

1																			
2													3	4					
Li	Be											B	C	N	O				
11	12											13	14	15	16				
Na	Mg											Al	Si	P	S				
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33					
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As					
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51					
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb					
55	56	57	72	73	74	75	76	77	78	79	80	81	82	83					
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi					
87	88	89	104	105	106	107	108	109	110										
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt	Uun										



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Section 1:

The Problem

The discovery of metals and the development of methods for refining and processing them have played an integral role in the development of the modern industrial world. Structural adhesives suitable for high-speed manufacturing processes are a comparatively recent innovation, however, the two technologies offer a range of synergistic benefits to the design and manufacturing engineers of today. The breadth of metal and adhesive choices available can make the selection of the best combination for a given assembly a daunting task. To find the optimal combination, the design parameters associated with the physical properties of the metal must be considered in conjunction with factors unique to the adhesive. For example, how will the metal substrate type affect the bond strength that can be achieved, the durability of the adhesive in moist, corrosive and high temperature situations, and the bond strength the adhesive will offer at the operating temperature of the assembly? In addition, the compatibility of the adhesive with the manufacturing process must be considered. Will the adhesive cure rapidly enough to allow in-line processing or will staging of the assemblies during cure be required? Will the adhesive require heating, exposure to ultraviolet light, or mixing which will result in capital equipment costs? Is the adhesive easily adapted to automated dispensing or will manual application be required? Clearly, the choice of the best metal/adhesive combination can be an involved process.

The Solution

Bond Strength Information

The goal of this design guide is to simplify the process of selecting the best metal/adhesive combination for a given application. To do this, the families of adhesives most commonly used for the structural bonding of metals were identified and representative adhesives were selected from these families. The bond strength that these adhesives could achieve on the most commonly used metals was then determined. In addition to determining the initial bond strength that could be achieved with these adhesives, the effect of environmental conditioning on the bond strength was then tested, in recognition of the fact that devices made from metallic substrates often see use in harsh environments. Specifically, bonded assemblies were subjected to condensing humidity, salt fog, and elevated temperatures from 250°F to 400°F (121°C to 204°C) prior to bond strength testing. The resulting matrix of data will allow the end-user to quickly determine which adhesives would be suitable for evaluation in their application.

Adhesive Information

An adhesive cannot be selected for an application solely on the basis of bond strength information. Other factors, such as cure speed, cure method and suitability for use in automated production, will all play a role in determining the best adhesive for a specific application. To give designers insight into these parameters, an in-depth description of the six types of adhesives commonly used for bonding metals has been included in this guide. These adhesive sections contain a general description of each adhesive, a detailed description of the chemical structure and cure mechanism on each adhesive, and the benefits and limitations associated with each type.

Metal Information

A manufacturer may have the flexibility to choose the metal that is best suited for the application in terms of performance and bondability. To aid the designer who is trying to choose between several different types of metal, an in-depth discussion of each of the metals tested is included. Information covered includes a general description, chemical structure, common types, and the main characteristics differentiating the common types of each metal.

Section 2:

How to Use This Guide

Selecting the proper adhesive for an application demands a consideration of the processing and performance characteristics of the adhesive. This guide has been designed to provide this information in a format that will allow the end-user to rapidly identify the best adhesive option for evaluation in their application.

Processing Characteristics

When selecting an adhesive for an application, it is important to consider whether the adhesive's processing characteristics will be compatible with the assembly production process. The processing characteristics of greatest interest to the end-user typically revolve around the dispensing and curing properties of the adhesive. Information about these characteristics is important because it will help the end-user answer questions such as:

- ✓ What types of dispensing equipment will be required for the adhesive? Is the adhesive easily dispensed using automated or manual methods?
- ✓ Will special curing equipment, such as ovens or UV light sources, be required?
- ✓ How will environmental factors, such as relative humidity, affect the curing rate of the adhesive?
- ✓ How long will it take the adhesive to develop sufficient strength for the assembly to proceed to the next step in the assembly process?
- ✓ Will racking of parts during cure be required? Will special fixtures be needed to hold the assembly while the adhesive is curing? How much floor space will be required for the racked parts?

To gain an understanding of the processing characteristics of the adhesives in this guide see:

- **Section 4: Adhesive Review** provides an overview of the dispensing and curing characteristics of each family of adhesives.

- **Section 5: Factors Affecting Activator Selection** provides detailed information on the effect that activator selection has on the processing and performance characteristics of two-part, no-mix acrylic products.
- **Section 6: Heat Cure Parameters for Two-Part, No-Mix Acrylic Adhesives** provides information on the times and temperatures needed to heat cure these products when an activator cannot be used.

Performance Characteristics

When selecting an adhesive for an application, it must have the performance characteristics required for the application. Some of the questions that should be considered to be sure that the adhesive will have the performance characteristics required for a given application include:

- ✓ Does the adhesive have sufficient bond strength to support the load the assembly will see at ambient conditions?
- ✓ Does the adhesive have sufficient hot strength to support the load the assembly will see at elevated temperatures?
- ✓ Does the adhesive have sufficient environmental resistance to maintain acceptable bond strength after exposure to elevated temperatures, high humidity, or corrosive conditions?
- ✓ Will roughening the surface prior to bonding offer a significant performance benefit?
- ✓ How will impact, peel forces and cyclic loading affect the long term performance of the adhesive?

To gain an understanding of the performance characteristics of the adhesives in this guide see:

- **Section 4: Adhesive Review** provides an overview of the general performance characteristics of each family of adhesives.
- **Section 5: Factors Affecting Activator Selection** provides detailed information on the effect that activator selection has on the processing and performance characteristics of two-part, no-mix acrylic products.
- **Section 7: Hot Strength Curves for Adhesives** provides curves of shear strength vs. temperature for each of the adhesives evaluated in the guide.

- **Section 8: Metal Bonding Chapters** provides detailed shear strength data for the adhesives evaluated in this guide on aluminum, anodized aluminum, stainless steel, steel, zinc dichromated steel, zinc galvanized steel, nickel plated steel, and copper. Bond strengths are evaluated at ambient conditions and after exposure to high temperatures as well as high humidity and corrosive environments. For aluminum, steel, stainless steel and copper, the effect of surface roughening on bond strength is also evaluated.

The examples below illustrate how the guide can be used to estimate the bond strength that various adhesives will provide in different conditions. It cannot be stressed enough that the results provided **can only be considered estimates** for use in selecting the best candidates for further evaluation on actual assemblies.

Example 1: You are considering the use of a cyanoacrylate on a stainless steel assembly and would like to know what is the best bond strength that can be expected at 200°F (93°C).

Step 1. Consult Section 7: Hot Strength Curves for Adhesives to compare the hot strength curves of the several families of cyanoacrylates evaluated in the guide. A cursory examination of the curves makes it apparent that the thermally resistant cyanoacrylates have the best strength retention at high temperatures. From Figure 7-4 you find that at 200°F (93°C), the thermally resistant cyanoacrylates retain 90% of their room temperature shear strength.

Step 2. Consult Section 8.3: Metal Bonding Chapters, Stainless Steel to find that the ambient bond strength of Loctite® 4205™ Instant Adhesive on stainless steel is 1205 psi.

Step 3. Multiply the ambient bond strength on anodized aluminum (1205 psi) by the % strength retained at 200°F (93°C) (90%) to estimate the bond strength at that temperature (1085 psi).

Example 2: You will be bonding steel on an assembly that will see periodic short-term exposure to 350°F (177°C). Your joint requires an adhesive that can bear a load of approximately 2000 psi at ambient conditions. You want to identify the adhesives that retain their strength best after this exposure. You would also like to identify the adhesives that fixture the fastest as you have an in-line assembly process. Finally, you would also like to determine if roughening the steel surface would offer a benefit.

Step 1. Consult Section 8.4: Metal Bonding Chapters, Steel. A comparison of the bond strength of the adhesives on steel after two weeks exposure to 350°F (177°C) shows that Loctite® 334™ Structural Adhesive, Loctite® H8000® Structural Adhesive, Loctite® E-20HP™ Hysol® Epoxy Adhesive, Loctite® E-20NS™ Hysol® Epoxy Adhesive, and Loctite® E-30CL™ Hysol® Epoxy Adhesive all provide bond strengths in excess of 2000 psi.

Step 2. Consult Section 4: Adhesive Review to compare the relative fixture speeds of these products. The data in this section shows that the two-part, no-mix acrylic adhesives offer faster fixture times than the epoxy systems. A detailed analysis of the effect of activator type on the fixture speed and performance of a two-part, no-mix acrylic, Loctite® 334™ Structural Adhesive can be found in Section 5: Factors Affecting Activator Selection. Based on the data in that section, Loctite® 7387™ Activator and Loctite® 7380™ Activator offer the best fixture speeds and performance characteristics.

Step 3. Consult Section 8.4: Metal Bonding Chapters, Steel to compare the bond strength of two-part, no-mix acrylic Loctite® 334™ Structural Adhesive on smooth and roughened steel. The bond strength on roughened steel is 2740 psi vs. 2590 psi for smooth steel, indicating that roughening the surface will offer improved bond strength.

Section 3:

Why Bond Metals with Loctite® Brand Adhesives?

Advantages Over Other Assembly Methods

Loctite® brand adhesives offer an array of benefits to the manufacturer who needs to join metallic substrates to other substrates in their manufacturing process. These benefits are best understood by comparing adhesive joining processes with the other options a manufacturing engineer can consider.

Advantages versus Mechanical Fasteners

Mechanical fasteners are quick and easy to use, but have a number of significant drawbacks.

- They create stress concentration points in the assembly, which may lead to premature failure; adhesives do not.
- They are extra components that must be purchased or inventoried. Adhesives require no extra components.
- They require altering the design of the product to include bosses or holes. Adhesives require no special features.
- Their appearance often interferes with the styling of the product. Adhesives are invisible inside a bonded joint.
- They concentrate all of the holding power at the fastener location, causing the applied load to be carried by a small area of metal. Adhesives spread the load evenly over the entire joint area.

Advantages versus Welding, Brazing, and other Thermal Joining Methods

Thermal joining methods offer benefits on certain substrates, but are limited by several factors.

- Thermal joining methods can cause distortion of the part, which may affect the assembly's performance. Adhesives do not distort parts.
- Thermal joining methods can result in aesthetically unacceptable discoloration of the part and/or the formation of visible seams, which may require secondary grinding and/or painting operations. Adhesives do not require secondary operations to obtain an aesthetically pleasing appearance.
- Thermal joining methods are limited to similar metals. Metals with widely differing melting points will be difficult, if not impossible, to join with thermal methods. Of course, metals cannot be joined to non-metallic substrates such as glass, rubber, or plastic with these methods. Adhesives can be used on dissimilar substrates with ease.

Section 4:

Adhesive Review

Section 4.1: Cyanoacrylate Adhesives

General Description

Cyanoacrylates are one-part, room-temperature-curing adhesives that are available in viscosities ranging from water-thin liquids to thixotropic gels. When pressed into a thin film between two surfaces, cyanoacrylates cure rapidly to form rigid thermoplastics with excellent adhesion to most substrates.

One of the benefits cyanoacrylates offer is the availability of a wide variety of specialty formulations with properties tailored to meet particularly challenging applications. For example, rubber-toughened cyanoacrylates offer high-peel strength and impact resistance to complement the high shear and tensile strengths characteristic of cyanoacrylates. Thermally-resistant cyanoacrylates are available which offer excellent bond strength retention after exposure to temperatures as high as 250°F for thousands of hours. Moreover, “surface insensitive” cyanoacrylates offer rapid fixture times and cure speeds on acidic surfaces, such as wood or dichromated metals, which could slow the cure of a cyanoacrylate. In some cases, the use of a general purpose cyanoacrylate adhesive was hampered by the appearance of a white haze around the bondline. This phenomenon is known as “blooming” or “frosting” and occurs when cyanoacrylate monomer volatilizes, reacts with moisture in the air, and settles on the part. To eliminate this problem, “low odor/low bloom” cyanoacrylates were developed. They have a lower vapor pressure than standard cyanoacrylates and, therefore, are less likely to volatilize. Light curing cyanoacrylates have also been formulated to address the blooming issue. Light cure cyanoacrylates utilize ultraviolet light of the appropriate wavelength to “flash” or instantly cure any adhesive that may have squeezed out of the bondline. Flash cure cyanoacrylates can also be used to cure in the bondline as long as one of the substrates is transparent to UV light. While advances in cyanoacrylate formulating technology have played a key role in offering additional benefits to the end user, there have also been important developments in cyanoacrylate primer and accelerator technology.

Accelerators speed the cure of cyanoacrylate adhesives and are primarily used to reduce fixture times, and to cure fillets on bondlines and/or excess adhesive. Accelerators consist of an active ingredient dispersed in a solvent. The accelerator is typically applied to a substrate surface prior to the application of the adhesive. Once the carrier solvent has evaporated, the cyanoacrylate can immediately be applied and its cure is initiated by the active species that the accelerator has left behind. Depending on the particular solvent and active species present in the accelerators, the solvent can require 10 to 60 seconds to evaporate, and the active species can have an on-part life ranging from 1 minute to 72 hours. Accelerators can also be sprayed over a drop of free cyanoacrylate to rapidly cure it. This technique has been widely used for wire tacking in the electronics industry.

Another benefit offered by cyanoacrylates is the availability of primers that enable them to form strong bonds with polyolefins and other difficult-to-bond plastics such as fluoropolymers and acetal resins. Like the accelerators, polyolefin primers consist of an active ingredient dispersed in a solvent. Once the carrier solvent has evaporated, the surface is immediately ready for bonding, and the primer will have an on-part life ranging from 4 minutes to one hour. Depending on the plastic, bond strengths of up to 20 times the unprimed bond strength can be achieved.

Chemistry

Cyanoacrylate adhesives are cyanoacrylate esters, of which methyl and ethyl cyanoacrylates are the most common. Cyanoacrylates undergo anionic polymerization in the presence of a weak base, such as water, and are stabilized through the addition of a weak acid. When the adhesive contacts a surface, the water present on the surface neutralizes the acidic stabilizer in the adhesive, resulting in the rapid polymerization of the cyanoacrylate. UV cyanoacrylates contain patented photoinitiators that decompose to yield free radicals upon exposure to light of the proper intensity and spectral output. The free radicals then initiate polymerization of the adhesive through the cyanoacrylate groups.

Advantages

- One-part system
- Solvent-free
- Rapid room temperature cure
- Excellent adhesion to many substrates
- Easy to dispense in automated systems
- Wide range of viscosities available
- Excellent bond strength in shear and tensile mode
- Primers available for polyolefins and difficult-to-bond plastics
- Ultraviolet curable formulations available to cure fillets.

Disadvantages

- Poor peel strength
- Limited gap cure
- Poor durability on glass
- Limited resistance to polar solvents
- Low temperature resistance
- Bonds skin rapidly
- May stress crack some plastics

Section 4.2: Epoxy Adhesives

General Description

Epoxy adhesives are typically two-part systems which cure at room temperature, although one-part, pre-mixed products which utilize a heat cure and one and two component UV curable formulations are also available. The two components react stoichiometrically, so maintaining proper mix ratio is important to consistent performance. Upon mixing, the curing reaction of the epoxy can release a great deal of heat (exotherm) and result in a significant temperature rise in the adhesive. In some applications, such as deep section potting, this heat rise can be sufficient to char the adhesive. Upon cure, epoxies form tough, rigid thermoset polymers with high adhesion to a wide variety of substrates and good environmental resistance. The viscosities of epoxy adhesives can range from a few thousand centipoise to thixotropic pastes.

The wide variety of chemical species that can react with the epoxide end group and the inherent stability of two-part adhesive systems lead to a wide variety of epoxy formulations available to the end-user. The performance properties of

epoxies can be tailored to specific needs through a wide variety of techniques. Epoxy adhesives are typically rigid and formulating techniques must be employed to produce flexible epoxies. These techniques include the use of non-reactive plasticizers, the incorporation of rubber into the epoxy, and the use of epoxy resins with flexible backbones. The properties of epoxy adhesives are also varied through the use of fillers. For example, quartz fillers can impart improved impact resistance, ceramic fillers can offer improved abrasion resistance, and silver can be used to produce epoxies which are electrically conductive.

Chemistry

Epoxy adhesives polymerize to form thermoset polymers when covalent bonds between the epoxy resin and the hardener are formed through the reaction of the epoxide ring with the ring-opening species on the hardener. Amines, amides, mercaptans, and anhydrides are some of the types of hardener that are commonly used. Catalysts can be employed to accelerate the reaction rate between the epoxy resin and hardener. In addition, heat (or photoinitiators) can also accelerate (or initiate) the reaction. If heat is used to accelerate the cure of the epoxy, the increase in temperature can result in a drop of viscosity and flow of the adhesive. If the epoxy is UV curable, it needs to be exposed to UV light of the appropriate wavelength in order to initiate the reaction. In addition, curing the epoxy at a higher temperature will usually result in a stiffer material with a higher crosslink density and glass transition temperature.

Advantages

- High cohesive strength
- High adhesion to a wide variety of substrates
- Good toughness
- Cure can be accelerated with heat
- Excellent depth of cure
- Good environmental resistance

Disadvantages

- Two-part systems require mixing
- One-part systems require heat cure
- Long cure and fixture times
- Limited pot life and work time

Section 4.3: Light Curing Acrylic Adhesives

General Description

Light curing acrylic adhesives are supplied as one-part, solvent-free liquids with viscosities ranging from 50 cP to thixotropic gels. Upon exposure to light of the proper intensity and spectral output, these adhesives cure rapidly to form thermoset polymers with excellent adhesion to a wide variety of substrates. The cure times of light curing acrylic adhesives are dependent on many parameters, however, cure times of 2 to 60 seconds are typical and cure depths in excess of 0.5" (13 mm) are possible. Light cure acrylic adhesive formulations are available which vary in cured properties from very rigid, glassy materials to soft, flexible elastomers.

Light curing acrylic adhesives cure rapidly on demand, which minimizes work in progress and offers virtually unlimited repositioning time. In addition, the wide range of viscosities available facilitates the selection of a product for automated dispensing. These qualities make light curing acrylics ideally suited for automated bonding processes.

Chemistry

Light curing acrylic adhesives are composed of a photoinitiator and a blend of monomers, oligomers, and polymers containing the acrylate functionality. Upon exposure to light of the proper intensity and spectral output, the photoinitiator decomposes to yield free radicals. The free radicals then initiate polymerization of the adhesive through the acrylate groups to yield a thermoset polymer.

When the adhesive is cured in contact with air, the free radicals created by the decomposition of the photoinitiator can be scavenged by oxygen prior to initiating polymerization. This can lead to incomplete cure of the adhesive at the adhesive/oxygen interface, yielding a tacky surface. To minimize the possibility of forming a tacky surface, the irradiance of light reaching the adhesive can be increased, the spectral output of the light source can be matched to the absorbance spectrum of the photoinitiator, and/or the adhesive can be covered with a nitrogen blanket during cure.

Advantages

- Cure on demand
- Very good environmental resistance
- Wide range of viscosities available
- Solvent-free
- Good gap filling
- One-part
- Dispensing is easily automated
- Clear bondlines
- Rapid fixture and complete cure
- Wide range of physical properties

Disadvantages

- Light must be able to reach bondline
- Oxygen can inhibit cure at the surface
- Equipment expense for light source
- If a high intensity light source is used, ozone must be vented

Section 4.4: Polyurethane Adhesives

General Description

Polyurethane adhesives are supplied as one and two-part systems which range in viscosity from self-leveling liquids to non-slumping pastes. They cure to form thermoset polymers with good solvent and chemical resistance. They are extremely versatile and can range in cured form from extremely soft elastomers to rigid, extremely hard plastics. Polyurethanes offer a good blend of cohesive strength and flexibility which makes them very tough, durable adhesives. They bond well to most unconditioned substrates, but may require the use of solvent-based primers to achieve high bond strengths. They offer good toughness at low temperatures, but typically degrade in strength after long-term exposure over 302°F(150°C). Since the cure of one-part, moisture-curing polyurethanes is dependent on moisture diffusing through the polymer, the maximum depth of cure that can be achieved in a reasonable time is limited at approximately 0.375" (9.5 mm). Two-part systems, on the other hand, offer unlimited depth of cure.

Chemistry

One-part polyurethane adhesives can react with moisture to polymerize. Another cure method involves the evolution of species that inhibit the cure of the polyurethane. In either case, cure is dependent on a chemical species diffusing through the polyurethane matrix, so the depth of cure is limited. Two-part polyurethanes, which generally cure through the reaction of an isocyanate and a polyol, avoid this limitation and offer superior depth of cure. In either case, the polyurethane polymer forms rigid and soft domains that give the polymer its balance of flexibility and high strength.

Advantages

- Extremely tough
- Good resistance to solvents
- High cohesive strength
- Good impact resistance
- Good abrasion resistance

Disadvantages

- Limited depth of cure for one-part polyurethanes
- Mixing required for two-part polyurethanes
- Primer may be needed for adhesion to some substrates
- Limited high temperature use

Section 4.5: Reactive Polyurethane

General Description

The latest advancement in hot melt technology is the reactive polyurethane adhesive (PUR). PURs initially behave like standard hot melts. That is where, heat is added to soften the urethane prepolymer and it is dispensed hot. Once the PUR cools it reacts with moisture to crosslink into a tough thermoset polyurethane adhesive.

Chemistry

Reactive polyurethanes are supplied as an urethane prepolymer, behaving much like a standard hot melt until it cools. Once the PUR cools, it reacts with

moisture over time (typically a few days – depending on the relative humidity) to crosslink into a tough thermoset polyurethane.

Advantages

- One-part, solvent-free
- Unlimited depth of cure
- Fast fixturing
- High adhesion
- Low volumetric cost

Disadvantages

- Operator safety – hot dispense point
- Can cool too quickly on metallic substrates
- Equipment required
- Moisture sensitivity

Section 4.6: Silicone Adhesives

General Description

Silicone adhesives are typically supplied as one-part systems that range in viscosity from self-leveling liquids to non-slumping pastes. They cure to soft thermoset elastomers with excellent property retention over a wide temperature range. Silicones have good adhesion to many substrates, but are limited in their utility as structural adhesives by their low cohesive strength.

Silicone adhesives are typically cured via reaction with ambient humidity, although formulations are also available which can be cured by heat, mixing of two components, or exposure to ultraviolet light. Since the cure of moisture-curing silicones is dependent on moisture diffusing through the silicone matrix, the cure rate is strongly affected by the ambient relative humidity and the maximum depth of cure is limited to 0.375-0.500". At 50% RH, moisture cure silicones will cure to a tack-free surface in 5-60 minutes, depending on the type used. Complete cure through thick sections of silicone can take up to 72 hours. It should be noted that adhesive strength may continue to develop for 1-2 weeks after the silicone has been applied. This occurs because the reaction between the reactive groups on the silicone polymer and the reactive groups on the substrate surface is slower than the crosslinking reaction of the silicone groups with themselves.

Moisture curing silicones are categorized by the by-product given off as they react with moisture. For example, acetoxycure silicones give off acetic acid. Alkoxy cure silicones give off alcohols, typically methanol or ethanol, and oxime curing silicones evolve methylethylketoxime. Acetoxycure silicones are known for their ability to cure rapidly and develop good adhesion to many substrates. The largest limitation of acetoxycure silicones is the potential for the by-product, acetic acid, to promote corrosion. Alkoxy cure silicones, on the other hand, do not have this limitation because the alcohol by-products are non-corrosive. This makes them well suited for electronic and medical applications where acetic acid could be a problem. Unfortunately, alkoxy silicones typically have lower adhesion and take longer to cure than acetoxycure silicones. Oxime-evolving silicones offer cure speeds and adhesion that rivals, and in some cases surpasses, that of acetoxycure silicones. In addition, the oxime they evolve will not corrode ferric substrates, although it can stain copper or brass. Consequently, oxime silicones have found widespread use in automotive gasketing applications. The chief limitation of all moisture curing silicones is the difficulty associated with accelerating the cure rate. This concern was addressed through the development of UV cure silicones and two-part silicones.

Ultraviolet light curing silicones generally also have a secondary moisture cure mechanism to insure that any silicone which is not irradiated with ultraviolet light will still cure. Upon exposure to ultraviolet light of the proper wavelength and intensity, they will form a tack-free surface and cure to a polymer with up to 80% of its ultimate physical strength in less than a minute. Initial adhesion can be good, but because ultimate bond strength is dependent on the moisture cure mechanism of the silicone, full bond strength can take 1-2 weeks to develop. Silicones with a secondary acetoxycure show good bond strength while those with a secondary alkoxy cure are lower.

Two-component or two-part silicones react via a moisture cure and an addition cure mechanism. The moisture cure mechanism provides fast tack-free times while the additional cure mechanism significantly increases the overall cure speed and cure through depth. Two-part silicones can develop 90% of its cured properties in as little as four hours and cure through an unlimited depth. Primers or adhesion promoters can also be incorporated directly in one part of the product eliminating the need for prepriming of parts in order to gain maximum adhesive properties.

Chemistry

Silicone formulations are available which can be cured through moisture, heat, mixing two components, and exposure to ultraviolet light. The silicones used for

adhesives are typically the one-part moisture curing and UV curing silicones. All silicones have a chemical backbone made up of silicone to oxygen bonds, known as siloxane bonds. It is the high energy of this bond that gives silicones their unique high temperature performance properties.

Advantages

- One-part systems available
- Solvent-free
- Room temperature cure
- Excellent adhesion to many substrates
- Extremely flexible
- UV curing formulations available

Disadvantages

- Poor cohesive strength
- Moisture cure systems have limited depth of cure
- Swelled by non-polar solvents

Section 4.7: No-Mix and Static-Mix Acrylic Adhesives

General Description

Acrylic adhesives consist of a resin and an activator/hardener. The resin component is a solvent-free, high-viscosity liquid, typically in the range of 10,000 to 100,000 cP, while the activator component can be a solvent dispersion of the cure catalyst (no-mix) or a high viscosity mix of the cure catalyst and performance additives.

If the carrier solvent present in the activator solvent dispersion is undesirable, the pure catalyst is also available as a solvent-free activator. However, when using a solvent-free activator, the amount of activator applied must be tightly controlled, as excessive activator will detrimentally affect the performance of the adhesive. With static-mix acrylics, the viscosity of the resin and hardener is formulated to be very similar in order to ensure thorough mixing through the static mix tip. A primer may also be incorporated into the resin or hardener in order to enhance the bond strength or some substrates.

The resin base of no-mix acrylic adhesives can also be heat cured. The cure speed of static mix acrylics is not effected by the addition of heat. A typical heat cure cycle is ten minutes at 300°F (149°C). Heat curing normally offers higher bond strengths and shorter cure times. However, heating the adhesive lowers the resin's viscosity and may result in some adhesive flow out of large gaps. In some instances, it is desired to use a combination of these two cure methods, fixturing the assembly with activator prior to heat cure.

Application Method

When an activator is used, the adhesive is cured in the following manner:

- ✓ The resin is applied to one of the substrate surfaces.
- ✓ The activator is typically applied to the other surface.
- ✓ The activator's carrier solvent is allowed to flash off.
- ✓ The two surfaces are mated together.
- ✓ The catalyst from the activator then initiates the polymerization of the resin.

Typically, these systems develop fixture strength in two minutes and full strength in 4-24 hours. The activator serves only as a catalyst for the polymerization of the resin, so when using an activator, the ratio of activator to resin is not critical. However, this is not the case for solventless activators, because the activator is so concentrated that excess activator can prevent the adhesive from forming an intimate bond with the substrate. Since polymerization is initiated at the interface between the activator and resin, the cure depth is limited. Typically, the maximum cure-through-depth is 0.30" (0.76 mm) from this interface.

Static-mix acrylic adhesives are dispersed using hand held applications and the appropriate static-mix tip (typically 24 elements). Static-mix acrylics offer unlimited depth of cure but due to the exothermic nature of the reaction, caution must be exercised. Since the exotherm may deform temperature sensitive substrates, or cause "read-through" on the opposite surface or even auto-ignite.

Chemistry

The resin base consists of an elastomer dissolved in acrylic monomers. Peroxides are then blended in to provide the resin with a source of free radicals. The elastomers form a rubbery phase which gives the adhesive its toughness, and the acrylic monomers form the thermoset polymer matrix which gives the adhesive its environmental resistance and strength.

The type of cure catalyst used in the activator will vary depending on the cure chemistry of the adhesive. In no-mix acrylics, the catalyst(s) are often diluted in a solvent, although in some cases, they are supplied in solventless formulations. In order to match the viscosity of the resin, the catalyst is blended in with a portion of the elastomer in static-mix acrylics. Upon contact of the cure catalyst(s) with the resin base, the peroxide in the resin base decomposes to yield free radicals. These radicals then initiate polymerization through the acrylate groups on the monomer in the resin base.

Advantages

- No mixing required (no-mix acrylics only)
- Good environmental resistance
- High peel and impact strength
- Bonds to lightly contaminated surfaces
- Fast fixture and cure
- Room temperature cure
- Good adhesion to many substrates
- Cure can be accelerated with heat (no-mix acrylics only)

Disadvantages

- Higher viscosity systems can make automated dispensing difficult
- Activator may contain solvents (no-mix acrylics only)
- Unpleasant odor
- Limited cure-through depth (no-mix acrylics only)
- High exotherm (static-mix acrylics)
- Short worklife of some formulations (static-mix acrylics)

Section 5:

Factors Affecting Activator Selection

Section 5.1: Introduction

No-Mix Acrylic Adhesives are cured through contact with an activator. Typically, the activator is applied to one of the substrates to be bonded, while the adhesive is applied to the other. Upon mating the two parts, the activator comes in contact with the adhesive and catalyzes the breakdown of the peroxide in the adhesive to form free radicals. These free radicals then cause the adhesive to polymerize to a thermoset plastic.

There are a wide variety of different types of activators available for use with two-part and no-mix acrylic adhesive systems. Generally activator selection is based on four criteria:

- 1. Fixture Time:** Fixture time is a measure of how quickly the adhesive cures. In this testing, it was evaluated as the length of time required for the adhesive to develop enough strength to bear a load of 13.5 psi for 10 seconds in a steel lapshear joint with 0.5" (13 mm) overlap and no induced gap. The faster an adhesive fixtures, the faster the assembly can proceed to the next step in the manufacturing process.
- 2. Bond Strength:** The type of activator chosen can have a strong effect on the ultimate bond strength that can be achieved with a given two-part or no-mix adhesive. In addition, the environmental durability of the bond can be affected by the type of activator chosen.
- 3. Activator On-Part Life:** Activators have a finite useful life when they are applied to a part. This useful life is known as the on-part life and can range from 30 minutes to 30 days. The longer the on-part life of the activator, the easier it is to integrate its use into a manufacturing process.
- 4. Activator Form:** Activators are supplied in three forms: 1) Active ingredient dispersed in a flammable solvent; 2) Active ingredient dispersed in a non-flammable solvent; or 3) 100% solids formulations containing no solvents. In essence, these three approaches result from adhesive manufacturers trying to offer the end-user as many options as possible for complying with the Montreal Protocol which effectively banned 1,1,1

trichloroethane and many fluorocarbon based solvents (such as freon) that were previously used as the carrier solvents for most activators. Each of the three approaches have unique processing and economic demands that must be considered to identify the optimum solution for each application.

The objective of this section is to provide the end-user with data concerning these four factors which will allow them to quickly identify the adhesive/activator system best suited for evaluation in their application. This information will be presented in the following sections:

Section 5.2: Activator Listing – Describes the activators evaluated in this section. It lists carrier solvent (if applicable), activator chemical type and on-part life.

Section 5.3: Fixture Time Matrix – In tabular and graphic format, this displays the fixture times achieved with the various activator/adhesive combinations.

Section 5.4: Performance Matrix – In tabular and graphic format, this displays the bond strengths achieved with the various activator/adhesive combinations on steel and stainless steel. Bond strengths were evaluated initially and after exposure to condensing humidity and salt fog.

Section 5.5: Solventless vs. Solvent-borne Activators – This section reviews the processing benefits and limitations of the various forms that activators are supplied in.

Section 5.2: Activator Listing

The table below summarizes key properties of the activators available for use with No-Mix Acrylic Adhesives. Please see sections 5.3 and 5.4 for detailed fixture time and performance data.

Table 5.2 –1 Summary of Loctite® Brand Activator Characteristics					
Activator (Common Name)	Solvent(s)	Active Ingredient(s)	Flash Point	Drying Time In Seconds	On-Part Life
Loctite® 736™ Primer NF™ Activator	Trichloroethylene Isopropyl Alcohol	Aldehyde-amine condensate Organocopper compound	168°F (76°C)	60 to 120	30 minutes
Loctite® 7075™ Activator	Acetone	Butanol – aniline condensate	0°F (-18°C) Highly Flammable	30 to 70	2 hours
Loctite® 7090™ Activator (Solventless Primer N™)	None (Monomer based)	Organocopper compound	> 200°F (93°C)	N/A	1 hour
Loctite® 7091™ Activator (Solventless Primer N™ for Zinc Dichromated Surfaces)	None (Monomer based)	Organocopper compound	> 200°F (93°C)	N/A	1 hour
Loctite® 7471™ Primer T™	Acetone Isopropyl Alcohol	N,N-dialkanol toluidine 2-Mercaptobenzothiazole	-4°F (-20°C) Highly Flammable	30 to 70	7 days
Loctite® 7644™ Activator (Non-Flammable Primer N™)	Decafluoropentane n-butanol	Organocopper compound	> 200°F (93°C)	20 to 30	30 days
Loctite® 7649™ Primer N™	Acetone	Organocopper compound	-4°F (-20°C) Highly Flammable	30 to 70	30 days
Loctite® 7380™ Activator (Solventless Depend® Activator)	None	Aldehyde-aniline condensate Organocopper compound	> 200°F (93°C)	N/A	2 hours
Loctite® 7387™ Depend® Activator	Heptane Isopropyl Alcohol	Aldehyde-aniline condensate Organocopper compound	25°F (-4°C) Highly Flammable	60 to 120	2 hours

Section 5.3: Factors Affecting Activator Selection: Fixture Time

The results of the fixture time evaluation of the various two-part, no-mix acrylic adhesive/ activator combinations are shown in Table 5.3-1 and graphically in

Figures 5.3-1 through 5.3-6. The results of the performance evaluation (initial bond strength, bond strength after condensing humidity exposure, bond strength after salt fog exposure) of the various no-mix acrylic adhesive/activator combinations are shown in Table 5.4-1 and graphically in Figures 5.4-1 through 5.4-12.

Table 5.3-1
Fixture Times of Several Loctite® Brand Structural Adhesive/Activator Combinations
All Fixture Times Given in HH:MM:SS format

Loctite® Brand Activator (Common Name)	Loctite® Brand Structural Adhesive					
	324™ Speedbonder™	326™ Speedbonder™	330™ Depend®	352™ Structural Adhesive	334™ Structural Adhesive	392™ Structural Adhesive
7649™ Primer N™	00:45:00	00:00:45	No fixture	01:00:00	No fixture	No fixture
7090™ Activator (Solventless Primer N™)	01:30:00	00:01:00	No fixture	02:45:00	No fixture	No fixture
7091™ Activator (Solventless Primer N™ for Chromated Surfaces)	02:00:00	00:00:40	No fixture	02:00:00	No fixture	No fixture
7471™ Primer T™	01:45:00	00:30:00	No fixture	01:30:00	No fixture	No fixture
7075™ Activator	00:01:45	00:05:00	00:15:00	00:03:00	00:21:00	00:00:15
7387™ Depend® Activator	00:00:30	00:01:05	00:02:25	00:00:25	00:02:45	00:00:10
7380™ Activator (Solventless Depend® Activator)	00:00:50	00:01:45	00:02:30	00:00:45	00:03:00	00:00:10
736™ Primer NF™	00:00:20	00:00:25	00:10:00	00:00:20	No fixture	00:00:25

Notes:

Fixture Time - defined as the time required for the adhesive/activator combination to develop sufficient strength in a 0.5" by 1.0" (13 mm by 25 mm) bond between two steel lap shears to support a 6.6 lb. (3 kg) weight (13.2 psi) for 10 seconds.

- Fixture times of 5 minutes or less were determined within 5 seconds.
- Fixture times of 5 minutes to 30 minutes were determined within 1 minute.
- Fixture times of 30 minutes to 60 minutes were determined within 5 minutes.
- Fixture times of 60 minutes to 180 minutes were determined within 15 minutes.
- If no fixture occurred after 3 hours, the testing was discontinued.

Figure 5.3-1
Fixture Time of Loctite® 324™ Speedbonder™
Structural Adhesive with Several Activators

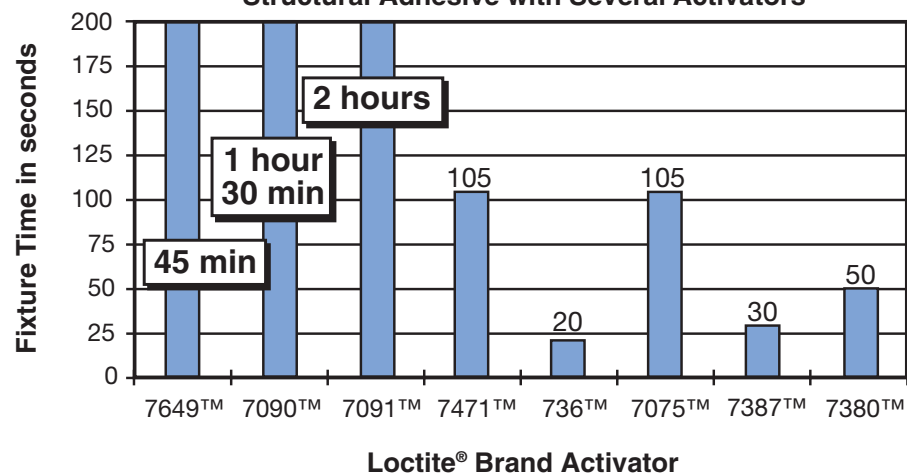


Figure 5.3-2
Fixture Time of Loctite® 326™ Speedbonder™
Structural Adhesive with Several Activators

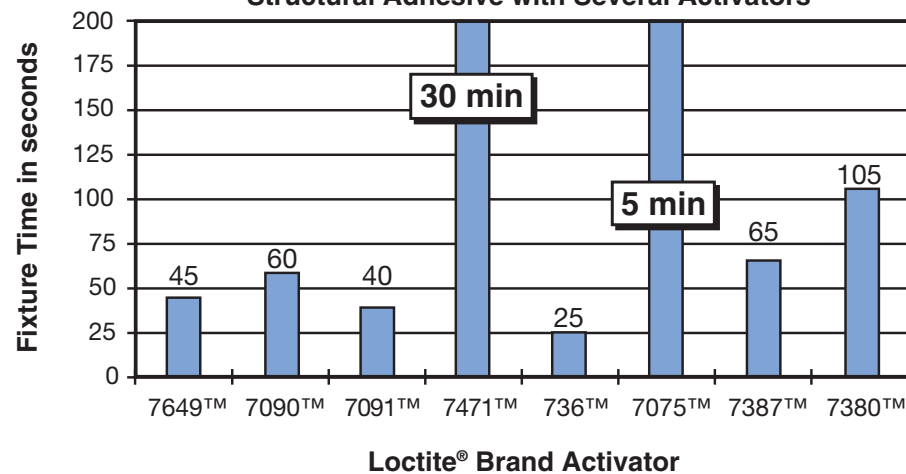


Figure 5.3-3
Fixture Time of Loctite® 330™ Depend®
Adhesive with Several Activators

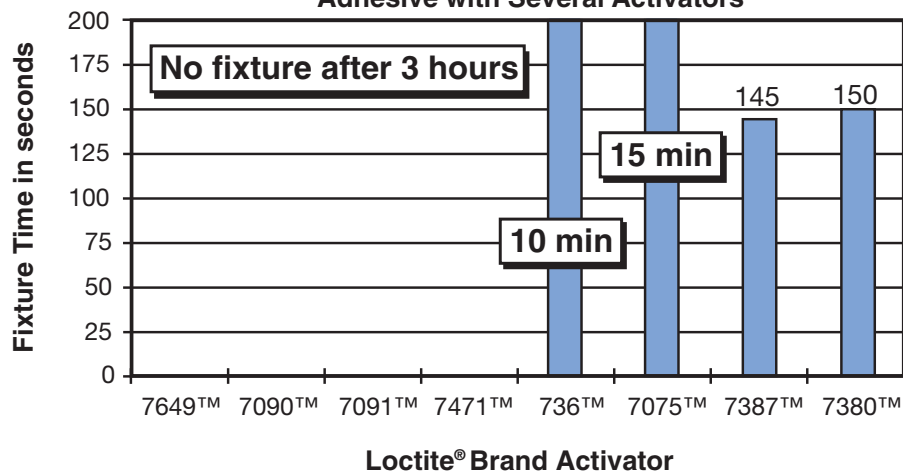


Figure 5.3-4
Fixture Time of Loctite® 352™
Structural Adhesive with Several Activators

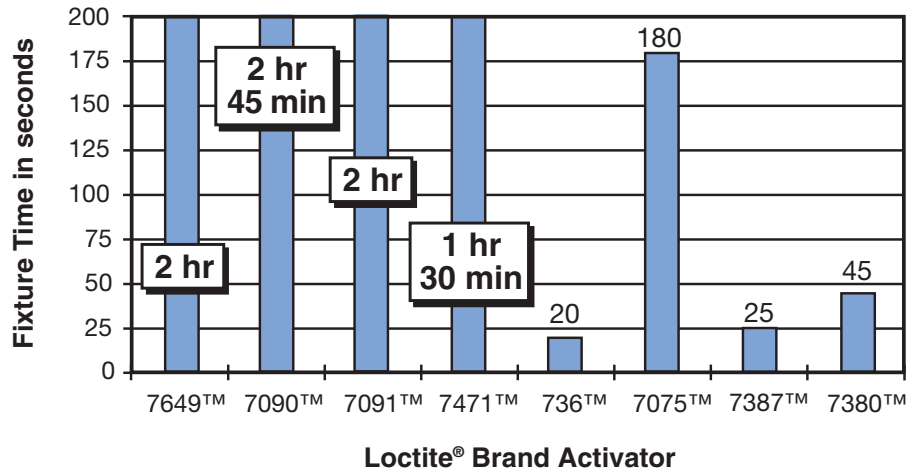


Figure 5.3-5
Fixture Time of Loctite® Brand 334™
Structural Adhesive with Several Activators

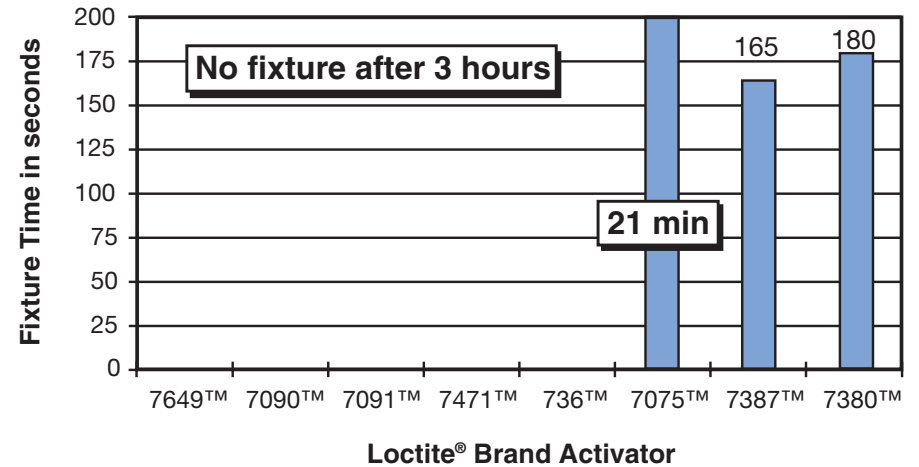
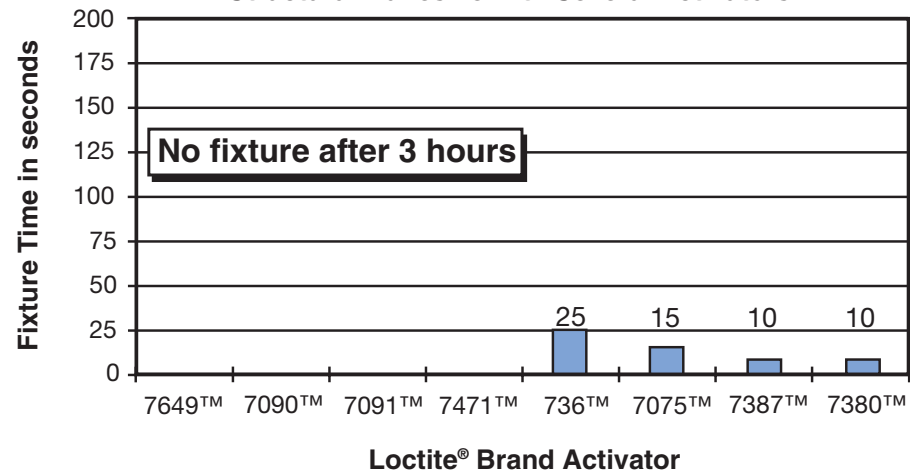


Figure 5.3-6
Fixture Time of Loctite® 392™
Structural Adhesive with Several Activators



Section 5.4: Factors Affecting Activator Selection: Performance

The results of the performance evaluation (initial bond strength, bond strength after condensing humidity exposure, and bond strength after salt fog exposure) of the various Loctite® brand no-mix acrylic adhesive/activator combinations are shown in Table 5.4-1 and graphically in Figures 5.4-1 through 5.4-12.

