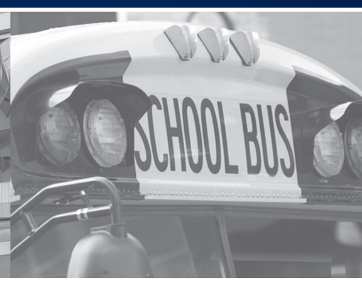
LOCTITE®

Design Guide for Bonding Metals

Volume 5
2011



Henkel

LOCTITE® Design Guide for Bonding Metals Volume 5 LT-3371

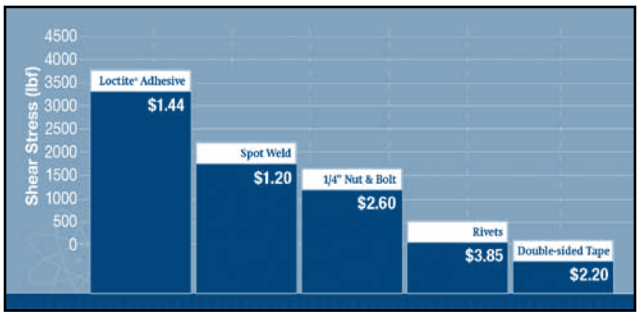
Contents

Section 1

Why Bond Metals with Loctite® Brand Adhesives?

Advantages of LOCTITE® Structural Adhesives vs. Mechanical Fasteners:

- Adhesives distribute stress evenly across the bond line while mechanical fasteners create stress concentration points which lead to premature failure.
- Improved aesthetics of the final assembly – no bolt heads sticking out
- Adhesives minimize or eliminate secondary operations like punching holes required with many fastener applications

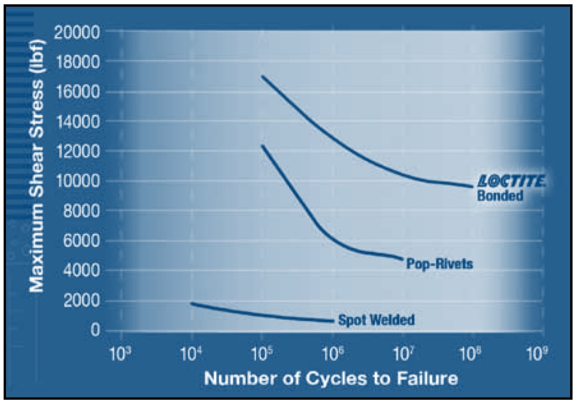


LOCTITE® Structural Adhesives are nearly 2x stronger than spot welds and bolts.

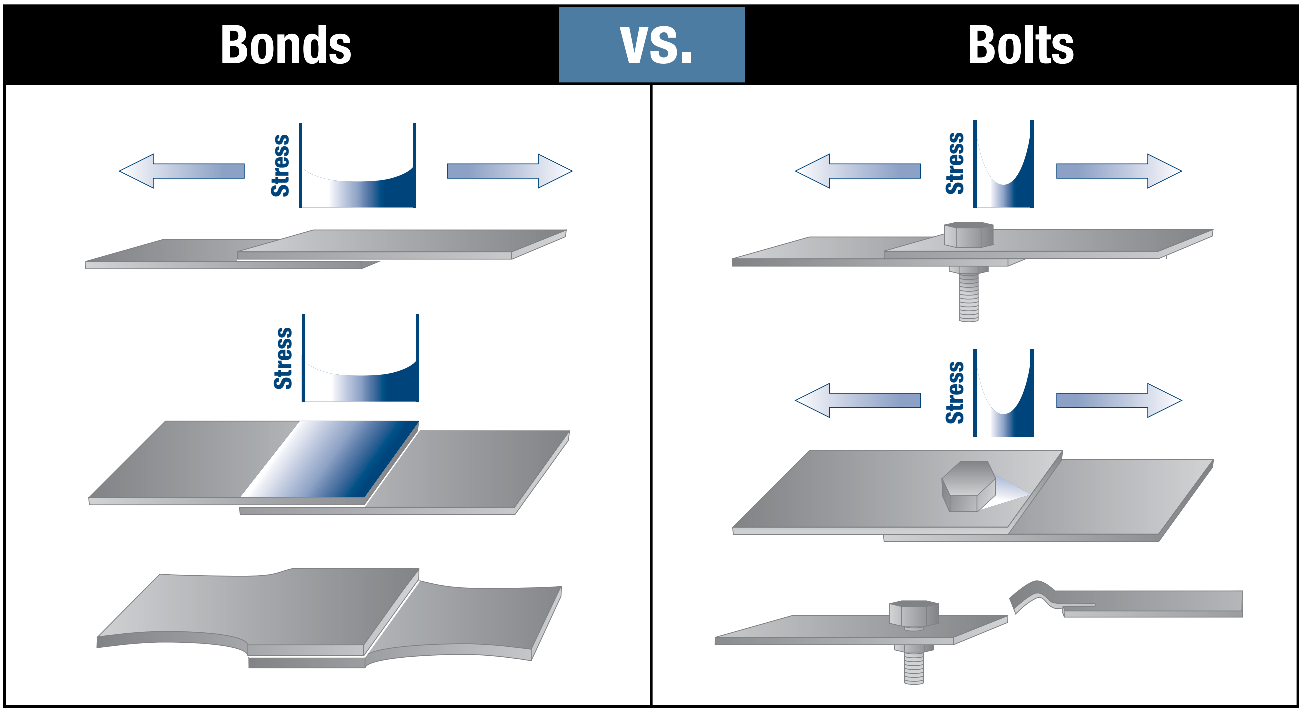
Visit www.henkelna.com/loctitestructurals and click on "Bonds vs. Bolts" to see video proof of bonds outperforming bolts, rivets, and spot welds.

Advantages of LOCTITE® Structural Adhesives vs. Welding, Brazing, and other Thermal Joining Methods:

- Allow joining of dissimilar substrates
- Thermal joining methods can cause distortion of the part, which may affect the assembly's performance. Adhesives do not distort parts.
- Improved aesthetics of the final assembly – no visible weld seams or discoloration
- Adhesives minimize or eliminate secondary operations like grinding and polishing



LOCTITE® Structural Adhesives withstand the test of time better than spot welds and rivets.



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.

Performance 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-step acrylic products.
- **Section 6: Heat Cure Parameters for Two-Step Acrylic Adhesives** provides information on the times and temperatures needed to heat cure these products when an activator cannot be used.
- **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.

Section 3

Adhesive Joint Design

Introduction

In this section, the terms and concepts related to joint design are divided into three categories which include:

- Types of Joints
- Joint Stress Distribution
- Design Guidelines

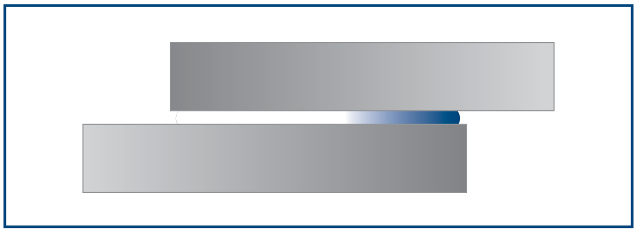
Before looking at different types of joints, a few terms need to be explained:

> **Joint:** A joint is the location where an adhesive joins two substrates.
>
> **Joint Geometry:** Joint geometry refers to the general shape of an adhesive bond. Is the shape of the bond long and narrow, short and wide, thick or thin?

Types of Joints

The specific types of joints which will be examined in this section include:

- Lap/Overlap
- Offset
- Butt
- Scarf
- Strap/Double Strap
- Cylindrical

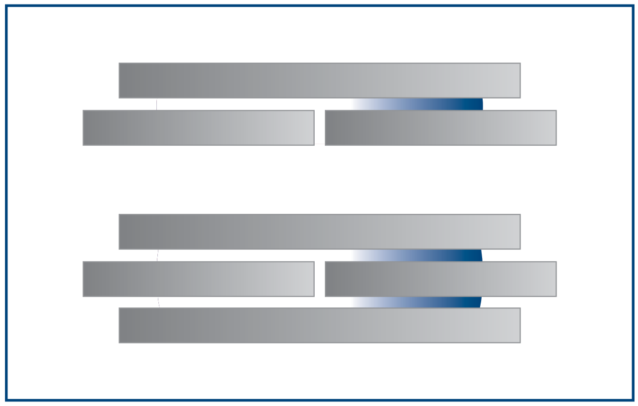


LAP/OVERLAP JOINT: A lap joint, also called an overlap joint, is formed by placing one substrate partially over another substrate.

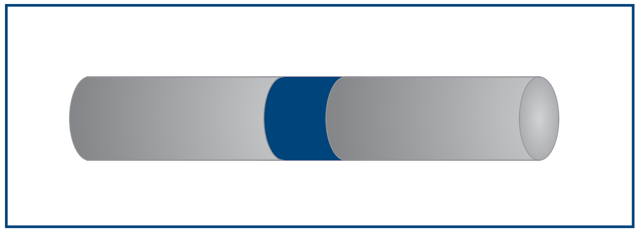
OFFSET JOINT: The offset joint is very similar to the lap joint.

BUTT JOINT: A butt joint is formed by bonding two objects end to end.

SCARF JOINT: A scarf joint is an angular butt joint. Cutting the joint at an angle increases the surface area.



STRAP JOINT (SINGLE OR DOUBLE): A strap joint is a combination overlap joint with a butt joint.



CYLINDRICAL JOINT: A cylindrical joint uses a butt joint to join two cylindrical objects.

Joint Stress Distribution

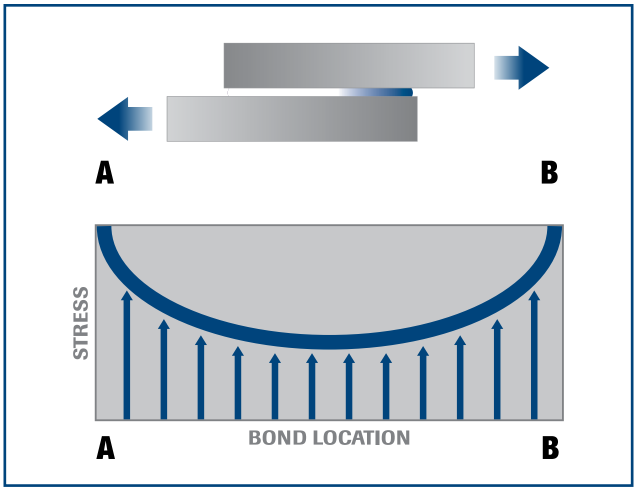
Joint stress distribution is the location of stresses within a bond.

Stress: Usually expressed as Newtons per square meter (N/M2), which is equivalent to a Pascal (Pa.) In the English system, stress is normally expressed in pounds per square inch (psi).

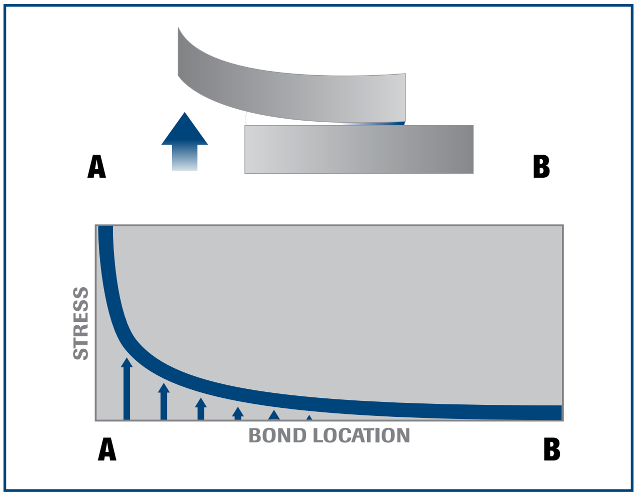
Types of Stresses

There are several types of stresses commonly found in adhesive bonds which include:

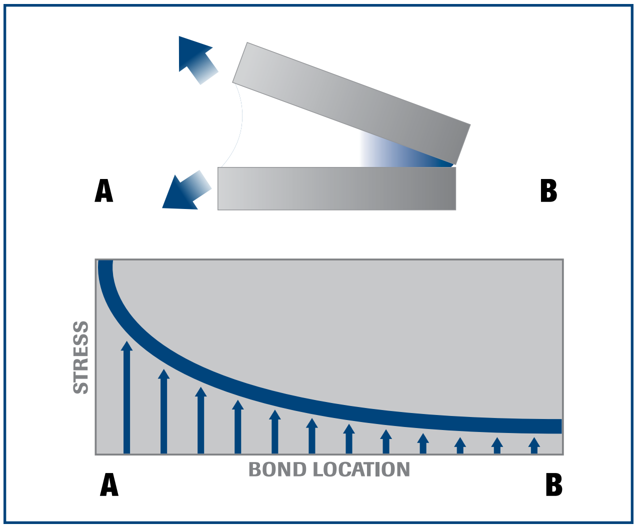
- Shear
- Tensile
- Compressive
- Peel
- Cleavage



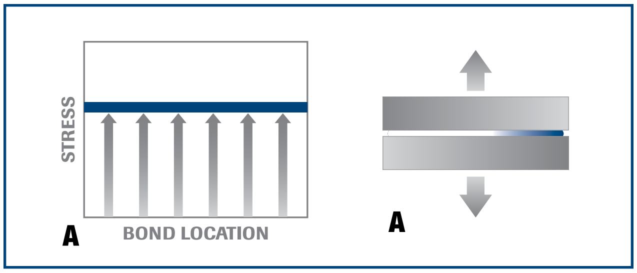
SHEAR STRESS: A shear stress results in two surfaces sliding over one another.



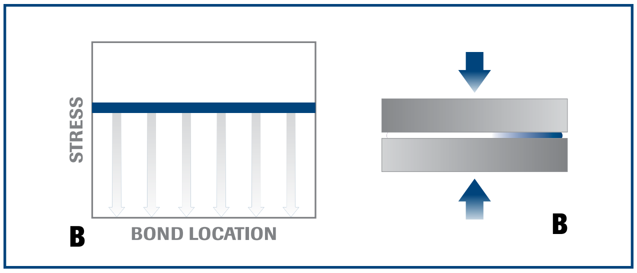
PEEL STRESS: A peel stress occurs when a flexible substrate is being lifted or peeled from the other substrate. *NOTE: The stress is concentrated at one end.*



CLEAVAGE STRESS: A cleavage stress occurs when rigid substrates are being opened at one end. *NOTE: The stress is concentrated at one end.*



TENSION STRESS DISTRIBUTION: When a bond experiences a tensile stress, the joint stress distribution is illustrated as a straight line. The stress is evenly distributed across the entire bond. Tensile stress also tends to elongate an object.



COMPRESSION STRESS DISTRIBUTION: When a bond experiences a compressive stress, the joint stress distribution is illustrated as a straight line. The stress is evenly distributed across the entire bond.

Design Guidelines

Engineers must have a good understanding of how stress is distributed across a joint which is under an applied force. There are several design guidelines which should be considered when designing an adhesive joint.

- **Maximize Shear/Minimize Peel and Cleavage**

  Note from the stress distribution curve for cleavage and peel, that these bonds do not resist stress very well. The stress is located at one end of the bond line. Whereas, in the case of shear, both ends of the bond resist the stress.

- **Maximize Compression/Minimize Tensile**

  Note from the stress distribution curve for compression and tension, that stress was uniformly distributed across the bond. In most adhesive films, the compressive strength is greater than the tensile strength. An adhesive joint which is feeling a compressive force is less likely to fail than a joint undergoing tension.

- **Joint Width More Important Than Overlap**

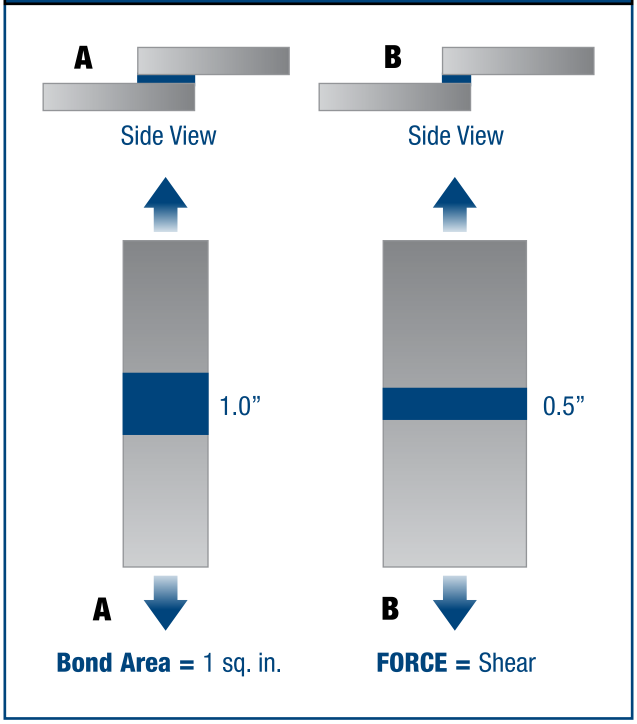
  Note from the shear stress distribution curve, that the ends of the bond receives a greater amount of stress than does the middle of the bond. If the width of the bond is increased, stress will be reduced at each end and the overall result is a stronger joint.

  In this same overlap joint, if the overlapping length is greatly increased, there is little, if any, change in the bond strength. The contribution of the ends is not increased. The geometry of the ends has not changed, thus their contribution to the bond strength has not changed.

- **Bond Shear Strength Width vs Overlap**

  As a general rule, increase the joint width rather than the overlap area ("wider is better").

JOINT AREA – WIDTH VS. OVERLAP



Section 4

Adhesive Review

Acrylics, Two-Step

Advantages

- Fast fixture speed
- Room temperature cure
- No mixing required
- High peel and impact strength
- Good environmental resistance
- Bonds to lightly contaminated surfaces
- Cure can be accelerated with heat

Considerations

- Limited cure through depth (0.040")
- Activator may contain solvents
- Activator requires controlled dispensing process
- Adhesive may have strong odor

General Description

Two-step acrylic adhesives consist of a resin and an activator. The resin component is a solvent-free, high-viscosity liquid typically in the range of 10,000 to 100,000 cP. The activator is a low viscosity liquid catalyst typically in the range of 2 to 50 cP. The activator is available either as a solvent dispersion or pure (also called “solventless”).

When the resin and activator contact each other the resin begins to cure very rapidly fixturing in 15 seconds to several minutes depending on the specific adhesive used and gap being cured through. The resin can also be cured with light or heat. Light cure can be used to fully cure resin that light can reach, fillets for example. While the fixture time depends on many factors, 15 to 30 seconds is typical.

A typical heat cure cycle is 10-20 minutes at 300°F (149°C). Heat curing normally offers higher bond strengths, improved thermal resistance, better chemical resistance and achieves complete cure faster. Heat cure is sometimes also used to eliminate any residual odor of the acrylic adhesive from the cured assembly.

Process Notes

Use the activator specified for the adhesive in the datasheet. All activators are not compatible with all adhesives.

Do not over apply. When using solventless activators, such as Loctite® 7380, 7090 or 7091, do not over apply them. The target quantity in normally 4-8 mg/in². Solventless activators generally require automated dispensing via a rotospray or atomized spray valve.

