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Functional Adhesive Trend for Assembly Industry

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Abstract

Recent applications in the industry require more and more cost-saving, more effective, and more reliable assembly of various substrate parts that are used for end-use product for manufacturers. This chapter can provide an insight on the solutions of different functional bonding and sealing technologies available to manufacturers who have used conventional methods for a long time which help them open their eyes to new solutions that can provide a faster, lighter, lower cost yet achieve more reliable assemblies resulting in more competitive assemblies in the market place. Various technologies provide an optimum solution to different industries and market segments for OEM industry such as appliance, HVAC, filter, medical, construction/agricultural equipment, recreational vehicles, railway, marine, electric motor, loudspeaker, elevator, small engine, valves, pumps, hydraulic system, etc. and for repair industry such as power plant, steel mill, mining, and car repair markets, too.

Keywords: anaerobic, cyanoacrylate, light cure (ultraviolet and visible), acrylic structural (two-part and no-mix), acrylic structural (two-part and pre- and post-mix), silicone, polyurethane

1. Introduction

Adhesives have been a long history ever since the presence of mankind on this earth. It was found out that the jewelry box unearthed from the tomb of ancient Egyptian Pharaoh Tutankhamen had used a glue to assemble it with a beautiful appearance. When the Genghis Khan of Mongolian Empire had conquered the most of Asia and some Europe, the most powerful weapon they had used a bow made of a buffalo bone with laminations bonded with a glue which had become much more powerful than that of enemies. Globally famous musical instrument Stradivarius violin had been found out that a glue was used for laminations that help generate a beautiful sound for generations to come. Through Industrial Revolution, the key trend was how many and how fast they can manufacture within a short amount of time. Nowadays assembly industries have been looking for ways to help how they can manufacture faster yet increase the reliability of their products more. Those functional reactive adhesive and sealants featuring their benefits and typical applications will be introduced in this article in comparison with conventional assembly methods.

They are mainly machinery adhesives (anaerobic), light cure adhesives (LCA), cyanoacrylate adhesives (CA), acrylic structural adhesives, silicone and polyurethane, etc.

2. Overview of adhesive solution

Bonding solution has provided a faster assembly, lighter assembly, and more reliable assembly than various conventional mechanical assemblies. The following section will help you understand the features and benefits of reactive adhesive and sealant technology with the target of explaining the adhesive engineering terminology in order to understand a common basis for the following chapters.

2.1 Universal truth on bonding

Wood is not a proper substrate for welding as it will burn, not melt, plastic is not a proper substrate for soldering or brazing as it will melt away, and steel is not a proper substrate for nail as it will not bond and cause a localized high stress peak. However, adhesive can bond wood, plastic, and steel without burning, without melting and without having a high localized stress peak.

2.2 The adhesive joint

Adhesives are connecting between two substrate surfaces, where they are of the same or different materials. The bonding mechanism depends on the adhesion and cohesion.

2.3 Adhesion

“Adhesion” is an interaction between adhesive and substrate surfaces. There are two main parameters for achieving a good bonding. One is molecular interactions called “van der Waals” force, and another one is a mechanical interaction called “mechanical keyway” in the assembly. Adhesive was applied on the surface flows, due to its rheology, into the valley of surface roughness to fill and grip the surface. This way the mechanical keyway assembly can exhibit a high resistance against external vibration or impact. In case of low surface energy substrates such as Teflon, polypropylene, and polyethylene, adhesive wetting the surface flow into the valley is not easy resulting in improper mechanical keyway effect. In order to overcome this, a surface treatment is required to increase the surface roughness and mechanical keyway effect such as primer, plasma and flame treatment, etc.

2.4 Cohesion

“Cohesion” is an interaction between the molecules of adhesive monomer. This is a combination of “van der Waals” force and molecular reaction of adhesive monomers. This helps to have a toughness of the adhesive. This property is one of the important parameters especially when a reliable structural bonding against impact and vibration is required and multifunctionality of oligomer is used together with elastomers.

3. Various functional adhesives

Most functional adhesives are reactive polymers; in most cases they change from liquid to solid through various chemical polymerization reactions. Numerous functional adhesives have been developed with special curing properties for specific application situations. Those adhesives can be classified into the following groups

according to the curing property. They are anaerobic reaction, exposure to light (ultraviolet and visible—also secondary curing option), anionic reaction (cyanoacrylate), activation system (modified acrylics), and moisture curing (silicones, polyurethane).

3.1 Adhesives cured by anaerobic cure

When adhesive is applied onto one side of a metal substrate, adhesives contact with metal ion (Fe^{2+} and Cu^{2+}) for some anaerobic initiator to be broken into free radicals which are unstable, but the presence of air to contact adhesive is stronger; therefore it remains as a liquid. As a next step, when the other mating part comes in contact with the first part with adhesive in between, more anaerobic initiators contact more metal ions to be broken into more free radicals, and at the same time, oxygen contact is blocked by both substrates; then those unstable free radicals react with a monomer nearby which becomes unstable, too, and then it reacts with other monomers nearby, and gradually all the monomers react and become polymerized (cure) (see **Figure 1**) [1].

In case of inactive metal substrates that contain low metal ions such as Cu^{2+} or Fe^{2+} and have a slow reaction with photo initiator and slow cure, an acceleration method such as primer and heating can be used to speed up the curing. Anaerobic adhesives become a very reliable thermoset plastic after cure [2].

3.1.1 Anaerobic adhesive features

This cured thermoset plastic property provides an excellent resistance to various chemical environment, excellent resistance against external impact, and vibrational force due to its mechanical “keyway” effect and high temperature environment up to 180°C and some special formulation is up to 350°C . It also has a controlled viscosity for optimum dispensing and controlled cure speed depending on the requirement of the application. This allows a normal machining by saving a machining cost, and it also allows an automatic dispensing of adhesive for more effective manufacturing.

