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. Because of this, this document will cover all 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 (e.g., printed circuit assemblies (PCA), and components (e.g., 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 properties 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 (e.g., 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
- To inhibit corrosion
- To improve fatigue life of solder joints to leadless packages
- To inhibit arcing and corona, in particular for high voltage applications
- To provide mechanical support and to prevent damages due to mechanical shock and vibration.
- To provide a mitigation method for the growth of tin-whiskers.

1.4 Terms and Definitions The following are examples of some of the terms typically associated with these types of potting and encapsulation protection processes as related to the electronics assembly process.

1.4.1 Material Terms and Definitions

1.4.1.1 Catalyst A chemical which accelerates the cure (or cross linking) of a resin system.

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 Diluents 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** See “Potting Compound, “Glob Topped Encapsulation”, or “Molding Compound” (See figures 1-1, 1-2, 1-3, & 1-4)

- **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**

1.4.1.5 **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)

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

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

1.4.1.6 **Filleting 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

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

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.

1.4.1.10 Pigment An insoluble material used to color a compound.

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 - Potting is 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 1-7 illustrates a potted assembly

Figure 1-7 Example of Encapsulated CCA Inside of Container (Potting Shell)

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.
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 & 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 paragraph 3.3.4 for more information on adhesion.

![Figure 1-8 Results of Poor Adhesion](image)

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.

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

1.4.2.4 Air Dry Air dry is associated with the act of a liquid or semi-liquid material becoming a solid at room temperature. It is typically the act of a solvent or solvents evaporating from a liquid matrix to create a solid film. Another example could be a liquid material that can cure at ambient room temperature, such as an acrylic. Temperature and relative humidity both play a role in how fast this can be achieved.

1.4.2.5 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.

1.4.2.6 Anisotropic Conducting in the Z-axis only.

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

1.4.2.8 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 texture, 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 1-9.
1.4.2.9 Backfilling The act of sealing the rear of a connector, thereby preventing other liquids from migrating into the connector body 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 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 1-10.
1.4.2.10 Bake Exposure to dry heat, normally in an, for a specific period of time to cure a product and/or drive moisture from a part. See figure 1-11

![Cure oven](image)

Figure 1-11 Cure oven

1.4.2.11 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.

1.4.2.12 Casting Casting is similar to potting except that the container or mold is removed from the part after curing. (AKA cast-in-mold)

1.4.2.13 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.

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

1.4.2.15 Cure Development of polymer network by means of a chemical reaction (turning a liquid into a solid). Curing can be affected by the application of heat through convection or conduction, by the use of radiation such as infrared or ultraviolet energy, humidity, or in standard temperature and pressure conditions.

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.
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 1-13 & 1-14.

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

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 1-15.
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 1-16, 1-17, 1-18, 1-19)
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 1-20.

1.4.2.23 Durometer A measure of the degree of hardness or the resistance to be deformed or fractured.

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 1-21.
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** Time taken for a liquid polymer to begin to exhibit pseudo-elastic properties or to be 'immobilized'.

1.4.2.30 **Glob-Topped Encapsulation** 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 1-22.

1.4.2.31 **Hardness** The 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 1-23 & 1-24.
1.4.2.32 **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.

1.4.2.33 **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. Figure 1-25

![Figure 1-25 Conveyor](image)

1.4.2.34 **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.

1.4.2.35 **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 1-26.
1.4.2.36 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.

1.4.2.37 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 (aka 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 & B pistons reciprocate within their cylinders.

1.4.2.39 Potting  Potting is 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 1-27.
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** - Spraying is 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 fluids to produce a 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 1-28
1.4.2.47 Tack-Free - The “tack-free” state is the point in time in which the surface of the film is unable to yield a fingerprint; is immobile but not dry and hard throughout.

1.4.2.48 Underfill Process – (Jason Keeping)

1.4.2.49 UV / Visible Light – Light curing in electronic assembly applications is typically associated with wavelengths in the UVA and blue visible light spectrums. It is used to cure light sensitive materials which contain photoinitiators. When exposed to light of the proper wavelengths, the photoinitiators produce radical species and cause the material to polymerize. Various high intensity light sources are designed to deliver the proper wavelengths. Visible light penetrates deeper than UV light, so visible light sensitive materials are often desirable for potting applications where depth of cure is required. Light will polymerize only the areas directly exposed to the light source so many materials have a secondary cure mechanism to cure shadowed areas. Reference the UV material manufacturers data sheets for specific source intensity, dosage and wave lengths. EPROM devices should be protected from the UV light to prevent accidental erasure on the memory chip.

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 1-29 for an example of equipment capable of 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 1-30.

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 1-31)

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 1-32.
2. APPLICABLE DOCUMENTS

2.1 ASTM

2.2 IPC Standards
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-CC-830 Qualification and Performance of Electrical Insulating Compound for Printed Board Assemblies
IPC-2221 Generic Standard on Printed Board Design
IPC-6012 Qualification and Performance Specification for Rigid Printed Boards
IPC-7711 Rework of Electronic Assemblies
IPC-7721 Repair and Modification of Printed Boards and Electronic Assemblies
IPC-AJ-820A Section 13, Encapsulation (Potting Molding)
IPC-HDBK-830B Guidelines for the Design, Selection and Application of Conformal Coatings
IPC-A-610 Acceptability of Electronics Assemblies

- 2.3.25 Detection and Measurement of Ionizable Surface Contaminants by Resistivity of Solvent Extract
- 2.3.25.1 Ionic Cleanliness Testing of Bare PWBs
- 2.3.27 Cleanliness Test - Residual Rosin
- 2.3.27.1 Rosin Flux Residue Analysis-HPLC Method
- 2.3.28 Ionic Analysis of Circuit Boards, Ion Chromatography Method
- 2.3.38 Surface Organic Contaminant Detection Test
- 2.3.39 Surface Organic Contaminant Identification Test (Infrared Analytical Method)
- 2.5.7.1 Dielectric Withstanding Voltage – Polymeric Encapsulation
- 2.6.1.1 Fungus Resistance – Encapsulation
- 2.6.3 Moisture and Insulation Resistance, Printed Boards
- 2.6.3.1 Moisture and Insulation Resistance-Polymeric Solder Masks and Encapsulation
- 2.6.3.4 Moisture and Insulation Resistance – Encapsulation
- 2.6.7.1 Thermal Shock – Encapsulation
- 2.6.11.1 Hydrolytic Stability – Encapsulation
2.3 Joint Industry Standard
J-STD-001 Requirements for Soldered Electrical and Electronic Assemblies
J-STD-004 Requirements for Soldering Fluxes

2.4 Military Standards
MIL-STD-202 Method 106 Test Methods For Electronic And Electrical Component Parts
MIL-I-46058 Insulating Compound, Electrical (For Encapsulation Printed Circuit Assemblies)

2.5 Underwriters Laboratories
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

International Standards

2.6 British Standards (DSTAN, UK Defense Standardization)
EN 61086-1 (BS) Specification for Encapsulations for Loaded Printed Wire Boards [Encapsulation]

2.7 IEC Standards
IEC 60664 Insulation coordination for equipment within low-voltage systems
IEC 61086 Specification for encapsulations for loaded printed wire boards (encapsulation)

2.8 Original Equipment Manufacturing (OEM) Specification
OEM specifications are engineering documents in the form of either an engineering drawing, showing areas of electronic hardware to be encapsulated.

2.9 Environmental, Health and Safety Considerations
Recent environmental regulations such as the Montreal Protocol and Clean Air Act have had a significant impact on both encapsulation materials and application methods, particularly with regard to control of Volatile Organic Compounds (VOCs) and ozone depleting chlorofluorocarbon (CFC) compounds. VOCs are the primary concern, as they react in the atmosphere to form ground level ozone (or smog). CFCs have been found to deplete earth's protective ozone layer in the upper stratosphere. Both VOCs and CFCs have been extensively used as solvent carriers. Manufacturers and suppliers of encapsulation materials have responded by developing non-solvent based encapsulations and environmentally acceptable methods of application, curing and removal.

