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Adhesives: A Selection Guide

Mark Turner
Medical Engineering Technologies Ltd, Ashford, UK

This article analyses the use of three types of adhesive for medical device assembly. The advantages and disadvantages, typical applications and key features are defined for cyanoacrylate, epoxies and UV- and light-cured adhesives.

How adhesives work

The mechanisms by which adhesives bond materials are not yet fully established.[1] A favoured candidate for the process is inter-molecular attraction, that is, the physical attraction between different materials, which is demonstrated by the meniscus of a liquid in a vessel. In the case of water, the inter-molecular forces (attraction to other materials) are stronger than the intra-molecular forces (internal attraction of molecules). This is why the surface tension causes the meniscus to curve upwards at the edge of a vessel. For mercury, the cohesive (intra-molecular) forces are generally stronger than the adhesive (inter-molecular) forces leading to the meniscus curving down. A good everyday example of these forces is when a beer mat sticks to the bottom of a wet glass.

It has been suggested that a chemical bond may be formed between substrate and adhesive.[2] This theory has largely been discounted on the grounds that the joint strength is not great enough. Achieving a strong bond through inter-molecular forces is dependent on obtaining intimate contact between the surface to be bonded and the adhesive.[1] This contact is crucial and it is the main factor governing the strength of a modern industrial adhesive bond. When a sample is submitted to an adhesive supplier's laboratory, the

Table I: Typical properties of cyanoacrylate.[3]

Surface compatibility	compatible with many materials including rubbers and plastics, less compatible with acidic surfaces because these can inhibit crosslinking reaction
Bond strength	usually very good (up to 35 Nmm^2 tensile), may need a primer
Environmental factors	prolonged exposure to water weakens bond
Method of application	hand or timer operated pressure pot or accurate dosing system using positive displacement
Cure mechanism	crosslinking polymerization
Activation mechanism	removal of inhibitor by the presence of water
Cure time	generally 1–10 s
Completeness of cure	reaction generally goes to completion
Lifetime of bond	comparable with lifetime of substrate
Toxicity	low toxicity in cured and uncured forms
Sterilization compatibility	most grades are not resistant to temperatures over 120 °C or repeated autoclave cycles. Compatible with gas and irradiation methods
Shelf life	several years when stored at 5 °C
Handling precautions	avoid contact with unreacted material — it sticks skin

Mark Turner
Business Development Manager
Medical Engineering Technologies Ltd
Webster House
Jesmond Street, Folkestone, Kent, UK
tel. +44 (0)845 458 8924
fax +44 (0)8700 562153
www.met.uk.com

aim is to find the adherant with the greatest surface compatibility.

The need to achieve intimate contact explains why adhesives are applied in the liquid phase when the bond is dependent on them being solid. Once the liquid adhesive is in position, it must be cured to form the joint between the substrate materials. This curing takes several forms. It can be a crosslinking polymerization reaction, an evaporation of solvent or a temperature-dependent phase change. The strongest bonds are formed when the adhesive undergoes a chemical change to secure the bond.[2]

Modern adhesives differ in their presentation and their method of curing. Those most relevant to the assembly of medical devices are cyanoacrylate, epoxies, and UV- and light-cured materials (often methacrylate based). When selecting an adhesive for any application the important factors are

- compatibility with surface to be bonded
- compatibility of bond with product application (bond strength, environment)
- method of application of adhesive
- method of curing
- strength and permanency of bond required
- amount and type of stress to be applied to joint
- compatibility of bond with downstream processes
- lifetime of bond
- handling and storage of uncured material
- health and safety implications of materials and processes.

For medical manufacturers there are additional considerations:

- toxicity or sensitization effects of cured material
- completeness of cure in application and toxicity of any uncured material
- compatibility with sterilization or other processes
- resistance to repeat sterilization.

Table II: The advantages and disadvantages of cyanoacrylate.