Curing, especially the reaction speed of anaerobic products, is mainly influenced by the following: substrates, as some are active substrates that contain a rich metal ion, whereas inactive substrates contain less metal ion; the bond line gap, as the reaction takes a short time with a thin bond line, while a thick bond line takes a long time to polymerize; temperature, as elevated temperature activates the reaction of adhesive, while low temperature slows down the reaction of adhesive; and activator, as it will activate the inactive surface as if an active substrate is used.

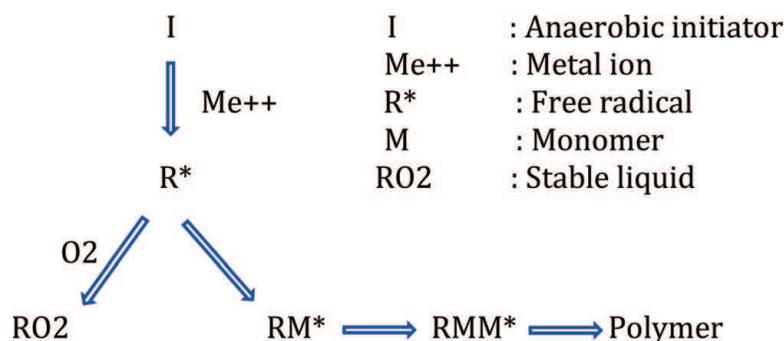


Figure 1.
 Anaerobic cure mechanism.

3.1.2 Active and inactive metal substrates

Anaerobic products react fast to active metal substrates and react slow to inactive substrates. Therefore, it is important to understand what type of substrates they have for bonding and sealing application. Active substrates contain more Cu^{2+} and Fe^{2+} ions, while inactive substrates have less Cu^{2+} and Fe^{2+} ions (see **Table 1**) [1].

3.1.3 Anaerobic shelf life

Anaerobic liquid products need a constant oxygen contact to stay as a liquid and to become stable. When a new bottle was opened and the adhesive product level is only half of the container, it is important to know that it is to ensure that adhesive is in constant contact with oxygen in the container. Therefore, if the product's net amount is "250 ml," then the total volume of packing is "500 ml"; likewise in case of a "50 ml" product, the total volume of packaging is "100 ml."

Anaerobic adhesives have a different shelf life depending on the size of the packaging. The smaller the packaging, the longer the shelf life; in other words, the bigger the packaging, the shorter the shelf life. The whole mechanism behind this is that for smaller packaging, the distance oxygen penetrated into the center of adhesive product is shorter, so the whole amount is under the influence of oxygen; however for bigger packaging, the distance of oxygen to penetrate into the center of adhesive product is longer, so the monomers in the center of adhesive products have less amount of oxygen contact and become unstable resulting in increased viscosity and premature reaction of monomers inside the packaging.

3.1.4 Recent technological trend

Recent technological trend of anaerobic adhesive and sealants is to bring the performance of core products to a next level so that those few core products can cover various application requirements; in the past, there were separate products to meet fast cure, high temp resistance, oily surface cutting, active reaction to inactive substrates, etc. However currently, those few core products can meet most of the above requirements at the same time such as this adhesive has a high temperature resistance up to 180°C (constant condition) so it can be used for those applications that could not be used due to high temp requirement; this adhesive has fast reaction to inactive substrates such as stainless steel, aluminum and zinc plated steel, and this adhesives cuts through a slight oil coating on the substrate and it adheres well to the substrate; therefore no special cleaning is required.

Active materials (speed cure)	Passive materials (slow cure)
Brass	Aluminum
Bronze	Ceramics
Copper	Chromate films
Iron	Glass
Steel	High-alloy steel
	Nickel
	Oxide films
	Plastics
	Stainless steel
	Zinc

Table 1.
Active and inactive substrates.

3.1.5 Typical applications

There are four major applications, namely, thread locking application for locking bolt and nut assembly, or stud and tap assembly, in place against loosening; thread sealing application for sealing various fittings and hydraulic and pneumatic thread connections against fluid leakage; retaining application for shaft and gear, bearing, and housing against slippage or free spinning; and gasketing application for machined metal flanges against fluid leakage.

3.1.5.1 Thread locking

3.1.5.1.1 Conventional fastening methods

Those conventional methods used in the assembly industry are flat washer, spring washer, nylon lined nut, serrated bolt, etc.

They have shortcomings such as the following: they loosen under vibration, thermal expansion, and/or plastic deformation, they do not seal thread as the space between bolt and nut is all empty, they require extensive inventory of several fastener shapes and sizes, they are prone to rust and damaged surface due to empty space and poor handling, they have a wide bolt tension scatter as each bolt assembled with the same tightening torque shows a different bolt tension on a flange, they show lower break loose torque than tightening torque resulting in unstable assembly, and they are more costly than liquid thread locking adhesive [3].

3.1.5.1.2 Liquid thread locking adhesive

Those liquid thread locking adhesives have the following benefits: they lock bolt and nut in place, they seal against leakage and internal pressure, they prevent thread corrosion, they provide a controlled lubricity for consistent bolt tension on a flange, they provide a torque augmentation with higher break loose torque than tightening torque, they provide a controlled strength for easy disassembly for repair, they have a low inventory with less storage space, and they have a cost saving [4].

3.1.5.2 Thread sealing

3.1.5.2.1 Conventional thread sealing method

Those conventional methods used in the assembly industry are polytetrafluoroethylene (PTFE) tape, O-ring, pipe dope, etc.

They have shortcomings such as PTFE tape shards generated during pipe assembly contaminate internal hydraulic pipe system, and PTFE tape can have a leak once readjusted after pipe location setting and requires a manual wrapping of time and cost. Another conventional method O-ring has no sealing effect at dynamic environment and requires an additional machining or molding. Pipe dope has a low pressure sealing [5].

3.1.5.2.2 Liquid thread sealing adhesive

Those liquid thread sealing adhesives have the following benefits: they provide a good sealing, they prevent a self-loosening, they cause no contamination inside hydraulic piping system, they cure slowly to allow pipe location adjustment after initial tightening yet provide an instant low pressure sealing, they protect pipe threads against corrosion and galling, and they show a high pressure resistance after cure [6].

