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Handbook on Adhesive Bonding in Electronic Assembly Operations

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Handbook on Adhesive Bonding in Electronic Assembly Operations

Developed by the Electronic Assembly Adhesives Task Group (5-11c) of
the Assembly & Joining Committee (5-20) of IPC

Users of this publication are encouraged to participate in the
development of future revisions.

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Introduction

As available materials have improved and as manufacturing efficiency drives consideration of alternatives to traditional processes, adhesive bonding has become increasingly more important industry wide. The major function of adhesives is to fasten two or more “adherents” (i.e., materials and/or parts which are to be bonded) together. This document covers known terminology associated with these materials and processes as related only to electronic assembly.

Adhesives are increasingly being used in applications, replacing the more traditional methods of fastening. In spot welding and mechanical fastening, the strength of the structure is limited to the areas where the members of the structure are in contact with the weld or fasteners. But when parts are bonded together with adhesives, the stress is transmitted from one member to another in such a way that stresses are uniformly distributed over the entire surface area of the bond. Adhesives can be used to bond together dissimilar materials, whereas welding and soldering are limited to a few materials that can be bonded together by these methods. In addition, adhesives are being specified in applications which require reduced weight and space that preclude the use of hardware fasteners. Adhesive bonding is used in conjunction with various types of assemblies and components (e.g., printed circuit assemblies (PCA), connectors, transformers, enclosures, etc.). The designer and the users of adhesive bonding for electronic applications must be aware of the properties of various types of adhesive bonding and their interactions with assemblies and components to protect them in the end-use environment for the design life of the end item. This document was written to assist designers and users of adhesive bonding in understanding the characteristics of various adhesive bonding types, as well as the factors that can modify those characteristics when the adhesive bonding is applied. Understanding and accounting for these materials can ensure the reliability and function of electronics.

Acknowledgment

Any document involving a complex technology draws material from a vast number of sources across many continents. While the principal members of the Electronic Assembly Adhesives Task Group (5-11c) of the Electronics & Joining Committee (5-20) are shown below, it is not possible to include all of those who assisted in the evolution of this handbook. To each of them, the members of the IPC extend their gratitude.

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Handbook on Adhesive Bonding in Electronic Assembly Operations

1 SCOPE

For the purpose of the initial version of this document, the discussion of adhesives will be limited to liquid, paste and gel materials and closely related film adhesives, which require some form of “cure” mechanism to achieve their full performance. Materials that rely primarily on pressure-sensitive bonds, whether coated on an inert film or not (generically “tapes”) will not be addressed at this time. Similarly, though there is much overlap in material chemistry and application, the subcommittee has chosen to defer the discussion of underfill materials at present. Underfill materials are discussed in J-STD-030. Surface mount adhesives are also not addressed in this document. Surface mount adhesives are discussed in IPC-SM-817.

Adhesives, for the purpose of this document, are defined as a material (e.g., epoxy, silicone, urethane, cyanoacrylate, polyimide, etc.) that is applied in an uncured state and subsequently processed (i.e., cured) to form a rigid or rubber-like state.

Processing characteristics and curing mechanisms are dependent on the adhesive chemistries used. The desired performance characteristics of an adhesive are dependent on the application and must be considered when selecting adhesive bonding materials and adhesive bonding processes. Users are urged to consult their suppliers for detailed technical data.

This guide enables a user to select an adhesive based on industry experience and pertinent considerations. It is the responsibility of the user to determine the suitability, via appropriate testing, of the selected adhesive and the application method for a particular end-use application.

Adhesive bonds may have several functions depending on the type of application. The most common are to:

- Attach one or more electronic functional devices to a substrate.
- Absorb mechanical stresses that would otherwise compromise electrical (e.g., solder) joints.
- Inhibit corrosion.
- Improve fatigue life of solder joints to leadless packages.
- Inhibit arcing and corona, in particular for high-voltage applications.
- Provide mechanical support and prevent damages due to mechanical shock and vibration.
- Provide a mitigation method for the growth of tin whiskers.

1.1 Purpose The term “adhesive bonding” can be ambiguous and be interpreted to mean many things in various industry assembly processes.

The purpose of this handbook is to assist individuals who must either make choices regarding adhesive bonding or who must work in adhesive bonding operations and also to provide guidelines for the design, selection and application of adhesive bonding as it pertains to electronic assembly only.

2 APPLICABLE DOCUMENTS

2.1 IPC¹

IPC-T-50 Terms and Definitions for Interconnecting and Packaging Electronic Circuits²

IPC-CH-65 Guidelines for Cleaning of Printed Boards and Assemblies

IPC-TM-650 Test Method Manual

2.6.1.1 Fungus Resistance - Conformal Coating

2.6.3.1 Solder Mask - Moisture and Insulation Resistance

1. www.ipc.org

2. Current and revised IPC Test Methods are available on the IPC Web site (www.ipc.org/html/testmethods.htm)

2.6.7.1 Thermal Shock - Conformal Coating

2.6.11.1 Hydrolytic Stability - Conformal Coating

IPC-SM-817 General Requirements for Dielectric Surface Mounting Adhesives

IPC-HDBK-830 Guidelines for Design, Selection and Application of Conformal Coatings

IPC-2221 Generic Standard on Printed Board Design

IPC-7711/7721 Rework, Modification and Repair of Electronic Assemblies

2.2 ASTM³

ASTM D150 Standard Test Methods for AC Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulation

ASTM D570 Standard Test Method for Water Absorption of Plastics

ASTM C603 Standard Test Method for Extrusion Rate and Application Life of Elastomeric Sealants

ASTM D635 Standard Test Method for Rate of Burning and/or Extent and Time of Burning of Plastics in a Horizontal Position

ASTM D638 Standard Test Method for Tensile Properties of Plastics

ASTM D695 Standard Test Method for Compressive Properties of Rigid Plastics

ASTM D790 Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials

ASTM D903 Standard Test Method for Peel or Stripping Strength of Adhesive Bonds

ASTM D1002 Standard Test Method for Apparent Shear Strength of Single-Lap-Joint Adhesively Bonded Metal Specimens by Tension Loading (Metal-to-Metal)

ASTM D1781 Test Method for Climbing Drum Peel for Adhesives

ASTM D1876 Standard Test Method for Peel Resistance of Adhesives (T-Peel Test)

