

LOCTITE®
BONDERITE®
TEROSON®

Volume 6

Design Guide for Bonding Metals



Excellence is our Passion

Contents

Section 1

Why Bond Metals with LOCTITE® Brand Adhesives?	2
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Section 2

How to Use this Guide	3
Performance Characteristics	3

Section 3

Adhesive Joint Design	4
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Section 4

Factors Affecting Activator Selection	7
Introduction	7
Activators and Primers	8
Fixture Time Matrix	9
Performance Matrix	10
Solventless vs. Solvent-borne Activators	11

Section 5

Heat Cure Parameters for Two-Step Acrylic Adhesives	13
--	----

Section 6

Adhesive Review	14
Acrylics, Two-Step	14
Acrylics, Two-Part	15
Cyanoacrylates	16
Epoxies	17
Hot Melts	18
Polyurethanes	19
Elastomers	20

Section 7

Metal Bonding Chapters	21
How to Use the Adhesive Sheer Strength Tables ..	21
Induced Gap	22
Aluminum	23
Anodized Aluminum	26
Copper	28
Nickel	30
Stainless Steel	32
Steel	34
Zinc Dichromated Steel	38
Galvanized Steel (Zinc)	40

Section 8

Functional Coatings (Surface Treatment)	42
Alkaline Cleaners	42
Acid Cleaners	42
Zinc Phosphate Process	43
Conditioners for Zinc Phosphate	43
Zinc Phosphate	44
Iron Phosphate Process	44
Non-Phosphate/Nanoceramic Technology	45
Aluminum Conversion Coating Processes	46
Light Metals	46

Section 9

Test Methodology	48
Substrate Preparation	48
Cure Conditions	48
Test Methods	49

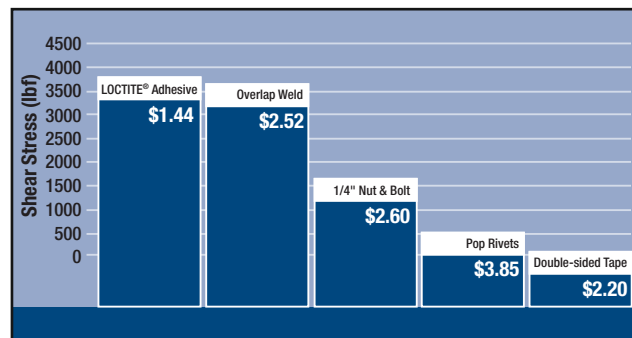
Disclaimer	50
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Section 1

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.

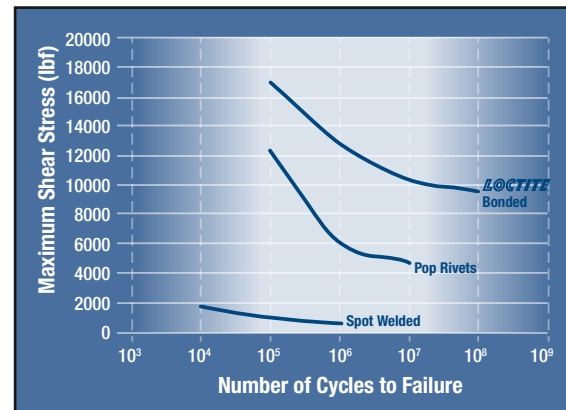


LOCTITE® Structural Adhesives are nearly as strong as overlap welds.

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.

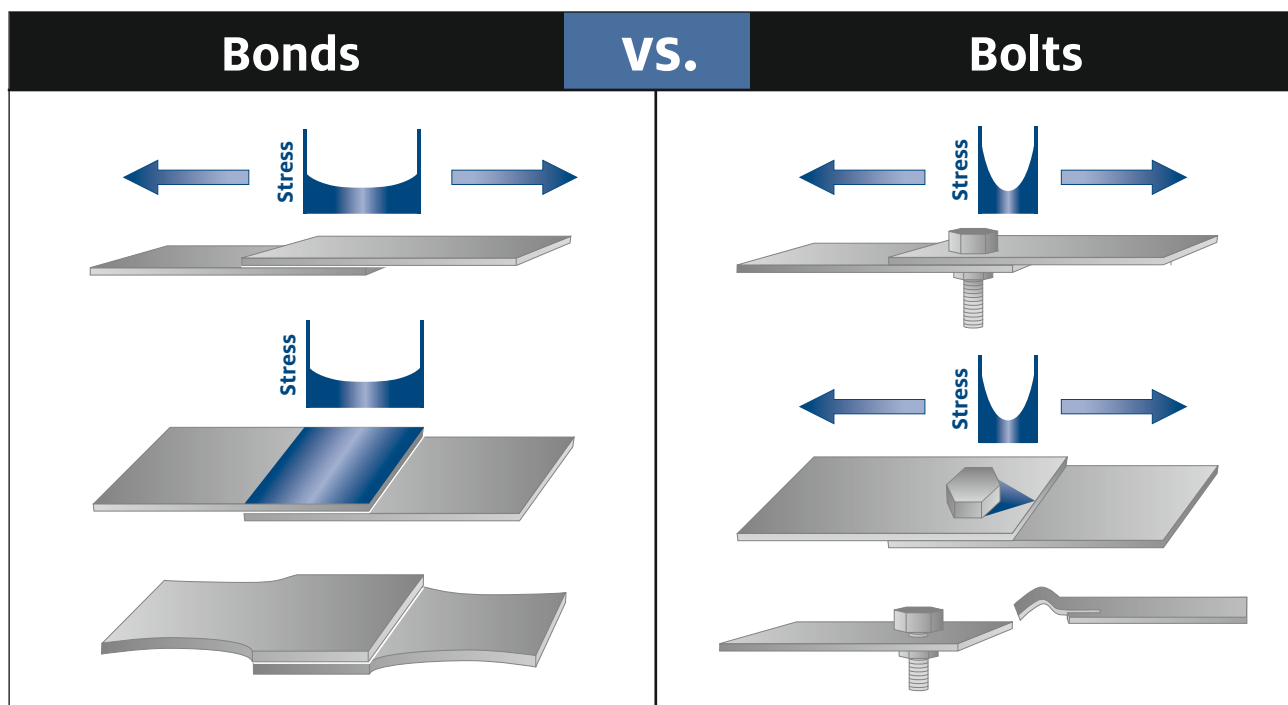
PERFORMANCE CHARACTERISTICS

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 3: Adhesive Joint Design** explains the basic terms and concepts relating to joint design, including a discussion of types of joints, common stresses associated with joints, and managing stress

distribution using key design guidelines and best practices.

- **Section 4: 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 5: 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 6: Adhesive Review** provides an overview of the dispensing and curing characteristics of each family of adhesives.
- **Section 7: 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 8: Functional Coatings (Surface Treatment)** provides a basic overview of cleaning and pre-treatment options for preparing metals for painting or additional processing steps. Topics covered include alkaline and acid cleaners/pickles, zinc and iron phosphate process conversion coatings, non-phosphate/nanoceramic technology, and aluminum conversion coatings.
- **Section 9: Test Methodology** includes an overview of metal coupon/substrate preparation, defines cure conditions by adhesive type and chemistry, and explains the various tests used to generate data for this guide. Tests conducted include shear strength (STM-700), peel strength (STM-710) and high speed impact.



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:

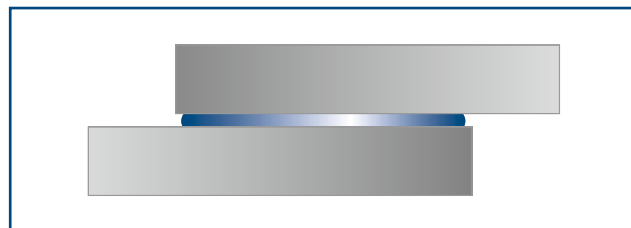
Joint: A joint is the location where an adhesive joins two substrates.

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?

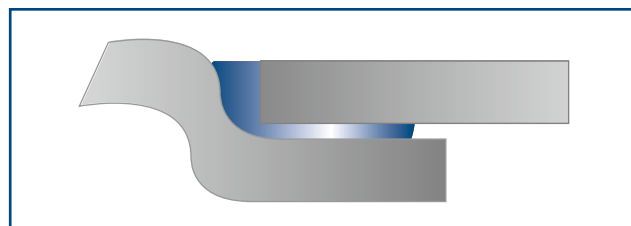
TYPES OF JOINTS

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

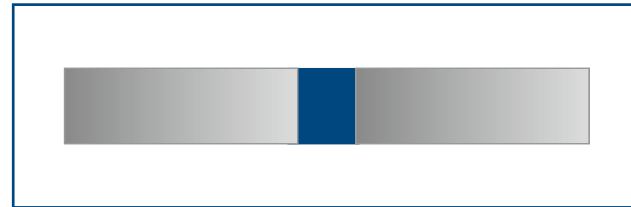
- Lap/Overlap
- Scarf
- Offset
- Single Strap/Double Strap
- Butt
- Cylindrical



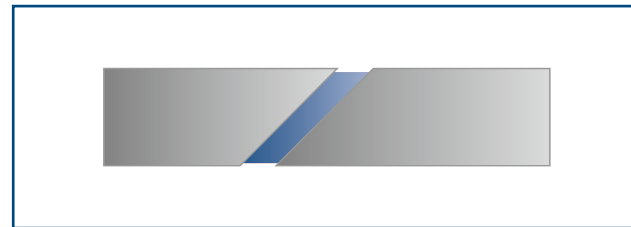
LAP/OVERLAP JOINT: A lap joint, also called an overlap joint, is formed by placing one substrate partially over another substrate.



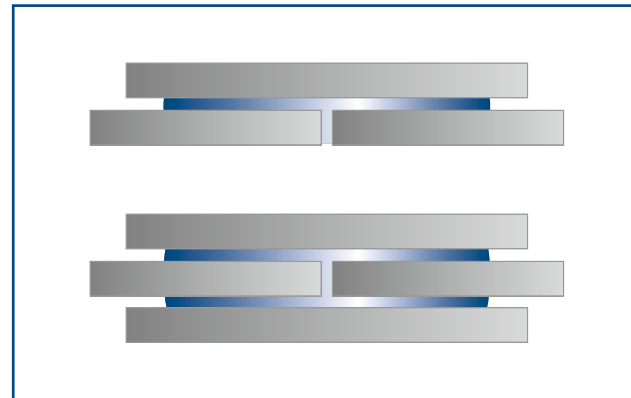
OFFSET JOINT: The offset joint is very similar to the lap joint.