Allow time for the carrier solvent to evaporate. If using a solvent-based activator, such as Loctite® 7387 or 7075, allow sufficient time for the carrier solvent to evaporate after applying the activator before mating the two assemblies. This is normally 30 to 60 seconds but can be longer based on the specific activator used.

Do not apply the activator and adhesive to the same part, unless they are assembled immediately after dispensing. The adhesive will start curing in as little as 5 to 15 seconds.

Do not apply the activator to porous surfaces, such as a ferrite magnet. The porous surface may absorb the activator taking it away from the adhesive joint.

Be sure to assemble the parts before the activator open time expires. After that time, the adhesive may not cure properly. Activator open times range widely from an hour to 30 days so refer to the technical data sheet to determine the open time for the activator you are using.

Protect Activators from air exposure. Depending upon their specific chemistry, some activators may oxidize readily upon exposure to air. Always close containers after use. Use nitrogen blanket if necessary to lessen air contact.

Acrylics, Two-Part

Advantages

- High cure through depth
- Room temperature cure
- High peel and impact strength
- Good environmental resistance
- Bonds to moderately contaminated surfaces
- Cure can be accelerated with heat

Considerations

- Slow fixture times (5-30 min)
- Waste associated with static mix process
- May have strong odor

General Description

Two-part acrylic adhesives consist of a resin and an activator both of which are normally high-viscosity liquids typically in the range of 5,000 to 100,000 cP. While the activator is chemically similar to that of a two-step acrylic, it is delivered as a high viscosity liquid that is normally similar in viscosity to the resin. The two components are mixed just prior to dispensing at mix ratios ranging from 1:1 and 10:1 by volume. By mixing the activator and resin, two-part acrylics have much larger cure through depths than two-step acrylics that only have the activator applied to the surface.

To maintain the ratio of the resin and activator equipment is required. For small to moderate volume applications, the adhesive is packaged in a dual cartridge that sets the ratio. For high volume applications, meter mix dispense equipment is used.

The resin and activator are mixed by passing them through a static mix tip which allows the material to be dispensed as a homogenous one-part material. Since the mixed adhesive is curing in the mix tip, there will be trade off between the open time and the fixture time. Faster curing products will require that mix tips be changed after shorter idle times.

Two-part acrylics can also be accelerated with heat, but care must be taken when determining the cure temperature.

Process Notes

Properly prime the mix tip by dispensing a small amount before attaching the mix tip (also called "bumping") to ensure both sides are flowing then dispensing several grams after attaching the tip to prime the mix tip before creating production parts.

Audit to ensure proper mixing. Many two-part acrylics are color coded to allow for visual inspection of the mixing. For example, a blue resin and yellow activator would result in a green product. There should not be pockets of unmixed (i.e. yellow or blue) product that can be visually observed.

Use equipment designed for two-part acrylics. Two-part acrylics are very reactive systems that may cure when contacting active metals such as steel, copper or brass. When dispensing from a meter-mix dispense system, two-part acrylics must be dispensed from inactive systems such as stainless steel. Care should be taken not to replace fitting during maintenance with active metals

Evaluate peak exotherm for large volume applications. Two-part acrylics cure very rapidly via an exothermic reaction that releases heat. When curing large volumes, the heat can be sufficient to warp plastic parts or degrade the adhesive.

Cyanoacrylates

Advantages

- One part, solvent-free
- Rapid room temperature cure
- Excellent adhesion to most substrates
- Wide range of viscosities available
- Primers available for polyolefins and difficult to bond plastics
- Light cure versions available

Considerations

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

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, the moisture present on the bonding surfaces neutralizes the acid stabilizer present in the cyanoacrylate formulation causing the adhesive to cure rapidly to form rigid thermoplastics with excellent adhesion to most substrates. Typical fixture times are 5 to 30 seconds.

In addition to standard cyanoacrylates, there are many specialty formulations with enhanced performance properties.

Rubber toughened grades offer high peel strength and impact resistance

Thermally resistant cyanoacrylates are available which offer excellent bond strength retention after exposure to temperatures as high as 250°F for thousands of hours.

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 standard cyanoacrylate.

Low Odor/Low Bloom grades minimize the potential for a white haze to occur around the bondline.

Light curing cyanoacrylates utilize proprietary photoinitiators to cure cyanoacrylates in seconds when exposed to light of the appropriate wavelength.

Accelerators such as Loctite® 712, 7109, 7113, 7452 and 7453, can be used to speed the cure of cyanoacrylate adhesives and are primarily used to reduce fixture times and to cure excess adhesive.

Primers such as Loctite® 770 and 793 dramatically increase the strength achieve on hard to bond plastics such as polypropylene, polyethylene and Delrin (Acetal).

Process Notes

A controlled environment is necessary for consistent fixture times. Temperature and, more importantly, relative humidity have a significant effect on cure speed. The optimum relative humidity is 40-60%. Hot and moist environments will result in faster cure speed, while cold and dry environments will slow cure.

Proper storage is critical. Cyanoacrylates should be stored refrigerated. If cyanoacrylates are exposed to high temperature during storage, their viscosity will rise and their cure speed will slow. Once a bottle is opened, is must not be returned to refrigerated storage.

Use equipment designed for cyanoacrylates. Because cyanoacrylates are so reactive, only equipment that has been tested for compatibility, such as the Loctite® 98013 dispense valve, should be used.

Ensure that dry air is used for reservoirs. When dispensing cyanoacrylates from pressure reservoirs, dyers should be used to remove moisture from the supply air, otherwise, the moisture could cause the cyanoacrylate to cure.

Ventilation may be required in some instances to minimize odor.

Epoxies

Advantages

- Wide variety of formulations available
- High adhesion to many substrates
- Good toughness
- Cure can be accelerated with heat
- Excellent depth of cure
- Superior environmental resistance

Considerations

- Two-part systems require mixing
- One-part systems require heat cure
- Long cure and fixture times

General Description

Epoxy adhesives are supplied as one and two-part systems with viscosities that range from a few thousand centipoise to thixotropic pastes. Upon cure, epoxies typically form tough, rigid thermoset polymers with high adhesion to a wide variety of substrates and superior environmental resistance. A major advantage of epoxies is that there are a wide variety of commercially available resins, hardeners and fillers for epoxies that allows the performance characteristics of epoxies to be tailored to the needs of almost any application.

When using a one-part heat-cure system, the resin and a latent hardener are supplied already mixed and typically need to be stored refrigerated or frozen. By heating the system, the latent hardener is activated causing cure to initiate. The epoxy will normally start to cure rapidly at temperatures of 100 to 125°C (212 to 257°F) and cure times of 30 to 60 minutes are typical. Heat curing also generally improves bond strengths, thermal resistance and chemical resistance.

When using a two-part system, the resin and hardener are packaged separately and are mixed just prior to use. This allows more active hardeners to be used so that the two-part epoxies will rapidly cure at ambient conditions.

Two-part system are normally mixed by passing them through a static mix tip. This allows the two-part material to be dispensed as a single homogenous liquid where it exits the mix tip.

Since the mixed adhesive is curing in the mix tip, the adhesive's viscosity and performance changes during idle times and the mix tip must be changed after the idle time exceeds the adhesive's open time. This creates a trade off between fixture time and open time. Faster curing products will require that mix tips be changed after shorter idle times.

To maintain the ratio of the resin and activator equipment is required. For small to moderate volume applications, the adhesive is normally packaged in a dual cartridge that sets the ratio. For high volume applications, meter mix dispense equipment is recommended.

Process Notes

Properly prime the mix tip by dispensing a small amount before attaching the mix tip (also called "bumping") to ensure both sides are flowing then dispensing several grams after attaching the tip to prime the mix tip before creating production parts.

Significant exotherms can occur for large volume applications. The curing reaction of the epoxy can release a great deal of heat (exotherm) and can result in a significant temperature rise in the adhesive.

Ensure that meter mix systems are on-ratio and air free. To maintain consistent performance when using a meter mix dispense system, it is critical that the equipment is at the required mix ratio. This should be audited periodically with QC tests. Air in the equipment is a frequent cause of the equipment becoming off ratio. Care should be taken not to introduce air in the equipment when changing packages.

Induction curing typically offers the fastest heat cures. Induction heats ferrous components much faster than convection or infrared ovens.

Hot Melts

Advantages

- One-part, solvent-free
- Fast fixturing
- High adhesion to plastics
- Wide variety of formulations available
- Low volumetric cost

Considerations

- Hot dispense point
- Poor adhesion on metals
- Cools quickly
- Equipment is required
- Thermoplastic parts may deform
- Charring in reservoir
- Moisture sensitivity

General Description

Hot melt adhesives are one-part solvent-free thermoplastic adhesives that are solid at room temperature and a low to medium viscosity (750-10,000 cP) adhesive at dispense temperatures (typically greater than 175°C). After dispense, hot melt adhesives rapidly cool to form a strong bond. In the cured or cooled state, hot melt adhesives can vary in physical properties from soft, rubbery and very tacky to hard and rigid. Hot melts have excellent long term durability and resistance to moisture, chemicals, oils, and temperature extremes.

The performance of the hot melt varies widely based on their chemistry:

Ethylene vinyl acetate (EVA) hot melts are the "original" hot melt. They have good adhesive to many substrates, the lowest cost and a wide range of open times, but typically have the poorest temperature resistance.

Polyamide hot melts are a higher cost, higher performing adhesive with excellent high temperature resistance (up to 300°F). Specialty formulations are available that carry a UL-94 V-0 flammability rating.

Polyolefin hot melts are specially formulated for adhesion to polyolefins such as polypropylene and polyethylene plastics. Compared to other chemistries, they have longer open times and they have excellent resistance against polar solvents.

Reactive polyurethanes (PUR) 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 (a few days) to crosslink into a tough thermoset polyurethane. They offers lower dispense temperatures, higher adhesion to metals and improved thermal resistance.

Process Notes

Operators should wear protective gloves to avoid burns. Cotton gloves are recommended.

Dispense equipment is required to heat the hot melt. Sticks are used in hand held guns for low to medium volume applications and pellets are loaded into large tanks for bulk hot melt dispensers.

Bonding metals with hot melts. Hot melt adhesives cool very rapidly on metals due to their high heat capacity. If this results in low strengths, the strength can be increased by using a longer open time hot melt, the metal can be heated before or after assembly or a reactive polyurethane, which inherently have excellent adhesion on metals, can be used

Polyamides and PURs must be handled carefully. Polyamides absorb water rapidly if not stored properly. This is generally not a problem for bulk dispensers that heat the product well above the boiling point of water in the tank, but can cause bubbles when dispensing sticks. Sticks should be stored in their original packages and packages should be sealed during storage. PUR hot melts cure when exposed to ambient humidity, so dispense tips must be protected from air during idle times.

Tanks must be maintained for bulk dispensers. All hot melts will char over time in the melt tank for bulk dispensers, so the tanks should be maintained periodically. To minimize charring, one can put a nitrogen blanket over the tank, program the tank to cool down for long idle time or dispense at lower temperatures.

Polyurethanes

Advantages

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

Considerations

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

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 that 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.

Two-part system are normally mixed by passing them through a static mix tip. This allows the two-part material to be dispensed as a single homogenous liquid where it exits the mix tip. Since the mixed adhesive is curing in the mix tip, the adhesive’s viscosity and performance changes during idle times and the mix tip must be changed after the idle time exceeds the adhesive’s open time. This creates a trade off between fixture time and open time. Faster curing products will require that mix tips be changed after shorter idle times.

To maintain the ratio of the resin and activator equipment is required. For small to moderate volume applications, the adhesive is packaged in a dual cartridge that sets the ratio. For high volume applications, meter mix dispense equipment is used.

Process Notes

Properly prime the mix tip by dispensing a small amount before attaching the mix tip (also called “bumping”) to ensure both sides are flowing then dispensing several grams after attaching the tip to prime the mix tip before creating production parts.

Audit to ensure proper mixing. When setting up a new process, the mix tip should be evaluated in application representative conditions including planned downtimes to ensure proper mixing. This should be audited periodically.

Significant exotherms can occur for large volume applications. The curing reaction of the epoxy can release a great deal of heat (exotherm) and can result in a significant temperature rise in the adhesive.

Protect the adhesive from moisture. Polyurethanes will absorb moisture from the ambient atmosphere which may cause premature gelling or bubbling of the adhesive. As a result, bulk system must be designed with dyers to prevent this.

Elastomers

Advantages

- One-part or two-part solvent-free
- Room temperature cure
- Excellent adhesion to many substrates
- Extremely flexible
- Superior thermal resistance
- Light curing formulations available

Considerations

- Poor cohesive strength
- Moisture cure systems have limited depth of cure
- May be swelled by non-polar solvents

General Description

Elastomeric adhesives, specifically silane modified polymers (SMP) and silicones, are available in one-part moisture curing systems as well as two-part static mix 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. SMP's and silicones have good primerless adhesion to many substrates, but are limited in their utility as structural adhesives by their low cohesive strength. Elastomeric 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 elastomers is dependent on moisture diffusing through the elastomeric matrix, the cure rate is strongly affected by the ambient relative humidity and the maximum depth of cure is limited to 0.375 to 0.500". At 50% relative humidity, moisture cure elastomers will generally cure to a tack-free surface in 5 to 60 minutes. Complete cure through thick sections of product can take up to 72 hours. It should be noted that adhesive strength may continue to develop for 1-2 weeks after the product has been applied. This occurs because the reaction between the reactive groups on the polymer and the reactive groups on the substrate surface is slower than the crosslinking reaction of the products groups with themselves.

The by-product given off as they react with moisture categorizes moisture-curing elastomers:

Acetoxy are general-purpose silicones. Their largest limitation is the potential for the by-product, acetic acid, to promote corrosion.

Alkoxy have alcohol by-products so they are non-corrosive. SMP's fall into this category which makes them well suited for electronic and medical applications where acetic acid could be a problem..

Oxime are non-corrosive, fast curing, have excellent adhesion. There are also grades available with improved chemical resistance.

Light curing silicones generally also have a secondary moisture cure mechanism to ensure that any silicone that 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 up to a week to develop. Silicones with a secondary acetoxy cure show good bond strength while those with a secondary alkoxy cure are lower.

Process Notes

A controlled environment is necessary for consistent fixture times. Temperature and, more importantly, relative humidity have a significant effect on cure speed. The optimum relative humidity is 40-60%. Hot and moist environments will result in faster cure speed, while cold and dry environments will prolong cure.

Use equipment designed for elastomers. Because SMP's and silicones moisture cure, the system must be designed to prevent moisture for penetrating the system. To that end, moisture-lock hoses and dryers should be used to remove moisture from supply air that could cause the product to cure.

Section 5

Factors Affecting Activator Selection

Introduction

Two-Step 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 two-step 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 two-step 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:

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

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

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.

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

Activator Listing

The table below summarizes key properties of the activators available for use with Two-Step Acrylic Adhesives. Please see table 2 & 3 for detailed fixture time and performance data.

Summary of Loctite® Brand Activator Characteristics

Table 1		Solvent(s)	Active Ingredient(s)	Flash Point	Drying Time (Seconds)	On-Part Life
Activator (Common Name)	**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

Fixture Time Matrix:

The results of the fixture time evaluation of the various two-step adhesive/activator combinations are shown in Table 2.

Fixture Times of Several Loctite® Brand Structural Adhesive/Activator Combinations
(Ultimate strength on Steel in PSI)

Loctite® Brand Activator (Common Name)

Table 2	324™ Speedbonder™	326™ Speedbonder™	330™ Depend™	331™ Depend™	334™ Structural Adhesive	352™ Structural Adhesive	392™ Structural Adhesive
736™ Primer NF™	20 Seconds (1990 psi)	25 Seconds (2205 psi)	10 Minutes (770 psi)	No fixture	No fixture	20 Seconds (2595 psi)	25 Seconds (2315 psi)
7075™ Activator	1 Minute 45 Seconds (2425 psi)	5 Minutes (1135) psi)	2 Minutes (2010 psi)	15 Seconds (1725 psi)	21 Minutes (680 psi)	15 Minutes (2170 psi)	15 Seconds (2435 psi)
7090™ Activator (Solventless Primer N™)	1 Hour 30 Minutes (3000 psi)	1 Minute (1995 psi)	No fixture	No fixture	No fixture	2 Hours 45 Minutes (2310 psi)	No fixture
7091™ Activator (Solventless Primer N™ for Chromated Surfaces)	2 Hours (2350 psi)	40 Seconds (2460 psi)	No fixture	No fixture	No fixture	2 Hours (2765 psi)	No fixture
7380™ Activator (Solventless Depend® Activator)	50 Seconds (1830 psi)	1 Minute 45 Seconds (2235 psi)	2 Minutes 30 Seconds (2400 psi)	10 Seconds (2248 psi)	3 Minutes (1945 psi)	45 Seconds (2415 psi)	10 Seconds (1865 psi)
7387™ Depend® Activator	30 Seconds (2590 psi)	1 Minute 5 Seconds (2445 psi)	2 Minutes 25 Seconds (2595 psi)	10 Seconds (2125 psi)	2 Minutes 45 Seconds (2590 psi)	25 Seconds (2140 psi)	10 Seconds (2305 psi)
7471™ Primer T™	1 Hour 45 Minutes (795 psi)	30 Minutes (2035 psi)	No fixture	No fixture	No fixture	1 Hour 30 Minutes (1070 psi)	No fixture
7649™ Primer N™	45 Minutes (2750 psi)	45 Seconds (1715 psi)	No fixture	No fixture	No fixture	1 Hour (2170 psi)	No fixture

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.

Performance Matrix

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 3.

Performance of Adhesive/Activator Combinations on Steel and Stainless Steel (psi)

Table 3		Condition	324™ Speedbonder™		326™ Speedbonder™		330™ Depend™		331™		334™		352™		392™	
			Steel	SS	Steel	SS	Steel	SS	Steel	SS	Steel	SS	Steel	SS	Steel	SS
Loctite® Brand Activator	7649™	I	2750	2210	1715	1090	NA	NA	NA	NA	NA	NA	2170	2350	NA	NA
		SF	1450	845	1180	1140	NA	NA	NA	NA	NA	NA	2375	1980	NA	NA
		HM	1430	1730	750	910	NA	NA	NA	NA	NA	NA	910	1010	NA	NA
	7090™	I	3000	2454	1995	1100	NA	NA	NA	NA	NA	NA	2310	2175	NA	NA
		SF	1710	1910	2585	2650	NA	NA	NA	NA	NA	NA	1785	1685	NA	NA
		HM	1340	1640	725	1030	NA	NA	NA	NA	NA	NA	1305	1170	NA	NA
	7091™	I	2350	2005	2640	1345	NA	NA	NA	NA	NA	NA	2765	1865	NA	NA
		SF	1915	1195	1750	1795	NA	NA	NA	NA	NA	NA	1755	1955	NA	NA
		HM	1455	1735	420	1235	NA	NA	NA	NA	NA	NA	935	1655	NA	NA
	7471™	I	795	930	2035	805	NA	NA	NA	NA	NA	NA	1070	1340	NA	NA
		SF	1045	1560	3105	1210	NA	NA	NA	NA	NA	NA	1335	1135	NA	NA
		HM	840	1320	1015	780	NA	NA	NA	NA	NA	NA	1060	1355	NA	NA
	736™	I	1990	1645	2205	815	770	315	765	455	NA	NA	2595	2215	2315	1725
		SF	1770	1685	1320	1355	840	180	1215	0	NA	NA	1275	955	2130	535
		HM	750	1435	650	885	790	125	1270	0	NA	NA	645	1515	775	880
	7075™	I	2425	890	1135	720	2010	1800	1725	1810	680	1860	2170	1630	2435	2050
		SF	1875	1300	830	2285	1715	450	950	310	1830	1365	1570	1025	1890	950
		HM	1270	940	545	1165	2010	255	910	300	1420	1180	1720	1200	755	1415
	7387™	I	2590	1260	2445	2375	2595	1325	2125	225	2590	2475	2140	1095	2305	2290
		SF	1645	1260	2510	2405	2765	1965	925	0	2745	1775	1415	1290	1585	1905
		HM	1895	1090	890	1825	2775	2785	780	900	2460	2140	1035	1495	1565	1635
	7380™	I	1830	1265	2235	1825	2400	1320	2250	2400	1945	2510	2415	1745	1865	1940
		SF	1670	1285	2740	2590	2025	380	1560	0	2395	1900	1625	1145	2295	1790
		HM	1075	810	940	1080	1750	470	1550	510	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.

