

# IPC-HDBK-850

2012 - July

## **Guidelines for Design, Selection and Application of Potting Materials and Encapsulation Processes Used for Electronics Printed Circuit Board Assembly**

*A standard developed by IPC*

*Association Connecting Electronics Industries*



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Developed by the Potting and Encapsulation Task Group (5-33f) of the  
Cleaning and Coating Committee (5-30) of IPC

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

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# Guidelines for Design, Selection and Application of Potting Materials and Encapsulation Processes Used for Electronics Printed Circuit Board Assembly

## 1 SCOPE

**1.1 Introduction** Potting and Encapsulation is a very broad topic and can include anything from toys to high power applications. There is no clear industry-wide definition that would decipher distinct differences between either. This document will cover known terminology associated with this process as related only to electronic printed circuit board assembly and protection.

Encapsulation is used in conjunction with various types of assemblies and components, e.g., printed circuit assemblies (PCA), connectors, transformers, etc. The designer and the users of encapsulation for electronics applications must be aware of the properties of various types of encapsulation and their interactions with assemblies and components in order to protect them in the end-use environment for the design-life of the end item. This document has been written to assist the designers and users of encapsulation in understanding the characteristics of various encapsulation types, as well as the factors that can modify those characteristics when the encapsulation is applied. Understanding and accounting for these materials can ensure the reliability and function of electronics.

**1.2 Purpose** The terms “potting” and “encapsulation” (P/E) can be confusing terms and be interpreted to mean many things in various industry assembly processes.

The purpose of this handbook is to assist the individuals who must either make choices regarding encapsulation or who must work in encapsulation operations and to provide guidelines for the design, selection, and application of Potting and Encapsulation as it pertains to electronic components and printed board assembly only.

**1.3 Scope** For the purpose of this document potting can be thought of as the “liquid material” and encapsulation can be interpreted as the application process and cure. Please keep in mind however that the terms potting and encapsulation are commonly interchanged with each other in a variety of electronic protection processes.

Encapsulation, for the purpose of this document, is defined as a potting material, e.g., epoxy, silicone, urethane that is applied in a liquid state and subsequently processed (i.e., cured) to form a rigid or rubber-like state.

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

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

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

- Inhibit current leakage and short circuit due to humidity and contamination from service environment.
- 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 to prevent damages due to mechanical shock and vibration.
- Provide a mitigation method for the growth of tin-whiskers.

**1.4 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.

### 1.4.1 Material Terms and Definitions

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

**1.4.1.2 Conformal Coating\*** An insulating protective covering and electrical insulation that conforms to the configuration of the objects coated (e.g., printed boards, printed board assembly) providing a protective barrier against deleterious effects from environmental conditions.

**1.4.1.3 Diluent** A material used in extending the volume of material or adjusting viscosity. A diluent can be reactive or non-reactive.

**1.4.1.4 Encapsulant\*** Materials used for potting, glob-topping or molding. See also “Potting Compound,” “Glob Topped Encapsulation,” or “Molding Compound” (see Figures 1-1, 1-2, 1-3 and 1-4).

**1.4.1.5 Filler** An insoluble material used to extend the volume of a compound, reduce cost, or modify thermal, physical, and electrical properties; also used to modify thixotrophy. 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 potting material (see Figure 1-5).

**NOTE:** Filler material increases viscosity of potting material and modifies durometer value after cure.

**1.4.1.6 Filletting Compound** A liquid potting material (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.

**1.4.1.7 Glob Top** A high viscosity or low-flowable liquid potting material usually used to encompass wire bonds at the bare die level. The glob top material provides for protection from moisture, shock and vibration, CTE mismatch, and replaces the conventional interposer package (see Figure 1-6).

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

**1.4.1.9 Molding Compound** Material used in conjunction with a mold for encapsulation. See also “Potting Compound.” Glob-topped encapsulants consist of very viscous compounds that are usually applied to a PB or substrate.



Figure 1-1 Potting Material in a Syringe



Figure 1-2 Injecting Potting Material onto a Module (Encapsulation)



Figure 1-3 Encapsulation Curing in Oven



Figure 1-4 Encapsulation of Pins Inside Connector Shell

**1.4.1.10 Pigment** An insoluble material used to color a compound (see Figure 1-7).

**1.4.1.11 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.

**1.4.1.12 Potting** A material used in the encapsulation process which involves the surrounding of a component(s) or an assembly in a container with a liquid resin which is then cured in place. The container usually becomes an integral part of the system such that the critical property that needs to be maintained is the interfacial adhesion between the cured resin system, the container substrate and critical components within an optimum long-lasting reliable package. Figure 1-8 illustrates a potted assembly.

**1.4.1.13 Potting Compound** The liquid material chosen for the potting application that is applied and cured to the manufacturer's recommendation. Chemistry chosen (epoxy, polyurethane, silicone, etc.) will be customer and application specific.

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

**1.4.1.15 Release Agent** A material used to aid in the de-molding of a part from a mold.

**1.4.1.16 Resin\*** A natural or synthetic resinous material.

**1.4.1.17 Underfill** A compound used to fill the area under various electronic devices. Underfill is commonly used to minimize stress differentials (CTE) between components and substrates, most often area array components.