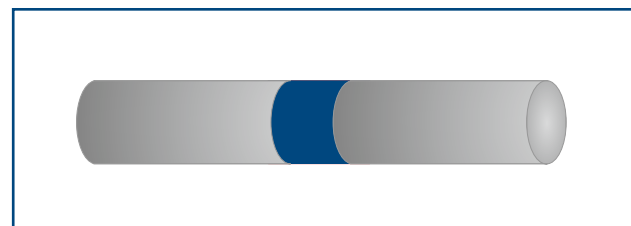
BUTT JOINT: A butt joint is formed by bonding two objects end to end.



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

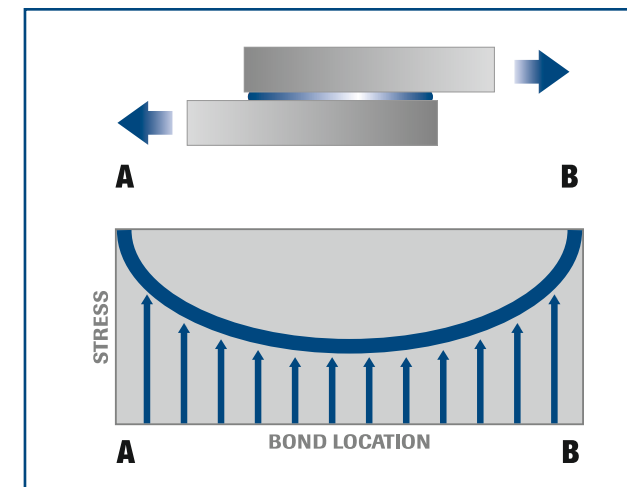
Joint stress distribution is the location of stresses within a bond.

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).

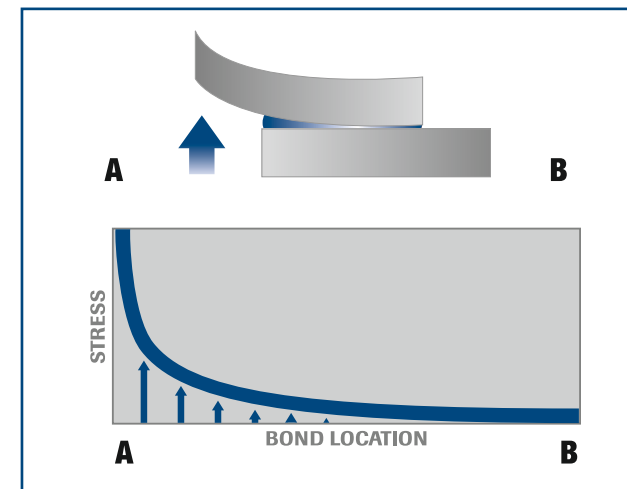
TYPES OF STRESSES

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

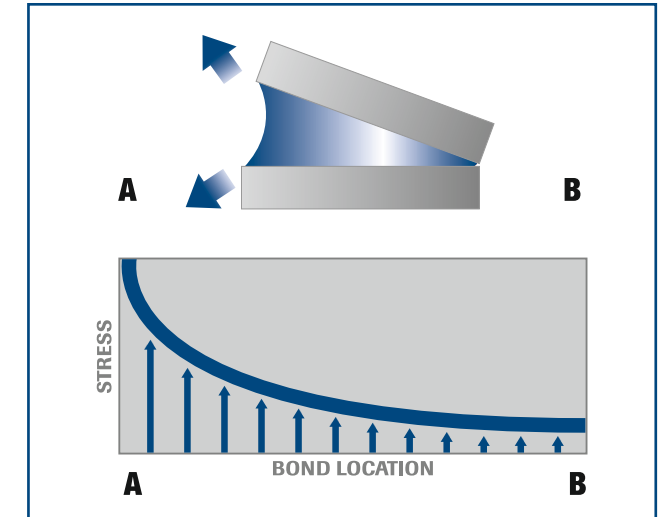
- Shear
- Tensile
- Compressive
- Peel
- Cleavage



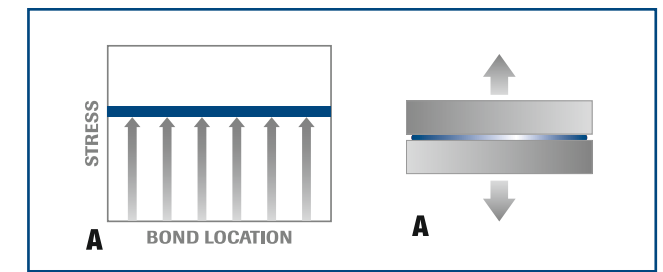
SHEAR STRESS: A shear stress results in two surfaces sliding over one another.



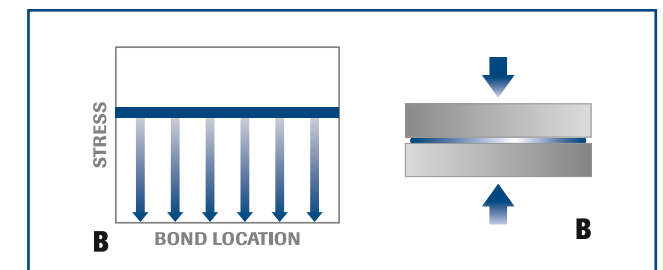
PEEL STRESS: A peel stress occurs when a flexible substrate is being lifted or peeled from the other substrate. *NOTE: The stress is concentrated at one end.*



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.

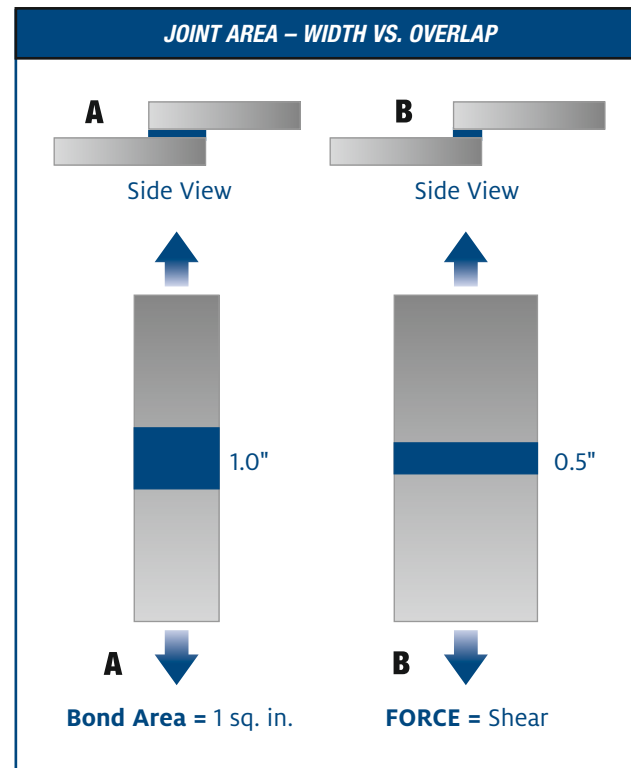
- **Joint Width More Important Than Overlap**

Note from the shear stress distribution curve, that the ends of the bond receive 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”).



Section 4

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 lap shear 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:
 - a) Active ingredient dispersed in a flammable solvent
 - b) Active ingredient dispersed in a nonflammable solvent
 - c) 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 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.

ACTIVATORS AND PRIMERS

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

Summary of LOCTITE® Activator/Primer Characteristics						
Table 1	Solvent(s)	Active Ingredient(s)	Flash Point	Drying Time (Seconds)	On-Part Life	
LOCTITE® 736™ Primer NF™ Activator	Trichloroethylene Isopropyl Alcohol	Aldehyde-amine condensate Organocopper compound	168°F (76°C)	60 to 120	30 Minutes	
LOCTITE® 7075™ Activator	Acetone	Butanol – aniline condensate	0°F (-18°C) Highly Flammable	30 to 70	2 Hours	
LOCTITE® 7090™ Activator (Solventless Primer N™)	None (Monomer based)	Organocopper compound	> 200°F (93°C)	N/A	1 Hour	
LOCTITE® 7091™ Activator (Solventless Primer N™ for Zinc Dichromated Surfaces)	None (Monomer based)	Organocopper compound	> 200°F (93°C)	N/A	1 Hour	
LOCTITE® 7471™ Primer T™	Acetone Isopropyl Alcohol	N,N-dialkanol toluidine 2-Mercaptobenzothiazole	-4°F (-20°C) Highly Flammable	30 to 70	7 Days	
LOCTITE® 7644™ Activator (Nonflammable 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® Structural Adhesive/Activator Combinations (Ultimate strength on steel in psi)							
Table 2	324™	326™	330™ Depend®	331™	334™ Structural Adhesive	352™ Structural Adhesive	392™ Structural Adhesive
LOCTITE® 736™ Primer NF™ Activator	20 Seconds (1990 psi)	25 Seconds (2205 psi)	10 Minutes (770 psi)	No fixture	No fixture	20 Seconds (2595 psi)	25 Seconds (2315 psi)
LOCTITE® 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)
LOCTITE® 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
LOCTITE® 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
LOCTITE® 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)
LOCTITE® 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)
LOCTITE® 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
LOCTITE® 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™†		326™†		330™ Depend†		331™†		334™ Structural Adhesive†		352™ Structural Adhesive†		392™ Structural Adhesive†		
		Steel	SS	Steel	SS	Steel	SS	Steel	SS	Steel	SS	Steel	SS	Steel	SS	
LOCTITE® ACTIVATORS AND PRIMERS	7649™ Primer N™	I	2750	2210	1715	1090	N/A	N/A	N/A	N/A	N/A	N/A	2170	2350	N/A	N/A
		SF	1450	845	1180	1140	N/A	N/A	N/A	N/A	N/A	N/A	2375	1980	N/A	N/A
		HM	1430	1730	750	910	N/A	N/A	N/A	N/A	N/A	N/A	910	1010	N/A	N/A
	7090™	I	3000	2454	1995	1100	N/A	N/A	N/A	N/A	N/A	N/A	2310	2175	N/A	N/A
		SF	1710	1910	2585	2650	N/A	N/A	N/A	N/A	N/A	N/A	1785	1685	N/A	N/A
		HM	1340	1640	725	1030	N/A	N/A	N/A	N/A	N/A	N/A	1305	1170	N/A	N/A
	7091™	I	2350	2005	2640	1345	N/A	N/A	N/A	N/A	N/A	N/A	2765	1865	N/A	N/A
		SF	1915	1195	1750	1795	N/A	N/A	N/A	N/A	N/A	N/A	1755	1955	N/A	N/A
		HM	1455	1735	420	1235	N/A	N/A	N/A	N/A	N/A	N/A	935	1655	N/A	N/A
	7471™ Primer T™	I	795	930	2035	805	N/A	N/A	N/A	N/A	N/A	N/A	1070	1340	N/A	N/A
		SF	1045	1560	3105	1210	N/A	N/A	N/A	N/A	N/A	N/A	1335	1135	N/A	N/A
		HM	840	1320	1015	780	N/A	N/A	N/A	N/A	N/A	N/A	1060	1355	N/A	N/A
	736™	I	1990	1645	2205	815	770	315	765	455	N/A	N/A	2595	2215	2315	1725
		SF	1770	1685	1320	1355	840	180	1215	0	N/A	N/A	1275	955	2130	535
		HM	750	1435	650	885	790	125	1270	0	N/A	N/A	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.
 N/A - Bond strength testing not done due to the fact that the adhesive/activator combination did not fixture within three hours.
 † Values expressed in psi. Tested according to STM-700.