3.1.5.3 Retaining

3.1.5.3.1 Conventional retaining methods

Those conventional methods used in the assembly industry are positive drive (pins, keys and splines), friction drive (press fit, shrink fit), and welding/soldering.

They have shortcomings such as the following: they have a notorious back lash that causes an extremely high stress, deformation, and consequent failure of assembly; they have a fretting corrosion that causes a lower torque transmitting capability, and their machining is costly and lengthy to meet the right assembly tolerance; they need additional equipment required for press fit and shrink fit; and in overall they are more complicated, time-consuming, and less reliable [7].

3.1.5.3.2 Liquid retaining compound adhesive

Those liquid retaining compound adhesives have following benefits such as they are less costly in machining as they don't need a tight tolerance; they cause no back lash, and therefore it allows a high durability and reliability of the assembly; they allow the assembly assembled simpler and easier; and they can be used to conventional designs if they can't change the design and it can increase the durability of the assembly, too [8].

3.1.5.4 Gasketing

3.1.5.4.1 Conventional gasketing methods

Those conventional methods used in the assembly industry are various compression gaskets (pre-cut gaskets, O-ring seals and profile packings).

They have shortcomings such as the following: they achieve a sealing by compression for a long time which is not realistic; they have a shrinkage, creep, and compression set under high flange pressure; they require to store multiple shapes to seal different flange shapes; they are costly with an intricate flange shape; they are susceptible to external or internal impact or pressure; and they require additional machining or smooth machining to achieve a sealing with a cut gasket [9].

3.1.5.4.2 Liquid gasketing sealant

Those liquid gasketing sealants have the following benefits: they have a metal-to-metal contact, thus becoming a very stable assembly, they can be used to all different shapes of flange with one product, they can provide a unitized assembly with "keyway effect" between flanges, they can eliminate all the mistakes that occur with the manual operation, they can be used for automatic dispensing and assembly, and in overall they can increase the durability, reliability, as well as the cost reduction of the assembly [10].

3.2 Adhesives cured by light (ultraviolet and visible)

The cure time of these adhesives depends on the intensity and on the wavelength of the light. Polymerization initiated by the light thus always requires a proper curing property of the adhesive and correct exposure to a light radiation. When a light cure adhesive is applied and goes through the area of light irradiation, the photo initiators in the adhesive are split to become free radicals which are very unstable. In this situation, unlike to anaerobic cure, there is no condition that

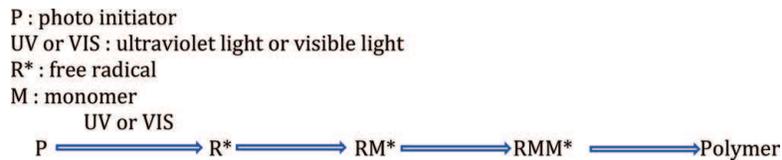


Figure 2.
Light curing mechanism.

prevents a curing of the adhesive as the power of light energy is so high to overcome all the other hindrance. The free radicals formed in turn start the polymerization by reacting with a monomer nearby, and it becomes unstable, too, and then reacts with the next monomer and finally polymerized in a very fast speed (see **Figure 2**). It is critically important to use a right light curing lamp equipment that emits a proper wavelength of radiation spectrum ideally matched to the curing properties of light cure adhesives [11].

There are three types of light cure adhesives, namely, UV cure adhesive, UV+ visible cure adhesive, and visible cure adhesive.

3.2.1 Ultraviolet (UV) light cure adhesive

UV light is in the range of 40–400 nm wavelength. The whole UV wavelength does not necessarily cure adhesive. A specific wavelength of UV light affects the adhesive. UVC is a short wavelength, and it cures the surface of adhesive as it is a short wavelength and not easy to penetrate the adhesive inside; therefore it is used for surface cure of adhesive. UVA is a long wavelength, and it cures the volume of adhesive as it is a long wavelength and easy to penetrate the adhesive depth; therefore it is used for a depth cure. Care should be taken when selecting a clear plastic for light cure. Some plastics such as UV stabilizer filled PC looks like a clear plastic to the eyes of people, but UV light cannot go through the plastic as the UV stabilizer inside the PC can absorb the UV light and cannot reach the adhesive bond line. It is also critical to know that the temperature inside UV curing chamber or conveyor should be kept less than 60–70°C depending on the thermal sensitivity of parts exposed to UV light as the UV light bulb can irradiate not only UV light but also emit infrared (IR) and heat. Otherwise temperature can reach above the limit of plastic parts. UV adhesive was the first-generation light cure adhesive introduced in the assembly industry.

3.2.2 Ultraviolet (UV) light + visible light cure adhesive

Ultraviolet (UV) + visible light is in the range of 40–405 nm wavelength. UV photo initiator had a limited cure through volume (CTV) capability, and some visible light initiators were added together to achieve better CTV and faster curing with less UV dependence that was harmful to operators. The photo initiator for visible light at the time had a limited (partial) visible light wavelength coverage. This is a second-generation light cure adhesive introduced in the assembly industry.

3.2.3 Visible light cure and adhesive

Visible light cure is in the range of 400–1000 nm wavelength. This is only for visible light cure adhesive, and it can cover wider visible light wavelength coverage; therefore it can cure through different colored clear plastics which previous light cure adhesive was not able to cure as it cannot go through the colored plastics. It also can cure CTV 12 mm deep as it has a longer wavelength. The visible light cure

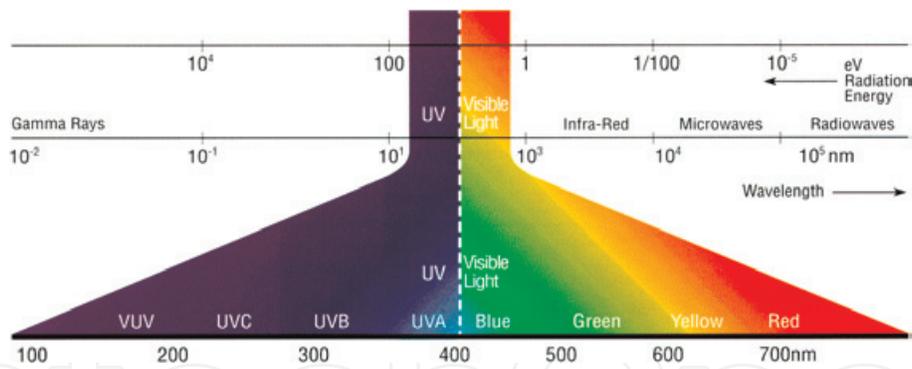


Figure 3.
Light wavelength.

lamp is safer than UV lamp as it emits no UV light. Therefore, there is also no need to wear safety UV block glasses and skin protection wear as well as it has lower cost than UV lamp (see **Figure 3**) [11].