Advantages[4]	Disadvantages[4]
No curing equipment required	Sometimes requires a primer
Many grades are available allowing a variety of properties and substrate compatibility	"Blooming"* can occasionally cause cosmetic problems
Bonds often stronger than substrate	Not generally suitable for repeated autoclaving
Nontoxic before and after curing	Not good for filling gaps, although gel grades are available
Single component — simple dispensing equipment required	Preassembly of components is usually required because bonding is instant
Good shelf life with no rigorous storage conditions	

*Blooming is the term generally used to describe the dulling of surfaces on which cyanoacrylate condenses. It can usually be avoided by sparing use of the adhesive.

Table III: Typical properties of epoxy adhesives.[5]

Surface compatibility	a wide variety of grades offers compatibility with many materials; traditionally used for bonding metals rather than plastics
Bond strength	good (up to 20 Nmm^2 shear steel to steel)
Environmental factors	very good at transmitting stress and load; also has excellent and wide-ranging chemical and temperature resistance
Method of application	usually hand or motor driven two-part mixer
Cure mechanism	crosslinking catalysed by activator component, accelerated by heat
Cure time	10 min–24 h
Completeness of cure	reaction generally goes to completion
Toxicity	uncured material is often an irritant when cured inert
Sterilization compatibility	compatible with all forms of sterilization, especially resistant to radiation, usually suitable for repeat sterilization
Shelf life	several years when stored below 25 °C
Handling precautions	often an irritant in unreacted form

Table IV: The advantages and disadvantages of epoxy adhesives.

Advantages[4]	Disadvantages[4]
Excellent for filling gaps	Usually requires mixing although single component; heat-cured grades are available
Many grades are available leading to a variety of properties and substrate compatibility	Viscosity can require more complicated dispensing equipment
Cure time allows for repositioning of work	Cure not instant, curing area required
Nontoxic after curing	Limited pot life after mixing
Can be combined with fillers to give heat or electrical conductivity	Because uncured material is an irritant, handling precautions such as gloves and masks are required as well as the extraction of emitted gases
Good shelf life with no rigorous storage conditions	

Cyanoacrylate

Cyanoacrylate (commonly known as super glue) is fast to react and tiny amounts will form very strong bonds. It has acquired its reputation, in part, through bonding skin and its use as an alternative to sutures is now well known. This propensity to stick skin is a result of crosslinking that is activated by the presence of water. The adhesive mixture contains an acid stabilizer that inhibits polymerization. Contact with water, even the

minute amounts found on most surfaces, neutralizes this acid and allows the monomers in the liquid to crosslink and form a structural polymer. Table I shows the typical properties of cyanoacrylate and Table II lists its advantages and disadvantages.

Cyanoacrylate is stable to ethylene oxide and performs well in gamma sterilization. It is not suitable for continuous immersion in water, but can withstand several days' contact with no reduction in bond strength. Strong silicone to silicone bonds can be achieved as well as plastic to rubber. Typical applications include suturing, catheter bonding, tubing assembly, cuff and balloon assembly, bonding flexible to rigid materials, flange mounting on bags, forming seams on thin materials and general assembly where gap filling is not required. Cyanoacrylate is simple to use, requiring only a "pressure pot" or metered valve dispensing. "Pressure pot" refers to placing a container of adhesive into a pressurized vessel and siphoning the material off through a tube with a valve that has a controlled opening.

Epoxies

Epoxies are much more viscous than cyanoacrylate and usually come in two parts. Mixing of the adhesive with the chemical activator initiates the exothermic crosslinking reaction. Single component epoxies are sometimes used. Curing is activated by heat, and these materials are often stored in a freezer. Dispensing and mixing often take place in a single piece of equipment, which can range from a double syringe with mixing nozzle to large equipment. "Pot life," that is, the amount of time the mixed material remains fluid, is an important factor. Heat is often a secondary curing system.