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 nonflammable 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 Nonflammable 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 nonflammable solvents typically used include trichloroethylene and decafluoropentane. 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 (nonflammable 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 these types of adhesives. 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. 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 Nonflammable	LOCTITE® 736™ Primer NF™ LOCTITE® 7644™ Primer Activator (Nonflammable Primer N™)	Rapid evaporation rate Difficult to over-apply Nonflammable Cost
	Solventless 100% Active Ingredient	LOCTITE® 7380™ Activator	No solvent “Flash Off” required Nonflammable 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 Nonflammable Excessive activator amounts should be avoided

Section 5

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™	326™	330™ Depend®	352™ Structural Adhesive	334™ Structural Adhesive	392™ Structural Adhesive	331™	
Temperature	200°F (93°C)	40 to 60 Minutes	10 to 20 Minutes	> 24 Hours	40 to 60 Minutes	> 24 Hours	60 to 120 Minutes	5 to 10 Minutes
	250°F (121°C)	5 to 10 Minutes	5 to 10 Minutes	40 to 60 Minutes	5 to 10 Minutes	20 to 40 Minutes	5 to 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 lap shears with 0.5" (13 mm) overlap. Each lap shear 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 6

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 in.)
- 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 to 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 is 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 to 30 minutes)
- 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 achieved 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 to 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, it 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, dryers 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
- Exceptional 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°C to 125°C (212°F 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 systems 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.

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 to 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 adhesion 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 a 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 offer 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 handheld 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 has 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 that 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 systems 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 systems must be designed with dryers 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. SMPs 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 to 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. SMPs 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, and 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 to 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 SMPs 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 7

Metal Bonding Chapters

HOW TO USE THE ADHESIVE SHEAR STRENGTH TABLES

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. Refer to the Test Methodology Section on page 48 to determine the cure parameters for a specific chemistry.

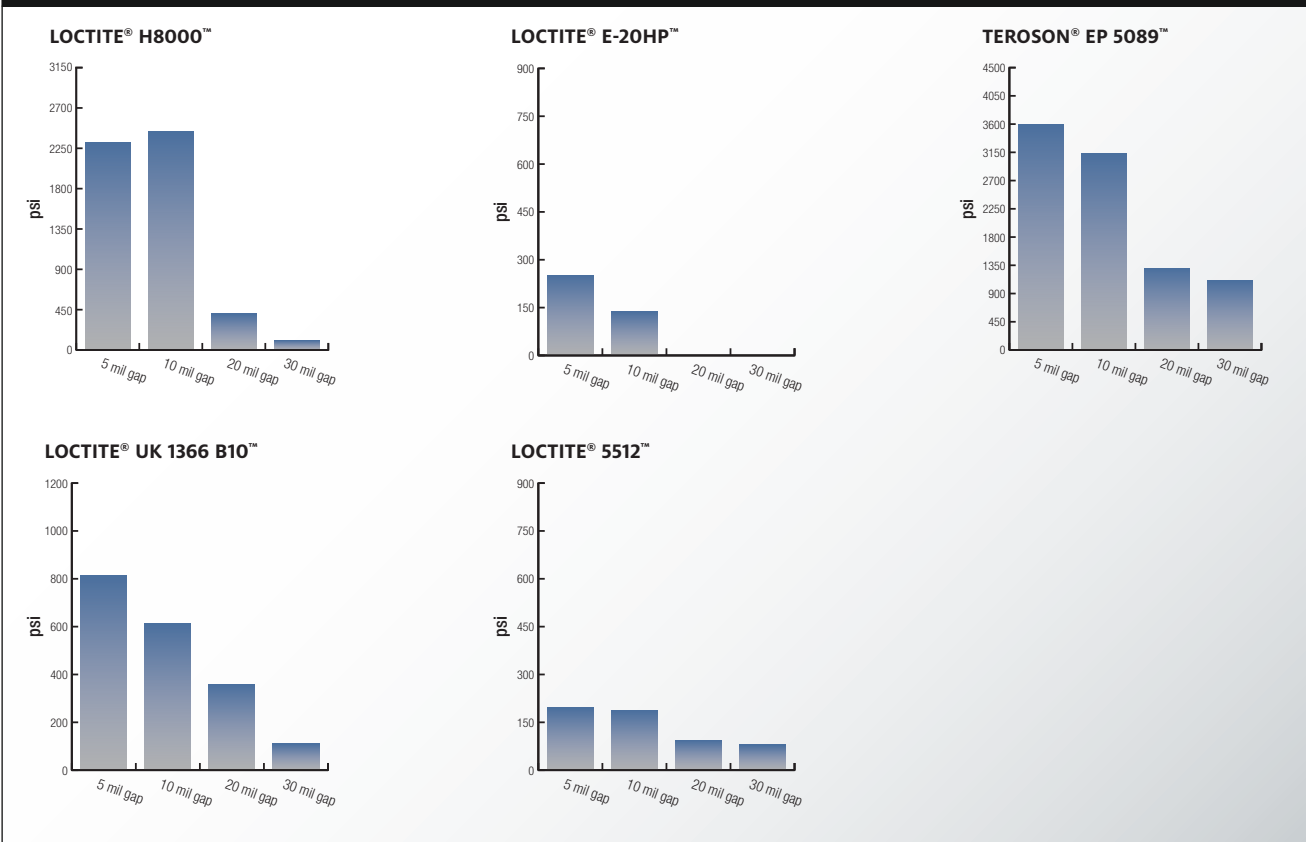
Surface Roughness

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.

Aluminum	Rounded Data Averages							
	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
Table 7 LOCTITE® Brand Adhesive								
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™	3058	2820	2510	2600	680	2800	1440	430
LOCTITE® H8110™	2173	0	1892	2310	2562	2399	2407	2458
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
LOCTITE® 324™	1540	1820	1280	610	1470	1520	680	440
LOCTITE® 326™	850	1150	740	560	790	910	360	370
Two-Step Acrylic								
LOCTITE® 330™ / 7387™*	1210	2330	800	790	1910	1840	1460	850
LOCTITE® 331™ / 7387™*	963	2110	740	820	2080	1410	960	330
LOCTITE® 334™ / 7387™*	2280	1870	1310	1170	2510	2580	3100	2150
LOCTITE® 392™ / 7387™*	1740	1770	550	620	830	630	220	350
LOCTITE® 406™	375	1933	0	0	0	0	0	0
LOCTITE® 411™	265	2726	0	0	168	135	0	0
Cyanoacrylate								
LOCTITE® 435™	1830	3170	320	60	270	0	0	0
LOCTITE® 454™	366	1921	0	0	203	0	0	0
LOCTITE® 480™	2420	3420	480	280	1090	0	0	0
LOCTITE® 4205™	270	470	210	110	350	190	0	0
LOCTITE® 3370™	207	306	274	344	158	276	0	0
LOCTITE® 5510™	510	260	520	440	0	0	0	0
LOCTITE® 5512™	264	331	309	228	0	0	0	0
LOCTITE® 5570™ (white)	190	210	270	230	0	0	0	0
LOCTITE® 5590™	250	400	352	425	0	0	0	0
LOCTITE® 5604™	330	320	330	310	390	380	360	380
LOCTITE® 5606™	98	277	182	193	134	289	377	357
LOCTITE® 5900®	130	260	200	220	260	250	210	210
LOCTITE® Superflex® Black	10	140	20	200	70	90	60	90
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™		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-214HP™	2480	3500	290	2320	3560	3220	3390	2610
LOCTITE® 3984™	1320	2020	720	1970	1310	1150	1150	570
TEROSON® EP 2400™	2573	2313	1657	1797	2610	2815	2273	2292
TEROSON® EP 5089™	3153	2354	1943	2477	3866	3142	3266	2128
LOCTITE® U-05FL™	970	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
LOCTITE® UK 1366 B10™	748	1575	542	799	1924	2086	2007	0

INDUCED GAP*

Aluminum



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.