ASTM D2240 Standard Test Method for Rubber Property - Durometer Hardness

ASTM D2452 Standard Test Method for Extrudability of Oil- and Resin-Base Caulking Compounds

ASTM D2520 Standard Test Methods for Complex Permittivity (Dielectric Constant) of Solid Electrical Insulating Materials at Microwave Frequencies and Temperatures to 1650°C

ASTM D3833 Standard Test Method for Water Vapor Transmission of Pressure Sensitive Tapes

ASTM D5470-06 Standard Test Method for Thermal Transmission Properties of Thermally Conductive Electrical Insulation Materials

ASTM E96 Standard Test Methods for Water Vapor Transmission of Materials

ASTM E595 Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment

ASTM F1249 Standard Test Method for Water Vapor Transmission Rate through Plastic Film and Sheeting Using Modulated Infrared Sensor

3. www.astm.org

2.3 Joint Industry Standard⁴

J-STD-001 Requirements for Soldered Electrical and Electronic Assemblies

J-STD-030 Guideline for Selection and Application of Underfill Material for Flip Chip and Other Micropackages

2.4 Military Standards⁵

MIL-STD-202 Method 106 Moisture Resistance

MIL-STD-810 Environmental Engineering Considerations and Laboratory Tests – Method 500.6 Low Pressure (Altitude)

2.5 UL⁶

UL94 Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances

UL746C Standard for Polymeric Materials - Use in Electrical Equipment Evaluations

UL746E Standard for Polymeric Materials - Industrial Laminates, Filament Wound Tubing, Vulcanized Fiber, and Materials Used in Printed Circuit Boards

2.6 Federal Standards⁷

FAR §25.853 Compartment Interiors

3 REQUIREMENTS

3.1 Terms and Definitions All terms and definitions used throughout this handbook are in accordance with IPC-T-50. Definitions noted with an asterisk (*) are quoted from IPC-T-50. Other specific terms and definitions, essential for the discussion of the subject, are provided below.

3.1.1 Material Terms and Definitions

3.1.1.1 Catalyst* A chemical that is used to initiate the reaction or increase the speed of the reaction between a resin and a curing agent.

3.1.1.2 Conformal Coating An insulating protective covering that conforms to the configuration of the objects coated (e.g., printed boards, printed board assemblies), providing a protective barrier against deleterious effects from environmental conditions. See IPC-HDBK-830 for more information on conformal coating materials and processes.

3.1.1.3 Diluent Material used to increase the volume of material or to adjust viscosity. A diluent can be reactive or non-reactive.

3.1.1.4 Filler An insoluble material used to increase the volume of a compound, reduce cost or modify thermal, physical and electrical properties; also used to modify rheology. During initial inquiries to formulators, consideration should be given to the types of fillers that may provide the desired properties for the application, as well as how these fillers may impact the choice of a suitable meter/mix system and compatibility with the adhesive (see Figure 3-1).

Note: Filler material increases viscosity of liquid material and modifies durometer value after cure.

4. www.ipc.org

5. <http://quicksearch.dla.mil/>

6. www.UL.com

7. www.faa.gov



Figure 3-1 Example of a Silica Filler Being Added to Epoxy as a Percentage by Weight

3.1.1.5 Filletting Compound A liquid adhesive (staking material) used to surround and seal the gap or stand-off area under a component. It can also be used to enhance, stabilize and provide mechanical support for larger components; also referred to as a staking material.

3.1.1.6 Hardener A chemical, sometimes referred to as a catalyst, added to a thermosetting resin for the purpose of causing curing or hardening.

3.1.1.7 Pigment A soluble or insoluble material used to color a compound (see Figure 3-2), as opposed to “dyes,” which are typically soluble compounds. Traditionally, anthracene derivatives and/or metallic salts are common.

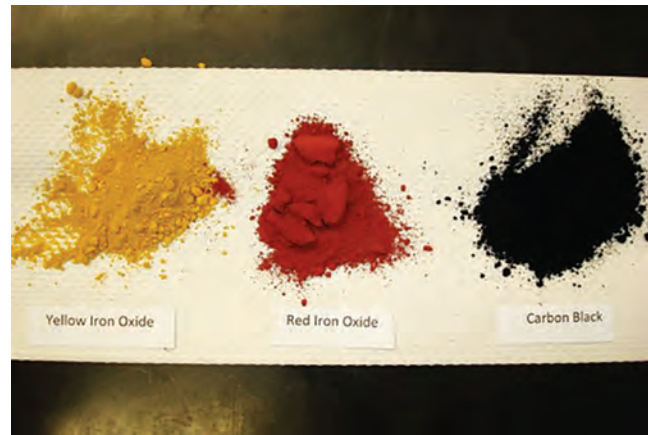


Figure 3-2 Variety of Insoluble Pigments

3.1.1.8 Plastic* Any of a group of synthetic or natural organic compounds produced by polymerization, optionally combined with additives (organic or inorganic fillers, modifiers, etc.) into a homogeneous material capable of being molded, extruded, coated or cast into various shapes and films.

3.1.1.9 Primer A material used to improve or enhance the chemical coupling or bonding of a polymeric material to a substrate.

3.1.1.10 Release Agent A material used to aid in the de-molding of a part from a mold. Misused or incompletely removed, these compounds can seriously hamper adhesive bonding.

3.1.1.11 Resin* A natural or synthetic resinous material.

3.1.1.12 Solvent A non-reactive liquid substance that is capable of dissolving another substance.

3.1.2 Application Terms and Definitions

3.1.2.1 Adhesion The ability of a material to adhere/bond to a substrate. The surface energy of both the substrate and the liquid being applied are critical factors in obtaining adequate adhesion. Cleanliness of the surface is paramount to prevent delamination. In protection chemistry applications (conformal coatings and potting materials), adhesion is critical to provide a barrier against moisture and other contaminants. Some materials have no chemical adhesion, yet they do have some level of adhering to the substrate. “Interfacial wet-out” provides the barrier; adhesion is desired to provide a more permanent wet-out condition.

Example: A coating of oil can protect metal from moisture and corrosion via wet-out. See 5.1 for more information on adhesion.

3.1.2.2 Adhesion Promotion The chemical process of preparing a surface to enhance its ability to be bonded to another surface (i.e., a layer of adhesive material).

3.1.2.3 Adhesion Failure Terms and Definitions

3.1.2.3.1 Adhesive Failure The rupture or bond failure of an adhesive bond such that the separation appears to be at the adhesive-adherent interface (see 5.1.3).