Epoxies are often referred to as structural adhesives because they can transmit load and stress. They are a good choice for applications that require gap filling or when other special features are involved such as heat or electrical conduction. They are also good for joining dissimilar materials and exhibit good resistance to frequent changes in environmental temperature, such as those experienced by products that are repeatedly autoclaved. Epoxies are suitable for large areas or lines of adhesive. Table III shows the typical properties of epoxies and Table IV lists their advantages and disadvantages. Applications include needle and transducer potting, tubing assembly, cuff and balloon assembly, assembly of capital equipment and general assembly where gap filling is required.

UV- and light-cured adhesives

Several classes of adhesive are activated by electromagnetic radiation; they are usually methacrylate-based and can be modified to be activated by light of different wavelengths or even heat. Other additives give properties such as fluorescence to demonstrate that curing has taken place. Table V shows the typical properties of UV- and light-cured adhesives. Table VI lists their advantages and disadvantages.

These adhesives are popular in industry because parts can be assembled with adhesive in place. The curing process, which is rapid, can therefore take place when required and when everything is ready. Dispensing can be performed via pressure pot, metered valve or air-powered syringes. A light source, for example a flood lamp in a curing chamber or a light guide, is required for curing.

UV-cured adhesives are flexible in their application and are useful for joining dissimilar plastics. They can be used for space filling but need to be accessible to the curing radiation. Typical applications include needle potting, catheter bonding, tubing assembly, cuff and balloon assembly, bonding of flexible to rigid materials, structural assembly such as

Table V: Typical properties of UV- and light-cured materials.[6]

Surface compatibility	many grades available giving good compatibility with most plastics and metals
Bond strength	good (up to 16 Nmm^2 shear glass to metal)
Environmental factors	inert when cured
Method of application	low-volume dosing system
Cure mechanism	driving of crosslinking reaction by light energy
Cure time	surface a few seconds up to a few minutes for deeper sections
Completeness of cure	can remain uncured in deep sections
Toxicity	low in cured and uncured states
Sterilization compatibility	good with all methods, but cannot withstand temperatures above 135 °C
Shelf life	several years
Handling precautions	often an irritant in unreacted form, vapour can cause headaches, requires extraction

Table VI: The advantages and disadvantages of UV- and light-cured adhesives.

Advantages[4]	Disadvantages[4]
Repositioning possible	Curing equipment required
Many grades are available, offering a variety of properties and substrate compatibility	Odour may cause irritation during curing, extraction recommended
Bonds often stronger than substrate	Can withstand a limited number of autoclave cycles
Nontoxic before and after curing	Needs to be in UV-transparent substrate to cure
Single component	May have a residual tacky surface
Gel grades allow limited gap filling	
Good shelf life with no rigorous storage conditions	

Table VII: The key properties of the main adhesives used in medical device manufacturing.[4]

Adhesive	Indications	Contra Indications
Cyanoacrylate	low-fill volume, rapid cycle (cure and dispense) time, strong bond, no special equipment required	need to reposition work, need to gap fill, use in continuous aqueous contact
Epoxy	gap filling or structural requirements, need to conduct heat or electricity, time needed to reposition	two-part requires mixing, need curing time and space
UV- and light-cured	allows repositioning	curing equipment required

Extraction and handling precautions are recommended with all unreacted materials.

oxygenators, and general assembly where extensive gap filling is not required.

Summary

Table VII gives a summary of the key properties of the main adhesives used in medical device manufacturing. This is not a comprehensive list of adhesives used in the industry. Pressure-sensitive adhesives are used when a temporary bond is required, polyurethane may be used with foams and laminates, and many other materials, including silicones, are also employed. In addition, there are several completely different joining technologies such as the various welding techniques, mechanical snap fits and insert moulding.

References

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4. URL: http://www.metech.demon.co.uk /adhesives/selection
5. Medical Engineering Technologies' specification sheet MET EP 4013 rev.2
6. Medical Engineering Technologies' specification sheet MET UV50 rev.2

General background information taken from G.L. Schneberger, Ed., *Adhesives in Manufacturing*, Marcel Dekker Inc., New York, New York, USA, (DSC Monograph No. 11) 1983.

Further reading

The Adhesives and Sealants Yearbook and Directory, BASA, London, UK.