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

Solventless vs. Solvent-borne Activators

Activators for use with two-step 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.

A Comparison of the Processing Benefits and Limitations of Several Types of Loctite® Brand Activators for Use with Two-Step Acrylic Adhesives

Table 4		Examples	Benefits	Limitations
Activator Type	**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 Two-Step Acrylic Adhesives

Most of the adhesives used in conjunction with activators in the Two-Step 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 5 contains heat cure parameters for several of these systems. 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.

Cure Profiles of Loctite® Brand No-Mix Structural Adhesives on Steel Using Heat and No Activator*

Table 5		324™ Speedbonder™	326™ Speedbonder™	330™ Speedbonder™	352™ Structural Adhesive	334™ Structural Adhesive	392™ Structural Adhesive	331™
Temperature	200°F (93°C)	40 - 60 Minutes	10 - 20 Minutes	> 24 Hours	40 - 60 Minutes	> 24 Hours	60 - 120 Minutes	5 - 10 Minutes
	250°F (121°C)	5 - 10 Minutes	5 - 10 Minutes	40 - 60 Minutes	5 - 10 Minutes	20 - 40 Minutes	5 - 10 Minutes	5 Minutes

Notes:

* 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® 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.

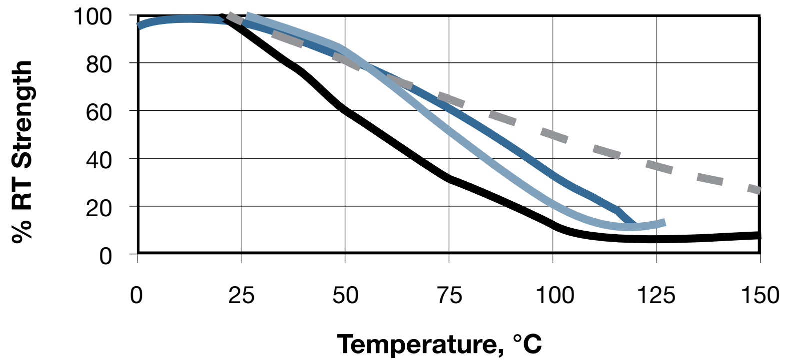
Section 7

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.

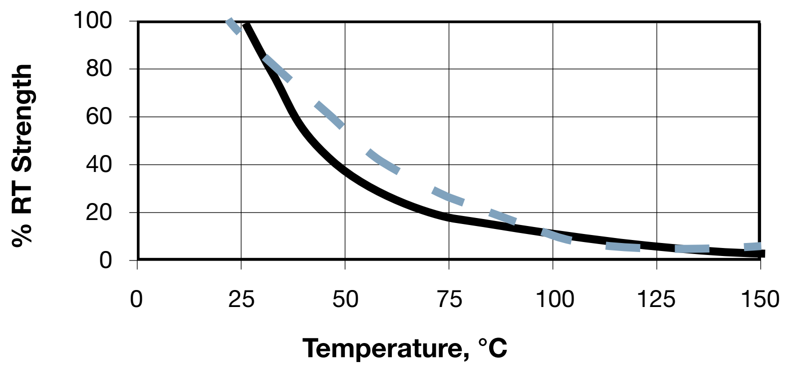
Acrylic Adhesives

FIGURE 1 - Two-Step



Loctite® 324™ Speedbonder® Structural Adhesive, High Impact
Loctite® 326™ Speedbonder® Structural Adhesive, Fast Fixture
Loctite® 330™ Depend® Adhesive, No Mix
Loctite® 334™ Speedbonder® Structural Adhesive, High Temperature

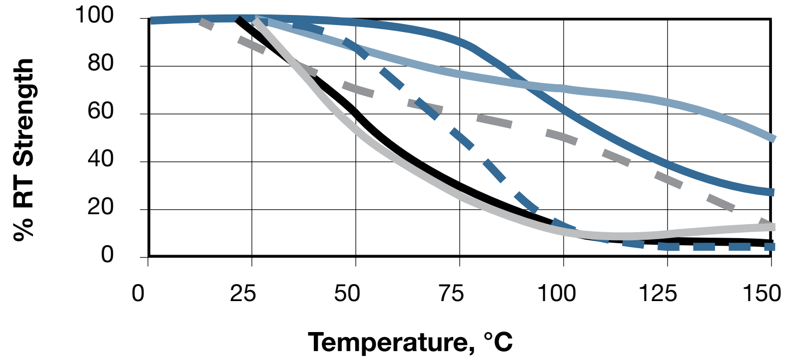
FIGURE 2 - Two-Part



Loctite® H8000™ Speedbonder® Structural Adhesive, Fast Fixture
Loctite® 392™ Structural Adhesive, Fast Fixture/Magnet Bonder

Epoxy Adhesives

FIGURE 3



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

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

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

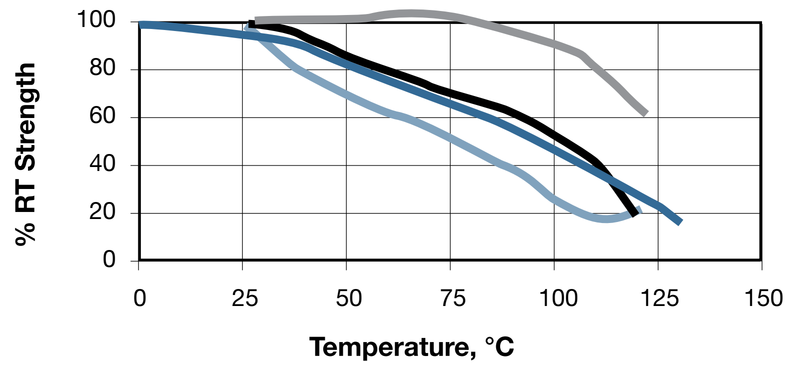
Loctite® E-40HT™ Hysol® Epoxy Adhesive, High Temperature

Loctite® Fixmaster® High Performance Epoxy

Loctite® E-30CL™ Hysol® Epoxy Adhesive, Glass Bonder

Cyanoacrylate Adhesives

FIGURE 4



Loctite® 416™ Super Bonder® Instant Adhesive

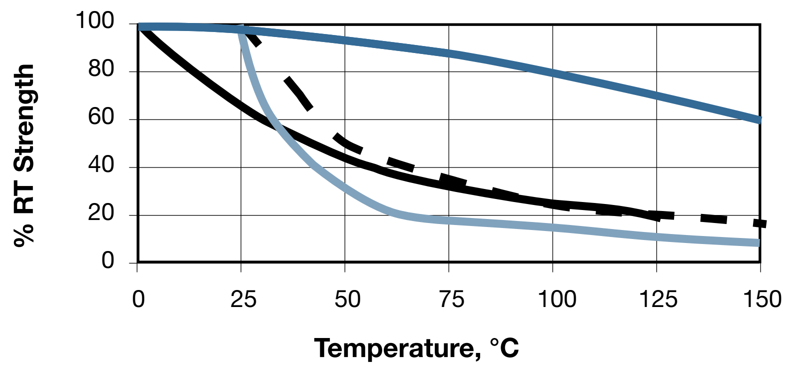
Loctite® 454™ Prism® Instant Adhesive, Surface Insensitive Gel

Loctite® 380™ Black Max® Instant Adhesive, Toughened

Loctite® 4205™ Prism® Instant Adhesive, Thermally Resistant Gel

Hot Melt/Urethane Adhesives and Flange Sealant

FIGURE 5



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

Loctite® 5900™ Flange Sealant, Heavy Body RTV Silicone

Loctite® 3631™ Hysol® Hot Melt Adhesive, Urethane

Loctite® Fixmaster™ Rapid Rubber Repair

Section 8

Metal Bonding Chapters

How To Use Adhesive Shear Strength Chapters

Conditioning

The columns indicate the environmental conditions (roughened, salt fog @ 95°F, condensing humidity @ 125°F, and heat aging) that the products were exposed to for 340 hours prior to testing. After conditioning all samples were allowed to equilibrate at ambient conditions for at least 24 hours prior to testing. Note that not all of the substrates tested possess a roughened column.

Adhesive Chemistry

The products are sorted by chemistry according to the row headers in the first column. Reference the Test Methodology Section on Page 57 to determine the cure parameters for a specific chemistry.

Surface Roughness

The root-mean squared (RMS) surface roughness of the material. This was evaluated on the substrates that possessed a roughened sample which was generated through a grit blasting process.

Table 7

Aluminum		Rounded Data Averages							
	Loctite® Brand Adhesive	Control - 9 rms	Roughened - 68 rms	Salt Fog @ 95°F	Condensing Humidity @ 120°F	Heat Age @ 250°F	Heat Age @ 300°F	Heat Age @ 350°F	Heat Age @ 400°F
Two-Part Acrylic	Loctite® H3151	3350	[illegible]	2100	1680	2310	640	100	50
	Loctite® H4500	2960	3530	2460	1960	3540	2210	2050	240
	Loctite® H4710	3860	3690	2160	2380	3500	2500	2880	280
	Loctite® H8000	2630	2820	2510	2600	680	2800	1440	430
	Loctite® H8500	1670	2500	1340	1930	2570	1230	750	220
	Loctite® H8600	3360	2670	2420	3290	3470	3210	2880	940
	Loctite® H8700	2700	3100	2240	2820	2350	1750	1840	220
Two-Part Acrylic	Loctite® 324	1540	1820	1280	610	1470	1520	680	440
	Loctite® 326	850	1150	740	560	790	910	360	370
	Loctite® 330	1210	2330	800	790	1910	1840	1460	850
	Loctite® 331	2170	2110	740	820	2080	1410	960	330
	Loctite® 334	2280	1870	1310	1170	2510	2580	3100	2150
	Loctite® 392	1740	1770	550	620	830	630	220	350
Cyanoacrylate	Loctite® 406	550	1730	100	0	210	0	0	0
	Loctite® 435	1830	3170	320	60	270	0	0	0
	Loctite® 454	670	2590	0	70	140	0	0	0
	Loctite® 480	2420	3420	480	280	1090	0	0	0
	Loctite® 4205	270	470	210	110	350	190	0	0
Elastomeric Adhesives	Loctite® 5510	510	260	520	440	0	0	0	0
	Loctite® 5570 (white)	190	210	270	230	0	0	0	0
	Loctite® 5604	330	320	330	310	390	380	360	380
	Loctite® 5900	130	260	200	220	260	250	210	210
	Loctite® Superflex Black	10	140	20	200	70	90	60	90
Two-Part Epoxy	Loctite® E-05MR	1150	3350	1870	820	3410	2220	1650	470
	Loctite® E-20NS	2140	3010	1740	230	2240	2120	2410	1500
	Loctite® E-20HP	1670	2160	1370	1390	2330	2100	1100	1250
	Loctite® E-30CL	1010	1520	1110	1670	2450	2470	2320	2100
	Loctite® E-30UT	2240	3710	1640	180	3030	1850	1780	1310
	Loctite® E-40HT	2670	3420	2400	2180	2470	1920	2470	2290
	Loctite® E-50GW	740	1470	380	1300	150	90	220	140
	Loctite® E-50CR	2480	2820	1800	2320	580	420	260	150
Other Epoxy	Loctite® FM HP Epoxy	2270	1750	1710	2030	2440	2050	1930	1840
	Loctite® E-214HP	2480	3500	290	2320	3560	3220	3390	2610
	Loctite® E-220IC	3400	4240	3590	3960	5570	4750	4040	3080
	Loctite® 3984	1320	2020	720	1970	1310	1150	1150	570
Urethane	Loctite® U-05FL	1220	1320	210	1040	1210	970	240	140
	Loctite® Rapid Rubber	260	890	740	540	1620	230	220	130
	Loctite® 3631	600	320	240	320	790	1020	480	80

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 6 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 summarized on Table 7 and in Figures 6 through 11.

Common Types of Wrought Aluminum

Table 6		Main Alloy Additions	Limitations
ASTM Series	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.

Aluminum		Rounded Data Averages							
Table 7 Loctite® Brand Adhesive		Control - 9 rms	Roughened - 68 rms	Salt Fog @ 95°F	Condensing Humidity @ 120°F	Heat Age @ 250°F	Heat Age @ 300°F	Heat Age @ 350°F	Heat Age @ 400°F
Two-Part Acrylic	Loctite® H3151	3350	3640	2100	1680	2310	640	100	50
	Loctite® H4500	2960	3530	2460	1960	3540	2210	2050	240
	Loctite® H4710	3860	3690	2160	2380	3500	2500	2880	280
	Loctite® H8000	2630	2820	2510	2600	680	2800	1440	430
	Loctite® H8500	1670	2500	1340	1930	2570	1230	750	220
	Loctite® H8600	3360	2670	2420	3290	3470	3210	2880	940
	Loctite® H8700	2700	3100	2240	2820	2350	1750	1840	220
Two-Part Acrylic	Loctite® 324	1540	1820	1280	610	1470	1520	680	440
	Loctite® 326	850	1150	740	560	790	910	360	370
	Loctite® 330	1210	2330	800	790	1910	1840	1460	850
	Loctite® 331	2170	2110	740	820	2080	1410	960	330
	Loctite® 334	2280	1870	1310	1170	2510	2580	3100	2150
	Loctite® 392	1740	1770	550	620	830	630	220	350
Cyanoacrylate	Loctite® 406	550	1730	100	0	210	0	0	0
	Loctite® 435	1830	3170	320	60	270	0	0	0
	Loctite® 454	670	2590	0	70	140	0	0	0
	Loctite® 480	2420	3420	480	280	1090	0	0	0
	Loctite® 4205	270	470	210	110	350	190	0	0
Elastomeric Adhesives	Loctite® 5510	510	260	520	440	0	0	0	0
	Loctite® 5570 (white)	190	210	270	230	0	0	0	0
	Loctite® 5604	330	320	330	310	390	380	360	380
	Loctite® 5900	130	260	200	220	260	250	210	210
	Loctite® Superflex Black	10	140	20	200	70	90	60	90
Two-Part Epoxy	Loctite® E-05MR	1150	3350	1870	820	3410	2220	1650	470
	Loctite® E-20NS	2140	3010	1740	230	2240	2120	2410	1500
	Loctite® E-20HP	1670	2160	1370	1390	2330	2100	1100	1250
	Loctite® E-30CL	1010	1520	1110	1670	2450	2470	2320	2100
	Loctite® E-30UT	2240	3710	1640	180	3030	1850	1780	1310
	Loctite® E-40HT	2670	3420	2400	2180	2470	1920	2470	2290
	Loctite® E-50GW	740	1470	380	1300	150	90	220	140
	Loctite® E-50CR	2480	2820	1800	2320	580	420	260	150
Other Epoxy	Loctite® FM HP Epoxy	2270	1750	1710	2030	2440	2050	1930	1840
	Loctite® E-214HP	2480	3500	290	2320	3560	3220	3390	2610
	Loctite® E-220IC	3400	4240	3590	3960	5570	4750	4040	3080
	Loctite® 3984	1320	2020	720	1970	1310	1150	1150	570
Urethane	Loctite® U-05FL	1220	1320	210	1040	1210	970	240	140
	Loctite® Rapid Rubber	260	890	740	540	1620	230	220	130
	Loctite® 3631	600	320	240	320	790	1020	480	80

FIGURE 6

Effect of Roughening on Bond Strength for Two-Step and Two-Part Acrylic Adhesives on Aluminum

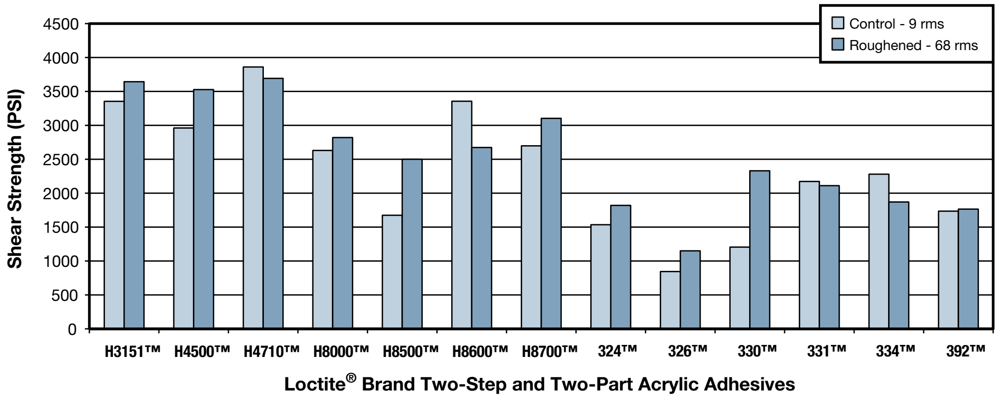


FIGURE 7

Effect of Salt Fog Exposure and Condensing Humidity on the Bond Strength of Two-Step and Two-Part Acrylic Adhesives on Aluminum

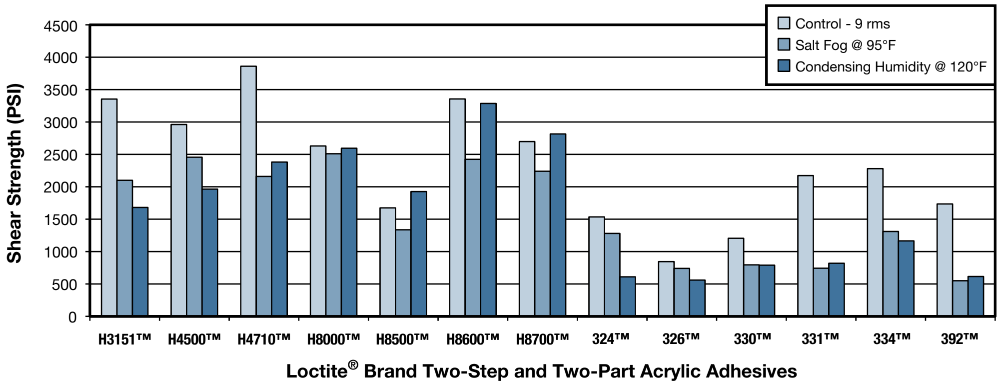


FIGURE 8

Effect of Heat Aging on the Bond Strength of Two-Step and Two-Part Acrylic Adhesives on Aluminum