Table 5.4-1
Performance of Several Adhesive/Activator Combinations on Steel and Stainless Steel
 All Bond Strength Values in psi.

Loctite® Brand Activator	Condition	Loctite® Brand Adhesive											
		324™		326™		330™		334™		352™		392™	
		Steel	SS	Steel	SS	Steel	SS	Steel	SS	Steel	SS	Steel	SS
7649™	I	2750	2110	1715	1090	ND	ND	ND	ND	2170	2350	ND	ND
	SF	1450	845	1180	1440	ND	ND	ND	ND	2375	1980	ND	ND
	HM	1430	1730	750	910	ND	ND	ND	ND	910	1010	ND	ND
7090™	I	3000	2454	1995	1100	ND	ND	ND	ND	2310	2175	ND	ND
	SF	1710	1910	2585	2650	ND	ND	ND	ND	1785	1685	ND	ND
	HM	1340	1640	725	1030	ND	ND	ND	ND	1305	1170	ND	ND
7091™	I	2350	2005	2640	1345	ND	ND	ND	ND	2765	1865	ND	ND
	SF	1915	1195	1750	1795	ND	ND	ND	ND	1755	1955	ND	ND
	HM	1455	1735	420	1235	ND	ND	ND	ND	935	1655	ND	ND
7471™	I	795	930	2035	805	ND	ND	ND	ND	1070	1340	ND	ND
	SF	1045	1560	3105	1210	ND	ND	ND	ND	1335	1135	ND	ND
	HM	840	1320	1015	780	ND	ND	ND	ND	1060	1355	ND	ND
736™	I	1990	1645	2205	815	770	315	ND	ND	2595	2215	2315	1725
	SF	1770	1685	1320	1355	840	180	ND	ND	1275	955	2130	535
	HM	750	1435	650	885	790	125	ND	ND	645	1515	775	880
7075™	I	2425	890	1135	720	2010	1800	680	1860	2170	1630	2435	2050
	SF	1875	1300	830	2285	1715	450	1830	1365	1570	1025	1890	950
	HM	1270	940	545	1165	2010	255	1420	1180	1720	1200	755	1415
7387™	I	2590	1260	2445	2375	2595	1325	2590	2475	2140	1095	2305	2290
	SF	1645	1260	2510	2405	2765	1965	2745	1775	1415	1290	1585	1905
	HM	1895	1090	890	1825	2775	2785	2460	2140	1035	1495	1565	1635
7380™	I	1830	1265	2235	1825	2400	1320	1945	2515	2415	1745	1865	1940
	SF	1670	1285	2740	2590	2025	380	2395	1900	1625	1145	2295	1710
	HM	1075	810	940	1080	1750	470	2380	2360	1045	1285	750	735

Notes:

For Condition, I - initial bond strength.

SF - bond strength after conditioning for 340 hours in 95°F (35°C) salt fog environment.

HM - bond strength after conditioning for 340 hours in 120°F (49°C) condensing humidity environment.

ND - Bond strength testing not done due to the fact that the adhesive/activator combination did not fixture within three hours.

Figure 5.4-1

Performance of Loctite® 324™ Speedbonder™
Structural Adhesive with Several Activators on Steel

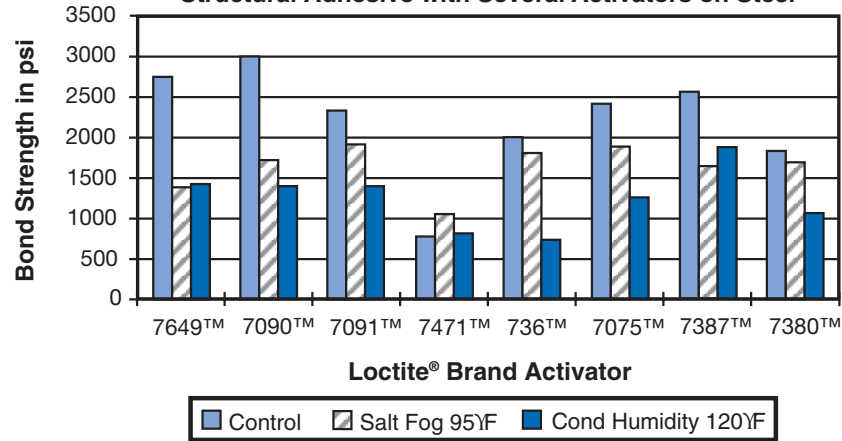


Figure 5.4-2

Performance of Loctite® 324™ Speedbonder™ Structural
Adhesive with Several Activators on Stainless Steel

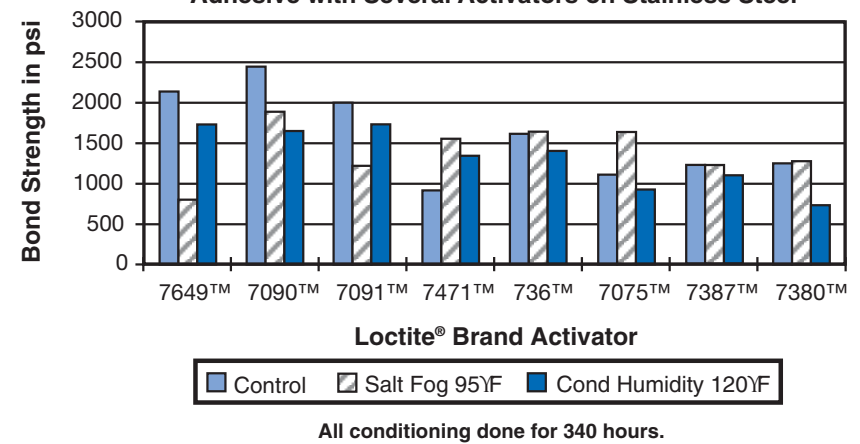
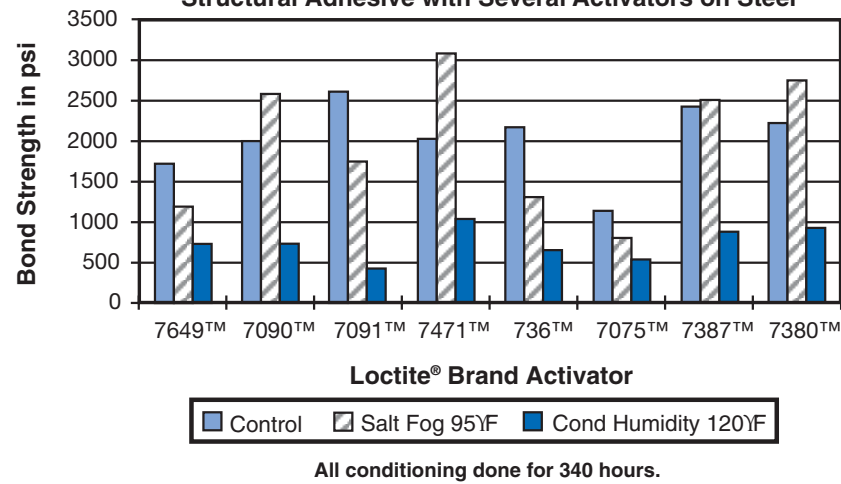


Figure 5.4-3

Performance of Loctite® 326™ Speedbonder™
Structural Adhesive with Several Activators on Steel



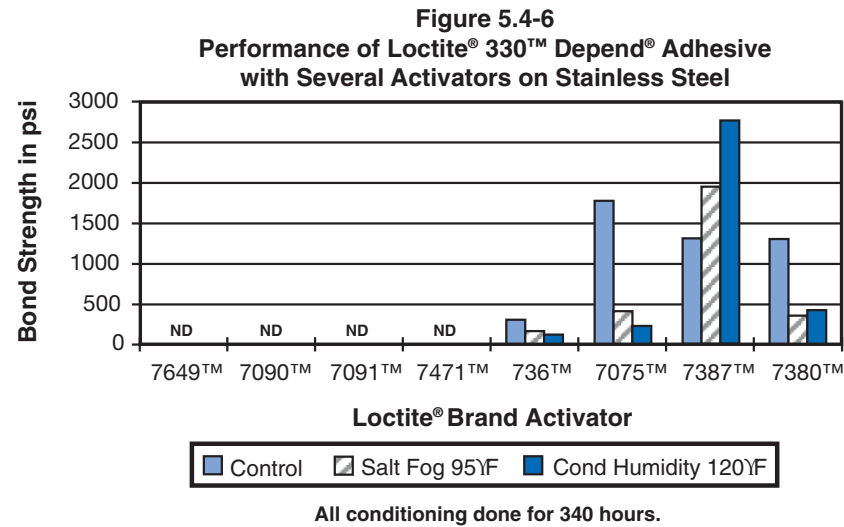
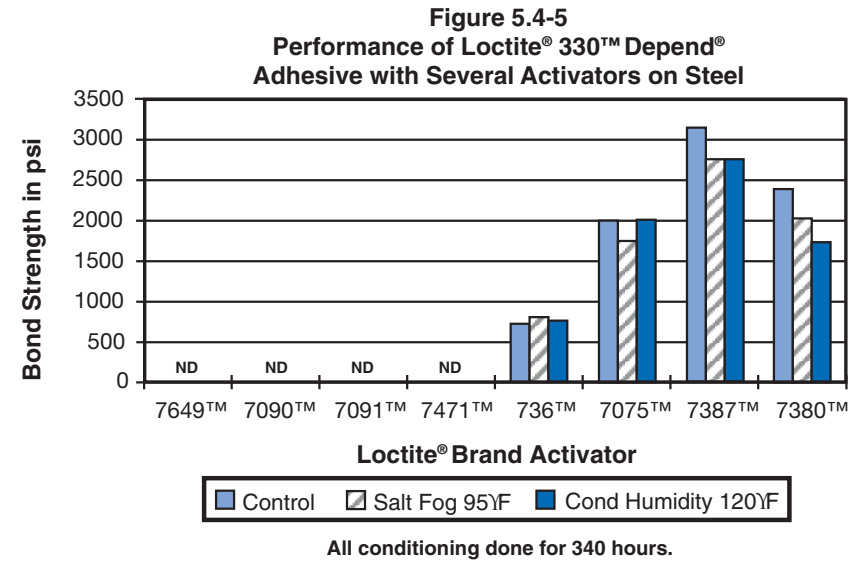
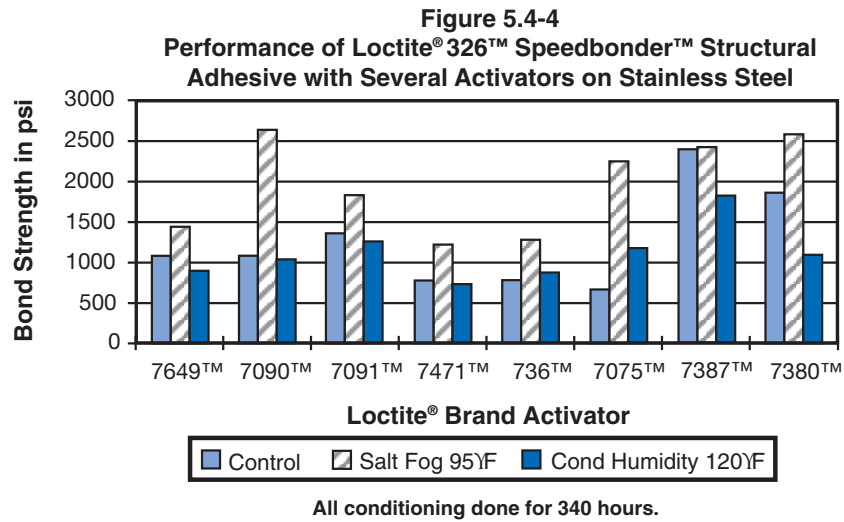
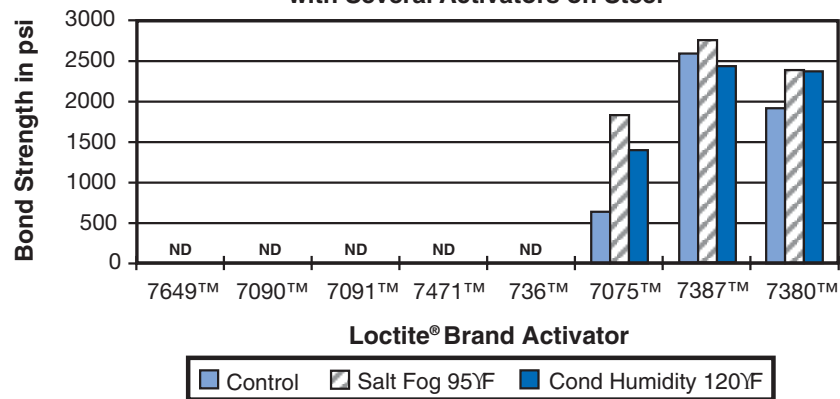
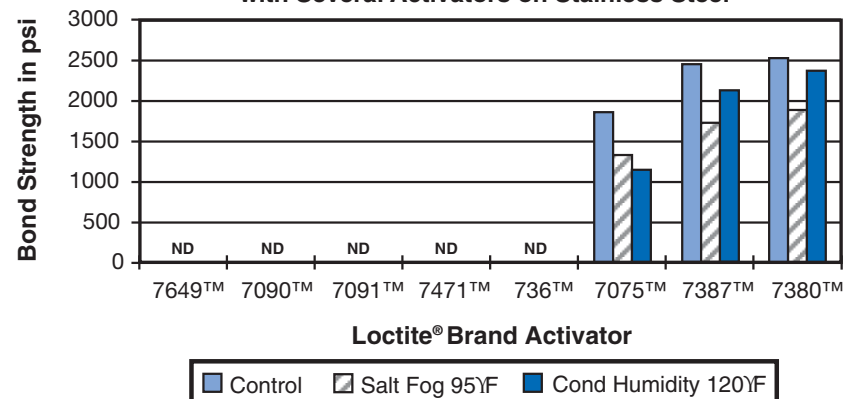


Figure 5.4-7
Performance of Loctite® 334™ Structural Adhesive
with Several Activators on Steel



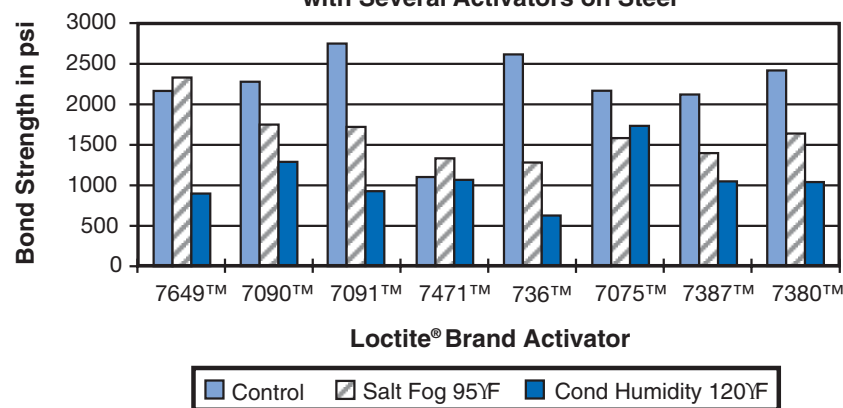
All conditioning done for 340 hours.

Figure 5.4-8
Performance of Loctite® 334™ Structural Adhesive
with Several Activators on Stainless Steel

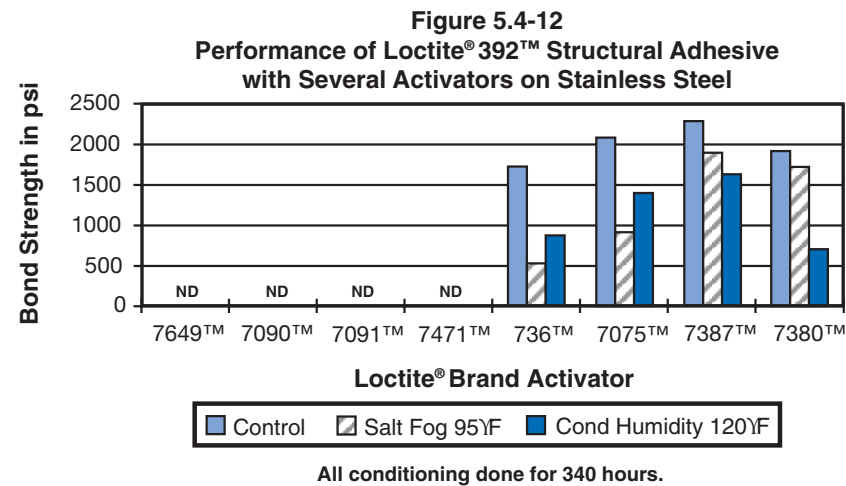
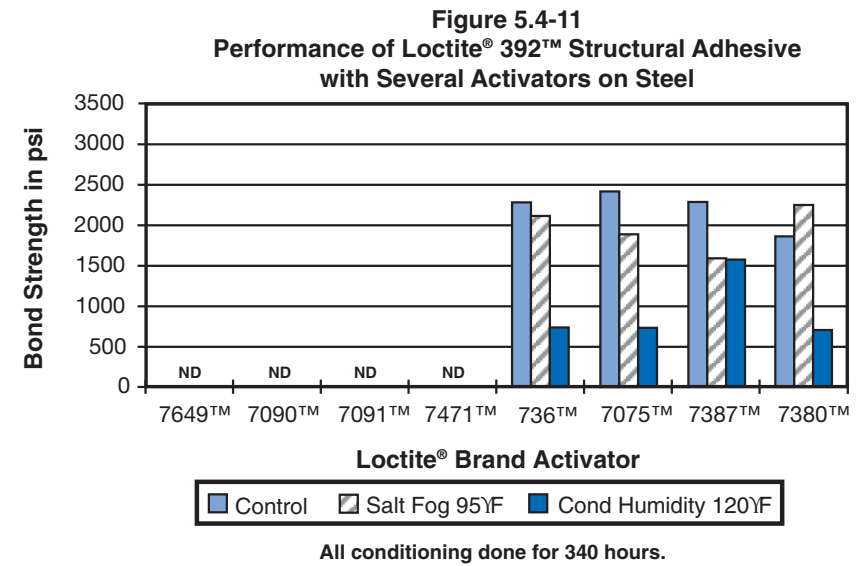
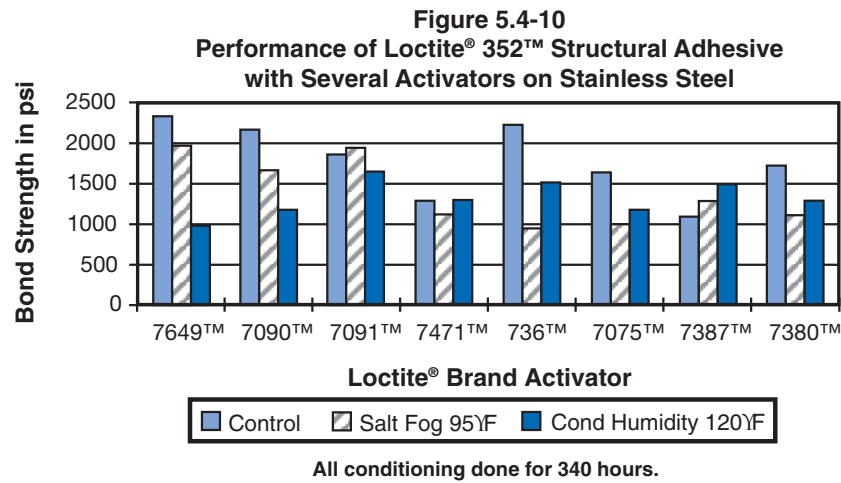


All conditioning done for 340 hours.

Figure 5.4-9
Performance of Loctite® 352™ Structural Adhesive
with Several Activators on Steel



All conditioning done for 340 hours.



Section 5.5: Factors Affecting Activator Selection: Solventless vs. Solvent-borne Activators

Activators for use with no-mix acrylic adhesives can be divided into two categories based on whether or not they contain solvents. For the purposes of discussing the relative processing benefits and limitations of activators, it is convenient to further divide these two groups into the four categories shown below:

Solvent-borne Activators

1. Active ingredient dispersed in flammable solvent.
2. Active ingredient dispersed in non-flammable solvent.

Solventless Activators

1. 100% active ingredient.
2. Active ingredient dissolved in monomer.

Solvent-borne Activators – Dispersed in Flammable Solvents

These activators are typically applied to one surface, the solvent is allowed to evaporate, and the activated surface is mated with the surface which has adhesive dispensed on it. The flammable solvents typically used include acetone and heptane. Their rapid evaporation is a benefit, in these systems, because it minimizes the time required between the activator dispensing step and the parts mating step. In addition, since the activator is dissolved in the solvents at low levels, it is very difficult to apply too much activator. The main limitation of these systems is the flammability of the carrier solvent. Proper precautions must be taken to use these activators safely, including in some cases the use of explosion-proof dispensing equipment. In addition, depending on local regulations, the solvents may be considered volatile organic compounds (VOCs) and their release to the environment may be regulated. Ventilation needs must also be considered to insure that the solvent level in the work environment does not present a health hazard. Examples of these types of activators include Loctite® 7649™ Primer N™ and Loctite® 7471™ Primer T™

Solvent-borne Activators – Dispersed in Non-Flammable Solvents

These activators are typically applied to one surface, the solvent is allowed to evaporate and the activated surface is mated with the surface which has adhesive dispensed on it. The non-flammable solvents typically used include trichloroethylene and decafluoropentane. Freon and trichloroethane were used extensively, in this family of activators, until regulations severely limited their use. These systems also offer rapid evaporation, which is a benefit because it minimizes the time required between the activator dispensing step and the parts mating step. In addition, since the activator is dissolved in the solvents at low levels, it is very difficult to apply too much activator. The main limitation of these systems is cost. The fluorinated solvents (such as decafluoropentane) are most commonly used and this family of solvents is substantially more expensive than their flammable equivalents. In addition, depending on local regulations, the solvents may be considered volatile organic compounds (VOCs) and their release to the environment may be regulated. Ventilation needs must also be considered to insure that the solvent level in the work environment does not present a health hazard. Examples of these activators include Loctite® 736™ Primer NF™ and Loctite® 7644™ Activator (Non-flammable Primer N™).

Solventless Activators – 100% Active Ingredient

Loctite® 7380™ Activator is a typical 100% active ingredient activator. This activator is typically applied to one surface, which is mated immediately with the surface which has adhesive dispensed on it. Since there is no solvent present, there are no concerns with flammability, health or evaporation rates due to solvent content. The biggest limitation of this activator is the need to control the dispense amount carefully. The active ingredient that makes up this activator is an oily substance commonly used as a rubber curative. When used in excess, there is a detrimental effect on bond strength. As a result, automated dispense equipment is commonly used with this activator to provide the dispense control required.

Solventless Activators – Active ingredient dissolved in monomer

Loctite® 7090™ and Loctite® 7091™ Activators take a different approach to providing the active ingredient in a form that is process friendly. In these activators, the active ingredient is dissolved in a monomer that is commonly used in the types of adhesives that are used with these activators. When the activated surface is mated with the adhesive-bearing surface, the monomer is absorbed by the adhesive and reacts to become part of the hardened adhesive. Since there is no solvent present, there are no concerns with flammability,

health or evaporation rates due to solvent content. The biggest limitation of this activator is the need to avoid applying an excessive amount of the primer. The monomer in the activator will become part of the cured adhesive, so its amount will have an effect on the final cured properties of the adhesive. Within a wide range, the adhesive properties will not be substantially affected, however, if a very large excess is applied, the final properties of the cured adhesive may be affected. As a result, it is important to keep the dispense amount within the desired ranges. In addition, the monomer present in these activators poses a potential dermatitis hazard and appropriate industrial hygiene practices should be followed.

Table 5.5–1
A Comparison of the Processing Benefits and Limitations of Several Types of
Loctite® Brand Activators for Use with Two-Part, No-Mix Acrylic Adhesives

Activator Type	Examples	Benefits	Limitations
Solvent-borne Flammable	Loctite® 7649™ Primer N™ Loctite® 7471™ Primer T™	Rapid evaporation rate Difficult to over-apply	Flammability VOC issues
Solvent-borne Non-flammable	Loctite® 736™ Primer NF™ Loctite® 7644™ Primer Activator (Non-flammable Primer N™)	Rapid evaporation rate Difficult to over-apply Non-flammable	Cost
Solventless 100% Active Ingredient	Loctite® 7380™ Activator	No solvent “Flash Off” required Non-flammable	Dispense amount must be tightly controlled – Automated dispense equipment
Solventless Active Ingredient dissolved in monomer	Loctite® 7090™ Activator Loctite® 7091™ Activator	No solvent “Flash Off” required Non-flammable	Excessive activator amounts should be avoided

Section 6:

Heat Cure Parameters for No-Mix Acrylic Adhesives

Most of the adhesives used in conjunction with activators in the No-Mix Acrylic Adhesive systems can also be cured through heat without the use of an activator. In some applications, the heat cure approach offers processing advantages. Table 6-1 contains heat cure parameters for several of these systems. It is important to

keep in mind that the times shown are the times that the adhesive inside the joint was at the desired temperature. Large assemblies with a large thermal mass may require longer times to bring the bond line to the desired temperature.

Table 6-1
Cure Profiles of Loctite® Brand Several No-Mix Structural Adhesives on Steel Using Heat and No Activator

Time at Temperature Required for No-Mix Structural Adhesives to Heat Cure to the Bond Strength Achieved with Activator on Steel.
All testing done on 1" (25 mm) wide steel lapshears with 0.5" (13 mm) overlap. Each lapshear assembly heated for 5 minutes to bring bond line to temperature prior to timing heat cure.

Loctite® Brand Structural Adhesive						
Temperature	324™ Speedbonder™	326™ Speedbonder™	330™ Depend®	352™ Structural Adhesive	334™ Structural Adhesive	392™ Structural Adhesive
200°F (93°C)	40 - 60 min	10 - 20 min	> 24 hours	40 - 60 min	> 24 hours	60 - 120 min
250°F (121°C)	5 - 10 min	5 - 10 min	40 - 60 min	5 - 10 min	20 - 40 min	5 - 10 min
300°F (149°C)	5 - 10 min	5 - 10 min	20 - 40 min	< 5 min	10 - 20 min	5 - 10 min
350°F (177°C)	< 5 min	< 5 min	< 5 min	ND	5 - 10 min	< 5 min
400°F (204°C)	ND	ND	ND	ND	< 5 min	ND

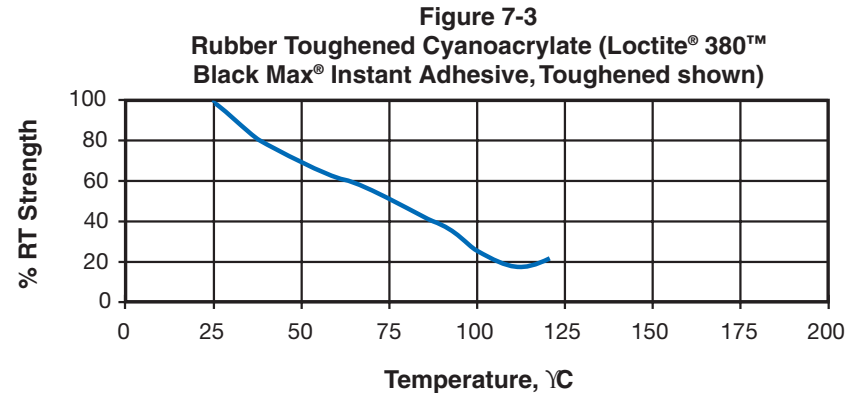
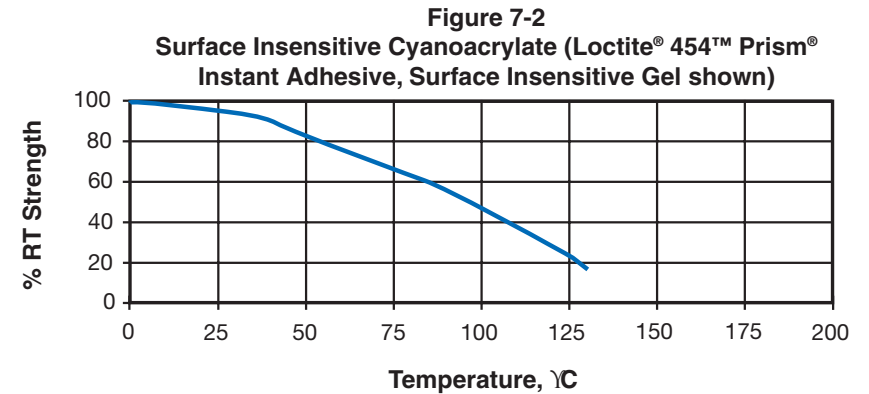
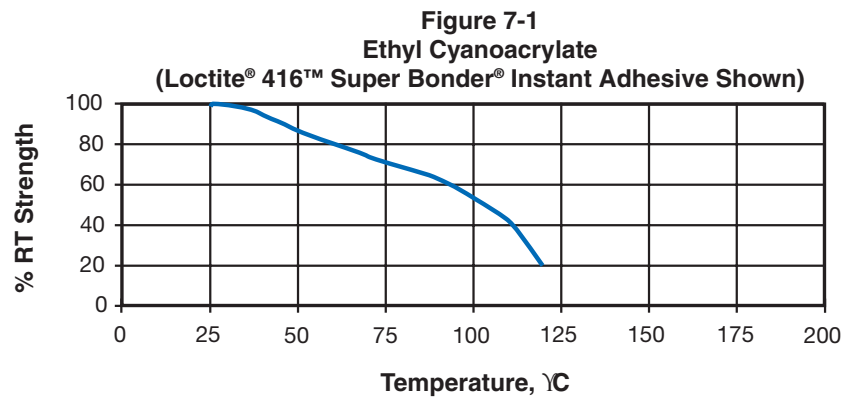
¹ Loctite® 330™ Depend® Adhesive did not heat cure to the bond strength achieved when the adhesive was cured with activator on steel (3170 psi). Times shown are the time it took the adhesive to reach a bond strength of 1000 psi.

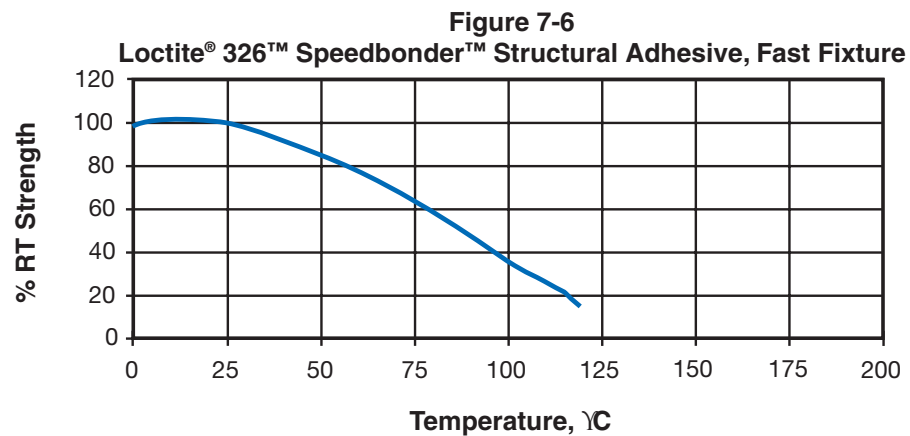
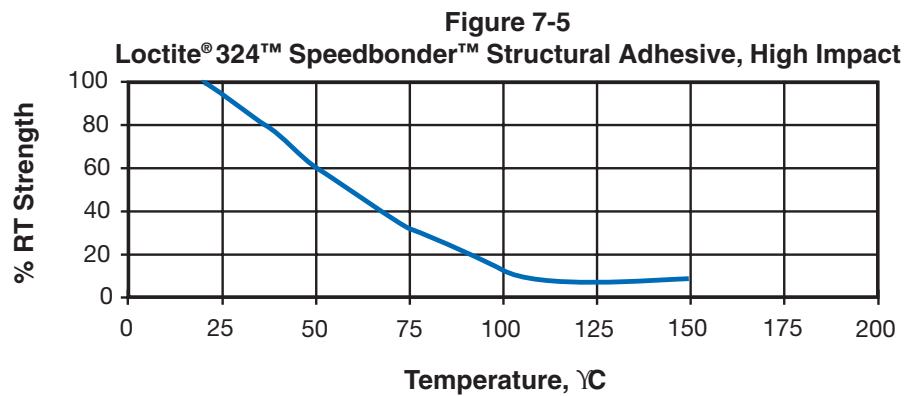
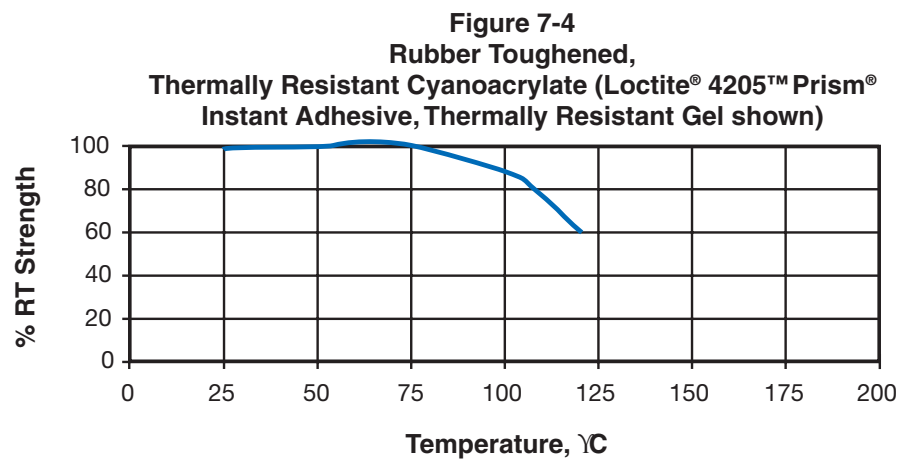
ND = Not Determined, Testing was discontinued when cure time dropped below 5 minutes.

Section 7:

Hot Strength Curves for Adhesives

The hot strength curves below display the effect of temperature on the load bearing capabilities of the adhesives evaluated in this guide. For each test, the assemblies were bonded to grit-blasted mild steel with no induced gap in the assembly. Assemblies were brought to the test temperature and bond strength was evaluated.