3.1.2.3.2 Cohesive Failure The separation of the adhesive bonding material from itself (see 5.1.3).

3.1.2.4 Air Dry Typically, the act of a solvent or solvents evaporating from a liquid matrix to create a solid film.

3.1.2.5 Air Cure Air cure is associated with a chemical reaction within a liquid or semi-liquid material which polymerizes at room temperature. An example could be a liquid material that can cure at ambient room temperature (such as a urethane or acrylic). Ambient temperature or relative humidity (RH) may play a role in how fast this can be achieved.

3.1.2.6 Air Line Flexible tubing or rigid piping of various forms that route the flow of gases (air, nitrogen, etc.) to components of equipment systems in the adhesive bonding process.

3.1.2.7 Anisotropic Conducting in one axis only, normally the Z-axis.

3.1.2.8 AR/UR Abbreviation standing for acrylic resin and urethane resin combination chemistries.

3.1.2.9 Automated Optical Inspection (AOI) Equipment Inspection devices used to examine the surface of target areas and to look for irregularities in dispensed materials, such as bubbles, contact angles and surface texture, etc. The typical magnification levels used are 4X to 10X for routine quality inspection processes, but magnification levels can be much greater in equipment used for investigatory purposes. Some of these AOI systems can be completely automated by using alignment fiducials (see Figure 3-3.)

3.1.2.10 Bake Exposure to dry heat, normally in an oven, for a specific period of time to cure a product and/or drive moisture from a part.

3.1.2.11 Brushing A process in which an adhesive is brushed onto the device using overlapping strokes.

3.1.2.12 Cross-Linking The formation of chemical bonds between molecules in a thermosetting resin during a polymerization reaction.

3.1.2.13 Cure Cross-linking or chemically turning into a non-flow material. See 4.2 for more information.

3.1.2.14 Degassing The process of removing bubbles and other volatile gases from material, usually by the application of a vacuum. See 11.1.6 for more information.

3.1.2.15 Dispense System Application equipment which delivers liquid or flowable polymeric materials from a reservoir, in properly mixed form, to a target location. These systems can be as simple as handheld caulking guns or as elaborate as high-speed computer-driven robots (see Figures 3-4, 3-5, 3-6 and 3-7).

3.1.2.16 Dispense Valve Typically found as the final component of a dispensing system, used with either a single-component material or a plural-component reactive material. The device exit regulates the flow of a fluid (e.g., gases, liquids, fluidized solids or slurries) by opening, closing or partially obstructing various fluid passageways. This delivers a dispensed flow of material either in a metered shot or in a unique pattern such as a bead, film curtain or spray pattern of varying size. It can contain both fluid and air ports (see Figure 3-8).

3.1.2.17 Durometer A device used to measure of the degree of hardness or the resistance to deformation or fracture.

3.1.2.18 Dwell/Waiting Period A period of time characterized by the absence of motion when a part or product has to remain in place (e.g., inside an oven, at room temperature, or in a vacuum environment).

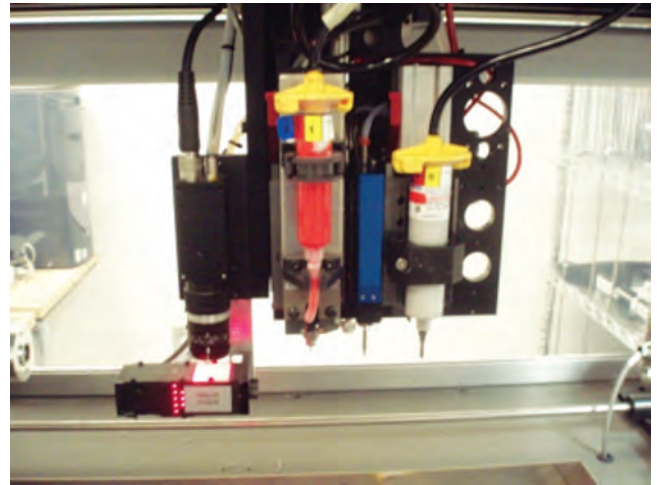


Figure 3-3 Dispensing Assembly with AOI Camera on the Left
(Image Courtesy of GDP Global)



Figure 3-4 Dispensing Via Manual Syringe



Figure 3-5 Dispensing Via Air-Assisted Caulking Gun

3.1.2.19 EMC Abbreviation for electromagnetic compatibility.

3.1.2.20 Filler A substance that is added to a material to improve its solidity, bulk or other properties (see 3.1.1.4).

3.1.2.21 Fluid Line Flexible or rigid piping of various forms that route the flow of either material components (parts A and B) or final mixed materials while they are still in their flowable states. Material composition of the fluid line material should be compatible with the liquid material.

3.1.2.22 Flash Point The lowest temperature at which vapors of a volatile combustible substance will ignite in air when exposed to a flame.

3.1.2.23 Gel Time The time taken for a liquid polymer to begin to exhibit pseudo-elastic properties or to be 'immobilized'.

3.1.2.24 Glass Transition Temperature (T_g) The temperature at which a polymer converts from a hard glassy state to a soft rubbery state. This is an important property used to characterize polymeric materials since many of a polymer's properties will change depending on whether it is above or below its T_g . Glass transition temperature is routinely measured using differential scanning calorimetry (DSC) (see Figure 3-9), thermo-mechanical analysis (TMA) or dynamic mechanical analysis (DMA) (see Figure 3-10). Pure polymers generally have a more distinct observed T_g . Since adhesive material formulations can be a complex mixture of materials, the observed glass transition behavior may be more accurately defined as a "glass transition range." Rigid plastic type materials like acrylic and epoxies are typically used well BELOW their T_g , while elastomeric rubbery materials like urethanes and silicones are typically used well ABOVE their T_g .

3.1.2.25 Green Strength The strength of a substance, joint or assembly before it has been cured (set). This represents the ability of an adhesive to be handled before it has completely cured, which allows the parts to remain immobile during the adhesive cure phase. Green strength allows an assembly to continue moving through the assembly line while the adhesive cures.

Examples of materials with different green strengths include peanut butter, which has high green strength, and maple syrup, which has a low green strength. Temperature also has an impact on green strength. Note that green strength will (normally) decrease with an increase in temperature.

3.1.2.26 Humidity The amount of water vapor in the atmosphere. See 4.1.1 for humidity effects on polyurethanes. See 4.2.3 for humidity effects on adhesive curing.