2.10 Emissions
Emission is defined as any substance discharged into the atmosphere such as solvents in encapsulation systems, fluxes, cleaners etc. Certain types of solvent such as isopropyl alcohol, xylene, etc. are volatile organic compound (VOC) liquids containing carbon and hydrogen that emit VOC vapors.

2.11 Disposal of Hazardous Waste
Hazardous waste is defined as any material which is classified as such and stated on the manufacturers Material Safety Data Sheet (MSDS). Disposal of hazardous waste must be in total compliance with the local, state and federal regulations.

2.12 Governmental Regulations
The user must be aware of any limitation with the use of any product or material used in their process. Frequently asked questions about hazardous waste are answered on the Environmental Protection Agency's website at http://www.EPA.gov.

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, but 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 most 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 reacting a portion of the isocyanate with a polyol.

Polyurethanes have significant versatility as potting material as 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 (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 these elevated temperatures.

When most epoxies are applied, a “buffer” material must be used around fragile components (glass) to prevent their 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.

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.

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

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

3.1.3 Acrylic- 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, reaching 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, 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 addition rate of the monomers and an initiator (usually a 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 these materials is -55°C to +200°C [-67 to 392 °F]. 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. It should also be considered 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 contribute to 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, no exothermic heat rise during cure, low toxicity, good dielectric properties, and high purity. 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 -55 to +200 °C [-67 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 Fluorosilicones: Get information from Steve

3.1.6 UV Cure - A recently developed method of curing is to utilize ultra-violet light. This permits curing of the material in seconds rather than in minutes or hours. They have been specifically developed for use on flat bare substrates and are of particular benefit for fiber optic filament encapsulation, as curing can be effected at speeds of up to 400ft/min. Their use on PCAs, however, is somewhat limited because of the shadowing effect produced by components and the thicknesses used. As a result of this, a catalyst is often required to ensure a chemical reaction to cure the compound in shaded areas. However, this produces the associated drawbacks of two-part systems such as short pot life and material blending for correct application. One-part materials have been developed, although they tend to be of an epoxy or polyurethane base. Two-part products are difficult to repair as subsequently reapplied encapsulants do not etch into the existing material surface, but produce discrete lamination.

3.1.7 Others 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 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

Long term exposure to these gasses or liquids can cause a degradation of the P/E material, or may leach critical elements from the cured polymer matrix.

The presence of contaminant chemicals during a P/E process can result in something called “inhibition”, which is a limitation of the necessary cure reactions. The inhibiting chemical may react with catalyst or react with a critical raw material needed for the cure reaction (e.g. hardener).

A P/E material should be chosen with a good knowledge of the end use environment.

Knowledge of the chemical susceptibility becomes useful when rework or repair is necessary, during which the encapsulation material must be removed.

3.2.2 Mechanical and Physical

3.2.1 Thermal Characteristics - As electronic assemblies get smaller and component densities grow greater, power density also tends to increase and thermal management becomes a critical consideration in the reliability of the assembly. Consequently, many designers are concerned with the flow of heat through organic materials, from hot components to cooler surrounding parts of the assembly.

There are a variety of terms in the industry used to express the ability of heat to flow through an organic material: thermal conductance, thermal conductivity, and thermal emissivity.

The most common measure is thermal emissivity. The emissivity of a material (usually written \( \varepsilon \) or \( e \)) is the relative ability of its surface to emit energy by radiation. It is the ratio of energy radiated by a particular material to energy radiated by a black body at the same temperature. A true black body would have an \( \varepsilon = 1 \) while any real object would have \( \varepsilon < 1 \). Emissivity is a dimensionless quantity. Emissivity depends on factors such as temperature, emission angle, and wavelength.

In practice, emissivity is determined by examining the thermal output between and uncoated/unspotted test sample and the thermal output with the candidate material in place. The ratio between the two measurements is the thermal emissivity for that material. Experimentally, heat flows are most often measured with calibrated digital thermal cameras. Most paints, conformal coatings and thin organic materials are in the 0.9 – 1.0 range.

Thermal conductivity of a material is often expressed in watts/meter-degree Kelvin (W/m-K), or in Imperial English
measurement, BTU/(hour foot-degree F). Thermal conductivity metrics predict the rate of energy loss (in watts) through the organic material. The reciprocal of thermal conductivity is thermal resistivity. See ASTM Standard D5470-06, “Standard Test Method for Thermal Transmission Properties of Thermally Conductive Electrical Insulation Materials” for more information. Table 3-1 gives examples.

Table 3-1 Thermal Conductivity

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal conductivity W/(m·K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica Aerogel</td>
<td>0.004 - 0.04</td>
</tr>
<tr>
<td>Air</td>
<td>0.025</td>
</tr>
<tr>
<td>Wood</td>
<td>0.04 - 0.4</td>
</tr>
<tr>
<td>Hollow Fill Fiber Insulation</td>
<td>0.042</td>
</tr>
<tr>
<td>Alcohols and oils</td>
<td>0.1 - 0.21</td>
</tr>
<tr>
<td>Mineral oil</td>
<td>0.138</td>
</tr>
<tr>
<td>Rubber</td>
<td>0.16</td>
</tr>
<tr>
<td>Silicone (filled)</td>
<td>0.20 – 0.64</td>
</tr>
<tr>
<td>Silicone (unfilled)</td>
<td>0.13 to 0.15</td>
</tr>
<tr>
<td>LPG</td>
<td>0.23 - 0.26</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>0.25</td>
</tr>
<tr>
<td>Cement, Portland</td>
<td>0.29</td>
</tr>
<tr>
<td>Epoxy (silica-filled)</td>
<td>0.30</td>
</tr>
<tr>
<td>Epoxy (unfilled)</td>
<td>0.59</td>
</tr>
<tr>
<td>Water (liquid)</td>
<td>0.6</td>
</tr>
<tr>
<td>Thermal grease</td>
<td>0.7 - 3</td>
</tr>
<tr>
<td>Thermal epoxy</td>
<td>1 - 7</td>
</tr>
<tr>
<td>Glass</td>
<td>1.1</td>
</tr>
<tr>
<td>Soil</td>
<td>1.5</td>
</tr>
<tr>
<td>Concrete, stone</td>
<td>1.7</td>
</tr>
<tr>
<td>Ice</td>
<td>2</td>
</tr>
<tr>
<td>Sandstone</td>
<td>2.4</td>
</tr>
<tr>
<td>Stainless steel</td>
<td>12.11 ~ 45.0</td>
</tr>
<tr>
<td>Lead</td>
<td>35.3</td>
</tr>
<tr>
<td>Aluminium (pure), 120—180 (alloys)</td>
<td>237</td>
</tr>
<tr>
<td>Gold</td>
<td>318</td>
</tr>
<tr>
<td>Copper</td>
<td>401</td>
</tr>
<tr>
<td>Silver</td>
<td>429</td>
</tr>
<tr>
<td>Diamond</td>
<td>900 - 2320</td>
</tr>
</tbody>
</table>

3.2.2. Outgassing Outgassing can be defined as the emission of vapor species from a material during the curing process or during subsequent thermal excursions during its service life. Some potting material chemistries evolve gaseous species during the chemical reactions that occur as the material converts from its liquid form to its cured solid state. Ideally the chemistry of the potting material system should be balanced so that once the material is fully cured; no further outgassing should be expected. Other sources of outgassing from potting materials are low molecular weight monomers / oligomers, surfactants, wetting agents etc. In many cases, these materials are not chemically reacted into the cured system. As a result, they are mobile enough to diffuse over time through the bulk material (especially under elevated temperature) to the surface, where they can volatilize. For many applications, it is desirable for potting materials to exhibit a low degree of outgassing. For example high altitude / space applications or any application where gaseous species could re-deposit as a contaminant onto other parts of the finished assembly (lenses, mirrors etc.) The degree of outgassing of a material can be measured using simple analysis on a TGA (Thermal Gravimetric Analyzer), where the material is heated to a temperature of interest and the change in weight of the sample is measured. The thermal outgassing of materials under vacuum can be measured using ASTM E595 Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment.