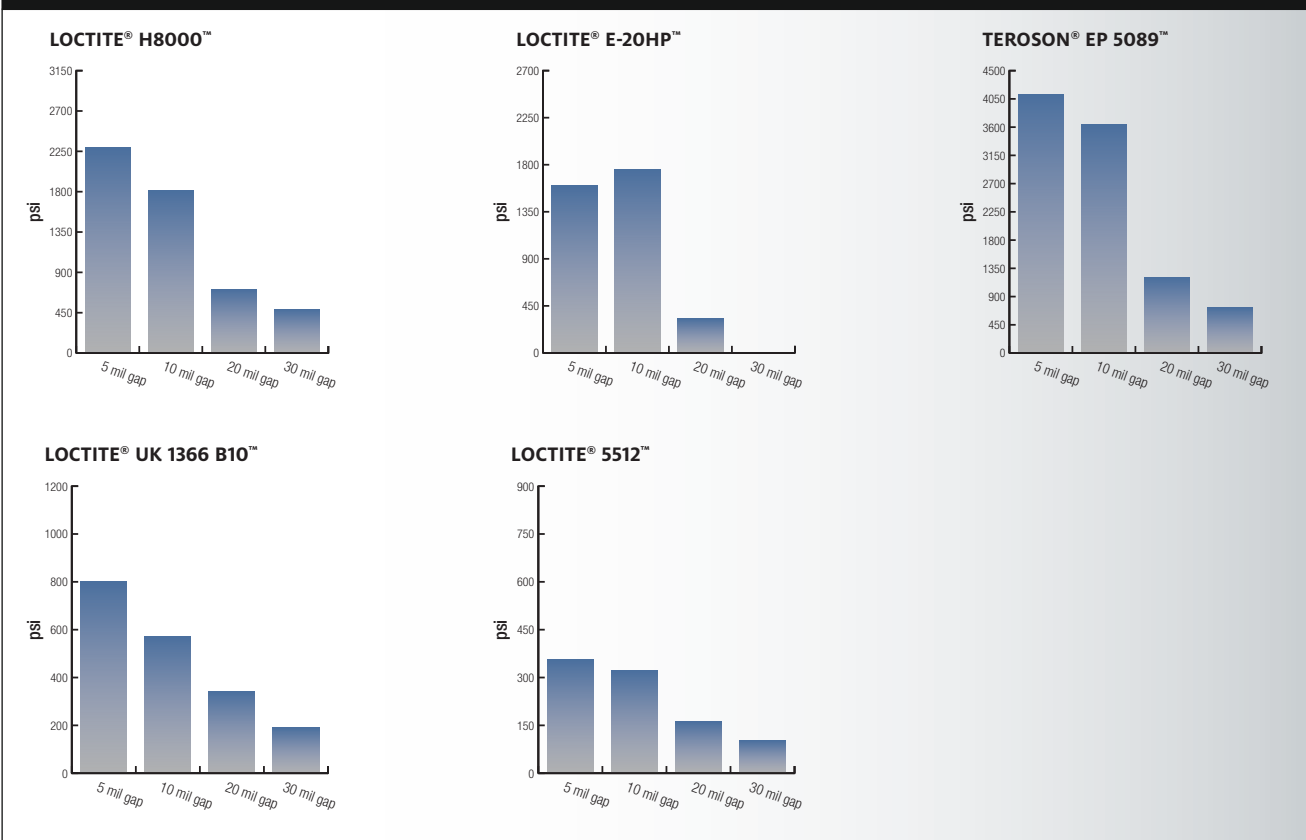
Aluminum alloys lose strength at elevated temperatures and specialty grades are required for good strength retention above 400°F (204°C). When alloyed with silicon, the melting point of aluminum is depressed further, which makes these alloys particularly well suited for welding wire because they melt 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 in Table 7.

Steel



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: <ol style="list-style-type: none"> 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 temper designations, e.g., 0, T3, T4, T5, T6 and T7. 			

For a description of test methodology, see Section 9, page 48.

* Induced gap tested according to STM-700. Surface roughness 9 rms.

Aluminum		Rounded Data Averages															
Table 7		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†		High Speed Drop Impact Test @ RT**	High Speed Drop Impact Test @ -40°C**	High Speed Drop Impact Test @ 140°C**	High Speed Drop Impact Test with 5 mil Gap**	High Speed Drop Impact Test with 10 mil Gap**	High Speed Drop Impact Test with 20 mil Gap**	High Speed Drop Impact Test with 30 mil Gap**
LOCTITE® Brand Adhesive																	
Two-Part Acrylic	LOCTITE® H3151™	3350	3640	2100	1680	2310	640	100	50		8.5	9.3	4.6	N/A	N/A	N/A	N/A
	LOCTITE® H4500™	2960	3530	2460	1960	3540	2210	2050	240		4.0	3.6	3.5	N/A	N/A	N/A	N/A
	LOCTITE® H4710™	3860	3690	2160	2380	3500	2500	2880	280		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	LOCTITE® H8000™	2630	2820	2510	2600	680	2800	1440	430		5.8	7.4	3.4	9.6	9.3	10.6	10.2
	LOCTITE® H8110™	2173	0	1892	2310	2562	2399	2407	2458		11.9	15.4	5.0	N/A	N/A	N/A	N/A
	LOCTITE® H8500™	1670	2500	1340	1930	2570	1230	750	220		9.1	14.3	5.7	N/A	N/A	N/A	N/A
	LOCTITE® H8600™	3360	2670	2420	3290	3470	3210	2880	940		5.8	4.0	4.7	N/A	N/A	N/A	N/A
LOCTITE® H8700™	2700	3100	2240	2820	2350	1750	1840	220		4.4	4.7	3.2	N/A	N/A	N/A	N/A	
Two-Step Acrylic	LOCTITE® 324™	1540	1820	1280	610	1470	1520	680	440		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	LOCTITE® 326™	850	1150	740	560	790	910	360	370		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	LOCTITE® 330™ / 7387™*	1210	2330	800	790	1910	1840	1460	850		1.6	0.7	2.1	N/A	N/A	N/A	N/A
	LOCTITE® 331™ / 7387™*	2170	2110	740	820	2080	1410	960	330		2.6	0.5	1.9	N/A	N/A	N/A	N/A
	LOCTITE® 334™ / 7387™*	2280	1870	1310	1170	2510	2580	3100	2150		4.0	3.1	3.0	N/A	N/A	N/A	N/A
LOCTITE® 392™ / 7387™*	1740	1770	550	620	830	630	220	350		6.0	2.8	0.9	N/A	N/A	N/A	N/A	
Cyanacrylate	LOCTITE® 406™	375	1933	0	0	0	0	0	0		0.4	0.2	0.2	N/A	N/A	N/A	N/A
	LOCTITE® 411™	265	2726	0	0	168	135	0	0		0.3	0.1	0.1	N/A	N/A	N/A	N/A
	LOCTITE® 435™	1830	3170	320	60	270	0	0	0		3.3	1.2	1.1	N/A	N/A	N/A	N/A
	LOCTITE® 454™	366	1921	0	0	203	0	0	0		0.3	0.2	0.2	N/A	N/A	N/A	N/A
	LOCTITE® 480™	2420	3420	480	280	1090	0	0	0		2.5	0.8	1.4	N/A	N/A	N/A	N/A
	LOCTITE® 4205™	270	470	210	110	350	190	0	0		N/A	N/A	N/A	N/A	N/A	N/A	N/A
Elastomeric Adhesives	LOCTITE® 3370™	207	306	274	344	158	276	0	0		2.6	4.0	0.7	N/A	N/A	N/A	N/A
	LOCTITE® 5510™	510	260	520	440	0	0	0	0		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	LOCTITE® 5512™	264	331	309	228	0	0	0	0		2.2	8.4	0.8	4.2	7.1	7.5	5.9
	LOCTITE® 5570™ (white)	190	210	270	230	0	0	0	0		0.5	5.7	0.8	N/A	N/A	N/A	N/A
	LOCTITE® 5590™	250	400	352	425	0	0	0	0		2.2	3.5	1.2	N/A	N/A	N/A	N/A
	LOCTITE® 5604™	330	320	330	310	390	380	360	380		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	LOCTITE® 5606™	98	277	182	193	134	289	377	357		14.4	14.8	14.2	N/A	N/A	N/A	N/A
	LOCTITE® 5900®	130	260	200	220	260	250	210	210		1.0	2.1	0.6	N/A	N/A	N/A	N/A
LOCTITE® Superflex® Black	10	140	20	200	70	90	60	90		N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Two-Part Epoxy	LOCTITE® E-05MR™	1150	3350	1870	820	3410	2220	1650	470		2.0	1.0	0.5	N/A	N/A	N/A	N/A
	LOCTITE® E-20NS™	2140	3010	1740	230	2240	2120	2410	1500		3.2	2.5	1.5	N/A	N/A	N/A	N/A
	LOCTITE® E-20HP™	1670	2160	1370	1390	2330	2100	1100	1250		2.4	1.0	0.3	1.4	2.1	1.7	1.3
	LOCTITE® E-30CL™	1010	1520	1110	1670	2450	2470	2320	2100		2.1	1.5	0.4	N/A	N/A	N/A	N/A
	LOCTITE® E-30UT™	2240	3710	1640	180	3030	1850	1780	1310		13.9	5.5	0.5	N/A	N/A	N/A	N/A
	LOCTITE® E-40HT™	2670	3420	2400	2180	2470	1920	2470	2290		2.8	2.6	1.3	N/A	N/A	N/A	N/A
Other Epoxy	LOCTITE® E-214HP™	2480	3500	290	2320	3560	3220	3390	2610		8.7	10.1	3.6	N/A	N/A	N/A	N/A
	LOCTITE® 3984™	1320	2020	720	1970	1310	1150	1150	570		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	TEROSON® EP 2400™	2573	2313	1657	1797	2610	2815	2273	2292		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	TEROSON® EP 5089™	3153	2354	1943	2477	3866	3142	3266	2128		19.3	21.0	4.8	34.6	42.3	47.2	45.5
Urethane	LOCTITE® U-05FL™	1220	1320	210	1040	1210	970	240	140		4.7	9.6	0.4	N/A	N/A	N/A	N/A
	LOCTITE® Rapid Rubber	260	890	740	540	1620	230	220	130		N/A	N/A	N/A	N/A	N/A	N/A	N/A
	LOCTITE® 3631™	600	320	240	320	790	1020	480	80		16.6	26.6	2.8	N/A	N/A	N/A	N/A
	LOCTITE® UK 1366 B10™	748	1575	542	799	1924	2086	2007	0		5.3	3.7	0.6	7.5	8.7	10.2	10.6

† Values expressed in psi. Tested according to STM-700.
 * With LOCTITE® 7387™ Depend® Activator
 ** Values expressed in joules
 N/A – Not Tested

For a description of test methodology, see Section 9, page 48.