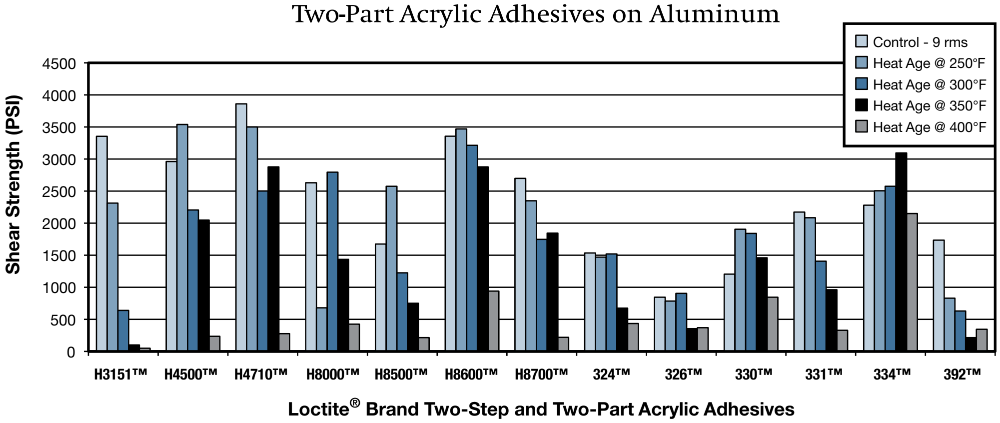


FIGURE 9

Effect of Surface Roughening on the Bond Strength of Epoxy and Polyurethane Adhesives on Aluminum

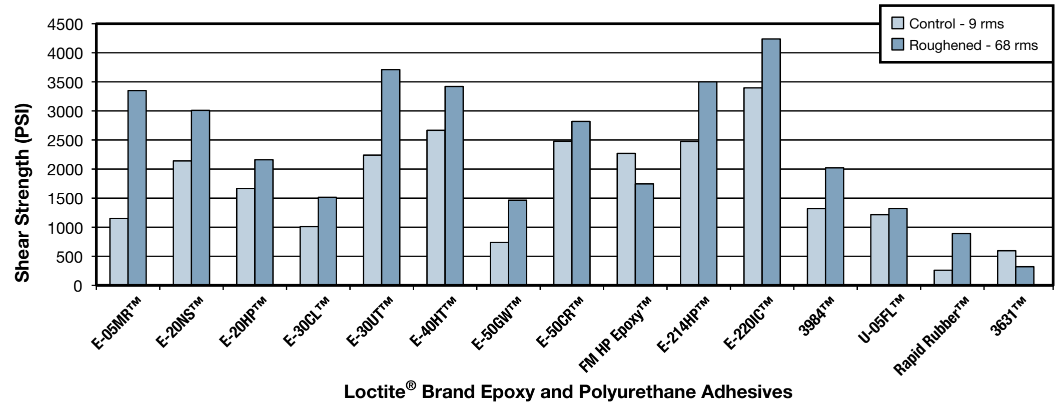


FIGURE 10

Effect of Condensing Humidity and Salt Fog on the Bond Strength of Epoxy and Polyurethane Adhesives on Aluminum

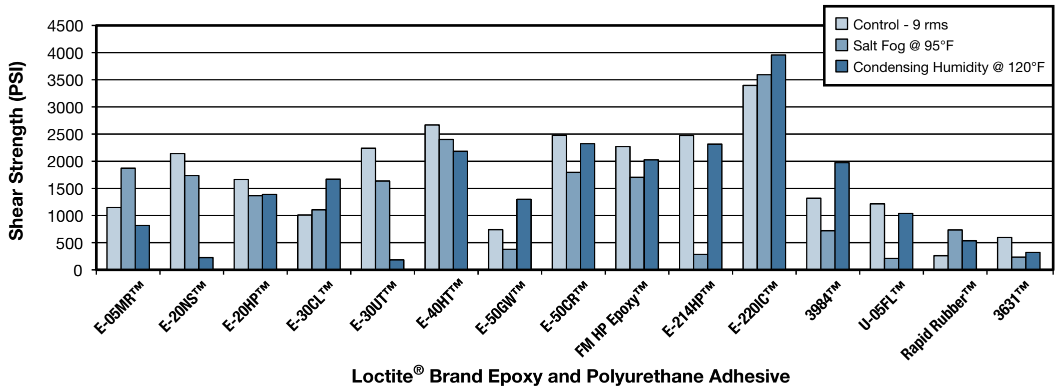
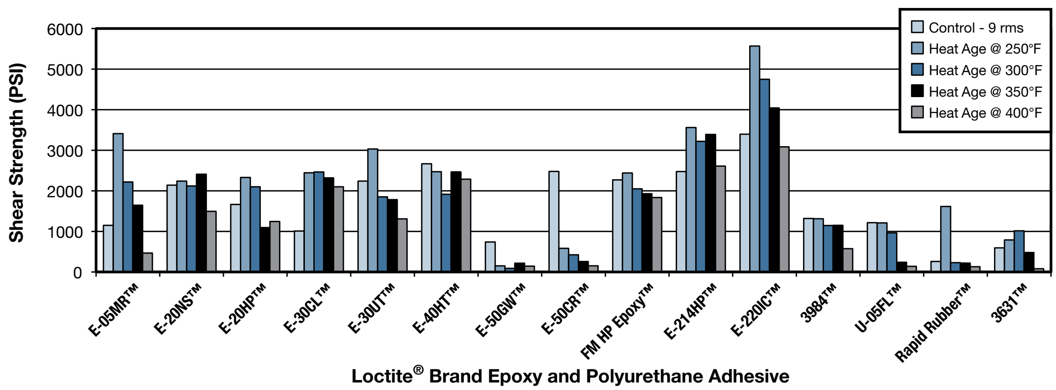


FIGURE 11

Effect of Heat Aging on the Bond Strength of Epoxy and Polyurethane Adhesives on Aluminum



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 summarized below.

Annodized Aluminum		Rounded Data Averages						
Table 8								
Loctite® Brand Adhesive		Control - 9 rms	Salt Fog @ 95°F	Condensing Humidity @ 120°F	Heat Age @ 250°F	Heat Age @ 300°F	Heat Age @ 350°F	Heat Age @ 400°F
Two-Part Acrylic	Loctite® H3151	3090	2460	2960	3740	2800	1140	530
	Loctite® H4500	2660	2560	2600	3000	2040	1440	730
	Loctite® H4710	3450	2970	3210	3180	1300	770	380
	Loctite® H8000	2340	2120	2030	2110	2260	2040	620
	Loctite® H8500	2060	1530	1490	2290	830	570	650
	Loctite® H8600	3310	2560	3010	2860	2270	1510	750
	Loctite® H8700	2660	2440	2530	2350	1830	1480	660
Two-Part Acrylic	Loctite® 324	1780	1310	650	1550	1500	860	200
	Loctite® 326	1310	1280	840	1120	890	720	280
	Loctite® 330	2320	2750	2180	3150	2830	2100	1860
	Loctite® 331	1800	1880	2010	1920	1120	770	610
	Loctite® 334	2010	2090	1980	2270	2250	2520	1760
	Loctite® 392	1580	1630	1440	1230	810	330	250
Cyanoacrylate	Loctite® 406	1430	890	130	0	0	0	0
	Loctite® 435	1500	1300	1130	0	0	0	0
	Loctite® 454	1310	680	270	0	0	0	0
	Loctite® 480	2030	1480	1190	0	0	0	0
	Loctite® 4205	1880	1180	530	310	30	0	0
Elastomeric Adhesives	Loctite® 5510	280	200	220	0	0	0	0
	Loctite® 5570 (white)	400	390	420	0	0	0	0
	Loctite® 5604	310	350	410	510	350	330	190
	Loctite® 5900	230	150	150	280	250	110	130
	Loctite® Superflex Black	100	150	80	100	40	20	40
Two-Part Epoxy	Loctite® E-05MR	1930	2600	1950	2580	2810	1840	730
	Loctite® E-20NS	2610	1810	1760	2280	2620	2090	1760
	Loctite® E-20HP	1210	1360	1250	1390	1390	1430	1120
	Loctite® E-30CL	1760	2200	2580	3380	2650	2480	1630
	Loctite® E-30UT	3690	3310	2160	3660	3160	3220	490
	Loctite® E-40HT	3220	3340	2000	3030	2590	3060	1190
	Loctite® E-50GW	1120	1570	1290	1300	610	970	620
	Loctite® E-50CR	2370	2540	2650	3190	3300	2750	2100
Other Epoxy	Loctite® FM HP Epoxy	1490	1310	1420	1970	1490	1650	1620
	Loctite® E-214HP	830	1060	1350	1730	1200	1710	980
	Loctite® E-220IC	3910	1860	1730	2590	1140	980	950
	Loctite® 3984	700	640	600	2160	1700	1600	500
Urethane	Loctite® U-05FL	1140	1160	970	590	500	300	110
	Loctite® Rapid Rubber	180	90	900	570	550	400	220
	Loctite® 3631	780	600	430	1080	340	250	190

FIGURE 12

Bond Strength for Two-Step and Two-Part Acrylic Adhesives on Anodized Aluminum

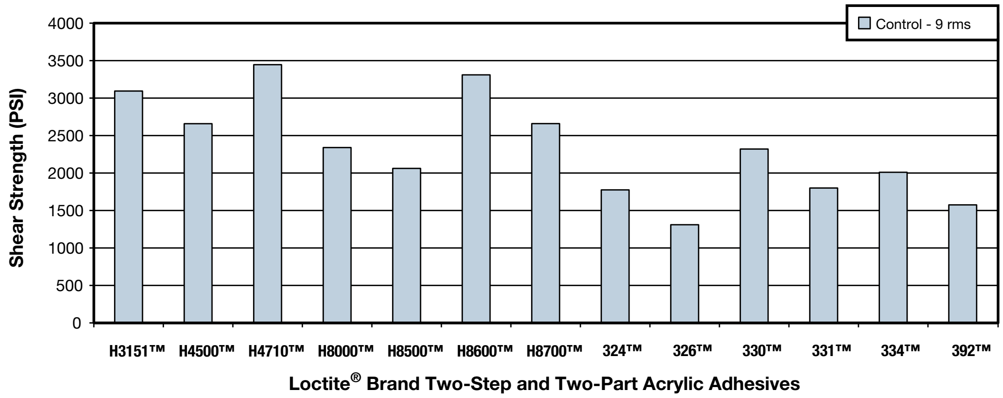


FIGURE 13

Effect of Salt Fog Exposure and Condensing Humidity on the Bond Strength of Two-Step and Two-Part Acrylic Adhesives on Anodized Aluminum

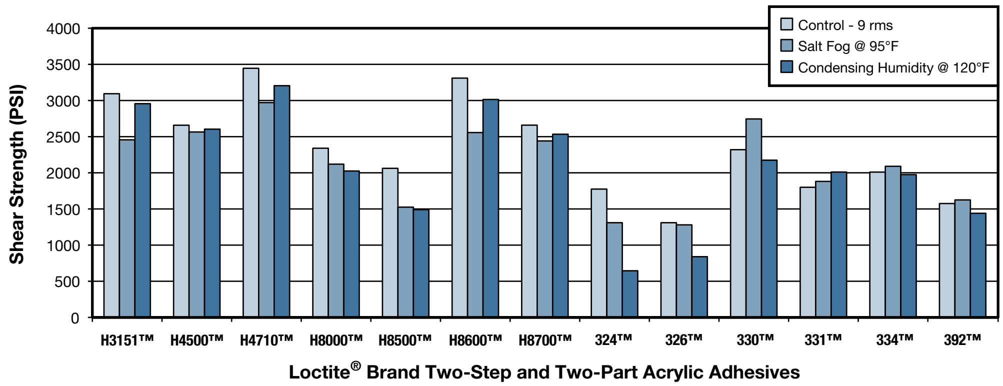


FIGURE 14

Effect of Heat Aging on the Bond Strength of Two-Step and Two-Part Acrylic Adhesives on Anodized Aluminum

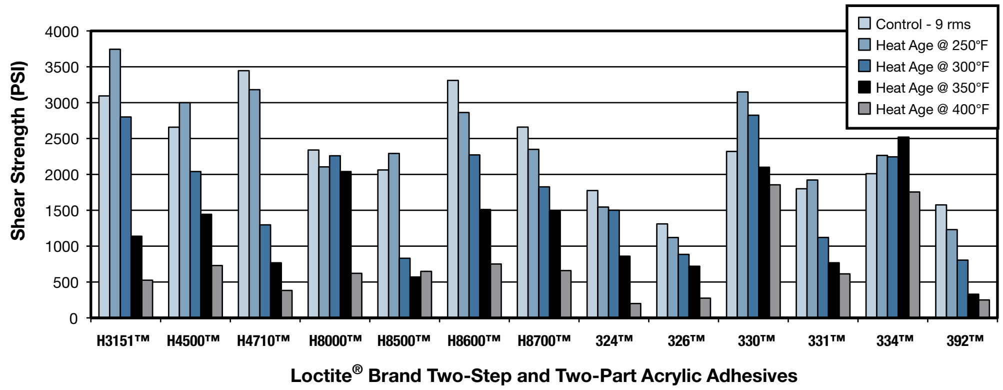


FIGURE 15

Bond Strength of Epoxy and Polyurethane Adhesives
on Anodized Aluminum

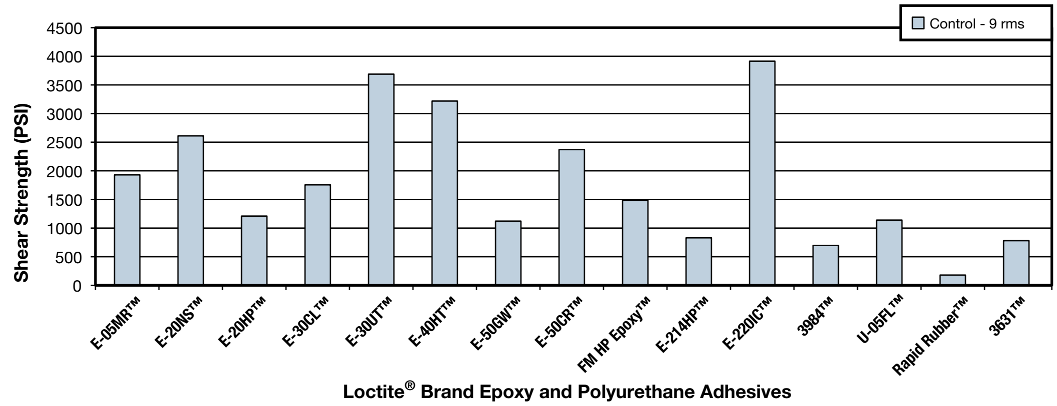


FIGURE 16

Effect of Condensing Humidity and Salt Fog on the Bond Strength of
Epoxy and Polyurethane Adhesives on Anodized Aluminum

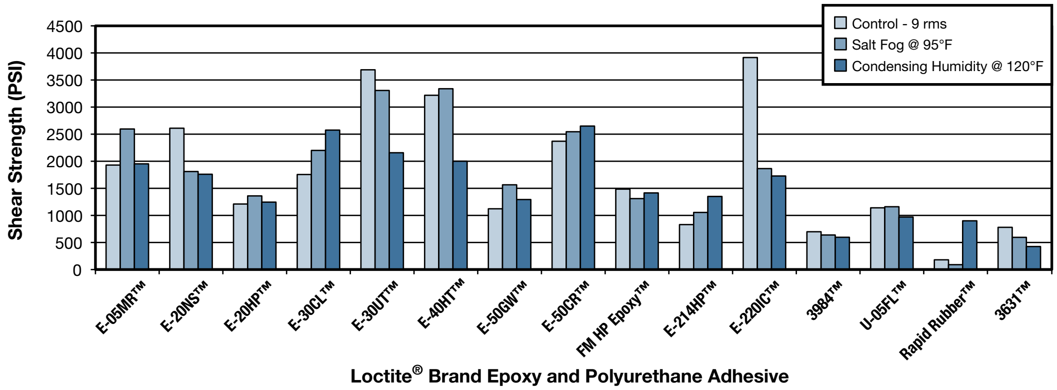
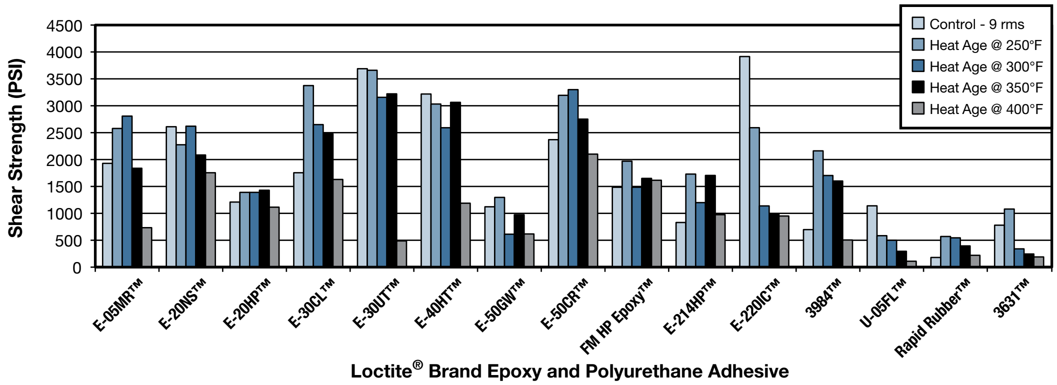


FIGURE 17

Effect of Heat Aging on the Bond Strength of Epoxy and
Polyurethane Adhesives on Anodized Aluminum



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 9 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 Table 10 and in Figures 18 through 23.