3.2.3 Shrinkage / Residual Stress As P&E compounds react, they may expand or contract during the cure process. The residual stresses formed during shrinkage or expansion can damage fragile components, such as glass bodied diodes, or may alter the functionality of a component by inducing stress on the package, such as oscillators. Some components, such as very low level wire wound inductors, are constructed from very fine wires which can be destroyed by material movement during cure.

3.2.4 Adhesion The ability of a material to adhere or bond to a substrate. The surface energy of both the substrate and the liquid potting material being dispensed are critical factors in obtaining adequate adhesion. Good adhesion between the potting material and the encapsulated substrates is critical to provide a barrier against moisture, liquid or gaseous contaminants. Adhesion can occur as a result of several mechanisms such as described in 3.3.4.1 through 3.3.4.3.
3.2.4.1 Mechanical Adhesion Obtained by physical mating of the applied potting material to the micro and macro topography of the assembly. This “lock and key” bonding provides mechanical anchor points between the potting material and the substrate. It is important that the liquid potting material is of a suitable viscosity and surface energy so that it can flow into and wet out the topography of the assembly substrate. This maximizes the contact between the two materials and thus mechanical anchoring as the potting material cures.

3.2.4.2 Chemical Bonds (Adhesion) Some potting material chemistries have the ability to form covalent chemical bonds to residual reactive chemical groups (silanol, amine, epoxy) present on the surface of the assembly. This can provide enhanced adhesion between the potting material and the assembly.

3.2.4.3 Weaker Chemical Interactions This includes weaker molecular level interactions between the chemistries of the potting material and the substrate. For example; hydrogen bonding, Van der Waal interactions, dipole/dipole interactions. Figure 3-1 shows an example of a Lap Shear test. The lap shear test evaluates the bond of materials to the substrates.

![Figure 3-1 Lap Shear](image)

3.2.5 Coefficient of Thermal Expansion (CTE) Thermal expansion is the tendency of matter to change its volume in response to a change in temperature. When a substance is heated, its composite molecules increase their rate of movement, therefore creating a greater average separation between them. The degree of this measured expansion divided by the change in temperature is called the material's coefficient of thermal expansion (CTE). Several types of coefficients have been developed: for example volumetric, area, or linear. Which coefficient is used depends on the application and which dimensions are considered most important. The CTE for a material generally varies with temperature. As a result of this relationship, it is important to know the CTE value for a material at a number of temperatures, both above and below its Glass Transition Temperature (Tg). With this information, the behavior of a potting material during the temperature changes expected during its service environment can be predicted. It is also important for the potting material specifier to know the CTEs for the other materials in the potted assembly, to avoid large disparities in CTE.

3.2.6 Hardness See durometer, paragraph 1.4.3.23

3.2.7 Green Strength The holding strength of a substance, joint, or assembly before it has been cured (set). From the perspective of potting and encapsulation materials, 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 Green Strength would be 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 decrease with an increase in temperature.

3.2.8 Young’s Modulus Also known as tensile modulus or modulus of elasticity 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. See figure 3-2

![Figure 3-2 Young’s Modulus Stress/Strain Curve](image)
Young’s modulus is reported in pressure units, PSI, Kg/cm² or MPa. See figure 3-x

3.2.9 Glass Transition Temperature (Tₙ) 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 Tₙ. Glass Transition temperature is routinely measured using Differential Scanning Calorimetry (DSC) (Figure 3-3), Thermo-Mechanical Analysis (TMA), or Dynamic Mechanical Analysis (DMA) (Figure 3-5). Pure polymers generally have a more distinct observed Tₙ. Since potting material formulations can be a complex mixture of materials the observed glass transition behavior may be more accurately defined as a “glass transition range”.

Figure 3-3 Sample DSC
3.3 Electrical

3.3.1 Insulation Characteristics Insulating capabilities of a potting or encapsulation material is critical to providing good electrical isolation to electronic components. Potting materials must not conduct electrical current in the cured state.

3.3.2 Dielectric Properties Potting materials when applied to a PWB become part of the dielectric system, affecting electrical parameters. If this is not taken into account during the design, then the circuit may not function as desired.

3.3.3 Dielectric Withstanding Voltage (DWV) is a measure of how well a potting material resists conducting electricity, usually at a high test voltage, for some period of time. DWV should be considered when designing high voltage equipment or equipment exposed to high amounts of corona.

3.3.4 Insulation Resistance is a measurement of the resistance to the flow of electricity. The higher the insulation resistance, the better the material is as an insulator.

3.3.5 Moisture and Insulation resistance (M&IR) Moisture resistance sometimes also called moisture and insulation resistance (M&IR) is a measure of how well the insulation characteristics are maintained when exposed to elevated conditions of temperature and humidity. A material with a low M&IR value would be a poor choice to protect a circuit in a high-humidity end-use.
3.3.6 Q-Resonance Q Values once used in the military are for reference only and are no longer used. They were often used in relation to conformal coatings. It is not a meaningful metric for encapsulation materials. Potting material polymers become part of the dielectric equation when they are applied to a PB surface. Some of the dielectric properties of a potting material are dependent upon the electromagnetic frequencies experienced. When hardware operates at high radio frequencies (RF), the potting material may alter the response of the circuit as its dielectric properties change with frequency.

3.4.7 Dielectric Constant and Dissipation Factor Measures how much a material may slow down electromagnetic propagation or how much energy an electromagnetic signal may lose. Materials such as PTFE (polytetrafluoroethylene) or ceramic have very low dielectric constant and dissipation factors. An RF signal does not lose much energy and rise/fall times are only minimally effected for these substrates, which is why they are chosen for high-speed/high-frequency hardware. In contrast, a material with a high dielectric constant may cause excessive energy loss in RF signals. As with the Q-Resonance, dielectric constant and dissipation factor are frequency dependent. Standard test frequencies are 1KHz and 1 MHz. High dielectric constant materials are often used in DC power applications, since there is no frequency effect at DC.

3.5 Processing Characteristics

3.5.1 Viscosity The viscosity of the encapsulation material needs to be considered based on the end use to ensure material flows to where it is required. Viscosity is essentially the resistance to flow. There are numerous methods for measuring the viscosity of a liquid, many developed specific to certain industries. Some of the more common methods used for measuring viscosity of potting materials involve a rotating disk or spindle in the fluid or a rotating flattened cone on a thin film of the liquid.

Viscosity is extremely dependent on temperature. At higher temperatures viscosity will decrease, and at lower temperatures viscosity will increase. Normal seasonal changes in plant temperature can have a significant effect on the flow characteristics of potting material. Controlling material and component temperature is important in getting consistent results. Viscosity also increases as the reaction proceeds and molecular mobility is reduced. Some systems show little viscosity increase until close to gelation.

Normally for potting applications a system with low viscosity is desired for optimum flow properties although this needs to be balanced with the need to add fillers or other materials to increase thermal conductivity, flame retardance, or other properties which increases the viscosity of the system.

While uncommon, there are a few potting materials that have a small level of shear thinning. Viscosity can be affected by shear forces. The faster it is pumped, the lower the apparent viscosity becomes. This usually quickly reverses once the shear reduces (after dispensing) resulting in slower flow-out. Glob-top materials may be designed for easy pumping and rapid dispense, yet have limited flow after dispensing.

