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Guidelines for Bonding Plastics

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Thu, 2000-06-15 11:30

The key to quick and permanent assembly is matching adhesives and plastics.

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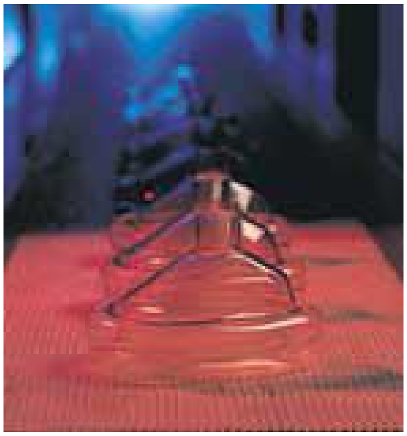
Plastics have become an integral part of everyday life. From packaging components and automotive parts to cosmetic and medical devices, plastics provide design flexibility, product durability, and a pleasing appearance.

To work effectively with plastics, manufacturers must be able to efficiently and permanently join plastic components into complete assemblies. More often than not, that means turning to adhesives.

ADHESIVE'S ADVANTAGES

Whether bonding plastic to plastic or other materials, adhesives offer several benefits over other joining methods. Adhesives distribute loads evenly over a broad area, reducing stress on the joint. Because adhesives are applied inside the joint, they are invisible within the assembly. Adhesives resist flex and vibration stresses and form a seal as well as a bond, which can protect the joint from corrosion. They join irregularly shaped surfaces more easily than mechanical or thermal fastening, barely increase assembly weight, create virtually no change in part dimensions or geometry, and quickly and easily bond dissimilar substrates and heat-sensitive materials. Adhesives are one-size-fits-all, and assembly can be easily automated.



They do have certain limitations. Adhesives require setting and curing time — the time it takes for the adhesive to fixture and strengthen fully. They also need some surface preparation prior to assembly. And, they may not be the best solution when there is a need to repeat-edly assemble and disassemble the joint.

When determining the best adhesive for an application, a lot depends on the substrate. Plastics are broadly characterized as thermoset materials or thermoplastics. Once polymerized, thermoset plastics such as polyester, phenolic, and epoxy resins cannot be melted or reformed. Thermoplastics, which will re-flow when heated after final processing, include a large number of common materials such as acrylonitrile butadiene styrene (ABS), polyamide (nylon), poly-carbonate, and polyolefins.

While each family of plastics has unique bond-strength performance characteristics, several families are designated as "difficult-to-bond." Linear or branched carbon-chain polymers, low surface energies, low porosity, and nonpolar/nonfunctional surfaces characterize these substrates. Difficult-to-bond plastics include polyolefins (such as polyethylene and polypropylene), fluoropolymers (such as Teflon), acetal resins, and thermoplastic vulcanizates (such as Santoprene).

SORTING OUT ADHESIVES

Out of the many adhesives currently available, seven families are most commonly used to bond plastics. Each offers a unique combination of performance and processing benefits.

Cyanoacrylates are high-strength, one-part adhesives that cure rapidly at room temperature to form thermoplastic resins when confined between two substrates that contain trace amounts of surface moisture. Because cure initiates at the substrate surface, these adhesives have a limited cure-through gap of about 0.010 in. A wide variety of cyanoacrylate formulations are available with varying viscosities, cure times, strength properties, and temperature resistance. Cyanoacrylates achieve fixture strength in seconds and full strength within 24 hr, which makes them suited for automated production.

Early cyanoacrylates exhibited low impact and peel strength, low-to-moderate solvent resistance, and operating temperatures only as high as 160 to 180°F. However, newer formulations address many prior limitations. For instance, rubber-toughened cyanoacrylates feature greater peel and impact strength. Polyolefin primers, applied to substrates before the adhesive, enhance bond strength on difficult-to-bond plastics. Accelerators ensure rapid cure in low-humidity environments. Surface-insensitive cyanoacrylates also cure quickly in low-humidity environments and on acidic surfaces. Manufacturers have also developed special nonblooming formulations to minimize frosting — the presence of a white haze around the bond line. And with the recent introduction of thermally resistant formulations, cyanoacrylates can withstand continuous exposure to temperatures up to 250°F.

While formulation changes have solved many cyanoacrylate shortcomings, some limitations must be addressed through proper bond design and processing techniques. On plasticized PVC assemblies, the bond strength of cyanoacrylates can drop over time. Therefore, manufacturers recommend heat aging and testing PVC assemblies to ensure that the bond withstands the effects of plasticizer leaching to the substrate surface. Cyanoacrylates will also stress crack many thermoplastics if left uncured. Minimizing the bond gap and limiting the adhesive dispensed generally controls this problem. Plastics that are highly prone to stress cracking may require an accelerator or surface-insensitive cyanoacrylate.