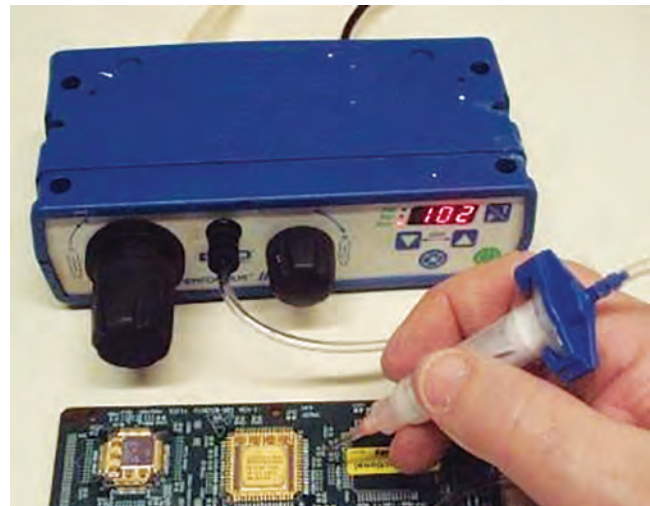


Figure 3-6 Dispensing Via Time-/Pressure-Controlled Manual Dispenser
(Image Courtesy of Nordson EFD)



Figure 3-7 Dispensing Via Fully Automatic X-Y-Z-Axis Computer-Controlled Systems

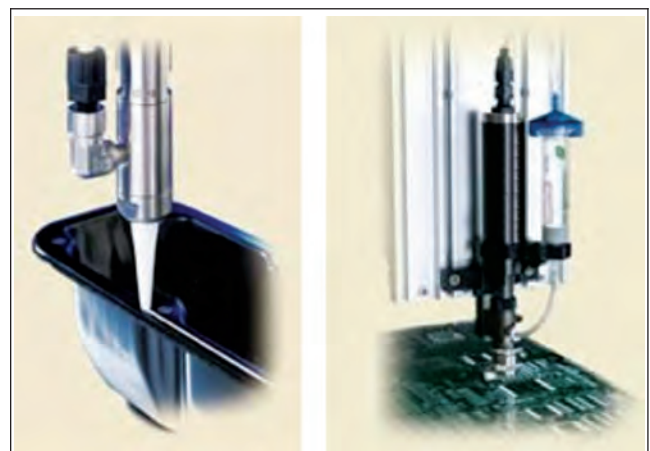


Figure 3-8 Examples of Dispensing Valves
(Image Courtesy of Nordson EFD)