3.2.4 Light curing lamp equipment by the application type

Light curing lamps by the application type consist of benchtop lamp that can be used for relatively big irradiation area of small batch production or testing at development lab, conveyor type that can be used for relatively big irradiation area of volume production, and fiber optic/pencil type that can be used for specific small irradiation area of development lab and small and volume productions that require a localized area curing.

3.2.5 Light curing lamp equipment by the lamp type

Types of light curing lamp consist of medium pressure mercury arc lamp, high pressure mercury arc lamp, metal halide lamp, fusion lamp, and LED lamp.

Also, light curing process demands are divided into three types, namely, depth curing by light radiation, surface curing by light radiation, and secondary cure systems.

3.2.6 Depth curing

To cure adhesive to maximum depth, light curing systems which emit high intensity light in the wavelength in the band from 300 to 400 nm (longer UV wavelength, UVA light) should be specified. This is useful for applications of potting or bigger gap and big fillet cure bonding [11].

3.2.7 Surface curing

Surface curing is especially important when potting or bonding with light cure adhesives are done. If adhesive surface becomes tacky after light cure, it can contaminate the adjacent area and sensitive components by collecting dust and outgassing of uncured adhesive. Wavelength at 254 nm is the one that can achieve a proper surface cure. A selection of proper light cure lamps that emit a proper wavelength is crucial for successful curing application. It is worthwhile to reiterate that this is very important for the application of surface coating or fillet cure to prevent contamination from tackiness on the cured adhesive surface (see **Figure 4**) [11].

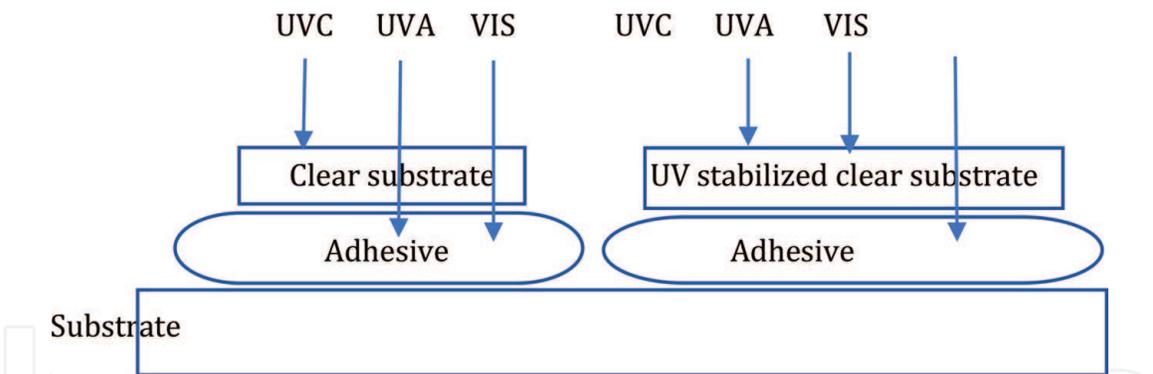


Figure 4.
Light penetration to different substrate.

Also as shown in **Figure 4**, care should be taken to select a right light curing lamp to some special clear plastics. One may think that UV stabilized clear plastics can be cured by UV light curing lamp because it looks clear to our eyes.

But our eyes use a visible light to see its clearness. Such clear plastics contain UV stabilizer that blocks the UV light that cannot reach out to the adhesive. It is all absorbed by the UV stabilizer in the plastic. In that case, visible light cure adhesive can be used to cure adhesive through the UV stabilized clear plastics [11].

3.2.8 Curing by secondary mechanisms

In numerous applications the light does not reach all areas of adhesive bond line due to opaque substrates. Therefore, other functional light cure adhesives have been developed with a secondary cure system for areas not exposed to the light such as anaerobic curing, heat, ambient moisture, and activators.

Also there are various dual cure adhesive technologies, namely, light cure anaerobic, light cure CA, light cure acrylic, light cure silicone, and light cure epoxy.

3.2.9 Light cure adhesive characteristics

Light cure adhesives have the following characteristics: on demand cure, high strength, high gap filling capability, very short curing time in handling strength, good to very good environmental resistance, and good dispensing capacity with automatic application systems as a single-component adhesive.

3.2.10 Typical applications

Typical applications of light cure adhesives such as bonding glass to itself or to metal, bonding transparent plastics, sealing electrical components (e.g., relays), bonding electrical components to printed circuit boards (PCBs), conformal coating of PCBs, bonding/sealing in high temperature applications, retaining metal parts + cure excess adhesive by light for fast fixturing, bonding metal and plastic parts + cure excess adhesive by light for fast fixturing, and magnet bonding with a fillet cure.

3.3 Adhesives cured by anionic reaction (cyanoacrylates)

Single-component cyanoacrylate adhesives polymerize on contact with slightly weak base (alkaline) surfaces. In general, ambient humidity in the air and on the substrate surface is sufficient to initiate curing within a few seconds. This is called “anionic” polymerization (see **Figure 5**) [12].

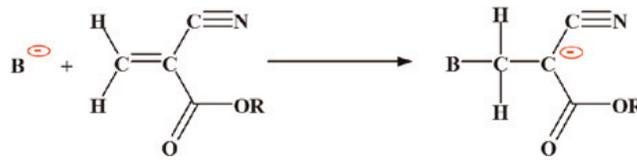


Figure 5.
CA anionic reaction 1.



