for Bonding Plastics

Structural Adhesives (Epoxy, Acrylic, Urethane)
Top product families for bonding plastics:

- Flexible epoxy adhesives
  (DP100 Plus Clear, DP125 Gray, 2216 Gray)
- MMA acrylic adhesives
  (DP8410NS Green)
- Low odor acrylic adhesives
  (DP8805NS Green)
- Low surface energy acrylic adhesives
  (DP8010 Blue)
- Flexible urethane adhesives
  (DP604NS Black, DP640 Brown)

Surface Preparation
Most plastics: IPA wipe + light abrasion + IPA wipe
Structural Adhesives for Bonding Plastics

(Cyanoacrylate) Instant Adhesives

- Cure at room temperature with moisture upon applying pressure
- Super fast cure speed
- Tight bond lines
- Limited gap filling
- Reduced peel and impact strength
- Excellent for bonding plastics and rubbers

Applications

- Sporting goods, jewelry, footwear
Structural Adhesives for Bonding Plastics

(Cyanoacrylate) Instant Adhesives

Top product families for bonding plastics:

- Plastic & rubber adhesives (PR100)
- Engineered grade adhesives (CA4, CA40H)

Surface Preparation

Most plastics: None
Low surface energy plastics: Primer AC77
Low surface energy elastomers: Primer AC79
Structural Adhesives for Bonding Plastics

(Curing Hot Melt) PUR Adhesives

- Applied warm as liquid
- Fast handling strength upon cool down
- Subsequent cure with moisture over time
- Medium strength and flexibility
- 100% solids; no VOC’s
- Eliminate damage to materials
- Bond woods and many plastics

Applications

- Furniture, displays, trim
Structural Adhesives for Bonding Plastics

(Curing Hot Melt) PUR Adhesives

Top products for bonding plastics:

- Longer open time; slower set time; lower viscosity (TS230)
- Shorter open time; faster set time; higher viscosity (TE031)

Surface Preparation

Medium surface energy plastics: Acetone or IPA wipe
Low surface energy plastics: Plasma treatment
Adhesive Selection Process
Adhesive Selection Process

Performance

• Which structural adhesive provides the strength and other performance requirements of the application?

Durability

• Which structural adhesive will survive the expected environmental conditions for the design life of the application?

Manufacturing Process

• Which structural adhesive fits best into the manufacturing process of the customer?
Performance

Candidate Adhesives

Performance

• Adhesion
  – Substrates, surface energy, surface prep

• Loads
  – Static, dynamic, impact
  – Tensile, shear, cleavage, peel, flexural

• Joint design
  – Bond area, failure modes

• Mechanical properties
  – Modulus, strength, elongation, Tg

• Special
  – Flame retardancy, electrical properties
  – 3rd party certifications
Performance

Performance of Epoxy Adhesives
Overlap shear to various plastics; 0.5 in/min pull rate; 72°F test temperature

- ABS
- Acrylic
- ASA
- Nylon
- Nylon/PPE
- PC/PBT
- PC/PET
- PET/PBT
- PS/PPE
- PVC

Overlap Shear (psi) vs. Type of Epoxy

Rigid Epoxy
Flexible Epoxy
Toughened Epoxy

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Durability

- Environmental resistance
  - Weather, thermal cycling
  - Temperature, humidity extremes
- Chemical resistance
  - Gasoline, oil, solvents, cleaning solutions
- Fatigue
  - Cyclic loading, vibration

Candidate Adhesives
Durability

No significant decrease in performance after 1,000 hours exposure to wide variety of conditions.

Durability of MMA Acrylic Adhesives
DP8410NS Green; overlap shear to PVC; 1,000 hours exposure; 0.5 in/min pull rate; 72°F test temperature.
Manufacturing Process

Manufacturing Process

- Form
  - One-component; two-component
  - Viscosity (free-flowing; non-sag)

- Cure
  - Work life, set time, full cure
  - Cure conditions (time, temperature)

- Storage / shelf life
  - Temperature, humidity
  - Packaging

- Equipment
  - Hand-held dispensing (manual, pneumatic)
  - Bulk dispensing
Manufacturing Process

Various packaging and applicators available to fit into manufacturing process

- **Work Life**: 20 minutes
- **Set Time**: 2 hours
- **Full Cure**: 16 hours
Adhesive Selection Process

Gather important details about application
- Performance, durability, manufacturing process

Select adhesive candidates

Conduct laboratory tests using actual materials
- Overlap shear, floating roller peel, impact strength, environmental aging

Build prototype and test real-life performance

Ramp to full production
- Dispensing equipment, operating training
Contact your local 3M sales representative or
3M customer service representative at
0870 6080050
or visit www.3m.co.uk/assemblysolutions
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