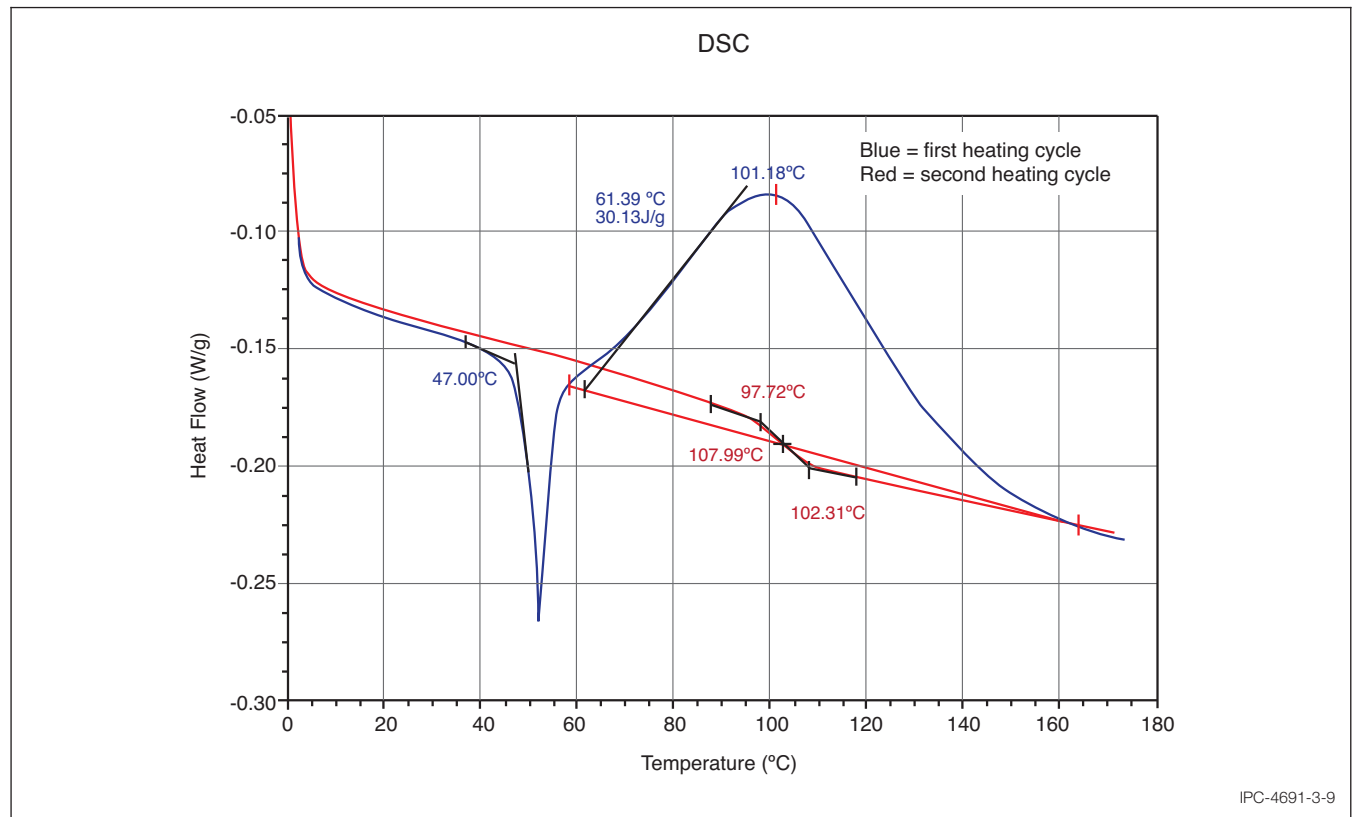


Figure 3-9 Differential Scanning Calorimetry Output

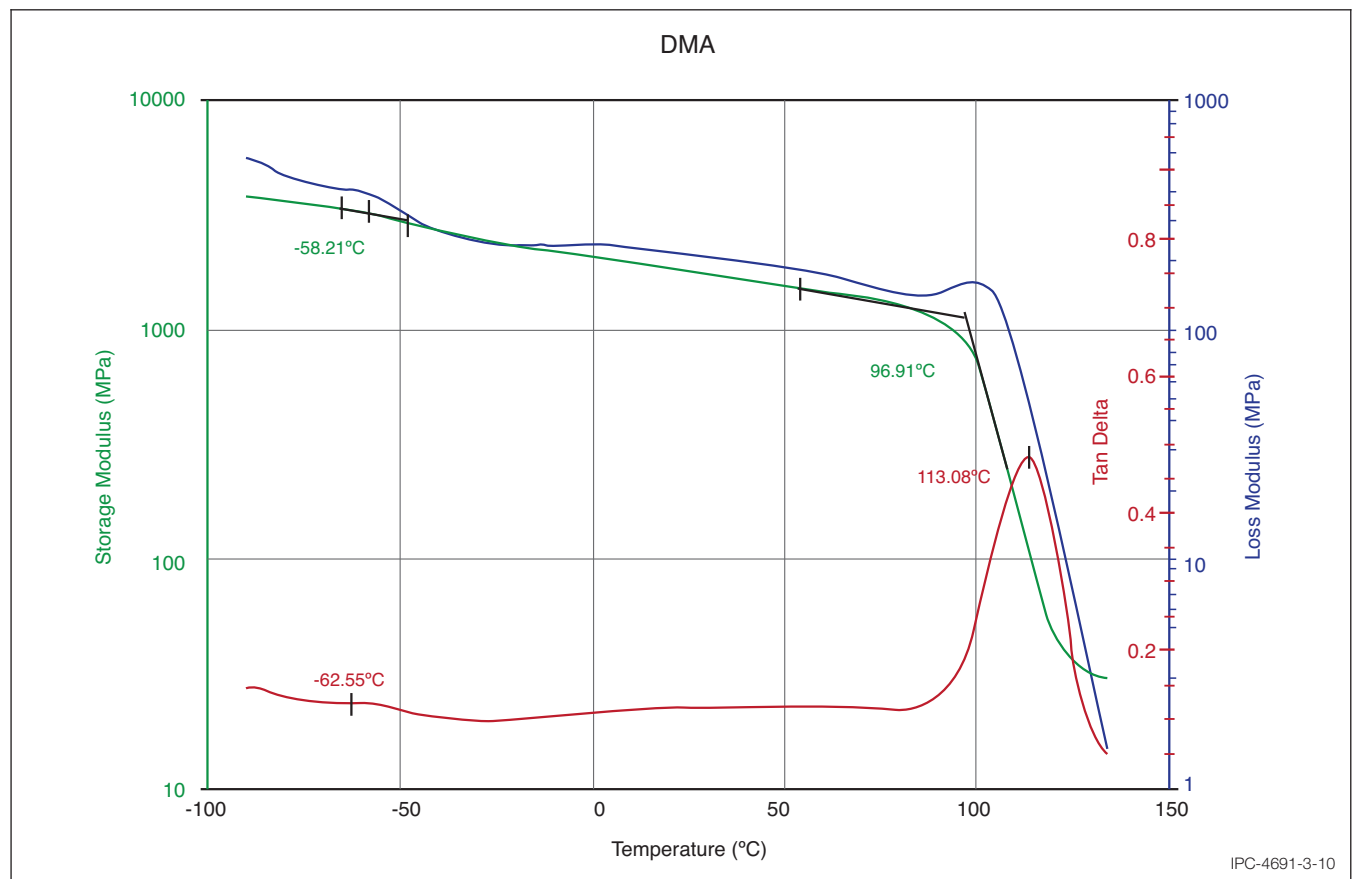


Figure 3-10 Differential Mechanical Analysis Output

As it relates to processing with meter/mix equipment, humidity can have adverse effects on certain elastomers, notably polyurethanes. The polyol component can absorb moisture and pass it on to the final mixed reaction with the isocyanate. Additionally, the isocyanate component can react with air. It is recommended that inert gas such as a “nitrogen blanket” be used to cover the surface of the liquid in the bulk supply, as well as a desiccant drying tube.

3.1.2.27 Indexer/Conveyor An electromechanical system that transports product from one adhesive bonding process capability to another. These systems, when used in an adhesive bonding process, typically meet the same Surface Mount Equipment Manufacturers Association (SMEMA) machine interface standards that were developed to facilitate the interface of equipment used in the manufacture of surface-mounted printed circuit boards (see Figure 3-11).

3.1.2.28 Light Curing Light curing in electronic assembly applications is typically associated with wavelengths in the UV and blue visible light spectrums. It is used to cure light-sensitive materials which contain photoinitiators or other light-sensitive catalysts. The adhesive is usually immobilized or fully cured within seconds of exposure to light. Various high-intensity light sources are designed to deliver the proper wavelengths for fast, optimum cure.

3.1.2.29 Meter Mix A device that provides a stream of properly proportioned (ratio) and mixed multiple-component polymeric material. Usually these are found as a component of a dispense system.

3.1.2.30 Osmotic Pressure The maximum pressure that develops in a solution separated from a solvent by a membrane which is permeable only to the solvent.

3.1.2.31 Oven Profiling A collection of time and temperature data points used to produce a visual representation of a part subjected to heat during a particular process (see 13.2.2). When performing these profiles it is common for temperature probes to be placed in multiple locations across the part for the report to show the heating and cooling characteristics for the entire part.

Normally, the profile will include the heat-up (ramp-up) and cool-down (ramp-down) sections of the profile. Some of the data that can be collected include:

- Length of time required to reach process temperature.
- Length of time at process temperature.
- Maximum temperature reached and the length of time at maximum temperature.
- Length of time required to reach room temperature.
- Speed of the conveyor, if a conveyORIZED process is being used.

3.1.2.32 Piston Displacement/Pneumatic Dispense A type of two-component meter/mix system that utilizes a pair of honed metering cylinders, with pistons, to displace A and B materials according to their volumetric mix ratio. The properly mixed materials are delivered to a mix head, where they are introduced into a disposable static mixer or to a spinning element mixer (also called dynamic mixer). The mixer combines the two materials into a homogenous blend. Piston displacement systems can be either “single-acting,” in which material is metered on one side of the pistons within the cylinders, or “double-acting,” in which the material is metered on both sides of the pistons within the cylinders. In the latter case, the flow is continuous as the A and B pistons reciprocate within their cylinders.