Figure 6.
CA anionic reaction 2.

The adhesive contains acidic stabilizer, and when adhesive was applied to a substrate surface, the acidic stabilizer that keeps the adhesive stable reacts with moisture on the surface. As the acidic stabilizer is consumed by moisture on the surface, the adhesive becomes unstable, and monomer reacts to each other, and the negative partial load is then passed to the next monomer in a chain reaction as seen in **Figure 6** [12].

The polymerization continues until no monomer is available or a molecule with positive partial load (e.g., stabilizer) is reached.

3.3.1 General characteristics

3.3.1.1 Rule of thumb

The rule of thumb for CA adhesives such as the lower the viscosity, the faster the curing speed; the higher the viscosity, the slower the curing speed, and it generates while curing (exothermic reaction); the thinner the bond line, the faster the curing time, and the bigger the package size, the longer the shelf life, and not recommended for glass or glazed ceramics, and not ideal for a large area bonding, and liquid monomer can cause a stress crack on some sensitive plastics, and some product may cause a blooming.

3.3.1.2 Cure versus bond line

To achieve the fastest cure to handling strength, a “zero gap” condition is desirable.

3.3.1.3 Cure versus moisture

The best results are achieved when the relative humidity in the working environment is 40–60% at room temperature. Lower humidity leads to slower curing; higher humidity accelerates it but may impair the final strength of the bond. Longer cure times, however, slow down production. With the help of a humidity control system, favorable humidity levels can be kept constant in the bonding workplace.

3.3.1.4 Cure versus surface pH

Acidic surfaces (pH value <7) may delay or even prevent curing, whereas alkaline surfaces (pH value >7) accelerate curing.

3.3.1.5 Cure versus open time

Even though cyanoacrylate fixtures and cures are relatively fast, there are various types with different fixture times depending on application requirements because some applications require a very fast fixture and others require some time to adjust the parts location then fix it. It is not recommended to apply too much adhesive as it needs more time to cure and will slow down the fixture time.

3.3.1.6 Cure versus activator

As cyanoacrylate cures by moisture, the lack of moisture causes a slow cure of adhesive. In this situation, accelerator can be used to speed up the cure even in dry environment. Accelerator can be applied to substrate before adhesive application or can be applied after adhesive application. Both ways can speed up the cure. The latter is often used when some part is secured by adhesive in an open area without two-part bonding such as wire tacking on a PCB board, etc.

When bonding a difficult to bond plastic or rubber, polyolefin primer can be used to enhance the bonding reliability.

3.3.1.7 Storage

The proper storage of cyanoacrylate adhesive is crucial for the best product shelf life. Refrigeration (4C) in an unopened state is recommended. If adhesive bottle opened already, it is recommended to close the bottle tightly and keep it at room temperature and continue to use it. It is not necessary to be refrigerated.

3.3.2 Cyanoacrylate adhesive characteristics

Characteristics of cyanoacrylate are the following: single-component, very fast fixture time (fixturing in seconds) and curing speed, almost all materials may be bonded, wide range of viscosities, very high shear and tensile strength, good aging resistance, and easy automation with dispensing equipment as a single component.

3.3.3 Cyanoacrylate by the monomer chemistry

The monomer chemistry of cyanoacrylate consists of methyl grade, ethyl grade, and alkoxy grade.

3.3.3.1 Methyl grade

This is the first-generation cyanoacrylate. Just like the chemistry, the molecular weight of “methyl” is the smallest, so the number of molecules that can be attached to the bonding surface is the most which means it has a high bonding strength but as the total weight is the lightest therefore it is easy to evaporate and stimulate people’s nose as a strong smell and cause a “blooming” phenomenon, too (see **Figure 7** and **Table 2**) [12].

3.3.3.2 Ethyl grade

This is the second-generation cyanoacrylate. Just like the chemistry, the molecular weight of “ethyl” is medium, it means the number of molecules that can be attached to the bonding surface is medium, consequently it has a medium bonding strength but as the total molecular weight is medium therefore it is still not light and

not easy to evaporate and stimulate people's nose as a less strong smell and cause less "blooming" phenomenon (see **Figure 8** and **Table 2**) [12].

3.3.3.3 Alkoxy grade

This is the third-generation cyanoacrylate. Just like the chemistry, the molecular weight of "methyl" is the biggest, so the number of molecules that can be attached to the bonding surface is the smallest which means it has a low bonding strength, but as the total weight is the highest, therefore it hardly evaporates, has no smell to people's nose, and causes almost no "blooming" phenomenon (see **Figure 9** and **Table 2**) [12].

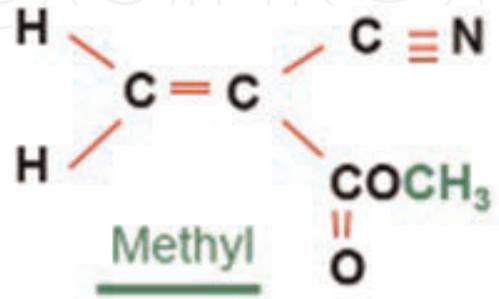


Figure 7.
Methyl grade molecule.

R (alkyl)	Odor	Adhesion	Temp. resistance
Methyl	High	High	High
Ethyl	High	High	High
Alkoxy	Moderate	Moderate	Moderate

Table 2.
Property difference among CA grades.

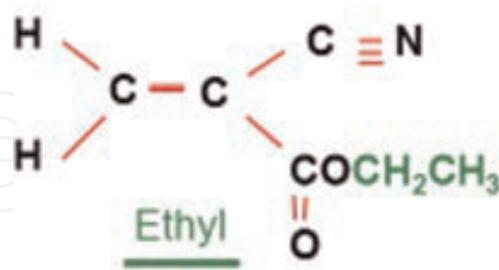


Figure 8.
Ethyl grade molecule.