3.5.1.1 Spindle Measurements Brookfield-style viscometers estimate a fluid’s dynamic viscosity with a rotating disk or T-shaped spindle. The disc or spindle type, rotation speed, and specimen temperature must be reported when quoting data generated with these instruments. See figures 3-6 & 3-7.
3.5.1.2 - Viscosity vs Rheology

There are essentially two methods to determine the suitability of the encapsulant for the application: either viscosity or rheology. Rheology uses “flow cup” to estimate the viscosity by measuring the time required for gravity flow through a calibrated orifice (e.g., Ford, Zahn, etc.). It is not practical to attempt a correlation of viscosity to the rheology of a product.

3.5.1.3 - Flow Cup Measurements

Flow cup viscometers estimate a fluid’s kinetic viscosity by measuring the time required for gravity flow through a calibrated orifice. The specimen density and temperature must be reported when quoting data generated with these instruments.

Dynamic Viscosity (cP) = kinetic Viscosity (cSt) x Specific Gravity of liquid dependent. To minimize such dependency the technique defined below is suggested. Immerse the flow cup in the liquid. Have the stopwatch in your hand as you lift the flow cup from the liquid with the other hand. Start the clock when the top of the flow cup breaks the surface of the liquid. Lift the cup quickly from the liquid. Stop the clock when the flow ceases to be continuous and steady.

There are many flow cup viscosity measurement standards. See Appendix B of IPC-HDBK-830 for details.

3.5.1.4 Effect of Temperature on Viscosity

Generally speaking the warmer a liquid gets the lower its viscosity becomes. Some materials are far more sensitive than others, but for good comparison of data the temperature at which the measurement is taken should be noted. 25°C is a common standard.

A temperature compensation chart can be made for a specific “control” material by plotting the viscosity (measured by whichever method) against temperature. Viscosity vs. temperature depends on the chemistry. Consult your material suppliers for viscosity vs. temperature profiles.

3.5.2 Thixotropy

A property of a substance, e.g., an adhesive system, which allows it to get thinner upon agitation and thicker upon subsequent rest.

From the perspective of potting and encapsulation, thixotropy is the property exhibited by certain gels or emulsions of becoming fluid when stirred or shaken, and returning to the semisolid state upon standing. This is less common for potting and encapsulation materials.

Many adhesives will “shear” or become thinner when placed under stress, such as squeezing through a dispense needle in a typical dispensing process. Once the stress has been removed after the dispensing step, the material recovers and returns to its original viscosity state. The speed at which the viscosity returns is known as the recovery time. A simple example of this would be ketchup.

3.5.3 Curing Exotherms

Many potting systems react exothermically – they give off heat. The amount of heat generated depends on the material chemistry (type of reaction) and the mass of reacting material. The exotherm temperature, how hot the material gets during reaction, is a function of the material and component temperature, cure temperature, product reactivity, and thermal transfer characteristics of the system.

By nature potting systems are fairly thermally insulating although some systems are designed to transfer heat more efficiently. In slow reacting systems, heat is lost to the surroundings almost as fast as it is generated and oven curing may be needed to generate sufficient cure. For fast reacting systems, heat is generated faster than it is transferred away and those applications which have a high concentration of mass of potting material will get hotter than those that are dispersed in thin sections, have small mass, or have large
heat sinks to dissipate heat.

When the initial material or component temperatures are elevated, the rate of reaction is increased and the generation of heat occurs in a shorter period of time, raising the exotherm temperature. Material shrinkage is also increased. In extreme cases the temperature will get hot enough to damage board components or even cause partial decomposition of the potting material itself.

For a given gel time, epoxy systems tend to generate greater exotherms than polyurethane systems, acrylics and silicones generally do not generate any noticeable exotherm at all.

3.5.4 Work time (Pot life) Much like exotherm, the work time or pot life is significantly affected by ambient temperature and to a lesser degree by the mass of material. Higher ambient temperatures lead to a reduction in work time. While this varies from system to system, a general rule of thumb is that a 10 degree (Celsius) increase in temperature cuts the work time in half. Since the amount of heat generated depends on the mass of material, work life can be optimized by mixing only the amount needed for the immediate application. Normally a longer pot life system is preferred for processing (material flow, release of air, etc.); however this needs to be balanced against the longer cure time required.

3.6 Selecting a P&E Material

3.6.1 Select with End Environment in Mind A P&E material protects an electronic assembly against its end use environment. The material must be chosen with that environment in mind, as well as secondary environmental considerations and OEM specifications. As indicated previously, P&E materials may have susceptibilities to harmful gases and liquids. If the end use environment contains these gases and liquids, then the next consideration is whether or not there are enclosures which limit or eliminate exposure to the harmful gases and liquids.

Example 1: The operating deck of an aircraft carrier may contain heat, humidity (water vapor), salt air, pollutant gases (combusted jet fuels), harsh solvents, jet fuels, greases, oils, etc. An electronic assembly left unprotected in such an environment would not last long. A P&E material would have to be robust against all of these factors to adequately protect an assembly with no higher level enclosures.

Example 2: In contrast, the power supply for the guidance package on an aircraft mounted missile is contained in a can filled with potting material. That can is placed inside another assembly which is then placed inside the sealed tube of the missile body, usually in the controlled atmosphere of the manufacturing contractor. In this case, the choice of the P&E material may be different, knowing there are two secondary enclosures to protect the assemblies.

3.6.2. Design for Encapsulation Application This section establishes design concepts, guidelines, and procedures intended to promote appropriate "Design for Reliability (DfR)" procedures and to ensure reliable characteristics of a encapsulated assembly or component.

Reliability is defined as the ability of a product to function under given conditions and for a specified period of time without failure. This section addresses reliability-related aspects of product design, process design, as well as material/component selection and qualification when using encapsulation in accordance with the design guidelines given in IPC-D-279. This section also identifies other appropriate existing IPC documents as reference for basic detailed information. The effort of this section is directed at making the designer and the users of encapsulation for electronic applications aware of the various factors that affect the protection afforded encapsulated items in the end-use environment for the design-life of the end-item.

3.6.2.1 Methods of Assessing Compatibility and Performance There are literally thousands of ways that you could go about either defining materials compatibility or testing the compatibility between any set of materials and the processing environment. Such an assessment becomes more focused if we concentrate only on assessing the ability of the processed hardware and encapsulation combination to achieve desired performance.

Whenever the assessment of performance is considered, an appropriate choice of test vehicle must be defined (test coupons, test boards, actual hardware, etc).

It is recommended that designed experiments be run on test boards, with a final verification run on actual hardware.

There are four basic questions to be answered in assessing encapsulation performance:
1. Does the encapsulation adhere reliably to the substrate?

Adhesion can usually be addressed by "exercising" the encapsulation in an environment of changing thermal conditions, such as temperature-humidity cycling. MIL-STD-202, method 106, and IPC-650 Method 2.6.3.1 are examples of cyclical temperature-humidity environments commonly used to test the adhesion of an encapsulant to a substrate. If the end-use environment has a severe vibration environment, then vibration testing may also be needed to test adhesion and thermal expansion. Such testing is commonly referred to as "shake and bake".
2. Does the encapsulation limit the electrical performance of the hardware?

Full functional testing of the hardware should be performed before and after application and curing of the encapsulant material. If there are no electrical failures as a result of the materials selected and the application and curing process, then the encapsulant is probably compatible. Performance considerations include increased rise times, propagation delays, cross-talk, etc.

3. Does the encapsulation protect the hardware from the end-use environment?

Depending on the end-use environment, the encapsulant may be called upon to provide both a mechanical, chemical and/or moisture barrier. Most test methods simply take the coated hardware and expose it to the environment in question. The environments may consist of one or more of the following:
- ozone
- Mixed flowing gasses
- Industrial pollutants
- Salt air
- Temperature extremes
- Humidity conditions

If the hardware can withstand an exposure to such environments, without degradation of the encapsulant properties, degradation of the electrical properties, or corrosion of the hardware under the encapsulation, then that encapsulant would be considered acceptable.