3.1.2.33 Pot Life (Work Time) Generally thought of as the time it takes a mixed material to double in viscosity (see 11.6.2).



Figure 3-11 Conveyor

3.1.2.34 Pressure Cooker Test Pressure cooker test (PCT), also known as autoclave test, or pressure pot test (PPOT), is a reliability test performed to assess the ability of a product to withstand severe temperature and humidity conditions. It is used primarily to accelerate corrosion in the metal parts of the product, including the metallization areas on the surface of a semiconductor die. It also subjects the samples to the high vapor pressure generated inside the autoclave chamber.

3.1.2.35 Reservoir Typically a uniquely designed container that holds the feedstock supply of material or a material component, making it available for subsequent dispensing system processes such as heating, vacuuming, agitation, stirring, meter mixing and/or dispensing. These range in size from small syringe-type cartridges to as large as those which can accommodate pail, drum or tote quantities of material (see Figure 3-12).



Figure 3-12 Examples of Reservoirs

3.1.2.36 Rework and Repair Correcting of defective, failed or nonconforming items during or after inspection. Rework includes all follow-on efforts such as disassembly, repair, replacement, reassembly, etc. Repair refers to operations required to replace damaged material (see Section 14).

3.1.2.37 Shelf Life The length of time a material, substance or product can be stored under specific environmental conditions while it meets all applicable specification requirements and remains suitable for its intended use.

3.1.2.38 Static Mixer Tube Sometimes referred to as “in-line mixers,” a disposable, sometime shielded tubular device comprised of repeating geometric mixing elements that are secured to the inside of a tube or pipe. This geometric design within the tube creates a mixing action between two or more fluids as they pass over and through these elements, resulting in properly mixed material at the exit of the tube. Diameter, length and configuration will have an impact on flow rate (see Section 11).

3.1.2.39 Tack-Free The point in time during drying or curing in which the surface is not gummy or sticky to the touch.

3.1.2.40 Vacuum Bake Exposure to dry heat within a controlled vacuum environment.

3.1.2.41 Vacuum Pump Vacuum pumps are typically used in preparation or dispensing processes to either degas materials while they are still in a reservoir or after the dispensing process to remove entrapped air bubbles. Also used with vacuum chambers in vacuum adhesive bonding systems to remove air from the part or dispensing environment (see 3.1.2.14 and Figure 3-13).



Figure 3-13 Vacuum Pump

3.1.2.42 Vapor Pressure The pressure exerted by vapor in equilibrium with its solid or liquid phase.

3.1.2.43 Volumetric Shot Size The volume of a dispensed or metered shot, typically expressed in cubic centimeters (cc). Alternatively, a shot can be metered by weight, typically expressed in grams, or in the case of larger shots by ounces or even pounds. The shot size of material can be used as a process control tool.

3.1.2.44 Waste Disposal This refers to proper disposition of a discarded or discharged material in accordance with local, state and federal environmental guidelines or laws.

3.1.2.45 Weight An object's mass as measured by a scale or balance.

3.1.2.46 Work Cell Broadly speaking, this is an arrangement of resources in a manufacturing environment created to improve quality and speed and to reduce the cost of a process. In an adhesive bonding process, these resources typically will include dispense and cure systems at a minimum but can also include preheat, inspection, rework and various other systems and capabilities.

3.1.2.47 Young's Modulus Also known as tensile modulus or modulus of elasticity, this is a measure of the rigidity of a material. A stricter definition of this modulus is the slope of the stress/strain curve while the material is in its "elastic regime," where the slope is fairly linear. This value represents basically the ratio between the stress and strain of a material, providing information about how much a material extends under tension, or shortens under compression. Young's modulus is reported in pressure units, pounds per square inch (PSI), kg/cm² or megapascals (MPa).

4 ADHESIVE CHEMISTRIES

4.1 Chemistry Types

4.1.1 Polyurethane Polyurethane adhesive bonding materials are available as either single- or two-component formulations. Both provide good humidity and chemical resistance plus higher sustained dielectric properties. Their chemical resistance, however, can be a major drawback since rework can become difficult and costly.

Early polyurethane compounds exhibited instability or reversion of the cured film to a liquid under high humidity and temperature conditions. Newer formulations eliminate this phenomenon.

Single-component materials, while easy to apply, sometimes require three to 30 days at room temperature for optimum cure. Two-component formulations, however, reach optimum cure properties at elevated temperatures within one to three hours and have pot lives of 30 minutes to three hours.

Polyurethanes are formed by the reaction of polymeric alcohols (polyols) and polymeric isocyanates. Polyols are usually polyester- or polyether-based and to lesser extents polybutadienes and others. Isocyanates are typically based on diphenylmethane diisocyanate (MDI), but other types such as toluene diisocyanate (TDI) may also be used. An isocyanate prepolymer is formed by a reaction between a portion of the isocyanate and a polyol.

Polyurethanes have significant versatility as adhesives, as the elasticity of the cured systems range from very high elongation to relatively rigid. Also, the reactivity of polyurethane systems can be varied from almost instant setting to a pot life of one to two hours by adjusting the catalyst level (usually a tin salt or amine).

Polyurethanes are fairly sensitive to variation in mix ratio, so the mix ratio should be maintained within a narrow window of < 5 % variation by weight or volume for proper cure. Pre-reacted polyurethanes are also sensitive to humidity/moisture, and proper storage is critical. Exposure to excessive moisture can result in undesirable foaming of the product on cure (There are specialty urethanes which take full advantage of this property.). In general, while adhesion, chemical resistance and high-temperature performance may not be as good as some other materials (i.e., epoxies), urethanes may be preferred for their ability to readily formulate highly elastic materials for bonds where stress absorption or peel strength are the primary requirements.

4.1.2 Epoxy Epoxy systems are usually available as two-part compounds (though some pre-mixed/pre-catalyzed versions may appear to be one-part materials). They provide reasonable humidity resistance and good abrasive and chemical resistance. They are difficult to chemically remove for rework, since any stripper that will remove epoxies may vigorously attack epoxy-potted components or epoxy-glass printed wiring boards (PWBs).