Figure 1-5 Example of a Silica Filler being added to Epoxy as a Percentage by Weight

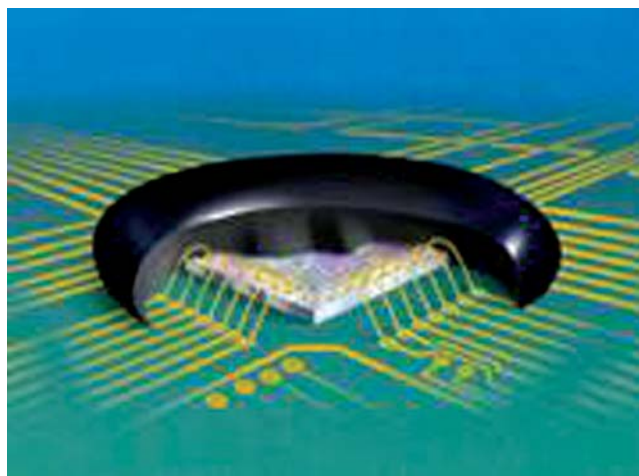


Figure 1-6 Cut-Away View of Glob Top Wire Bond Encapsulation (Image Courtesy of Loctite)



Figure 1-7 Variety of Pigments

## 1.4.2 Application Terms and Definitions

**1.4.2.1 Adhesion** The ability of a material to adhere or bond to a substrate. The surface energy of both substrate and the liquid being applied are critical factors in obtaining adequate adhesion. Cleanliness of the surfaces is paramount to prevent delamination. In protection chemistry applications, (conformal coatings and potting materials), adhesion is critical to provide a barrier against moisture 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. Ex, A decent coating of oil can protect metal from moisture and corrosion via wet-out. See 3.2.5 for more information on adhesion.

**1.4.2.2 Adhesion Promotion** The chemical process of preparing a surface to enhance its ability to be bonded to another surface, i.e. A layer of encapsulation

### 1.4.2.3 Adhesion Failure

**1.4.2.3.1 Adhesive Failure** The rupture or bond failure of an adhesive bond such that the separation appears to be at the adhesive-adherent interface (see Figure 1-9).

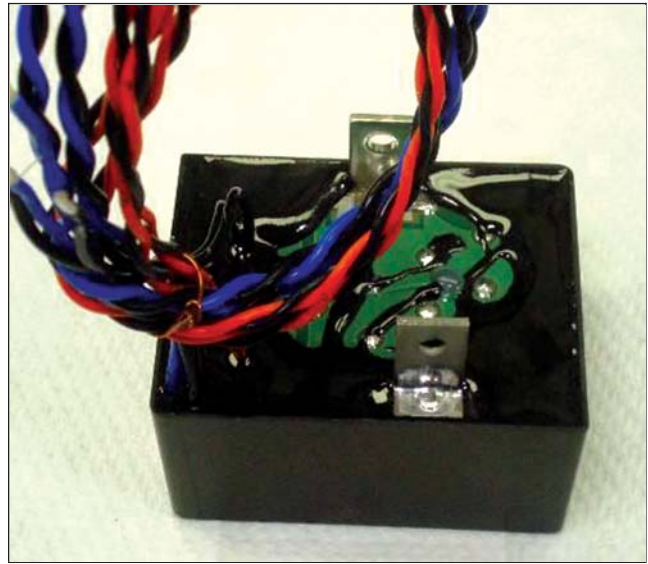


Figure 1-8 Example of Encapsulated CCA Inside of Container (Potting Shell)

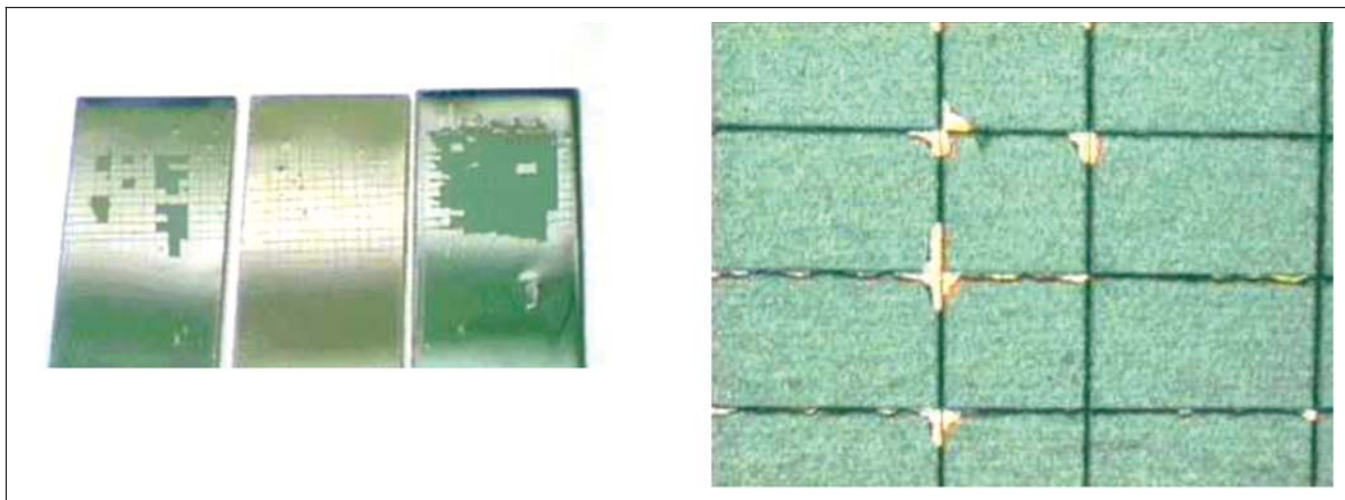


Figure 1-9 Results of Poor Adhesion

**1.4.2.3.2 Cohesive Failure** The separation of the encapsulation material from itself.

**1.4.2.4 Air Dry** It is typically the act of a solvent or solvents evaporating from a liquid matrix to create a solid film

**1.4.2.5 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 may play a role in how fast this can be achieved.

**1.4.2.6 Air Line** Flexible tubing or rigid piping of various forms that route the flow of gases, (air, nitrogen, or other), to components of equipment systems in the encapsulation process.