4. Do the thermal expansion properties of the encapsulant compromise the hardware?

In some cases, the encapsulant has not been selected to match the thermal characteristics of the end-use environment. If the encapsulant is too rigid and the substrate thermally expands or contracts, then the encapsulant may crack and crumble. If the encapsulant expands or contracts too much, it may break solder joints or fragile components such as glass bodied diodes.

3.6.3 Design Philosophy

Before the product design effort can begin, the designers of the product and assembly process need to know the customer's reliability requirements for the product. These requirements should be defined and ranked by a concurrent engineering or cross-functional team through a process such as Quality Function Deployment (QFD) used to capture the voice of the customer. The design team can include, but is not limited to, the members who participate in at least the design activities identified in the IPC-D-279. In this section, DfA/M stands for Design for Assembly/Manufacturability, DfT for Design for Testability, DfR for Design for Reliability.

The design team can consider the general design guidelines presented in the body of this section as a methodology for achieving its reliability goals. The IPC-D-279 contains information that illustrates the general design steps and process flow using concurrent engineering. The IPC-D-279 also includes information that illustrates the interactive nature of the design for reliability process. Areas that need to be defined are the reliability requirements, the product life cycle, and the product environment. For details see IPC-HDBK-830.

3.7 Qualifying a P&E Material

There are generally two different evaluations of P&E materials that are performed: (1) a material qualification, which focuses on the material properties and materials compatibility issues; and (2) a process validation, which focuses on the use of the material with the target hardware.

When developing a qualification test battery, the following should be considered. Substrates are most often items like standard test boards, test coupons, etc., but usually not on production hardware.

3.7.1 Vendor’s Data Sheet

In a material qualification, the vendor’s data sheet is the starting point. Be aware that the vendor’s data sheet represents a best case condition as the vendor optimally prepares the material for test. A vendor’s data sheet should not be used for establishing a specification. A materials qualification test should determine if the user of the P&E material can replicate critical properties outlined on the data sheet, i.e. can the user mix the material and get the same properties as the data sheet.

3.7.2 Compatibility with Process Materials

It is important when reading the following section, to recognize that all encapsulants seal in as well as out. In seal order to successfully apply an encapsulant to a PCA, compatibility of the encapsulant with various materials on the PCA during the application and curing processes need to be considered. This includes compatibility with board or component surfaces, solder masks, common contaminants such as flux residues, and chemicals such as plasticizer, defoamer, and mold release agent.

Materials compatibility testing with target assembly material sets. This forms the bulk of a materials evaluation. Questions to be answered should include:
1. Will the material adhere to the solder mask and other surfaces of the assembly?
2. Will the cure characteristics of the material damage components on the assembly?
3. Will the material interact with flux residues or cleaning chemistries?
4. Will the material interact or adhere to other adhesives or other assembly materials?
5. What are the thermal conductance characteristics of the material?
6. Where is “the edge of the cliff”? In any good material evaluation, the user should determine the bounds of the material and/or process. A target condition is good, but what are the minimums and maximums of the process?
7. What kinds of harsh test environments are required for product? Does the material stand up well for those harsh elements?
8. Is there anything that will be in contact with the potting material which could cause inhibition?

Some Residues to be aware of:
- Adhesives
- Human agents – perspiration, acids and/or oils
- Lanolin from hands
- Mold release agents
- Oils
- Silicones
- Surfactants
- Ionic contamination
- Others depending on the process your supplier is using and the process you are using.

It is suggested that pre-production products be processed prior to the validation of actual production.

3.7.3 Residues Related to PCB and Components

Printed Circuit Boards (PCBs) are one of the major subcomponents of an encapsulated printed circuit assembly (PCA). Other sub-elements of the PCA that are considered in the encapsulation design and selection include, but are not limited to, surface finish, spacing between component leads or printed wiring features, discrete and integrated circuit components, and solder joint configuration. However, it is the PCB that is the singular largest feature of the PCA that is encapsulated and therefore has a significant impact in determining which encapsulant and process of application is most appropriate to use. The chemical make-up and thermal expansion characteristics of the PCB need to be considered when selecting the final encapsulant properties.

3.7.3.1 Plating Surfaces

Plating surfaces are the metallic areas that remain on the exterior surface of the PCB as well as through-holes and solder pads after etching and removal of photoresists. These areas are typically bare copper that are then plated with a protective finish. In most of these instances, the plated surfaces will have some dissimilar metal interfaces that will be coated with an encapsulant. In addition, there may be designs in which an encapsulant will either partially or completely cover the plated surface areas. In situations with partial encapsulation coverage, the edge of the encapsulation may delaminate or lose adhesion to the surface of the plated metal.

3.7.3.2 Alternate Surface Finishes

One of the areas on a PCA to which an encapsulant needs to adhere is the surface finish of the PCB. Surface finish is the material on exposed metallized areas of the exterior PCB. Newer technologies have resulted in materials other than Sn/Pb being used as the finish on the PCB prior to assembly processing. These materials include, but are not limited to, bare copper, immersion tin, immersion silver, immersion gold, electrolytic or electroless nickel combined with gold and/or palladium, organic soldering preservative (OSP), and other similar types of alloys.

In many situations, some surface finish areas are not being soldered and therefore are part of the overall board substrate. Depending on the type of board surface finish, there may be dissimilar metal interfaces that could lead to corrosion if not protected from humid environments. Encapsulation materials would then need to be considered as a corrosion prevention aid in addition to an environmental protection barrier. The dissimilar metal combination of an alternate surface finish over bare copper is also a surface in which encapsulation adhesion will also need to be evaluated.

In many cases, these conditions may necessitate conducting a qualification test using a representative PCB sample before approving the intended encapsulant as “acceptable for use”.

3.7.3.3 Spacing

Reduced heat extraction from the PCA (and increased junction temperatures) may result if encapsulation covers heat conduction surfaces on the PCA edge or margin which mate with heat sinks such as card-edge clamps and cold plates. A resolution is to widen conductors which function as heat dissipaters. If possible, it is recommended to limit (delta)T conductor to less than 5°C.

The other issue concerning the aspect of spacing on PCAs involves the areas between adjacent printed circuit traces or between solder pads at the PCB level. Other spacing issues are the physical volume between adjacent leads of soldered electronic components. In all these instances, an encapsulant is usually required to cover these areas. Soldered components with leads usually require complete encapsulation coverage without solder bridging between adjacent leads in order to maintain the
necessary dielectric insulation. The type of encapsulation that would be used usually depends on spacing between the leads (lead pitch) and whether the leads are cylindrical or rectangular. For fine pitched leaded devices, i.e. smaller spacing and clearance between adjacent leads, an encapsulant with lower viscosity should be considered to achieve uniform thickness while providing edge and point coverage.

The protection chemistry used should not be used in lieu of proper conductor spacing.

3.7.3.4 Solder Mask
Compatibility issues between solder mask and encapsulation should be considered when designing a PCA for encapsulation application. Depending on the chemistry of the solder mask there may be failures associated with non-compatibility including contamination, adhesion, ionics and surface energy. Many solder mask technologies also contain a variety of solvents and glycol components, the latter of which can be hydroscopic in nature and can also absorb and leach ionic species and other process contaminants. The cleanliness levels should be routinely measured and monitored. Many solder masks are also imaged via a UV photo initiator or lithography step. In these cases it is imperative that the applied solder mask be completely cured especially in areas that may be shadowed from direct UV exposure. Some solder masks depending on the applied thickness can act like a sponge, absorbing and excreting various process residues picked up along the way in the manufacture of the PCA so the user in encouraged to insure cleanliness testing is performed and within the limits specified by the assembler and the end user.