As discussed in 4.1.1, "single-component" epoxy resin adhesives with pre-mixed temperature-activated hardeners are also available, though refrigerated or frozen storage prior to use is normally required. These adhesives require elevated cure temperatures. Epoxy is a thermosetting polymer that is formed when an epoxide resin is combined with a curing agent. A curing agent may also include a reaction rate modifier. This would be a characteristic of a formulated epoxy system for a specific application such as a field repair where fast cure properties are desired.

Curing of epoxy systems can vary from a matter of minutes to days and may occur at ambient temperature or elevated temperatures.

4.1.3 Acrylic Acrylics are easy to apply and can easily be reworked after adhesive bonding using solvents. Acrylics can be formulated to cure rapidly by a variety of initiating mechanisms, reach optimum physical properties in minutes, are fungus resistant, are perhaps slightly more tolerant of organic surface contaminants than other adhesive varieties.

(depending on formulation) provide long pot life. Furthermore, slower-curing acrylics give off relatively little heat during cure (minimizing damage to heat-sensitive components) and have good humidity resistance. Relatively high coefficients of thermal expansion (CTE) for non-reinforced acrylic adhesives can be a problem in a poorly designed adhesive joint.

Acrylic resins are used in adhesive bonding applications because of their ease of application and their impact resistance. Early acrylic formulations could be brittle compared to some other options, limiting their use where toughness and flexibility are key performance factors, but improvements in formulation have made more elastic options available.

Acrylic resins are made from acrylate or methacrylate monomers, usually starting with acrylic or methacrylic acid. The choice of monomer and the ratios of those monomers are what determine the viscosity of the product and the final properties of the finished resin, though additives (i.e., very finely divided synthetic rubber particles to improve impact resistance and elasticity) can have a significant effect as well. These resins are generally thermosetting, meaning they are cross-linked into a solid film.

The synthesis of acrylic resins is performed by a controlled rate addition of the monomers and an initiator (usually peroxide) into a reaction vessel at an elevated temperature. The extent of the reaction is controlled by the ratios of the various monomers, and reaction completion is determined when viscosity stabilizes. This viscosity stabilization also indicates the molecular weight or size of the polymer is as large as it can be before any cross-linking is performed. Cross-linking of the double bonds in the acrylic resin by further peroxide addition leads to a thermoset resin.

An important sub-category of acrylic adhesives are the families of cyanoacrylate resins. These are best known for their extremely rapid cure (in thin bond-lines and in the presence of a minimum of humidity, at least) and have gained wide acceptance in “staking” or fixturing adhesive bonds, wire-tacking and other relatively low-criticality applications where slow-curing materials would result in unacceptable delays in process. Most cyanoacrylates do not excel in environmental resistance (e.g., moisture, heat, UV exposure, etc.), so they are rarely used for high-durability structural applications.

4.1.4 Silicone Silicone adhesives are a family of products based on the polydimethylsiloxane (PDMS) molecule, with unique characteristics. They are particularly useful in providing protection to electronics devices in moist and other severe environments, in insulating against high voltage and in providing a low-stress environment. Silicone adhesives have a combination of properties which provide proven long-term reliability and performance in electronics applications. These features include:

- Good thermal stability
- Flexibility
- Moisture resistance
- Adhesion to many common substrates used in electronics
- Low ionic impurity
- Low toxicity
- Good dielectric properties
- High purity
- No exothermic heat rise during cure

Among all these characteristics that are shared by the majority of silicone materials, one property is recognized as one of the most useful in electronics applications. That is their consistent performance over a very wide temperature range, from -45 °C to 200 °C [-49 °F to 392 °F]. There are special silicone adhesives formulated to withstand exposures to temperatures as high as 250 °C [482 °F] or as low as -80 °C [-112 °F]. Silicone adhesives are available in a wide range of hardness, from extremely soft materials (gels) to hard elastomers with hardness in the range from 30 type A to 80 type A.

Note: J-STD-001 states, “Equipment used for measuring viscosity of or mixing, applying and curing silicone material **shall not** be used for processing other material.” This cautionary statement derives from the ability of even very small amounts of low-molecular-weight fractions of silicone materials to spread thinly over some surfaces and reduce the ability to significantly form an adhesive bond (or adhere coatings, etc.). Some industrial firms have gone to the extreme of having any operation requiring silicone applications segregated in a separate building away from adhesive, coating or other non-silicone applications.

4.1.5 Other Chemistry Types Many different types of chemistries can be used for adhesive bonding in electronics protection applications. Some hybrids can include foams, solid films, various liquids, visible light-curable materials and some UV-curable materials.

4.2 Cure Mechanisms Depending on the chemistry of the adhesive, cure mechanisms can be categorized as in 4.2.1 through 4.2.6. Some materials employ dual cure to ensure complete cure of all the material applied on an assembly.

4.2.1 Heat Cure This method typically uses a thermal excursion to initiate or accelerate the cure mechanism. Typical temperatures required can range from 55 °C to 150 °C [131 °F to 302 °F]. Just prior to polymerization of the adhesive material, there will be a drop in viscosity. Precautions against inadvertent flow-out may be required (see 10.1.6). The time and temperature profile needs to be evaluated for the mass of the parts and how many parts are being cured at one given time. Also keep in mind that the entire collection of parts or assembly needs to “ramp up” to temperature before the adhesive material will begin to cure. In extreme cases of thermal exposure, the overall system may increase in hardness or brittleness beyond the optimum for the application.

Heat is required to cure the adhesive. In general, these adhesives may be faster-curing than room temperature or moisture-cure adhesives. Some adhesives must be heat cured; some may only use heat as a means of accelerating cure.

4.2.2 Heat Accelerable Some room-temperature curing may be accelerated by the application of heat. The acceleration of moisture-cure adhesives may require additional humidity. Consult the adhesive supplier for specific conditions for acceleration.

4.2.3 Humidity Humidity is quite common for moisture-cured room temperature vulcanizing (RTV) silicones. The general rule of thumb for RTV chemistries is 0.64 cm [0.25 in] depth of cure for every seven days at ambient RH, because RH needs to permeate through the adhesive. This is particularly problematic in a large-area bond between impermeable adherents. For this reason, RTVs are non-preferred where excessive cure depths exist. Adsorbed moisture is required for the curing of cyanoacrylates.

