High Performance Adhesives for Medical Device Assembly

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Introduction

Over the past three decades, the disposable medical market has undergone a variety of changes including the types of devices produced, substrates selected, and sterilization procedures employed. With the advent of the 20th and 21st centuries, significant medical and scientific advancements have yielded highly effective and much less invasive devices for a wide range of diagnostic, treatment, and prevention purposes.

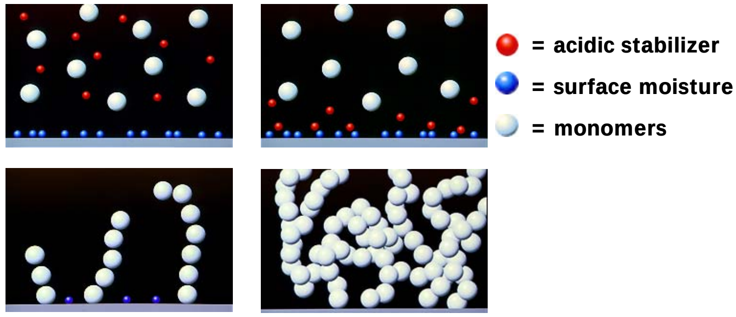
Adhesives for the Assembly of Medical Devices

Adhesives have long played an integral part in the assembly of various Class I, II, and III medical devices. Cyanoacrylates, light curing acrylics, epoxies, polyurethane, and silicones are used in diverse applications ranging from pre-filled syringes and respiratory masks to blood oxygenators and orthopedic braces. Each application has unique requirements ranging from appearance and bond performance to sterilization resistance. In general, adhesives offer numerous benefits over other medical device assembly methods including:

- Join dissimilar substrates
- Distribute stresses evenly
- Fill large gaps
- Seal & bond
- Offer a neat final appearance
- Easily automated

As with any assembly method, there are several considerations regarding the use of adhesives including: most develop handling strength over time (often referred to as the "fixture time"), all require a curing process, the majority of adhesives are difficult to disassemble once applied and cured.

CYANOACRYLATE ADHESIVES are polar, linear molecules that undergo an anionic polymerization reaction. A weak base, such as moisture present on essentially all surfaces, triggers the reaction causing the linear chains to form. The products are maintained in their liquid form via the addition of weak acids which act as stabilizers. A wide variety of cyanoacrylate formulations are available with varying viscosities, cure times, strength properties and temperature resistance.



The cyanoacrylate polymerization reaction

Cyanoacrylates form thermoplastic resins when cured. Standard unfilled cyanoacrylates typically exhibit low impact and peel strengths, low to moderate solvent resistance, and maximum operating temperatures of 160 – 180°F.

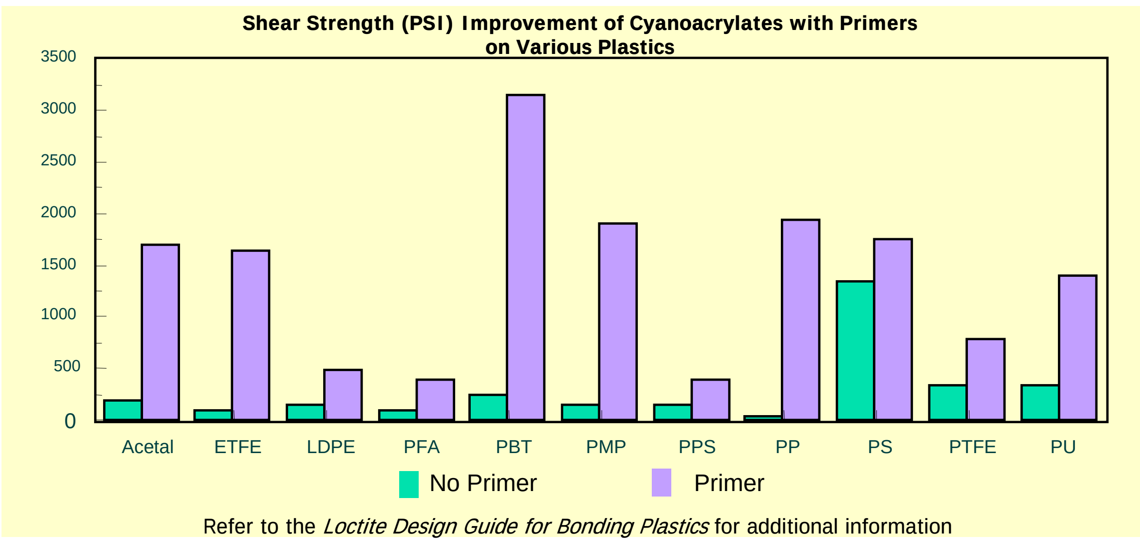
In the late 1970s, rubber was added to standard ethyl cyanoacrylate formulations resulting in significant improvements in peel and impact strengths. A standard ethyl cyanoacrylate tested in peel mode provides an average strength of less than 3 PWI. In comparison, a rubber modified cyanoacrylate exhibits peel strength of approximately 40 PWI. The addition of compounded rubber to the ethyl formulations does have a slight effect on fixture time – a typical fixture time for a standard ethyl being as low as three seconds on select substrates and a rubber toughened ethyl being between thirty seconds and two minutes.