Common Grades of Copper

Table 9		Type	Name	Alloying Metals
UNS Number	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

Copper

Table 10

	Loctite® Brand Adhesive	Control - 58 rms	Salt Fog @ 95°F	Condensing Humidity @ 120°F	Heat Age @ 250°F	Heat Age @ 300°F	Heat Age @ 350°F	Heat Age @ 400°F
		Rounded Data Averages						
Two-Part Acrylic	Loctite® H3151	2940	610	520	1090	270	220	140
	Loctite® H4500	2970	1430	1200	1020	840	380	170
	Loctite® H4710	2200	930	1530	600	290	310	290
	Loctite® H8000	1270	380	1160	2170	2060	570	70
	Loctite® H8500	790	690	790	0	0	0	0
	Loctite® H8600	3240	870	930	610	510	310	270
	Loctite® H8700	2660	2470	1570	2100	560	600	0
Two-Part Acrylic	Loctite® 324	2300	990	740	1430	1060	380	190
	Loctite® 326	2250	750	570	1800	890	540	230
	Loctite® 330	1800	1320	270	510	420	250	250
	Loctite® 331	1470	570	1340	2500	1380	690	210
	Loctite® 334	2480	1500	1490	1520	2420	2400	420
	Loctite® 392	2220	990	630	770	570	10	0
Cyanoacrylate	Loctite® 406	780	390	0	90	0	0	0
	Loctite® 435	1130	790	30	90	0	0	0
	Loctite® 454	580	510	0	30	0	0	0
	Loctite® 480	2640	570	10	40	0	0	0
	Loctite® 4205	1520	1180	410	100	80	30	0
Elastomeric Adhesives	Loctite® 5510	220	270	180	50	0	0	0
	Loctite® 5570 (white)	470	320	180	0	0	0	0
	Loctite® 5604	350	400	340	260	410	380	370
	Loctite® 5900	150	130	110	120	120	110	100
	Loctite® Superflex Black	100	100	120	170	130	130	180
Two-Part Epoxy	Loctite® E-05MR	2220	2590	1460	2260	1880	1390	310
	Loctite® E-20NS	3470	2100	1560	2240	1630	580	330
	Loctite® E-20HP	900	800	800	690	670	490	210
	Loctite® E-30CL	2560	2160	1780	2090	1690	1450	690
	Loctite® E-30UT	3220	2330	1810	2850	2230	1590	420
	Loctite® E-40HT	2960	2730	1540	2120	1610	1550	750
	Loctite® E-50GW	880	850	670	560	570	370	60
	Loctite® E-50CR	2080	2230	1570	1370	1270	1010	600
Other Epoxy	Loctite® FM HP Epoxy	1850	2060	1980	1970	1510	1640	1050
	Loctite® E-214HP	5150	4990	3340	4670	4490	3920	1420
	Loctite® E-220IC	2650	1680	1740	2250	1680	1170	660
	Loctite® 3984	1250	1660	1060	1390	940	830	280
Urethane	Loctite® U-05FL	1210	1200	1220	1820	850	370	30
	Loctite® Rapid Rubber	710	590	590	630	290	110	50
	Loctite® 3631	440	380	270	550	440	210	100

FIGURE 18

Bond Strength for Two-Step and Two-Part Acrylic Adhesives on Copper

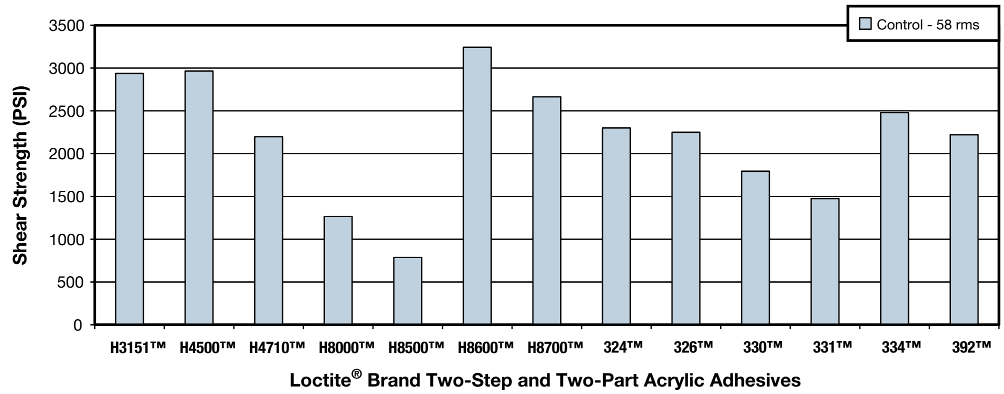


FIGURE 19

Effect of Salt Fog Exposure and Condensing Humidity on the Bond Strength of Two-Step and Two-Part Acrylic Adhesives on Copper

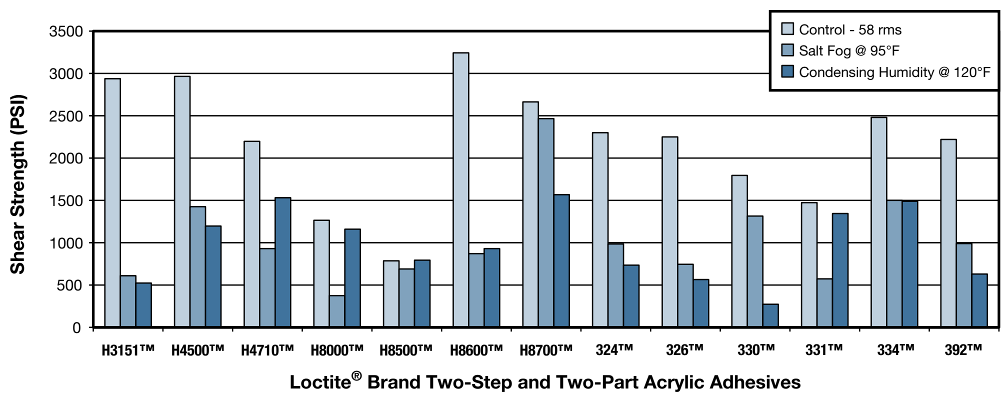


FIGURE 20

Effect of Heat Aging on the Bond Strength of Two-Step and Two-Part Acrylic Adhesives on Copper

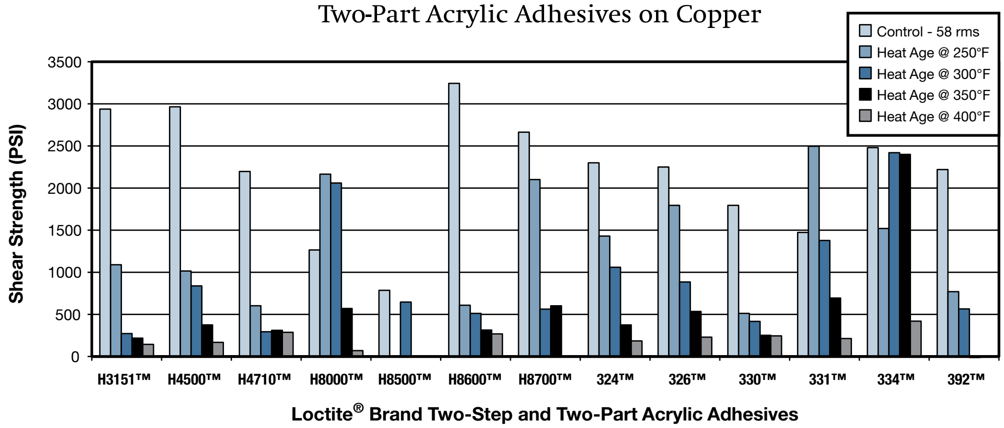


FIGURE 21

Bond Strength for Epoxy and Polyurethane Adhesives on Copper

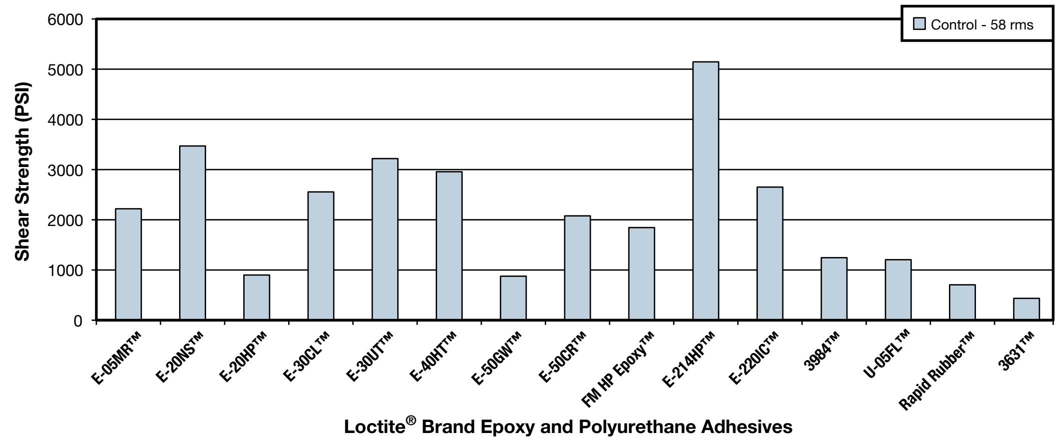


FIGURE 22

Effect of Condensing Humidity and Salt Fog on the Bond Strength of Epoxy and Polyurethane Adhesives on Copper

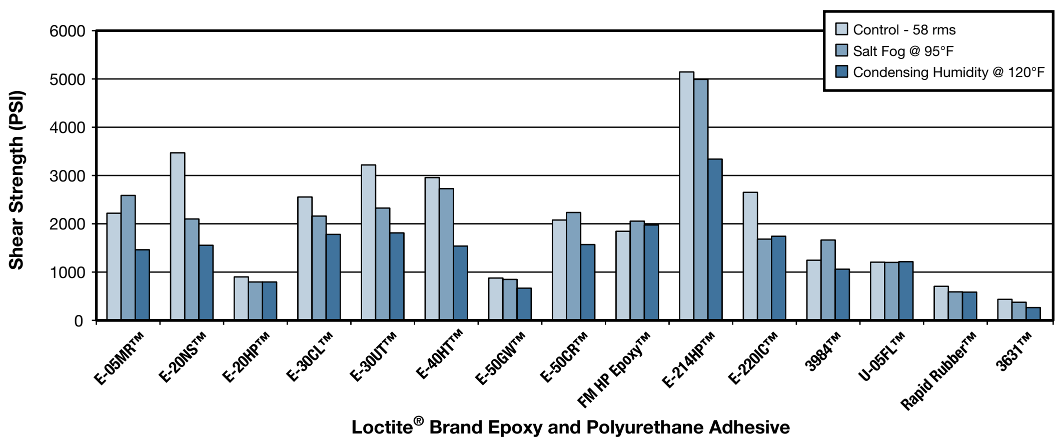
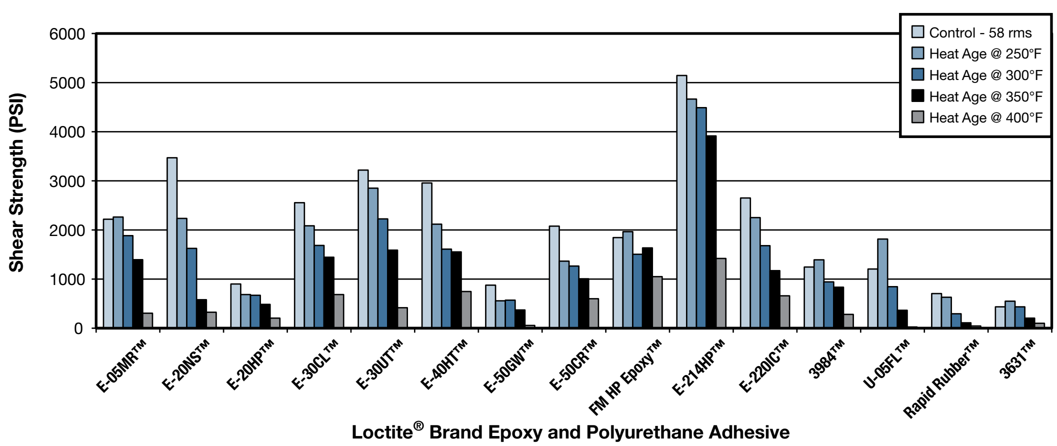


FIGURE 23

Effect of Heat Aging on the Bond Strength of Epoxy and Polyurethane Adhesives on Copper



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 Table 11 and in Figures 24 through 29.

Nickel		Rounded Data Averages						
Table 11								
Loctite® Brand Adhesive		Control - 9 rms	Salt Fog @ 95°F	Condensing Humidity @ 120°F	Heat Age @ 250°F	Heat Age @ 300°F	Heat Age @ 350°F	Heat Age @ 400°F
Two-Part Acrylic	Loctite® H3151	3270	1890	1170	2010	400	0	0
	Loctite® H4500	3230	600	790	1940	650	740	10
	Loctite® H4710	2940	2880	1550	1900	1200	1550	0
	Loctite® H8000	3600	2480	2610	3360	470	590	490
	Loctite® H8500	2440	870	1050	2880	640	0	0
	Loctite® H8600	2910	1820	2470	2540	1250	260	20
	Loctite® H8700	3370	2480	2810	3190	2570	2160	0
Two-Part Acrylic	Loctite® 324	2380	1190	270	600	390	290	0
	Loctite® 326	1260	220	160	380	560	150	0
	Loctite® 330	2880	1370	660	1750	980	480	230
	Loctite® 331	1810	580	1270	2640	1820	1190	0
	Loctite® 334	2310	620	390	3490	3380	2770	1230
	Loctite® 392	3110	1020	0	460	350	160	10
Cyanoacrylate	Loctite® 406	430	0	0	0	0	0	0
	Loctite® 435	2250	0	0	0	0	0	0
	Loctite® 454	220	70	0	0	0	0	0
	Loctite® 480	2990	0	0	210	0	0	0
	Loctite® 4205	360	10	0	30	0	0	0
Elastomeric Adhesives	Loctite® 5510	200	200	160	0	0	0	0
	5570 (white)	490	340	360	140	0	0	0
	Loctite® 5604	340	300	320	390	370	280	350
	Loctite® 5900	130	120	90	170	170	160	100
	Loctite® Superflex Black	70	0	80	110	50	150	80
Two-Part Epoxy	Loctite® E-05MR	1000	1820	480	2850	1470	1160	580
	Loctite® E-20NS	2610	970	0	1340	660	350	210
	Loctite® E-20HP	1380	1510	920	500	240	130	10
	Loctite® E-30CL	1490	1060	920	1090	590	760	650
	Loctite® E-30UT	2380	2300	0	1560	1500	1270	70
	Loctite® E-40HT	2640	2730	1180	1900	150	310	160
	Loctite® E-50GW	490	500	280	0	0	0	0
	Loctite® E-50CR	1640	2120	1130	1340	440	220	180
Other Epoxy	Loctite® FM HP Epoxy	2530	2610	1200	740	210	130	90
	Loctite® E-214HP	4060	290	20	3260	2990	2740	2010
	Loctite® E-220IC	3240	3250	2600	4600	3140	2850	2420
	Loctite® 3984	1000	430	750	630	630	540	0
Urethane	Loctite® U-05FL	1410	800	990	1500	1250	350	60
	Loctite® Rapid Rubber	700	60	300	750	160	220	260
	Loctite® 3631	400	440	130	770	850	330	120

FIGURE 24

Bond Strength for Two-Step and Two-Part Acrylic Adhesives on Nickel

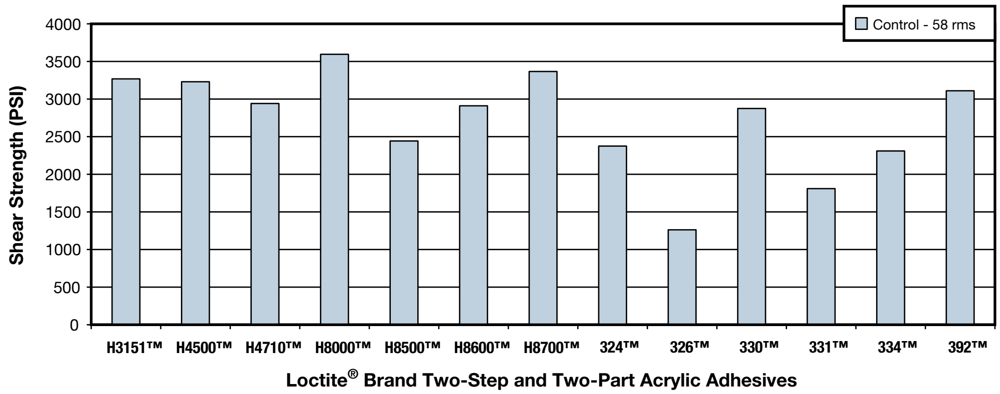


FIGURE 25

Effect of Salt Fog Exposure and Condensing Humidity on the Bond Strength of Two-Step and Two-Part Acrylic Adhesives on Nickel

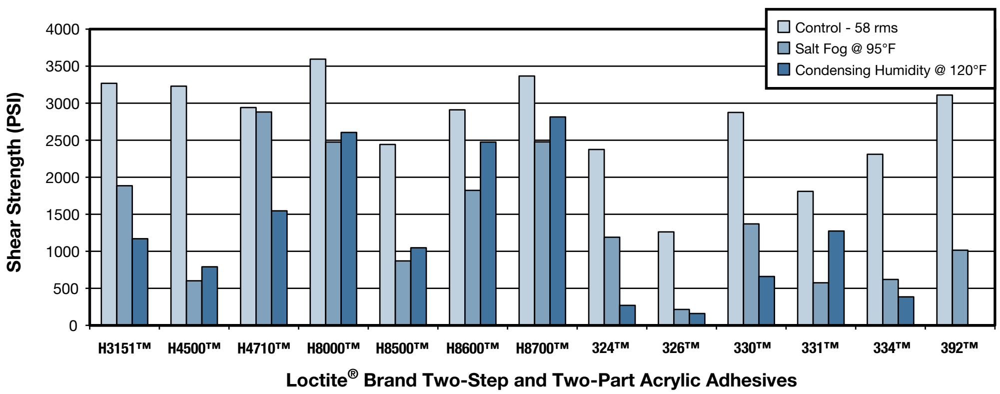


FIGURE 26

Effect of Heat Aging on the Bond Strength of Two-Step and Two-Part Acrylic Adhesives on Nickel

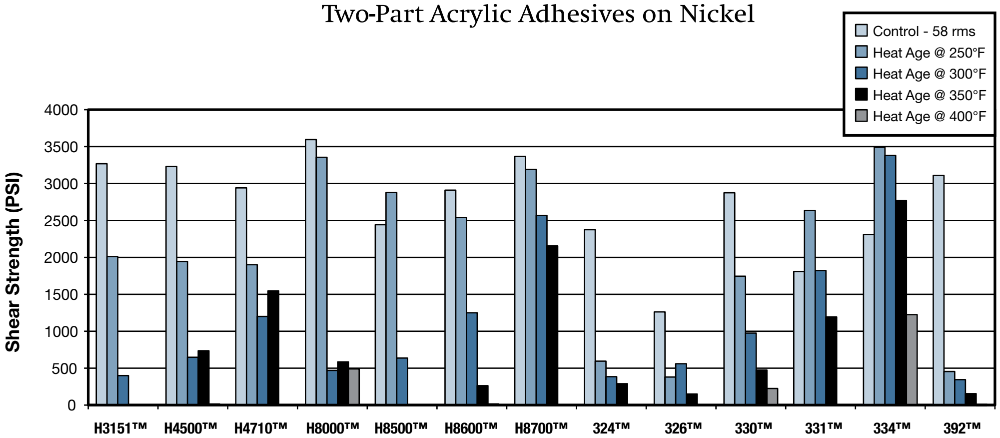


FIGURE 27

Bond Strength for Epoxy and Polyurethane Adhesives on Nickel

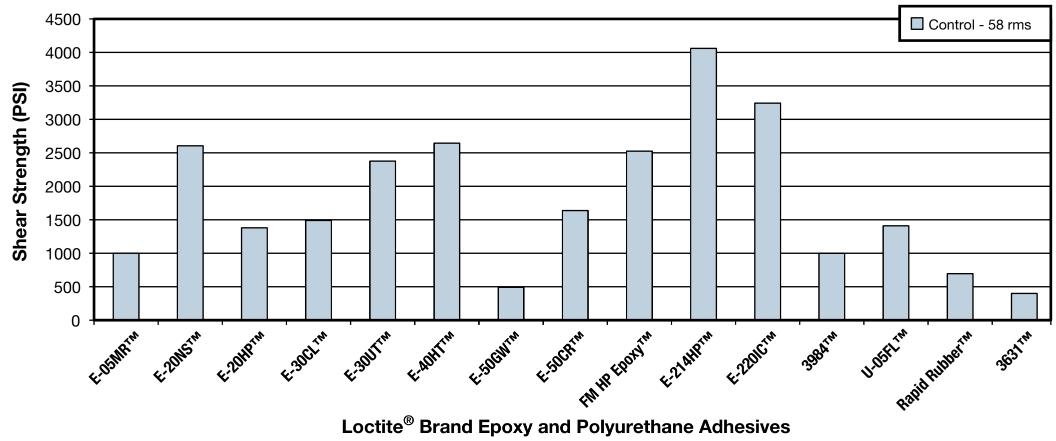


FIGURE 28

Effect of Condensing Humidity and Salt Fog on the Bond Strength of Epoxy and Polyurethane Adhesives on Nickel