4.2.4 Room-Temperature Cure Many two-part adhesives can cure at ambient room temperature. This cure system is considered “free,” as there is no cost associated with curing the material, but it is a relatively slow process, affecting process flow, “work in process” (WIP) inventory, etc. The adhesive is cured in an ambient environment. Solvent-based adhesives must be subjected to room-temperature cure to evaporate the solvent prior to any other cure to prevent entrapped solvent. Some adhesives may be accelerated by the application of mild heat and/or humidity.

Some epoxies cure very quickly at room temperature. With these adhesives, the exothermic reaction provides heat to facilitate the cure.

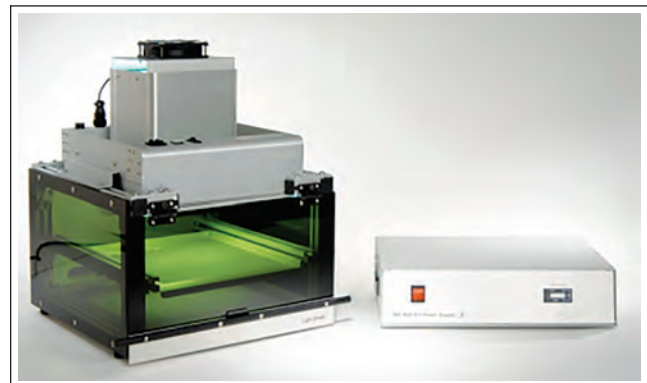


Figure 4-1 Typical UV Curing System (Image Courtesy of Dymax Corporation)

4.2.5 UV/Visible-Light Cure Light-curing materials containing photoinitiators or other light-sensitive catalysts polymerize upon exposure to light. Light curing is useful for very quickly immobilizing the surface or entire body of the adhesive material, usually within seconds. For small cross-section bonds, it may be sufficient to permit the product to move on through the process. Various high-intensity light sources are designed to deliver the proper wavelengths (see Figure 4-1). UV/visible light cure is particularly advantageous in bonding materials transparent to the wavelengths needed to initiate cure (e.g., optoelectronics, photovoltaics, etc.). Large area bonds of opaque materials are less likely candidates.

Guidelines for wavelength and intensity needed by the material should be verified with the material supplier. Cure time required is application specific and is influenced by adhesive thickness, distance and intensity of the light source. Visible light penetrates deeper than UV light, so visible-light-sensitive materials are often desirable for applications where depth of cure is required.

Functional properties for light-cure materials are generally similar to the chemical- or heat-induced cure type. For instance, light-curable silicones will perform like silicones, light-cure epoxies like epoxies, etc. Acrylated urethane materials have characteristics of both acrylics and urethanes. This makes them desirable for applications requiring high chemical or abrasion resistance, similar to urethanes. The acrylate component allows for easy modification of properties such as cure speed, flow and flexibility. The above materials are available in one component format. Some adhesive materials have secondary cure functionality for areas not exposed to light, and they are activated by heat or ambient moisture, with the light cure acting as a fixturing or “tacking” bond to facilitate further processing.

Light will polymerize only the areas directly exposed to the light. Most one-component, light-curable adhesives have a secondary cure mechanism (i.e., heat or moisture) for curing areas that migrate under devices that will block light from reaching the material. If shadowed areas are present, an adhesive with a secondary cure mechanism should be selected to ensure full cure. Insufficient light exposure results in incomplete cure, while excess exposure can scorch the material surface and begin degrading the material. Two-component, light-curing materials are available to limit the secondary cure step, but they require mixing prior to application.

4.2.6 Catalytic Cure Catalytic adhesives cure by a reaction between two parts. Catalytic materials will start to cure once the two components are in contact with each other. A primary cure mechanism such as UV or heat may be incorporated into these materials to speed the cure. Catalytic reaction allows UV-curable materials that are not irradiated by UV (i.e., adhesive “shadowed” under components) to cure with no added process steps or induced stress on the components, solder joints or adhesive fillets. Catalytic cure is popular with solvent-free organic materials.

4.3 Inhibition Inhibition is defined as the inability for certain adhesives and sealants to obtain optimum properties at the manufacturer’s specified time and temperature. Inhibition is not a concern with all adhesives. The chemistries and related details are explained in 4.3.1 through 4.3.2.

4.3.1 Silicones Within silicone formulations, inhibition is only associated with the addition cure, platinum-catalyzed systems. These can be either single-component heat-cure or two-component formulas. Organotin- or titanate-catalyzed formulas cannot be inhibited (i.e., one-part silicone RTVs). It is important to identify the type of silicone formula being used.

Inhibition is caused by the contamination of the platinum catalyst when exposed to trace quantities of certain types of chemicals. These chemicals interfere with the cure reaction and thus prevent conversion of the material to the desired solid. Extremely small quantities of inhibitors may be sufficient to produce this effect. If the contamination is extreme, the entire cross section of the silicone will not cure. This material will remain liquid regardless of any subsequent attempts to convert it to a solid.

Inhibition is often confused with improper mixing of two-component adhesives. The user should ensure that it is a true inhibition problem and not a mixing problem.

The most common causes of inhibition are:

- Plasticized polyvinylchloride (PVC)
- Latex rubber (gloves or masking compounds)
- Sulfur or sulfur-containing chemical compounds
- Amine-cured epoxy
- Cellophane tape
- Masking tape
- Vinyl electric tape
- Neoprene rubber
- Buna-N rubber
- Styrene-butadiene rubber (SBR)
- Acid- or rosin-core solder flux and certain other nitrogen-containing chemical compounds
- Acidic materials (usually organic acids)
- Organotin RTV silicone rubber catalysts

There are three levels of inhibition—interfacial, mild and gross—as detailed in 4.3.1.1 through 4.3.1.3.

4.3.1.1 Interfacial Inhibition Interfacial inhibition occurs at the interface between the substrate and the adhesive. This is the most difficult type of inhibition to detect. It is most often diagnosed as an adhesion problem rather than a compatibility mismatch. Interfacial inhibition can be remedied by cleaning the surface of the substrate, baking out the substrate to flash off volatiles or applying a barrier coating prior to adhesive bonding (i.e., primer and/or changing the cure system).

4.3.1.2 Mild Inhibition Mild inhibition is most often observed when the adhesive takes longer to cure than what the material supplier has stated the cure time to be on the technical data sheet. Most cases of inhibition can be overcome by cleaning the surface of the substrate, baking out the substrate to flash off volatiles, heat-accelerating the cure, applying a barrier