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" to 0.001" (0.0025 to 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.

Anodized Aluminum		Rounded Data Averages						
Table 8		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
LOCTITE® Brand Adhesive								
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® H8110™	2524	2451	2356	2611	2140	2027	1568
	LOCTITE® H8500™	2060	1530	1490	2290	830	570	650
	LOCTITE® H8600™	3310	2560	3010	2860	2270	1510	750
Two-Step Acrylic	LOCTITE® H8700™	2660	2440	2530	2350	1830	1480	660
	LOCTITE® 324™	1780	1310	650	1550	1500	860	200
	LOCTITE® 326™	1310	1280	840	1120	890	720	280
	LOCTITE® 330™ / 7387™*	2320	2750	2180	3150	2830	2100	1860
	LOCTITE® 331™ / 7387™*	1800	1880	2010	1920	1120	770	610
Cyanacrylate	LOCTITE® 334™ / 7387™*	2010	2090	1980	2270	2250	2520	1760
	LOCTITE® 392™ / 7387™*	1580	1630	1440	1230	810	330	250
	LOCTITE® 406™	1098	234	152	241	0	0	0
	LOCTITE® 411™	1578	194	34	38	0	0	0
	LOCTITE® 435™	1500	1300	1130	0	0	0	0
Elastomeric Adhesives	LOCTITE® 454™	1733	89	165	0	0	0	0
	LOCTITE® 480™	2030	1480	1190	0	0	0	0
	LOCTITE® 4205™	1880	1180	530	310	30	0	0
	LOCTITE® 3370™	271	298	346	59	129	0	0
	LOCTITE® 5510™	280	200	220	0	0	0	0
	LOCTITE® 5512™	433	331	193	0	0	0	0
	LOCTITE® 5570™ (white)	400	390	420	0	0	0	0
	LOCTITE® 5590™	358	515	428	0	0	0	0
	LOCTITE® 5604™	310	350	410	510	350	330	190
	LOCTITE® 5606™	403	199	289	235	216	234	0
Two-Part Epoxy	LOCTITE® 5900®	230	150	150	280	250	110	130
	LOCTITE® Superflex® Black	100	150	80	100	40	20	40
	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
Other Epoxy	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-214HP™	830	1060	1350	1730	1200	1710	980
Urethane	LOCTITE® 3984™	700	640	600	2160	1700	1600	500
	TEROSON® EP 2400™	2317	2403	1764	1998	2019	1394	1506
	TEROSON® EP 5809™	3600	2328	2525	2983	1909	1629	1421
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
	LOCTITE® UK 1366 B10™	953	942	1288	735	378	801	0

† Values expressed in psi. Tested according to STM-700.
* with LOCTITE® 7387™ Depend® Activator

For a description of test methodology, see Section 9, page 48.

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.

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		Rounded Data Averages						
Table 10		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†
LOCTITE® Brand Adhesive								
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
Two-Step Acrylic	LOCTITE® H8700™	2660	2470	1570	2100	560	600	0
	LOCTITE® 324™	2300	990	740	1430	1060	380	190
	LOCTITE® 326™	2250	750	570	1800	890	540	230
	LOCTITE® 330™ Depend®	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
Cyanocrylate	LOCTITE® 392™	2220	990	630	770	570	10	0
	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
Elastomeric Adhesives	LOCTITE® 4205™	1520	1180	410	100	80	30	0
	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
Two-Part Epoxy	LOCTITE® Superflex® Black	100	100	120	170	130	130	180
	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
Other Epoxy	LOCTITE® E-40HT™	2960	2730	1540	2120	1610	1550	750
	LOCTITE® E-214HP™	5150	4990	3340	4670	4490	3920	1420
Urethane	LOCTITE® 3984™	1250	1660	1060	1390	940	830	280
	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

† Values expressed in psi. Tested according to STM-700.

For a description of test methodology, see Section 9, page 48.

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 to 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 to 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 in.). 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.

Nickel		Rounded Data Averages						
Table 11		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†
LOCTITE® Brand Adhesive								
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
Two-Step Acrylic	LOCTITE® H8700™	3370	2480	2810	3190	2570	2160	0
	LOCTITE® 324™	2380	1190	270	600	390	290	0
	LOCTITE® 326™	1260	220	160	380	560	150	0
	LOCTITE® 330™ Depend®	2880	1370	660	1750	980	480	230
	LOCTITE® 331™	1810	580	1270	2640	1820	1190	0
Cyanocrylate	LOCTITE® 334™	2310	620	390	3490	3380	2770	1230
	LOCTITE® 392™	3110	1020	0	460	350	160	10
	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
Elastomeric Adhesives	LOCTITE® 480™	2990	0	0	210	0	0	0
	LOCTITE® 4205™	360	10	0	30	0	0	0
	LOCTITE® 5510™	200	200	160	0	0	0	0
	LOCTITE® 5570™ (white)	490	340	360	140	0	0	0
	LOCTITE® 5604™	340	300	320	390	370	280	350
Two-Part Epoxy	LOCTITE® 5900®	130	120	90	170	170	160	100
	LOCTITE® Superflex® Black	70	0	80	110	50	150	80
	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
Other Epoxy	LOCTITE® E-30UT™	2380	2300	0	1560	1500	1270	70
	LOCTITE® E-40HT™	2640	2730	1180	1900	150	310	160
Urethane	LOCTITE® E-214HP™	4060	290	20	3260	2990	2740	2010
	LOCTITE® 3984™	1000	430	750	630	630	540	0
	LOCTITE® U-05FL™	1410	800	990	1500	1250	350	60
Urethane	LOCTITE® Rapid Rubber	700	60	300	750	160	220	260
	LOCTITE® 3631™	400	440	130	770	850	330	120

† Values expressed in psi. Tested according to STM-700.

For a description of test methodology, see Section 9, page 48.

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.

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		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†
LOCTITE® Brand Adhesive									
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® H8110™	2456	0	1312	2162	2679	2357	2448	1810
	LOCTITE® H8500™	2720	2640	2030	1770	1400	1340	930	250
	LOCTITE® H8600™	3300	2080	2190	2730	3260	1830	400	0
Two-Step Acrylic	LOCTITE® H8700™	3460	3590	2310	2240	3480	2710	2320	650
	LOCTITE® 324™	1150	2440	1720	940	2070	1650	950	410
	LOCTITE® 326™	1090	2320	1440	910	1300	540	560	320
	LOCTITE® 330™ / 7387™*	1330	3180	1970	2790	3350	2760	1180	550
	LOCTITE® 331™ / 7387™*	2380	2070	630	2130	2670	1970	1690	550
	LOCTITE® 334™ / 7387™*	2480	2950	1780	2140	2140	3170	2980	1820
Cyanacrylate	LOCTITE® 392™ / 7387™*	2290	2460	1910	1640	1260	1450	0	0
	LOCTITE® 406™	550	2533	0	0	0	0	0	0
	LOCTITE® 411™	674	3192	190	189	265	574	0	0
	LOCTITE® 435™	2980	3200	0	1120	810	0	0	0
	LOCTITE® 454™	1005	2575	166	264	151	0	0	0
Elastomeric Adhesives	LOCTITE® 480™	3290	3350	2470	1790	210	0	0	0
	LOCTITE® 4205™	1210	3760	210	1700	1020	940	0	0
	LOCTITE® 3370™	279	345	309	256	250	423	0	0
	LOCTITE® 5510™	220	190	210	190	20	0	0	0
	LOCTITE® 5512™	261	358	297	113	0	0	0	0
	LOCTITE® 5570™ (white)	400	240	330	210	0	0	0	0
	LOCTITE® 5590™	268	444	498	531	0	0	0	0
	LOCTITE® 5604™	410	300	330	330	370	300	360	340
	LOCTITE® 5606™	289	279	375	192	235	316	354	318
	LOCTITE® 5900®	200	210	310	180	250	140	100	220
Two-Part Epoxy	Superflex® Black	100	150	30	140	180	110	130	60
	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
Other Epoxy	LOCTITE® E-30UT™	650	3260	1160	820	1820	1700	670	960
	LOCTITE® E-40HT™	1150	3900	1860	1720	2370	2510	2260	1820
	LOCTITE® E-214HP™	4420	4740	3300	2030	3100	4360	4310	2960
	LOCTITE® 3984™	1530	3250	850	1140	910	1040	520	1000
Urethane	TEROSON® EP 2400™	3330	3625	2196	2140	2862	3562	2676	3280
	TEROSON® EP 5089™	4171	2751	3096	2797	3969	4161	3918	3233
	LOCTITE® U-05FL™	860	1040	1090	1660	1890	1580	410	90
Urethane	LOCTITE® Rapid Rubber	540	1060	200	200	350	170	150	120
	LOCTITE® 3631™	620	380	440	360	1040	530	230	120
	LOCTITE® UK 1366 B10™	551	1561	785	722	721	487	288	306

† Values expressed in psi. Tested according to STM-700.
* with LOCTITE® 7387™ Depend® Activator

For a description of test methodology, see Section 9, page 48.

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 austenite, ferrite, perlite, and martensite.

Austenite is an 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.