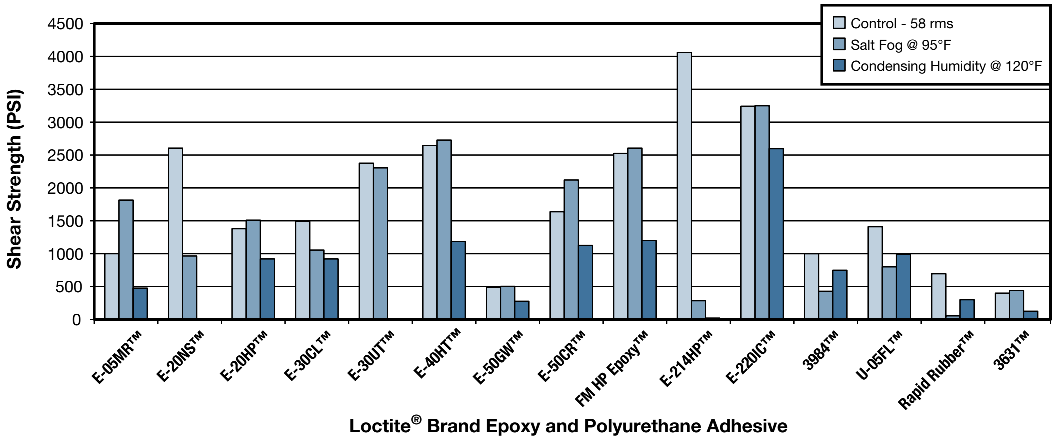
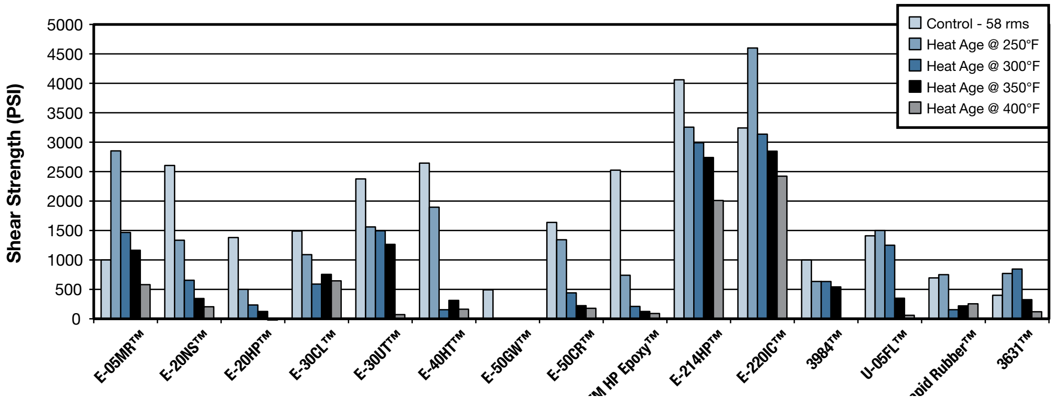


FIGURE 29

Effect of Heat Aging on the Bond Strength of Epoxy and Polyurethane Adhesives on Nickel



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.

Summary of Results

The results of the bond strength testing are shown in Table 13 and in Figures 30 through 35.

Common Grades of Stainless Steel		
Table 12		General Characteristics of this Series
AISI 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

Stainless Steel		Rounded Data Averages							
Table 13	Loctite® Brand Adhesive	Control - 9 rms	Roughened - 68 rms	Salt Fog @ 95°F	Condensing Humidity @ 120°F	Heat Age @ 250°F	Heat Age @ 300°F	Heat Age @ 350°F	Heat Age @ 400°F
Two-Part Acrylic	Loctite® H3151	3900	3500	2610	510	1740	350	0	0
	Loctite® H4500	2820	2920	1620	1380	1690	1300	440	160
	Loctite® H4710	3740	3000	2810	1890	2900	650	380	0
	Loctite® H8000	2320	3000	1370	1690	2860	2600	1740	490
	Loctite® H8500	2720	2640	2030	1770	1400	1340	930	250
	Loctite® H8600	3300	2080	2190	2730	3260	1830	400	0
	Loctite® H8700	3460	3590	2310	2240	3480	2710	2320	650
Two-Part Acrylic	Loctite® 324	1150	2440	1720	940	2070	1650	950	410
	Loctite® 326	1090	2320	1440	910	1300	540	560	320
	Loctite® 330	1330	3180	1970	2790	3350	2760	1180	550
	Loctite® 331	2380	2070	630	2130	2670	1970	1690	550
	Loctite® 334	2480	2950	1780	2140	2140	3170	2980	1820
	Loctite® 392	2290	2460	1910	1640	1260	1450	0	0
Cyanoacrylate	Loctite® 406	450	2230	270	0	280	0	0	0
	Loctite® 435	2980	3200	0	1120	810	0	0	0
	Loctite® 454	970	2450	0	0	230	0	0	0
	Loctite® 480	3290	3350	2470	1790	210	0	0	0
	Loctite® 4205	1210	3760	210	1700	1020	940	0	0
Elastomeric Adhesives	Loctite® 5510	220	190	210	190	20	0	0	0
	Loctite® 5570 (white)	400	240	330	210	0	0	0	0
	Loctite® 5604	410	300	330	330	370	300	360	340
	Loctite® 5900	200	210	310	180	250	140	100	220
	Superflex Black	100	150	30	140	180	110	130	60
Two-Part Epoxy	Loctite® E-05MR	650	2200	850	700	1310	1310	330	390
	Loctite® E-20NS	1630	3520	1770	1470	3190	3340	2510	1270
	Loctite® E-20HP	1720	3220	1270	940	2430	2070	490	540
	Loctite® E-30CL	1070	1640	1050	720	1650	1670	1970	560
	Loctite® E-30UT	650	3260	1160	820	1820	1700	670	960
	Loctite® E-40HT	1150	3900	1860	1720	2370	2510	2260	1820
	Loctite® E-50GW	470	1590	390	410	140	290	0	0
	Loctite® E-50CR	2030	3190	1890	1290	3160	2220	410	300
Other Epoxy	Loctite® FM HP Epoxy	1640	3220	680	1280	2380	1270	1540	920
	Loctite® E-214HP	4420	4740	3300	2030	3100	4360	4310	2960
	Loctite® E-220IC	3860	3240	4030	3820	4840	4200	2620	2500
	Loctite® 3984	1530	3250	850	1140	910	1040	520	1000
Urethane	Loctite® U-05FL	860	1040	1090	1660	1890	1580	410	90
	Loctite® Rapid Rubber	540	1060	200	200	350	170	150	120
	Loctite® 3631	620	380	440	360	1040	530	230	120

FIGURE 30

Effect of Roughening on Bond Strength for Two-Step and Two-Part Acrylic Adhesives on Stainless Steel

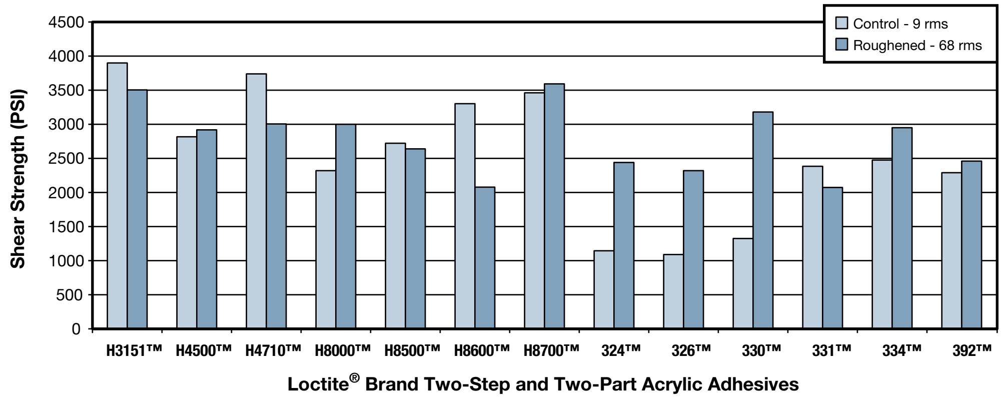


FIGURE 31

Effect of Salt Fog Exposure and Condensing Humidity on the Bond Strength of Two-Step and Two-Part Acrylic Adhesives on Stainless Steel

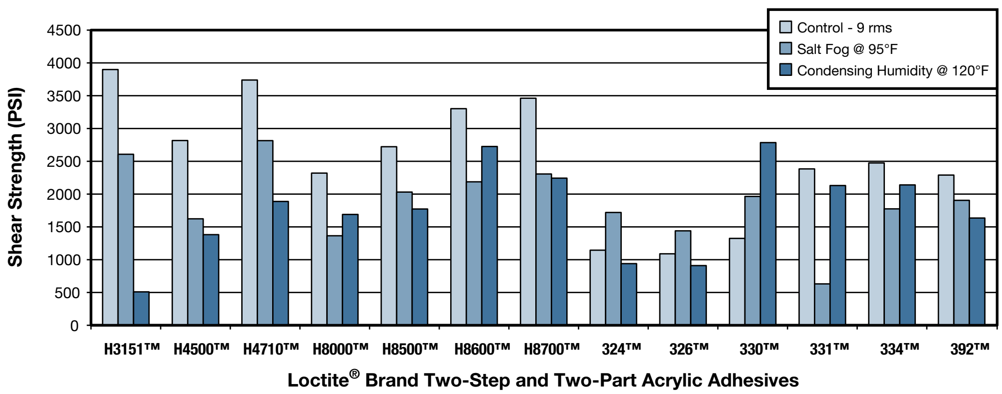


FIGURE 32

Effect of Heat Aging on the Bond Strength of Two-Step and Two-Part Acrylic Adhesives on Stainless Steel

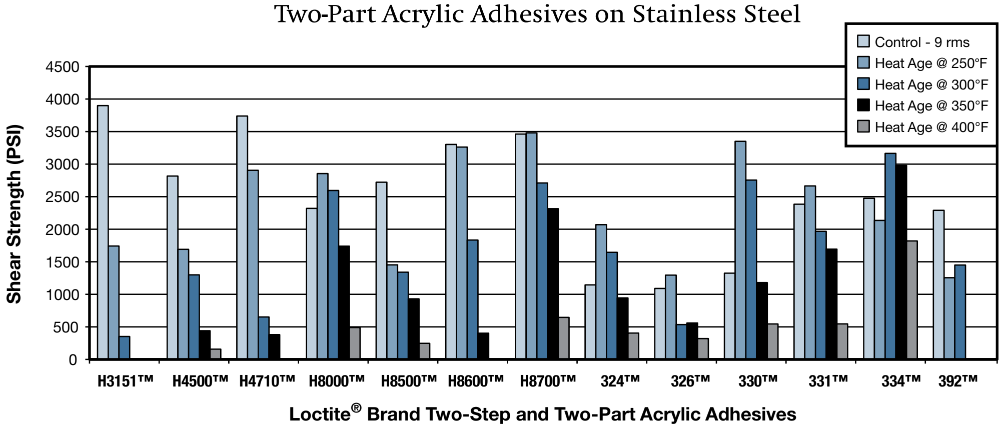


FIGURE 33

Effect of Surface Roughening on the Bond Strength of
Epoxy and Polyurethane Adhesives on Stainless Steel

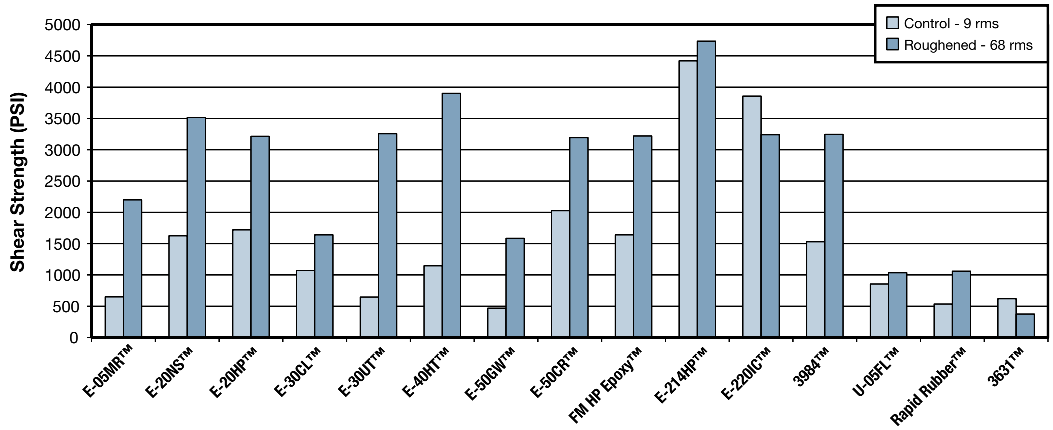


FIGURE 34

Effect of Condensing Humidity and Salt Fog on the Bond Strength of
Epoxy and Polyurethane Adhesives on Stainless Steel

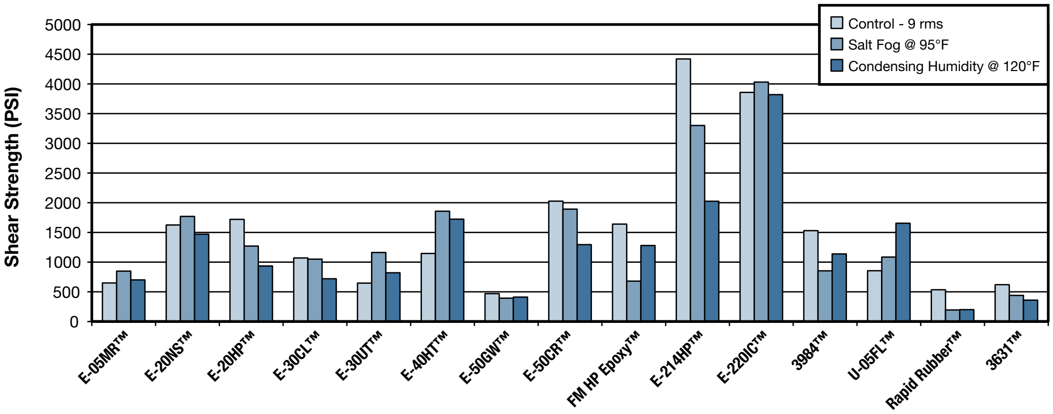
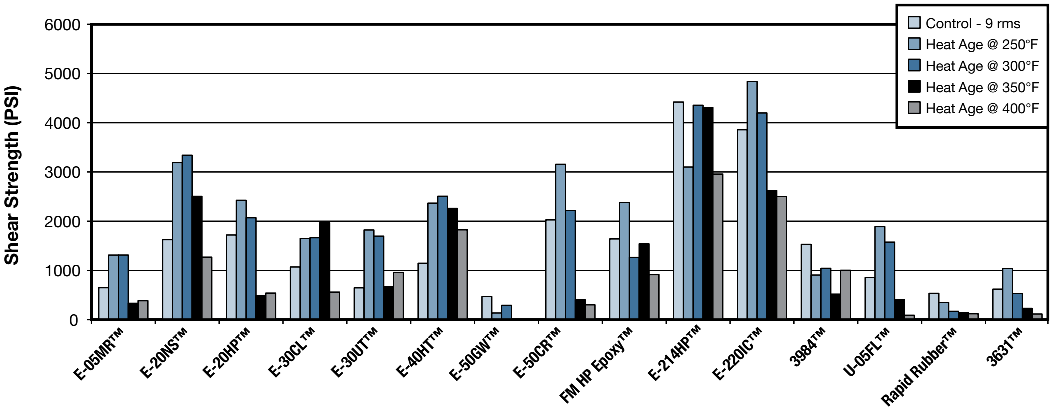


FIGURE 35

Effect of Heat Aging on the Bond Strength of Epoxy and
Polyurethane Adhesives on Stainless Steel



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 14 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 austentite, ferrite, perlite, and martensite.

Austentite 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.

Summary of Results

The results of the bond strength testing are shown in Table 15 and in Figures 36 through 41.

Common Grades of Steel

Table 14	AISI/SAE Number	Alloy Additions	Main Alloying 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. Sulfur - improves machinability, lowers transverse ductility and notch impact toughness with minimal impact on longitudinal mechanical properties. Diminishes surface quality and weldability.
	11xx	Sulfur	
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 - strengthens unhardened steels, can improve toughness and hardenability depending on composition and crystalline structure.
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	Nickel - strengthens unhardened steels, can improve toughness and hardenability depending on composition and crystalline structure. 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.
	43xx	Nickel Chromium Molybdenum	
	44xx	Molybdenum	
	8xxx	Nickel Chromium Molybdenum	
Chromium Steels	46xx	Nickel, Molybdenum	Nickel - strengthens unhardened steels, can improve toughness and hardenability depending on composition and crystalline structure. Molybdenum - increases hardenability, resistance to softening in tempering, high temperature tensile and creep strengths, minimizes tendency to temper embrittlement.
Chromium Vanadium Steels	5xxx	Chromium	Chromium - increases hardenability, corrosion resistance, high temperature strength and abrasion resistance in high carbon alloys.
Nickel Chromium	6xxx	Chromium Vanadium	Chromium - increases hardenability, corrosion resistance, high temperature strength and abrasion resistance in high carbon alloys. Vanadium - increases hardenability, resists softening in hardening and causes marked secondary hardening, elevates coarsening temperature of austenite.
Silicon Steels	92xx	Silicon	Deoxidizer, improves oxidation resistance, slightly increases strength of ferrite.

Classification

Notes:
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%.