"Blooming" or "frosting", not necessarily cited as a performance limitation, but nonetheless a potential drawback of cyanoacrylate adhesives, is the presence of a white haze around the bondline. Blooming/frosting is caused by the reaction of volatilized cyanoacrylate monomer in air that, because it's heavier than air, falls back to the surface and settles around the bondline. A selection of cyanoacrylate adhesives now use monomers that have a higher molecular weight and lower vapor pressure thus minimizing the potential for blooming/frosting. Users of these types of products should be cautioned, however, since the change in monomer can have an effect on cure speed, physical properties, and operating temperatures. These low bloom products offer the additional advantage of having a reduced odor in the uncured state as compared to traditional ethyl cyanoacrylates.

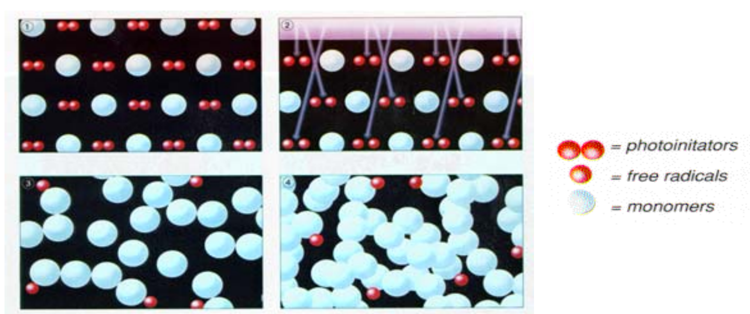
Traditional cyanoacrylates can typically withstand maximum temperatures of approximately 180°F. Recent advancements in ethyl cyanoacrylate technology now allow thermally resistant products to withstand continuous exposure temperatures up to and including

250°F. Such thermal resistant materials are usually modified thoughened cyanoacrylate products and therefore share the decreased fixture times.

Besides advancements in cyanoacrylate technology, there have also been significant advancements in primer and accelerator formulations that not only offer speed of cure but also the ability to bond “hard-to-bond” plastics. The primers are solvent-based systems, which deposit reactive species onto otherwise “dead” substrates. Such reactive species allow for significant increases in bond strength of the majority of difficult to bond materials including polyethylene, polypropylene, fluoropolymer, and acetal homopolymer.



LIGHT CURING ACRYLICS cure via a free radical reaction to form thermoset resins when exposed to light of the appropriate wavelength and intensity. Like cyanoacrylates, light curing acrylic adhesives are available in a wide range of viscosities from low (~ 50 cP) to thixotropic gels. In addition, light curing adhesives vary in final cured form from hard, glass-like resins to soft flexible resins.



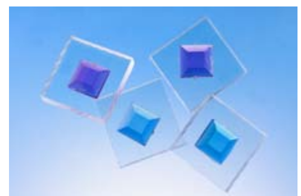
The light cure polymerization reaction

The critical processing key with light curing acrylic adhesives is that light must reach the full bondline in order to cure the adhesive. Adhesive in shadowed areas will not cure. In addition, the maximum depth of cure for the majority of light curing acrylic systems is approximately 0.5". Another consideration when selecting a light cure adhesive is the equipment required for the processing of the product. Light curing adhesives require specific radiant energy (i.e. light energy) in order for the polymerization reaction to occur. It is, therefore, critical that the end user match the adhesive with the appropriate light source.