Common Grades of Steel			
Table 14	AISI/SAE Number	Alloy Additions	Main Alloying Effects
Classification	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.
		11xx	Sulfur Sulfur – improves machinability, lowers transverse ductility and notch impact toughness with minimal impact on longitudinal mechanical properties. Diminishes surface quality and weldability.
	Manganese Steels	13xx	Manganese, Nickel Manganese – eliminates hot shortness, slightly increases strength and hardenability. Nickel – strengthens unhardened steels, can improve toughness and hardenability depending on composition and crystalline structure.
	Nickel Steels	2xxx	Nickel Nickel – 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.
		43xx	Nickel, Chromium, Molybdenum Chromium – increases hardenability, corrosion resistance, high temperature strength, and abrasion resistance in high carbon alloys.
		44xx	Molybdenum Molybdenum – increases hardenability, resistance to softening in tempering, high temperature tensile and creep strengths, minimizes tendency to temper embrittlement.
		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.	
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		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†				High Speed Drop Impact Test @ RT**	High Speed Drop Impact Test @ -40°C**	High Speed Drop Impact Test @ 140°C**	High Speed Drop Impact Test With 5 mil Gap**	High Speed Drop Impact Test With 10 mil Gap**	High Speed Drop Impact Test With 20 mil Gap**	High Speed Drop Impact Test With 30 mil Gap**	Hot Strength Steel RMS Test @ 50°C	Hot Strength Steel RMS Test @ 100°C	Hot Strength Steel RMS Test @ 150°C	Hot Strength Steel RMS Test @ 200°C	
LOCTITE® Brand Adhesive																								
Two-Part Acrylic	LOCTITE® H3151™	4050	3600	3270	2890	1100	460	0	0				11.3	5.1	2.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
	LOCTITE® H4500™	3720	3430	3190	2790	2440	1220	900	0				9.3	5.8	2.5	N/A	N/A	N/A	N/A	1656	638	323	173	
	LOCTITE® H4710™	3770	3420	2540	2930	1410	630	170	0				N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	LOCTITE® H8000™	3320	2970	2260	2060	3390	3090	3460	3150				6.7	8.7	1.9	8.5	9.9	19.3	20.2	N/A	N/A	N/A	N/A	
	LOCTITE® H8110™	2619	N/A	1756	1789	2634	2521	2306	3149				12.9	9.9	4.8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	LOCTITE® H8500™	2890	1920	1120	1810	1670	630	140	0				8.8	7.5	5.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	LOCTITE® H8600™	2850	2790	3050	3130	1290	680	290	0				7.9	4.4	3.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Two-Step Acrylic	LOCTITE® 324™	2420	2680	1870	1270	1950	1810	1240	210				N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
	LOCTITE® 326™	1720	2020	1180	750	1380	1210	630	380				N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
	LOCTITE® 330™ / 7387™	3170	3240	2770	2780	1600	1780	1160	980				8.6	1.2	1.8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
	LOCTITE® 331™ / 7387™	1650	2210	1910	1750	2800	2300	1460	350				4.7	0.9	1.2	N/A	N/A	N/A	N/A	926	186	105	N/A	
	LOCTITE® 334™ / 7387™	2590	2740	2750	2460	3380	3320	4070	3160				3.9	3.3	2.6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
LOCTITE® 392™ / 7387™	2310	2570	1590	1570	1020	1120	160	0				11.8	5.8	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Cyanacrylate	LOCTITE® 406™	1592	2580	0	0	N/A	N/A	0	0				3.8	0.5	2.0	N/A	N/A	N/A	N/A	480	209	105	N/A	
	LOCTITE® 411™	742	3292	197	421	514	133	0	0				0.5	0.6	1.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
	LOCTITE® 435™	2830	3460	1500	1640	1790	0	0	0				4.1	1.2	2.8	N/A	N/A	N/A	N/A	2092	1787	203	N/A	
	LOCTITE® 454™	1033	2424	297	373	428	0	0	0				3.3	0.8	3.3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
	LOCTITE® 480™	3520	3460	1680	1680	1320	0	0	0				8.7	2.5	2.4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
LOCTITE® 4205™	1120	3840	620	1310	1120	860	0	0				N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Elastomeric Adhesives	LOCTITE® 3370™	174	304	267	303	178	369	0	0				1.6	3.3	0.6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
	LOCTITE® 5510™	220	250	160	180	0	0	0	0				N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
	LOCTITE® 5512™	403	339	55	87	0	0	0	0				2.1	3.9	1.1	4.0	5.8	8.7	9.4	297	226	157	0	
	LOCTITE® 5570™ (white)	410	310	270	270	0	0	0	0				2.8	5.7	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	LOCTITE® 5590™	239	401	211	420	0	0	0	0				1.7	4.5	0.7	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	LOCTITE® 5604™	350	330	0	220	260	300	420	350				N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	LOCTITE® 5606™	225	247	57	256	57	185	288	283				0.8	1.2	0.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	LOCTITE® 5900®	140	190	90	110	120	110	110	210				2.2	2.6	0.8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
LOCTITE® Superflex® Black	60	160	130	170	140	140	160	170				N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Two-Part Epoxy	LOCTITE® E-05MR™	1460	3180	1360	1540	4020	2820	2410	810				4.2	2.5	0.7	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
	LOCTITE® E-20NS™	4330	4330	2510	2270	4290	3680	3510	1680				4.6	3.3	1.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
	LOCTITE® E-20HP™	3170	3360	2470	1590	3290	2920	2540	1400				7.8	5.8	0.5	5.1	10.4	6.4	7.4	N/A	N/A	N/A	N/A	
	LOCTITE® E-30CL™	2470	2240	1900	2140	3330	2890	2080	1640				5.5	4.8	0.7	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
	LOCTITE® E-30UT™	3460	3480	2080	1820	3610	4160	3310	1170				22.2	5.8	0.6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Other Epoxy	LOCTITE® E-40HT™	4150	3860	3870	2720	3720	3920	3740	1500				11.4	8.9	1.7	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
	LOCTITE® E-214HP™	3280	5200	720	1100	4320	4000	3010	1460				31.6	8.2	7.3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
	LOCTITE® 3984™	2600	3310	1360	1350	1380	1520	1130	1120				N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
	TEROSON® EP 2400™	3428	3377	2570	2860	3606	3361	3048	3183				N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Urethane	TEROSON® EP 5089™	5135	4505	2895	2918	4413	4593	4607	3135				27.2	28.6	3.1	51.3	62.1	75.9	98.3	3432	2276	396	290	
	LOCTITE® U-05FL™	1040	1250	1290	1540	2270	1450	720	210				4.4	7.7	1.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
	LOCTITE® Rapid Rubber	150	1310	210	220	1130	540	440	630				N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
	LOCTITE® 3631™	610	480	480	320	920	300	180	40				14.2	19.4	3.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
LOCTITE® UK 1366 B10™	942	1286	524	797	2559	1468	2064	0				7.2	6.0	0.8	7.5	9.4	12.6	15.6	N/A	N/A	N/A	N/A		

† Values expressed in psi. Tested according to STM-700.
 * With LOCTITE® 7387™ Depend® Activator
 ** Values expressed in joules
 N/A - Not Tested

For a description of test methodology, see Section 9, page 48.

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.

Zinc Dichromated Steel		Rounded Data Averages						
Table 16		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†
LOCTITE® Brand Adhesive								
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-Step Acrylic	LOCTITE® 324™	550	1050	1140	860	210	0	0
	LOCTITE® 326™	1000	1050	740	400	210	240	0
	LOCTITE® 330™ Depend®	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
Other Epoxy	LOCTITE® E-214HP™	640	580	550	3410	3010	2960	140
	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

† Values expressed in psi. Tested according to STM-700.

For a description of test methodology, see Section 9, page 48.

GALVANIZED STEEL (ZINC)

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 to 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.

Galvanized Steel		Rounded Data Averages						
Table 17		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†
LOCTITE® Brand Adhesive								
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® H8110™	1517	1014	1323	582	708	443	132
	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-Step Acrylic	LOCTITE® 324™	560	870	680	850	590	340	140
	LOCTITE® 326™	860	590	620	740	400	250	260
	LOCTITE® 330™ / 7387™*	790	920	1190	790	380	400	180
	LOCTITE® 331™ / 7387™*	1000	840	1500	1750	1120	890	250
	LOCTITE® 334™ / 7387™*	1590	770	1920	2340	1710	1400	130
	LOCTITE® 392™ / 7387™*	1260	1040	830	540	450	180	150
Cyanocrylate	LOCTITE® 406™	132	76	70	79	0	0	0
	LOCTITE® 411™	201	181	121	270	192	0	0
	LOCTITE® 435™	1240	680	620	610	0	0	0
	LOCTITE® 454™	243	211	287	84	0	0	0
	LOCTITE® 480™	1600	1230	920	1310	0	0	0
	LOCTITE® 4205™	1070	330	530	660	730	0	0
Elastomeric Adhesives	LOCTITE® 3370™	151	151	290	131	313	0	0
	LOCTITE® 5510™	220	110	150	20	0	0	0
	LOCTITE® 5512™	438	313	188	0	0	0	0
	LOCTITE® 5570™ (white)	320	210	260	0	0	0	0
	LOCTITE® 5590™	123	359	310	0	0	0	0
	LOCTITE® 5604™	270	290	330	380	310	320	240
	LOCTITE® 5606™	171	253	154	187	172	229	215
	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
Other Epoxy	LOCTITE® E-214HP™	3020	220	1640	3070	2800	2020	1900
	LOCTITE® 3984™	1490	810	980	1030	1170	870	1000
	TEROSON® EP 2400™	3345	2540	2679	3207	3302	2655	3163
	TEROSON® EP 5089™	4760	3001	3310	4078	3595	4260	2963
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
	LOCTITE® UK 1366 B10™	782	671	484	529	316	213	0

† Values expressed in psi. Tested according to STM-700.
* with LOCTITE® 7387™ Depend® Activator

For a description of test methodology, see Section 9, page 48.

Section 8

Functional Coatings (Surface Treatment)

ALKALINE CLEANERS

- Alkaline cleaners remove organic soils such as rust preventatives, oils, and lubricants. Multi-metal cleaners reduce or eliminate etch on all non-ferrous metals such as galvanized steel and aluminum. Steel-only cleaners are heavier duty cleaners optimized for only ferrous metals such as cold rolled steel and hot rolled steel; they will severely etch non-ferrous metals.
- In addition, cleaners are designed within a specific operating temperature to reduce foaming and provide maximum cleaning effectiveness. Increasing temperature within the operating window will increase cleaning power.
- Cleaners with high levels of phosphate provide maximum cleaning power while cleaners with no phosphate or minimal levels are environmentally responsible alternatives.