3.7.3.5 Component
Different types of component packages are used in electronic circuitry. The materials used in packages vary greatly and may contain plastics, ceramics, marking inks, metals, glass and various other materials. The degree of encapsulation adhesion, CTE mismatch, shear modulus and general wetting characteristics of these materials need to be considered when application of encapsulant is anticipated.

3.7.4 Component Material Types

3.7.4.1 Plastic Various mold release agents are used to assist in the release of these packages from the mold after the injection molding process. Component suppliers consider these release agents proprietary and are reluctant to reveal the exact formula used. These agents may impact the degree of wetting and the adhesion of encapsulation (or any adhesive) to the package. The plastic packages may absorb various process materials such as fluxes, moisture, and cleaning agents and the release agents may exit the porous plastic matrix in subsequent heat excursions in processes or end use environments.

3.7.4.2 Ceramic When encapsulating assemblies containing ceramic components, one needs to consider the impact of CTE mismatch to preclude damage (e.g., cracks) to the components. Ceramic components are sometimes color-coded and the pigments pose problems with the encapsulation. Marking inks, however, may contain polysiloxane agents, which may cause de-wetting and adhesion loss of the encapsulation, but usually only occurs in the proximity area of legend markings.

3.7.4.3 Metal Metal packages are of the least concern of all types of package materials currently used. Most encapsulation formulations are designed to wet and adhere well to these surfaces. The marking inks and/or decals used should be considered as localized de-wetting and/or delamination may occur.

3.7.4.4 Glass When encapsulating assemblies containing glass bodied components, one needs to consider the impact of CTE mismatch to preclude damage (e.g., cracks) to the components. Low modulus “buffering” compounds can be used as an adjunct in end use applications consisting of high vibration and thermal cycling.

3.7.4.5 Through Hole Components As for other types of components, one needs to consider the impact of CTE mismatch, material compatibility issues, and voiding due to processing of the assembly.

3.7.4.6 Leaded SMT Components The “pitch” or distance between leads is a design concern for encapsulation. Some higher viscosity encapsulation materials may not penetrate past and under fine pitch leads and may not migrate under the device. This causes bubbles to form in the encapsulation during cure as air voids under the device heat up and the air attempts to escape from under the component. If the bubble does not pop before polymerization, it can bridge conductors and limit the degree of insulation provided by encapsulation within the cured bubble.

Encapsulating materials may need to be applied by a method (hypodermic needle, vacuum) to ensure that the material flows to cover all required areas and to minimize the formation of bubbles.

3.7.4.7 Leadless SMT Components Components with terminations formed as an integral part of the body are specified as leadless. This would include BGA, PGA, and Flip Chip, chip scale package (CSP), chip on board (COB), leadless chip carrier (LCC), and chip type components.
3.7.4.8 Ball Grid Array (BGA) Ball Grid Array devices are leadless. They contain solder bumps on the underside, which can be peripheral or area dispersed. The finished gap under the device after solder collapse can be 0.5 mm [0.020 in] to 1.3 mm [0.051 in]. This is generally enough to allow good capillary flow of encapsulation under the device depending on how large the BGA is. BGAs in excess of 650 mm² [1.01 in²] may limit the amount of encapsulation penetrating under the device via capillary flow. Post soldering residues are of prime concern as cleaning and inspection under these types of devices can be difficult or even impossible. Many of these devices are now being “under-filled” with epoxy prior to the encapsulation operation.

3.7.4.9 Pin Grid Array (PGA) Pin Grid Arrays are similar to the BGA except for the fact that pins have replaced the solder bumps. The characteristics affecting the encapsulation are identical to those of the BGA.

3.7.4.10 Flip Chip (COB, CSP) Flip Chip devices are package-less die, which have been bumped with solder on the contact sites. The solder bumps are fluxed and the silicon chip is inverted, placed and passed through solder reflow. The device is then “underfilled” with an organic material creating a complete seal and fillet around the device. The encapsulation can be applied over the die. Adhesion and wetting to the organic material underfill fillet is usually not an issue.

Underfill can also be applied at the wafer level with B-staged anisotropic adhesives. Some versions also contain flux within the epoxy matrix, hence “fluxing underfills” which eliminate the fluxing step.

3.7.4.11 Dam and Fill This type of device is similar to flip chip except the die is turned face up and connected with wire die bonds. Because of this, it can be considered a leaded device before encapsulation.

The die is connected on the bottom side with die attach adhesive which is usually a non-conductive organic material. The wire die bonds are made from the die face to the substrate or lead frame. Using a high viscosity organic material, a dam is dispensed around the outside parameter of the device. The height profile of the dam must exceed the tallest die wires. A second organic material, which is low in viscosity, is then dispensed within the dam parameter and both materials are cured simultaneously. This completely encapsulates the device. Rework is not practical. If encapsulated, the dam and fill epoxy package does not generally pose wetting or adherence problems with the encapsulation.

3.7.4.12 Glob Top Glob top is similar to dam and fill with the only difference being a high viscosity encapsulant is dispensed in the center of the die. The material shall encapsulate the wire die bonds without breaking the fine leads and flow over the entire device. It is then cured. The height profile of the glob must exceed the highest bend in the die wires by 30%. Encapsulation shall perform in the same manner as in dam and fill applications.

4 Electrical Considerations The effect of encapsulation on the electrical functioning of a PCB can be either beneficial or detrimental. This depends primarily on the design parameters of the circuit and the material of the encapsulation. How beneficial or how detrimental depends on good engineering, as outlined below.

There are several distinct categories of electronic circuits/assemblies that will be briefly discussed with regards to the possible effects of encapsulation. These include high voltage, high current, RF and microwave, high speed digital, along with the effect on ESD and EMI. It’s important to note, the effects discussed only apply to circuit traces on the outer layers of the PCB. The traces which are in direct contact with the encapsulation.

4.1 High Voltage (HV)/High Current (HC) “High Voltage (HV) circuits” is one case where encapsulation may be necessary for the PCA to function in some environments. Encapsulation is used to provide greater insulation between HV leads than is provided by the air. Such additional insulation is needed to prevent HV arcing or corona. The best method to produce HV circuits with a high degree of robustness is by using encapsulation after assembly. Encapsulation is not to be used in lieu of electric insulation on high voltage wire. An important characteristic of an encapsulation used in HV circuitry is its dielectric strength, but for High Current (HC) circuits, encapsulation is generally detrimental. High current means high heat, and encapsulation interferes with the dispersion of that heat. Therefore, good thermal conductivity is the key property for encapsulations used in high current circuits. Other important factors include high melting point and glass transition temperature (Tg). If the melting point and/or the Tg are too low the encapsulation may melt or deform from the dissipated heat.

Circuits which are both high voltage and high current need encapsulation with both good electrical insulation to contain the HV and good thermal conductivity to dissipate the heat generated by the high current. Unfortunately, materials that are good electrical insulators are typically not good thermal conductors. Therefore, tradeoffs are required based upon the design of the circuit, how it will be used, environmental conditions, etc. Good engineering in board design, component selection, as well as materials, is necessary to produce the best PCA.

4.2 RF and Microwave These types of items should normally not be encapsulated since the encapsulating material will change the dielectric constant of the circuit.

4.3 High Speed Digital These types of items should normally not be encapsulated since the encapsulating material will change the
4.4 Controlled Impedance These types of items should normally not be encapsulated since the encapsulating material will change the dielectric constant of the circuit.

4.5 EMI/ESD

4.5.1 EMI (Electromagnetic Interference) There is little an encapsulation can do to alleviate EMI. Many factors need to be understood to properly control EMI. One of those items is how to properly shield a PCA to prevent radiation of EMI or susceptibility to EMI. Shielding a PCA from EMI requires enclosing the PCA in a conductor that is then connected to ground. In theory a conductive encapsulation could do an excellent job, but in practice the likelihood of short-circuiting leads of the various components makes this an impractical process.