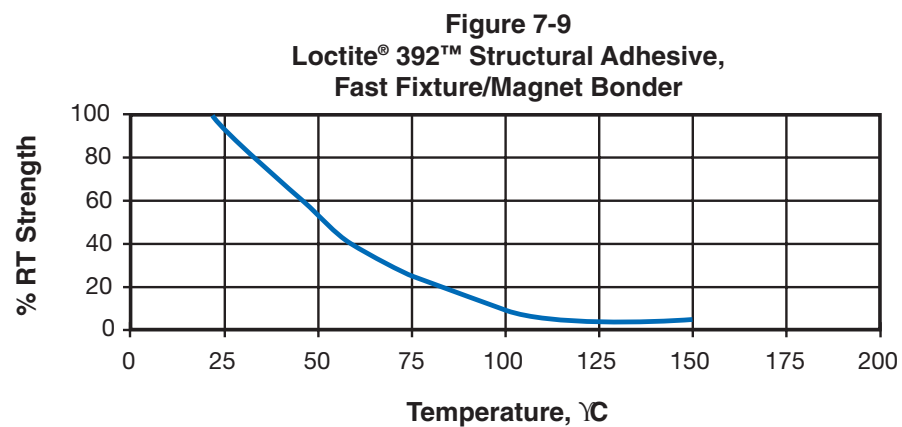
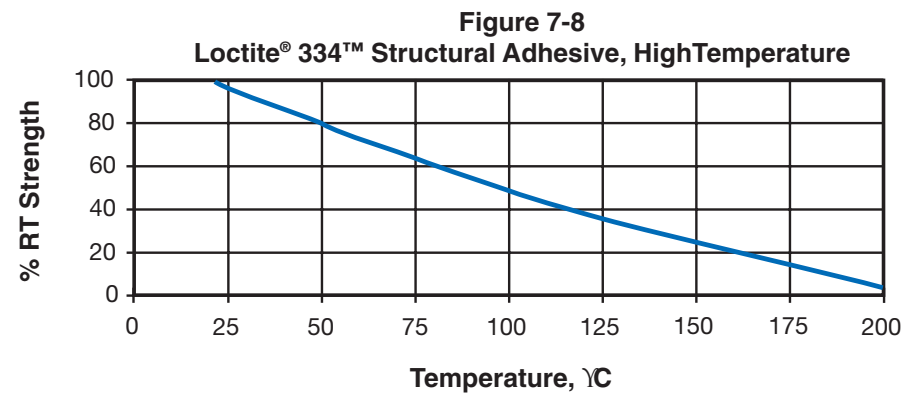
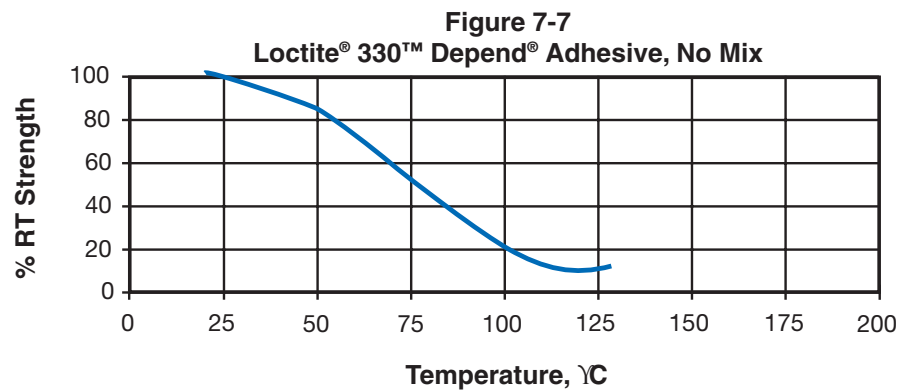


Figure 7-10
Loctite® 352™ Light Cure Adhesive

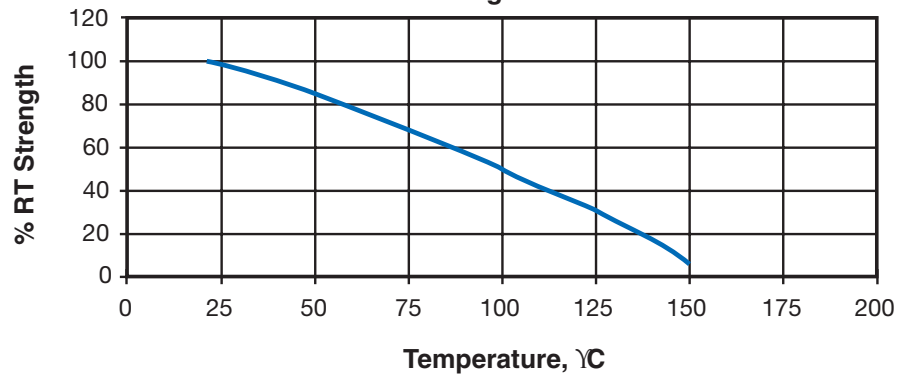


Figure 7-11
Loctite® 3106™ Light Cure Adhesive

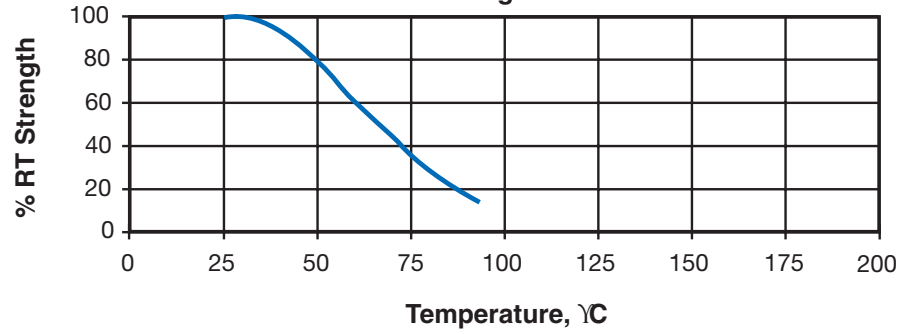


Figure 7-12
Loctite® E-20HP™ Hysol® Epoxy Adhesive, Fast Setting

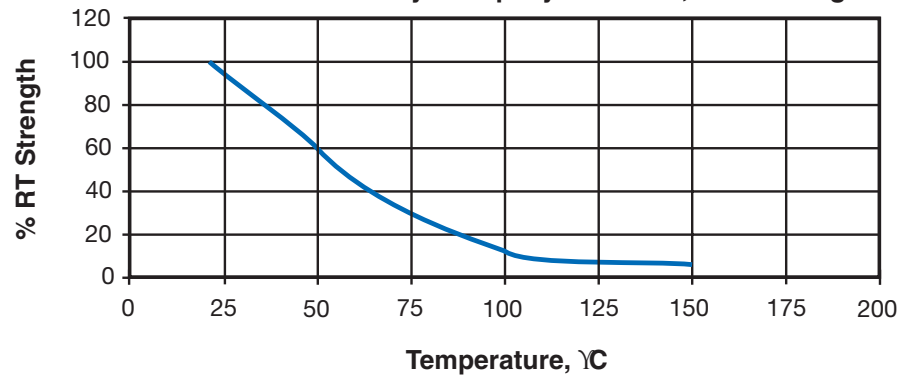


Figure 7-13

Loctite® E-20NS™ Hysol® Epoxy Adhesive, Metal Bonder

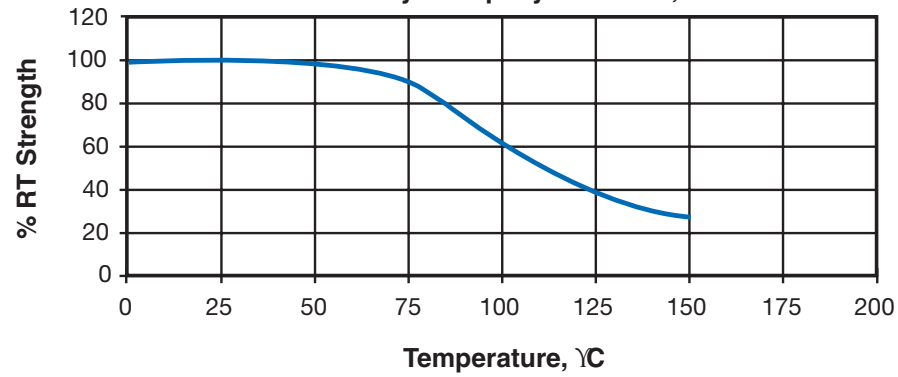


Figure 7-14

Loctite® E-214HP™ Hysol® Epoxy Adhesive, High Strength

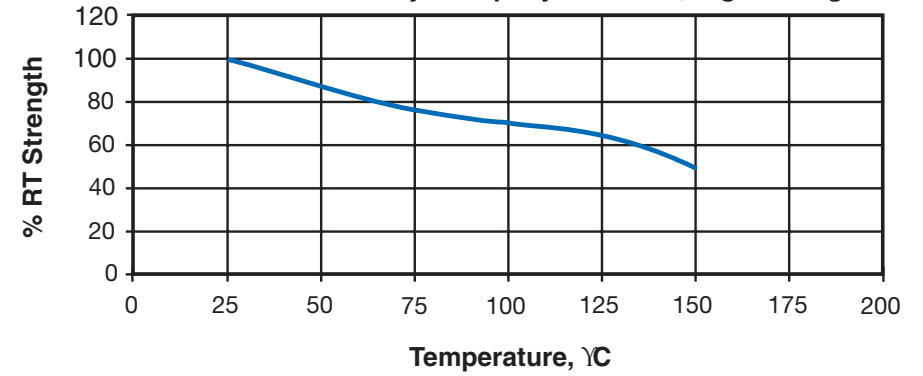
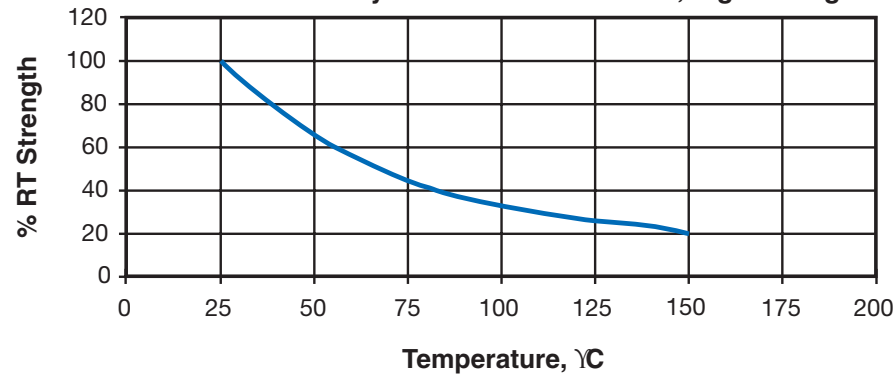
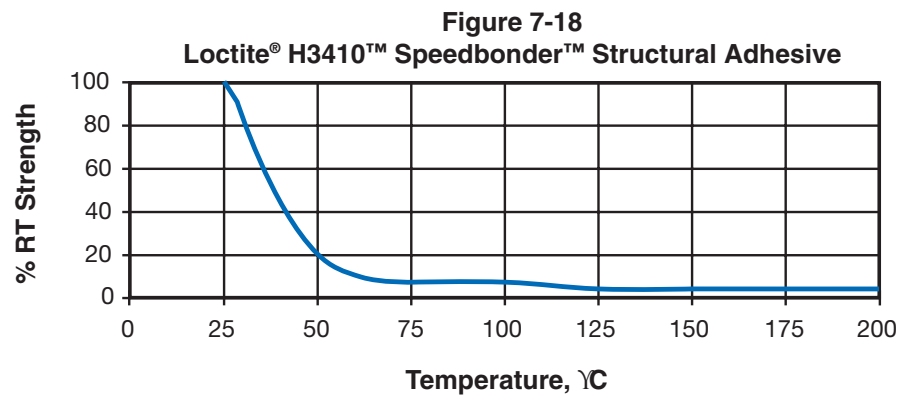
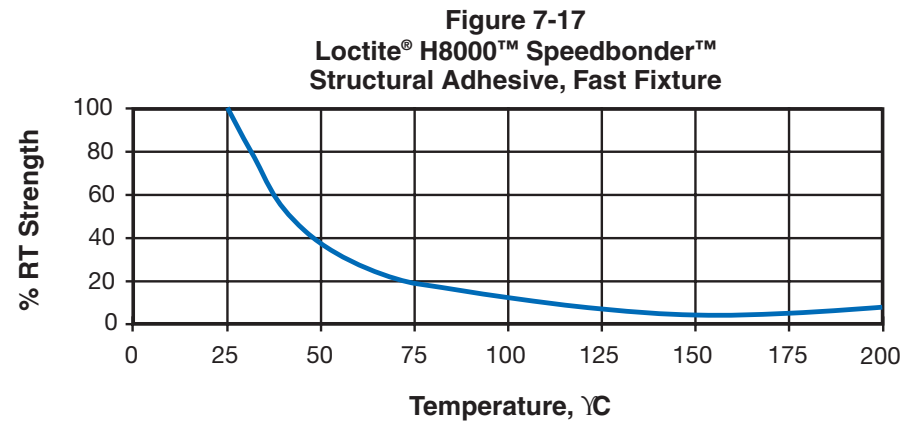
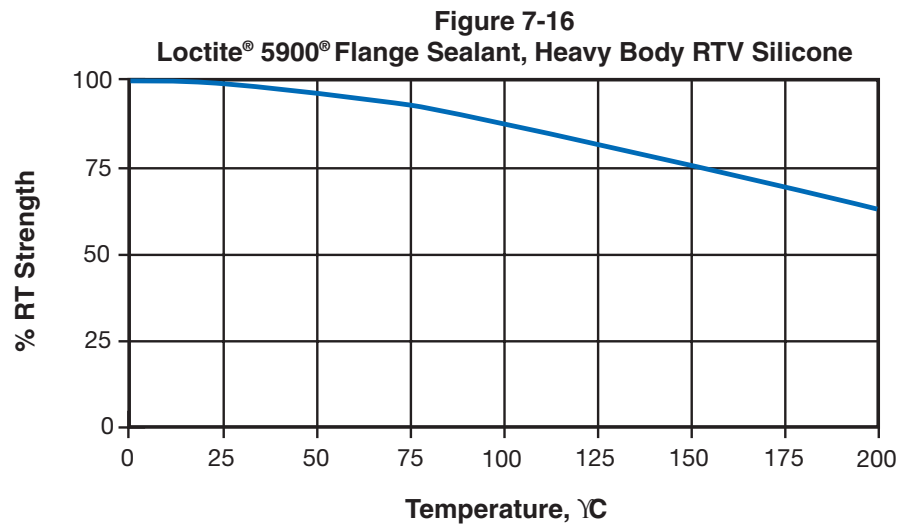
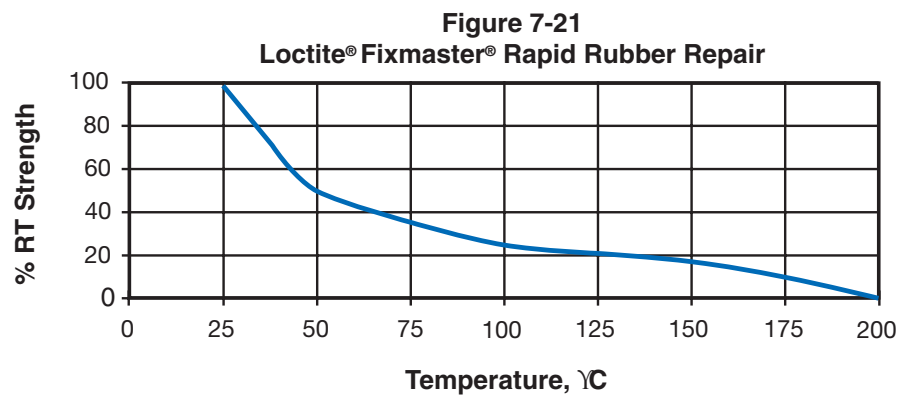
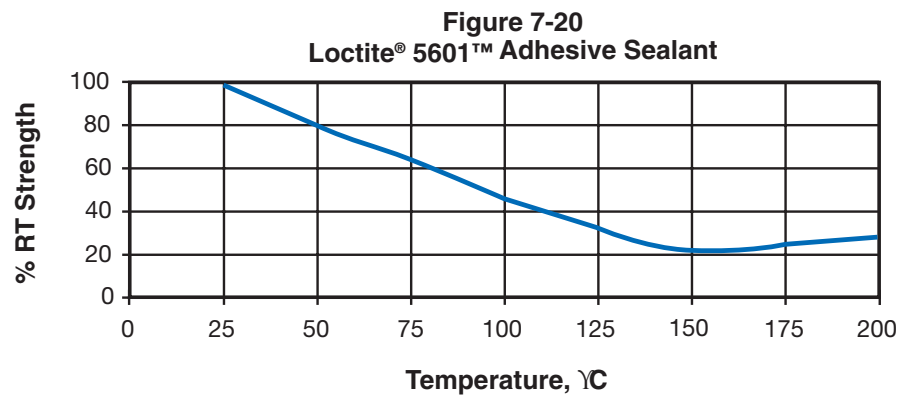
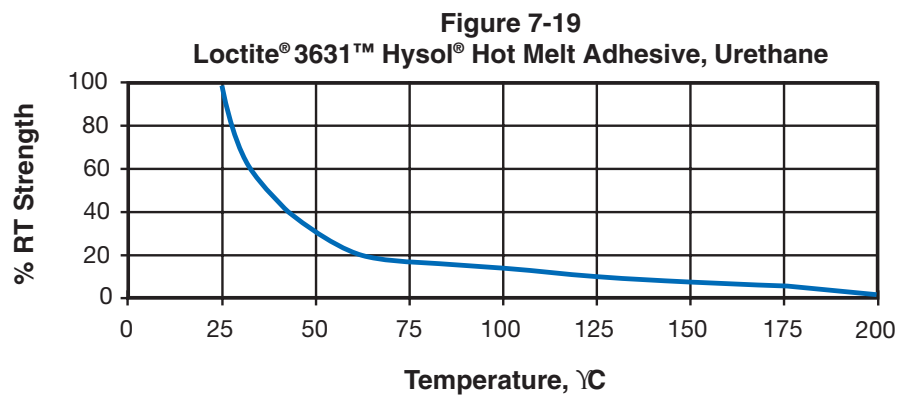


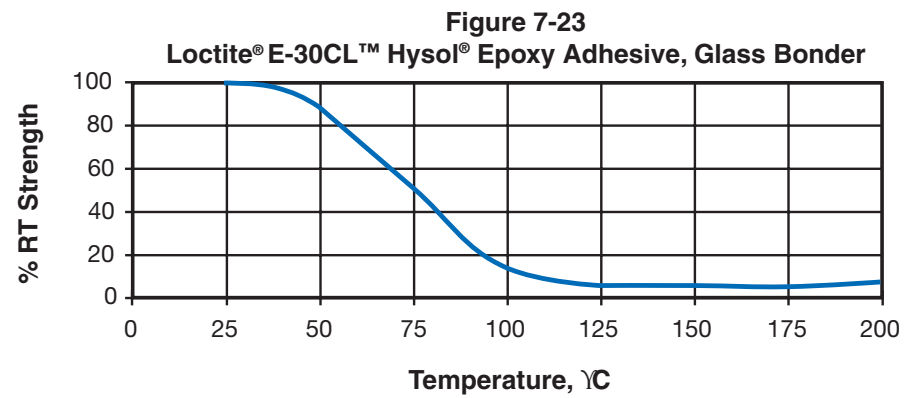
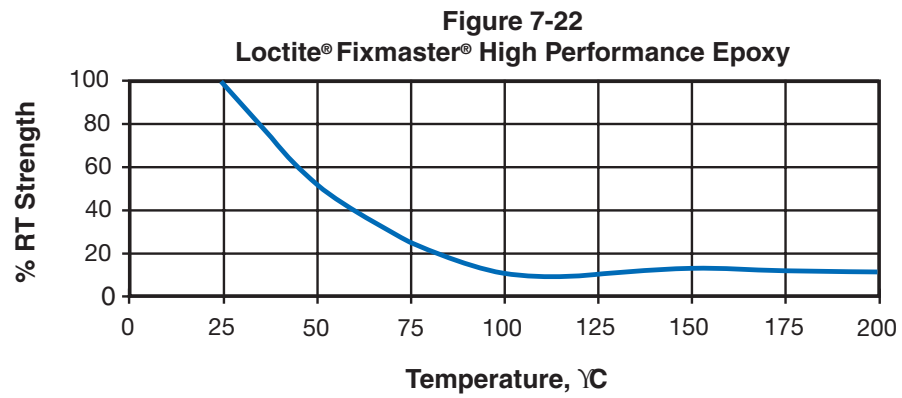
Figure 7-15

Loctite® U-05FL™ Hysol® Urethane Adhesive, High Strength









Section 8:

Metal Bonding Chapters

Section 8.1: Aluminum

General Description

Aluminum and its alloys are the most widely used non-ferrous metals because they offer the benefits of corrosion resistance, desirable appearance, ease of fabrication, low density, and high electrical and thermal conductivity. Limitations of these metals include low fatigue and wear resistance, low melting point, and lower modulus of elasticity than most ferrous alloys. Table 8.1-1 shows a summary of the common aluminum alloys and their ASTM designations.

Aluminum alloys generally have good corrosion resistance due to the fact that aluminum reacts with oxygen to form a hard microscopic layer that inhibits further reaction between corrosive elements and the base aluminum alloy.

Due to its lower modulus of elasticity, aluminum will deflect further than steel when bearing a load. However, since aluminum also has a density that is about one third that of ferrous-based alloys, the strength to weight ratio for high strength grades of aluminum is superior to the ferrous-based alternatives. Alloying aluminum with other metals can significantly improve its strength, as will cold working the metal. The strength of some aluminum alloys can also be improved through heat treating, although distortion and dimensional changes in the part are a concern. The heat treatable aluminum alloys will usually have lower corrosion resistance and in some cases are roll bonded with alloy 1100 to form a product with the dual benefits of high strength and corrosion resistance.

Aluminum alloys lose strength at elevated temperatures and specialty grades are required for good strength retention above 400°F (204°C). When alloyed with silicon, the melting point of aluminum is depressed further, which makes these alloys particularly well suited for welding wire because they melt before the aluminum sections being joined.

The ability of aluminum to reflect radiant energy throughout the entire spectrum and be finished through a variety of mechanical and chemical means make aluminum a good choice when aesthetics of the final finished metal part are important. The mechanical techniques that can be employed to finish aluminum

include buffing and texturing. Chemical finishes include non-etch cleaned, etched, brightened or conversion coatings such as chromates and phosphates. Other finishing techniques involve the application of coatings, including organic coatings (such as paint or powder coatings), vitreous coatings (such as porcelainizing and ceramics), and electroplating.

Summary of Results

The results of the bond strength testing are shown in Tables 8.1-2 and 8.1-3 and in Figures 8.3-1 through 8.3-12. The results are summarized below.

Cyanoacrylates

Surface Roughening - Loctite® 454™ Prism® and Loctite® 4250™ Prism® showed a significant increase in bond strength, while Loctite® 416™ Super Bonder® and Loctite® 426® Prism® showed a slight increase in bond strength.

Salt Fog 95°F (35°C) - Significant decrease in all cases, although Loctite® 4205™ Prism® decreased much less than the other cyanoacrylates.

Condensing Humidity 120°F (49°C) - Significant decrease for all cyanoacrylates

Heat Aging - Loctite® 4205™ Prism® showed a significant increase in bond strength after 340 hours at 250°F (121°C), and decreased significantly at higher temperatures. All other cyanoacrylates experienced a significant drop in bond strength after 340 hours at temperatures as low as 250°F (121°C). The ability of Loctite® 416™ Super Bonder® to maintain bond strength after exposure to temperatures as high as 400°F (204°C) is surprising since cyanoacrylates revert to cyanoacrylate monomer at temperatures above 320°F (160°C). The bond strength is likely due to the presence of the polymethylmethacrylate filler used in Loctite® 416™ Super Bonder®.

No-Mix and Static Mix Acrylic Adhesives

Surface Roughening - Significant improvement for Loctite® 326™ Speedbonder™ Structural Adhesive, Loctite® 330™ Depend® Adhesive, and Loctite® H3410™ Speedbonder™ Structural Adhesive. Slight improvement for Loctite® 324™ Speedbonder™ Structural Adhesive, and Loctite® H8000™ Speedbonder™ Structural

Adhesive. No change for Loctite® 392™ Structural Adhesive, and a slight decrease for Loctite® 394™ Structural Adhesive.

Salt Fog 95°F (35°C) - Loctite® 324™ Speedbonder™ Structural Adhesive, Loctite® 326™ Speedbonder™ Structural Adhesive and Loctite® H8000™ Speedbonder™ Structural Adhesive showed a slight decrease in bond strength, while Loctite® 330™ Depend® Adhesive, Loctite® 334™ Structural Adhesive, Loctite® 392™ Structural Adhesive, and Loctite® H3410™ Speedbonder™ Structural Adhesive significantly decreased in bond strength.

Condensing Humidity 120°F (49°C) - All adhesives showed a significant decrease in bond strength, except for Loctite® H8000™ Speedbonder™ Structural Adhesive which showed no change.

Heat Aging - Loctite® 324™ Speedbonder™ Structural Adhesive, Loctite® 326™ Speedbonder™ Structural Adhesive and Loctite® H3000™ Speedbonder™ Structural Adhesive showed no significant change in bond strength after 340 hours at 250°F (121°C) and 300°F (150°C), but decreased in bond strength significantly at higher temperatures. Loctite® 330™ Depend® Adhesive increased significantly in bond strength after exposure at temperatures up to 350°F (177°C), but showed a slight decrease at 400°F (204°C). The bond strength of Loctite® 334™ Structural Adhesive to aluminum improved slightly at 250°F (121°C) and 300°F (149°C), significantly at 350°F (177°C), and was unchanged at 400°F (204°C). Loctite® 392™ Structural Adhesive generally decreased in bond strength at 250°F (121°C) and above. Loctite® H3410™ Speedbonder™ Structural Adhesive decreased significantly at all temperatures.

Light Cure Adhesives

Surface Roughening - Significant improvement for Loctite® 352™ Light Cure Adhesive, significant decrease for Loctite® 3106™ Light Cure Adhesive.

Salt Fog 95°F(35°C) - No change for Loctite® 352™ Light Cure Adhesive, significant decrease for Loctite® 3106™ Light Cure Adhesive.

Condensing Humidity 120°F (49°C) - The bond strength of Loctite® 352™ Light Cure Adhesive improved slightly while the bond strength of Loctite® 3106™ Light Cure Adhesive decreased significantly.

Heat Aging - The bond strength of Loctite® 3106™ Light Cure Adhesive decreased significantly after 340 hours at 250°F (121°C) and above, while that of Loctite® 352™

Light Cure Adhesive showed a slight increase at 250°F (121°C), no change at 300°F (149°C), and a significant decrease at 350°F (177°C) and 400°F (204°C).

Epoxy Adhesives

Surface Roughening - The bond strength of most epoxy adhesives increased significantly.

Fixmaster® High Performance Epoxy decreased significantly in bond strength to aluminum, while that of Loctite® E-20NS™ Hysol® Epoxy Adhesive decreased slightly, and the bond strength of Loctite® E-214HP™ Hysol® Epoxy Adhesive was unchanged. Loctite® E-30CL™ Hysol® Epoxy Adhesive increased slightly.

Condensing Humidity 120°F (49°C) - Loctite® E-20HP™ Hysol® Epoxy Adhesive was unaffected, while Loctite® E-20NS™ Hysol® Epoxy Adhesive and Loctite® E-214HP™ Hysol® Epoxy Adhesive decreased significantly. Loctite® Fixmaster® High Performance Epoxy decreased slightly while Loctite® E-30CL™ Hysol® Epoxy Adhesive increased significantly.

Heat Aging - Loctite® E-214HP™ Hysol® Epoxy Adhesive's bond strength to aluminum showed significant improved after exposure to 250°F (121°C), 300°F (149°C), and 350°F (177°C) for 340 hours. At 400°F (204°C), the bond strength did not show a significant change from the control value. The bond strength of Loctite® E-20HP™ Hysol® Epoxy Adhesive did not change significantly until the conditioning temperature reached 400°F, then it decreased significantly. Loctite® E-20NS™ Hysol® Epoxy Adhesive and Loctite® Fixmaster® High Performance Epoxy improved significantly in bond strength at temperatures as high as 300°F (149°C) but declined significantly at 350°F (177°C) and above. Loctite® E-30CL™ Hysol® Epoxy Adhesive showed significant improvements at all temperatures tested.

Polyurethane Adhesives

Surface Roughening - Slight improvement.

Salt Fog 95°F (35°C) - Significant decrease in bond strength for Loctite® U-05FL™ Hysol® Epoxy Adhesive and Loctite® 3631™ Hysol® Hot Melt Adhesive. Significant increase for Loctite® Fixmaster® Rapid Rubber Repair.

Condensing Humidity 120°F (49°C) - Slight decrease in bond strength for Loctite® U-05FL™ Hysol® Epoxy Adhesive. Significant decrease and increase for Loctite® 3631™ Hysol® Hot Melt Adhesive and Loctite® Fixmaster® Rapid Rubber Repair respectively.

Heat Aging - Compared to the room temperature bond strength, the bond strength for Loctite® U-05FL™ Hysol® Epoxy Adhesive showed no change after conditioning at 250°F (121°C), however, decreased significantly after exposure to 300°F (149°C), 350°F (177°C) and 400°F (204°C) for 340 hours. Loctite® Fixmaster® Rapid Rubber Repair showed significant improvement when exposed to 250°F (121°C), while decreasing in bond strength when conditioned at all higher temperatures. Loctite® 3631™ Hysol® Hot Melt Adhesive improved slightly when conditioned at 250°F (121°C) and significantly at 300°F (149°C), and its bond strength then decreased slightly when exposed to 350°F (177°C) and significantly at 400°F (204°C).

Silicone Adhesives

Surface Roughening - Significant improvement.

Salt Fog 95°F (35°C) - Significant improvement for Loctite® 5900® Flange Sealant, significant decrease in bond strength for Loctite® 5601™ Adhesive Sealant.

Condensing Humidity 120°F (49°C) - Significant improvement.

Heat Aging - Significant improvement at all temperatures and time periods tested.

Table 8.1–1
Common Types of Wrought Aluminum

ASTM Series	Main Alloy Additions	Metal Properties
1XXX	None	Soft, low strength, excellent workability, excellent corrosion resistance, high thermal and electrical conductivity.
2XXX	Copper	Heat treatable, high strength, elevated temperature performance, some weldability, and lower corrosion resistance.
3XXX	Manganese	Non-heat treatable, good strength, good workability, and corrosion resistance.
4XXX	Silicon	Non-heat treatable, lower melting point.
5XXX	Magnesium	Non-heat treatable, good strength, formability, welding characteristics, finishing characteristics, and corrosion resistance.
6XXX	Magnesium and Silicon	Heat treatable, good strength, formability, welding characteristics, machinability, and corrosion resistance.
7XXX	Zinc	Heat treatable, good strength and formability, poor corrosion resistance.
8XXX	Other Elements	Various.

Notes: 1) The second digit signifies modifications of original alloy or impurity limits.
 2) In the 100 series, the last two digits indicate the minimum aluminum content in the alloy, e.g. 1060 has a minimum aluminum content of 99.60%.
 3) In the 200-900 series, the last two digits are assigned to new alloys as they are registered.
 4) Alloys that are heat treated carry the temper designations 0, T3, T4, T5, T6 and T7.

Table 8.1-2
Bond Strength of Several Loctite® Brand Adhesives on Aluminum (psi)
Aluminum 2024T3

Loctite® Brand Medical Device Adhesive	—	4541™ Prism®	—	—	—	—	—	—	—	—	—	—	—	—	—	M-31CL™ Hysol®	M-06FL™ Hysol®	—	U-04FL™ Hysol® (Industrial)	—	—	—	3321™
Loctite® Brand Industrial Adhesive	416™ Super Bonder®	454™ Prism®	426™ Prism®	4205™ Prism®	324™ Speed-Bonder™	326™ Speed-Bonder™	330™ Depend®	334™	392™	H8000™ Speed-Bonder™	H3410™ Speed-Bonder™	E-20HP™ Hysol®	E-20NS™ Hysol®	E-214HP™ Hysol®	Fixmaster® High Perf. Epoxy	E-30CL™ Hysol®	U-05FL™ Hysol®	3631™	Fixmaster® Rapid Rubber Repair (MRO)	5900®	5601™	352™	3106™
Control - 5 rms	525	345	2045	265	1535	845	1205	2280	1735	2630	1760	2140	1665	2475	2270	1010	1215	595	260	125	170	1480	975
Roughened - 41 rms	625	465	2430	470	1820	1150	2330	1870	1765	2820	2560	3010	2160	3500	1745	1515	1320	320	890	260	125	1820	490
Salt fog @ 95°F	85	0	0	210	1280	740	795	1310	550	2510	260	1735	1365	285	1705	1105	210	235	735	195	70	1430	690
Condensing Humidity @ 120°F	170	125	0	105	610	560	790	1165	615	2595	0	225	1390	2315	2025	1670	1040	320	535	215	105	1745	650
Heat Age @ 250°F	70	115	290	345	1470	785	1905	2505	830	680	780	2240	2330	3560	2440	2445	1210	790	1615	255	230	1645	125
Heat Age @ 300°F	80	95	0	185	1520	905	1840	2575	630	2795	656	2120	2100	3220	2050	2465	965	1015	230	250	260	1470	155
Heat Age @ 350°F	0	0	0	0	675	355	1460	3095	215	1435	280	2410	1095	3390	1930	2320	240	480	220	205	270	810	ND
Heat Age @ 400°F	185	0	0	0	435	370	845	2150	345	425	0	1495	1245	2610	1835	2100	140	80	130	205	250	550	ND

Table 8.1-3
Normalized
Bond Strength of Several Loctite® Brand Adhesives on Aluminum
Aluminum 2024T3

Loctite® Brand Medical Device Adhesive	—	4541™ Prism®	—	—	—	—	—	—	—	—	—	—	—	—	—	M-31CL™ Hysol®	M-06FL™ Hysol®	—	U-04FL™ Hysol® (Industrial)	—	—	—	3321™
Loctite® Brand Industrial Adhesive	416™ Super Bonder®	454™ Prism®	426™ Prism®	4205™ Prism®	324™ Speed-Bonder™	326™ Speed-Bonder™	330™ Depend®	334™	392™	H8000™ Speed-Bonder™	H3410™ Speed-Bonder™	E-20HP™ Hysol®	E-20NS™ Hysol®	E-214HP™ Hysol®	Fixmaster® High Perf. Epoxy	E-30CL™ Hysol®	U-05FL™ Hysol®	3631™	Fixmaster® Rapid Rubber Repair (MRO)	5900®	5601™	352™	3106™
Control - 5 rms	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Roughened - 41 rms	119	135	119	177	119	136	193	82	102	107	145	141	130	141	77	150	109	50	342	208	74	123	50
Salt fog @ 95°F	16	0	0	79	83	88	66	57	32	95	15	81	82	12	75	109	17	39	283	156	41	97	71
Condensing Humidity @ 120°F	32	36	0	40	40	66	66	51	35	99	0	11	83	94	89	165	86	54	206	172	62	118	67
Heat Age @ 250°F	13	33	14	130	96	93	158	110	48	102	44	105	140	144	107	242	100	133	621	204	135	111	13
Heat Age @ 300°F	15	28	0	70	99	107	153	113	36	106	37	99	126	130	90	244	79	171	88	200	153	99	16
Heat Age @ 350°F	0	0	0	0	44	42	121	136	12	55	16	113	66	137	85	230	20	81	85	164	159	55	ND
Heat Age @ 400°F	35	0	0	0	28	44	70	94	20	16	0	70	75	105	81	208	12	13	50	164	147	37	ND

Note: Loctite® 324™ Speedbonder™ and Loctite® 352™ Structural Adhesive were cured with Loctite® 7075™ Activator.
Loctite® 326™ Speedbonder™ was cured with Loctite® 7649™ Primer N™.
Loctite® 330™ Depend® Adhesive, Loctite® 334™ Speedbonder™ Structural Adhesive, and Loctite® 392™ Structural Adhesive were cured with Loctite® 7387™ Depend® Activator.
Loctite® 3106™ Light Cure Adhesive was tested bonded to polycarbonate and could not be conditioned above 300°F.
All environmental conditioning done for 340 hours, samples allowed to equilibrate at ambient conditions for at least 24 hours prior to testing.
ND = Not determined. Polycarbonate lapshear melted at temperature.

Figure 8.1-1
Effect of Roughing on the Bond Strength
of Cyanoacrylates to Aluminum

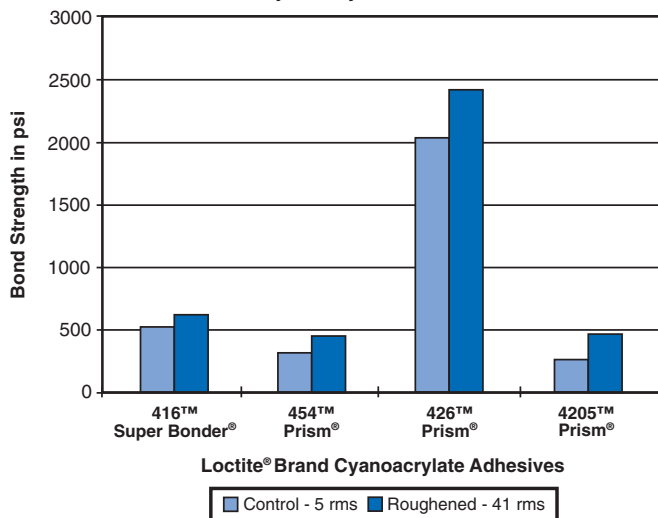


Figure 8.1-2
Effect of Salt Fog Exposure and Condensing Humidity
on the Bond Strength of Cyanoacrylates to Aluminum

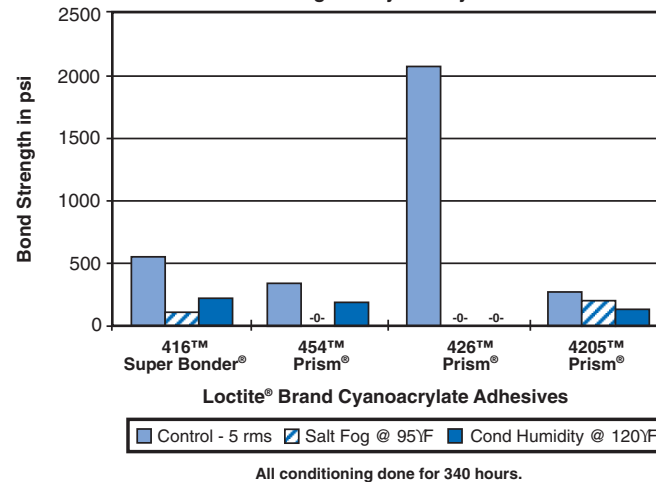


Figure 8.1-3
Effect of Heat Aging on the Bond Strength
of Cyanoacrylates to Aluminum

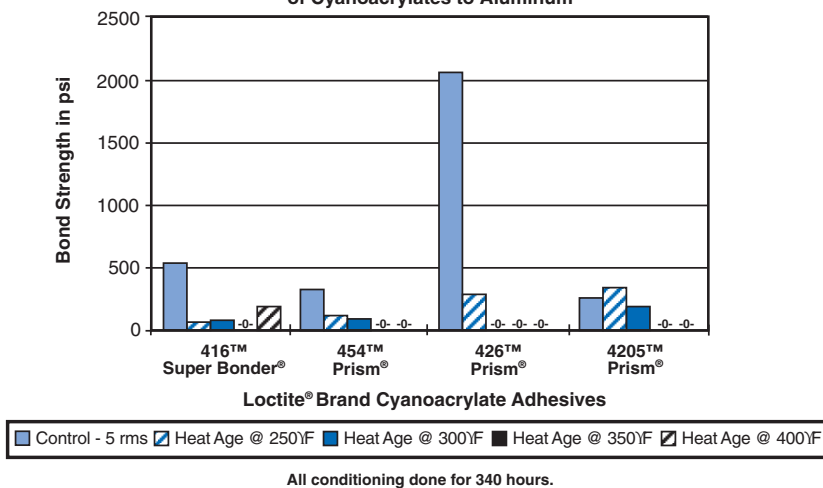


Figure 8.1-4
Effect of Roughing on the Bond Strength of
No-Mix and Static-Mix Acrylic Adhesives to Aluminum

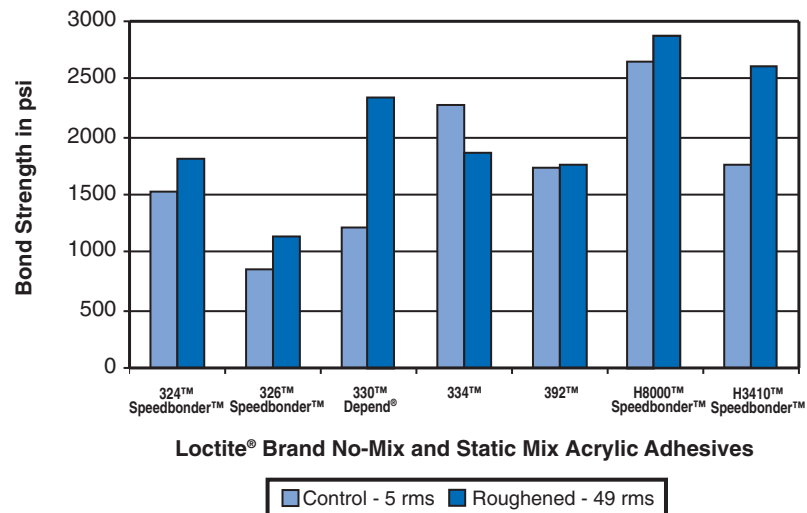


Figure 8.1-5
Effect of Salt Fog Exposure and Condensing
Humidity on the Bond Strength of
No-Mix Acrylic Adhesives to Aluminum

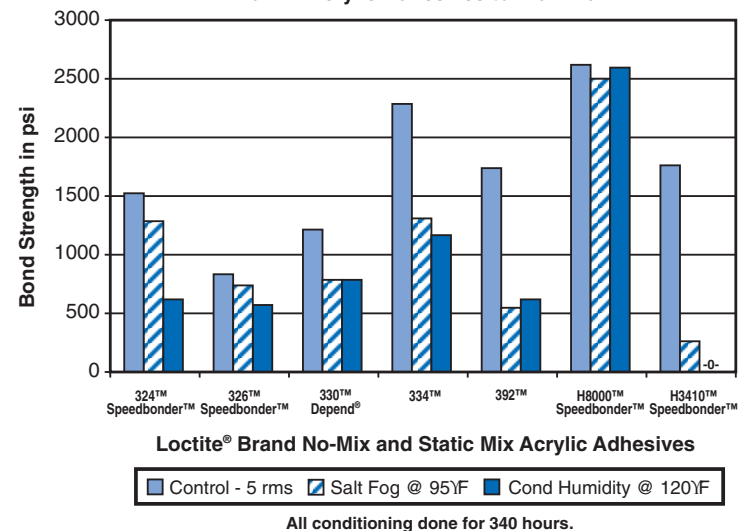


Figure 8.1-6
Effect of Heat Aging on the Bond Strength of
No-Mix and Static-Mix Acrylic Adhesives to Aluminum

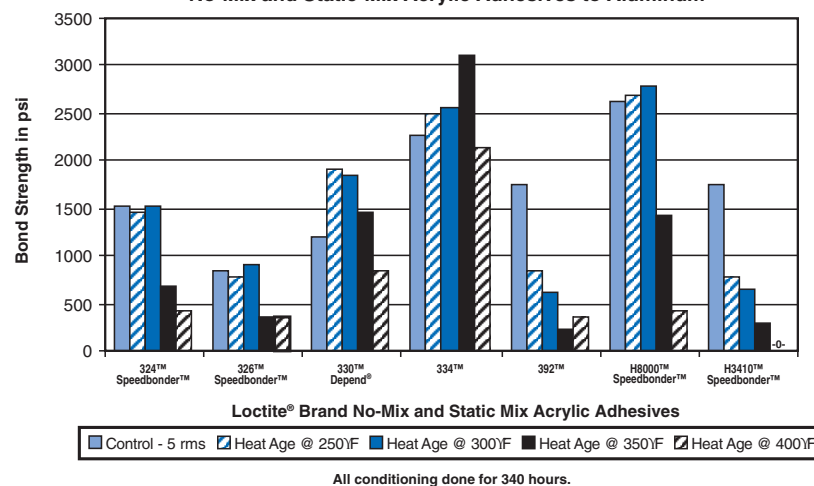


Figure 8.1-7
Effect of Surface Roughening on Bond Strength of
Epoxy, Polyurethane and Silicone Adhesives to Aluminum

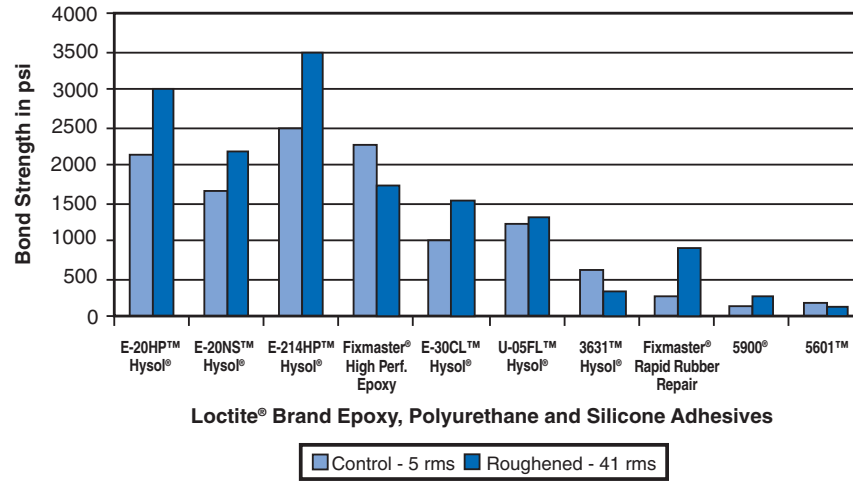


Figure 8.1-8
Effect of Condensing Humidity and Salt Fog Exposure on the Bond Strength
of Epoxy, Polyurethane and Silicone Adhesives to Aluminum

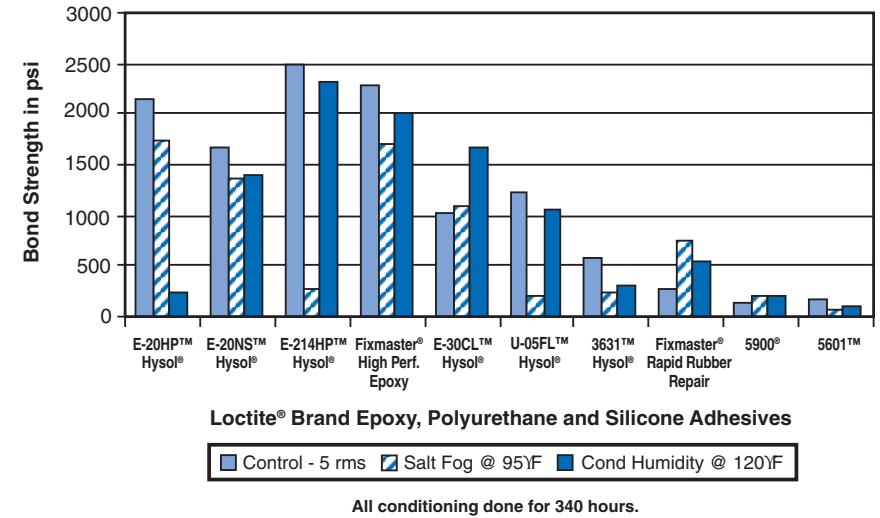


Figure 8.1-9
Effect of Heat Aging on Bond Strength of
Epoxy, Polyurethane and Silicone Adhesives to Aluminum

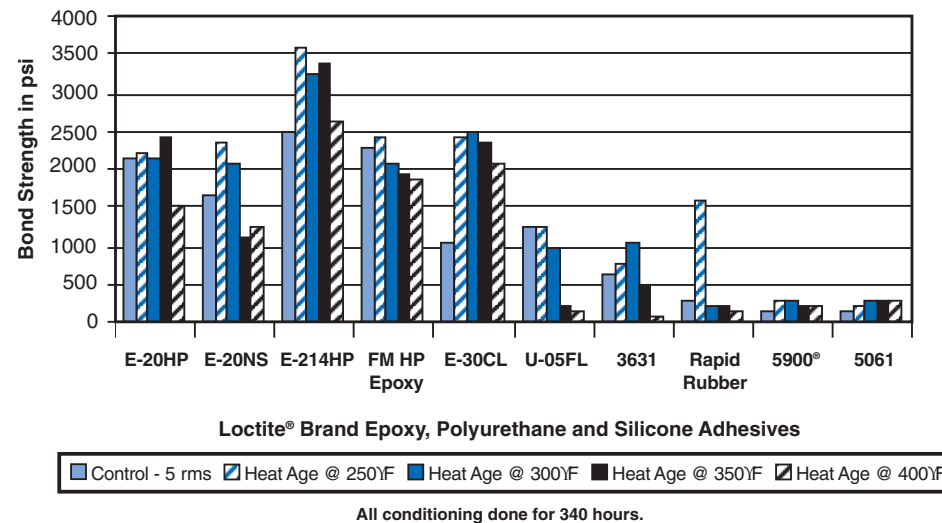


Figure 8.1-10
Effect of Roughing on the Bond Strength of
Light Cure Adhesives to Aluminum

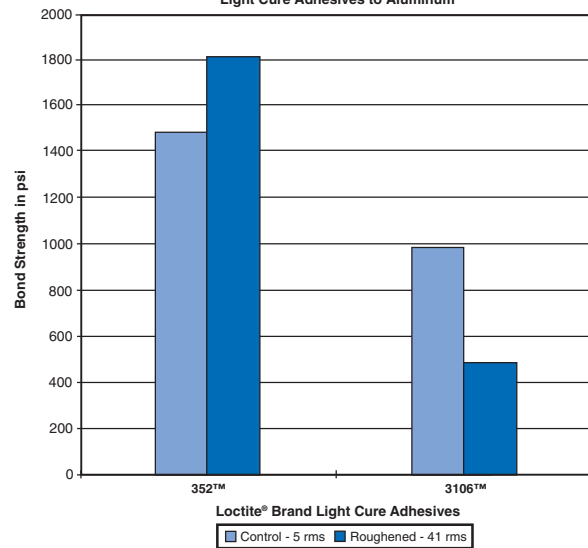


Figure 8.1-11
Effect of Salt Fog Exposure and Condensing Humidity on the
Bond Strength of Light Cure Adhesives to Aluminum

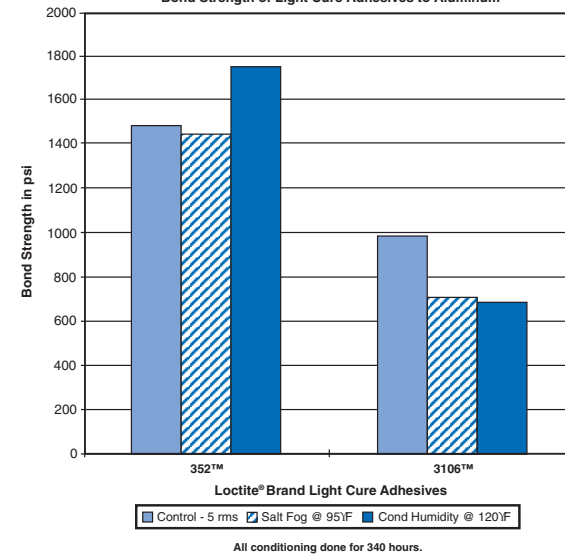
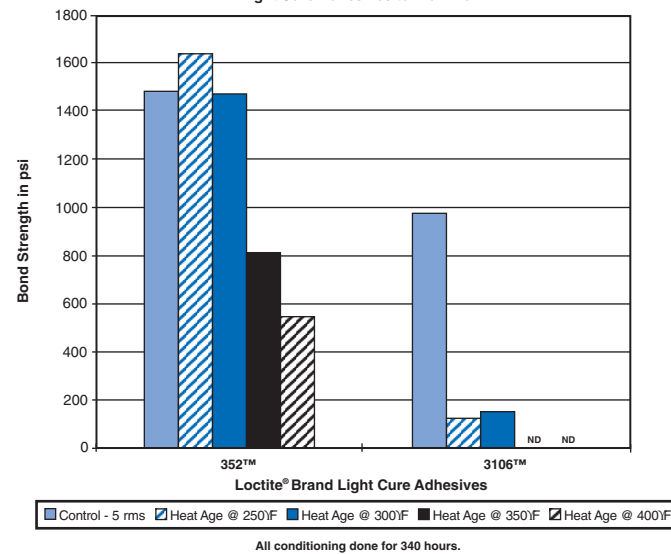


Figure 8.1-12
Effect of Heat Aging on the Bond Strength of
Light Cure Adhesives to Aluminum



Section 8.2: Anodized Aluminum

General Description

Aluminum and many of its alloys react with oxygen to form a stable, extremely hard surface coating that protects the base metal from further corrosion. The anodizing process exploits this phenomenon to build up the oxide layer to a thicker coating which is tightly bound to the base aluminum alloy. The resulting aluminum oxide layer can offer electrical insulation, protection from corrosion, improved abrasion resistance, provide a lasting decorative finish, and offer a stable surface for bonding, coating or other secondary operations.