**1.4.2.7 Anisotropic** Conducting in the Z-axis only.

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

**1.4.2.9 Automated Optical Inspection (AOI) Equipment** Inspection devices used to examine the surface of target areas. A device often used to look for irregularities in dispensed materials such as bubbles, contact angles, and surface finish.

amongst others. The typical magnification levels used are 4X - 10X for routine quality inspection processes, but 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 1-10).

**1.4.2.10 Backfilling** The act of sealing the rear of a connector, thereby preventing other liquids from migrating into the connector insert by way of capillary action. Care needs to be taken to choose a high enough viscosity material, preventing migration of the backfilling material to the inside of the connector insert or any mating surfaces. The material should not interfere with the normal insertion or removal forces rated for the mating connector and should be compatible with the mating surfaces. Backfilling may also apply to the injecting of a compound, such as thermal compounds under components from an access point on the opposite side of the board (see Figure 1-11).

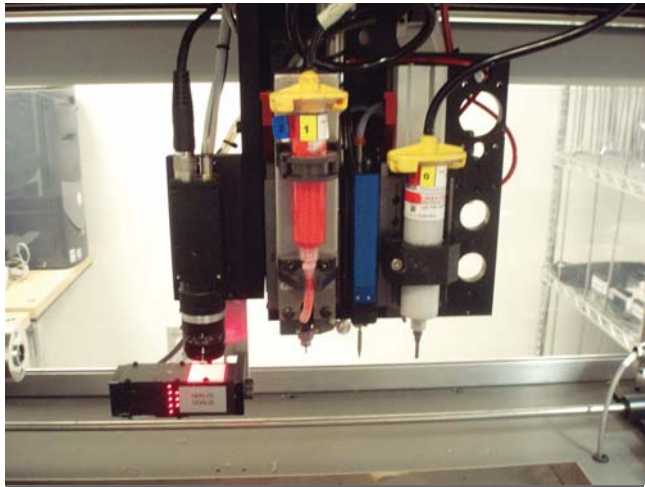


Figure 1-10 Dispensing assembly with AOI camera on the left. (Image Courtesy of GDP Global)

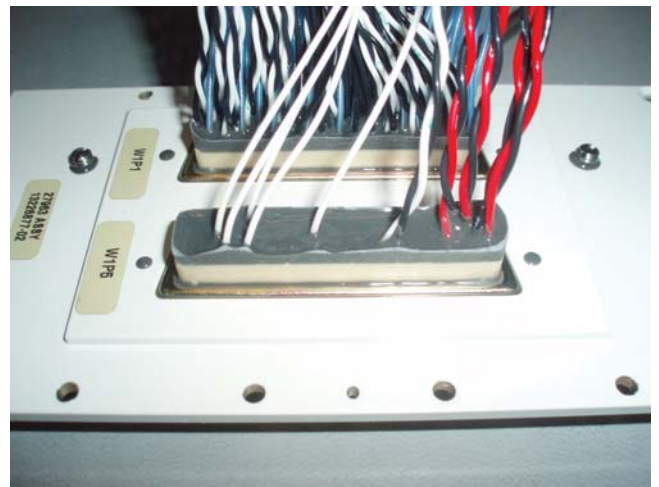


Figure 1-11 Backfilled Connector

**1.4.2.11 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 (see Figure 1-12).

**1.4.2.12 Brushing** A process in which the potting compound is brushed onto the device using overlapping strokes. Caution should be taken to avoid trapping any air in the encapsulant or compound.

**1.4.2.13 Casting** Similar to potting except that the container or mold is removed from the part after curing (sometimes called cast-in-mold).

**1.4.2.14 Conformal Coating Process** Conformal coatings are not intended for use as a potting or encapsulation material, even though they are sometimes used as such. When conformal coatings, which are designed for thin cross sections, are applied in very thick cross sections, undesirable effects can occur. Examples include shrinkage, cracks, entrapped solvents, and bubbles, and poor adhesion. Potting and encapsulation should be done with materials designed for these functions.

See IPC-HDBK-830 for more information on conformal coating materials and processes.



Figure 1-12 Cure Oven



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**1.4.2.15 Crosslinking** The formation of chemical bonds between molecules in a thermosetting resin during a polymerization reaction.

**1.4.2.16 Cure** Crosslinking or chemically turning into a non-flow material. Curing can be affected by the application of heat through convection, conduction, and/or by the use of radiation such as infrared or ultraviolet energy, humidity, or in standard temperature and pressure conditions. In practice Cure Time is not just the time needed to turn a material into a solid and reach full properties. Cure can mean the time required to impart all of the important performance characteristics to the material, which can include adhesion. Refer to the manufacturer's data sheet and validation for each material used.

**1.4.2.17 Dam and Fill** Technology utilizing both a low viscosity and a high viscosity potting material. In most cases, the high viscosity, non-flowable potting material is applied as a barrier around the perimeter (dam) of the die or part and then followed by dispensing of the lower viscosity material (fill) to encompass and cover the die or component (Figure 1-13).