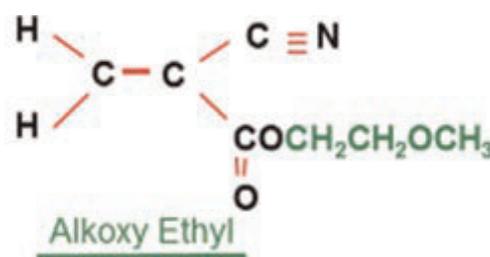


Figure 9.
Alkoxy grade molecule.

3.3.4 Recent trend of CA adhesive properties

Recent bonding performance improvements achieved are for fast fixture time for porous and acid surface, good impact resistance, high temperature resistance, and more clean appearance of bonded assembly.

3.3.4.1 Surface insensitive grade

Typical CA products are surface sensitive which means no effective bonding to porous substrates and acidic surface. It wicks into the porous area and leaves nothing on the surface, so there is no good bonding and the curing time is slow when applied to acidic surface. This surface insensitive grade when applied to porous substrate stays on the porous surface to bond well and, due to some special chemistry, bond fast to the acidic surface. They have a higher temperature resistance and more surface insensitive property (faster fixture time), this is ethyl grade [12].

3.3.4.2 Toughened grade

Typical CA products are not tough which means there is no effective resistance against impact and vibration. It breaks very easily when the assembly is exposed to impact. This toughened grade contains some elastomer inside, so when bonded the bond line absorbs the external impact and maintains a very good bonding. They have a higher temperature and moisture resistance and have surface insensitive property (fast fixture), too. This is ethyl grade [12].

3.3.4.3 Low bloom/low odor grade

Typical CA products have a strong odor and “blooming” which means there are no good working environment and no good assembly appearance quality. This low bloom/low odor grade due to a heavy molecular weight has no pungent smell and almost no blooming. They have a higher temperature resistance and surface insensitive property (fast fixture), too. This is alkoxy grade [12].

3.3.5 Typical applications

Typical applications of cyanoacrylates are used broadly in the various assembly industries and can cover various applications and their requirements such as bonding of porous substrates, acidic surfaces, difficult to bond plastics, dissimilar materials, flexible materials with very fast fixturing, high impact and vibration resistance, high temperature resistance (120C), high humidity resistance, high heat aging resistance, high optical appearance as well as bonding of the most general metal, plastic and elastomer substrates.

3.4 Adhesives cured with activator systems (modified acrylics)

These adhesives are regarded as structural adhesives. Structural adhesive is different from others essentially in the bond of the adhesive, in the monomer type, and in the cure chemistry. The compositional differences result in differences in cure characteristics and in surface affinity and in basic cured properties such as durability of adhesive. Structural adhesives are strong and tough as they possess a high cohesive and adhesive strength. The cohesive strength represents the ability of the material to tolerate stress without failure. Adhesive strength is the ability of the

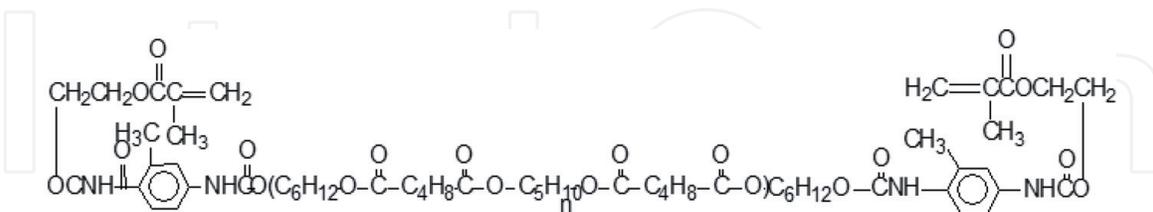
material to stick to the surface. Cohesive failure will leave adhesive on both substrates. Adhesive failure occurs at the interface of the adhesive and the substrate and after debonding, one side substrate will have no cured adhesive left bonded while all the cured adhesive will be left bonded to the other side substrate. These adhesives cure at room temperature when used with activators. Depending on the adhesive, for two-part no-mix type, both the adhesive and activator can be applied separately to the bonding surfaces. It does not react as long as they are not mated allowing some flexibility of application condition. After mating both surfaces with a pressure, reaction starts and adhesive cures to a tough structural adhesive. For two-part premix type, product is dispensed through a double cartridge by a double plunger, and it is mixed and dispensed through static mixer. This way, separate mixing procedure is not required. A precise amount is mixed by volume. For two-part separate dispensing type, adhesive parts A and B are dispensed through a separate nozzle on to the substrate bead by bead or bead beside bead. This way the product is not cured after dispensing, and when the two substrates are mated, the adhesive will be mixed by pressing movement and cures to a tough acrylic adhesive. This is useful when the high-speed production and wide mixing ratio tolerance are required. Three types can be selected properly according to application requirements.

3.4.1 Structural adhesive characteristics

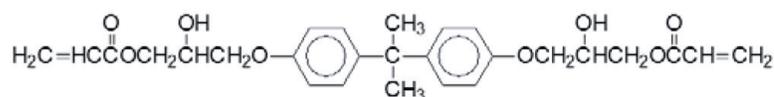
Structural adhesive characteristics are very high shear and tensile strengths, good impact resistance, wide operating temperature range (-55°C to $+120^{\circ}\text{C}$), almost all materials can be bonded, good gap-filling capacity (especially premixed acrylics), and good environmental resistance.

3.4.2 Structural adhesive (two-component no-mix)

Some grades have special oligomers to provide more toughness. Other grades have multifunctional acrylate and elastomeric oligomer. They are minimally crosslinked. They have a big portion of elastomeric toughening agent, and they generate free radical through redox reaction. The following is the typical oligomeric structure of structural acrylic adhesives (see **Figure 10**) [13].



Epoxy Acrylate



Polyester Acrylate

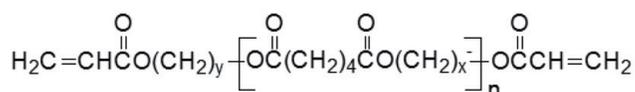


Figure 10.
Different acrylate molecular structures.