Steel		Rounded Data Averages							
Table 15 — Loctite® Brand Adhesive		Control - 9 rms	Roughened - 68 rms	Salt Fog @ 95°F	Condensing Humidity @ 120°F	Heat Age @ 250°F	Heat Age @ 300°F	Heat Age @ 350°F	Heat Age @ 400°F
Two-Part Acrylic	Loctite® H3151	4050	3600	3270	2890	1100	460	0	0
	Loctite® H4500	3720	3430	3190	2790	2440	1220	900	0
	Loctite® H4710	3770	3420	2540	2930	1410	630	170	0
	Loctite® H8000	3320	2970	2260	2060	3390	3090	3460	3150
	Loctite® H8500	2890	1920	1120	1810	1670	630	140	0
	Loctite® H8600	2850	2790	3050	3130	1290	680	290	0
	Loctite® H8700	3540	3910	2720	2770	2120	2420	2580	760
Two-Part Acrylic	Loctite® 324	2420	2680	1870	1270	1950	1810	1240	210
	Loctite® 326	1720	2020	1180	750	1380	1210	630	380
	Loctite® 330	3170	3240	2770	2780	1600	1780	1160	980
	Loctite® 331	1650	2210	1910	1750	2800	2300	1460	350
	Loctite® 334	2590	2740	2750	2460	3380	3320	4070	3160
	Loctite® 392	2310	2570	1590	1570	1020	1120	160	0
Cyanoacrylate	Loctite® 406	860	2320	180	180	630	0	0	0
	Loctite® 435	2830	3460	1500	1640	1790	0	0	0
	Loctite® 454	1600	2480	370	600	670	0	0	0
	Loctite® 480	3520	3460	1680	1680	1320	0	0	0
	Loctite® 4205	1120	3840	620	1310	1120	860	0	0
Elastomeric Adhesives	Loctite® 5510	220	250	160	180	0	0	0	0
	Loctite® 5570 (white)	410	310	270	270	0	0	0	0
	Loctite® 5604	350	330	0	220	260	300	420	350
	Loctite® 5900	140	190	90	110	120	110	110	210
	Loctite® Superflex Black	60	160	130	170	140	140	160	170
Two-Part Epoxy	Loctite® E-05MR	1460	3180	1360	1540	4020	2820	2410	810
	Loctite® E-20NS	4330	4330	2510	2270	4290	3680	3510	1680
	Loctite® E-20HP	3170	3360	2470	1590	3290	2920	2540	1400
	Loctite® E-30CL	2470	2240	1900	2140	3330	2890	2080	1640
	Loctite® E-30UT	3460	3480	2080	1820	3610	4160	3310	1170
	Loctite® E-40HT	4150	3860	3870	2720	3720	3920	3740	1500
	Loctite® E-50GW	980	1780	840	1250	310	590	380	0
	Loctite® E-50CR	3080	3520	2500	2690	3570	3670	2400	1020
Other Epoxy	Loctite® FM HP Epoxy	2840	2880	1700	2080	2750	1470	1040	1150
	Loctite® E-214HP	3280	5200	720	1100	4320	4000	3010	1460
	Loctite® E-220IC	5270	3450	2680	3860	5000	3440	2730	820
	Loctite® 3984	2600	3310	1360	1350	1380	1520	1130	1120
Urethane	Loctite® U-05FL	1040	1250	1290	1540	2270	1450	720	210
	Loctite® Rapid Rubber	150	1310	210	220	1130	540	440	630
	Loctite® 3631	610	480	480	320	920	300	180	40

FIGURE 36

Effect of Roughening on Bond Strength for Two-Step and Two-Part Acrylic Adhesives on Steel

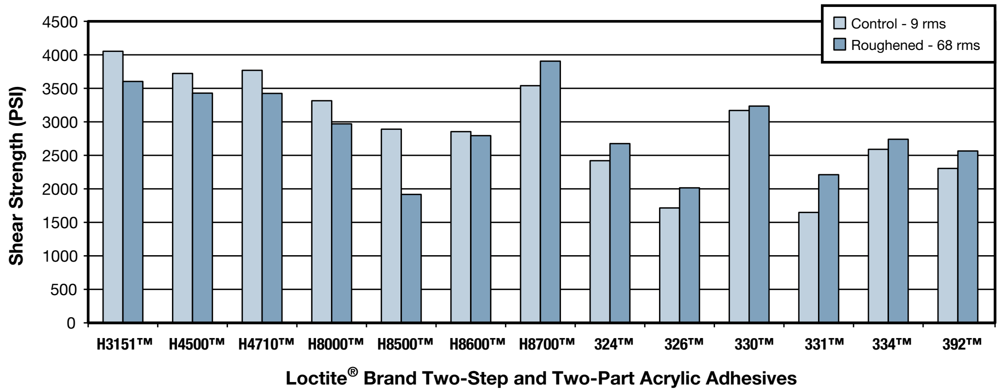


FIGURE 37

Effect of Salt Fog Exposure and Condensing Humidity on the Bond Strength of Two-Step and Two-Part Acrylic Adhesives on Steel

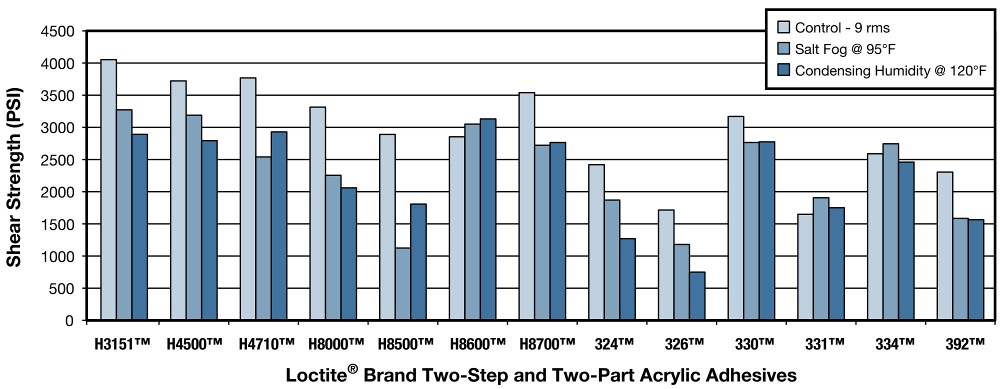


FIGURE 38

Effect of Heat Aging on the Bond Strength of Two-Step and Two-Part Acrylic Adhesives on Steel

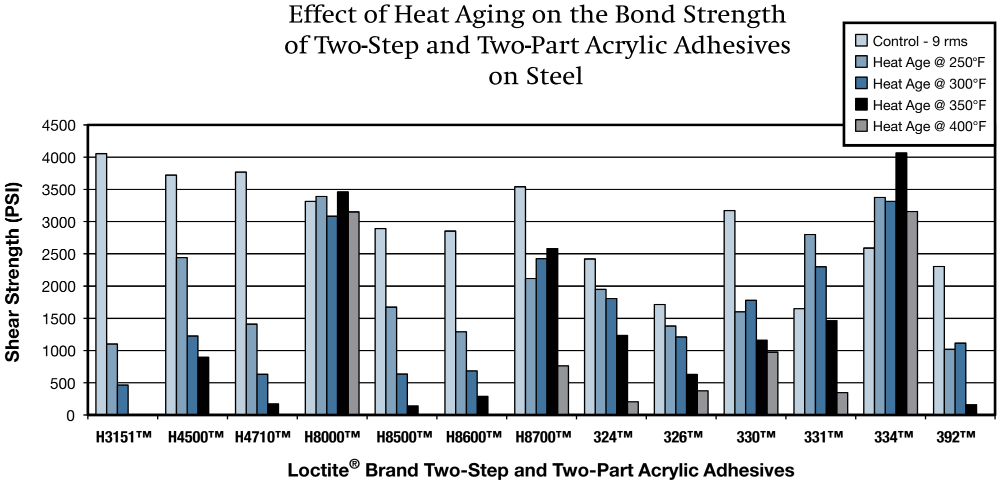


FIGURE 39

Effect of Surface Roughening on the Bond Strength of Epoxy and Polyurethane Adhesives on Steel

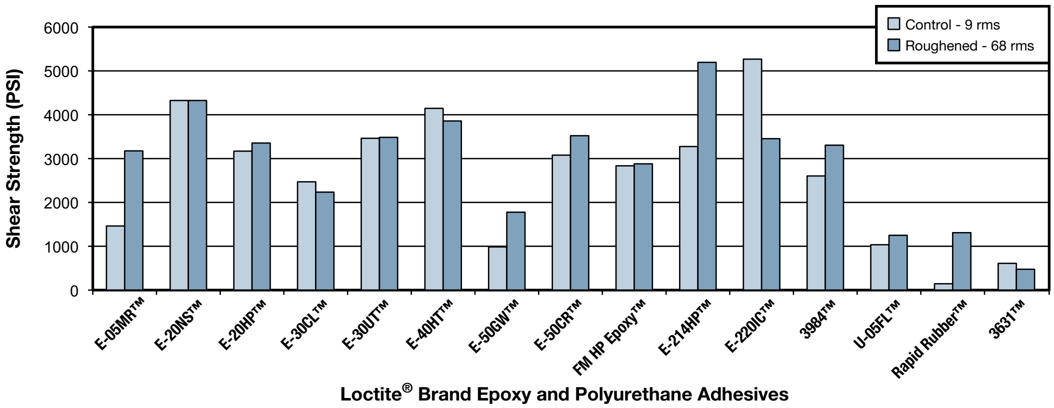


FIGURE 40

Effect of Condensing Humidity and Salt Fog on the Bond Strength of Epoxy and Polyurethane Adhesives on Steel

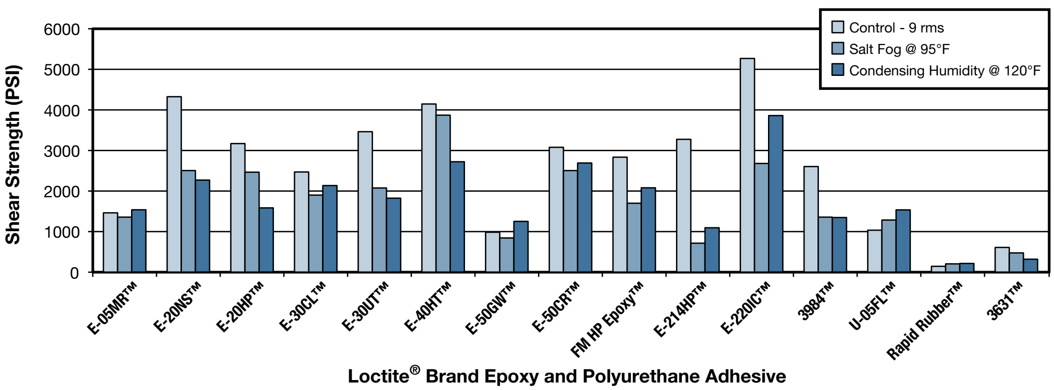
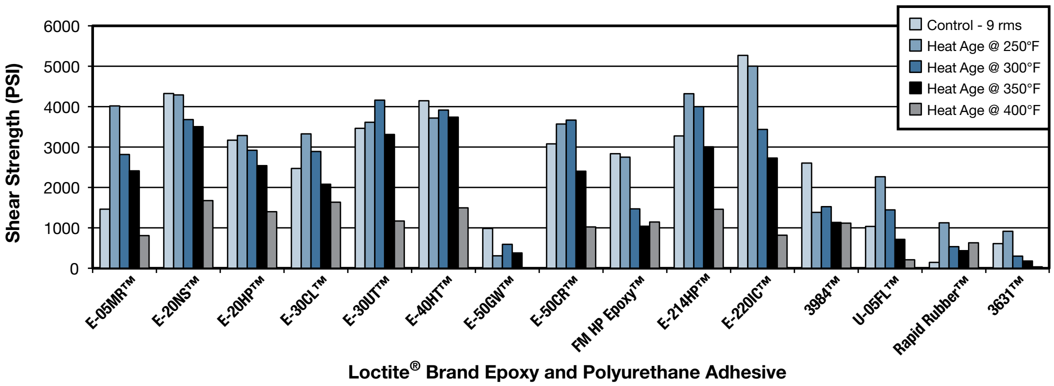


FIGURE 41

Effect of Heat Aging on the Bond Strength of Epoxy and Polyurethane Adhesives on Steel



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 Table 16 and in Figures 42 through 47.

Zinc Dichromated Steel		Rounded Data Averages						
Table 16								
Loctite® Brand Adhesive		Control - 58 rms	Salt Fog @ 95°F	Condensing Humidity @ 120°F	Heat Age @ 250°F	Heat Age @ 300°F	Heat Age @ 350°F	Heat Age @ 400°F
Two-Part Acrylic	Loctite® H3151	840	870	1350	660	0	0	0
	Loctite® H4500	2300	1540	1580	1610	0	0	0
	Loctite® H4710	1280	1780	1770	0	0	0	0
	Loctite® H8000	1010	960	1210	1440	810	360	140
	Loctite® H8500	900	520	930	790	0	0	0
	Loctite® H8600	1560	1350	1500	1710	0	0	0
	Loctite® H8700	1170	1480	1160	860	620	0	0
Two-Part Acrylic	Loctite® 324	550	1050	1140	860	210	0	0
	Loctite® 326	1000	1050	740	400	210	240	0
	Loctite® 330	1860	1840	1450	190	220	120	0
	Loctite® 331	1470	1520	760	1620	400	0	0
	Loctite® 334	880	800	920	1300	1160	960	0
	Loctite® 392	1520	1010	920	560	480	140	0
Cyanoacrylate	Loctite® 406	270	120	0	0	0	0	0
	Loctite® 435	220	0	260	0	0	0	0
	Loctite® 454	350	230	0	0	0	0	0
	Loctite® 480	640	710	270	200	0	0	0
	Loctite® 4205	410	910	280	470	270	0	0
Elastomeric Adhesives	Loctite® 5510	240	210	210	0	0	0	0
	Loctite® 5570 (white)	520	370	270	0	0	0	0
	Loctite® 5604	330	340	290	320	300	230	120
	Loctite® 5900	220	250	200	220	230	190	50
	Loctite® Superflex Black	70	110	130	100	90	50	0
Two-Part Epoxy	Loctite® E-05MR	720	430	230	530	290	100	0
	Loctite® E-20NS	1190	1000	450	1350	1360	410	0
	Loctite® E-20HP	1280	610	820	730	570	290	0
	Loctite® E-30CL	1510	1760	1310	1400	1810	710	230
	Loctite® E-30UT	770	500	620	230	140	190	0
	Loctite® E-40HT	1410	1480	690	1140	1110	170	0
	Loctite® E-50GW	910	740	660	0	0	0	0
	Loctite® E-50CR	930	730	690	500	290	310	0
Other Epoxy	Loctite® FM HP Epoxy	3390	2840	2150	790	1540	1020	350
	Loctite® E-214HP	640	580	550	3410	3010	2960	140
	Loctite® E-220IC	890	1100	920	1490	1240	1360	510
	Loctite® 3984	840	430	880	980	880	530	0
Urethane	Loctite® U-05FL	1230	1100	1460	1900	1350	320	80
	Loctite® Rapid Rubber	1610	1000	820	1570	190	70	260
	Loctite® 3631	550	610	640	310	80	120	30

FIGURE 42

Bond Strength for Two-Step and Two-Part Acrylic Adhesives on Zinc Dichromated Steel

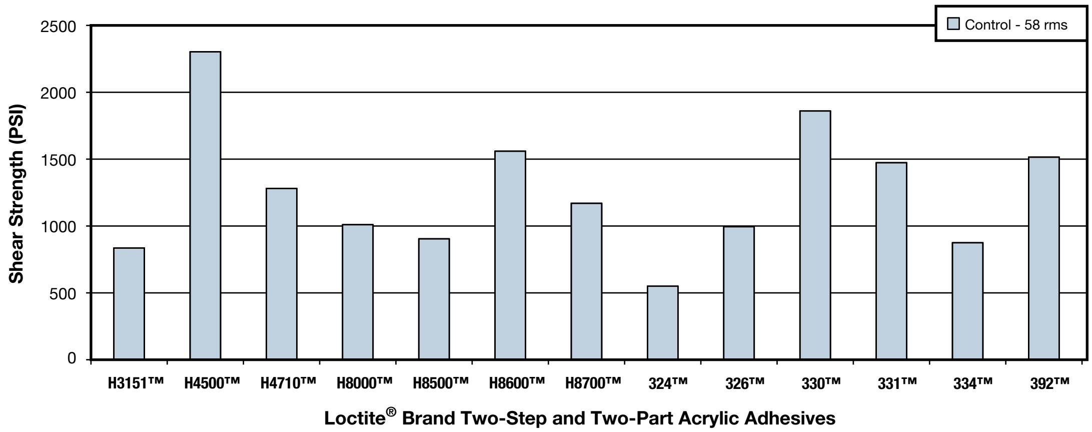


FIGURE 43

Effect of Salt Fog Exposure and Condensing Humidity on the Bond Strength of Two-Step and Two-Part Acrylic Adhesives on Zinc Dichromated Steel

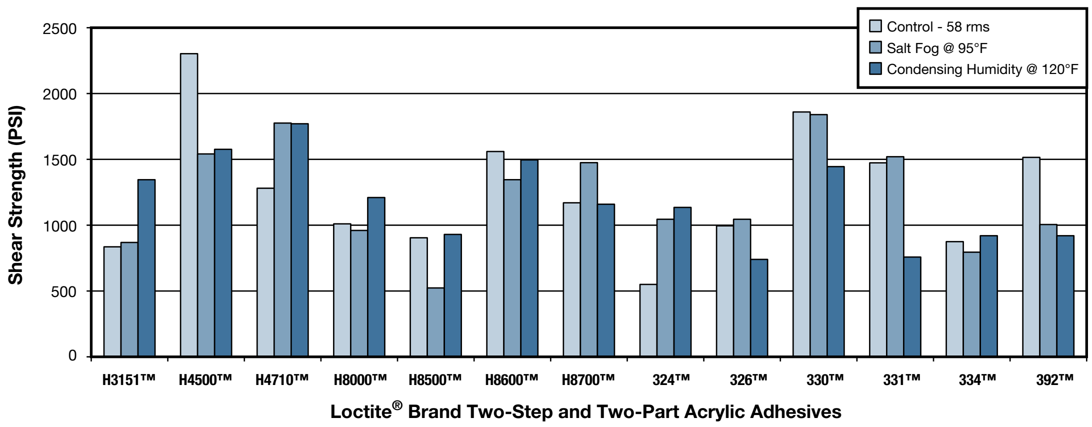


FIGURE 44

Effect of Heat Aging on the Bond Strength of Two-Step and Two-Part Acrylic Adhesives on Zinc Dichromated Steel