BONDERITE® C-AK™ 305™ – Alkaline cleaner designed to prepare aluminum, steel, hot-dip galvanized and electrogalvanized steel surfaces.

Products	Order Item Number	Container Size	Liquid	Spray	Immersion	Substrate		Etch	Temperature	Builders				
						Steel/Heavy Duty	Multi-Metal*			Sodium	Potassium	Phosphate	Glucanate	Inter-Stage Protection
BONDERITE® C-AK™ 305™	670363	5 Gallon	X	X	X		X	X	100°F to 140°F		X	X	X	
	593947	55 Gallon	X	X	X		X	X	100°F to 140°F		X	X	X	

* Steel, Zinc, Aluminum

BONDERITE® C-AK™ 212™ – Concentrated, liquid, silicate-free, mildly alkaline cleaner designed to remove oils and light oxide films from aluminum and its alloys.

Products	Order Item Number	Container Size	Liquid	Spray	Immersion	Substrate		Etch	Temperature	Builders				
						Steel/Heavy Duty	Aluminum/Magnesium			Sodium	Potassium	Phosphate	Glucanate	Inter-Stage Protection
BONDERITE® C-AK™ 212™	597967	5 Gallon	X	X	X		No Magnesium	X	100°F to 185°F			X		
	593946	55 Gallon	X	X	X		No Magnesium	X	100°F to 185°F			X		

* Steel, Zinc, Aluminum

ACID CLEANERS

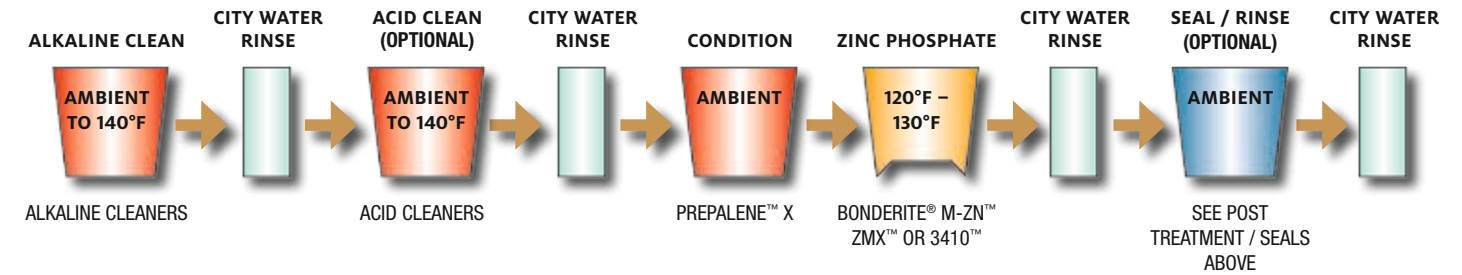
- Acid cleaners / pickles are designed to remove inorganic soils such as rust, laser scale, weld scale, and mill scale from ferrous substrates such as steel. Strong acids are required to remove these alkaline insoluble soils.
- BONDERITE® C-IC™ Acid Cleaners and Pickles include BONDERITE® S-AD™ inhibitors in the formulation to protect steel from over etching while still providing effective removal of inorganic soils.
- A selection of different BONDERITE® C-IC™ products allows for different acids based on customer preference and pickling requirements.

ZINC PHOSPHATE PROCESS

Technology Overview:

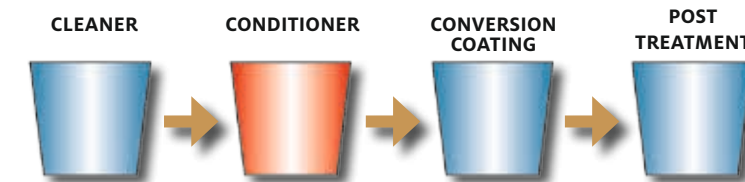
BONDERITE® zinc phosphate coatings offer high performance corrosion protection beyond iron phosphate and are compatible with all paint systems. A surface activation step, known as a conditioner, is required for most zinc phosphate processes and aids in formation of the coating itself, yielding much better performance.

RECOMMENDED ZINC PHOSPHATE PROCESS



CONDITIONERS FOR ZINC PHOSPHATE

Surface treatment conditioners for manganese and zinc phosphate processes are used prior to the conversion coating stage with no rinse between the stages to leave a chemical deposit of conditioner to aid in the development of the proper phosphate crystals on the metal surface.



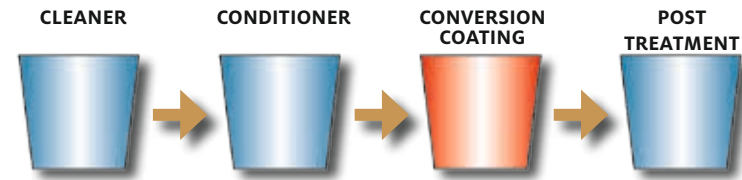
Prepalene™ X – Is a patented polymer-based conditioning rinse that promotes the formation of a dense, uniform, refined phosphate coating which is preferred for paint-based coatings. Prepalene™ X provides a greater tolerance for hard water conditions and results in superior and more complete phosphating of otherwise difficult to coat substrates.

Easy-to-handle liquid conditioning rinse that prepares iron, steel, aluminum, zinc, and zinc-alloy surfaces for subsequent phosphate coating applications.

Products	Order Item Number	Container Size	Liquid	Powder	Spray	Immersion	Application	
							Zinc Phosphate Conditioner	Temperature Range
Prepalene™ X	772525	5 Gallon	X		X	X	X	Ambient to 120°F
	687530	55 Gallon	X		X	X	X	Ambient to 120°F

ZINC PHOSPHATE

These products convert the metal surface to a nonmetallic, polycrystalline zinc phosphate coating.



BONDERITE® M-Z™ ZMX™ – Converts the surface of a metal substrate into a fine polycrystalline, nonmetallic, zinc phosphate coating. The coating increases the adhesion and durability of organic paints and finishes, and helps to inhibit corrosion. The BONDERITE® M-Z™ ZMX™ phosphate coating is free of regulated heavy metals such as nickel. BONDERITE® M-Z™ ZMX™ may be applied by either spray or immersion to cold rolled steel, galvanized, and/or aluminum surfaces in mixed production.

This zinc phosphate conversion coating converts metallic substrate surfaces to a fine-crystalline, nonmetallic, zinc phosphate coating that inhibits corrosion, and increases the adhesion and durability of organic paints and finishes.

Products	Order Item Number	Container Size	Spray	Immersion	Substrate			Acceleration	Crystal Type	Contents		Temperature Range
					Steel	Zinc	Aluminum			Manganese	Nickel	
BONDERITE® M-Z™ ZMX™	772424	5 Gallon	X	X	X	X		Internal	Micro	X		120°F to 135°F

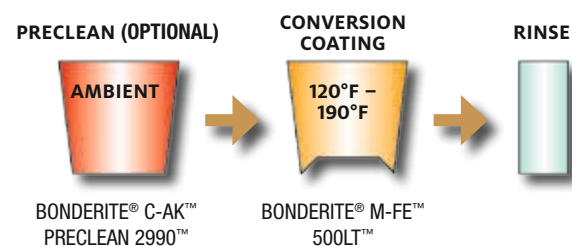
Most products require multiple components. For a Technical Process Bulletin, please visit www.henkelna.com/industrial, consult a Henkel representative or call 1-800-562-8483.

IRON PHOSPHATE PROCESS

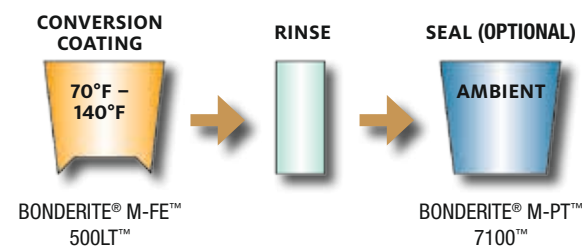
Technology Overview:

A non-crystalline, nonmetallic, iron phosphate coating that is chemically adherent to the metal substrate to provide two major benefits to paint systems: increased paint adhesion and increased corrosion protection. This is a very versatile process which, depending on product selection, can include stand-alone coater products or combination cleaner/coater products. There are recommended line layouts for manual spray wand applications and for automated spray washers or automated immersion lines.

RECOMMENDED SPRAY WAND PROCESS

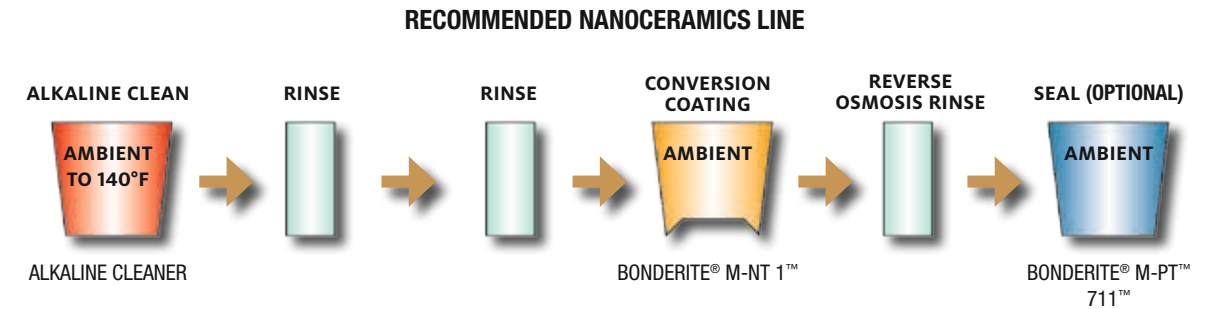


RECOMMENDED 3-STAGE PROCESS



NON-PHOSPHATE/NANOCERAMIC TECHNOLOGY

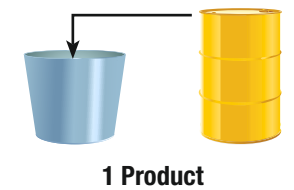
These next generation nanotechnology conversion coatings provide an alternative to traditional phosphate coatings. Tremendous cost savings are achieved due to the low energy, low maintenance and low waste treatment costs associated with this technology.