Anodizing Mechanism

The anodic coating is aluminum oxide that is formed from the reaction of aluminum with oxygen or the hydroxyl ion of the water. This means the acid used as the electrolyte must have an oxygen containing anion. The first layer of aluminum oxide forms at the outer surface of the aluminum. As the reaction progresses, the oxide layer grows into the metal in the following manner. The interface between the aluminum alloy and the oxide layer that has been formed is known as the barrier layer. It is in this layer that the oxidation of the aluminum takes place. As the aluminum is oxidized, this layer moves further into the aluminum leaving the aluminum oxide layer behind. Since the aluminum oxide layer is in contact with the electrolyte, it tends to be dissolved to some extent by the electrolyte and takes on a porous structure. It is this porosity that allows fresh electrolyte to reach the barrier layer and take part in the oxidation reaction. If the oxide formed is not soluble in the electrolyte, only very thin anodic layers of the barrier-layer type are formed. In contrast to the porous aluminum oxide layer, the barrier layer is non-porous and thus has a strong effect on the corrosion resistance and electrical properties of the coating even though it is extremely thin in comparison to the aluminum oxide layer.

The Anodizing Process

The aluminum part is cleaned of greases, oils and other surface contaminants that may interfere with the electrolytic anodizing process. Following this, the natural oxide layer which forms on aluminum in the presence of oxygen is removed from the surface. This is typically done by soaking the part in a heated acid bath. Once the surface oxide layer has been removed, the aluminum surface is chemically etched to provide a suitable surface for the oxide layer to form. The degree of etching can be controlled and will have a strong effect on the type of finish that the anodized part will have. The etching of the aluminum

can result in the formation of “smut” on the part, particularly when aluminum alloys containing copper, manganese or silicon are used. This results because the oxides of these elements have low solubility in the caustic solutions used for etching. The dark smut can be physically removed by wiping the part, but an acid etch is more commonly used.

The part is now placed in the anodizing bath. The type of acid bath used will depend on the type of anodizing required (see Types of Anodizing). An electrolytic cell is established by applying a voltage between the aluminum part (as the anode) and a cathode (typically lead, though other materials can be used). Current density and time are controlled to obtain the proper thickness and quality of the oxide layer. Once the anodizing process is complete, the part is removed and thoroughly rinsed with water. If it is desired to dye the part, the part is dipped in a dye bath. The thickness of the oxide layer, dye concentration and soak time of the part will determine the darkness of the coloration of the part. Whether or not the part is dyed, the pores of the anodized layer must be sealed. This is done by immersing the freshly anodized parts in a hot aqueous solution for 30 minutes. Boiling water or aqueous solutions of acetate salts or potassium dichromate can be used for this step. The sealing of the pores results as the oxide coating is converted into a more stable hydrated form and swells, thus closing the pores.

Types of Anodizing

The three most common types of anodizing used on aluminum are chromic acid anodize, sulfuric acid anodize, and hard coat. Mil-A-8625: Anodic Coatings for Aluminum and Aluminum Alloys classifies these types of coatings in the following manner:

Type I - Conventional Chromic Acid Anodize

Type II - Conventional Sulfuric Acid Anodize

Class 1 - Non-dyed Coatings

Class 2 - Dyed Coatings

Type III - Hard Coatings

Class 1 - Non-dyed Coatings

Class 2 - Dyed Coatings

Conventional Chromic Acid Anodize - The oxide layer formed from chromic acid anodizing tends to be less porous than those formed from sulfuric acid anodizing, and thus thinner. As a result, they impart excellent corrosion resistance but have poor abrasion resistance. Environmental concerns and disposal costs associated with chromic acid militate against this type of anodizing process.

Conventional Sulfuric Acid Anodize - This is the most widely used anodizing process. Coating thicknesses range from 0.0001-0.001" (0.0025-0.025 mm).

Hard Coating - This is a sulfuric acid anodize process with additives which minimize the porosity of the anodize layer and thus provide a harder finish coating. This coating is typically built up as thick as 4 mils.

Summary of Results

The results of the bond strength testing are shown in Tables 8.2-1 and 8.2-2 and in Figures 8.2-1 through 8.2-8. The results are summarized below.

Cyanoacrylates

Salt Fog 95°F (35°C) - Significant decrease in bond strength for all cyanoacrylates.

Condensing Humidity 120°F (49°C) - Significant decrease in bond strength for all cyanoacrylates.

Heat Aging - Significant decrease in bond strength for all cyanoacrylates at all times and temperatures tested.

No-Mix and Static Mix Acrylic Adhesives

Salt Fog 95°F (35°C) - Loctite® 330™ Depend® Adhesive increased slightly in bond strength, Loctite® 326™ Speedbonder™, Loctite® 334™ and 392™ Structural Adhesives showed no change in bond strength, and Loctite® 324™ Speedbonder™ Structural Adhesive decreased significantly in bond strength. Loctite® H8000™ Speedbonder™ Structural Adhesive decreased slightly in bond strength, while Loctite® H3410™ Speedbonder™ Structural Adhesive decreased significantly.

Condensing Humidity 120°F (49°C) - Loctite® 324™, 326™, H3410™ and H8000™ Speedbonder™ Structural Adhesives showed slight or significant decreases in bond strength, while the other adhesives did not show any significant change in bond strength.

Heat Aging - Loctite® 334™ Structural Adhesive increased in bond strength significantly after 340 hours at temperatures ranging from as high as 350°F (177°C) and then showed a slight decrease in bond strength at 400°F (204°C). Loctite® 330™ Depend® Adhesive increased significantly in bond strength at 250°F (121°C) and 300°F (149°C), showed little change at 350°F (177°C), and decreased significantly at 400°F (204°C). To different degrees, Loctite® 324™, 326™, H3410™, and 392™ Speedbonder™ Structural Adhesives all decreased in bond strength to anodized aluminum for all times and temperatures tested. Loctite® H8000™ Speedbonder™ Structural Adhesive showed no significant change at each temperature tested.

Light Cure Adhesives

Salt Fog 95°F (35°C) - Loctite® 352™ Light Cure Adhesive decreased significantly while Loctite® 3106™ Light Cure Adhesive increased significantly in bond strength.

Condensing Humidity 120°F (49°C) - Loctite® 352™ Light Cure Adhesive decreased significantly while Loctite® 3106™ Light Cure Adhesives increased significantly in bond strength.

Heat Aging - Loctite® 3106™ Light Cure Adhesive increased significantly in bond strength after 340 hours at 250°F (121°C), and showed a slight decrease at 300°F (149°C). Loctite® 352™ Light Cure Adhesive decreased slightly in bond strength to anodized aluminum after 340 hours at 300°F (149°C) and significantly at the higher temperatures.

Epoxy Adhesives

Salt Fog 95°F (35°C) - Loctite® E-20HP™ Hysol® Epoxy Adhesive dropped significantly in bond strength, Loctite® E-20NS™ Hysol® Epoxy Adhesive increased slightly and Loctite® E-214HP™ Hysol® Epoxy Adhesive increased significantly. Loctite® Fixmaster® High Performance Epoxy decreased slightly and Loctite® E-30CL™ Hysol® Epoxy Adhesive increased significantly.

Condensing Humidity 120°F (49°C) - Loctite® E-20HP™ Hysol® Epoxy Adhesive dropped significantly in bond strength, Loctite® E-20NS™ Hysol® Epoxy Adhesive increased slightly, and Loctite® E-214HP™ Hysol® Epoxy Adhesive and Loctite® E-30CL™ Hysol® Epoxy Adhesive increased significantly. Loctite® Fixmaster® High Performance Epoxy showed no significant change.

Heat Aging - Loctite® E-214HP™ Hysol® Epoxy Adhesive increased in bond strength to anodized aluminum at all times and temperatures tested. Loctite® E-20NS™ Hysol® Epoxy Adhesive and Loctite® Fixmaster® High Performance Epoxy also showed either a slight improvement or no significant change for all conditions. Loctite® E-20HP™ Hysol® Epoxy Adhesive dropped significantly in bond strength at 350°F (177°C) and above. Loctite® E-30CL™ Hysol® Epoxy Adhesive showed significant improvement when exposed to temperatures 350°F (177°C) and below, but showed a slight decrease in bond strength at 400°F (204°C).

Polyurethane Adhesives

Salt Fog 95°F (35°C) - No effect for Loctite® U-05FL™ Hysol® Urethane Adhesive, slight decrease for Loctite® 3631™ Hysol® Hot Melt Adhesive and Loctite® Fixmaster® Rapid Rubber Repair.

Condensing Humidity 120°F (49°C) - Slight decrease in bond strength for Loctite® U-05FL™ Hysol® Urethane Adhesive, significant decrease for Loctite® 3631™ Hysol® Hot Melt Adhesive and significant increase in bond strength for Loctite® Fixmaster® Rapid Rubber Repair.

Heat Aging - Significant decrease in bond strength for all times and temperatures tested for Loctite® U-05FL™ Hysol® Urethane Adhesive. Loctite® 3631™ Hysol® Hot Melt Adhesive showed a slight improvement in bond strength when exposed to 250°F (121°C) and significant decrease at all higher temperatures tested. Overall increase in bond strength for Loctite® Fixmaster® Rapid Rubber Repair at all temperatures tested.

Silicone Adhesives

Salt Fog 95°F (35°C) - Significant decrease in bond strength.

Condensing Humidity 120°F (49°C) - Significant decrease in bond strength.

Heat Aging - After 340 hours at 250°F (121°C) the bond strength improved significantly, at 300°F (149°C) the bond strength showed no change from the control, and at the higher temperatures the bond strength decreased significantly.

Table 8.2-1
Bond Strength of Several Loctite® Brand Adhesives on Anodized Aluminum (psi)
Type II, Class I Clear Anodized Aluminum

Loctite® Brand Medical Device Adhesive	—	4541™ Prism®	—	—	—	—	—	—	—	—	—	—	—	—	—	M-31CL™ Hysol®	M-06FL™ Hysol®	—	U-04FL™ Hysol® (Industrial)	—	—	—	3321™
Loctite® Brand Industrial Adhesive	416™ Super Bonder®	454™ Prism®	426™ Prism®	4205™ Prism®	324™ Speed-Bonder™	326™ Speed-Bonder™	330™ Depend®	334™	392™	H8000™ Speed-Bonder™	H3410™ Speed-Bonder™	E-20HP™ Hysol®	E-20NS™ Hysol®	E-214HP™ Hysol®	Fixmaster® High Perf. Epoxy	E-30CL™ Hysol®	U-05FL™ Hysol®	3631™	Fixmaster® Rapid Rubber Repair (MRO)	5900®	5601™	352™	3106™
Control - 48 rms	1985	2425	2345	1875	1775	1310	2320	2010	1575	2340	3865	2610	1210	830	1485	1755	1140	780	180	230	155	1540	1045
Salt fog @ 95°F	1050	405	885	1175	1310	1280	2745	2090	1625	2120	1875	1810	1360	1055	1310	2200	1160	595	90	150	65	1140	1270
Condensing Humidity @ 120°F	315	400	400	525	645	840	2175	1975	1440	2025	1210	1760	1245	1350	1415	2575	970	425	900	150	40	950	1410
Heat Age @ 250°F	155	55	0	310	1545	1120	3150	2265	1230	2105	2345	2275	1390	1730	1970	3375	585	1080	570	275	225	1505	1980
Heat Age @ 300°F	25	25	0	25	1500	885	2825	2245	805	2260	1280	2620	1390	1200	1485	2650	500	340	545	245	245	1375	900
Heat Age @ 350°F	110	0	0	0	860	720	2100	2520	330	2040	895	2085	1430	1705	1650	2480	295	245	395	105	165	1040	ND
Heat Age @ 400°F	290	0	0	0	200	275	1855	1755	250	2025	290	1755	1115	975	1615	1630	110	190	220	130	130	430	ND

Table 8.2-2
Normalized
Bond Strength of Several Loctite® Brand Adhesives on Anodized Aluminum
Type II, Class I Clear Anodized Aluminum

Loctite® Brand Medical Device Adhesive	—	4541™ Prism®	—	—	—	—	—	—	—	—	—	—	—	—	—	M-31CL™ Hysol®	M-06FL™ Hysol®	—	U-04FL™ Hysol® (Industrial)	—	—	—	3321™
Loctite® Brand Industrial Adhesive	416™ Super Bonder®	454™ Prism®	426™ Prism®	4205™ Prism®	324™ Speed-Bonder™	326™ Speed-Bonder™	330™ Depend®	334™	392™	H8000™ Speed-Bonder™	H3410™ Speed-Bonder™	E-20HP™ Hysol®	E-20NS™ Hysol®	E-214HP™ Hysol®	Fixmaster® High Perf. Epoxy	E-30CL™ Hysol®	U-05FL™ Hysol®	3631™	Fixmaster® Rapid Rubber Repair (MRO)	5900®	5601™	352™	3106™
Control - 48 rms	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Salt fog @ 95°F	53	17	38	63	74	98	118	104	103	91	49	69	112	127	88	125	102	76	50	65	42	74	122
Condensing Humidity @ 120°F	16	16	17	28	36	64	94	98	91	87	31	67	103	163	95	147	85	54	500	65	26	62	135
Heat Age @ 250°F	8	2	0	17	87	85	136	113	78	90	61	87	115	208	133	192	51	138	317	120	145	98	189
Heat Age @ 300°F	1	1	0	1	85	68	122	112	51	97	33	100	115	145	100	151	44	44	303	107	158	89	86
Heat Age @ 350°F	6	0	0	0	48	55	91	125	21	87	23	80	118	205	111	141	26	31	219	46	106	68	ND
Heat Age @ 400°F	15	0	0	0	11	21	80	87	16	87	8	67	92	117	109	93	10	24	122	57	84	28	ND

Note: Loctite® 324™ Speedbonder™ and Loctite® 352™ Structural Adhesive were cured with Loctite® 7075™ Activator.
Loctite® 326™ Speedbonder™ was cured with Loctite® 7649™ Primer N™.
Loctite® 330™ Depend® Adhesive, Loctite® 334™ Speedbonder™ Structural Adhesive, and Loctite® 392™ Structural Adhesive were cured with Loctite® 7387™ Depend® Activator.
Loctite® 3106™ Light Cure Adhesive was tested bonded to polycarbonate and could not be conditioned above 300°F.
All environmental conditioning done for 340 hours, samples allowed to equilibrate at ambient conditions for at least 24 hours prior to testing.
ND = Not determined. Polycarbonate lapshear melted at temperature.

Figure 8.2-1
Effect of Salt Fog Exposure and Condensing Humidity on the Bond Strength of Cyanoacrylates to Anodized Aluminum

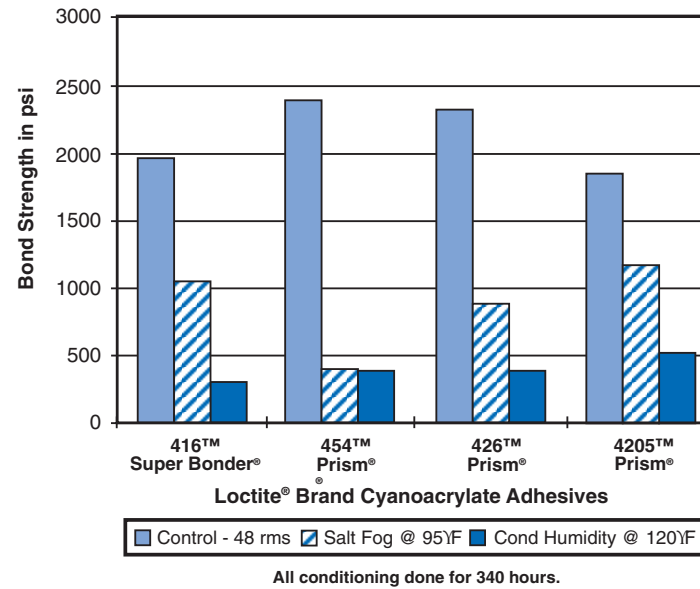


Figure 8.2-2
Effect of Heat Aging on the Bond Strength of Cyanoacrylates to Anodized Aluminum

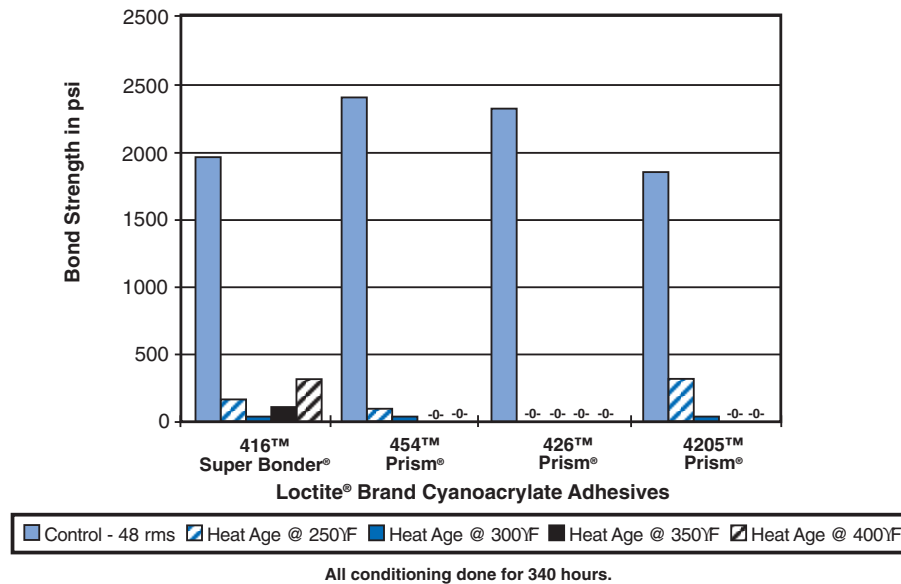
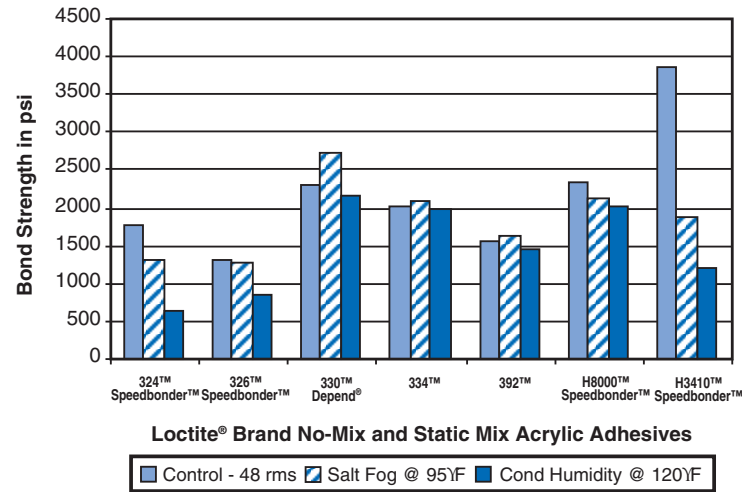
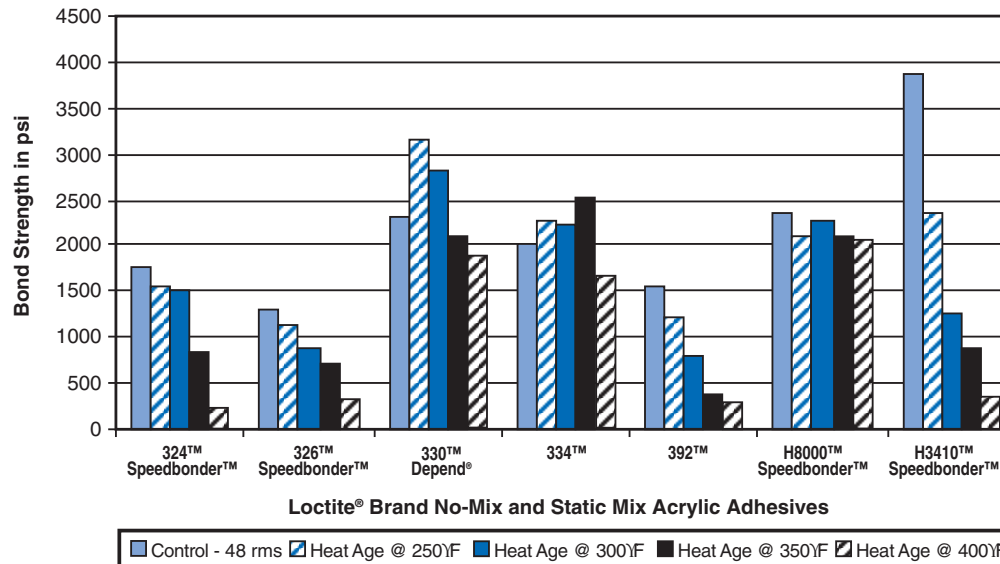


Figure 8.2-3
Effect of Salt Fog Exposure and Condensing Humidity
on the Bond Strength of No-Mix and Static Mix
Acrylic Adhesives to Anodized Aluminum



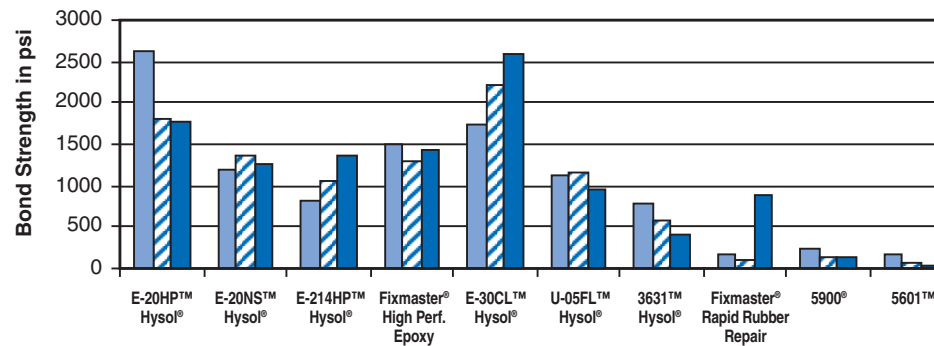
All conditioning done for 340 hours.

Figure 8.2-4
Effect of Heat Aging on the Bond Strength of
No-Mix and Static Mix Acrylic Adhesives to Anodized Aluminum



All conditioning done for 340 hours.

Figure 8.2-5
Effect of Salt Fog Exposure and Condensing Humidity on the Bond Strength of Epoxy, Polyurethane, and Silicone Adhesives to Anodized Aluminum

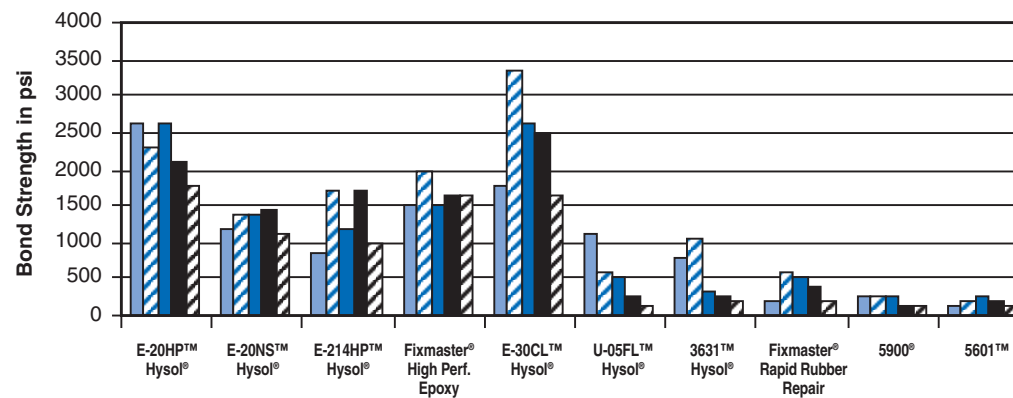


Loctite® Brand Epoxy, Polyurethane, and Silicone Adhesives

Control - 48 rms Salt Fog @ 95°F Cond Humidity @ 120°F

All conditioning done for 340 hours.

Figure 8.2-6
Effect of Heat Aging on the Bond Strength of Epoxy, Polyurethane, and Silicone Adhesives to Anodized Aluminum



Loctite® Brand Epoxy, Polyurethane, and Silicone Adhesives

Control - 48 rms Heat Age @ 250°F Heat Age @ 300°F Heat Age @ 350°F Heat Age @ 400°F

All conditioning done for 340 hours.

Figure 8.2-7
Effect of Condensing Humidity and Salt Fog Exposure on the Bond Strength of Light Cure Adhesives to Anodized Aluminum

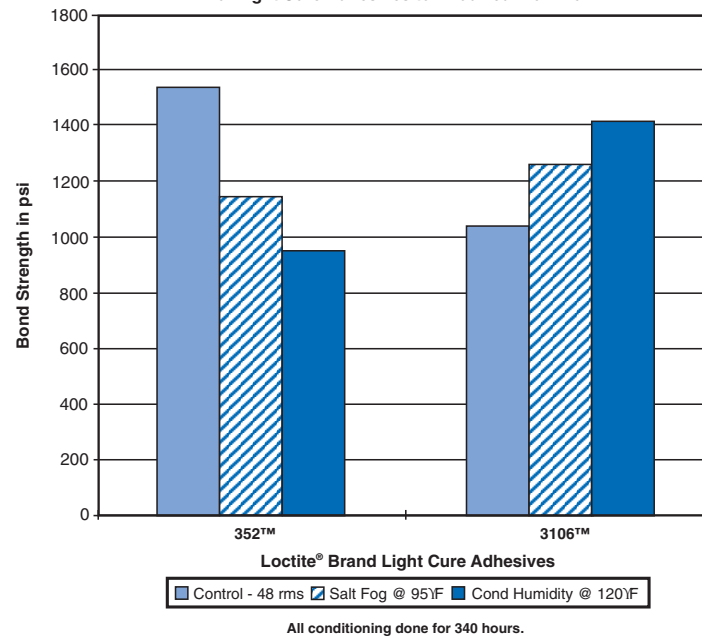
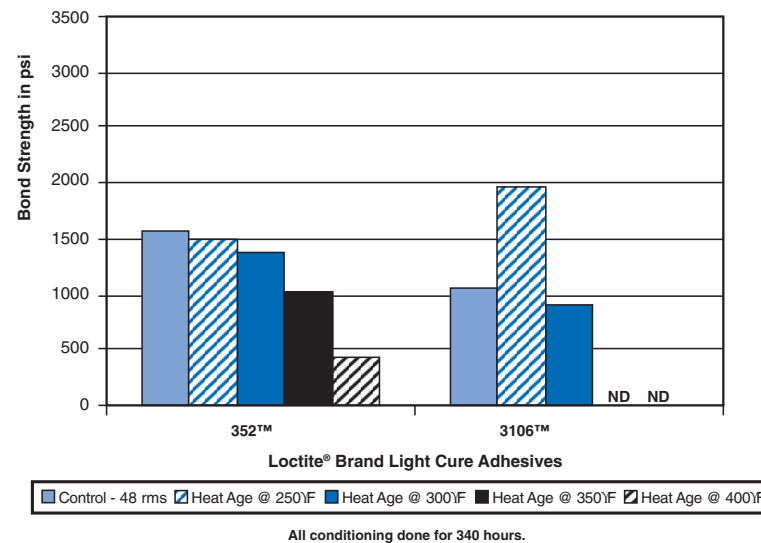


Figure 8.2-8
Effect of Heat Aging on Bond Strength of Light Cure Adhesives to Anodized Aluminum



Section 8.3: Copper

General Description

Copper was one of the first metals utilized by and has become one of the most useful metals known to man. Today there are almost 400 different copper alloys available for manufacturing. Copper and its alloys have become widely used because they offer a variety of desirable properties including excellent thermal conductivity (between silver and gold), electrical conductivity (second only to silver), excellent workability, high ductility, and outstanding corrosion protection. Copper also has good joining and forming capabilities. When high mechanical strength is required, copper alloys are more suitable than pure copper. Copper and its alloys can either be cast or wrought depending on the properties desired and the end use. Cast copper generally has a broader range of alloying elements than wrought because of the nature of the casting process. Table 8.3-1 summarizes the common copper alloys and their UNS designations.

Cast and wrought copper-base alloys are used in building, construction, plumbing and marine applications, chemical industry, consumer and industrial electronics and electricity and data distribution networks (to name a few). Copper is also used as an alloying element in aluminum, nickel, tin, zinc and lead-based alloys as well as in steels and cast irons.

Copper is highly resistant to atmospheric corrosion by industrial, marine and rural atmospheres. It has good corrosion resistance to fresh and salt water as well as non-oxidizing acids (e.g. hydrochloric acid). Its excellent corrosion resistance can be partially attributed to it being a relatively noble metal. The main mechanism for offering corrosion protection in service environments is the formation of thin corrosion products (copper carbonate, copper oxide or copper hydroxide) on the surface of the metal, which act as a barrier to chemical attack. It is these corrosion products that give copper its characteristic green patina.

Summary of Results

The results of the bond strength testing are shown in Tables 8.3-1 and 8.3-2 and in Figures 8.3-1 through 8.3-8. The results are summarized below.

Cyanoacrylates

Salt Fog 95°F (35°C) - Decreased significantly in bond strength.

Condensing Humidity 120°F (49°C) - Decreased significantly in bond strength.

Heat Aging - Decreased significantly in bond strength at all temperatures tested.

Table 8.3-1
Common Grades of Copper

UNS Number	Type	Name	Alloying Metals
C10100-C15999	Wrought	Copper	99.5% Minimum Copper
C16000-C19999	Wrought	High Copper Alloys	Cadmium/Beryllium/Chromium
C21000-C49999	Wrought	Brass	Tin/Lead/Zinc
C50000-C69999	Wrought	Bronze	Tin/Phosphorus/Lead/Silver/Zinc/Aluminum/Silicon
C70000-C73499	Wrought	Copper Nickel	Nickel
C73500-C79999	Wrought	Copper Silver	Nickel/Zinc
C80000-C81399	Cast	Copper	99.70% Minimum Copper
C81400-C83299	Cast	High Copper Alloys	Cadmium/Beryllium/Chromium
C83300-C89999	Cast	Brass	Tin/Zinc/Lead/Manganese/Silicon/Bismuth/ Selenium
C89000-C95999	Cast	Bronze	Tin/Lead/Nickel/Aluminum/Iron
C96000-C96999	Cast	Copper Nickel	Nickel/Iron
C97000-C97999	Cast	Nickel Silver	Nickel/Zinc
C98000-C98999	Cast	Leaded Copper	Lead
C99000-C99999	Cast	Special Alloys	Tin/Lead/Nickel/Iron/Aluminum/Co/Silicon/Manganese/Zinc

Acrylic Adhesives

Salt Fog 95°F (35°C) - Decreased significantly in bond strength.

Condensing Humidity 120°F (49°C) - Decreased significantly in bond strength.

Heat Aging - Loctite® 324™, 326™ and H3410™ Speedbonder™ and 392™ Structural Adhesives and Loctite® 330™ Depend® Adhesive all decreased slightly in bond strength through all temperatures tested. Loctite® H8000™ Speedbonder™ Structural Adhesive showed a significant increase in bond strength at 250°F (121°C), and then significantly dropped off.

Light Cure Adhesives

Salt Fog 95°F (35°C) - Loctite® 352™ Light Cure Adhesive decreased significantly in bond strength, Loctite® 3106™ Light Cure Adhesive showed no significant change.

Condensing Humidity 120°F (49°C) - Loctite® 352™ Light Cure Adhesive decreased significantly in bond strength, Loctite® 3106™ Light Cure Adhesive decreased slightly.

Heat Aging - Loctite® 352™ Light Cure Adhesive improved significantly when conditioned at all temperatures tested up to 350°F (177°C), but then decreased slightly at 400°F (204°C). Loctite® 3106™ Light Cure Adhesive decreased significantly when exposed to 250°F (121°C).

Epoxy Adhesives

Salt Fog 95°F (35°C) - Loctite® E-20HP™ Hysol® Epoxy Adhesive decreased significantly, Loctite® E-20NS™ and E-214HP™ Hysol® Epoxy Adhesives decreased slightly, Loctite® Fixmaster® High Performance Epoxy increased slightly, and Loctite® E-30CL™ Hysol® Epoxy Adhesive increased significantly in bond strength.

Condensing Humidity 120°F (49°C) - Loctite® E-20HP™, E-214HP™ and E-30CL™ Hysol® Epoxy Adhesives decreased significantly in bond strength, Loctite® E-20NS™ Hysol® Epoxy Adhesive decreased slightly, while Loctite® Fixmaster® High Performance Epoxy increased slightly in bond strength.

Heat Aging - Loctite® E- 20HP™, E-20NS™, E-214HP™ and E-30CL™ Hysol® Epoxy Adhesives decreased slightly or significantly at all temperatures tested. Loctite® Fixmaster® High Performance Epoxy increased slightly when conditioned at 250°F (121°C), and decreased significantly in bond strength at all higher temperatures tested.

Polyurethane Adhesives

Salt Fog 95°F (35°C) - Loctite® U-05FL™ Hysol® Urethane Adhesive showed no significant change, while Loctite® 3631™ Hysol® Hot Melt Adhesive and Loctite® Fixmaster® Rapid Rubber Repair decreased slightly in bond strength.

Condensing Humidity 120°F (49°C) - Loctite® U-05FL™ Hysol® Urethane Adhesive showed no significant change, while Loctite® 3631™ Hysol® Hot Melt Adhesive decreased significantly and Loctite® Fixmaster® Rapid Rubber Repair decreased slightly.

Heat Aging - Loctite® U-05FL™ Hysol® Urethane Adhesive showed a significant increase at 250°F (121°C), and then dropped off dramatically. Loctite® 3631™ Hysol® Hot Melt Adhesive showed a significant increase at 250°F (121°C), and no change at 300°F (149°C), and then dropped. Loctite® Fixmaster® Rapid Rubber Repair showed a significant drop through the temperature range.

Silicone Adhesives

Salt Fog 95°F (35°C) - Loctite® 5900® Flange Sealant showed no significant change, while Loctite® 5601™ Adhesive Sealant decreased significantly in bond strength.

Condensing Humidity 120°F (49°C) - Loctite® 5900® Flange Sealant showed no significant change, while Loctite® 5601™ Adhesive Sealant decreased slightly in bond strength.

Heat Aging - Loctite® 5900® Flange Sealant decreased significantly in bond strength at all temperatures tested. Loctite® 5601™ Adhesive Sealant improved significantly at all temperature up to 350°F (177°C), but showed no significant change at 400°F (204°C).