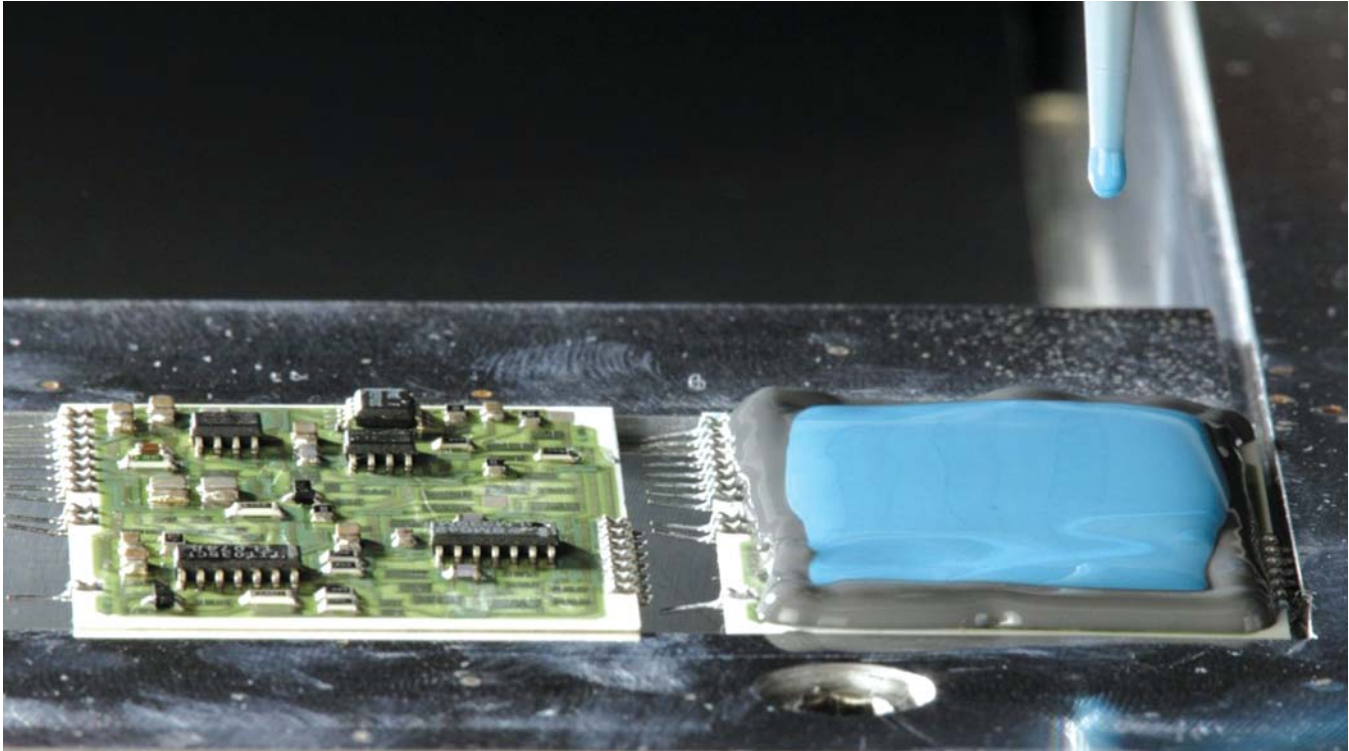


Figure 1-13 Assembly which has been through the Dam and Fill process (Image courtesy of ELANTAS PDG)

**1.4.2.18 Degassing** This refers to the process of removing bubbles and other volatile gases from a mixed coating or encapsulant material, usually by the application of a vacuum (see Figure 1-14 and 1-15).

**1.4.2.19 Delamination** A separation between an encapsulation layer and the surface to which it is adhering.

**1.4.2.20 Dipping** After degassing, gently dip and remove the device in the liquid as slowly as possible allowing any air to be released. A common insertion and removal rate is 10 inches/minute depending on the viscosity and part geometry (see Figure 1-16).

**1.4.2.21 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 hand held caulking guns or elaborate as high speed computer driven robots. (Figures 1-17, 1-18, 1-19 and 1-20.)



Figure 1-14 Unit which is capable of degassing an assembly



**Figure 1-15 Bell Jar Vacuum Pump (Used for evacuating air bubbles from mixed epoxies prior to or after encapsulation)**



**Figure 1-16 Dip Coating Machine (Image Courtesy of Specialty Coating Systems)**



**Figure 1-17 Dispensing Via Manual Syringe**



**Figure 1-18 Dispensing Via Air Assisted Caulking Gun**



**Figure 1-19 Dispensing Via Time/Pressure Controlled Manual Dispenser (Image Courtesy of Nordson EFD)**

**1.4.2.22 Dispense Valve** Typically found as the final component of a dispense system, used with either a single component material or a plural component reactive material. The exit of this device regulates the flow of a fluid (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. Can contain both fluid and air ports (see Figure 1-21).

**1.4.2.23 Durometer** A measure of the degree of hardness or the resistance to deformation or fracture.

**1.4.2.24 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.

**1.4.2.25 EMC** Abbreviation for Electromagnetic Compatibility

**1.4.2.26 Encapsulation** The encasement of a component in a potting material by dipping, spraying, or embedding with or without a mold, to provide mechanical support environmental protection and for security purposes (see Figure 1-22).



Figure 1-20 Dispensing via Fully Automatic X-Y-Z Axis Computer Controlled Systems (Image Courtesy of GPD Global)

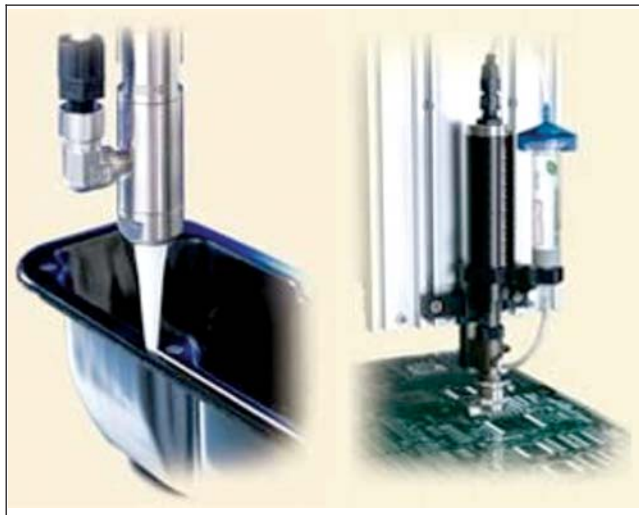


Figure 1-21 Examples of Dispensing Valves (Image Courtesy of Nordson EFD)



Figure 1-22 Potted Assembly

**1.4.2.27 Filler** A substance that is added to a material to improve its solidity, bulk, or other properties (see 1.4.1.5).