BONDERITE® M-NT 1™ – This zirconium-based nanotechnology provides an alternative to traditional iron phosphate. It runs at low temperatures and is completely phosphate-free and regulated heavy metal-free, to reduce energy consumption and waste removal.

MAKE-UP AND REPLENISHMENT

BONDERITE® M-NT 1™ bath make-up and replenishment:



NANOCERAMICS PROCESS

BONDERITE® M-NT 1™

- BONDERITE® M-NT 1™ phosphate-free conversion coating is single-part zirconium-based nanotechnology which provides an alternative to traditional iron phosphate. It runs at low temperatures and is completely phosphate-free and regulated heavy metal-free, to reduce energy consumption and waste removal.
- BONDERITE® M-NT 1™ is suitable for dip and spray applications.

Products	Order Item Number	Container Size	Spray	Immersion	Substrate			Temperature Range
					Steel	Zinc	Aluminum	
BONDERITE® M-NT 1™	772427	5 Gallon	X	X	X	X	X	55°F to 100°F
	611359	55 Gallon	X	X	X	X	X	55°F to 100°F

Most products require multiple components. For a Technical Process Bulletin, please visit www.henkelna.com/industrial, consult a Henkel representative or call 1-800-562-8483.

ALUMINUM CONVERSION COATING PROCESSES

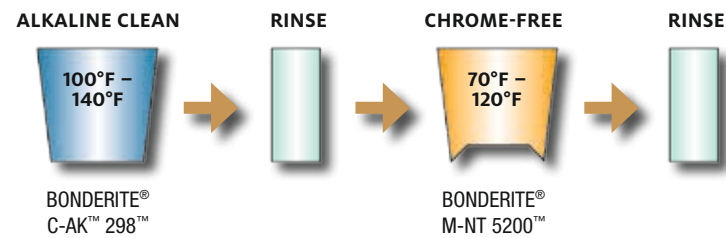
Technology Overview:

Henkel offers a full line of aluminum-specific conversion coatings including chromates, chrome phosphates, and non-chrome conversion coatings. Additionally, a full line of aluminum-specific cleaners and deoxidizers are available.

LIGHT METALS

The BONDERITE® light metal conversion coating products provide an excellent paint base and bonding surface for aluminum substrates. RoHS compliant, chrome-free or trivalent chrome environmentally responsible products are available. Standard chromate conversion coatings for MIL-Spec applications are also part of the product line.

RECOMMENDED BONDERITE® M-NT 5200™ CHROME-FREE PROCESS



Chrome-Free Conversion Coating:

BONDERITE® M-NT 5200™ – Treatment is a chromium-free product and specifically formulated for treating non-ferrous alloys. Spray or immersion application may be used. The process provides an excellent base for bonding of adhesives and organic finishes.

Products	Order Item Number	Container Size	Form				Application Method				Substrate			Chemistry		
			Liquid	Spray	Immersion	Brush	Immersion	Spray	Brush	Magnesium	Aluminum	Reactive	Dry in Place	Military Approvals	Hex Chrome	Tri Chrome
BONDERITE® M-NT 5200™	596088	5 Gallon	X	X	X		X	X	X	X						X
	594142	55 Gallon	X	X	X		X	X	X	X						X

Most products require multiple components. For a Technical Process Bulletin, please visit www.henkelna.com/industrial, consult a Henkel representative or call 1-800-562-8483.

FUNCTIONAL COATINGS (SURFACE TREATMENT)

Aluminum	Rounded Data Averages*						
Table 18	LOCTITE® H8000™	LOCTITE® E-20HP™	LOCTITE® 331™ / 7387™	TEROSON® 5089™	LOCTITE® U-05FL™	LOCTITE® 406™	LOCTITE® 5512™
Test Specimen Description							
Untreated Aluminum (Control)†	3058	1119	963	3153	970	375	264
IPA Wipe – Cataplasma	2089	408	272	3008	784	0	223
BONDERITE® C-AK™ 298™ / BONDERITE® M-NT 5200™ – Cataplasma	2222	517	911	2444	1203	0	329
IPA Wipe – Powder Coat	1363	283	996	3833	733	94	438
BONDERITE® C-AK™ 298™ / BONDERITE® M-NT 5200™ – Powder Coat	2726	1387	603	3942	1421	113	466

Steel	Rounded Data Averages*						
Table 19	LOCTITE® H8000™	LOCTITE® E-20HP™	LOCTITE® 331™ / 7387™	TEROSON® 5089™	LOCTITE® U-05FL™	LOCTITE® 406™	LOCTITE® 5512™
Test Specimen Description							
Untreated Steel (Control)†	3111	2798	2266	5135	2068	1592	403
IPA Wipe – Cataplasma	966	1279	550	2961	699	296	188
BONDERITE® C-AK™ 305™ / BONDERITE® M-NT 1™ – Cataplasma	1768	1389	978	2992	1242	448	211
BONDERITE® C-AK™ 305™ / BONDERITE® M-ZN™ ZM-1™ – Cataplasma	2782	995	1236	3333	1541	333	245
BONDERITE® M-FE™ 500LT™ – Cataplasma	2085	1096	1250	3403	1508	0	267
IPA Wipe – E-Coat	1914	496	1579	3170	426	0	377
BONDERITE® C-AK™ 305™ / BONDERITE® M-NT 1™ – E-Coat	2707	880	423	3907	806	0	240
BONDERITE® C-AK™ 305™ / BONDERITE® M-ZN™ ZM-1™ – E-Coat	2246	781	738	3906	746	447	288
BONDERITE® M-FE™ 500LT™ – E-Coat	1670	3448	649	3501	583	0	319
IPA Wipe – Powder Coat	1025	1355	1824	3547	1622	0	400
BONDERITE® C-AK™ 305™ / BONDERITE® M-NT 1™ – Powder Coat	2964	1988	1573	4666	1121	0	320
BONDERITE® C-AK™ 305™ / BONDERITE® M-ZN™ ZM-1™ – Powder Coat	3204	2474	2512	4824	1695	1006	219
BONDERITE® M-FE™ 500LT™ – Powder Coat	3351	3149	2884	5035	1725	544	338

† Surface roughness 9 rms.
* Values expressed in PSI. Tested according to STM-700.

Section 9

Test Methodology

SUBSTRATE PREPARATION

Surface Roughness

Surface roughness was evaluated using a Surfalyzer® 4000 with a traverse distance of 0.03 in. and a traverse speed of 0.01 in./second.

Cleaning

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

Adhesive Application Method

Two-Step Acrylic Adhesives

1. Activator was applied to the end of one lap shear.
 - 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 lap shear and the solvent was allowed to evaporate.
 - b. For Solventless Activator (LOCTITE® 7380™ Activator), the activator was applied at a weight per unit area of 4 milligrams per in².
 - c. For Solventless Activators (LOCTITE® 7090™ and 7091™ Activators), the activator was dispensed at a weight per unit area of 6 milligrams/in².
2. The adhesive was applied to the end of a second lap shear.
3. The second lap shear was mated with the first lap shear so the activator-coated section of the first lap shear was pressed against the adhesive on the second lap shear to yield a total bond area of 0.5 in².

Two-Part Static Mixed Adhesives

1. The adhesive was dispensed onto the end of one lap shear through an appropriate static mixing nozzle to achieve thorough mixing of the two adhesive components.
2. A second lap shear was mated to the first with an overlap area of 0.5 in².

Cyanoacrylates

1. Adhesive was applied in an even film to the end of one lap shear.
2. A second lap shear was mated to the first with an overlap area of 0.5 in².

One-Part Heat Cure Epoxy Adhesive

1. Adhesive was applied in an even film to the end of one lap shear.
2. A second lap shear was mated to the first with an overlap area of 0.5 in².

Moisture Cure Products

1. Adhesive was applied in an even film to the end of one lap shear.
2. A short length of 10 mil thick wire was embedded in the sealant to induce a 10 mil gap between the bonded lap shears (except for LOCTITE® 3631™ Hysol® Hot Melt Adhesive).

CURE CONDITIONS

Cyanoacrylate, Two-Step Two-Part 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 (STM-700)

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 in./min.
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.

Peel Strength Test Method (STM-710)

For this testing, the standard peel strength test ASTM D-1876 was used to evaluate peel strength of the bonded assemblies.

1. Bend the unbonded ends of the assembly and clamp in the test grips of the testing machine.
2. Test the assembly at a crosshead speed of 200 mm/min (7.9 in./min.) unless otherwise specified in the quality specification, product profile, or test program.
3. During the peel test, make a recording of load versus head movement or load versus distance peeled.
4. Determine the peel strength over at least 100 mm (4 in.) length of the bond line, disregarding the first 25 mm (1 in.).
5. Five replicates were tested for each data set.

High Speed Impact Test Method

1. A Dynatup® impact tester was set up using the appropriate tup, 1.5kN, 3kN, 7.7kN or 22kN maximum force, to accurately measure the failure of the bond. The lap shear holder was set up to place the samples such that the point of impact was mid-way through the bond and the lap shear was incapable of shifting from side to side during testing.
2. The lap shears were conditioned to the temperature specified in the test method for one hour prior to testing, and tested within 30 seconds of removal from the conditioning chamber.

3. The samples were impacted from 0.2264 m height. The initial impact mass of 9.9 kg, for a force of roughly 21 joules, was used to help determine the ideal impact energy. The resultant was multiplied by 2, then by 3 and the impact energy selected from available amounts to be between those two values. For example, if the energy absorbed was 8 joules, the factors would be 15 and 24, making the 21 joule impact energy ideal.
4. In the event that twisting of the metal specimen was observed during testing, the assemblies were re-bonded using the thicker lap shears in order to minimize the influence of energy being absorbed by the metal rather than by the adhesive.
5. Impact energy, absorbed energy, drop height, drop weight and failure mode, and any twisting of the samples were recorded and a photo taken of each run of samples.
6. Five replicates were tested for each data set.

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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