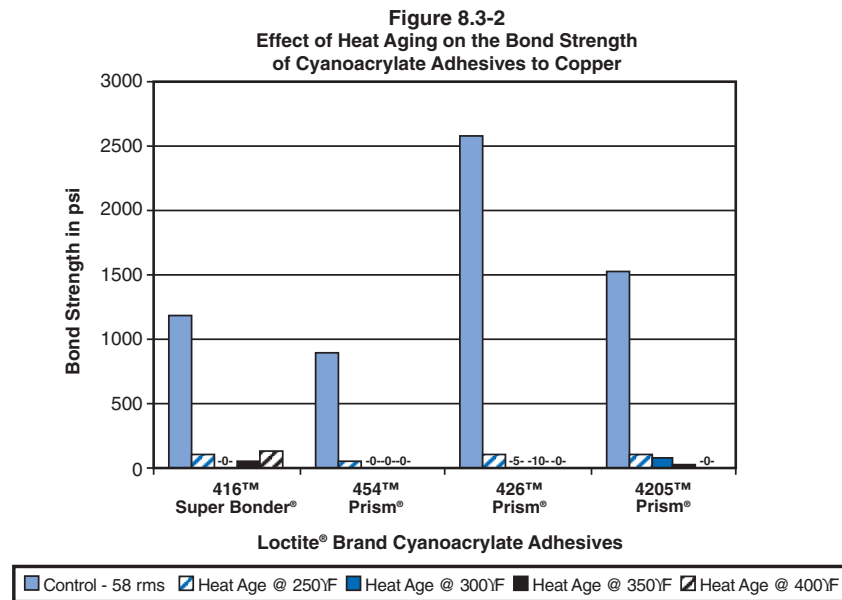
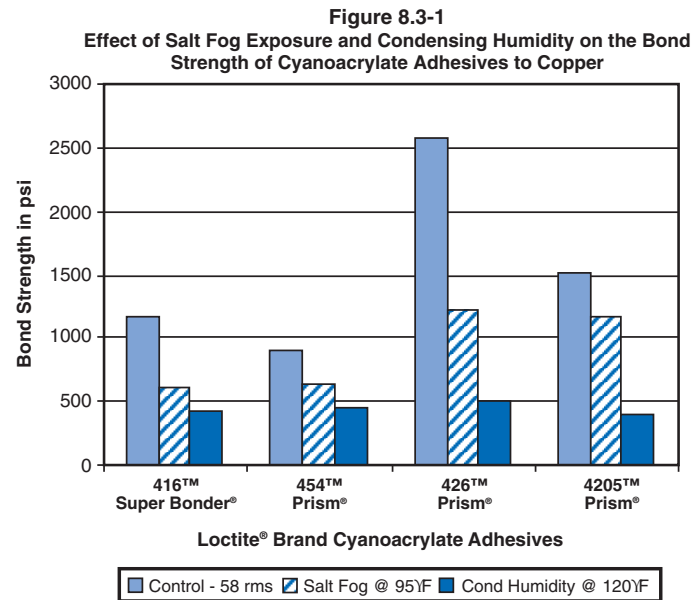
Table 8.3-2
Bond Strength of Several Loctite® Brand Adhesives on Copper (psi)
99.997% Cu: CDA101

Loctite® Brand Medical Device Adhesive	—	4541™ Prism®	—	—	—	—	—	—	—	—	—	—	—	—	—	M-31CL™ Hysol®	M-06FL™ Hysol®	—	U-04FL™ Hysol® (Industrial)	—	—	—	3321™
Loctite® Brand Industrial Adhesive	416™ Super Bonder®	454™ Prism®	426™ Prism®	4205™ Prism®	324™ Speed-Bonder™	326™ Speed-Bonder™	330™ Depend®	334™	392™	H8000™ Speed-Bonder™	H3410™ Speed-Bonder™	E-20HP™ Hysol®	E-20NS™ Hysol®	E-214HP™ Hysol®	Fixmaster® High Perf. Epoxy	E-30CL™ Hysol®	U-05FL™ Hysol®	3631™	Fixmaster® Rapid Rubber Repair (MRO)	5900®	5601™	352™	3106™
Control - 58 rms	1180	895	2585	1520	2300	2250	1795	2480	2220	1265	2140	3470	900	5145	1845	2555	1205	435	705	145	175	1995	525
Salt fog @ 95°F	620	650	1220	1180	985	745	1315	1500	990	375	1700	2100	795	4990	2055	2160	1200	375	590	130	145	950	510
Condensing Humidity @ 120°F	425	455	510	410	735	565	273	1490	630	1160	575	1555	795	3340	1975	1780	1215	265	585	110	195	820	480
Heat Age @ 250°F	105	50	115	95	1430	1795	512	1520	770	2165	860	2235	685	4665	1965	2085	1815	550	630	120	205	915	770
Heat Age @ 300°F	0	0	5	75	1060	885	417	2420	565	2060	625	1625	670	4490	1505	1685	845	435	294	115	240	905	ND
Heat Age @ 350°F	65	0	10	30	375	535	252	2400	5	570	295	580	485	3915	1635	1445	365	205	110	110	225	530	ND
Heat Age @ 400°F	120	0	0	0	185	230	245	420	0	70	155	325	205	1420	1050	685	25	100	45	95	170	270	ND

Table 8.3-3
Normalized
Bond Strength of Several Loctite® Brand Adhesives on Copper
99.997% Cu: CDA101

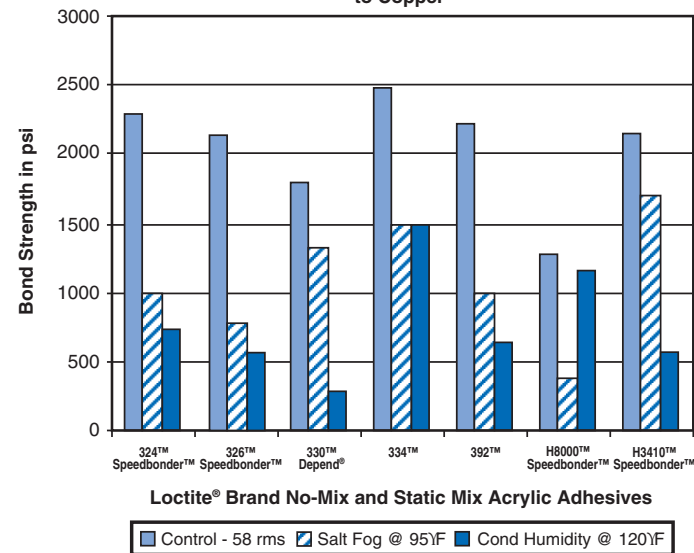
Loctite® Brand Medical Device Adhesive	—	4541™ Prism®	—	—	—	—	—	—	—	—	—	—	—	—	—	M-31CL™ Hysol®	M-06FL™ Hysol®	—	U-04FL™ Hysol® (Industrial)	—	—	—	3321™
Loctite® Brand Industrial Adhesive	416™ Super Bonder®	454™ Prism®	426™ Prism®	4205™ Prism®	324™ Speed-Bonder™	326™ Speed-Bonder™	330™ Depend®	334™	392™	H8000™ Speed-Bonder™	H3410™ Speed-Bonder™	E-20HP™ Hysol®	E-20NS™ Hysol®	E-214HP™ Hysol®	Fixmaster® High Perf. Epoxy	E-30CL™ Hysol®	U-05FL™ Hysol®	3631™	Fixmaster® Rapid Rubber Repair (MRO)	5900®	5601™	352™	3106™
Control - 58 rms	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Salt fog @ 95°F	53	73	47	78	43	33	73	60	45	30	79	61	88	97	111	85	100	86	84	90	83	48	97
Condensing Humidity @ 120°F	36	51	20	27	32	25	15	60	28	92	27	45	88	65	107	70	101	61	83	76	111	41	91
Heat Age @ 250°F	9	6	4	6	62	80	29	61	35	163	40	64	76	91	107	82	151	126	89	83	117	46	147
Heat Age @ 300°F	0	0	0	5	46	39	23	98	25	45	29	47	74	87	89	66	70	100	42	79	137	45	ND
Heat Age @ 350°F	6	0	0	2	16	24	14	97	0	6	14	17	54	76	57	57	30	47	16	76	129	27	ND
Heat Age @ 400°F	10	0	0	0	8	10	14	17	0	6	7	9	23	28	57	27	2	23	6	66	97	14	ND

Note: Loctite® 324™ Speedbonder™ and Loctite® 352™ Structural Adhesive were cured with Loctite® 7075™ Activator.
Loctite® 326™ Speedbonder™ was cured with Loctite® 7649™ Primer N™.
Loctite® 330™ Depend® Adhesive, Loctite® 334™ Speedbonder™ Structural Adhesive, and Loctite® 392™ Structural Adhesive were cured with Loctite® 7387™ Depend® Activator.
Loctite® 3106™ Light Cure Adhesive was tested bonded to polycarbonate and could not be conditioned above 300°F.
All environmental conditioning done for 340 hours, samples allowed to equilibrate at ambient conditions for at least 24 hours prior to testing.
ND = Not determined. Polycarbonate lapshear melted at temperature.



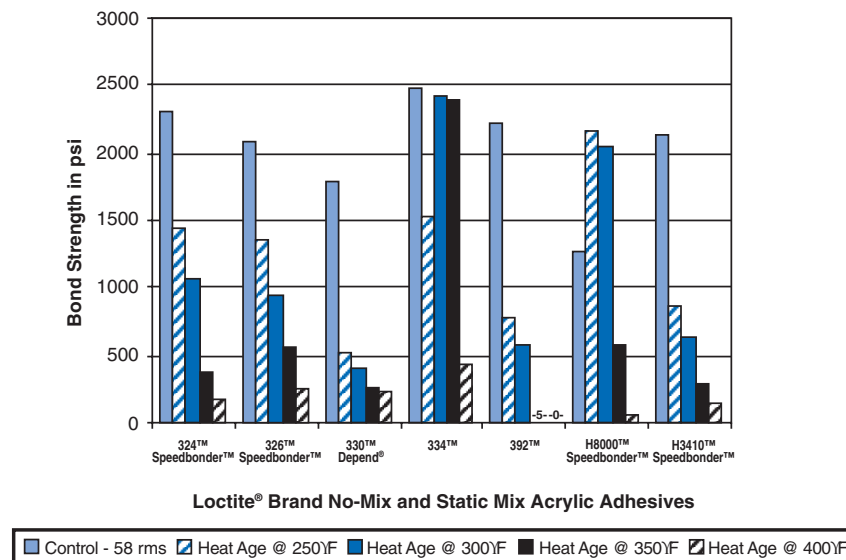
All conditioning done for 340 hours.

Figure 8.3-3
Effect of Salt Fog Exposure and Condensing Humidity on the Bond Strength of No-Mix and Static Mix Acrylic Adhesives to Copper



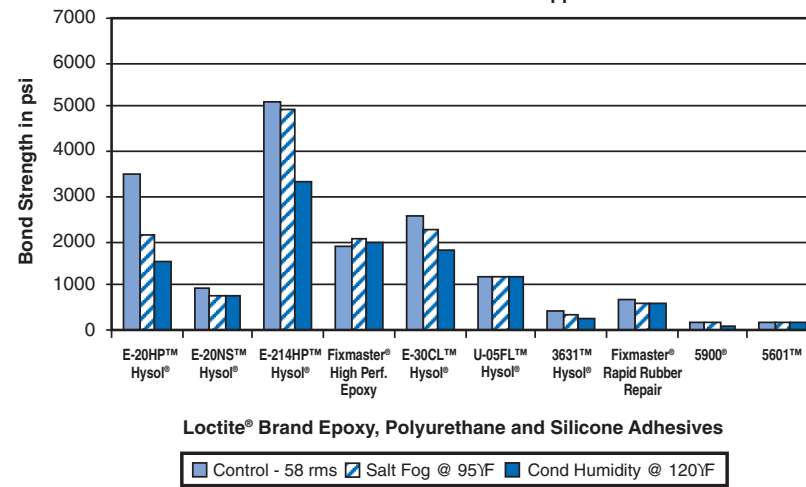
All conditioning done for 340 hours.

Figure 8.3-4
Effect of Heat Aging on the Bond Strength of No-Mix and Static Mix Acrylic Adhesives to Copper



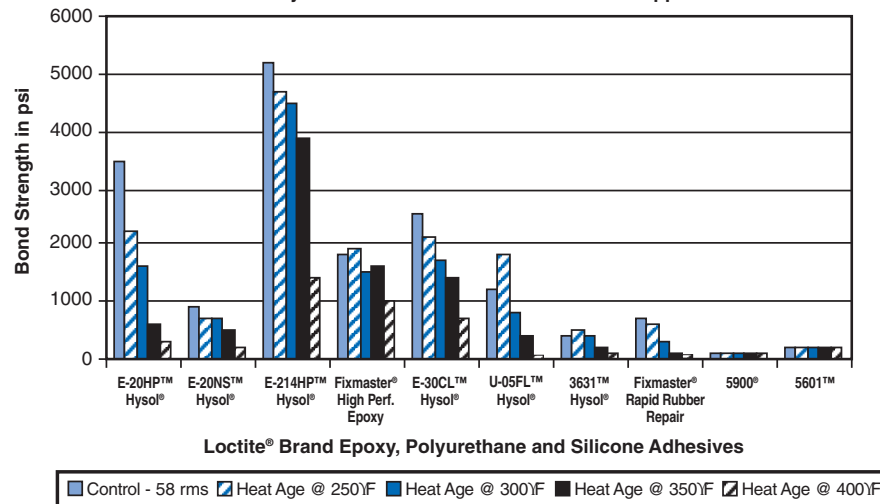
All conditioning done for 340 hours.

Figure 8.3-5
Effect of Salt Fog Exposure and Condensing Humidity
on the Bond Strength of Epoxy, Polyurethane and
Silicone Adhesives to Copper



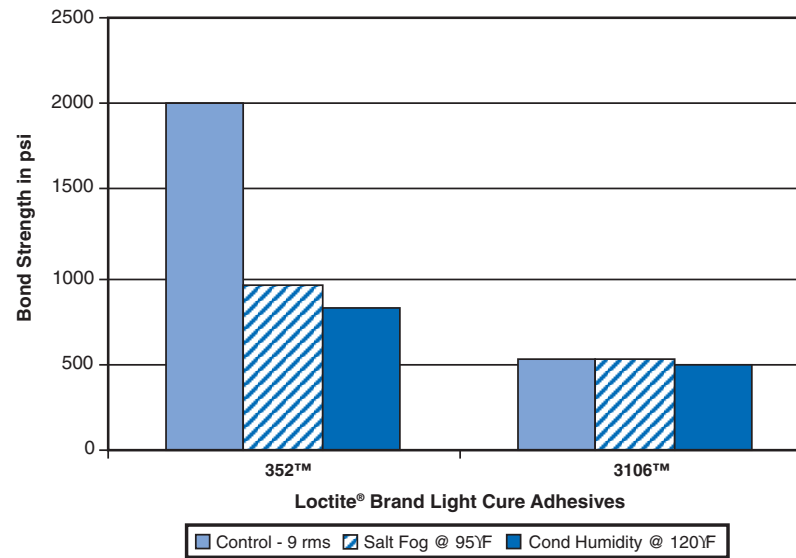
All conditioning done for 340 hours.

Figure 8.3-6
Effect of Heat Aging on Bond Strength of Epoxy,
Polyurethane and Silicone Adhesives to Copper



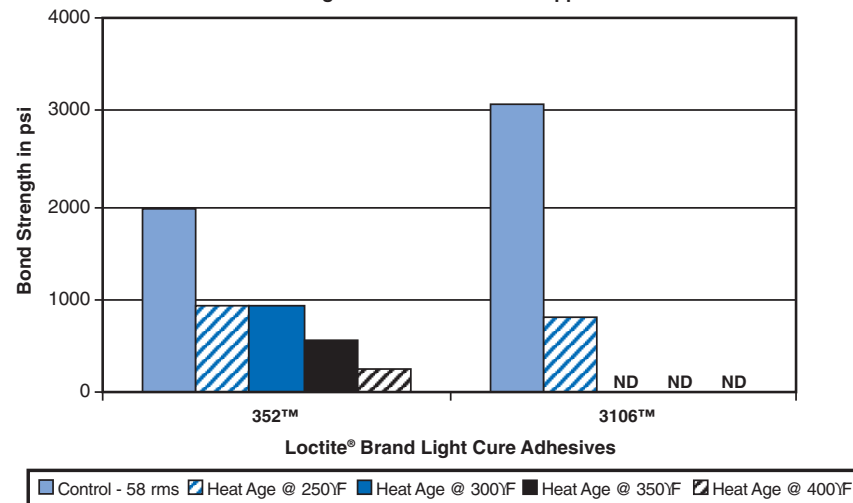
All conditioning done for 340 hours.

Figure 8.3-7
Effect of Salt Fog Exposure and Condensing Humidity on the
Bond Strength of Light Cure Adhesives to Copper



All conditioning done for 340 hours.

Figure 8.3-8
Effect of Heat Aging on Bond Strength of
Light Cure Adhesives to Copper



All conditioning done for 340 hours.

Section 8.4: Nickel

General Description

Elemental nickel is a lustrous, silvery-white metal with relatively low thermal and electrical conductivity, high resistance to corrosion and oxidation, excellent strength and toughness at elevated temperatures, and is capable of being magnetized. It is attractive and very durable as a pure metal, and alloys readily with many other metals.

Nickel products are classified by the amount of nickel they contain. Class I products contain almost 100 percent nickel, whereas Class II products vary widely in their nickel content. The primary use of nickel is in making alloys, the most important of which is as one alloying metal in stainless and heat resistant steels. Other uses include electroplating, foundries, catalysts, batteries, welding rods, and the manufacture of coins. The list of end-use applications for nickel is, for all practical purposes, limitless. Nickel can be found in products for transportation/aerospace, electronic equipment, military, marine, chemicals, construction materials, petroleum products, and consumer goods.

Electroplating

Electrodeless plating (also known as autocatalytic plating) is a process that involves metal deposition without any applied current. The process is an autocatalytic chemical reaction and is typically used to deposit a metal (usually nickel or copper). The metal deposition rate is on the order of 0.0003-0.0008 inch/hour and formation of coatings several mils thick are possible provided the plating solutions are replenished. The plating solution for electrodeless nickel deposition consists of a nickel salt (e.g. nickel chloride) and reducing agent (e.g. sodium hypophosphite) and an organic acid which serves a dual purpose as a buffer and chelating agent. Without the organic acid it is difficult to control the nickel ion concentration and to prevent the deposition of nickel phosphite. As a result of the plating process, electrodeless nickel always contains 6-10% phosphorus. The higher the phosphorus content, the “brighter” the coating.

Displacement Plating

Displacement plating can only take place as long as the surface of the steel article to be plated is exposed to the plating solution. Because of this limitation, coating thickness is usually less than 1.25 microns (0.00005"). The displacement plating procedure consists of immersing the iron article to be coated in a bath of nickel sulfate or nickel chloride (acidic pH) at a temperature of 70°C. The

iron has a higher solution potential than the nickel and is displaced by the nickel with the iron passing into the solution. Immersion times of 5 minutes are common and constant filtration of the nickel bath is necessary in order to remove the iron sludge. A final neutralization rinse is needed in order to complete the process.

Summary of Results

The results of the bond strength testing are shown in Tables 8.4-1 and 8.4-2 and in Figures 8.4-1 through 8.4-8. The results are summarized below.

Cyanoacrylates

Salt Fog 95°F (35°C) - Decreased significantly in bond strength.

Condensing Humidity 120°F (49°C) - Decreased significantly in bond strength.

Heat Aging - Decreased significantly in bond strength at all temperatures tested.

No-Mix and Static Mix Acrylic Adhesives

Salt Fog 95°F (35°C) - Decreased significantly in bond strength.

Condensing Humidity 120°F (49°C) - Decreased significantly in bond strength.

Heat Aging - Loctite® 324™, 326™ and H3410™ Speedbonder™ and 392™ Structural Adhesives and Loctite® 330™ Depend® Adhesive decreased significantly in bond strength at all temperatures tested. Loctite® H8000™ Speedbonder™ Structural Adhesive decreased slightly when conditioned at 250°F (121°C), and decreased significantly at all higher temperatures. Loctite® 334™ Structural Adhesive increased significantly at all temperatures up to 350°F (177°C), and decreased significantly in bond strength when conditioned at 400°F (204°C).

Light Cure Adhesives

Salt Fog 95°F (35°C) - Loctite® 352™ Light Cure Adhesive decreased significantly in bond strength, while Loctite® 3106™ Light Cure Adhesive decreased slightly.

Condensing Humidity 120°F (49°C) - Loctite® 352™ Light Cure Adhesive decreased significantly in bond strength, while Loctite® 3106™ Light Cure Adhesive decreased slightly.

Heat Aging - Loctite® 352™ Light Cure Adhesive increased significantly in bond strength when conditioned at all temperatures up to 350°F (177°C). Loctite® 3106™ Light Cure Adhesive decreased significantly when treated at 250°F (121°C).

Epoxy Adhesives

Salt Fog 95°F (35°C) - Loctite® E-20HP™, E-214HP™ and E-30FL™ Hysol® Epoxy Adhesives decreased significantly in bond strength. Loctite® E-20NS™ Hysol® Epoxy Adhesive and Loctite® Fixmaster® High Performance Epoxy increased slightly in bond strength.

Condensing Humidity 120°F (49°C) - Decreased significantly in bond strength.

Heat Aging - Decreased significantly in bond strength at all temperatures tested.

Polyurethane Adhesives

Salt Fog 95°F (35°C) - Loctite® U-05FL™ Hysol® Urethane Adhesive and Loctite® Fixmaster® Rapid Rubber Repair decreased significantly in bond strength, while Loctite® 3631™ Hysol® Hot Melt Adhesive increased slightly.

Condensing Humidity 120°F (49°C) - Decreased significantly in bond strength.

Heat Aging - Loctite® U-05FL™ Hysol® Urethane Adhesive and Loctite® Fixmaster® Rapid Rubber Repair increased slightly when conditioned at 250°F (121°C), while Loctite® 3631™ Hysol® Hot Melt Adhesive increased significantly. Loctite® U-05FL™ Hysol® Urethane Adhesive decreased slightly when exposed to 300°F (149°C), while Loctite® Fixmaster® Rapid Rubber Repair decreased significantly and Loctite® 3631™ Hysol® Hot Melt Adhesive increased significantly in bond strength at the same temperature. All epoxies decreased significantly at each of the higher temperatures tested.

Silicone Adhesives

Salt Fog 95°F (35°C) - Loctite® 5900® Flange Sealant showed no significant change, while Loctite® 5601™ Adhesive Sealant decreased slightly in bond strength.

Condensing Humidity 120°F (49°C) - Loctite® 5900® Flange Sealant decrease significantly in bond strength, while Loctite® 5601™ Adhesive Sealant decreased slightly.

Heat Aging - Loctite® 5900® Flange Sealant increased significantly when conditioned at temperatures up to 300°F (149°C), increased slightly at 350°F (177°C), and decreased significantly in bond strength at 400°F (204°C). Loctite® 5601™ Adhesive Sealant increased significantly in bond strength at temperatures up to 350°F (177°C), while increasing slightly when conditioned at 400°F (204°C).

Table 8.4-1
Bond Strength of Several Loctite® Brand Adhesives on Nickel Plated Steel (psi)
 Electodeless Ni Plate: 0.0005-.001" Thick

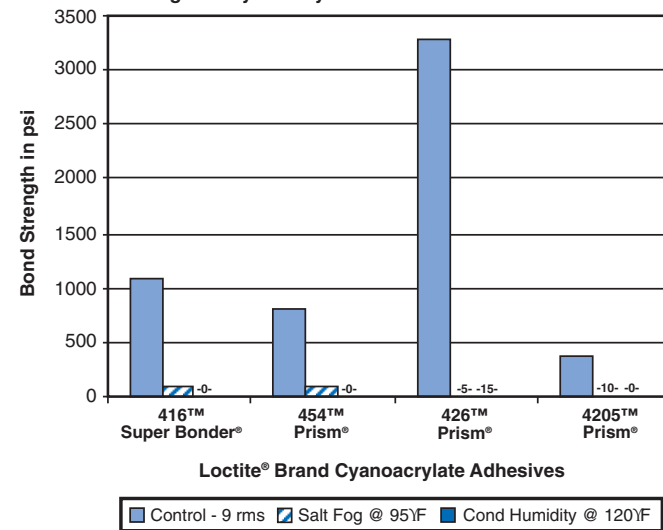
Loctite® Brand Medical Device Adhesive	—	4541™ Prism®	—	—	—	—	—	—	—	—	—	—	—	—	—	M-31CL™ Hysol®	M-06FL™ Hysol®	—	U-04FL™ Hysol® (Industrial)	—	—	—	3321™
Loctite® Brand Industrial Adhesive	416™ Super Bonder®	454™ Prism®	426™ Prism®	4205™ Prism®	324™ Speed-Bonder™	326™ Speed-Bonder™	330™ Depend®	334™	392™	H8000™ Speed-Bonder™	H3410™ Speed-Bonder™	E-20HP™ Hysol®	E-20NS™ Hysol®	E-214HP™ Hysol®	Fixmaster® High Perf. Epoxy	E-30CL™ Hysol®	U-05FL™ Hysol®	3631™	Fixmaster® Rapid Rubber Repair (MRO)	5900®	5601™	352™	3106™
Control - 9 rms	1095	805	3280	360	2375	1262	2875	2310	3110	3595	3440	2605	1380	4060	2525	1490	1410	400	695	125	170	1815	475
Salt fog @ 95°F	90	90	5	10	1190	215	1370	620	1015	2475	1975	965	1510	285	2605	1055	800	440	55	115	110	845	365
Condensing Humidity @ 120°F	0	5	15	0	270	160	660	385	0	2605	0	0	920	21	1200	920	990	125	300	90	130	685	390
Heat Age @ 250°F	95	70	55	25	595	380	1745	3490	455	3355	1160	1335	500	3255	740	1090	1500	770	750	170	260	1030	390
Heat Age @ 300°F	70	0	0	0	385	560	975	3380	345	470	820	655	235	2990	210	590	1250	845	155	170	270	1075	ND
Heat Age @ 350°F	25	0	0	0	290	150	475	2770	155	585	275	345	125	2740	125	755	350	325	220	155	275	835	ND
Heat Age @ 400°F	85	0	0	0	0	0	225	1225	10	490	0	205	5	2010	90	645	60	120	255	100	205	0	ND

Table 8.4-2
Normalized
Bond Strength of Several Loctite® Brand Adhesives on Nickel Plated Steel
 Electodeless Ni Plate: 0.0002-.0005" Thick

Loctite® Brand Medical Device Adhesive	—	4541™ Prism®	—	—	—	—	—	—	—	—	—	—	—	—	—	M-31CL™ Hysol®	M-06FL™ Hysol®	—	U-04FL™ Hysol® (Industrial)	—	—	—	3321™
Loctite® Brand Industrial Adhesive	416™ Super Bonder®	454™ Prism®	426™ Prism®	4205™ Prism®	324™ Speed-Bonder™	326™ Speed-Bonder™	330™ Depend®	334™	392™	H8000™ Speed-Bonder™	H3410™ Speed-Bonder™	E-20HP™ Hysol®	E-20NS™ Hysol®	E-214HP™ Hysol®	Fixmaster® High Perf. Epoxy	E-30CL™ Hysol®	U-05FL™ Hysol®	3631™	Fixmaster® Rapid Rubber Repair (MRO)	5900®	5601™	352™	3106™
Control - 9 rms	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Salt fog @ 95°F	8	11	0	3	50	17	48	27	33	69	57	37	109	7	103	71	57	110	8	92	65	47	77
Condensing Humidity @ 120°F	0	1	0	0	11	13	23	17	0	72	0	0	67	1	48	62	70	31	43	72	76	38	82
Heat Age @ 250°F	9	9	2	7	25	30	61	151	15	13	34	51	36	80	29	73	106	193	108	136	153	57	82
Heat Age @ 300°F	6	0	0	0	16	44	34	146	11	16	24	25	17	74	8	40	89	211	22	136	159	59	ND
Heat Age @ 350°F	2	0	0	0	12	12	17	120	5	14	8	13	9	67	5	51	25	81	32	124	162	46	ND
Heat Age @ 400°F	8	0	0	0	0	0	8	53	0	14	0	8	0	50	4	43	4	30	37	80	121	0	ND

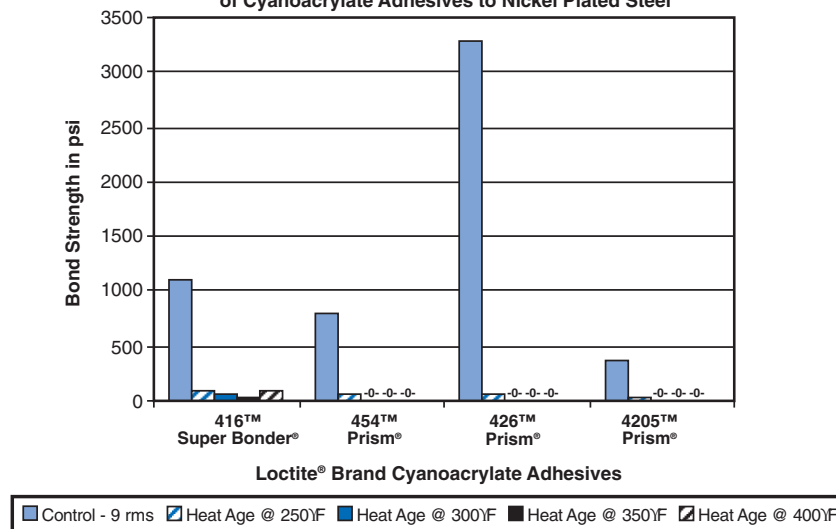
Note: Loctite® 324™ Speedbonder™ and Loctite® 352™ Structural Adhesive were cured with Loctite® 7075™ Activator.
 Loctite® 326™ Speedbonder™ was cured with Loctite® 7649™ Primer N™.
 Loctite® 330™ Depend® Adhesive, Loctite® 334™ Speedbonder™ Structural Adhesive, and Loctite® 392™ Structural Adhesive were cured with Loctite® 7387™ Depend® Activator.
 Loctite® 3106™ Light Cure Adhesive was tested bonded to polycarbonate and could not be conditioned above 300°F.
 All environmental conditioning done for 340 hours, samples allowed to equilibrate at ambient conditions for at least 24 hours prior to testing.
 ND = Not determined. Polycarbonate lapshear melted at temperature.

Figure 8.4-1
Effect of Salt Fog Exposure and Condensing Humidity on the Bond Strength of Cyanoacrylate Adhesives to Nickel Plated Steel



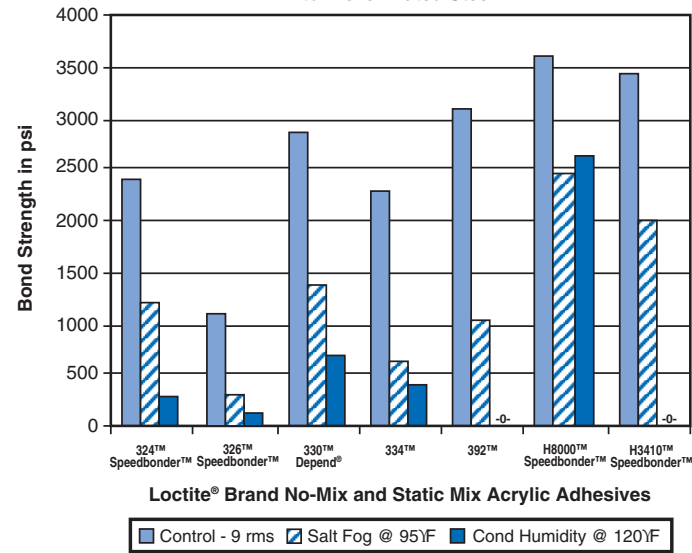
All conditioning done for 340 hours.

Figure 8.4-2
Effect of Heat Aging on the Bond Strength of Cyanoacrylate Adhesives to Nickel Plated Steel



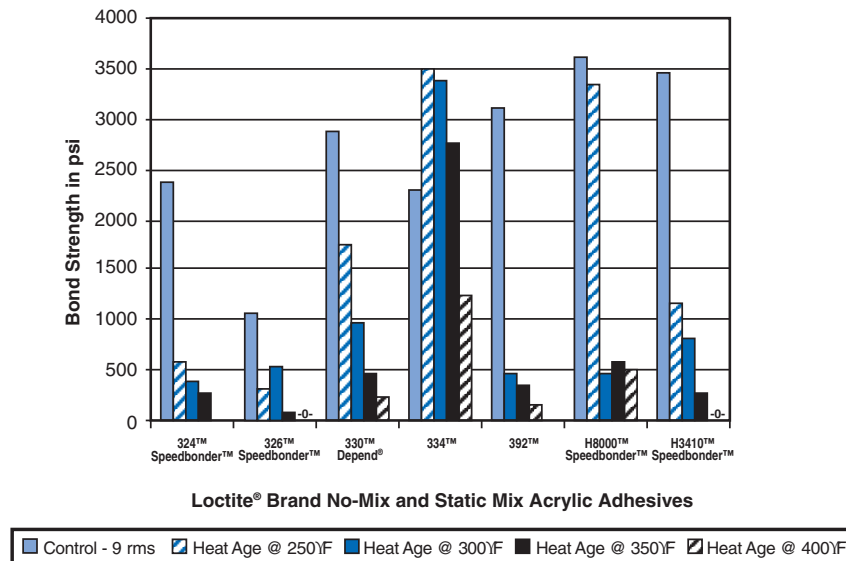
All conditioning done for 340 hours.

Figure 8.4-3
Effect of Salt Fog Exposure and Condensing Humidity on the Bond Strength of No-Mix and Static Mix Acrylic Adhesives to Nickel Plated Steel



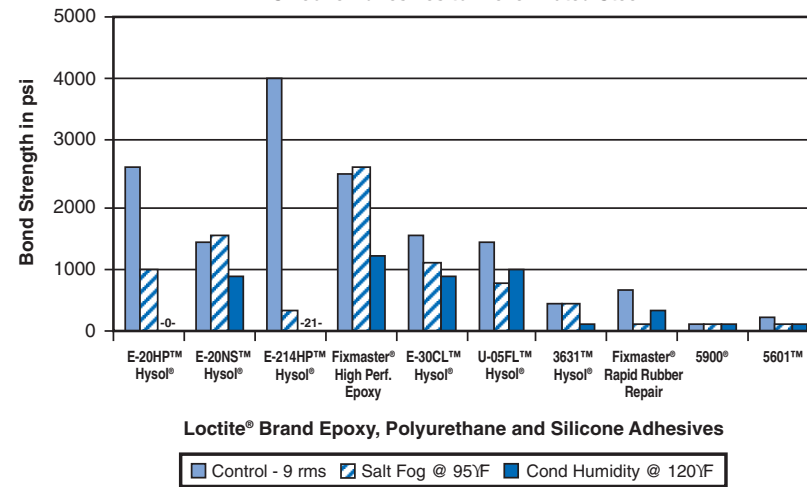
All conditioning done for 340 hours.

Figure 8.4-4
Effect of Heat Aging on the Bond Strength of No-Mix and Static Mix Acrylic Adhesives to Nickel Plated Steel



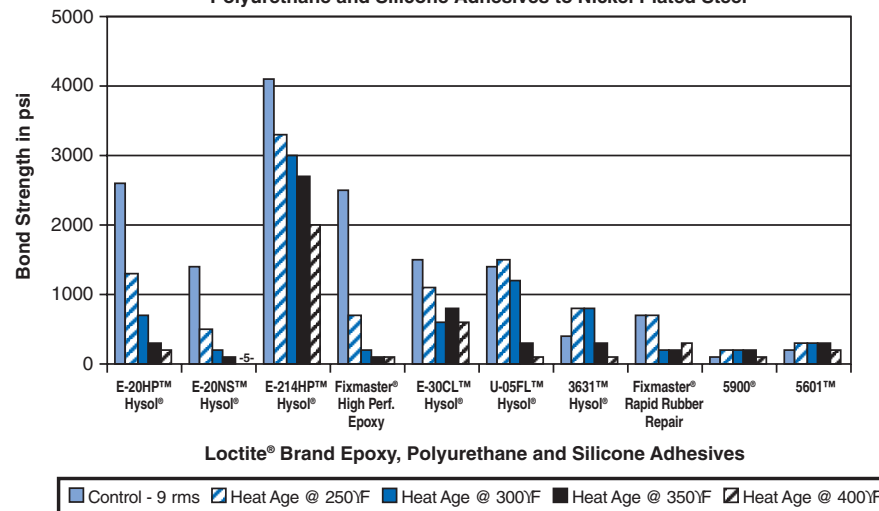
All conditioning done for 340 hours.

Figure 8.4-5
Effect of Salt Fog Exposure and Condensing Humidity
on the Bond Strength of Epoxy, Polyurethane and
Silicone Adhesives to Nickel Plated Steel



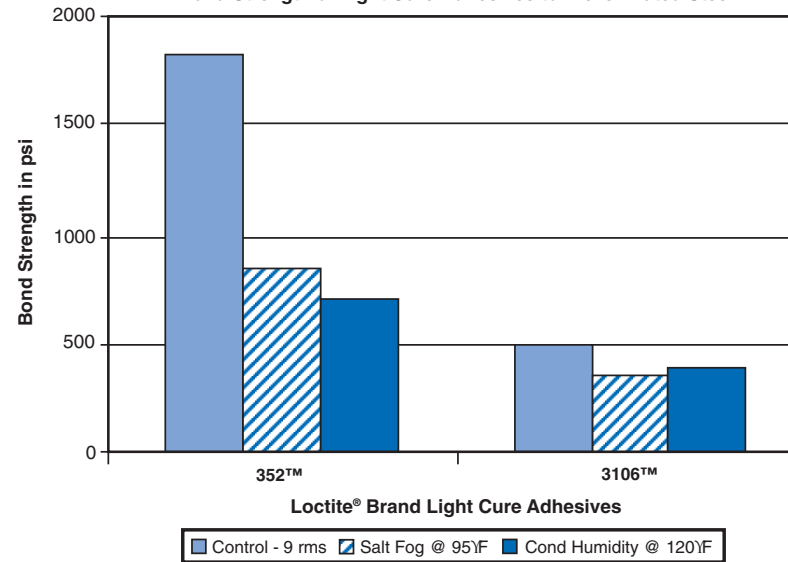
All conditioning done for 340 hours.

Figure 8.4-6
Effect of Heat Aging on Bond Strength of Epoxy,
Polyurethane and Silicone Adhesives to Nickel Plated Steel



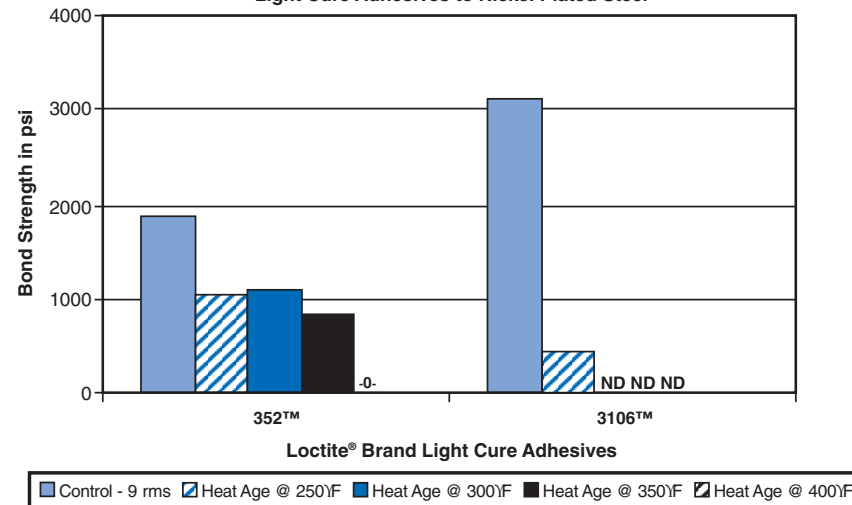
All conditioning done for 340 hours.

Figure 8.4-7
Effect of Salt Fog Exposure and Condensing Humidity on the
Bond Strength of Light Cure Adhesives to Nickel Plated Steel



All conditioning done for 340 hours.

Figure 8.4-8
Effect of Heat Aging on Bond Strength of
Light Cure Adhesives to Nickel Plated Steel



All conditioning done for 340 hours.

Section 8.5: Stainless Steel

General Description

The factors that have the largest effect on the mechanical properties of stainless steel are its chemical composition and its crystalline microstructure. Stainless steel is an alloy of iron and chromium that has at least 10.5% chromium, and may contain other alloying elements as well. Some of the other alloying elements that are commonly used include manganese, silicon and nickel. Carbon and nitrogen may also be present, however, unlike the metallic alloying elements which replace an iron atom in the metallic crystalline structure, carbon and nitrogen occupy the interstitial spaces between the metallic atoms. Stainless steels can generally be grouped into five main categories, based on how they respond to heat treatment:

Austenitic - These alloys typically have a low carbon content and a chromium content of at least 16% which allows them to maintain an austenitic structure from cryogenic temperatures up to the melting point of the steel. Nickel content ranges from 3.5 to 22% and maximum manganese content can be as high as 10%, though it is usually 2%. These alloys cannot be hardened through heat treatment. The key benefits these types of stainless steel offer are excellent corrosion resistance and toughness.

Ferritic - Chromium content of these alloys can range from 10.5 to 27%. While some new ferritic grades of stainless steel contain nickel and/or molybdenum, generally, only chromium and silicon are present as metallic alloying elements. Like the austenitic alloys, they cannot be hardened through heat treating. Ferritic stainless steel alloys are magnetic and chosen when toughness is not a primary need but corrosion resistance, particularly to chloride stress corrosion cracking, is important.

Martensitic - These magnetic alloys have a chromium content that ranges from 11.5 to 18%. Nickel is rarely used, and when it is, it is used at concentrations from 1.25 to 2.50%. Sulfur, selenium and molybdenum can also be used. These alloys can be hardened through heat treatment to offer good strength and toughness, making them well suited for uses where machinability is required. While these alloys offer the benefit of heat treatability, they have lower corrosion resistance than the austenitic and ferritic alloys and are consequently limited to applications with low corrosion resistance requirements.

Precipitation-Hardened - High strength, middling corrosion resistance and ease of fabrication are the primary benefits offered by this class of stainless steel alloys. These alloys develop very high strength after exposure to low temperature heat treatment. Since lower temperatures can be used, concerns with part distortion are minimized, allowing them to be used for high precision parts. Precipitation-hardened stainless steels have an initial microstructure of austenite or martensite. Austenitic alloys are converted to martensitic alloys through heat treatment before precipitation hardening can be done. Precipitation hardening results when the heat aging treatment causes hard intermetallic compounds to precipitate from the crystal lattice as the martensite is tempered. The high chromium content of these grades give them superior corrosion resistance.

Duplex - These alloys have a mixed structure of ferrite and austenite and offer physical properties which reflect this mixture. These alloys are magnetic, and offer higher tensile and yield strengths than austenitic stainless steels. Their toughness and corrosion resistance is middling between the properties of the two types. While this combination of structure types does not offer many synergistic improvements in performance, in some applications, the balance of properties offered by this family make it the best choice.

Table 8.5-1
Common Grades of Stainless Steel

AISI Series	General Characteristics of this Series
2XX	Austenitic alloys in which some of the nickel has been replaced by manganese and nitrogen.
3XX	Nickel stabilized austenitic alloys.
4XX	Ferritic and martensitic classes which are nickel free or contain at most 2.5% nickel.

Summary of Results

The results of the bond strength testing are shown in Tables 8.5-2 and 8.5-3 and in Figures 8.5-1 through 8.5-12. The results are summarized below.

Cyanoacrylates

Surface Roughening - With the exception of Loctite® 454™ Prism® Instant Adhesive, bond strength improved in all cases.

Salt Fog 95°F (35°C) - With the exception of Loctite® 426™ Prism® Instant Adhesive, which was essentially unchanged, decrease in all cases.

Condensing Humidity 120°F (49°C) - With the exception of Loctite® 4205™ Prism® Instant Adhesive, which increased, bond strength decreased in all cases, although the decrease for Loctite® 426™ Prism® Instant Adhesive was much less than that of the non-rubber-filled cyanoacrylates.

Heat Aging - Loctite® 4205™ Prism® Instant Adhesive maintained strength after 340 hours at temperatures as high as 300°F (149°C). All other cyanoacrylates dropped off after 340 hours at temperatures as low as 250°F (121°C). The ability of Loctite® 416™ Super Bonder® Instant Adhesive to maintain bond strength after exposure to temperatures as high as 350°F (177°C) and 400°F (204°C) is surprising since cyanoacrylates revert to cyanoacrylate monomer at temperatures above 320°F (160°C). The bond strength is likely due to the presence of the polymethylmethacrylate filler used in Loctite® 416™ Super Bonder® Instant Adhesive.

No-Mix and Static Mix Acrylic Adhesives

Surface Roughening - Significant improvement for Loctite® 324™, 326™, H8000™ and H3410™ Speedbonder™ Structural Adhesives and Loctite® 330™ Depend Adhesive. Slight improvement for Loctite® 334™ Structural Adhesive and no improvement for Loctite® 392™ Structural Adhesive.

Salt Fog 95°F (35°C) - Loctite® 324™ and 326™ Speedbonder™ Structural Adhesives and Loctite® 330™ Depend® Adhesive increased significantly in bond strength, while Loctite® 334™ and 392™ Structural Adhesives and Loctite® H8000™ Speedbonder™ Structural Adhesive decreased in bond strength, with Loctite® H8000™ Speedbonder™ Structural Adhesive showing the most drastic decline in bond strength.

Condensing Humidity 120°F (49°C) - Loctite® 330™ Depend® Adhesive increased significantly in strength, while all others showed a slight (Loctite® 324™, and 326™ Speedbonder™ and 334™ Structural Adhesives) or significant (Loctite® H8000™ Speedbonder™ and 392™ Structural Adhesives) decline.

Heat Aging - Loctite® 324™ and H8000™ Speedbonder™ Structural Adhesives and Loctite® 330™ Depend® Adhesive increased significantly after exposure at temperatures up to 300°F (149°C), showed a slight decrease at 350°F (177°C), and a significant decline after 340 hours at 400°F (204°C). Loctite® 334™ Structural Adhesive increased significantly after 340 hours exposure to 300°F (149°C) and 350°F (177°C), but showed a significant decline after exposure to 400°F (204°C). Loctite® 326™ Speedbonder™ Structural Adhesive increased slightly after exposure to 250°F (121°C) but dropped significantly at higher temperatures. Loctite® H3410™ Speedbonder™ and 392™ Structural Adhesives declined significantly at all temperatures.

Light Cure Adhesives

Surface Roughening - Significant improvement for Loctite® 352™ Light Cure Adhesive, slight improvement for Loctite® 3106™ Light Cure Adhesive.

Salt Fog 95°F (35°C) - Significant decrease for Loctite® 352™ Light Cure Adhesive, slight decrease for Loctite® 3106™ Light Cure Adhesive.

Condensing Humidity 120°F (49°C) - Loctite® 352™ Light Cure Adhesive decreased while Loctite® 3106™ Light Cure Adhesive showed no change.

Heat Aging - Loctite® 3106™ Light Cure Adhesive decreased significantly at 250°F (121°C) while Loctite® 352™ Light Cure Adhesive showed a slight increase at this temperature before declining significantly at higher temperatures.