**1.4.2.28 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.

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

**1.4.2.30 Glob-Topped Encapsulation** The application of highly viscous compounds that are usually applied to a printed board, other substrate, or component/wire to provide mechanical support and environmental protection (see Figure 1-23).

**1.4.2.31 Texture Analyzer** Encapsulants can range from very hard materials (essentially dispensable plastics) to extremely soft gels. Soft gels are typically used when thermal movement stresses of harder materials can cause preman

wirebonds, solder joints, ceramics, and other stress-sensitive components. Measuring durometer hardness is relatively simple for hard to medium soft materials. However, for materials that transition the properties between a solid rubber and a viscous liquid, alternative tests are required to quantify and differentiate the relative firmness or hardness of these materials. For encapsulants that fall below the Shore 00 scale in hardness, two main tests have been developed to characterize their relative stiffness or hardness. Penetration tests have been used for a very many years. These tests require a relatively large sample size and cannot typically be done on potted parts. Texture analysis is a more recent test method widely used in the food industry to measure consistency/hardness of materials such as thick creams, puddings, gelatin and other very soft items not suitable for measurement by other tests. TA is very sensitive and quantitative, and in some cases can be performed on potted modules in-situ. TA has become a common standard test method for characterizing the hardness of super-soft gels commonly used to encapsulate stress sensitive electronics.

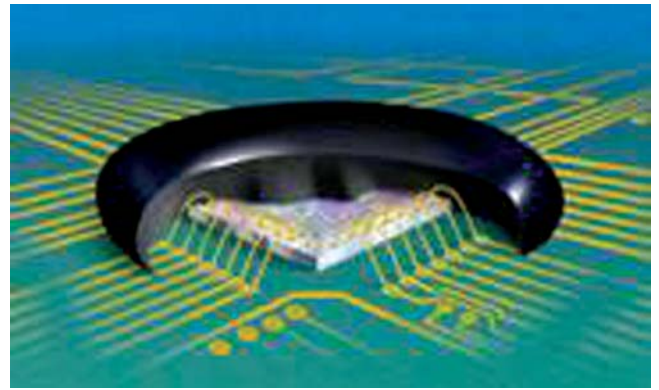


Figure 1-23 Glob-Topped Assembly (Image Courtesy of Loctite)

**1.4.2.32 Hardness** Resistance to indentation. Hardness for polymeric materials are typically measured on five scales; Penetration, the Shore OO, A, D, and Rockwell. The term “Durometer” is often used in place of “Hardness,” especially when referring to the Shore scales. For very soft materials, i.e., gels, the Penetration scale is used (see Figure 1-24 and 1-25).



Figure 1-24 Cured Witness Sample of Epoxy (1cc)

**NOTE:** Sample represents a particular mixed batch or lot cured in the same oven at the same time on a module.

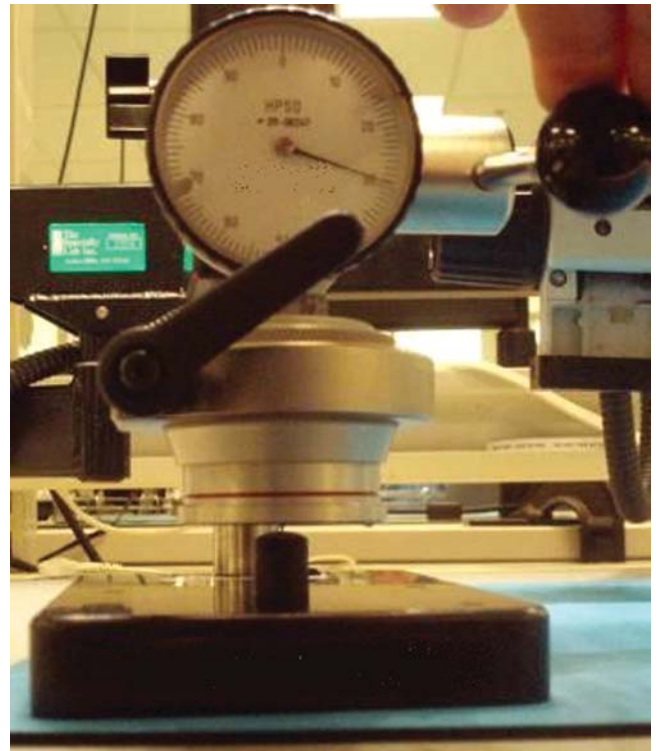


Figure 1-25 Shore D Durometer Being Used to Measure Hardness of Witness Sample (Image Courtesy of Check Line)

**1.4.2.33 Humidity** As it relates to processing with meter/mix equipment. Humidity can have adverse effects on certain elastomers, most often 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.

**1.4.2.34 Indexer/Conveyor** An electro-mechanical system that transports product from one encapsulation process capability to another. These systems, when used in an encapsulation process, typically meet the same 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 1-26).

**1.4.2.35 Injection Molding** A process in which molten or liquid polymeric materials are forced into a mold, then either cooled or cured. Reaction Injection Molding (RIM) process is similar, a two or more part material is mixed and injected, then the chemical reaction occurs, and the finished part is removed.

**1.4.2.36 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 (see Figure 1-27).

**1.4.2.37 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. When performing these profiles it is common for temperature probes to be placed in multiple locations across the part in order 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 would include:

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



Figure 1-26 Conveyor



Figure 1-27 Metered Mixer. This system will dispense a two-part epoxy mixed to the desired (set) ratio. Shown with the reservoir covers removed for clarity.