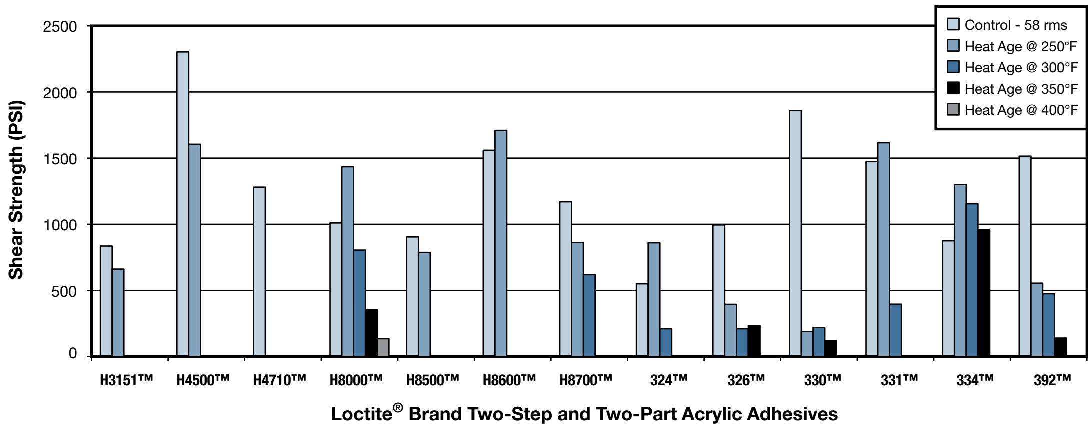


FIGURE 45

Bond Strength of Epoxy and Polyurethane Adhesives on Zinc Dichromated Steel

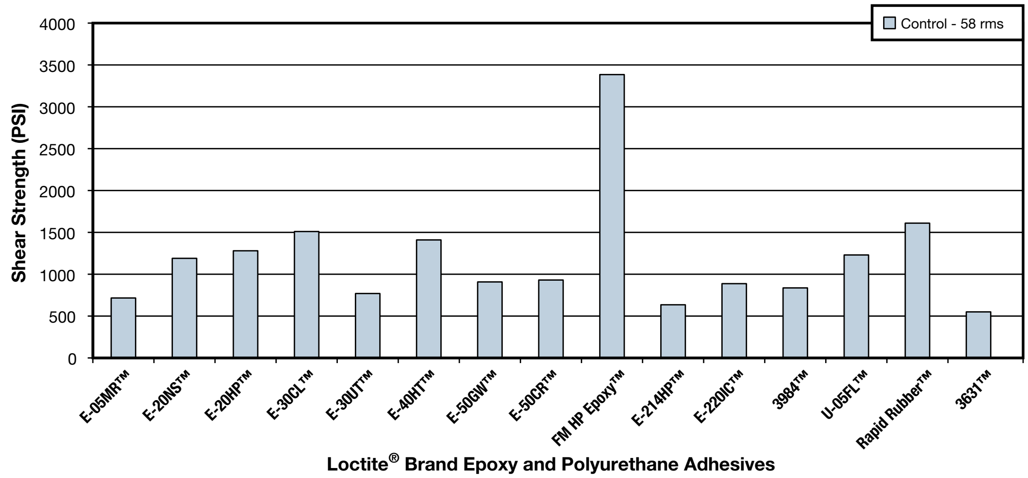


FIGURE 46

Effect of Condensing Humidity and Salt Fog on the Bond Strength of Epoxy and Polyurethane Adhesives on Zinc Dichromated Steel

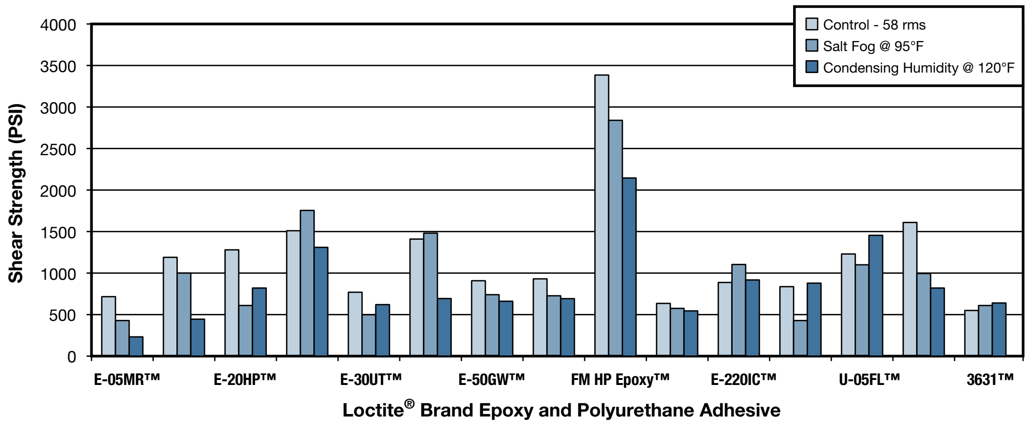
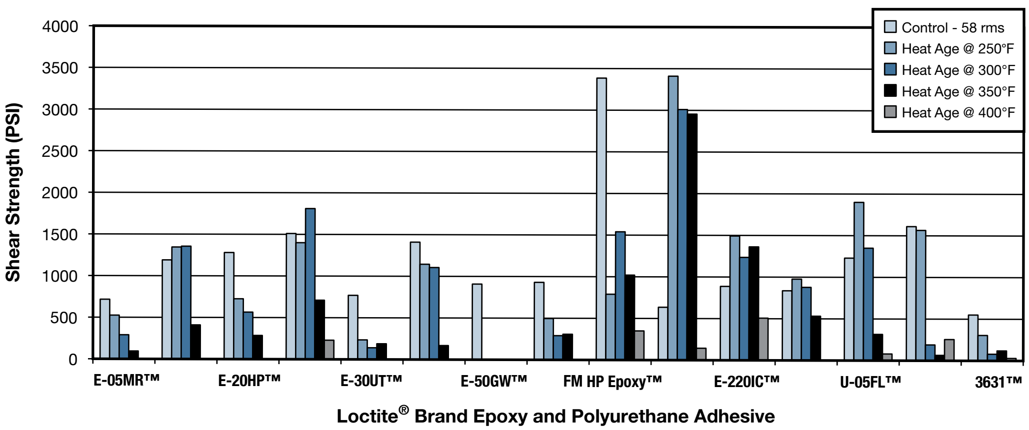


FIGURE 47

Effect of Heat Aging on the Bond Strength of Epoxy and Polyurethane Adhesives on Zinc Dichromated Steel



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 Table 17 and in Figures 48 through 53.

Galvanized Steel		Rounded Data Averages						
Table 17								
Loctite® Brand Adhesive		Control - 58 rms	Salt Fog @ 95°F	Condensing Humidity @ 120°F	Heat Age @ 250°F	Heat Age @ 300°F	Heat Age @ 350°F	Heat Age @ 400°F
Two-Part Acrylic	Loctite® H3151	1470	900	420	310	210	130	80
	Loctite® H4500	2140	2790	2070	2130	520	290	80
	Loctite® H4710	1940	760	2970	1160	290	260	0
	Loctite® H8000	300	410	250	640	650	960	500
	Loctite® H8500	660	920	1100	1610	730	600	0
	Loctite® H8600	1590	1910	2380	1250	520	150	100
	Loctite® H8700	630	1340	1420	1450	1430	440	510
Two-Part Acrylic	Loctite® 324	560	870	680	850	590	340	140
	Loctite® 326	860	590	620	740	400	250	260
	Loctite® 330	790	920	1190	790	380	400	180
	Loctite® 331	1000	840	1500	1750	1120	890	250
	Loctite® 334	1590	770	1920	2340	1710	1400	130
	Loctite® 392	1260	1040	830	540	450	180	150
Cyanoacrylate	Loctite® 406	450	300	290	160	0	0	0
	Loctite® 435	1240	680	620	610	0	0	0
	Loctite® 454	500	230	280	330	0	0	0
	Loctite® 480	1600	1230	920	1310	0	0	0
	Loctite® 4205	1070	330	530	660	730	0	0
Elastomeric Adhesives	Loctite® 5510	220	110	150	20	0	0	0
	Loctite® 5570 (white)	320	210	260	0	0	0	0
	Loctite® 5604	270	290	330	380	310	320	240
	Loctite® 5900	260	180	230	310	400	180	290
	Loctite® Superflex Black	60	70	90	130	50	80	50
Two-Part Epoxy	Loctite® E-05MR	550	810	170	560	510	320	390
	Loctite® E-20NS	1850	710	750	1110	1000	710	330
	Loctite® E-20HP	820	640	690	1160	670	440	390
	Loctite® E-30CL	950	680	710	660	640	370	290
	Loctite® E-30UT	570	460	260	640	470	310	0
	Loctite® E-40HT	1370	670	670	1140	840	440	230
	Loctite® E-50GW	450	550	360	130	110	0	0
	Loctite® E-50CR	1410	1260	950	500	630	380	230
Other Epoxy	Loctite® FM HP Epoxy	1490	690	890	980	840	640	510
	Loctite® E-214HP	3020	220	1640	3070	2800	2020	1900
	Loctite® E-220IC	1880	1680	1480	1650	1690	740	510
	Loctite® 3984	1490	810	980	1030	1170	870	1000
Urethane	Loctite® U-05FL	960	1410	1120	2230	1100	250	60
	Loctite® Rapid Rubber	450	590	410	570	40	10	0
	Loctite® 3631	580	670	310	860	380	200	110

FIGURE 48

Bond Strength for Two-Step and Two-Part Acrylic Adhesives on Galvanized Steel

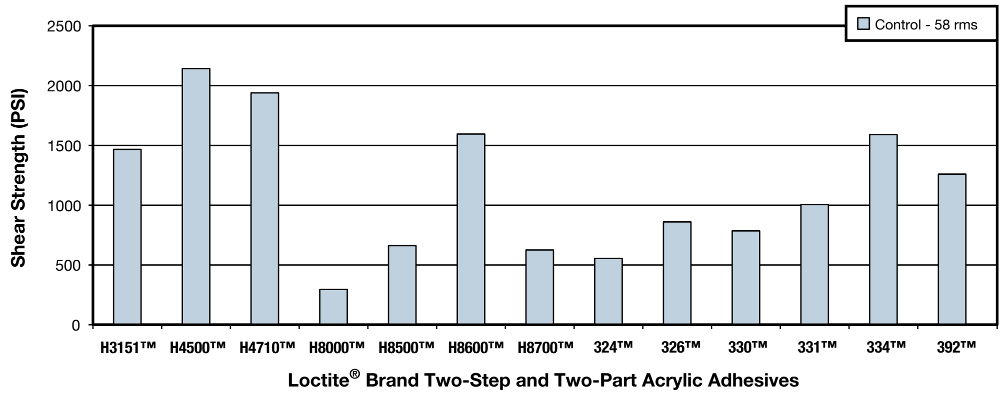


FIGURE 49

Effect of Salt Fog Exposure and Condensing Humidity on the Bond Strength of Two-Step and Two-Part Acrylic Adhesives on Galvanized Steel

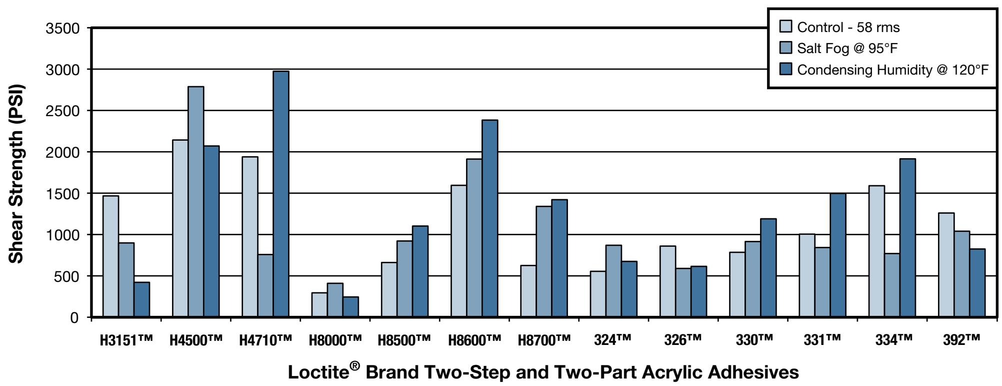


FIGURE 50

Effect of Heat Aging on the Bond Strength of Two-Step and Two-Part Acrylic Adhesives on Galvanized Steel

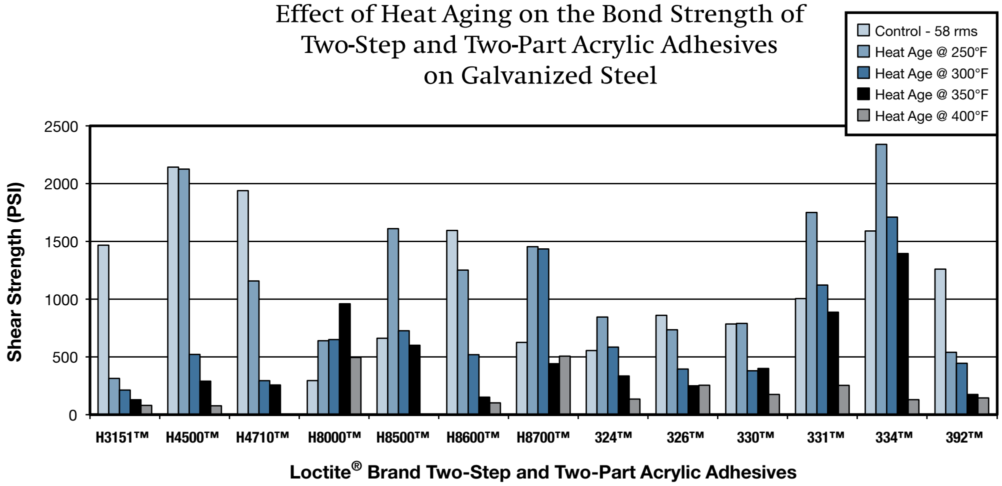


FIGURE 51

Bond Strength for Epoxy and Polyurethane Adhesives on Galvanized Steel

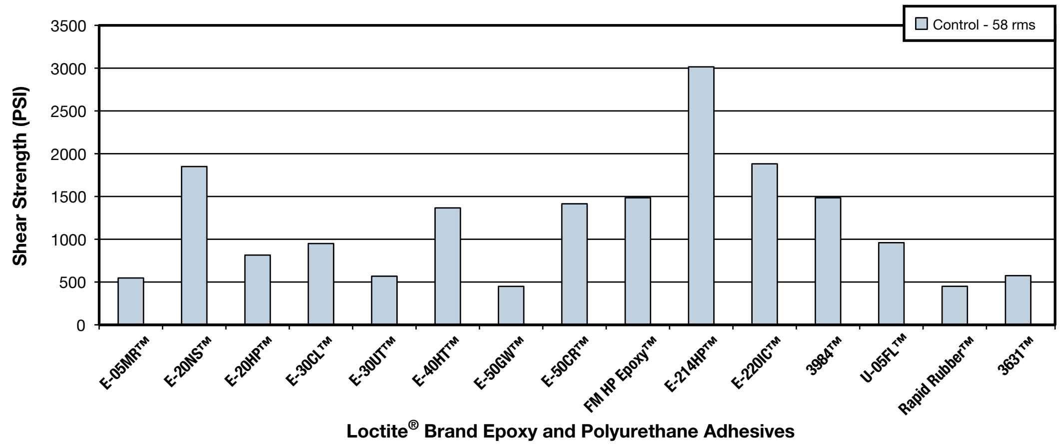


FIGURE 52

Effect of Condensing Humidity and Salt Fog on the Bond Strength of Epoxy and Polyurethane Adhesives on Galvanized Steel

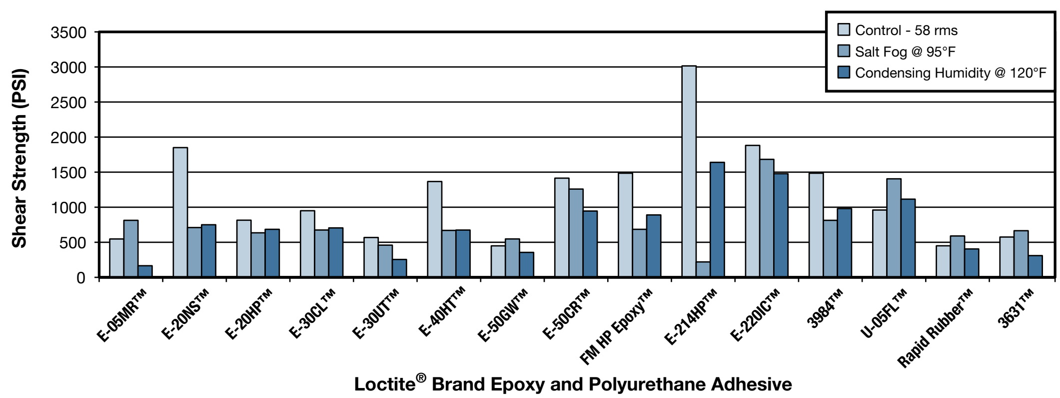
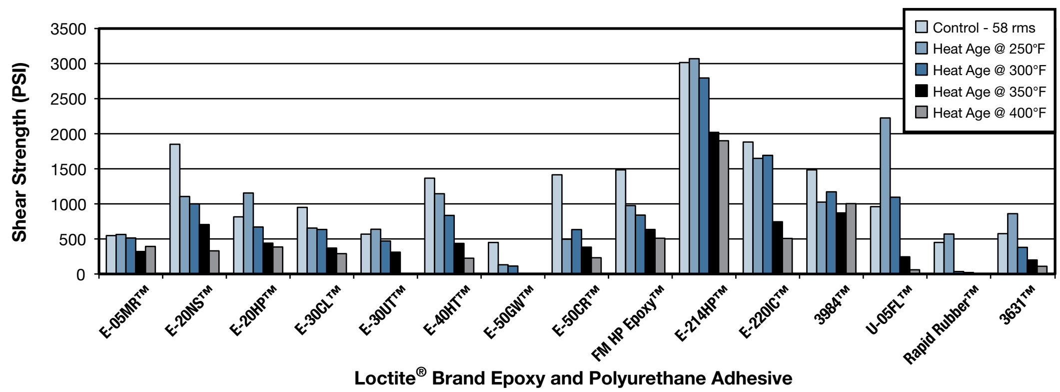


FIGURE 53

Effect of Heat Aging on the Bond Strength of Epoxy and Polyurethane Adhesives on Galvanized Steel



Section 9

Test Methodology

Substrate Preparation

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

Adhesive Application Method

Cyanoacrylates

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 in^2.

Two-Step Acrylic Adhesives

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 in^2.
   c. For Solventless Activators (Loctite® 7090™ and 7091™ Activators), the activator was dispensed at a weight per unit area of 6 milligrams/in^2.
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 in^2.

Two-Part Static Mixed Adhesives

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 in^2.

One-Part Heat Cure 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 in^2.

Moisture Cure Products

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).

Cure Conditions

Cyanoacrylate, Two-Step Acrylic, Two-Part Static Mixed Adhesives, UV/Activator Cure Acrylic Adhesive, Moisture Cure Products

1. The mated assembly was clamped with two clamps that exerted a clamping force of approximately 20 lb.
2. The bonded assembly was allowed to cure for one week at ambient conditions before conditioning and testing.

One-Part Heat Cure Epoxy Adhesive

1. The mated assembly was clamped with two clamps that exerted a clamping force of approximately 20 lb.
2. The clamped assembly was heated at 350°F (177°C) for 1 hour.
3. The assembly was left at ambient conditions 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

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.

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.

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NOTES

NOTES

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