Light-cure acrylics are one-part, solvent-free liquids with typical cure times of 2 to 60 sec and cure depths exceeding 0.5 in. Available in various formulations, light-curing acrylics provide good environmental resistance, superior gap filling, and clear bond lines that improve aesthetics. Like cyanoacrylates, light-curing acrylic adhesives come in a wide range of viscosities from thin liquids (≈50 cP) to thixotropic gels.

The adhesives remain liquid until exposure to light of a specific wavelength and irradiance causes them to fixture rapidly and cure. Secondary cure mechanisms, such as heat or chemical activators, completely cure adhesives in shadowed areas. Because cured acrylic adhesives are thermoset plastics, they offer superior thermal, chemical, and environmental resistance.

As curing is on demand, light-cure acrylics allow ample time for aligning and repositioning parts. The adhesives offer high bond strength to a wide variety of plastics, and are available with flexibility ranging from soft elastomers to glassy plastics.

Light-cure cyanoacrylate is an adhesive technology introduced to the United States in 1998 that combines the benefits of cyanoacrylates and light-curing acrylics. Light-curing cyanoacrylates are fast-fixturing adhesives that cure naturally in shadowed areas due to a secondary moisture cure mechanism. This hybrid technology overcomes many limitations of cyanoacrylates and light-cure acrylics, offering minimal bloom-ing/frosting, increased cure depth, rapid dry-surface cure, high-bond strength, and compatibility with primers for difficult-to-bond plastics.

Light-cure cyanoacrylates also minimize vapor emissions, surface cure immediately when exposed to light, adapt easily into production lines, and require no second-step accelerators or activators. The adhesives are surface insensitive and versatile, offering excellent adhesion to numerous substrates, including rubber and plastic. These adhesives limit stress cracking on sensitive substrates such as polycarbonate and acrylic, and will bond polyolefin plastics when used with special adhesion promoters compounded into the molded parts or applied to the part surface.

Ideal for high-volume bonding applications, light-cure cyanoacrylates are increasingly used for bonding medical devices, cosmetic packaging, speakers, electronic assemblies, and small plastic parts. Rapid cure speed allows parts to be processed in seconds rather than minutes, often delivering 60% of their final strength after only five sec of exposure to light. Light-cure cyanoacrylates are especially recommended for bonding overlap-ping, nontransparent parts.

Hot-melt adhesives have been used for decades to assemble industrial and consumer products. Traditional hot melts are thermoplastic resins that essentially reflow onto a bonding surface. Once cooled, the adhesive holds the components together. While many types of hot melts are available, higher performance varieties include ethyl vinyl acetate (EVA), polyamide, polyolefin, and reactive urethane. Hot melts have the ability to fill large gaps and provide high bond strength as soon as they cool.

EVA hot melts are typically used for low-cost potting, while polyamide hot melts are used in similar applications with more stringent temperature and environmental demands. Polyolefin hot melts provide good moisture resistance, superior adhesion to polypropylene substrates, and excellent resistance to polar solvents, acids, bases, and alcohols.

The newest hot-melt classification, reactive urethanes, performs well on difficult-to-bond plastics. Whereas most traditional hot melts are thermoplastic resins that can be repeatedly reheated, reactive urethanes form thermoset plastics when fully processed. Initial strength develops a bit slower than traditional thermoplastic hot melts; however, for structural bonding, reactive urethanes are generally the hot-melt adhesive of choice. Process temperatures are approximately 250°F, as much as 200°F cooler than other hot-melt chemistries.

Epoxies are common one or two-part structural adhesives that bond well to many substrates, give off no by-products, and shrink minimally upon cure.

Cured epoxies typically have excellent cohesive strength and good chemical and heat resistance. The adhesives can also fill large volumes and gaps. The major disadvantage, however, is epoxies tend to cure much slower than other adhesive families, with typical fixture times between 15 min and 2 hr. While heat can accelerate curing, temperature limits of plastic substrates often prevent heat curing. In addition, epoxies generate considerable heat as they cure, which may result in high temperatures that can damage certain plastic substrates.

Polyurethanes are tough polymers that offer greater flexibility, better peel strength, and lower modulus than epoxies. Available as one or two-part systems these adhesives contain soft regions that add flexibility to the joint and rigid regions that contribute cohesive strength, temperature resistance, and chemical resistance. Varying the ratio of hard and soft regions lets manufacturers tailor physical properties to a designer's specific application.