Adhesives with multifunctional oligomers cure faster than monofunctional oligomer. Multifunctional oligomers have faster cure speed, better surface cure, better durability, better hardness, and much low odor and toxicity than monofunctional oligomer.

Elastomers are responsible for flexibility and toughness; therefore the structural adhesives result in a high viscosity, and many different types of elastomers are used in this adhesive.

3.4.2.1 Product selection criterion

The following requirements have to be considered when selecting a right adhesive such as fixture time, ultimate bond strength, on-part life, toughness, temperature resistance, and carrier solvent.

3.4.2.2 Typical applications

Typical applications of structural adhesive are magnet bonding for different types of electric motors, magnet bonding for loudspeakers, security alarm sensor bonding, metal structure bonding, flat coil bonding, ferrite core bonding, and voice coil magnet plate bonding for hard disk drive.

3.4.3 Structural adhesive (two-component premix: MMA)

Methyl methacrylate (MMA) adhesives are structural adhesives which are toughened by special elastomers which are “super tough” because they result in a graft polymer that has both excellent peel and impact strength. They cure at room temperature. Their two-component cure is based on redox system. They have a good performance on most substrates especially plastics. They have a good performance on dissimilar substrates. They have a good adhesion to fiber-reinforced plastic (FRP) and gel coat with little or no surface preparation. They have a high modulus and toughness. They have an off-ratio tolerant within 20% during mixing. However, cure rate is temperature dependent, such as in summer and winter, and heat of cure and shrinkage can cause a distortion to read-through at FRP panel.

They will cure when adhesive (part A) and activator (part B) are statically mixed. They will fillet cure and cure speed is dependent on mass. Plastics that are solvated by MMA will fixture fast. The type of mixing ratio is ranging from 1:1 to 10:1. Some products which contain glass or polymer beads that can control bond line thickness are ranging from 0.1 to 0.8 mm diameter.

3.4.3.1 Glass (or polymer) beads

For some special applications, if MMA is used with “0” gap, then the assembly cannot take the advantage of “toughness” of MMA. By using beads, the cohesive strength and impact strength become very high as the bond line absorbs all the external impact. Beads also ensure a controlled exotherm reaction in the bond line, too. **Figure 11** shows a certain bond line gap achieved with spacer. This design

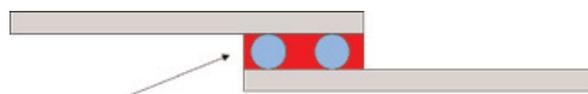


Figure 11.
Structural bonding with spacer.

provides a very high toughness to the assembly as a very high bond line stress is eliminated with this design (see **Figure 11**) [14].

3.4.3.2 Typical applications

Typical applications are galvanized steel bonding for construction to prevent corrosion bonding failure; school bus structure bonding for fire wall, side wall, and roof; marine yacht bonding for deck, stringer, hull, and gel coat; boom bonding for special vehicles; structure bonding with spot welding; office cubicle bonding; composite structure bonding; and case bonding of hand-held display device.

3.5 Adhesives cured by ambient moisture

These adhesives and sealants are polymerized by (in most cases) a condensation reaction which involves reaction with ambient moisture. Two general chemistry types fall into two categories which are silicone and polyurethane.

3.5.1 Silicone

Depending on the curing mechanism, it consists of one-component RTV silicone and two-component silicone. For one-component silicone, it vulcanizes at room temperature either by reaction with moisture in the air and substrates. It starts to cure from the surface and cures into depth. Depending on the type of formulation, it generates a by-product and evaporates. For two-component silicone, it vulcanizes at room temperature by part A and B reactions. Its curing starts from both surface and inside of mixed product. Therefore, its curing is not affected by the lack of moisture in the air.

3.5.1.1 One-component RTV silicone

This is widely used in various industries. Depending on the type of formulation, a by-product is generated such as vinegar smell and non-vinegar smell. Acetic acid type has a pungent odor and is mainly used in the construction area and some machinery repair applications. Oxime type is the most popular in the assembly industry as it has no pungent odor and is regarded as non-acetic acid silicone. The cure speed of silicone primarily depends on the relative humidity which means it is fast in summer time and slow in winter time (see **Figure 12**) [15].

Because of the nature of the curing mechanism, silicones vulcanize from the outside to the inside of the bond line. Due to the necessary moisture migration to

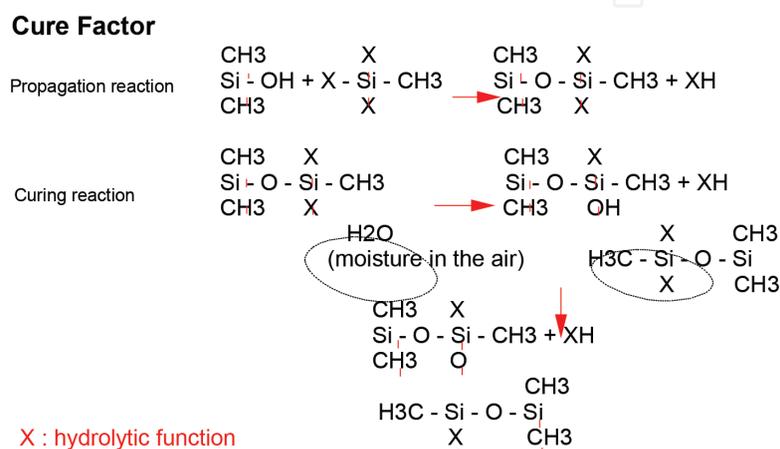


Figure 12.
RTV silicone curing mechanism.

the site of crosslinking, once surface is cured, moisture becomes more difficult to penetrate the already cured layer of silicone to react with internal uncured silicone; therefore the whole curing takes relatively a long time. The depth of cure is limited to 10–15 mm.

3.5.1.1.1 Silicone characteristics

One-component silicone characteristics are the following: excellent thermal resistance (“up to 270°C”), flexible, tough, high elongation, low to medium modulus, effective sealants for a variety of fluid types, and excellent gap filling.