Epoxy Adhesives

Surface Roughening - Loctite® E-20HP™, E-20NS™, and E-30CL™ Hysol® Epoxy Adhesives and Loctite® Fixmaster® High Performance Epoxy all increased significantly while the bond strength of Loctite® E-214HP™ Hysol® Epoxy Adhesive was not affected.

Salt Fog 95°F (35°C) - Loctite® E-20HP™ and E-30CL™ Hysol® Epoxy Adhesives were unaffected while Loctite® E-20NS™ and E-214HP™ Hysol® Epoxy Adhesives and Fixmaster® High Performance Epoxy decreased significantly.

Condensing Humidity 120°F (49°C) - Loctite® E-20HP™ Hysol® Epoxy Adhesive was unaffected while Loctite® E-20NS™, E-214HP™ and E-30CL™ Hysol® Epoxy Adhesives decreased significantly; Loctite® Fixmaster® High Performance Epoxy decreased slightly.

Heat Aging - Loctite® E-20HP™ and E-30CL™ Hysol® Epoxy Adhesives improved significantly in bond strength at temperatures as high as 350°F (177°C) but declined significantly at 400°F (204°C). Loctite® E-20NS™ Hysol® Epoxy Adhesive improved significantly in bond strength at temperatures as high as 300°F (149°C) but declined significantly at 350°F (177°C) and above. Loctite® E-214HP™ Hysol® Epoxy Adhesive showed no significant change at 300°F (149°C) and 350°F (177°C), but declined significantly at 400°F (204°C). Loctite® Fixmaster® High Performance Epoxy improved significantly in bond strength at 250°F (121°C) and decreased at all higher temperatures tested.

Polyurethane Adhesives

Surface Roughening - Significant improvement for Loctite® U-05FL™ Hysol® Urethane Adhesive and Loctite® Fixmaster® Rapid Rubber Repair. Significant decrease for Loctite® 3631™ Hysol® Hot Melt Adhesive.

Salt Fog 95°F (35°C) - Significant improvement for Loctite® U-05FL™ Hysol® Urethane Adhesive. Slight and significant decreases for Loctite® 3631™ Hysol® Hot Melt Adhesive and Loctite® Fixmaster® Rapid Rubber Repair respectively.

Condensing Humidity 120°F (49°C) - Significant improvement for Loctite® U-05FL™ Hysol® Urethane Adhesive. Significant decrease for Loctite® 3631™ Hysol® Hot Melt Adhesive and Loctite® Fixmaster® Rapid Rubber Repair.

Heat Aging - Compared to the room temperature bond strength, the bond strength improved significantly for Loctite® U-05FL™ Hysol® Urethane Adhesive

and Loctite® 3631™ Hysol® Hot Melt Adhesive after conditioning at 250°F (121°C) and 300°F (149°C), however, decreased significantly after exposure to 350°F (177°C) and 400°F (204°C) for 340 hours. Loctite® Fixmaster® Rapid Rubber Repair showed a significant decrease in bond strength at all tested temperatures.

Silicone Adhesives

Surface Roughening - Slight improvement for Loctite® 5900® Flange Sealant. Significant decrease for Loctite® 5601™ Adhesive Sealant.

Salt Fog 95°F (35°C) - Significant improvement for Loctite® 5900® Flange Sealant, significant decrease for Loctite® 5601™ Adhesive Sealant.

Condensing Humidity 120°F (49°C) - No significant change for Loctite® 5900® Flange Sealant, significant decrease for Loctite® 5601™ Adhesive Sealant.

Heat Aging - At 250°F (121°C), the bond strength for both adhesives improved significantly while at 400°F (204°C) the bond strength showed no significant change from the room temperature control values. At 300°F (149°C) and 350°F (177°C), the bond strength showed a significant decrease.

Table 8.5-2
Bond Strength of Several Loctite® Brand Adhesives on Stainless Steel (psi)
Type 304 Stainless Steel

Loctite® Brand Medical Device Adhesive	—	4541™ Prism®	—	—	—	—	—	—	—	—	—	—	—	—	—	M-31CL™ Hysol®	M-06FL™ Hysol®	—	U-04FL™ Hysol® (Industrial)	—	—	—	3321™
Loctite® Brand Industrial Adhesive	416™ Super Bonder®	454™ Prism®	426™ Prism®	4205™ Prism®	324™ Speed-Bonder™	326™ Speed-Bonder™	330™ Depend®	334™	392™	H8000™ Speed-Bonder™	H3410™ Speed-Bonder™	E-20HP™ Hysol®	E-20NS™ Hysol®	E-214HP™ Hysol®	Fixmaster® High Perf. Epoxy	E-30CL™ Hysol®	U-05FL™ Hysol®	3631™	Fixmaster® Rapid Rubber Repair (MRO)	5900®	5601™	352™	3106™
Control - 9 rms	1120	2680	2515	1205	1145	1090	1325	2475	2290	2320	1690	1625	1720	4420	1640	1070	855	620	535	195	175	1630	950
Roughened - 68 rms	3210	2150	3795	3760	2440	2320	3180	2950	2460	3000	3285	3515	3215	4735	3220	1640	1035	375	1060	210	125	2450	1080
Salt fog @ 95°F	75	370	2350	210	1720	1440	1965	1775	1905	1365	1375	1770	1270	3300	680	1050	1085	440	195	310	95	1025	830
Condensing Humidity @ 120°F	335	250	1870	1695	940	910	2785	2140	1635	1690	0	1470	935	2025	1280	720	1655	360	200	175	100	1195	930
Heat Age @ 250°F	345	615	295	1020	2070	1295	3350	2135	1255	2855	780	3190	2425	3100	2380	1650	1890	1040	350	245	200	1905	620
Heat Age @ 300°F	445	905	0	940	1645	535	2755	3165	1450	2595	715	3340	2070	4355	1265	1665	1575	530	170	140	270	1075	785
Heat Age @ 350°F	120	0	0	0	945	560	1180	2980	0	1740	355	2505	485	4310	1540	1970	405	230	145	100	150	490	ND
Heat Age @ 400°F	215	0	0	0	405	320	545	1820	0	490	0	1270	540	2955	915	560	90	115	120	220	130	250	ND

Table 8.5-3
Normalized
Bond Strength of Several Loctite® Brand Adhesives on Stainless Steel (psi)
Type 304 Stainless Steel

Loctite® Brand Medical Device Adhesive	—	4541™ Prism®	—	—	—	—	—	—	—	—	—	—	—	—	—	M-31CL™ Hysol®	M-06FL™ Hysol®	—	U-04FL™ Hysol® (Industrial)	—	—	—	3321™
Loctite® Brand Industrial Adhesive	416™ Super Bonder®	454™ Prism®	426™ Prism®	4205™ Prism®	324™ Speed-Bonder™	326™ Speed-Bonder™	330™ Depend®	334™	392™	H8000™ Speed-Bonder™	H3410™ Speed-Bonder™	E-20HP™ Hysol®	E-20NS™ Hysol®	E-214HP™ Hysol®	Fixmaster® High Perf. Epoxy	E-30CL™ Hysol®	U-05FL™ Hysol®	3631™	Fixmaster® Rapid Rubber Repair (MRO)	5900®	5601™	352™	3106™
Control - 9 rms	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Roughened - 68 rms	287	80	151	312	213	213	240	119	107	130	194	216	187	107	196	153	121	60	198	108	71	150	114
Salt fog @ 95°F	7	14	93	17	150	132	148	72	83	59	81	109	74	75	41	98	127	71	36	159	54	63	87
Condensing Humidity @ 120°F	30	9	74	141	82	83	210	86	71	73	0	90	54	46	78	67	194	58	37	90	57	73	98
Heat Age @ 250°F	31	23	12	85	181	119	253	86	55	123	46	196	141	70	145	154	221	168	65	126	114	117	65
Heat Age @ 300°F	40	34	0	78	144	49	208	128	63	112	42	206	120	99	77	156	184	85	32	72	154	66	83
Heat Age @ 350°F	11	0	0	0	83	51	89	120	0	75	21	154	28	98	94	184	47	37	27	51	86	30	ND
Heat Age @ 400°F	19	0	0	0	35	29	41	74	0	21	0	78	31	67	56	52	11	19	22	113	74	15	ND

Note: Loctite® 324™ Speedbonder™ and Loctite® 352™ Structural Adhesive were cured with Loctite® 7075™ Activator.
Loctite® 326™ Speedbonder™ was cured with Loctite® 7649™ Primer N™.
Loctite® 330™ Depend® Adhesive, Loctite® 334™ Speedbonder™ Structural Adhesive, and Loctite® 392™ Structural Adhesive were cured with Loctite® 7387™ Depend® Activator.
Loctite® 3106™ Light Cure Adhesive was tested bonded to polycarbonate and could not be conditioned above 300°F.
All environmental conditioning done for 340 hours, samples allowed to equilibrate at ambient conditions for at least 24 hours prior to testing.
ND = Not determined. Polycarbonate lapshear melted at temperature.

Figure 8.5-1
Effect of Surface Roughening on Bond Strength of
Cyanoacrylates to Stainless Steel

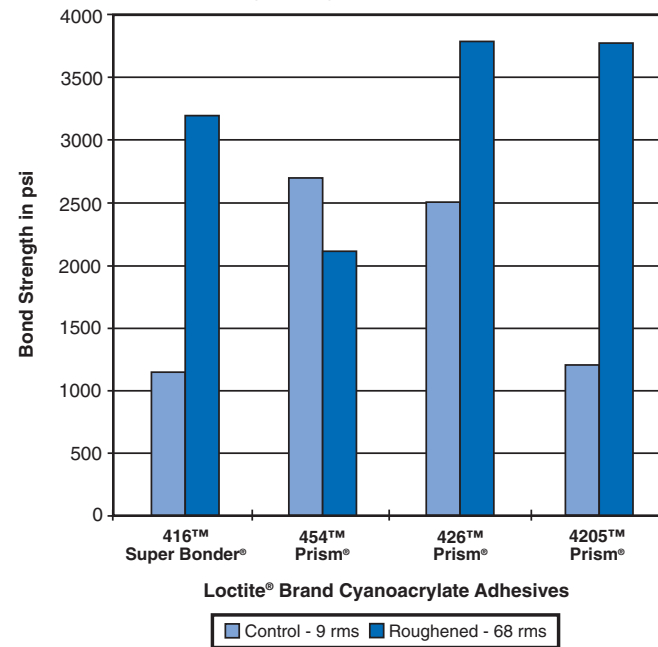
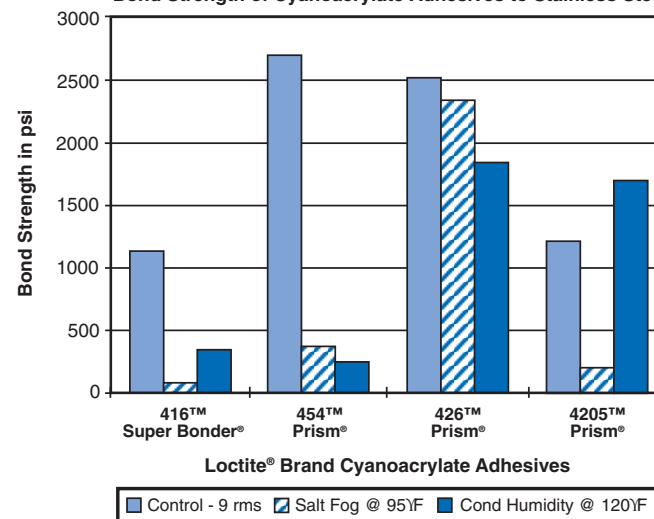
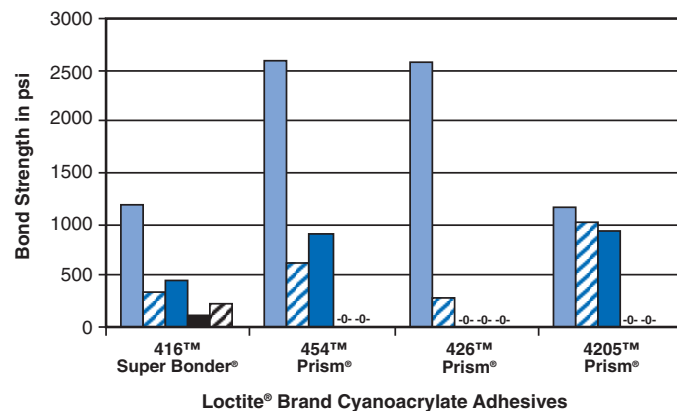


Figure 8.5-2
Effect of Condensing Humidity and Salt Fog Exposure on the
Bond Strength of Cyanoacrylate Adhesives to Stainless Steel



All conditioning done for 340 hours.

Figure 8.5-3
Effect of Heat Aging on the Bond Strength
of Cyanoacrylate Adhesives to Stainless Steel

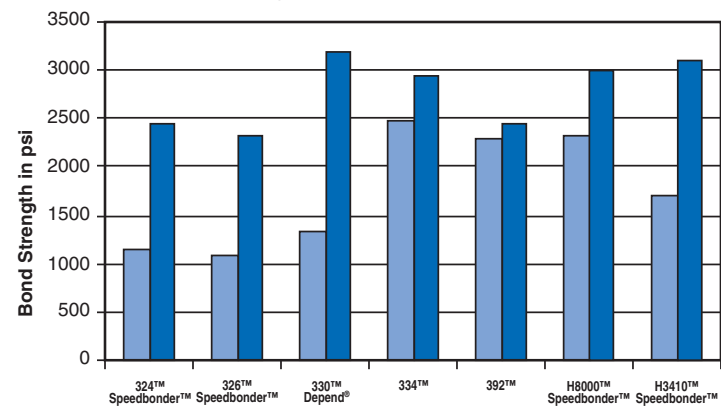


Loctite® Brand Cyanoacrylate Adhesives

Control - 9 rms Heat Age @ 250°F Heat Age @ 300°F Heat Age @ 350°F Heat Age @ 400°F

All conditioning done for 340 hours.

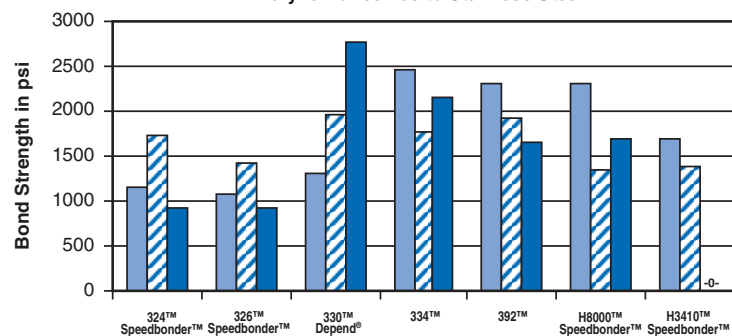
Figure 8.5-4
Effect of Roughing on the Bond Strength of No-Mix and Static Mix
Acrylic Adhesives to Stainless Steel



Loctite® Brand No-Mix and Static Mix Acrylic Adhesives

Control - 9 rms Roughened - 68 rms

Figure 8.5-5
Effect of Condensing Humidity and Salt Fog Exposure on
Bond Strength of No-Mix and Static Mix
Acrylic Adhesives to Stainless Steel

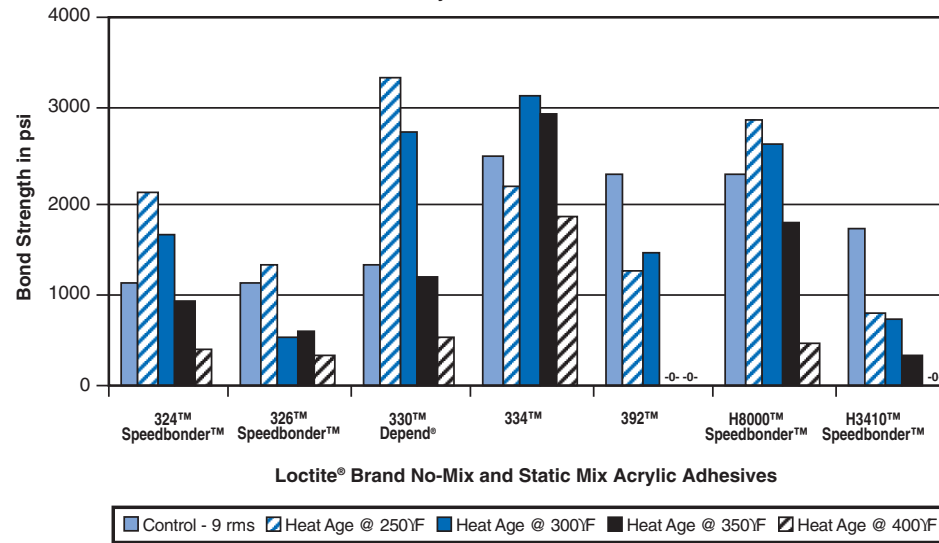


Loctite® Brand No-Mix and Static Mix Acrylic Adhesives

Control - 9 rms Salt Fog @ 95°F Cond Humidity @ 120°F

All conditioning done for 340 hours.

Figure 8.5-6
Effect of Heat Aging on the Bond Strength of No-Mix and Static Mix Acrylic Adhesives to Stainless Steel



All conditioning done for 340 hours.

Figure 8.5-7
Effect of Surface Roughening on the Bond Strength of Epoxy, Polyurethane and Silicone Adhesives to Stainless Steel

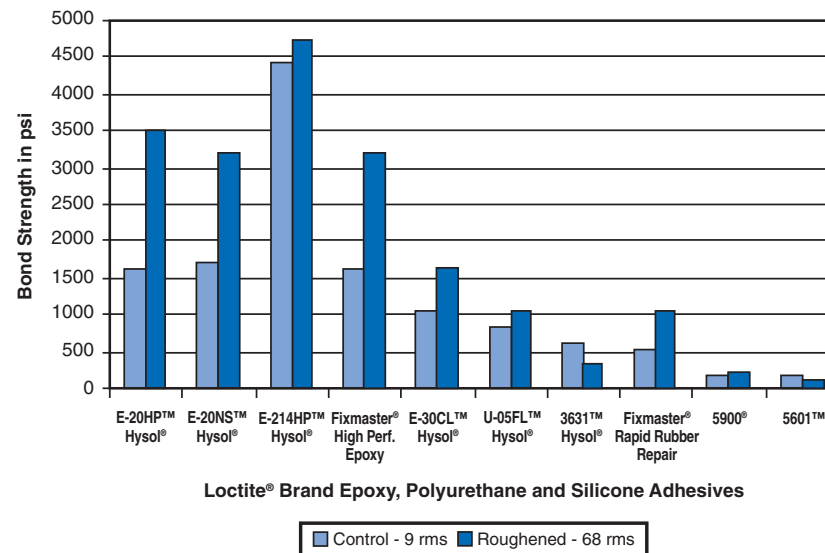


Figure 8.5-8
Effect of Condensing Humidity and Salt Fog Exposure on the Bond Strength of Epoxy, Polyurethane and Silicone Adhesives to Stainless Steel

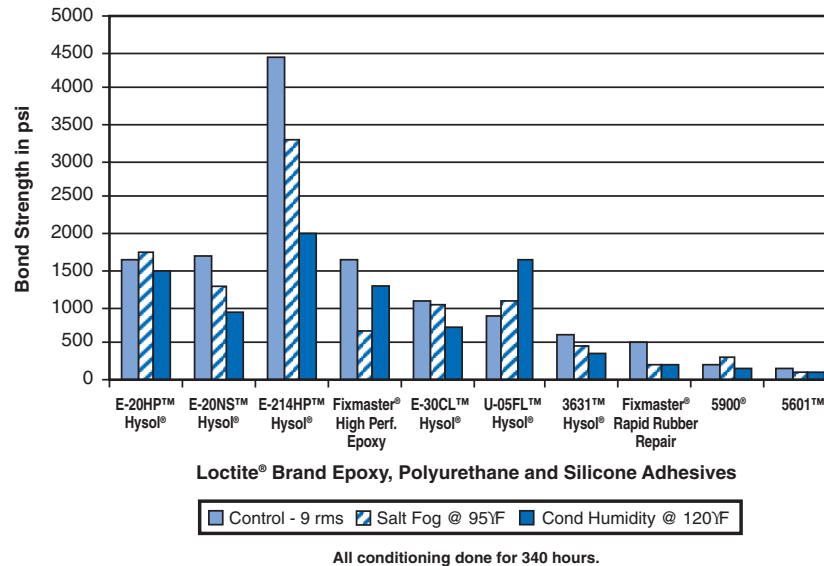


Figure 8.5-9
Effect of Heat Aging on Bond Strength of Epoxy, Polyurethane and Silicone Adhesives to Stainless Steel

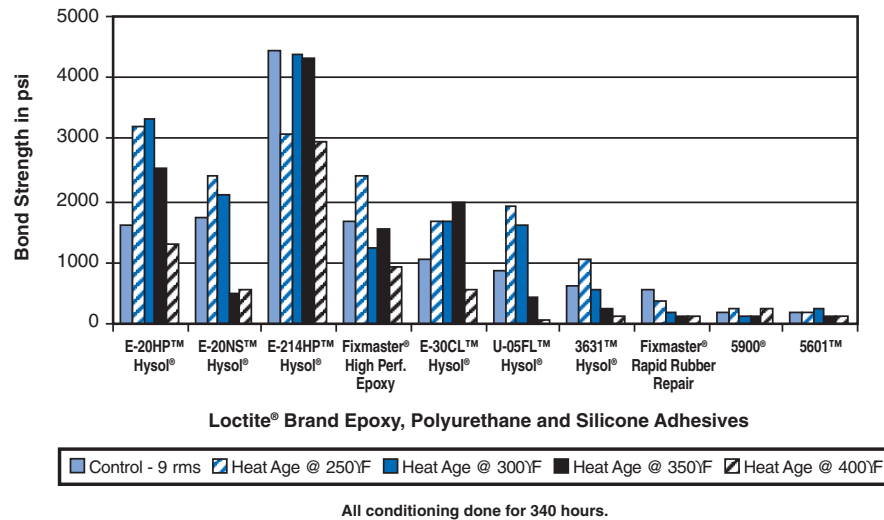


Figure 8.5-10
Effect of Surface Roughening on Bond Strength of
Light Cure Adhesives to Stainless Steel

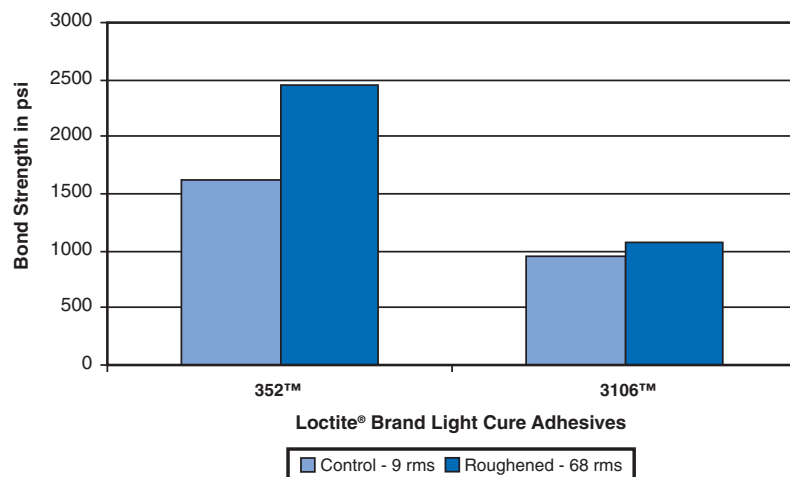


Figure 8.5-11
Effect of Condensing Humidity and Salt Fog Exposure on the Bond Strength
of Light Cure Adhesives to Stainless Steel

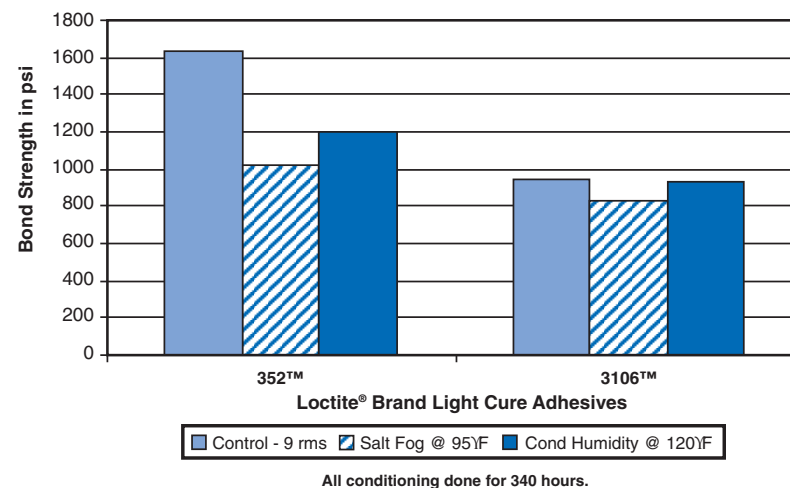
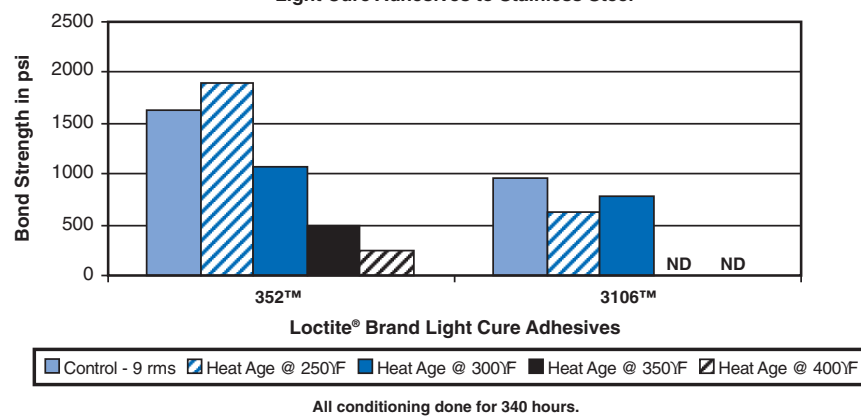


Figure 8.5-12
Effect of Heat Aging on Bond Strength of
Light Cure Adhesives to Stainless Steel



Section 8.6: Steel

General Description

Steels are alloys of iron and carbon with other metals, and typically have a carbon content of 2% or less, with some alloys having no carbon at all. The physical properties of steel are chiefly influenced by the interaction between the chemical composition of the steel, the thermal treatment of the steel, and the method used to remove oxygen from the steel.

Composition

The addition of carbon to steel increases its hardness and hardenability at the expense of ductility and weldability. Most steels contain 0.5 to 1.5% manganese to eliminate hot shortness. Hot shortness is brittleness in the steel that results when sulfur segregates to form low-melting-point grain boundary films after the metal is worked above its recrystallization temperature. Table 8.6-1 lists the common grades of steel, the principal alloying element of each grade and the main effect that the alloying elements have on the physical properties of the alloy.

Thermal Treatment

The thermal history that steel sees will have a dramatic effect on its microstructure, and thus its mechanical properties. Steel's microstructure is largely dependent on whether the steel forms a crystal lattice which is face centered cubic (FCC) or body centered cubic (BCC) and how carbon atoms fit in the crystal matrix. Some structures have enough space between the iron atoms for carbon to fit between the atoms; in other structures, the iron atoms pack so closely that the carbon is squeezed out of the crystalline lattice. Some of the types of microstructures that can be formed in steel alloys are austenite, ferrite, perlite, and martensite.

Austenite is a FCC structure that is formed at high temperatures and is a solid solution of carbon in iron, i.e., it has enough space between the iron atoms for carbon atoms to fit.

Ferrite is formed when steel is cooled slowly and the iron atoms convert to a BCC structure and “squeeze out” the carbon atoms.

Perlite is characterized by its softness and ductility and is the lowest strength steel microstructure. Perlite forms when high concentrations of carbon form in the steel and precipitate to form iron carbide, also known as cementite, within the ferrite.

Martensite is a body centered tetragonal lattice with carbon atoms trapped between the iron atoms. This structure is achieved by rapidly cooling the steel to prevent the carbon atoms from being displaced from the crystal lattice. This microstructure leads to steel with much higher hardness and strength.

The thermal history of the steel will also have a strong effect on the microstructure of the alloy carbides in the steel. Alloy carbides are compounds that result from alloying elements forming chemical compounds with carbon. These compounds can take on different shapes (spheroidal and needlelike or rodlike) and form fine or coarse grain structures in the steel. Depending on the final form of the alloy carbide in the steel matrix, other microstructures can be formed. If the alloy carbides take on spheroidal structures, the microstructure is referred to as spheroidite, while the microstructure that results when the alloy carbides have rodlike shape is bainite. Various combinations of the microstructures can be formed depending on the thermal cycle that the steel sees. This technique makes it possible to optimize the properties of the steel for specific end-uses.

Oxygen Removal Method

Another factor that will affect the mechanical properties of steel is the method used to remove oxygen from the steel. Oxygen is present in molten steel and is removed by one of two methods. In “rimmed” steels, oxygen leaves the steel in the form of carbon monoxide during the solidification process. This results in a lower concentration of carbon in the steel at the surface and thus a skin on the steel that is much more ductile than the bulk of the material. A more uniform product is obtained by combining an element such as aluminum or silicon with the molten steel and allowing them to react with the oxygen and form compounds that are separated from the molten steel. Steel that is produced in this manner is known as “killed” steel. Some steels offer properties which fall between these two types of steel and are known as “capped” or “semi-killed” steels.

Table 8.6-1
Common Grades of Steel

Alloy additions for common grades of steel and the effect they have on steel properties.
The last two digits in the classification refer to carbon content in hundredths of a percent, e.g., 1020 steel has a carbon content of 0.20%.

Classification	AISI/ SAE Number	Alloy Additions	Main Alloy Effects
Carbon Steels	10xx	Carbon, Manganese	Carbon - improves hardness and hardenability at the expense of ductility and weldability. Manganese - eliminates hot shortness, slightly increases strength and hardenability.
Carbon Steels	11xx	Sulfur	Sulfur - improves machinability, lowers transverse ductility and notch impact toughness with minimal impact on longitudinal mechanical properties. Diminishes surface quality and weldability.
Manganese Steels	13xx	Manganese Nickel	Manganese - eliminates hot shortness, slightly increases strength and hardenability. Nickel - strengthens unhardened steels, can improve toughness and hardenability depending on composition and crystalline structure.
Nickel Steels	2xxx	Nickel	Nickel - (see above) also renders high chromium steels austenitic.
Nickel Chromium Steels	3xxx	Chromium	Chromium - increases hardenability, corrosion resistance, high temperature strength and abrasion resistance in high carbon alloys.
Molybdenum Steels	41xx	Chromium, Molybdenum	Chromium - increases hardenability, corrosion resistance, high temperature strength and abrasion resistance in high carbon alloys. Molybdenum - increases hardenability, resistance to softening in tempering, high temperature tensile and creep strengths, minimizes tendency to temper embrittlement.
Molybdenum Steels	43xx	Nickel, Chromium, Molybdenum	See above.
Molybdenum Steels	44xx	Molybdenum	See above.
Chromium Steels	46xx	Nickel, Molybdenum	See above.
Chromium Vanadium Steels	5xxx	Chromium	See above.
Nickel Chromium	6xxx	Chromium Vanadium	Chromium - see above. Vanadium - increases hardenability, resists softening in hardening and causes marked secondary hardening, elevates coarsening temperature of austenite.
Molybdenum Steels	8xxx	Nickel Chromium Molybdenum	See above.
Silicon Steels	92xx	Silicon	Deoxidizer, improves oxidation resistance, slightly increases strength of ferrite.

Summary of Results

The results of the bond strength testing are shown in Table 8.6-2 and 8.6-3 and in Figures 8.6-1 through 8.6-12. The results are summarized below.

Cyanoacrylates

Surface Roughening - Significant improvement for Loctite® 454™ and 4205™ Prism® and 416™ Super Bonder® Instant Adhesives. Slight improvement for Loctite® 426™ Prism® Instant Adhesive.

Salt Fog 95°F (35°C) - Significant decrease in all cases.

Condensing Humidity 120°F (49°C) - With the exception of Loctite® 4205™ Prism® Instant Adhesive, which improved slightly, significant decrease in all cases.

Heat Aging - Significant decrease in the bond strength of Loctite® 426™ and 454™ Prism® and 416™ Super Bonder® Instant Adhesives after 340 hours at 250°F (121°C) and above. Loctite® 4205™ Prism® Instant Adhesive showed no change in bond strength after 340 hours at 250°F (121°C), showed a significant decrease at 300°F (149°C), and no bond strength after 340 hours at the higher temperatures. The ability of Loctite® 416™ Super Bonder® Instant Adhesive to maintain bond strength after exposure to temperatures as high as 350°F (177°C) and 400°F (204 °C) is surprising since cyanoacrylates revert to cyanoacrylate monomer at temperatures above 320°F (160°C). The bond strength is likely due to the presence of the polymethylmethacrylate filler used in Loctite® 416™ Super Bonder® Instant Adhesive.

No-Mix and Static Mix Acrylic Adhesives

Surface Roughening - Significant improvement for Loctite® 334™ Structural Adhesive. The bond strengths of Loctite® 324™, 326™ and H3410™ Speedbonder™ and 392™ Structural Adhesives showed slight improvement, while Loctite® 330™ Depend® Adhesive was unaffected. Loctite® H8000™ Speedbonder™ Structural Adhesive decreased slightly.

Salt Fog 95°F (35°C) - Loctite® 334™ Structural Adhesive showed no significant change, Loctite® 330™ Depend® Adhesive decreased slightly, and the other products decreased significantly in bond strength.

Condensing Humidity 120°F (49°C) - Loctite® 334™ Structural Adhesive increased slightly, Loctite® 330™ Depend® Adhesive decreased slightly, and the other products decreased significantly in bond strength.

Heat Aging - Loctite® 334™ Structural Adhesive showed significant increases in bond strength after exposure to temperatures as high as 400°F (204°C) for 340 hours. Loctite® H8000™ Speedbonder™ Structural Adhesive showed slight improvement when conditioned at 250°F (121°C) and 350°F (177°C), a slight decrease at 300°F (149°C), and a significant improvement when exposed to 400°F (204°C). All other products steadily declined in bond strength as the conditioning temperature increased.

Light Cure Adhesives

Surface Roughening - Loctite® 3106™ Light Cure Adhesive increased significantly while Loctite® 352™ Light Cure Adhesive showed a slight increase.

Salt Fog 95°F (35°C) - Loctite® 3106™ Light Cure Adhesive and Loctite® 352™ Light Cure Adhesive decreased significantly.

Condensing Humidity 120°F (49°C) - Loctite® 352™ Light Cure Adhesive decreased significantly while Loctite® 3106™ Light Cure Adhesive showed no change.

Heat Aging - Loctite® 3106™ Light Cure Adhesive showed no significant change after conditioning for 340 hours at temperatures as high as 300°F (149°C). Loctite® 3106™ Light Cure Adhesive could not be tested above 300°F (149°C) due to the fact that it was bonded to polycarbonate. Loctite® 352™ Light Cure Adhesive declined in bond strength slightly at 250°F (121°C), and significantly at the higher temperatures.

Epoxy Adhesives

Surface Roughening - Loctite® E-214HP™ Hysol® Epoxy Adhesive increased significantly in bond strength, while the other epoxies were unchanged.

Salt Fog 95°F (35°C) - All decreased significantly.

Condensing Humidity 120°F (49°C) - All decreased significantly.

Heat Aging - Loctite® E-20HP™ and E-20NS™ Hysol® Epoxy Adhesives showed no significant change after 340 hours at temperatures as high as 350°F (177°C), but did show a significant drop after 340 hours at 400°F (204°C). Loctite® E-214HP™ and E-30CL™ Hysol® Epoxy Adhesives showed a significant increase after 340 hours at 250°F (121°C) and 300°F (149°C), no significant change after 340 hours at 350°F (177°C), and a significant decrease after 340 hours at 400°F (204°C). Loctite® Fixmaster® High Performance Epoxy decreased slightly at 250°F (121°C) and significantly at all higher temperatures.

Polyurethane Adhesives

Surface Roughening - Significant improvement.

Salt Fog 95°F (35°C) - Significant improvement except for Loctite® 3631™ Hysol® Hot Melt Adhesive which showed a slight decrease.

Condensing Humidity 120°F (49°C) - Significant improvement except for Loctite® 3631™ Hysol® Hot Melt Adhesive which showed a slight decrease.

Heat Aging - For Loctite® U-05FL™ Hysol® Urethane Adhesive the bond strength improved significantly after conditioning at 250°F (121°C) and 300°F (149°C), however, decreased significantly after exposure to 350°F (177°C) and 400°F (204°C) for 340 hours. Loctite® 3631™ Hysol® Hot Melt Adhesive showed significant improvement when conditioned at 250°F (121°C), and decreased significantly at all higher temperatures. Loctite® Fixmaster® Rapid Rubber Repair increased significantly at all temperatures.

Silicone Adhesives

Surface Roughening - Significant improvement seen for Loctite® 5900® Flange Sealant. Slight decrease for Loctite® 5601™ Adhesive Sealant.

Salt Fog 95°F (35°C) - Significant decrease in bond strength.

Condensing Humidity 120°F (49°C) - Significant decrease in bond strength.

Heat Aging - Loctite® 5601™ Adhesive Sealant showed slight improvement for all temperatures up to 350°F (177°C), while decreasing slightly at 400°F (204°C). For Loctite® 5900® Flange Sealant there was a slight decrease at 250°F (121°C) and 400°F (204°C), significant decrease at 300°F (149°C) and 350°F (177°C), however for all temperatures the values ranged from 75 to 89% of the original bond strength values. The low absolute values of the silicone bond strength very likely contributed to the variation in the data.

Table 8.6-2
Bond Strength of Several Loctite® Brand Adhesives on Steel (psi)
Cold Rolled SAE 1010 steel, full hard temper, ground on one side

Loctite® Brand Medical Device Adhesive	—	4541™ Prism®	—	—	—	—	—	—	—	—	—	—	—	—	—	M-31CL™ Hysol®	M-06FL™ Hysol®	—	U-04FL™ Hysol® (Industrial)	—	—	—	3321™
Loctite® Brand Industrial Adhesive	416™ Super Bonder®	454™ Prism®	426™ Prism®	4205™ Prism®	324™ Speed-Bonder™	326™ Speed-Bonder™	330™ Depend®	334™	392™	H8000™ Speed-Bonder™	H3410™ Speed-Bonder™	E-20HP™ Hysol®	E-20NS™ Hysol®	E-214HP™ Hysol®	Fixmaster® High Perf. Epoxy	E-30CL™ Hysol®	U-05FL™ Hysol®	3631™	Fixmaster® Rapid Rubber Repair (MRO)	5900®	5601™	352™	3106™
Control - 49 rms	2065	2800	3280	1115	2420	1715	3170	2590	2305	3315	3210	4325	3170	3275	2835	2470	1035	610	145	140	170	2170	1060
Roughened - 108 rms	3765	4135	3825	3835	2675	2015	3235	2740	2565	2970	3450	4325	3355	5195	2880	2235	1250	475	1310	185	140	2550	1335
Salt fog @ 95°F	135	200	315	615	1870	1180	2765	2745	1585	2255	2130	2505	2465	715	1700	1900	1285	475	205	90	20	1570	340
Condensing Humidity @ 120°F	665	475	460	1310	1270	750	2775	2460	1565	2060	0	2270	1585	1095	2080	2135	1535	320	215	110	140	1720	1120
Heat Age @ 250°F	635	530	485	1120	1950	1380	1600	3375	1020	3390	1315	4290	3285	4320	2750	3326	2265	915	1125	120	240	1850	865
Heat Age @ 300°F	285	175	0	855	1805	1210	1780	3315	1115	3085	550	3680	2920	4000	1470	2890	1445	300	535	110	275	1695	965
Heat Age @ 350°F	125	0	0	0	1235	630	1160	4065	160	3460	125	3505	2540	3005	1040	2080	715	180	435	105	240	1180	ND
Heat Age @ 400°F	130	0	0	0	205	375	975	3155	0	4265	0	1675	1400	1460	1145	1635	210	35	630	125	205	470	ND

Table 8.6-3
Normalized
Bond Strength of Several Loctite® Brand Adhesives on Steel
Cold Rolled SAE 1010 steel, full hard temper, ground on one side

Loctite® Brand Medical Device Adhesive	—	4541™ Prism®	—	—	—	—	—	—	—	—	—	—	—	—	—	M-31CL™ Hysol®	M-06FL™ Hysol®	—	U-04FL™ Hysol® (Industrial)	—	—	—	3321™
Loctite® Brand Industrial Adhesive	416™ Super Bonder®	454™ Prism®	426™ Prism®	4205™ Prism®	324™ Speed-Bonder™	326™ Speed-Bonder™	330™ Depend®	334™	392™	H8000™ Speed-Bonder™	H3410™ Speed-Bonder™	E-20HP™ Hysol®	E-20NS™ Hysol®	E-214HP™ Hysol®	Fixmaster® High Perf. Epoxy	E-30CL™ Hysol®	U-05FL™ Hysol®	3631™	Fixmaster® Rapid Rubber Repair (MRO)	5900®	5601™	352™	3106™
Control - 49 rms	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Roughened - 108 rms	182	148	117	344	111	117	102	106	111	90	110	100	106	159	102	90	121	78	900	132	82	118	126
Salt fog @ 95°F	7	7	10	55	77	69	87	106	69	68	66	58	78	22	60	77	124	78	141	64	12	72	32
Condensing Humidity @ 120°F	32	17	14	117	52	44	88	95	68	62	0	52	50	33	73	86	148	52	148	79	82	79	106
Heat Age @ 250°F	31	19	15	100	81	80	50	130	44	102	41	99	104	132	97	135	219	150	776	86	141	85	82
Heat Age @ 300°F	14	6	0	77	75	71	56	128	48	93	17	85	92	122	52	117	140	49	369	79	162	78	91
Heat Age @ 350°F	6	0	0	0	51	37	37	157	7	104	4	81	80	92	37	84	69	30	300	75	141	54	ND
Heat Age @ 400°F	6	0	0	0	8	31	31	122	0	129	0	39	44	45	40	66	20	6	434	89	121	22	ND

Note: Loctite® 324™ Speedbonder™ and Loctite® 352™ Structural Adhesive were cured with Loctite® 7075™ Activator.
Loctite® 326™ Speedbonder™ was cured with Loctite® 7649™ Primer N™.
Loctite® 330™ Depend® Adhesive, Loctite® 334™ Speedbonder™ Structural Adhesive, and Loctite® 392™ Structural Adhesive were cured with Loctite® 7387™ Depend® Activator.
Loctite® 3106™ Light Cure Adhesive was tested bonded to polycarbonate and could not be conditioned above 300°F.
All environmental conditioning done for 340 hours, samples allowed to equilibrate at ambient conditions for at least 24 hours prior to testing.
ND = Not determined. Polycarbonate lapshear melted at temperature.