4.5.2 ESD (Electrostatic Discharge) Electronic assemblies which will be handled, repaired, modified or etc. on a regular basis need some protection from the discharges produced by human beings. The standard model used in ESD control is the human body model consisting of a voltage but with only a small amount of charge behind it. Encapsulations are not commonly used for ESD protection.

4.6 Encapsulation Coverage Encapsulating materials should be applied to the areas specified on the assembly drawing/documentation.

4.7 Masking The purpose for masking is to prevent encapsulating materials from un-intentionally adhering to unwanted areas such as mating interface points, electrical contacts, etc.

Masking will prevent encapsulation from being applied in a specific area. However, a masking process can be labor intensive, especially around intricate assemblies. Therefore, minimizing masking should be a consideration while designing a PCA. Choosing a mask that is easy to apply and remove could be helpful in the event that masking is needed.

Users are cautioned that certain types of masking such as liquid masking materials that subsequently harden to a rubber-like consistency can cause problems in the event that they are not completely removed from electrical contacts in connectors, sockets, and other similar electrical interface areas.

Masking and de-masking is a labor intensive process. Therefore, PCAs should be designed with encapsulation operation in mind such that the number of areas that need to be masked is minimized.

4.8 Drawings & Design Guidelines In order for an encapsulation to be used on a PCA, there must be a reference to a material and process specification as well as a pictorial drawing. The material specification usually governs all the requirements for the encapsulation material. The process specification usually specifies all the requirements associated with applying the encapsulation material. This specification should also include details for processes preceding and subsequent to the encapsulation step. Examples of these would include but are not limited to cleaning after soldering, masking, handling (as electrostatic discharge safe), de-masking and inspection. A pictorial diagram to be used as a guideline should indicate either by chain-line, hatched region, or something similar the areas to be encapsulated.

4.9 Chemical Susceptibility Testing If the end use environment is known, the material should be tested to determine susceptibility to known factors. For example industrial controllers in a Vidalia onion processing plant should be tested for sulfur susceptibility (Vidalia onions are high in sulfur). Chemical susceptibility testing should also determine if the electronic assemblies, where P&E materials are to be used, contain materials which would cause cure inhibition during production.

4.10 Accelerated Aging Tests Accelerated aging tests should be done to determine how well the P&E material maintains critical properties with time. Such testing should also determine whether exposure to a particular accelerating factor (e.g. high humidity) cause the material to change significantly (e.g. reversion).

4.11 Validating a P&E Material After the engineers have completed evaluating the material in the lab, it is time to see whether the material works on product, which is the validation phase of the testing. Most often, this kind of validation starts with scrap product, and culminates with full qualification testing on product using factory approved methods. Full qualification testing will depend on the industry sector (telecommunication vs. aerospace), the customer requirements, and available accelerated test methodologies. MIL-STD-202, MIL-STD-810 and MIL-STD-883 outline many available accelerated test protocols.

4.12 Discussion of Material Properties and Dependence on Processing Methods

4.12.1 Encapsulation Properties All polymeric encapsulation have varying physical properties, depending on the polymeric backbones and other modifying chemical elements or additives. When selecting an encapsulation for an application, the designer must be aware of:

- The physical properties of cured encapsulations. Example: an encapsulation with no resistance to salt air would not be a good choice for Navy hardware.
- How these properties may change from published values as a result of variables in the encapsulation operation.
- Example: rise times and propagation delays may be affected dramatically if an encapsulation is used that is drastically beyond its shelf life.
- How these properties may change with time as a result of the end-use environment. Example: encapsulations may be embrittled or darkened with exposure to high heat.
- “Qualified” or “Approved” encapsulations to the various standards and specifications will have been tested to verify that the following issues have been addressed. It is recommended that the relevant encapsulation manufacturer be asked for a copy of the test reports.

4.12.2 Appearance/Color The transparency or color of the encapsulation may be an issue for some applications. Most specifications require that the encapsulations maintain their transparent or color properties. Desired appearance, color and transparency must be maintained through various environmental stress screenings.

4.12.3 Dielectric Properties Encapsulation, when applied to an assembly, becomes a part of the dielectric system, affecting electrical parameters. If this is not taken into account during the design, then the circuit may not function as desired. Voids in the encapsulation process can cause electrical problems.

4.12.4 Dielectric Withstanding Voltage Dielectric Withstanding Voltage (DWV) is a measure of how well an encapsulation will resist conducting electricity, usually at a high test voltage, for a set period of time. DWV should be a consideration when designing high voltage equipment or equipment exposed to high amounts of corona. The encapsulation process should contain no voids.

4.12.5 Dielectric Insulation Resistance Insulation resistance is a measure of the resistance to the flow of electricity. The higher the insulation resistance, the better the material is as an insulator.

Moisture resistance, sometimes also called moisture and insulation resistance (M&IR), is a measure of how well the insulation characteristics are maintained when exposed to elevated conditions of temperature and humidity. A material with a low M&IR value would be a poor choice to protect a circuit in a high humidity end-use environment.

4.12.6 Dielectric Q-Resonance Encapsulation polymers become part of the dielectric equation when they are applied to an assembly surface. Some of the dielectric properties of an encapsulation are dependent upon the electromagnetic frequencies experienced. When hardware operates at high RF frequencies, the encapsulation may alter the response of the circuit as its dielectric properties change with frequency. Therefore, RF assemblies are not encapsulated.

4.12.7 Dielectric Constant and Dissipation Factor Dielectric constant and dissipation factor are a measure of how much a material may slow down electromagnetic propagation or how much energy an electromagnetic signal may lose. Materials with very low dielectric constants, such as polytetrafluoroethylene (PTFE) or ceramic, have very low dielectric constant and dissipation factors. An RF signal will not lose much energy and rise/fall times are only minimally affected for these substrates, which is why they are chosen for high-speed / high-frequency hardware. In contrast, a material with a high dielectric constant may cause excessive energy loss in RF signals. Since encapsulation materials normally have a high dielectric constant, encapsulation is not used for this application.

4.12.8 Thermal Properties Thermal properties of an encapsulation are an important characteristic because the encapsulation must be able to withstand local hot spots generated by components or from environmental temperature exposure of the electronic device it has been applied to. Some end-use applications may involve extreme temperature, or widely ranging temperature, for example, automotive, space and geothermal applications. Thermal profiles, which include ambient and operational temperature extremes, must be considered when selecting encapsulations. When temperature changes, other conditions, e.g. humidity and pressure may vary too. It is advisable to evaluate all these potential changes and their effect on encapsulation.

Thermal analysis techniques can be used to determine encapsulation properties with changes in temperature such as:
- The useful state of cure (usable state in which a product will be acceptable for final test)
- Glass transition temperature (Tg)
- Degree of cure (optimization)
- The amounts of moisture and volatiles present (ambient condition)
- Mechanical properties such as expansion, contraction and modulus. (Chemistry dependent)

Examples of thermal analysis techniques are differential scanning calorimetry (DSC), thermal mechanical analysis (TMA), dynamic mechanical analysis (DMA) and thermal gravimetric analysis (TGA). More information on these techniques can be found in Appendix D of IPC-HDBK-830.

4.12.9 Thermal Stability High temperature can cause short-term changes in encapsulation characteristic such as softening and potentially lower electrical resistance. Long-term effects of high temperature operation can cause encapsulations to discolor, embrittle, crack, and shrink, effecting dielectric strength and insulation resistance. Low temperatures can cause cracking and delamination due to differences in CTE, vibration, or flexing. Thermal cycle testing, using dummy components, is recommended to determine suitability
One must consider modulus and CTE together when designing electronic controllers (especially with fine-pitch components).