3.5.1.1.2 Typical applications

One-component silicone applications are gasketing and sealing in automotive industry, sealing in high temperature applications, sealing and bonding for small parts, sealing and potting, and coating of PCBs.

3.5.1.2 Two-component silicone

When part A and part B are mixed in a proper mixing ratio, a chemical reaction occurs initiated by the catalyst reacting with water. This chemical reaction occurs not only at the surface but also inside the mixed product. Therefore, it has a very fast fixturing and curing time for faster fixture and assembly, and it allows a structural bonding assembly in more compact assembly line and automated assembly with less manpower. This technology can replace various assemblies that have used double-sided tape or RTV silicone that requires a manual and lengthy assembly line and time with much manpower. During the chemical reaction, moisture (“H₂O”) comes in and alcohol (“OH”) that was generated during chemical reaction as a by-product comes out and evaporates (see **Figure 13**) [15].

3.5.1.2.1 Silicone characteristics

Two-component silicone characteristics are such as fast tack free time, fast fixture time and fast full curing time. Its curing speed is not affected by moisture and bond line thickness. It is flexible, tough, high modulus and UL 746C listed for high temperature applications. It also has an excellent gap filling capability and high temperature resistance up to 270C. Three colors such as black, gray and almond are available.

3.5.1.2.2 Typical applications

Typical applications of two-component silicone are glass bonding for refrigerator, washing machine, microwave, cook top, dish washer, air conditioner and bridge structure bonding.

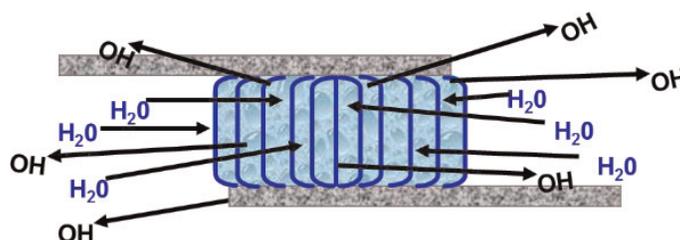


Figure 13.
Two-component silicone curing mechanism.

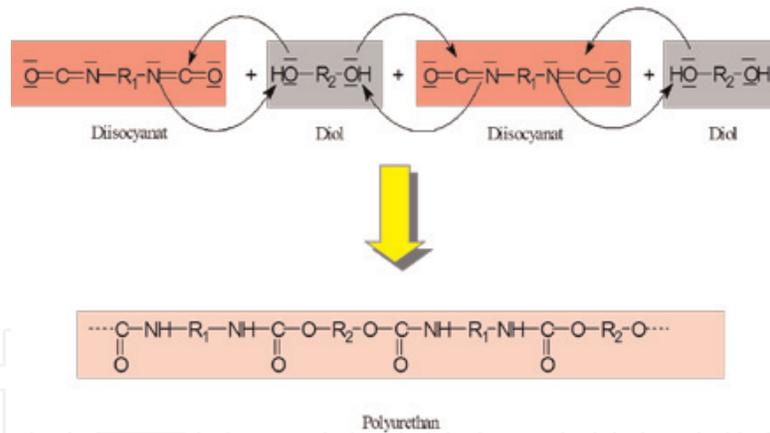


Figure 14.
Curing mechanism of two-component polyurethane.

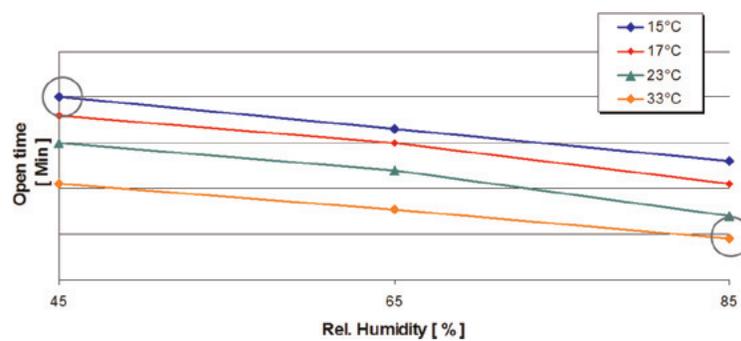


Figure 15.
Open time versus ambient temperature of two-component polyurethane.

3.5.2 Polyurethane

Polyurethane adhesives cure with polyol and isocyanate at room temperature. During the reaction, it generates some carbon dioxide (CO₂). One unique feature of polyurethane adhesive is that its cure is sensitive to the moisture level. For some applications to achieve the best and most durable adhesion, the use of appropriate cleaners and primers (adhesion promoters) is recommended. Depending on the substrates, different primers are used. According to where it is used, they consist of one-component PU and two-component PU. PU has a different open time according to the ambient temperature and mixed amount. **Figures 15** explains that the open time in high temperature environment such as summer time reacts fast and has a short open time while it does a long open time in cold environment such as winter time (see **Figures 14** and **15**) [16].

3.5.2.1 Polyurethane characteristics

Polyurethane characteristics are excellent toughness and flexibility, high elongation, excellent gap filling, paintable when cured, and excellent chemical resistance.

3.5.2.2 Typical applications

Typical applications of polyurethane are bonding/sealing of direct glazing window for automotive, railway, and earth movers (one-component, two-component);

panel lamination bonding for recreational vehicle and mobile home; wind blade bonding (one-component, two-component); sport goods lamination bonding (two-component); and filter bonding or casting for water filter, air filter, mechanical filter, and blood filter (two-component).

4. Conclusion

Major reactive functional adhesives and sealants have been described with conventional methods and benefits of adhesive and sealant solutions in this chapter. The assembly industry still has numerous area that can improve their assembly process with cost saving and increase reliability of their assembly. It would be worthwhile that all the information be thoroughly reviewed and studied, and with this material, it is hoped that ideas to improve a cost and to increase a reliability of various assemblies with such adhesives and sealants would be materialized as a life time guide.

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