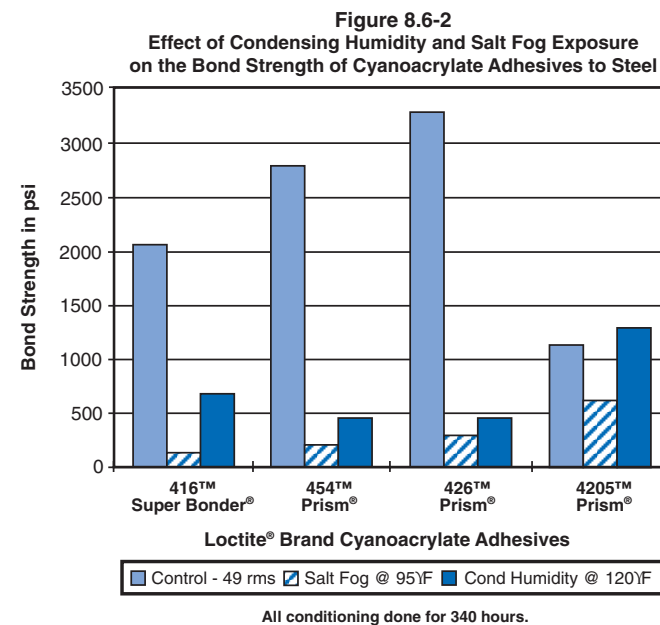
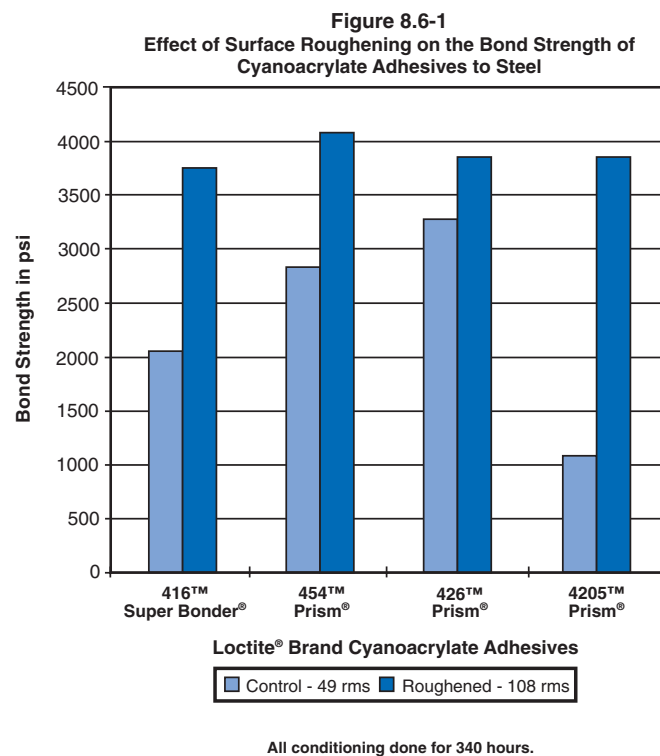


Figure 8.6-3
Effect of Heat Aging on the Bond Strength
of Cyanoacrylate Adhesives to Steel

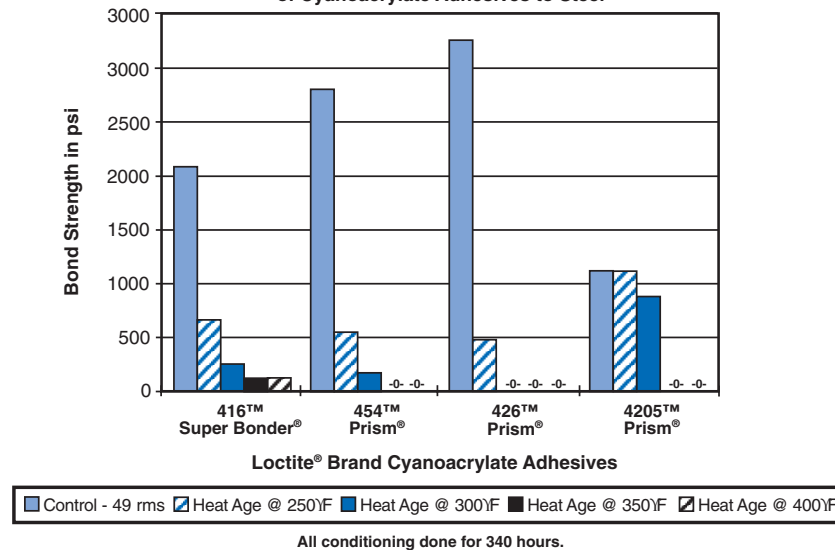


Figure 8.6-4
Effect of Roughing on the Bond Strength of
No-Mix and Static Mix Acrylic Adhesives to Steel

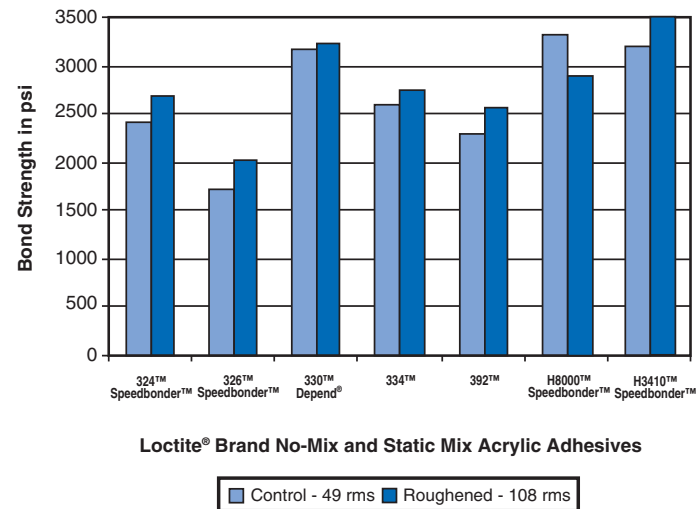
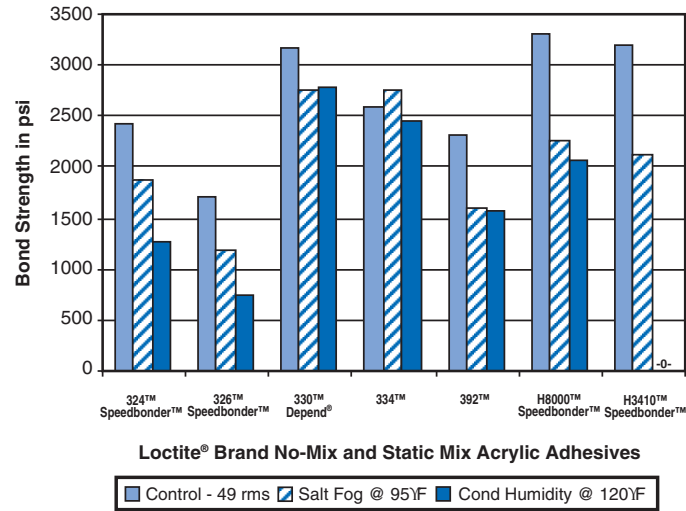
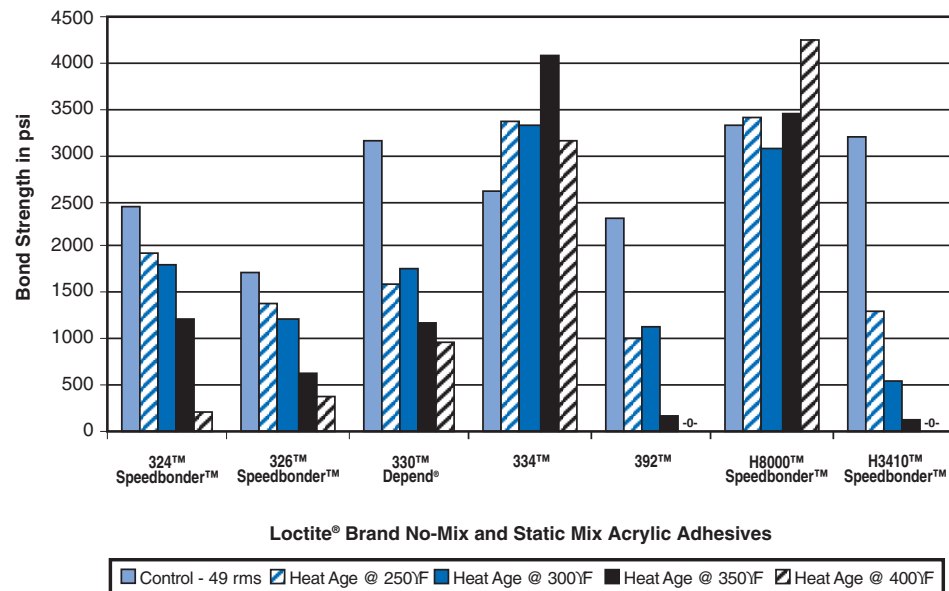


Figure 8.6-5
Effect of Salt Fog Exposure and Condensing Humidity on the Bond Strength of No-Mix and Static Mix Acrylic Adhesives to Steel



All conditioning done for 340 hours.

Figure 8.6-6
Effect of Heat Aging on the Bond Strength of No-Mix and Static Mix Acrylic Adhesives to Steel



All conditioning done for 340 hours.

Figure 8.6-7
Effect of Surface Roughening on the Bond Strength of Epoxy, Polyurethane and Silicone Adhesives to Steel

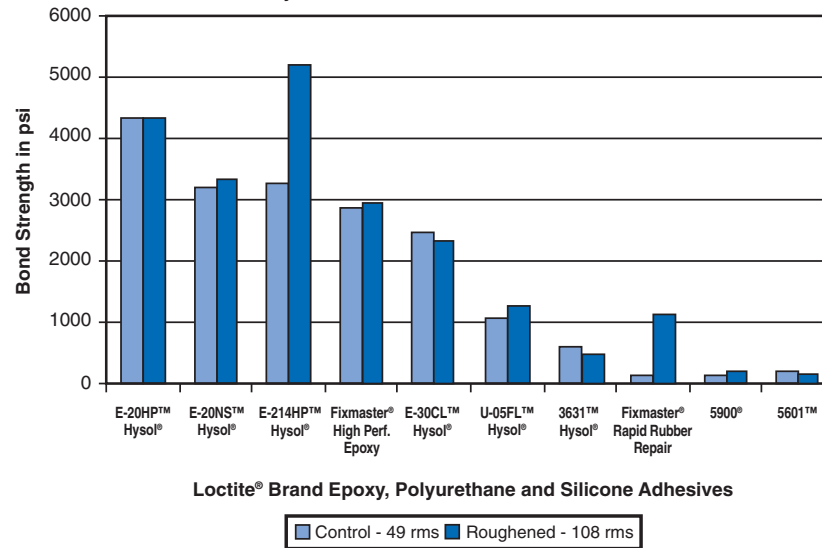


Figure 8.6-8
Effect of Condensing Humidity and Salt Fog Exposure on the Bond Strength of Epoxy, Polyurethane and Silicone Adhesives to Steel

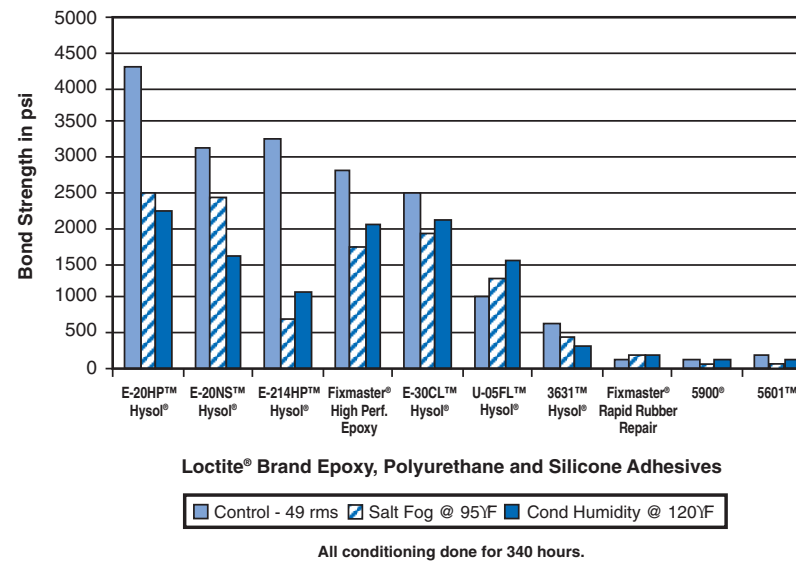
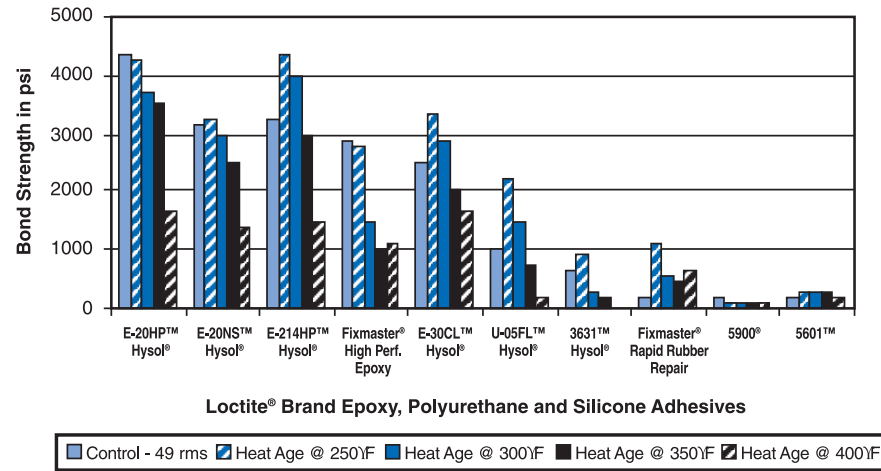


Figure 8.6-9
Effect of Heat Aging on the Bond Strength of Epoxy, Polyurethane and Silicone Adhesives to Steel

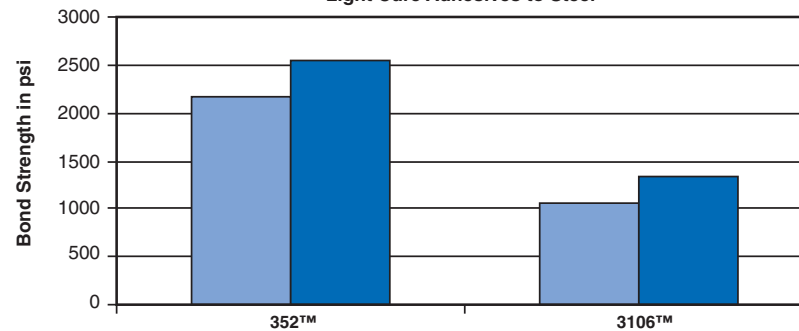


Loctite® Brand Epoxy, Polyurethane and Silicone Adhesives



All conditioning done for 340 hours.

Figure 8.6-10
Effect of Surface Roughening on the Bond Strength of Light Cure Adhesives to Steel



Loctite® Brand Light Cure Adhesives



Figure 8.6-11
Effect of Condensing Humidity and Salt Fog Exposure on the Bond Strength of Light Cure Adhesives to Steel

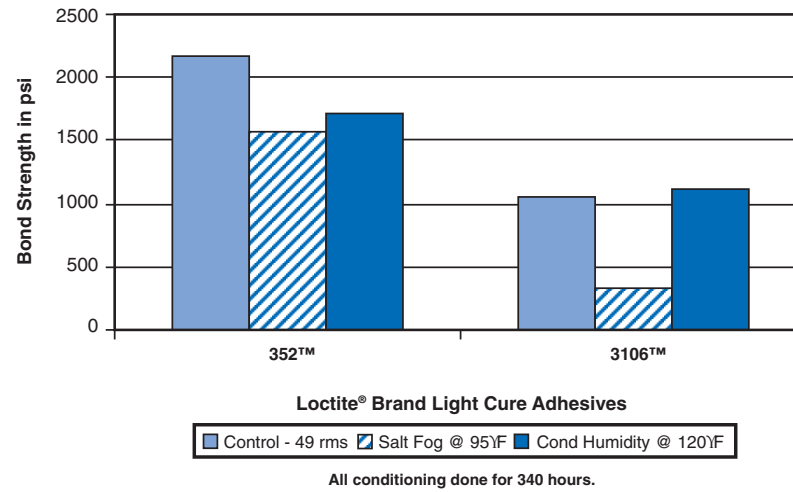
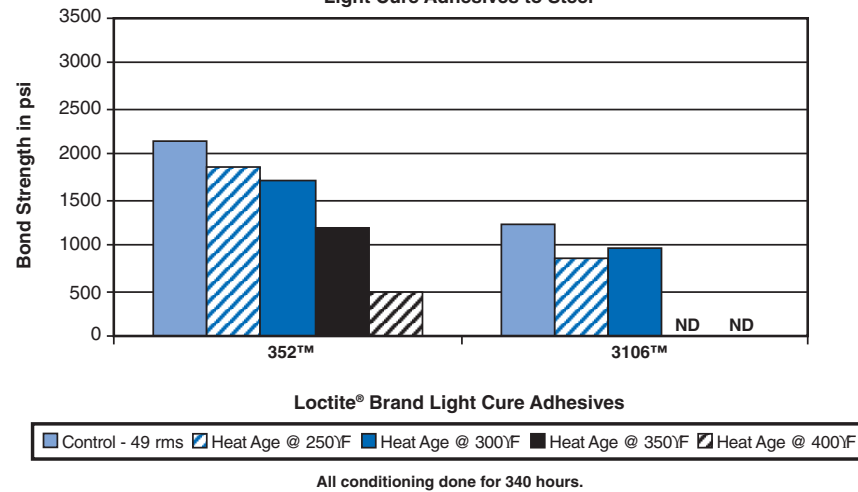


Figure 8.6-12
Effect of Heat Aging on Bond Strength of Light Cure Adhesives to Steel



Section 8.7: Zinc Dichromated Steel

General Description

Galvanized steel is steel which has been coated with zinc either through hot-dipping or electroplating. When the protective zinc layer corrodes in high humidity conditions, it can react with moisture and carbon dioxide to form a basic carbonate of zinc which appears as a white crystalline bloom on the coating. Unlike the zinc oxide layer that forms under drier conditions, the bloom does not serve as a protective coating against further moisture attack. To improve the corrosion protection offered by zinc coatings in these conditions, chromate conversion coatings are used on the zinc surface. Chromate conversion coatings are formed by dissolving a very thin layer of the zinc coating and depositing a colloid film of chromium dichromate.

Summary of Results

The results of the bond strength testing are shown in Tables 8.7-1 and 8.7-2 and in Figures 8.7-1 through 8.7-8. The results are summarized below.

Cyanoacrylates

Salt Fog 95°F (35°C) - Loctite® 4205™ Prism® Instant Adhesive increased significantly in bond strength, Loctite® 454™ Prism® Instant Adhesive was unchanged, and Loctite® 416™ Super Bonder® and Loctite® 426™ Prism® Instant Adhesives decreased significantly.

Condensing Humidity 120°F (49°C) - Loctite® 426™ Prism® Instant Adhesive increased slightly while the other cyanoacrylates decreased significantly in bond strength.

Heat Aging - Loctite® 4205™ Prism® Instant Adhesive increased slightly in bond strength after 340 hours at 250°F (121°C) and then decreased significantly at all other temperatures. The remaining cyanoacrylates decreased significantly in bond strength for all times and temperatures evaluated. The ability of Loctite® 416™ Super Bonder® Instant Adhesive to maintain bond strength after exposure to temperatures as high as 350°F (177°C) and 400°F (204°C) is surprising since cyanoacrylates revert to cyanoacrylate monomer at temperatures above 320°F (160°C). The bond strength is likely due to the presence of the

polymethylmethacrylate filler used in Loctite® 416™ Super Bonder® Instant Adhesive.

No-Mix and Static Mix Acrylic Adhesives

Salt Fog 95°F (35°C) - Loctite® 324™ Speedbonder™ Structural Adhesive increased significantly in bond strength, while Loctite® 326™ Speedbonder™ Structural Adhesive with Loctite® 7649™ Primer N™ and Loctite® 330™ Depend® Adhesive were unchanged. Loctite® 326™ Speedbonder™ Structural Adhesive with Loctite® 7091™ Activator dropped in bond strength significantly, but still had higher bond strength than Loctite® 326™ Speedbonder™ Structural Adhesive with Loctite® 7649™ Primer N™. Loctite® H3410™ Speedbonder™ and Loctite® 392™ Structural Adhesive also showed a significant drop in bond strength. Loctite® H8000™ Speedbonder™ Structural Adhesive showed a slight decrease.

Condensing Humidity 120°F (49°C) - Loctite® 324™ Speedbonder™ Structural Adhesive increased significantly in bond strength, while Loctite® 326™ Speedbonder™ Structural Adhesive with Loctite® 7649™ Primer N™, Loctite® 326™ Speedbonder™ Structural Adhesive with Loctite® 7091™ Activator, Loctite® 330™ Depend® Adhesive, Loctite® 392™ and Loctite® H3410™ Speedbonder™ Structural Adhesives all experienced significant decreases in bond strength. Loctite® 334™ Structural Adhesive was unchanged. Even though Loctite® 326™ Speedbonder™ Structural Adhesive with Loctite® 7091™ Activator dropped in bond strength significantly, it still had higher bond strength than Loctite® 326™ Speedbonder™ Structural Adhesive with Loctite® 7649™ Primer N™. Loctite® H8000™ Speedbonder™ Structural Adhesive showed a slight improvement in bond strength.

Heat Aging - Loctite® 324™ and H8000™ Speedbonder™ and 334™ Structural Adhesives showed significant increases in bond strength, while all others decreased significantly. At 300°F (149°C), Loctite® 324™, H8000™ and H3410™ Speedbonder™ Structural Adhesives decreased significantly in bond strength and at 350°F (177°C), Loctite® H8000™ and H3410™ Speedbonder™ and 334™ Structural Adhesives decreased significantly in bond strength as well.

Light Cure Adhesives

Salt Fog 95°F (35°C) - Significant increase for Loctite® 352™ Light Cure Adhesive, no change in bond strength for Loctite® 3106™ Light Cure Adhesive.

Condensing Humidity 120°F (49°C) - Loctite® 352™ Light Cure Adhesive increased slightly while Loctite® 3106™ Light Cure Adhesive decreased significantly.

Heat Aging - Both products increased to some extent after 340 hours at 250°F (121°C) but decreased significantly at all higher temperatures.

Epoxy Adhesives

Salt Fog 95°F (35°C) - Loctite® E-214HP™ Hysol® Epoxy Adhesive was unchanged, Loctite® E-20HP™ Hysol® Epoxy Adhesive and Loctite® Fixmaster® High Performance Epoxy decreased slightly, and Loctite® E-20NS™ and E-30FL™ Hysol® Epoxy Adhesives dropped significantly in bond strength.

Condensing Humidity 120°F (49°C) - Loctite® E-214HP™ Hysol® Epoxy Adhesive and Loctite® Fixmaster® High Performance Epoxy dropped slightly in bond strength while Loctite® E-20HP™, E-20NS™ and E-30FL™ Hysol® Epoxy Adhesives dropped significantly in bond strength.

Heat Aging - Loctite® E-20HP™ Hysol® Epoxy Adhesive improved slightly in bond strength at 250°F (121°C) and 300°F (149°C) but decreased significantly at 350°F (177°C). Loctite® E-20NS™ Hysol® Epoxy Adhesive decreased significantly at all temperatures and times. Loctite® E-214HP™ Hysol® Epoxy Adhesive increased significantly at all times and temperatures tested except 400°F (204°C). Loctite® Fixmaster® High Performance Epoxy improved significantly when exposed to all temperatures up to 350°F (177°C), and decreased significantly at 400°F (204°C). Loctite® E-30CL™ Hysol® Epoxy Adhesive decreased significantly at 250°F (121°C), 350°F (177°C) and 400°F (204°C), while improving significantly at 300°F (149°C).

Polyurethane Adhesives

Salt Fog 95°F (35°C) - Slight decrease for Loctite® 3631™ Hysol® Hot Melt Adhesive and slight improvement for Loctite® U-05FL™ Hysol® Urethane Adhesive and Loctite® Rapid Rubber Repair.

Condensing Humidity 120°F (49°C) - Slight increase for Loctite® 3631™ Hysol® Hot Melt Adhesive and Loctite® Fixmaster® Rapid Rubber Repair, and slight decrease for Loctite® U-05FL™ Hysol® Urethane Adhesive.

Heat Aging - Compared to the room temperature bond strength, the bond strength for Loctite 3631™ Hysol® Hot Melt Adhesive improved significantly after conditioning at 250°F (121°C) and slightly at 300°F (149°C), however, decreased significantly after exposure to 350°F (177°C) and 400°F (204°C) for 340 hours. Loctite® U-05FL™ Hysol® Urethane Adhesive decreased slightly at 250°F (121°C), increased slightly at 300°F (149°C), and decreased significantly at all higher temperatures. Loctite® Fixmaster® Rapid Rubber Repair decreased at all temperatures tested.

Silicone Adhesives

Salt Fog 95°F (35°C) - Slight improvement for Loctite® 5900® Flange Sealant, significant decrease for Loctite® 5601™ Adhesive Sealant. **Condensing Humidity 120°F (49°C)** - No significant change.

Heat Aging - Up to 350°F (177°C) the bond strength for Loctite® 5900® Flange Sealant did not show a significant decrease, however at 400°F (204°C) the bond strength decreased significantly. Up to 350°F (177°C) the bond strength for Loctite® 5601™ Adhesive Sealant increased significantly, however at 400°F (204°C) the bond strength showed little change.

Table 8.7-1
Bond Strength of Several Loctite® Brand Adhesives on Zinc Dichromated Steel (psi)
 Yellow dichromated Zinc Plated Steel

Loctite® Brand Medical Device Adhesive	—	4541™ Prism®	—	—	—	—	—	—	—	—	—	—	—	—	—	—	M-31CL™ Hysol®	M-06FL™ Hysol®	—	U-04FL™ Hysol® (Industrial)	—	—	—	3321™
Loctite® Brand Industrial Adhesive	416™ Super Bonder®	454™ Prism®	426™ Prism®	4205™ Prism®	324™ Speed-Bonder™	326™ Speed-Bonder™ w/7649™	326™ Speed-Bonder™ w/7091™	330™ Depend®	334™	392™	H8000™ Speed-Bonder™	H3410™ Speed-Bonder™	E-20HP™ Hysol®	E-20NS™ Hysol®	E-214HP™ Hysol®	Fixmaster® High Perf. Epoxy	E-30CL™ Hysol®	U-05FL™ Hysol®	3631™	Fixmaster® Rapid Rubber Repair (MRO)	5900®	5601™	352™	3106™
Control - 75 rms	1295	460	1115	405	550	995	1835	1860	875	1515	1010	3285	1190	1280	635	3385	1510	1230	550	1610	215	185	685	475
Salt fog @ 95°F	710	495	795	905	1045	1045	1040	1840	795	1005	960	2195	1000	610	575	2840	1755	1100	610	995	250	110	1215	495
Condensing Humidity @ 120°F	800	260	1285	280	1135	740	1045	1445	920	920	1210	615	445	820	545	2145	1310	1455	640	820	200	155	775	375
Heat Age @ 250°F	140	0	320	465	860	395	680	190	1300	555	1435	870	1345	725	3410	790	1400	1900	305	1565	220	285	845	530
Heat Age @ 300°F	160	0	100	265	210	210	750	220	1155	475	805	530	1355	565	3010	1540	1810	1350	80	190	230	275	285	190
Heat Age @ 350°F	135	0	0	0	0	235	290	120	960	140	355	500	410	285	2955	1020	710	315	120	65	190	270	330	ND
Heat Age @ 400°F	65	0	0	0	0	0	0	0	0	0	135	0	0	0	144	350	230	80	30	255	50	165	0	ND

Table 8.7-2
Normalized
Bond Strength of Several Loctite® Brand Adhesives on Zinc Dichromated Steel
 Yellow dichromated Zinc Plated Steel

Loctite® Brand Medical Device Adhesive	—	4541™ Prism®	—	—	—	—	—	—	—	—	—	—	—	—	—	—	M-31CL™ Hysol®	M-06FL™ Hysol®	—	U-04FL™ Hysol® (Industrial)	—	—	—	3321™
Loctite® Brand Industrial Adhesive	416™ Super Bonder®	454™ Prism®	426™ Prism®	4205™ Prism®	324™ Speed-Bonder™	326™ Speed-Bonder™ w/7649™	326™ Speed-Bonder™ w/7091™	330™ Depend®	334™	392™	H8000™ Speed-Bonder™	H3410™ Speed-Bonder™	E-20HP™ Hysol®	E-20NS™ Hysol®	E-214HP™ Hysol®	Fixmaster® High Perf. Epoxy	E-30CL™ Hysol®	U-05FL™ Hysol®	3631™	Fixmaster® Rapid Rubber Repair (MRO)	5900®	5601™	352™	3106™
Control - 75 rms	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Salt fog @ 95°F	55	108	71	223	190	105	57	99	91	66	95	67	84	48	91	84	116	89	111	62	116	59	177	104
Condensing Humidity @ 120°F	62	57	115	69	206	74	57	78	105	61	120	19	37	64	86	63	87	118	116	51	93	84	113	79
Heat Age @ 250°F	11	0	29	115	156	40	37	10	149	37	142	26	113	57	537	23	93	154	55	97	102	154	123	112
Heat Age @ 300°F	12	0	9	65	38	21	41	12	132	31	80	16	114	44	474	45	120	110	15	12	107	149	42	40
Heat Age @ 350°F	10	0	0	0	0	24	16	6	110	9	35	15	34	22	465	30	47	26	22	4	88	146	48	ND
Heat Age @ 400°F	5	0	0	0	0	0	0	0	0	0	13	0	0	0	23	10	15	7	5	16	23	89	0	ND

Note: Loctite® 324™ Speedbonder™ and Loctite® 352™ Structural Adhesive were cured with Loctite® 7075™ Activator.
 Loctite® 326™ Speedbonder™ was cured with Loctite® 7649™ Primer N™.
 Loctite® 330™ Depend® Adhesive, Loctite® 334™ Speedbonder™ Structural Adhesive, and Loctite® 392™ Structural Adhesive were cured with Loctite® 7387™ Depend® Activator.
 Loctite® 3106™ Light Cure Adhesive was tested bonded to polycarbonate and could not be conditioned above 300°F.
 All environmental conditioning done for 340 hours, samples allowed to equilibrate at ambient conditions for at least 24 hours prior to testing.
 ND = Not determined. Polycarbonate lapshear melted at temperature.

Figure 8.7-1
Effect of Condensing Humidity and Salt Fog Exposure on the Bond Strength of Cyanoacrylate Adhesives to Zinc Dichromated Steel

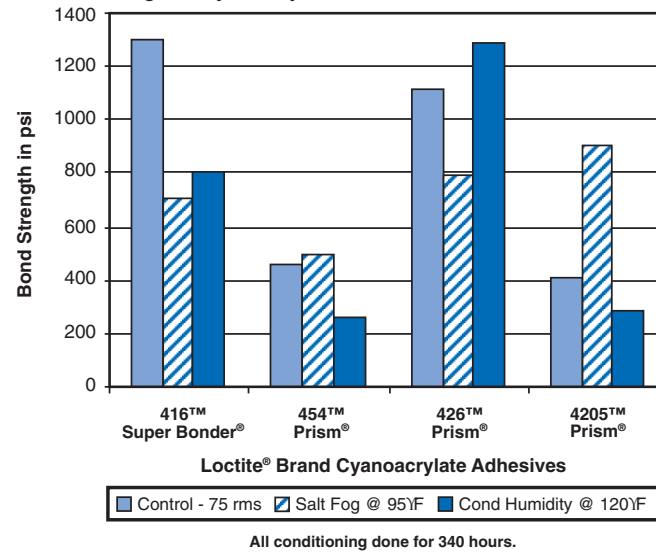


Figure 8.7-2
Effect of Heat Aging on the Bond Strength of Cyanoacrylate Adhesives to Zinc Dichromated Steel

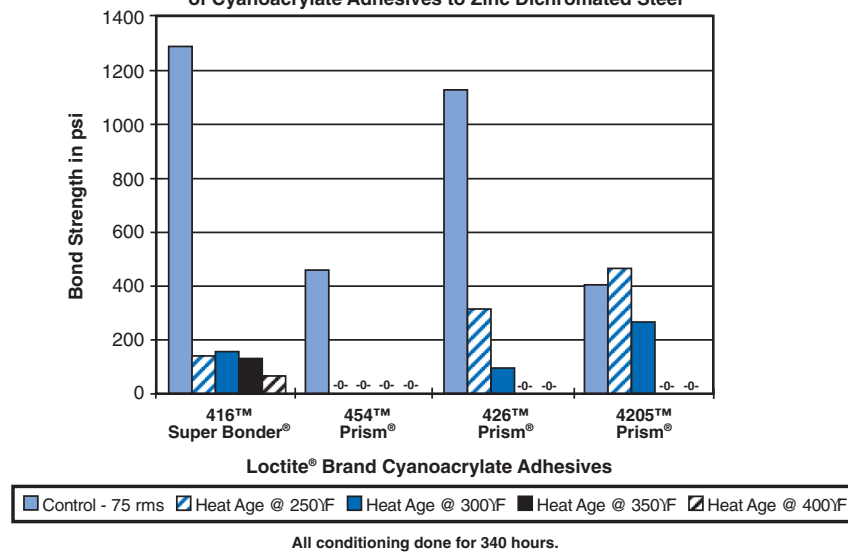
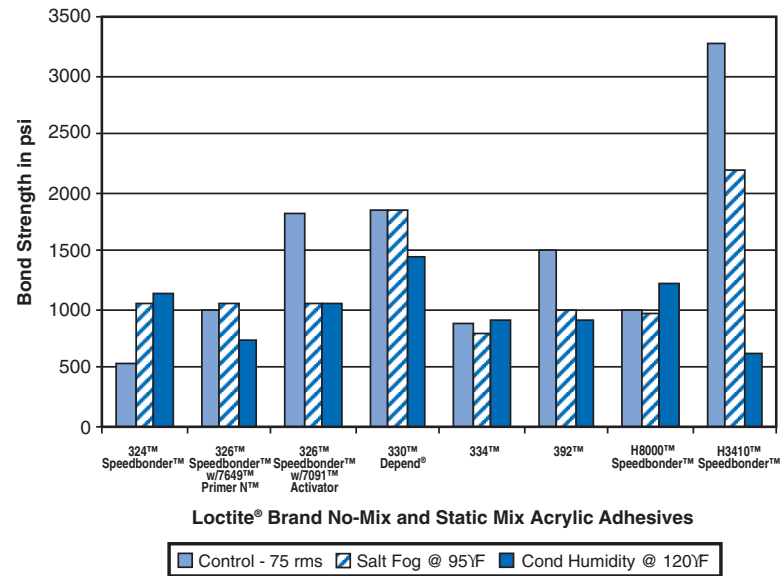
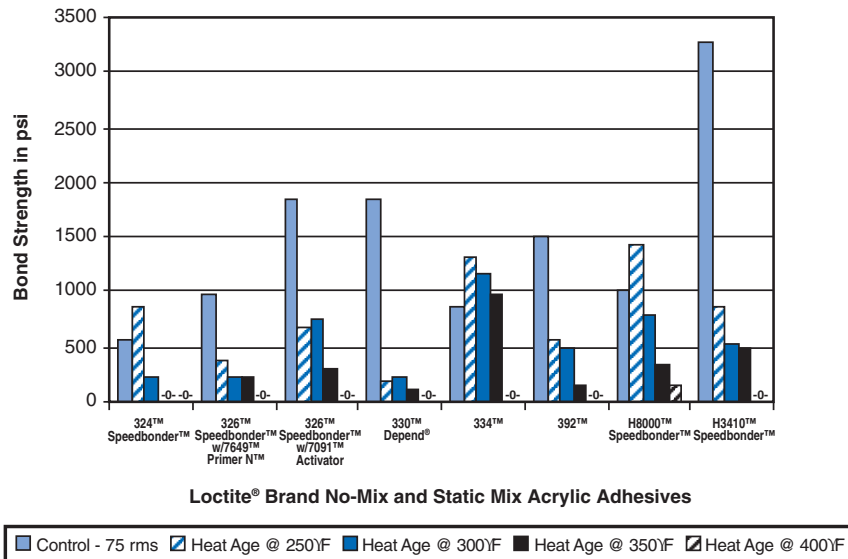


Figure 8.7-3
Effect of Salt Fog Exposure and Condensing Humidity on the Bond Strength
No-Mix and Static Mix Acrylic Adhesives to Zinc Dichromated Steel



All conditioning done for 340 hours.

Figure 8.7-4
Effect of Heat Aging on the Bond Strength of
No-Mix and Static Mix Acrylic Adhesives to Zinc Dichromated Steel



All conditioning done for 340 hours.

Figure 8.7-5
Effect of Condensing Humidity and Salt Fog Exposure on the Bond Strength of Epoxy, Polyurethane and Silicone Adhesives to Zinc Dichromated Steel

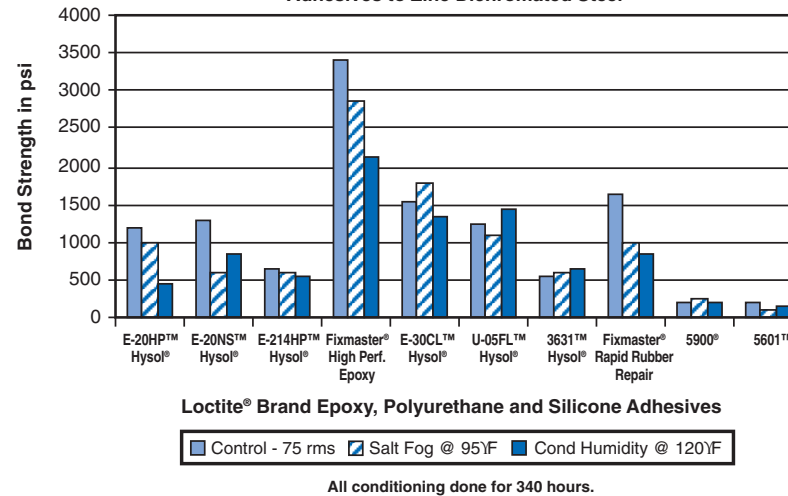


Figure 8.7-6
Effect of Heat Aging on the Bond Strength of Epoxy, Polyurethane and Silicone Adhesives to Zinc Dichromated Steel

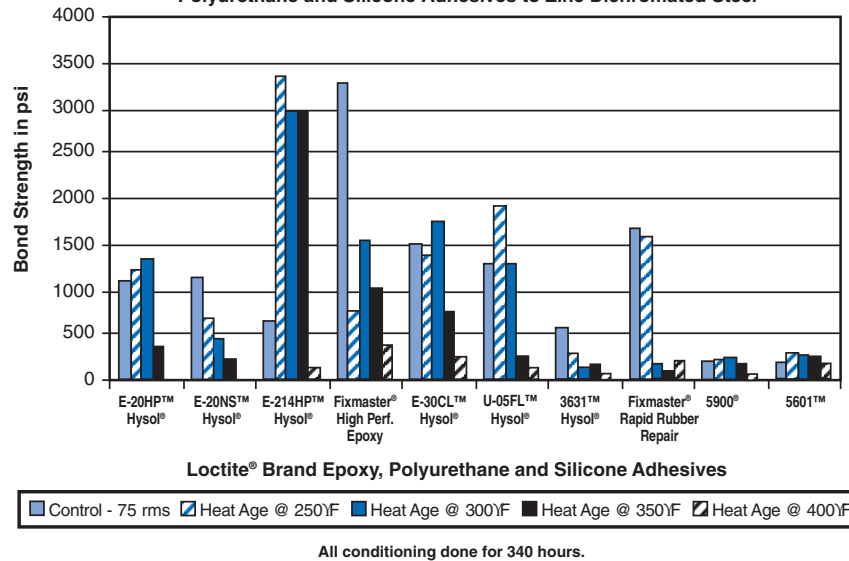
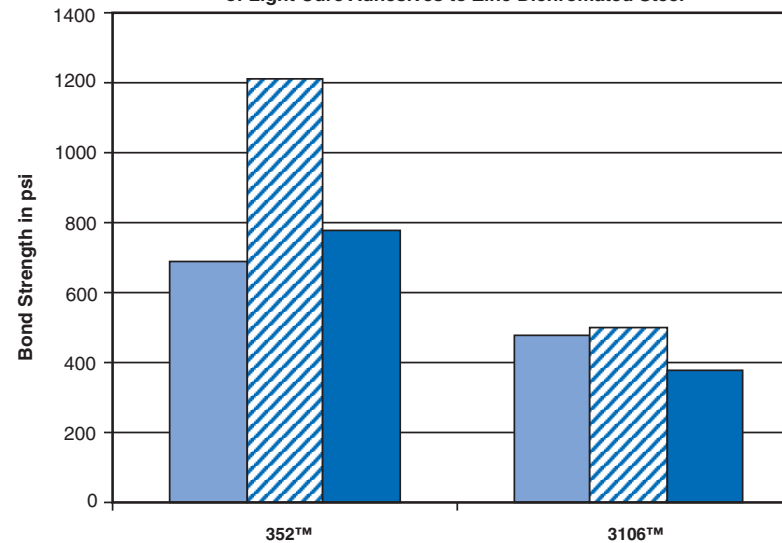


Figure 8.7-7
Effect of Condensing Humidity and Salt Fog Exposure on the Bond Strength of Light Cure Adhesives to Zinc Dichromated Steel

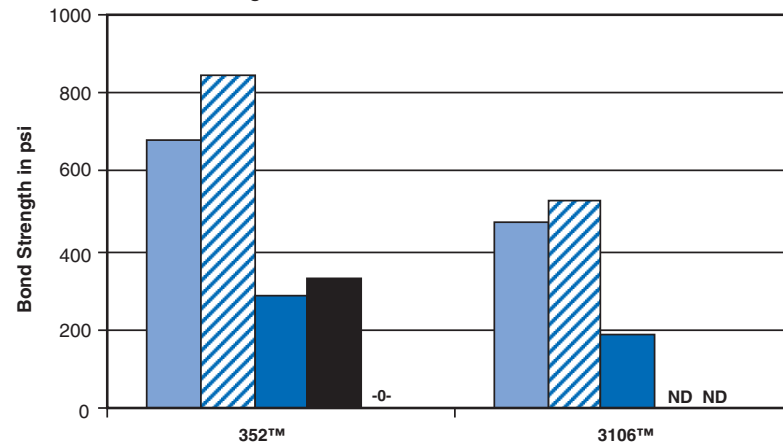


Loctite® Brand Light Cure Adhesives

Control - 75 rms Salt Fog @ 95°F Cond Humidity @ 120°F

All conditioning done for 340 hours.

Figure 8.7-8
Effect of Heat Aging on the Bond Strength of Light Cure Adhesives to Zinc Dichromated Steel



Loctite® Brand Light Cure Adhesives

Control - 75 rms Heat Age @ 250°F Heat Age @ 300°F Heat Age @ 350°F Heat Age @ 400°F

All conditioning done for 340 hours.