NEW Technology

New grades of acrylic adhesives that cure solely with higher wavelength visible light (>425 nm) have recently been introduced to medical device manufacturers. The use of such visible light provides significant benefits to design and production personnel including:

- Ability to cure through select colored materials
- Low to no heat output from visible light curing systems
- Minimal personal protective equipment requirements
- Longer life and initial lower cost visible curing systems
- Enhanced cure depths (in excess of 0.5" with proper light source)



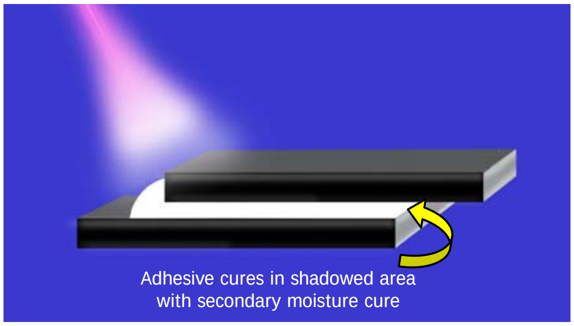
Light curing acrylic technology offers the significant benefit of rapid fixture and cure following exposure (as little as 5 seconds for select joints), thus minimizing work in process (WIP). In addition, light curing acrylic formulations have been designed to bond a wide variety of substrates and yield a clear bondline when used in thin sections. Because the final resins are thermoset plastics, thermal, chemical and environmental resistance of light curing acrylics is enhanced versus cyanoacrylate adhesives.

Typical applications involving light curing acrylic adhesives are numerous since it is one of the most selected (if not the most selected) adhesive joining methods employed by device manufacturers.

A technology introduced in the United States in 1998 combines the benefits of cyanoacrylate technology and light curing acrylic technology. *LIGHT CURING CYANOACRYLATES* are cyanoacrylate based products which have photoinitiators added to the formulation. The end result is rapid cure in exposed areas (like that of a traditional light curing acrylic) *and* cure in shadowed areas. The overall physical performance characteristics are similar to those obtained with a traditional cyanoacrylate. Additional benefits gained with this technology include minimized blooming/frosting since exposed uncured cyanoacrylate can be immediately cured using ultraviolet and/or visible light, increased depth of cure over the traditional cyanoacrylate cure maximum of 0.010 inches, and compatibility with primers for "hard-to-bond" plastics.

NEW Technology

New tough/fracture resistant grades of light curing cyanoacrylates are now being introduced to device manufacturers. These adhesives offer significant improvement in side impact, fracture resistance and peel testing making them particularly suited for devices which incorporate materials with varying CTEs (coefficient of thermal expansion) or requiring additional toughness than a traditional light curing cyanoacrylate.

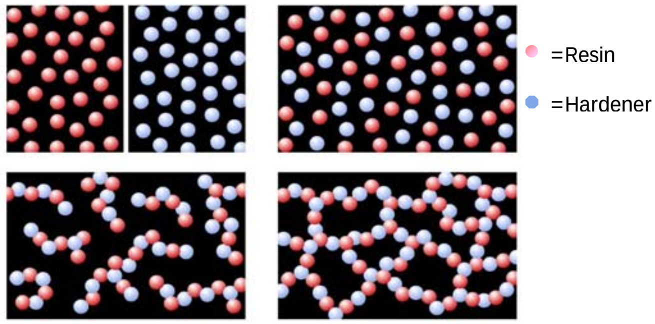


Shadow cure of light curing cyanoacrylates

EPOXY ADHESIVES, like the previously mentioned light curing acrylic adhesives, cure to form thermoset plastics. The polymerization reaction occurs via ring opening of an epoxide group initiated by a catalyst such as an amine or mercaptan. Room temperature and heat curing one and two part systems are available. Due to their ability to crosslink, epoxies offer superior chemical, environmental and thermal resistance. The ability to bond a wide variety of substrates and fill large gaps make epoxies useful for deep section potting of medical components and needle assembly. In addition, the superior temperature resistance of this class of adhesives makes them particularly suited for devices requiring multiple autoclave exposures.

Because epoxies cure via an exothermic reaction (giving off heat during cure) their use on temperature sensitive components must be closely monitored. .

POLYURETHANE ADHESIVES are similar to epoxies in that one and two part formulations are available. A urethane linkage is formed when the two main formulation components – the polyol and isocyanate – react to form hard and soft segments in the resultant polymer. Such segments contribute to the unique flexible yet tough cured materials. Like several previously mentioned chemistries, polyurethane adhesives form thermoset resins when cured thus exhibiting good chemical and environmental resistance. It is important to note, however, that the overall thermal resistance of cured polyurethanes is less than that of cured epoxies.