Like epoxies, polyurethanes bond well to many substrates, including heavily plasticized PVC, although a surface primer is sometimes required. Polyurethanes also have fixture times similar to epoxies (15 min to 2 hr) which can require racking of parts and substantial work-in-progress. Although polyurethanes do not present much of a stress-cracking hazard, the solvents used in primers do. Polyurethanes offer good chemical and temperature resistance. However, long-term exposure to high temperatures degrades polyurethanes more rapidly than epoxies. When bonding with polyurethanes, moisture can impair both performance and appearance and must be excluded from adhesive components.

Two-part acrylics are similar to epoxies and polyurethanes in that they offer good gap-filling abilities, along with good environmental and thermal resistance. Two-part acrylics can be formulated to fixture faster than epoxy and polyurethane adhesives and improve adhesion to many plastics. Acrylics are highly flexible and bond well to many metals and plastics, which makes them a good choice for applications that require long-term fatigue resistance and durability.

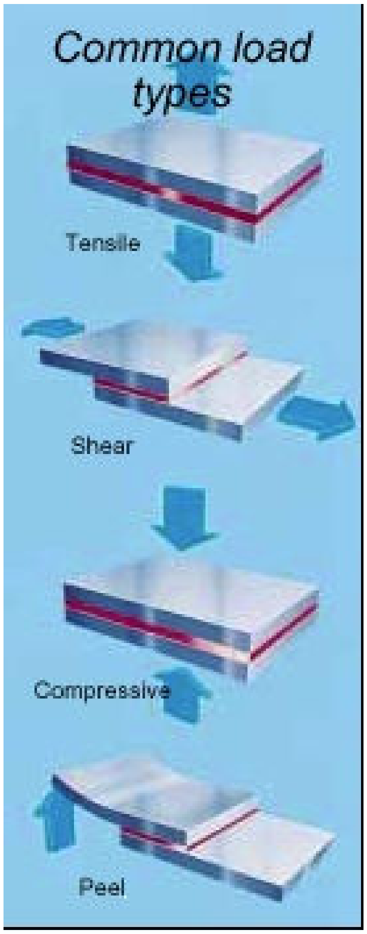
For more information

One source of additional information on adhesives and plastics is the "Designing With Plastics" educational seminars developed by A-B Lasers, Branson, GE Plastics, Loctite, and PPG Industries. The seminars provide design, process, manufacturing, and systems engineers with an understanding of plastic and process selection, assembly, coatings, and decorating technology to help reinforce product quality and productivity. For more information on these seminars, visit www.designwithplastics.com or call (860) 571-5253.

FUNDAMENTALS OF JOINT DESIGN

Stress plays a significant role in the success or failure of a joint bonded with adhesives. Engineers must have a solid understanding of stress distribution across two mating substrates to design the strongest possible joint.

Five types of stress commonly effect assemblies bonded with adhesives. Tensile stress tends to elongate and pull an assembly apart. Compressive stress squeezes an assembly together. Shear stress pulls parallel objects apart lengthwise, causing a sliding motion in opposite directions. Peel stress results when a flexible substrate lifts or peels away from the substrate to which it is bonded. Cleavage stress is similar to peel stress, but it arises in inflexible substrates when a joint is forced open at one end. In use, most joints experience a combination of these forces.



Most adhesives offer excellent resistance to tensile, shear, and compressive stresses, but are weak in cleavage and peel strength. To design the strongest possible adhesive joints, distribute loads as evenly as possible over the entire joint area. The goal should be to maximize tensile and compressive stresses, minimize shear stress, and avoid cleavage and peel forces.

The best joint designs maximize the bond area and rely on both mechanical locking methods and adhesive bond strength. Because the ends of a bond resist more stress than the middle, joint width is more important than substrate overlap to successful joint design. By increasing the width, the bond area at each end increases, along with overall joint strength.

Regardless of the adhesive, surface preparation is critical to the bonding process. The degree of adhesion between substrate and adhesive to a great extent determines bond strength. Recommended practice includes removing unwanted surface films, using primers to create active surfaces on substrates, and preparing the plastic substrates for bonding using plasma treatment, corona discharge, or chemical etching techniques.

The most frequent reasons for joint failure do not involve adhesive strength. Typically, an adhesive joint fails due to poor design, inadequate surface preparation, or selecting an adhesive incompatible with the substrates and operating environment. Always thoroughly test assemblies during the design phase to en-sure successful bonding over the life of the device.

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