Section 8.8: Zinc Galvanized Steel

General Description

Galvanized steel is steel which has been coated with zinc either through hot dipping or electroplating. The zinc coating protects the steel by forming a barrier of relatively corrosion resistant material around the steel, and forming a self-protecting film of fairly impermeable corrosion by-products when corrosion does occur. In addition, the zinc provides electrochemical protection for the steel by sacrificially corroding in place of the steel base substrate. As a result, the zinc coating provides corrosion protection for the underlying steel layer even if there are breaks in the coating.

Hot Dipping

Hot dipping applies a zinc coating to steel by drawing the steel through a bath of molten zinc. When the steel is withdrawn, it is coated in a layer of zinc that will dramatically improve the corrosion resistance of the steel. The coating thickness can be controlled by varying the zinc temperature, immersion time and withdrawal rate of the steel from the bath. The zinc coating actually forms three layers of iron-zinc alloy phases with decreasing proportions of zinc near the steel interface, with the outer layers primarily zinc. Since the ability of the zinc to alloy with the steel is critical to good coating formation, it is important that the grades of steel used be low in other alloying constituents that may interfere with this process. Other constituents may be added to the molten zinc bath to improve the characteristics of the coating layer. When aluminum is added in small amounts (0.05 - 0.25 percent), it improves the fluidity of the bath and thus its ability to wet out to irregularly shaped objects. Aluminum also contributes to a reduction in the thickness of the alloy layer, which gives coatings that are more ductile and thus better able to handle deformation and drawing operations without peeling or cracking. Tin can also be added to improve the surface appearance, the uniformity, and the adherence of the coating. The degree of corrosion protection offered by the zinc coating is directly related to the thickness of the zinc layer, so efforts to reduce the thickness of the coatings to improve their ductility will have a detrimental effect on the amount of corrosion resistance that the coating affords the steel substrate.

Electroplating

Electroplating offers better control over coating thickness and uniformity than hot dipping and avoids potential problems stemming from alloying constituents in the steel having a detrimental effect on the quality of the zinc coating that is formed.

Zinc plating solutions can be acid bath or alkaline cyanide bath, though the alkaline cyanide bath type is more frequently used. The coating deposited is largely pure zinc and extremely ductile.

Summary of Results

The results of the bond strength testing are shown in Tables 8.8-1 and 8.8-2 and in Figures 8.8-1 through 8.8-8. The results are summarized below.

Cyanoacrylates

Salt Fog 95°F (35°C) - All cyanoacrylates decreased significantly in bond strength.

Condensing Humidity 120°F (49°C) - All cyanoacrylates decreased significantly in bond strength.

Heat Aging - All cyanoacrylates decreased significantly in bond strength for all times and temperatures tested, although Loctite® 4205™ Prism® Instant Adhesive retained in excess of 60% of its initial strength after 340 hours at temperatures as high as 300°F (149°C). The ability of Loctite® 416™ Super Bonder® Instant Adhesive to maintain bond strength after exposure to temperatures as high as 350°F (177°C) and 400°F (204°C) is surprising since cyanoacrylates revert to cyanoacrylate monomer at temperatures above 320°F (160°C). The bond strength is likely due to the presence of the polymethylmethacrylate filler used in Loctite® 416™ Super Bonder® Instant Adhesive.

No-Mix and Static Mix Acrylic Adhesives

Salt Fog 95°F (35°C) - Loctite® 324™ Speedbonder™ Structural Adhesive increased significantly in bond strength after this exposure. Loctite® 330™ Depend® Adhesive increased slightly in bond strength. Loctite® 392™ Structural Adhesive decreased slightly in bond strength, while Loctite® 326™ Speedbonder™ and 334™ Structural Adhesives decreased significantly. Loctite® H8000™ Speedbonder™ Structural Adhesive increased slightly in bond strength, whereas Loctite® H3410™ Speedbonder™ Structural Adhesive showed no significant change.

Condensing Humidity 120°F (49°C) - Loctite® 324™ Speedbonder™ and 334™ Structural Adhesives and Loctite® 330™ Depend® Adhesive increased significantly in bond strength. Loctite® 326™ Speedbonder™ and 392™ Structural Adhesives decreased significantly in bond strength. Loctite® H8000™ Speedbonder™ Structural Adhesive decreased slightly in bond strength, while Loctite® H3410™ Speedbonder™ Structural Adhesive decreased significantly in bond strength.

Heat Aging - Loctite® 324™ Speedbonder™ and 334™ Structural Adhesives increased significantly after exposure to 250°F (121°C) for 340 hours, showed little change when conditioned at 300°F (149°C), decreased slightly or significantly at 350°F (177°C), and then all three decreased significantly after 340 hours at 400°F (204°C). Loctite® 326™ Speedbonder™ Structural Adhesive and Loctite® 330™ Depend® Adhesive showed a slight or no decrease after 340 hours at 250°F (121°C) but decreased significantly in bond strength to galvanized steel after 340 hours at the higher temperatures. Loctite® 392™ Structural Adhesive showed a significant decrease in bond strength for all times and temperatures tested. Loctite® H8000™ Speedbonder™ Structural Adhesive increased significantly or slightly in bond strength after exposure to 250°F (121°C), 300°F (149°C), at 350°F (177°C) and 400°F (204°C) for 340 hours. Loctite® H3410™ Speedbonder™ Structural Adhesive decreased significantly in bond strength following exposure to 250°F (121°C), 300°F (149°C) and 400°F (204°C) for 340 hours, but showed a significant increase in bond strength after exposure to 350°F (177°C).

Light Cure Adhesives

Salt Fog 95°F (35°C) - Slight decrease for Loctite® 352™ Light Cure Adhesive, significant decrease for Loctite® 3106™ Light Cure Adhesive.

Condensing Humidity 120°F (49°C) - Significant decrease in bond strength for both adhesives

Heat Aging - Loctite® 3106™ Light Cure Adhesive decreased significantly at 250°F (121°C), while Loctite® 352™ Light Cure Adhesive showed no significant change at this temperature before declining significantly at higher temperatures.

Epoxy Adhesives

Salt Fog 95°F (35°C) - All epoxies evaluated decreased significantly in bond strength. Loctite® Fixmaster® High Performance Epoxy showed a significant decrease in bond strength. Loctite® E-30CL™ Hysol® Epoxy Adhesive showed a slight decrease.

Condensing Humidity 120°F (49°C) - Loctite® E-20NS™ Hysol® Epoxy Adhesive decreased in bond strength slightly while Loctite® E-20HP™ and E-214HP™ Hysol® Epoxy Adhesives decreased significantly. Both Loctite® Fixmaster® High Performance Epoxy and Loctite® E-30CL™ Hysol® Epoxy Adhesive showed slight decreases.

Heat Aging - Loctite® E-20HP™ Hysol® Epoxy Adhesive decreased significantly in bond strength after 340 hours at 250°F (121°C), while Loctite® E-20NS™ and E-214HP™ Hysol® Epoxy Adhesives showed no change at this temperature but decreased significantly after 340 hours at 300°F (149°C) and above. Both Loctite® Fixmaster® High Performance Epoxy and Loctite® E-30CL™ Hysol® Epoxy Adhesive showed a significant decrease in bond strength when being exposed to 250°F (121°C), and then showed slight but consistent decreases in bond strength at each of the higher temperatures.

Polyurethane Adhesives

Salt Fog 95°F (35°C) - Slight improvement for Loctite® 3631™ Hysol® Hot Melt Adhesive and Loctite® Fixmaster® Rapid Rubber Repair.

Condensing Humidity 120°F (49°C) - Significant decrease in bond strength for Loctite® 3631™ Hysol® Hot Melt Adhesive, while there was no significant change for Loctite® Fixmaster® Rapid Rubber Repair.

Heat Aging - Compared to the room temperature bond strength, the bond strength improved significantly after conditioning at 250°F (121°C), slightly at 300°F (149°C), and then decreased significantly after exposure to 350°F (177°C) and 400°F (204°C) for 340 hours. Loctite® 3631™ Hysol® Hot Melt Adhesive showed significant improvement when exposed to 250°F (121°C), and then slight but consistent decreases at each of the higher temperatures. Loctite® Fixmaster® Rapid Rubber Repair showed no significant change when exposed to 250°F (121°C), and then significant at higher temperatures.

Silicone Adhesives

Salt Fog 95°F (35°C) - Significant decrease. Slight increase for Loctite® 5601™ Adhesive Sealant.

Condensing Humidity 120°F (49°C) - Slight decrease. Slight increase for Loctite® 5601™ Adhesive Sealant.

Heat Aging - In general, the silicones showed improved bond strength at the times and temperatures tested. No significant change for Loctite® 5601™ Adhesive Sealant when exposed to all temperatures.

Table 8.8-1
Bond Strength of Several Loctite® Brand Adhesives on Zinc Galvanized Steel (psi)
 G-90 Galvanized Steel (0.9 oz. Zinc/ft²)

Loctite® Brand Medical Device Adhesive	—	4541™ Prism®	—	—	—	—	—	—	—	—	—	—	—	—	—	M-31CL™ Hysol®	M-06FL™ Hysol®	—	U-04FL™ Hysol® (Industrial)	—	—	—	3321™
Loctite® Brand Industrial Adhesive	416™ Super Bonder®	454™ Prism®	426™ Prism®	4205™ Prism®	324™ Speed-Bonder™	326™ Speed-Bonder™	330™ Depend®	334™	392™	H8000™ Speed-Bonder™	H3410™ Speed-Bonder™	E-20HP™ Hysol®	E-20NS™ Hysol®	E-214HP™ Hysol®	Fixmaster® High Perf. Epoxy	E-30CL™ Hysol®	U-05FL™ Hysol®	3631™	Fixmaster® Rapid Rubber Repair (MRO)	5900®	5601™	352™	3106™
Control - 19 rms	860	695	1150	1070	555	860	785	1590	1260	295	650	1850	815	3015	1485	950	960	575	450	260	70	1125	795
Salt fog @ 95°F	140	115	200	325	870	590	915	770	1040	410	590	710	635	220	685	675	1405	665	590	175	75	985	570
Condensing Humidity @ 120°F	145	335	720	530	675	615	1190	1915	825	245	75	750	685	1640	890	705	1115	310	405	230	140	705	505
Heat Age @ 250°F	480	200	575	660	845	735	790	2340	540	640	460	1105	1155	3070	975	655	2225	860	570	310	250	1055	405
Heat Age @ 300°F	205	0	45	730	585	395	380	1710	445	650	400	1000	670	2795	840	635	1095	380	35	395	295	470	110
Heat Age @ 350°F	120	0	0	0	335	250	400	1395	175	960	1580	705	440	2020	635	370	245	200	5	175	255	330	ND
Heat Age @ 400°F	160	0	0	0	135	255	175	130	145	495	85	330	385	1900	510	290	60	110	0	285	250	185	ND

Table 8.8-2
Normalized
Bond Strength of Several Loctite® Brand Adhesives on Zinc Galvanized Steel
 G-90 Galvanized Steel (0.9 oz. Zinc/ft²)

Loctite® Brand Medical Device Adhesive	—	4541™ Prism®	—	—	—	—	—	—	—	—	—	—	—	—	—	M-31CL™ Hysol®	M-06FL™ Hysol®	—	U-04FL™ Hysol® (Industrial)	—	—	—	3321™
Loctite® Brand Industrial Adhesive	416™ Super Bonder®	454™ Prism®	426™ Prism®	4205™ Prism®	324™ Speed-Bonder™	326™ Speed-Bonder™	330™ Depend®	334™	392™	H8000™ Speed-Bonder™	H3410™ Speed-Bonder™	E-20HP™ Hysol®	E-20NS™ Hysol®	E-214HP™ Hysol®	Fixmaster® High Perf. Epoxy	E-30CL™ Hysol®	U-05FL™ Hysol®	3631™	Fixmaster® Rapid Rubber Repair (MRO)	5900®	5601™	352™	3106™
Control - 19 rms	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Salt fog @ 95°F	16	17	17	30	157	69	117	48	83	139	91	38	78	74	46	71	146	116	131	67	107	88	72
Condensing Humidity @ 120°F	17	48	63	50	122	72	152	120	65	83	12	41	84	54	60	74	116	54	90	88	200	63	64
Heat Age @ 250°F	56	29	50	62	152	85	101	147	43	217	71	60	142	102	66	69	232	150	127	119	357	94	51
Heat Age @ 300°F	24	0	4	68	105	46	48	108	35	220	62	54	82	93	57	67	114	66	8	152	421	42	14
Heat Age @ 350°F	14	0	0	0	60	29	51	88	14	325	243	38	54	67	43	39	26	35	1	67	364	29	ND
Heat Age @ 400°F	19	0	0	0	24	30	22	8	12	168	13	18	47	63	34	31	6	19	0	110	357	16	ND

Note: Loctite® 324™ Speedbonder™ and Loctite® 352™ Structural Adhesive were cured with Loctite® 7075™ Activator.
 Loctite® 326™ Speedbonder™ was cured with Loctite® 7649™ Primer N™.
 Loctite® 330™ Depend® Adhesive, Loctite® 334™ Speedbonder™ Structural Adhesive, and Loctite® 392™ Structural Adhesive were cured with Loctite® 7387™ Depend® Activator.
 Loctite® 3106™ Light Cure Adhesive was tested bonded to polycarbonate and could not be conditioned above 300°F.
 All environmental conditioning done for 340 hours, samples allowed to equilibrate at ambient conditions for at least 24 hours prior to testing.
 ND = Not determined. Polycarbonate lapshear melted at temperature.

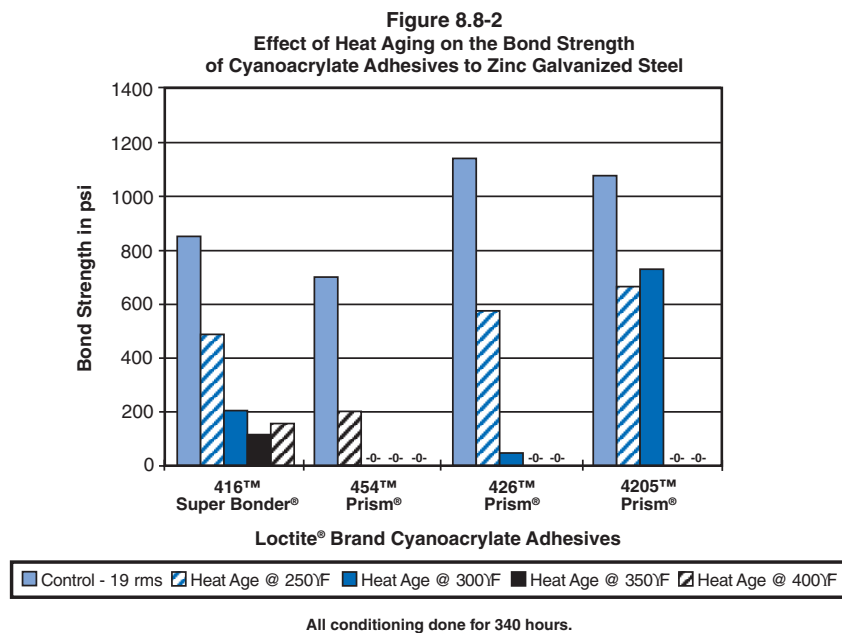
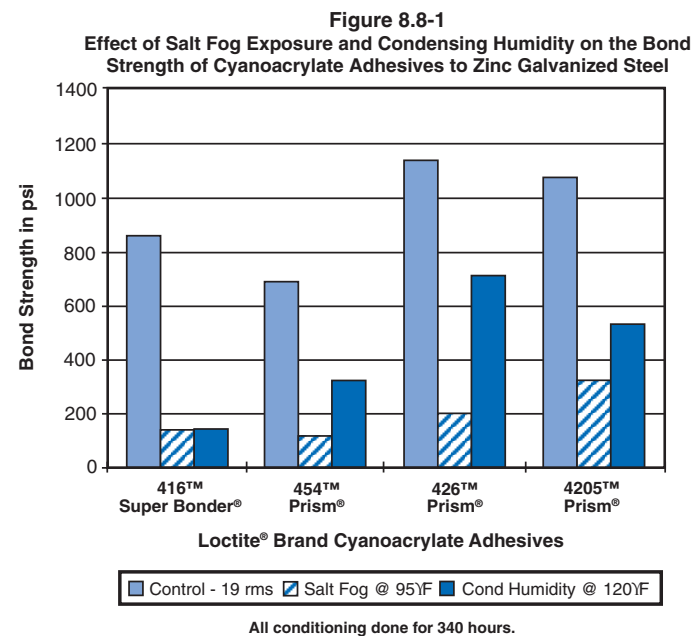


Figure 8.8-3
Effect of Salt Fog Exposure and Condensing Humidity on
the Bond Strength of No-Mix and Static Mix Acrylic Adhesives
to Galvanized Steel

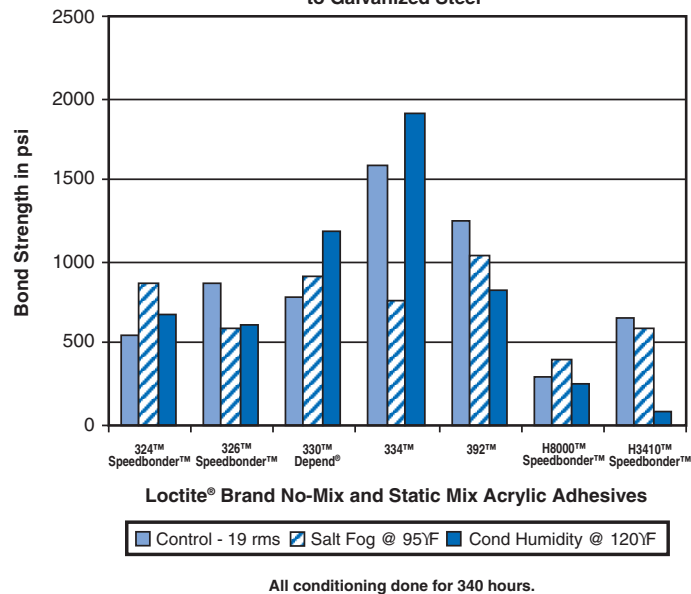


Figure 8.8-4
Effect of Heat Aging on the Bond Strength of
No-Mix and Static Mix Acrylic Adhesives to Galvanized Steel

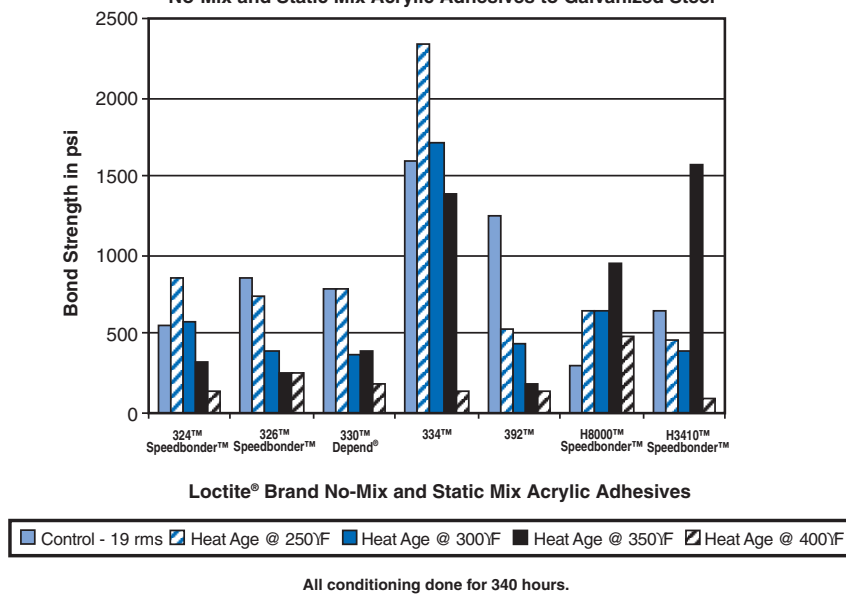


Figure 8.8-5
Effect of Salt Fog Exposure and Condensing Humidity
on the Bond Strength of Epoxy, Polyurethane and
Silicon Adhesives to Zinc Galvanized Steel

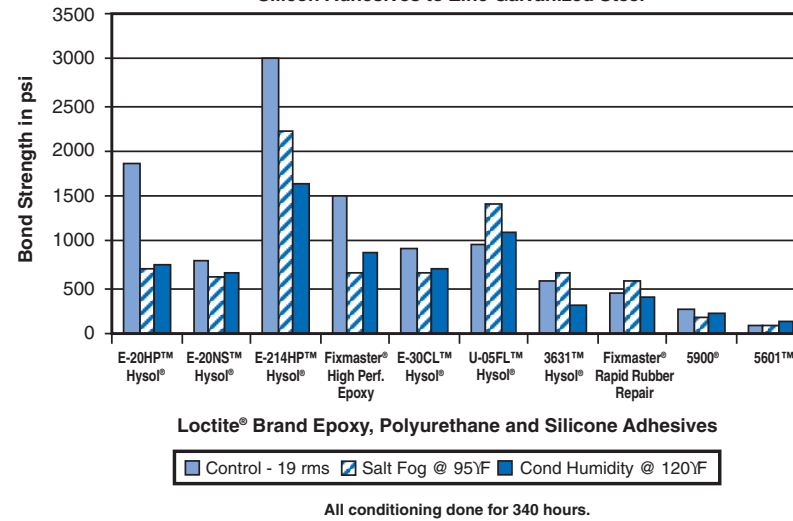


Figure 8.8-6
Effect of Heat Aging on Bond Strength of Epoxy,
Polyurethane and Silicone Adhesives to Galvanized Steel

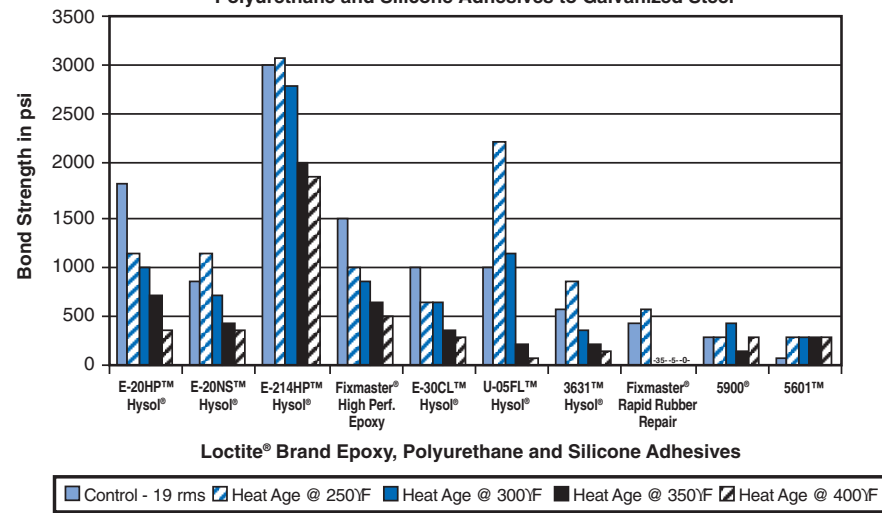


Figure 8.8-7
Effect of Salt Fog Exposure and Condensing Humidity on the
Bond Strength of Light Cure Adhesives to Zinc Galvanized Steel

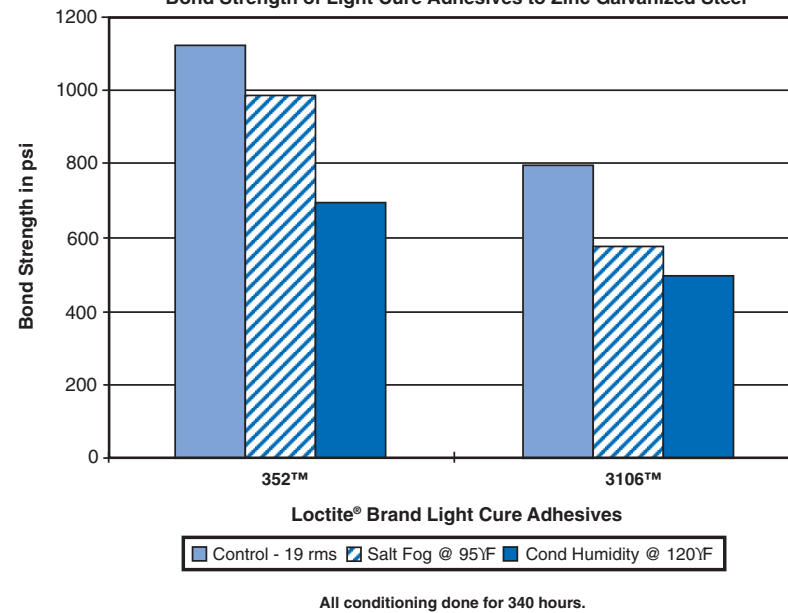
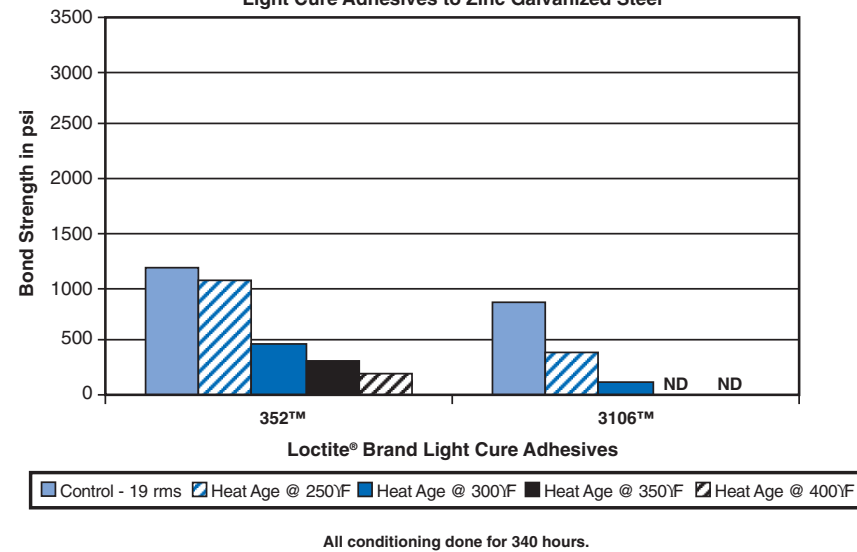


Figure 8.8-8
Effect of Heat Aging on Bond Strength of
Light Cure Adhesives to Zinc Galvanized Steel



Section 9: Test Methodology

The Selection of Adhesives

It was desired to evaluate families of adhesives which are commonly used for bonding metals. For each family of adhesives, a specific adhesive formulation was selected as representative of that family and used in the test program. Table 9-1 lists the families of adhesives included in the test matrix and the adhesive(s) chosen to represent them.

Table 9-1 Adhesives Evaluated in the Test Program		
Adhesive Family	Loctite® Brand Industrial Adhesive	Loctite® Brand Medical Device Adhesive
Ethyl Cyanoacrylate	Loctite® 416™ Super Bonder® Instant Adhesive	-
Surface Insensitive Cyanoacrylate	Loctite® 454™ Prism® Instant Adhesive	Loctite® 4541™ Prism® Instant Adhesive
Rubber Toughened Cyanoacrylate	Loctite® 426™ Prism® Instant Adhesive	-
Thermally Resistant, Rubber Toughened Cyanoacrylates	Loctite® 4205® Prism® Instant Adhesive	-
Two Part, No-Mix Acrylic	Loctite® 324™ Speedbonder™ Structural Adhesive	-
Two Part, No-Mix Acrylic	Loctite® 326™ Speedbonder™ Structural Adhesive	-
Two-Part, No-Mix Acrylic	Loctite® 330™ Depend® Adhesive	-
Two-Part, No-Mix Acrylic	Loctite® 334™ Structural Adhesive	-
Two-Part, No-Mix Acrylic	Loctite® 392™ Structural Adhesive	-
UV/Activator Cure Acrylic	Loctite® 352™ Light Cure Adhesive	-
UV/Visible Light Cure Acrylic	Loctite® 3106™ Light Cure Adhesive	Loctite® 3321™ Light Cure Adhesive
Two-Part Epoxy (amine hardener)	Loctite® E-20HP™ Hysol® Epoxy Adhesive Loctite® E-20NS™ Hysol® Epoxy Adhesive Loctite® E-30CL™ Hysol® Epoxy Adhesive Loctite® Fixmaster® High Performance Epoxy	- - Loctite® M-31CL™ Hysol® Medical Device Epoxy Adhesive -
One-Part Heat Cure Epoxy (polyamide hardener)	Loctite® E-214HP™ Hysol® Epoxy Adhesive	-
Two-Part Polyurethane	Loctite® U-05FL™ Hysol® Urethane Adhesive Loctite® Fixmaster® Rapid Rubber Repair (MRO)	Loctite® M-06FL™ Hysol® Medical Device Adhesive Loctite® U-04FL™ Hysol® Urethane Adhesive (Industrial)
Reactive Polyurethane Hot Melt	Loctite® 3631™ Hysol® Hot Melt Adhesive	-
Oxime Cure Silicone	Loctite® 5900® Flange Sealant	-
Two-Part, Condensation Cure Silicone	Loctite® 5601™ Adhesive Sealant	-
Two-Part, Static Mix Acrylic	Loctite® H8000™ Speedbonder™ Structural Adhesive	-
Two-Part, Static Mix Acrylic	Loctite® H3410™ Speedbonder™ Structural Adhesive	-

Substrate Preparation

1. All substrates were cleaned with isopropyl alcohol prior to bonding.

Adhesive Application and Cure Method

Cyanoacrylates

(Loctite® 416™ Super Bonder® Instant Adhesive, Loctite® 454™ Prism® Instant Adhesive, Loctite® 426™ Prism® Instant Adhesive, Loctite® 4205® Prism® Instant Adhesive)

1. Adhesive was applied in an even film to the end of one lapshear.
2. A second lapshear was mated to the first with an overlap area of 0.5 in².
3. The mated assembly was clamped with two clamps that exerted a clamping force of approximately 20 lb.
4. The bonded assembly was allowed to cure for one week at ambient conditions before conditioning and testing.

No-Mix Acrylic Adhesives

(Loctite® 324™ Speedbonder™ Structural Adhesive, Loctite® 326™ Speedbonder™ Structural Adhesive, Loctite® 330™ Depend® Adhesive, Loctite® 334™ Structural Adhesive, Loctite® 392™ Structural Adhesive)

1. Activator was applied to the end of one lapshear.
 - a. For solvent-borne activators (Loctite® 7649™ Primer N™, 7471™ Primer T™ and 736™ Primer NF™ and Loctite® 7387™ Depend® and 7075™ Activators), an even film was sprayed onto the end of the lapshear and the solvent was allowed to evaporate.
 - b. For Solventless Activator (Loctite® 7380™ Activator), the activator was applied at a weight per unit area of 4 milligrams per in².
 - c. For Solventless Activators (Loctite® 7090™ and 7091™ Activators), the activator was dispensed at a weight per unit area of 6 milligrams/in².
2. The adhesive was applied to the end of a second lapshear.
3. The second lapshear was mated with the first lapshear so the activator coated section of the first lapshear was pressed against the adhesive on the second lapshear to yield a total bond area of 0.5 in².
4. The mated assembly was clamped with two clamps that exerted a clamping force of approximately 20 lb.

5. The bonded assembly was allowed to cure for one week at ambient conditions before conditioning and testing.

Two-Part Static Mixed Adhesives

(Loctite® E-20HP™ Hysol® Epoxy Adhesive, Loctite® E-20NS Hysol® Epoxy Adhesive, Loctite® E-214HP™ Hysol® Epoxy Adhesive, Loctite® U-05FL™ Hysol® Urethane Adhesive, Loctite® H8000™ Speedbonder™ Structural Adhesive, Loctite® H3410™ Speedbonder™ Structural Adhesive, Loctite® Fixmaster® High Performance Epoxy, Loctite® E-30CL™ Hysol® Epoxy Adhesive, Loctite® 3631™ Hysol® Hot Melt Adhesive, Loctite® Fixmaster® Rapid Rubber Repair)

1. The adhesive was dispensed onto the end of one lapshear through an appropriate static mixing nozzle to achieve thorough mixing of the two adhesive components.
2. A second lapshear was mated to the first with an overlap area of 0.5 in².
3. The mated assembly was clamped with two clamps that exerted a clamping force of approximately 20 lb.
4. The bonded assembly was allowed to cure for one week at ambient conditions before conditioning and testing.

UV/Activator Cure Acrylic Adhesive

(Loctite® 352™ Light Cure Adhesive)

1. Activator Loctite® 7075™ Activator was applied to the end of one lapshear and the solvent was allowed to evaporate.
2. The adhesive was applied to the end of a second lapshear.
3. The second lapshear was mated with the first lapshear so the activator coated section of the first lapshear was pressed against the adhesive on the second lapshear to yield a total bond area of 0.5 in².
4. The mated assembly was clamped with two clamps that exerted a clamping force of approximately 20 lb.
5. The bonded assembly was allowed to cure for one week at ambient conditions before conditioning and testing.

Light Cure Adhesive

(Loctite® 3106™ Light Cure Adhesive)

1. Adhesive was applied to one end of a metal lapshear.
2. A polycarbonate lapshear was mated with the metal lapshear to yield a total bond area of 0.5 in₂.
3. The adhesive in the mated assembly was cured by irradiating it through the polycarbonate lapshear for 30 seconds with a medium pressure mercury arc light source having an irradiance of 100 mW/cm₂ at 365 nm.
4. The assembly was left at ambient conditions for one week prior to conditioning and testing.

One-Part Heat Cure Epoxy Adhesive

(Loctite® H-214HP™ Hysol® Epoxy Adhesive)

1. Adhesive was applied in an even film to the end of one lapshear.
2. A second lapshear was mated to the first with an overlap area of 0.5 in₂.
3. The mated assembly was clamped with two clamps that exerted a clamping force of approximately 20 lb.
4. The clamped assembly was heated at 350°F (177°C) for 1 hour.
5. The assembly was left at ambient conditions for one week prior to conditioning and testing.

Moisture Cure Products

(Loctite® 5900® Flange Sealant, Loctite® 5601™ Adhesive Sealant, Loctite® 3631™ Hysol® Hot Melt Adhesive)

1. Adhesive was applied in an even film to the end of one lapshear.
2. A short length of 10 mil thick wire was embedded in the sealant to induce a 10 mil gap between the bonded lapshears (except for Loctite® 3631™ Hysol® Hot Melt Adhesive).
3. A second lapshear was mated to the first with an overlap area of 0.5 in₂.
4. The mated assembly was allowed to moisture cure for one week prior to conditioning and testing.

Test Methods

Shear Strength Test Method

For this testing, the standard shear strength test ASTM D-1002 was used to evaluate shear strength of the bonded assemblies.

1. The bonded assemblies were gripped in the pneumatic jaws of the MTS physical properties tester.
2. The assemblies were pulled apart at a rate of 0.05"/minute.
3. The peak force required to pull the assemblies apart was recorded as the bond strength of the assembly.
4. Five replicates were tested for each data set.

Surface Roughness

1. Surface roughness was evaluated using a Surfanalyzer 4000 with a traverse distance of 0.03 inches and a traverse speed of 0.01 inches/second.

Section 10:

Did You Know?

DUROMETER HARDNESS

Durometer hardness is a property presented on technical data sheets that shows how hard the resin is in the cured state. A durometer gauge is the actual measuring device consisting of a small drill or blunt indenter point under pressure. Different measurement scales are used for different materials depending on how soft or hard the material. The following chart compares three (3) different graduated measurement scales and relates hardness values to some common objects as well as Loctite® brand products.

Shore A	Shore D	Rockwell M	Reference Object	Loctite® Brand Product
30			Art Gum Eraser	5140™
40			Pink Pearl Eraser	5900®
50	15		Rubber Stamp	—
60			Pencil Eraser	5699™
70	30		Rubber Heel	—
80			Rubber Sole	—
90	45		Typewriter Roller	366™
100	55		Pipe Stem	3106™
	74	0	Textbook Cover	334™
	78	32	Douglas Fir Plywood	—
	82	63		E-60HP™
	86	95	Hardwood Desktop	—
	90	125	Glass or Formica	—

The higher the number within each scale, the harder the material. Shore readings are typically used for plastics. Shore A is for softer materials; Shore D is for harder materials. Rockwell M readings are typically used for metals.

MATHEMATICAL CONVERSIONS

The following are some common conversions that might be helpful when utilizing Loctite® brand products:

- 1 milliliter (ml) = 1 cubic centimeter (cc)
- 1,000 ml = 1 liter
- 29.5 ml = 1 fl. oz.
- 3.78 liters = 1 gallon
- 473 ml = 1 pint
- 454 grams = 1 lb.
- 947 ml = 1 quart
- 1 kilogram = 2.2 lbs.
- Weight to Volume: grams ÷ specific gravity = cc (ml)
- Volume to Weight: cc (ml) x specific gravity = grams
- Density = specific gravity x 0.99823
- Centipoise = centistoke x density (at a given temp.)
- Temperature: degrees F - 32 x 0.556 = degrees C
degrees C x 2 - 10% + 32 = degrees F
- Square Inches to Square Feet: ÷ by 144
- Square Feet to Square Inches: x by 144
- In./lbs. ÷ 12 = ft./lbs.
- Ft./lbs. x 12 = in./lbs.
- 16 in. oz. = 1 in. lb.
- 192 in. oz. = 1 ft. lb.

AREA COVERAGE

Flat Parts:

Length x Width x Bondline Thickness x 16.4 = cc/ml requirement per part

Non-threaded Cylindrical Parts:

Diameter x Engagement Length x Bondline Thickness (on radius/per side)
x 3.14 x 16.4 = cc/ml requirement per part

Potting/ Encapsulating Applications:

Area (3.14 x R²) x Potting Depth x 16.4 = cc/ml requirement per part

For no induced gap, make the bondline thickness figure 0.001". 16.4 is a constant for converting cubic inches to cubic centimeters.

VISCOSITY

Viscosity is a product property you'll find associated with all Loctite® brand adhesive/sealants. Viscosity is defined as a measure of the resistance of a fluid to flow (usually through a specific orifice). A measure of this fluid "thickness" is expressed in centipoise values. The higher the number, the thicker the product. Thicker products are less flowable, and in most cases, will fill a larger gap if necessary. The following chart relates viscosity to some products we are all familiar with:

LOCTITE® BRAND PRODUCT EXAMPLES

Product	Approximate Viscosity in Centipoise (cP)	Cyanoacrylates	Anaerobics
Water @ 70°	1-5	420™ Super Bonder®	—
Blood or Kerosene	10	—	290™
Anti-Freeze or Ethylene Glycol	15	406™ Prism®	Letter Grade A
Motor Oil SAE 10 or Mazola Corn Oil	50-100	414™ Super Bonder®, 496™ Super Bonder®	609™
Motor Oil SAE 30 or Maple Syrup (Log Cabin)	150-200	—	675™
Motor Oil SAE 40 or Castor Oil	250-500	4203™ Prism®, 4471™ Prism®	640™
Motor Oil SAE 60 or Glycerin	1,000-2,000	403™ Prism®, 422™ Super Bonder®	222MS™, 242®, 262™
Karo® Corn Syrup or Honey	2,000-3,000	410™ Prism®, 4211™ Prism®	635™
Uncle Tom's® Blackstrap Molasses	5,000-10,000	411™ Prism®, 382™ Prism®	277™, 620™
Hershey® Chocolate Syrup	10,000-25,000	—	324™ Speedbonder™, 326™ Speedbonder™
Heinz® Ketchup or French's Mustard	50,000-70,000	409™ Super Bonder®	330™ Depend®
Tomato Paste or Peanut Butter	150,000-250,000	—	592™ PST®
Crisco® Shortening – Lard	1,000,000-2,000,000	—	660™ Quick Metal®
Caulking Compound	5,000,000-10,000,000	—	593™
Window Putty	100,000,000	—	—

Some products are considered thixotropic. This describes materials that are gel-like at rest but fluid when agitated. Heinz® Ketchup is a good example that exhibits this property. Loctite® brand products include Loctite® 262™ Threadlocker and Loctite® 509™ Flange Sealant.

SHELF LIFE

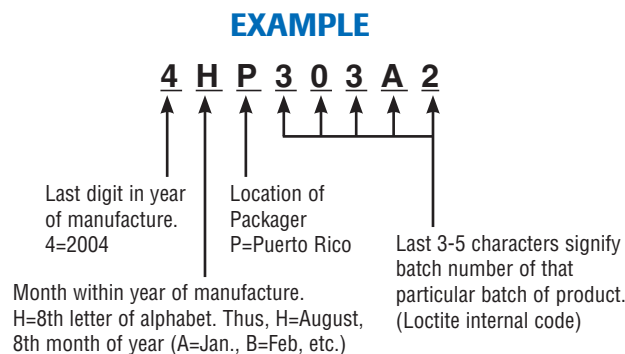
What is the Henkel shelf life policy?

Most Loctite® brand products have a one year shelf life from date of shipment from Henkel facilities, unless otherwise specified by product label. One year holds true for unopened containers only. Once opened, Henkel does not put a time frame on shelf life due to lack of control over how the product is handled once sold. Cyanoacrylates are the primary line of products that should be refrigerated (40° ± 5°F) prior to opening. Once opened, store these products at room temperature (below 80°F) in a cool, dry location. Do not rerefrigerate cyanoacrylates after opening. Most other Loctite® brand products should be stored at room temperature (below 80°F) in a cool, dry location before and after opening.

Do the 6 or 7 character batch codes on containers signify the date of shipment?

No... This code signifies date of manufacture. Certified shelf life is based on this code only if date of shipment cannot be determined. This is generally 2 years from date of manufacturing for most products.

How do you read this 6 or 7 character batch code?



Once a product reaches its “1 year from date of shipment” date, does this mean it can no longer be used?

No... Henkel offers a policy for extension of shelf life. Contact Henkel Customer Service (800-243-4874) for details.

Henkel Corporation is in the process of implementing a new “Use By Date” label on all product packages to make the shelf life policy easier to understand.

Section 11:

Disclaimer

The information contained herein is intended solely as an indicator of the bondability of the evaluated metals. The information is believed to be accurate, and is well suited for comparative analysis, however, the testing was performed using a limited number of adhesive lots, metal lots, and replicates. Consequently, this makes the information contained herein inappropriate for specification purposes.

Henkel Corporation can not assume responsibility for the results obtained by others over whose methods we have no control. It is the user's responsibility to determine suitability for the user's purpose of any production method mentioned herein and to adopt such precautions as may be advisable for the protection of property and of persons against any hazards that may be involved in the handling and use thereof.

In light of the foregoing, Henkel Corporation specifically disclaims all warranties of merchantability or fitness for a particular purpose arising from sale or use of Loctite® brand products. Henkel Corporation specifically disclaims any liability for consequential or incidental damages of any kind, including lost profits. The discussion herein of various process or compositions is not to be interpreted as representation that they are free from domination of patents owned by others or as a license under any Henkel Corporation patents which may cover such processes or compositions. We recommend that each prospective user test the proposed application in its manufacturing process using this data as a guide. This product may be covered by one or more United States or foreign patents or patent applications.



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