This presentation is courtesy of
Fundamentals of Plastics Bonding
Fundamentals of Plastics Bonding

• Surface considerations
• Joint design
• Application process
• Environment
• Adhesive selection factors
Surface Considerations

**Surface Energy**: A critical property that affects how an adhesive flows onto a surface

- High Surface Energy
- Low Surface Energy
Surface Considerations

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

Low Surface Energy
Surface Considerations

**High Surface Energy**
- Polyvinyl Acetate
- Polystyrene
- Acetal
- EVA
- Polyurethane elastomer
- Polyethylene
- Polypropylene
- PVF
- PTFE
- EPDM (Prime)

**Low Surface Energy**
The extent to which a liquid wets a solid is measured by the contact angle $\theta$. The figure here shows a liquid droplet on a flat surface. When $\theta$ is large, the liquid tends to minimize its area of contact with the solid (poor wetting) and when $\theta = 0$, the liquid spreads over the surface (good wetting).

One needs to be aware of the surface tension of the plastic and the adhesive being used to bond the plastic substrates.

“Contact angle measurements provide an extremely sensitive tool by which the gross chemistry of a surface can be examined. The contact angle measurement provides a ‘dull edge’ to a knife that is cutting into the analysis of surfaces.” - Dr. Al Pocius, 3M
# Surface Considerations

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<th>Substrate</th>
<th>Surface Energy (dynes/cm)</th>
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Typical: <40 dynes requires a tackified adhesive
40-44 use tackified or non-tackified with care
>44 use tackified or non-tackified
Joint Design

- Lap Joints
- Angle Joints
- Butt Joints
- Cylindrical Joints
- Corner Joints
- Stiffener Joints

✓ Consider type of stress – shear, peel, tensile, etc.
✓ Evaluate different joints
Joint Design
Joint Design

- Lap Joints
- Angle Joints
- Butt Joints
- Cylindrical Joints
- Corner Joints
- Stiffener Joints

Good

Fair

Good
Joint Design

- Lap Joints
- Angle Joints
- Butt Joints
- Cylindrical Joints
- Corner Joints
- Stiffener Joints
Joint Design

- Lap Joints
- Angle Joints
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Adhesive
Joint Design

- Lap Joints
- Angle Joints
- Butt Joints
- Cylindrical Joints
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Joint Design

- Lap Joints
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**Joint Design**

**Tensile stress** is exerted equally over the entire joint straight and away from the adhesive bond.

**Shear stress** is across the adhesive bond. The bonded materials are being forced to slide over each other.

**Cleavage stress** is concentrated at one edge and exerts a prying force on the bond.

**Peel stress** is concentrated along a thin line at the bond’s edge. One surface is flexible.
Joint Design

Design Guidelines

Most applications combine stresses.

The following six points elaborate on the advantages of using adhesives for stress resistance and more.

1. Uniform distribution of stress over the entire bonded area can eliminate stress concentration caused by rivets, spot welds, and similar mechanical fastening. Lighter, thinner materials can often be used without sacrificing strength.

2. Bonding laminates of dissimilar materials can produce combinations superior in strength and performance to either adherent alone. Adhesive flexibility compensates for differences in coefficients of expansion.
3. Elastomeric flexibility improves resistance to vibration fatigue.

4. Holes are eliminated maintaining the integrity of the bonded material. This can reduce finishing and increase design flexibility.

5. Continuous contact between mating surfaces can effectively bond and seal against many environmental conditions.

6. Costs can be lowered by reducing material requirements and weight; eliminating drilling, welding, screwing and similar operations.
Joint Design

Design Guidelines (cont’d)

Shear Strength

Overlap

Width

Overlap
Application Process

- Surface preparation – contamination
- Method of application
- Pressure to mate surfaces – hold in place
- Time – to dry, cure or build strength
- Temperature/application conditions
Application Process

Surface Preparation

- Low Surface Energy
- Mold Release Agents
- Plasticizers
- Wetting of Surface
Application Process

Surface Preparation

**Adhesive Abrading**
Adhesive abrading is performed by abrading the plastic’s surface prior to the presence of liquid adhesive. Two of the abraded, adhesive-coated adherends are then mated, and the adhesive is allowed to cure. This increases the bond strengths achieved on PTFE by approximately 700 percent. It is speculated that when abrasion is carried out in the presence of the adhesive, free radicals are created which react directly with the adhesive. This does not normally occur because the free radicals are scavenged by the oxygen present in air, or decay, before the adhesive is applied.