**1.4.2.38 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 ratioed 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.

**1.4.2.39 Potting** The material used in the process of encapsulating. See 1.4.1.12.

**1.4.2.40 Pot Life (Work Time)** Generally thought of as the time it takes a mixed material to double in viscosity. See 3.5.4.

**1.4.2.41 Pouring** A process in which, after the mixture has been degassed, the liquid is poured down one side of the potted device, allowing the liquid to fill the device in a manner that allows any air to flow out to the surface and evacuate as the module is filled. In some cases gentle vibration will help to allow the entrapped air to be relieved. Gentle heating of the part and/or potting compound will lower the viscosity to aid in the release of air bubbles.

**1.4.2.42 Pressure Cooker** Autoclave Test, or Pressure Cooker Test (PCT), 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.

**1.4.2.43 Reservoir** Typically a uniquely designed container that holds the feedstock supply of material or a material component (part A or B) making it available for subsequent dispense 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 that can accommodate pail, drum, or tote quantities of material (see Figure 1-28).



**Figure 1-28 Examples of Reservoirs**

**1.4.2.44 Rework and Repair** Correcting of defective, failed, or non-conforming 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.

**1.4.2.45 Spraying** A manual or automated technique used to apply a variety of liquid materials to a surface, producing a line-of-site uniform layer of liquid material generally associated with the atomization of low viscosity materials.

fine mist of material directed at a target. Atomization involves the breaking up of liquid droplets into fine particles. In an external atomization system a fluid stream is bombarded with pressurized air to form a mist. Atomization can be internal or external to the spray nozzle.

**1.4.2.46 Static Mixer Tube** Sometimes referred to as “in-line mixers,” a disposable, sometime shielded tubular device composed 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 Figure 1-29).

**1.4.2.47 Tack-Free** The ability to process the article without unwanted tack. The lack of unwanted tack is process dependent with some materials requiring a higher degree than others. Note that a soft gel has a permanently tacky surface even when fully cured.

**1.4.2.48 Underfill Process** Underfill is the process of applying a specially engineered material to fill the area between a component surface and the substrate. Underfill materials are designed to control the stress on the solder joints.

**1.4.2.49 UV/Visible Light** Light curing in electronic assembly and potting applications is typically associated with wavelengths in the ultraviolet and blue visible light spectrums. It is used to cure light sensitive materials which contain photoinitiators or other light sensitive catalysts. The potting is usually mobilized 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.

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

**1.4.2.51 Vacuum Encapsulation** Encapsulating electronic components in an air free environment, typically using a vacuum chamber. Typical components include connectors, coils and Printed Circuit Board (PCB)/Printed Wiring Board (PWB). The vacuum process provides improved impregnation or saturation in difficult to reach areas (i.e., around pins, under circuit boards) and improves void free encapsulation. This is especially important for applications involving high voltage devices, which can be prone to corona effect. See Figure 1-30 for an example of equipment capable of vacuum encapsulation.



Figure 1-29 Examples of Static Mixer Tubes (Image Courtesy of Nordson EFD)



Figure 1-30 Vacuum Encapsulation

**1.4.2.52 Vacuum Impregnation** The VPI process is used when it's important to ensure insulation of parts that incorporate tight, small places and crevices. This process is very popular in the manufacture of motors where the protection of coil windings is required. This process requires the full submersion of the part being impregnated. Normally there is a holding tank for the liquid potting material which may be maintained at an elevated temperature.

The part to be processed is placed in a holding system or rack and placed in the vacuum chamber. The size of the vacuum chamber is application dependent. Once the vacuum chamber is closed and placed under vacuum the liquid potting material is transferred from the holding tank to the vacuum chamber. A vacuum is drawn and maintained during the impregnation cycle. Once the cycle is completed the liquid potting material in the vacuum chamber is transferred back to the holding system. The encapsulated part is removed from the vacuum chamber for subsequent cure i.e., heat, anaerobic, etc.

**1.4.2.53 Vacuum Pump** The pumps are typically used in dispense processes to either degas material while they are still in a reservoir or after the dispense process to remove entrapped air bubbles. Also used with Vacuum Chambers in Vacuum Encapsulation Systems to remove air from the part or dispense environment (see Figure 1-31).

**1.4.2.54 Volumetric Shot Size** The volume of a dispensed or metered shot used to fill a cavity, typically expressed in cc's (cubic centimeters). 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 potting material can be used as a process control tool.

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

**1.4.2.56 Weight** An object's mass as measured by a scale (Figure 1-32).

**1.4.2.57 Work Cell** Broadly speaking this is an arrangement of resources in a manufacturing environment created to improve quality, speed and reduce the cost of a process. Typically in an encapsulation process, these resources will include dispense and cure systems at minimum but can also include preheat, inspection, rework, and various other systems and capabilities (see Figure 1-33).