The epoxy and polyurethane polymerization reaction

Polyurethane adhesives are substrate versatile but do, on occasion, require the use of a surface primer to increase the reactivity of the surface to be bonded. Many of the primers require long on-part times in order to effectively prepare the surface for the adhesive. A second potential drawback to the use of polyurethane adhesives is their inherent moisture sensitivity. Excess moisture on a part or in one of the constituents can cause a reaction resulting in the evolution of carbon dioxide and thus bubbles apparent in the finished component.

SILICONE ADHESIVES are similar to polyurethane adhesives in that they form flexible polymers when cured. Silicones, however, possess no rigid segment and therefore exhibit lower cohesive strengths – the ability of the polymer to adhere to itself. Like previously mentioned epoxies and polyurethanes, silicone adhesives are available in several forms including one part moisture cure, one part heat cure, one part light cure and one part dual moisture and light cure. Although two part silicone systems do exist industrially, the catalysts used in such materials typically cause the system to fail biocompatibility screening.

Several new light curing only and light/moisture cure medical device grades of silicones were introduced in early 2009. The use of such adhesives eliminates the typical work-in-process inventories while offering high adhesion to silicone materials as well as many typical device plastics (i.e. polycarbonate, acrylic, ABS, etc..)

ISO 10993 – The Biocompatibility Standard for Medical Device Adhesives

Along with performance issues, medical device manufacturers must also consider regulatory issues. ISO 10993, a globally accepted standard for biocompatibility testing, has replaced Class VI for most adhesive suppliers. The International Standardization Organization (ISO) standard typically involves revised tests, extract solutions, extract temperatures, and test durations that more closely match actual body conditions. The end user should ask a variety of questions during the adhesive supplier selection process including:

- What biocompatibility standard is the adhesive supplier testing to?
- What qualification tests does the supplier include in the standard?
- How frequently are products retested to verify compliance?
- How were the test specimens prepared? Bonded assemblies or coating?
- What were the extraction conditions?
- What type of documentation can the supplier provide to verify compliance?

Summary

As indicated in the "Engineer's Guide to Plastics" published by Materials Engineering, adhesives are the most versatile assembly method for plastics, capable of joining thirty-six types of plastics. Mechanical fasteners, which are cited as being capable of joining approximately twenty-eight plastics, are the second most versatile plastic assembly method. Ultrasonic welding, one of the more commonly used welding techniques for medical devices, is referenced as being capable of joining only about eighteen plastics.

The numerous benefits cited coupled with the variety of biocompatible formulations available ensure that the majority of device assembly applications can be quickly, effectively, and safely completed with today's adhesive technology. Table 1 offers a comparison of a variety of performance and use considerations for medical device adhesives.

Table 1: Typical Characteristics of Biocompatible Medical Device Adhesives					
Performance Considerations	**Medical Device Adhesive Type**				
	Cyanoacrylates	**Light Cure Acrylics**	**Epoxies**	**Polyurethanes**	**Silicones**
Key Benefit	• Substrate versatility • Rapid RT fixture	• Rapid cure • Adhesion to plastics	• Wide range of formulations • Chemical and temperature resistance	• Superior toughness and flexibility	• Excellent temperature resistance
Key Consideration	• Moderate solvent resistance	• Cure system required	• Mixing or heat cure required	• Sensitivity to H_20 in uncured state	• Cure system required
Typical Temp. Resistance	• -65 to 180°F • Highest = 250°F	• -65 to 300°F	• -65 to 300°F	• -65 to 250°F	• -65 to 400°F
Tensile Strength	• High	• High	• High	• Medium	• Low
Elongation / Flexibility	• Low	• Medium	• Low	• High	• Very High
Hardness	• Rigid	• Semi-Rigid	• Rigid	• Soft	• Soft
# of Components	• 1	• 1	• 1 or 2	• 2	• 1
Cure Type/ Temperature	• Room Temp	• UV/Visible	• Room Temp or 100°C (min)	• Room Temp	• UV and/or Room Temp
Full Cure Time	• 24 hours	• 30 to 60 secs	• 12 -24 hours (for RT) • 30 mins (for 100°C)	• 24 hours	• 10 mins (for UV) • 24-72 hours (for RT)
Gap Fill Max	• 0.010”	• 0.5” +	• 0.5” +	• 0.5” +	• 0.25”
Typical Device Applications	• Catheter components • Tubeset bonding • Polyolefin bonding	• Needle assembly • Anesthesia masks • Heat exchangers • Oxygenators • Tubeset bonding	• Needle assembly • Deep section potting • Repeated autoclave exposure	• Deep section potting • Bonding of tips onto various components	• Bonding of silicone components • Flexible bonding and coating

[1]*Cyanoacrylates typically offer good moisture resistance on plastics*