*Common uses:* fluorocarbons

**Chromic Acid Etching**
Chromic acid etching increases the bondability of a plastic by introducing reactive sites, such as hydroxyl, carbonyl, carboxylic acid, and SO$_3$H groups, to the plastic’s surface and forming root-like cavities which provide sites for mechanical interlocking. The effects of this treatment vary from substrate to substrate. For example, increasing the etch time and temperature increases only the etch depth when etching polypropylene. On the other hand, both the degree of oxidation and etch depth increase with time for polyethylene.

*Common uses:* polylefins, ABS, polystyrene, polyphenyleneoxide, acetals

**Corona Discharge**
In a corona discharge process, the plastic is exposed to an electrical discharge, usually in the presence of air and at atmospheric pressure so as to create a plasma “field”. This roughens the surface, which provides sites for mechanical interlocking, and introduces reactive sites on the plastic’s surface, consequently increasing the wettability and reactivity of the surface. The reactive functionalities which are theorized to be introduced to the surface may include, but are not proven to be, carbonyl, hydroxyl, hydroperoxide, aldehyde, ether, ester, and carboxylic acid groups, as well as unsaturated bonds.

*Common uses:* polylefins

**Flame Treatment**
Flame treatment increases the bondability of a plastic by oxidizing the surface through brief exposure to flame. The oxidation proceeds by a free radical mechanism, accompanied by chain scissions and some crosslinking. The functionalities introduced by oxidation are hydroxyl, carbonyl, carboxyl, and amide groups with a typical oxidation depth of approximately 4 to 9 nanometers. The improved bondability results from increased wettability, due to increased surface energy, and interfacial diffusivity, caused by chain scissions.

*Common uses:* polylefins, polyacetsals, polyethylene terephthalate
Application Process

Surface Preparation

**Iodine Treatment**
Iodine treatment increases the bond strengths achieved on a substrate by altering the surface crystallinity from alpha form (where the N-H groups lie parallel to the surface) to beta form (where the N-H groups stand perpendicular to the surface). The surface remains relatively smooth after treatment, so it is believed that increased chemical reactivity, rather than mechanical interlocking, is the mechanism for improved adhesion.

*Common uses:* nylon

**Plasma Treatment**
Plasma treatment increases the bondability of a substrate by bombarding the substrate surface with ions of a gas, such as Ar₂, He₂, N₂, and O₂ at low pressure. Several mechanisms have been proposed to explain the enhanced bondability created by plasma treating. For example, plasma treatment is hypothesized to crosslink the substrate's surface, which strengthens the joint boundary and prevents a thin layer of substrate from peeling off. In addition, the surface oxidation caused by plasma treatment is thought to introduce reactive functionalities which then increase the surface's reactivity and wettability. Another theory attributes plasma treatment's effectiveness to an increased interfacial diffusion which is created by chain scissions in the substrate's surface. Chain scissions increase the interfacial diffusion by lowering the surface viscosity and increasing the molecular mobility of the plastic's surface.

*Common uses:* polyolefins, polyesters, many more

**Primers**
Primers typically consist of a reactive chemical species dispersed in a solvent. To use the primer, the solution is brushed or sprayed onto the substrate surface. The carrier solvent is then allowed to flash off, leaving the active species behind. Depending on the type of primer, the surface may be ready to bond immediately, as in the case of polyolefin primers for cyanoacrylates, or may require time to react with atmospheric moisture before the application of the adhesive. Primers that must react with atmospheric moisture include silane and isocyanate-based primers which are typically used for silicone and polyurethane-based adhesives respectively. Surface primers generally improve substrate bondability by acting as a chemical bridge between the substrate and the adhesive. Typically, the reactive species in a primer will be multifunctional, with one set of reactive groups that will preferentially react with the substrate surface, and additional groups that will have a high affinity for the adhesive.