Figure 1-31 Vacuum Pump



Figure 1-32 Example of a Scale

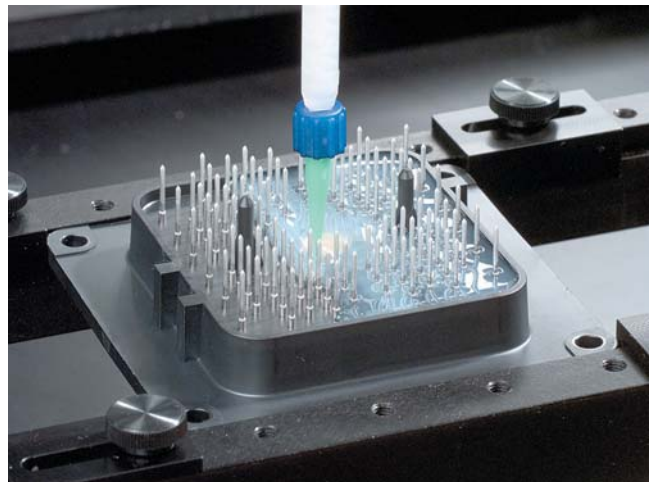


Figure 1-33 Close Up of One Section of a Work Cell

## 2 APPLICABLE DOCUMENTS

### 2.1 ASTM<sup>1</sup>

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

**ASTM D570** Standard Test Method for Water Absorption of Plastics

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

**ASTM D2520** Standard Test Method 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 Method 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

### 2.2 IPC Standards<sup>2</sup>

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

**IPC-D-279** Design guidelines for Reliable Surface Mount Technology Printed Board Assemblies

**IPC-TM-650** Test Method Manual<sup>3</sup>

2.6.1.1 Fungus Resistance - Encapsulation

2.6.3 Moisture and Insulation Resistance, Printed Boards

2.6.7.1 Thermal Shock - Encapsulation

**IPC-CC-830** Qualification and Performance of Electrical Insulating Compound for Printed Board Assemblies

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

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

### 2.3 Joint Industry Standard<sup>4</sup>

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

### 2.4 Military Standards<sup>5</sup>

**MIL-STD-202** Method 106, Test Methods for Electronic And Electrical Component Parts

1. [www.astm.org](http://www.astm.org)

2. [www.ipc.org](http://www.ipc.org)

3. Current and revised IPC Test Methods are available on the IPC Web site ([www.ipc.org/html/testmethods.htm](http://www.ipc.org/html/testmethods.htm))

4. [www.ipc.org](http://www.ipc.org)

5. <http://assist.daps.dla.mil/online/start>

## 2.5 Underwriters Laboratories<sup>6</sup>

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

**UL746C** Polymeric Materials - Use in Electrical Equipment Evaluations

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

## 2.6 British Standards (DSTAN, UK Defense Standardization)<sup>7</sup>

**EN 61086-1 (BS)** Specification for Encapsulations for Loaded Printed Wire Boards [Encapsulation]

## 2.7 IEC Standards<sup>8</sup>

**IEC 60664** Insulation coordination for equipment within low-voltage systems

**IEC 61086** Specification for encapsulations for loaded printed wire boards (encapsulation)

## 2.8 Federal Standards<sup>9</sup>

**FAR §25.853** Compartment Interiors

## 3 P/E MATERIALS

### 3.1 Chemistry Types

**3.1.1 Polyurethane and Polysulfide** Polyurethane encapsulations 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 re-work 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 3-30 days at room temperature for optimum cure. Two component formulations, on the other hand, reach optimum cure properties at elevated temperatures within 1-3 hours with pot lives of 30 minutes to 3 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 diphenyl methane diisocyanate (MDI) but other types such as toluene diisocyanate (TDI) may also be used (see Figure 3-1). An isocyanate prepolymer is formed by a reaction between a portion of the isocyanate and a polyol.

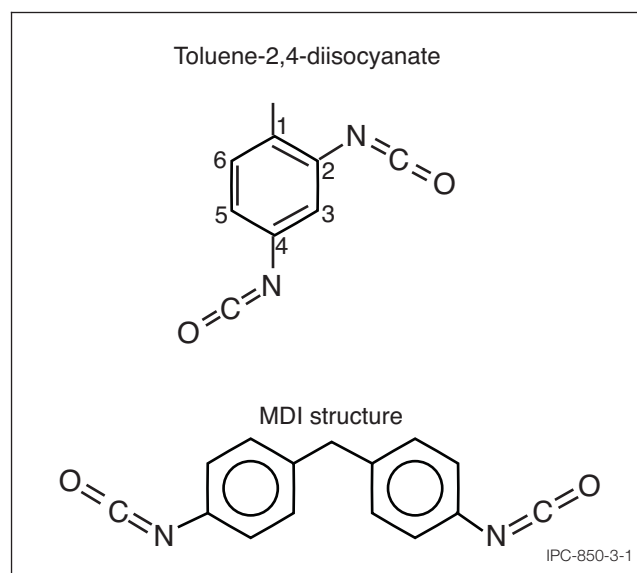


**Figure 3-1 Chemical Structures for the 4,4 Isomer of MDI (also found as the 2,4 Isomer) and the 2,4 Isomer of TDI (also present as the 2,6 Isomer)**

6. [www.ul.com](http://www.ul.com)

7. [www.bsi-global.com](http://www.bsi-global.com)

8. [www.iee.ch](http://www.iee.ch)

9. [www.faa.gov](http://www.faa.gov)

Polyurethanes have significant versatility as potting material because the hardness of the cured systems ranges from very soft, gel-like material for re-enterable systems to rigid high durometer material. Also, the reactivity of polyurethane systems can be varied from almost instant setting to a pot life of 1-2 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 less than 5% variation by weight or volume for proper cure. Pre-reacted polyurethanes are also sensitive to moisture and proper storage is critical. Exposure to excessive moisture can result in undesirable foaming of the product on cure. In general adhesion, chemical resistance, and high temperature performance may not be as good as some other potting materials such as epoxy.

**3.1.2 Epoxy** Epoxy systems are usually available as two part compounds. They provide reasonable humidity resistance and good abrasive and chemical resistance. They are virtually impossible to remove chemically for re-work since any stripper that will remove the encapsulants may vigorously attack epoxy-potted components as well as the epoxy-glass board itself. Single part epoxy resin encapsulants with temperature-activated hardeners are also available. These encapsulants require elevated temperatures. Epoxy is a thermosetting polymer that is formed when an epoxide resin is combined with a hardener. A catalyst can also be incorporated to accelerate the formula setup and hardening. 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.