*Common uses:* acetal, fluoropolymers, polybutylene, terephthalate, polyolefins, polyurethane, silicone
**Application Process**

**Surface Preparation**

**Sodium Treatment**
Sodium treatment is carried out by immersing the substrate in an aggressive etching solution containing either a sodium-naphthalene complex dissolved in tetrahydrofuran or a sodium-ammonia complex dissolved in ammonia. The etching process results in the dissolution of the amorphous regions of the substrate's surface, consequently increasing the substrate's surface roughness and potential for mechanical interlocking. Moreover, sodium treatment introduces unsaturated bonds, carbonyl groups, and carboxyl groups to the substrate's surface, which increases the substrate's reactivity and wettability. Due to carbonaceous residue which results from the defluorination of the surface, sodium treatment darkens the surface to an approximate depth of 1 micrometer. The on-part life of the treatment is very long (years), however, heating and UV exposure rapidly degrade the treated surface. Major disadvantages of using sodium treatments are that extended exposure to the solution will result in a substantial degradation of the substrate's surface, the etchants are highly hazardous, and that the solution degrades very rapidly in the presence of oxygen.

**Common uses:** fluorocarbons

**Surface Grafting**
Surface grafting is accomplished by grafting a chemical species to the substrate's surface which increases the substrate's bondability. For example, polyethylene can be exposed to gamma radiation in the presence of vinyl acetate monomer, which then becomes chemically grafted to the polyethylene surface.

**Common uses:** vinylic compounds on polyolefins

**Surface Roughening**
Surface roughening is a simple, low cost method of increasing the bondability of many plastics. Surface roughening increases the bondability by dramatically increasing the number of mechanical interlocking sites.

**Common uses:** effective for many plastics
Application Process

Surface Preparation

**Thermal Treatment**

Thermal treatment increases the bondability of plastics by exposing the plastic to a blast of hot air (approximately 500°C), which oxidizes the surface. This mainly introduces carbonyl, carboxyl, and amide groups to the surface, but some hydroperoxide groups are also formed. Very similar to flame treatments, this process also utilizes a free radical mechanism accompanied by chain scission and some crosslinking. The improved bondability results from increased wettability, due to the introduction of polar groups, and interfacial diffusivity, caused by chain scissions.

**Common uses:** polyolefins

**Transcrystalline Growth**

Transcrystalline growth improves bondability of a plastic by molding adherends against a high energy metallic substrate that induces transcrystalline growth in the plastic's surface regions. The metallic substrate induces the formation of crystallites at the plastic’s surface and results in rod-like or columnar spherulites that form inward from the interface. This is thought to strengthen the surface by driving low molecular weight material into the interior. In addition, some metallic substrates may oxidize the plastic's surface, resulting in a substantial increase in the reactivity and wettability of the plastic's surface. The effectiveness of this treatment is dependent on such molding conditions as the cooling rate and mold surface.

**Common uses:** polyolefins, polyamides, polyurethanes

**UV Exposure**

UV exposure increases the bondability of plastics by irradiating them with high intensity UV light. However, the effectiveness of UV exposure is very dependent on the wavelength of light being used. For example, light with a wavelength of 184 nm will crosslink the surface of polyethylene, while light at 253.7 nm will not. UV irradiation causes chain scissions, crosslinking, and oxidation of the polymer's surface, even in inert gases. Many different mechanisms describing why UV exposure increases the bondability of plastics have been proposed, including: increasing the wettability; strengthening the plastic’s boundary layer through crosslinking; and inducing hydrogen bonding. The predominant view is that the bondability is improved by the formation of polymeric scission products, which promote interfacial flow, interdiffusion, and polar interactions.

**Common uses:** polyolefins
Application Process

• Method of Application
  – Hand held applications
    • One part adhesives
    • Two part adhesives
    • Hot melt adhesives
  – Bulk hot melt applications
  – Cartridge dispensing systems (>300 ml)
  – Robotic systems

• Considerations
  – Size of parts to be bonded
  – Time to dispense/cure
  – Volume of adhesive needed
  – Production rate

Consult your adhesive supplier.
Application Process

**Pressure** – to mate surfaces, hold in place

**Time** – to dry, cure or build strength, green strength, fixture strength, final cure

**Temperature** – application conditions
  1. Adhesive
  2. Plastic part
  3. Processing conditions
  4. Storage/staging condition

Allow the adhesive to wet the surface, flow into joint design and achieve the desired bond strength.
Environment

Exposure to:

- Moisture
- Solvents/Chemicals
- Temperature
- UV Light
Moisture

A monolayer of water will reduce wetting of most adhesives. One wants the surface to be free of moisture to optimize wetting and bond formation. Polymers that are more hydroscopic in nature, one needs to be aware of this and take measures to reduce the water content. Materials will charge their moisture content based on the temperature and humidity.
Moisture: An example is wood

Wood is gaining or losing water and shrinking or swelling prior to, during the process of, and after bond formation. These dimensional changes influence the bonding process. Glueline stresses can develop during the curing process prior to the development of adequate cohesive strength. The shrinking and swelling of wood can also stress the glueline after the composite has been manufactured. Because of these possible stresses, wood is generally dried to a moisture content approximating that to be encountered during use.
When materials with different coefficients of thermal expansion (CTE) are joined, shear stresses result when the assembly is heated or cooled.

If expansion problems cannot be solved by revising materials selections using thicker bond lines and more flexible adhesives can help reduce problems.
• **Environment – Solvents/Chemicals**

Subjection of polymeric materials to organic liquids can promote formation of crazing. Crazing often occurs prior to and in front of a crack tip. A crack is an open fissure. If the polymer is under stress, solvent action will increase the probability of crazing and cracking.

• **Environment – Ultraviolet wavelength of light**

Exposure to high energy wavelength of light (190-350 nm) can cause plastic to degrade. Selection of additives to help stabilize the plastic are essential.
# Adhesive Selection Factors

## Suitability of Joining Methods for Plastic Assembly

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Directions: (1) For plastics to themselves, consider adhesives marked “Y”. (2) For mixed substrate joints, consider adhesives marked “Y” on both substrate lines.

**Adhesive Code Numbers**

- **Elastomeric**
  1. Natural Rubber
  2. Reclaim
  3. Neoprene
  4. Nitrile
  5. Urethane (also thermosetting)
  6. Styrene-butadiene

- **Thermoplastic Resin**
  10. Acrylic
  11. Cellulosic nitrate
  12. Polyamide
  13. Hot-melt copolymer blends
  14. Cyanoacrylate

- **Thermosetting Resin**
  21. Resorcinol phenolic
  22. Epoxy
  23. Reactive acrylic
  24. Butyral phenolic
  25. Polyester
  26. Anaerobic
  27. Silicone

- **Miscellaneous**
  41. Rubber latices
  42. Resin emulsions

[ADHESIVES.ORG]
Design Guides/References

• Henkel/Loctite Design Guide for Bonding Plastics, Volume 2
• Pocius, Alphonsus V., in “Adhesion and Adhesives Technology”, 1997, Hanser, New York
• Carraher, Charles E. Jr., in “Polymer Chemistry Seymour/Carraher’s”, 2000, Marcel Dekker, New York.
Locate an adhesive supplier...

For a list of ASC members, log onto:

www.ascouncil.org/membership/companies

The Adhesive and Sealant Council, Inc.
7101 Wisconsin Avenue, Suite 990
Bethesda, MD 20814
Tel: (301) 986-9700
www.ascouncil.org
THE END

Questions?