When most epoxies are applied a “buffer” material must be used around fragile components, e.g., glass, to prevent damage from film shrinkage during polymerization. Curing at low temperature, if possible, is encouraged to reduce shrinkage.

Curing of epoxy systems may require up to 3 hours at an elevated temperature or up to 7 days at room temperature. Short pot life creates a limitation on their effective use.

The applications for epoxy-based resin systems seem to continuously grow. For the purpose of our discussions in this handbook the scope has been limited to electronics manufacture.

Epoxy resins are excellent electrical insulators and are used in many applications throughout the manufacturing process of both bare printed boards and printed board assemblies.

Two examples of applications where epoxies are used in the electronic industry are:

- a. Substrate and copper foil bonding.
- b. Solder mask.

**3.1.3 Acrylics** Acrylics are normally used where low cost or clarity of the encapsulated item is desired. Acrylics are easy to apply and can easily be reworked after encapsulation which can easily be accomplished using solvents. Acrylics dry rapidly, reach optimum physical properties in minutes, are fungus resistant, and provide long pot life. Furthermore, acrylics give off little or no heat during cure (eliminating damage to heat-sensitive components), do not shrink during cure, and have good humidity resistance.

Acrylic resins are used in potting and encapsulation applications due to their ease of application and their impact and abrasion resistance. Acrylics cure and dry rapidly and produce relatively little heat during cure, minimizing potential damage to heat-sensitive components. Additional benefits of acrylic resins include good humidity resistance, low shrinkage, fungus resistance, and long pot life. Acrylics can be brittle compared to some other options, limiting their use where toughness and flexibility are key performance factors.

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. These resins can be thermosetting meaning they are crosslinked into a solid film or thermoplastic. Thermoplastic means they can be reheated and will reflow.

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 that the molecular weight or size of the polymer is as large as it can get before any crosslinking is performed. Crosslinking of the double bonds in the acrylic resin by further peroxide addition is what leads to a thermoset resin. A thermoplastic resin will be solid when cooled to ambient temperature and can be reheated to reflow as there are no crosslinked sites within the resin.

These resins can also be modified with solvents and diluents to lower their viscosity for easier application. Acrylate or methacrylate monomers, styrene, vinyl toluene, organic solvents, and even water can be used depending on the application.

and how the resin was formulated. Acrylic resins can be modified with other materials to improve adhesion, gloss, and toughness and can be pigmented for applications requiring color.

**3.1.4 Silicone** Silicone encapsulants are extremely useful materials when components must endure extreme temperature cycling environments. The useful operating range of many of these materials is -45 °C to +200 °C [-49 °F to +392 °F]. If the end use application is outside of this range the suitability of the material should be tested. They provide high humidity resistance along with good thermal endurance making them desirable for PCAs with heat dissipating components such as power resistors. For high impedance circuitry, silicones offer a very low dissipation factor. They are very forgiving materials in production because they coat over and adhere to most surfaces found on a PCB and offer good resistance to polar solvents. Secondary cure for the UV curable versions is accomplished with a very effective ambient moisture mechanism. Another consideration when selecting silicone is that high temperature protection may generally demand that the silicone encapsulant be cured at or near to the maximum temperature it is designed to withstand.

**NOTE:** J-STD-001 states, "Equipment used for measuring viscosity, mixing, applying, and curing silicone material **shall not** be used for processing other material."

Silicone encapsulants are a family of products based on the polydimethyl siloxane (PDMS) molecule with unique characteristics. They are particularly useful in providing protection to electronics devices in moist and other severe environments, in insulating from high voltage, and in providing a low stress environment. Silicone encapsulants have a combination of properties which provide a 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, and no exothermic heat rise during cure. Among all these characteristics that are shared by the majority of silicone encapsulants, one property is recognized as one of the most useful in electronics applications and that is their consistent performance over a very wide temperature range, from -45 ° to +200 °C [-49 ° to +392 °F]. There are special silicone encapsulants formulated to withstand exposures to temperatures as high as 250 °C [482 °F] or as low as -80 °C [-112 °F]. Silicone encapsulants are available in a wide range of hardnesses from extremely soft materials (gels) to hard elastomers with hardness in the range from 30 to 80 Shore A.

Typical applications for silicones include: very wide temperature variations, vibration damping, thermal dissipation, and general encapsulation.

**3.1.5 UV/Visible Light Cure** Light curing is useful for immobilizing the surface or entire body of the potting material very quickly, usually within seconds, rather than in minutes or hours.

Functional properties for light cure materials are generally similar to the chemistry 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. Most potting materials have secondary cure functionality for areas not exposed to light, and are activated by heat or ambient moisture.

**3.1.6 Others Chemistry Types** Many different types of chemistries can be used for potting and encapsulation in electronics protection applications. Some hybrids can include foams, solid films, various liquids, visible light curable, and some UV curable materials.

## 3.2 Discussion of Properties

**3.2.1 Chemical Resistance** There is no such thing as a completely impervious material. All materials, organic or metallic, can be susceptible to some chemical elements or chemical agents. For potting and encapsulation materials, depending on the chemical composition of the material, this may include permeability to some gasses or to some liquids.

The degree of susceptibility may be dependent on the following factors:

- The chemical constituents of the P/E (Potting/Encapsulation) material.
- The chemical nature of the gas or liquid.
- Concentration of the gas or liquid.
- The forcing function of the gas or liquid, e.g., minor occasional exposure vs. high pressure concentrated exposure.
- The ability of the P/E material to "rest" or "recover" after exposure to the gas or liquid.
- Exposure to elevated temperatures.