CTE is an important design consideration because if the thermal expansion characteristics of the encapsulation are radically different than for the substrate, cracking of the encapsulation may occur, compromising encapsulation integrity, and the encapsulation may unduly stress component leads, compromising reliability. This is particularly true for the more rigid encapsulations, such as epoxy. If the end-use environment has large or rapid swings in thermal conditions, a CTE mismatch can prematurely fatigue an encapsulation or cause fatigue failures in components. Some users express this as Thermal Coefficient of Expansion (CTE).

CTE is chemistry and application dependent. The user must consider the application and chemistry chosen for the specific need and evaluate appropriately.

4.12.10 Flammability
An encapsulation covers most of the components and assembly surfaces. Therefore, it has the potential to either isolate or propagate the effect of any electrical short that might occur. Flammability of the encapsulation material is thus an important property to consider when selecting an encapsulation, especially if it is for an end use environment susceptible to combustion.

Some encapsulations may contain flame-retardants. Flammability of encapsulation can be tested as per ASTM D 635 or FAR §25.853 and/or certified to UL746C, UL746E, or UL94 (vertical and horizontal burn tests) when required. Users should familiarize themselves with appropriate specifications for their applications.

4.12.12 Abrasion Resistance
Potential for mechanical abrasion should be considered when selecting an encapsulation. This may occur due to improper handling, storage or shipping and may result in scratches, scrapes, dents, creases, and marred surfaces which can become areas of concentrated stress or contamination ingress. Encapsulated assemblies in direct contact with other subassemblies, such as wire harnesses, may abrade the encapsulation. Excessive handling, insertion and removal of assemblies may also cause abrasion. High velocity air flow caused by venturi situations may erode encapsulations due to dust particles in the air stream.

4.12.13 Hydrolytic Stability
Some end use applications may require the encapsulation to be in contact with moisture consistently. Others may have moisture condensing on the surface of the encapsulation occasionally. For both scenarios, the encapsulation may be required to maintain its properties for a specific length of time. Encapsulations that are not hydrolytically stable would experience degradation of properties after exposure to a humid environment.

At the molecular level, aqueous layers of water will begin to form when the RH reaches 40%. At 60% RH a layer of water 2 to 4 molecules thick can be present. A layer 3 to 4 molecules thick is enough to cause chemical reactions to begin with any hygroscopic particulates on the surface. At 80% humidity the aqueous layer is up to 10 molecules thick and deposited materials will begin to dissolve. This creates free flowing ions which are capable of penetrating encapsulations. The presence of hydrocarbon compounds for each application. Consult the material technical data sheet for temperature ranges.
will aid the formation of aqueous surfaces layers on materials.

The general rule is what RH is >60% problems may occur. Experimentation has shown that submicron dust particles in the atmosphere can be acidic or basic when exposed to humidity >60%. At humidity >80% ion flow begins which can lead to leakage currents, dendritic growth, and corrosion. Any of these conditions; gas, acids, and sub-micron dust, can degrade circuitry with or without power applied to the circuit. Refer to Section 9.1.3. See also Appendices E through I for more information.

IPC-650 TM 2.6.11.1, verifies the hydrolytic stability of an encapsulation by examining the potential of the encapsulation to turn into liquid or powder forms when exposed to high humidity at a specific temperature. Particular attention should be made to the tendency of urethane materials to revert to a semi-solid state.

4.12.14 Permeability Permeability refers to the ability of one material, such as water vapor, moisture, fumes, particles, etc., to flow through another, such as an encapsulation. All organic materials are permeable to some degree, depending on the chemical composition involved. Encapsulations such as epoxies may be more resistant to pollutant gasses, such as H2S, than silicones. Permeability is an important factor to be considered for the selection of encapsulation, especially if it is for applications in humid or corrosive environments. Permeability of an encapsulation may increase when the encapsulation is degraded by chemicals in the end-use environment. Moisture and gasses that permeate the encapsulation may accumulate on the conductive surface of assemblies, leading to leakage currents, dendritic growth, corrosion and delamination of encapsulations over the surface.

The polymer matrix for all encapsulation types is larger than the size of water molecule. Therefore, all encapsulations are water permeable. As a result, it is only a matter of when the water vapors get through, not if the vapors get through. However, with good adhesion and no voids, moisture protection can be achieved. In fact, low permeability of water may be disadvantageous since it will take a longer time for an assembly to dry up. When the polymer absorbs moisture, the dielectric properties can be affected. Thus, it is not recommended to submerge an encapsulated PCA in any liquid material for an extended period of time. If submersion is a requirement of the end use environment, a sealed enclosure should be considered and long term compatibility of the encapsulation with the liquid should be evaluated.

Variations in permeability may also occur with temperature changes. If the Glass Transition Temperature (Tg) of the encapsulation material is exceeded these variations are quite large.

The permeability of encapsulation can be tested using the following test methods:


4.12.15 Chemical Compatibility and Chemical Resistance Encapsulation may be exposed to various chemicals in their end use environment. Examples of chemical exposure include the common ones such as pollutant gas, fuel and cleaning media, to application specific chemicals such as body fluid and nuclear biological chemical warfare agents. When encapsulations are selected, the chemical compatibility of the encapsulations must be considered if contact with these agents is possible. Encapsulations are required to be resistant to these chemicals, i.e. not degraded by them, and to be able to protect the assemblies from any undesired effects of these chemicals. Bilateral chemical compatibility may be important in some applications. In these cases, it is important to ensure that the encapsulation materials would not pollute or degrade the end use environments or other products that they are in contact with.

4.12.16 Chemical Resistance In the end use applications where the coated assemblies have the possibility of coming into contact with fuel and/or machinery fluid, the compatibility of encapsulation materials with these substances should be verified by the end users. Petroleum based products, e.g. petrol, jet fuel, diesel fuel, etc, may act as organic solvents that may attack some encapsulation types. Hydraulic fluids and coolants may also contain chemicals that may degrade the quality of the encapsulation and thus, long-term reliability of the product.

4.12.17 Biological Compatibility For medical applications, there should be a bilateral long-term compatibility and non-reactive relationship between the encapsulation and body fluids (e.g. blood, urine) and tissues. It must not contaminate the substrate with outgassing or byproducts from its catalysts, solvents, or plasticizers that could be harmful to the patient.

4.12.18 Vapor Resistance For applications whereby the assemblies are exposed to gaseous environments, users need to consider gas resistance from two aspects. First is the permeability of encapsulation to these gases. The gases may not be harmful to the encapsulation, but may have negative effect on the conductive surface, e.g. gases which dissolve in moisture and react with surfaces, leading to electrical failure. Second is the chemical compatibility of the encapsulation to these gases.

4.12.19 Corrosion Resistance Moisture and ionic species may result in corrosion. Encapsulation may inhibit or delay penetration of moisture to the assembly surfaces, thereby increasing corrosion resistance. Corrosion resistance is thus heavily dependent on permeability of the encapsulation. Good adhesion, elimination of pin holes/voids, and appropriate thickness would minimize the
potential of corrosion.

The ionic species needed in mechanisms of corrosion may permeate onto conductive surfaces from environments outside the encapsulated assemblies. However, there may also be corrosive species on the assemblies (process residues including flux, uncured solder mask and handling contamination). Encapsulations can inhibit mobility of ions on the surface and hence enhance corrosion resistance. Proper cleaning and baking of the assembly prior to encapsulation is highly recommended to prevent this type of corrosion.

4.12.20 Fungus Resistance Most specifications require that an encapsulation not support fungus growth. Some encapsulation materials may contain fungus resistance chemicals. Also, fungus resistance of an encapsulation should be considered for biomedical applications and hardware that is exposed to environments that are conducive to fungus growth. Even though some encapsulation materials may be fungus static in nature, cleanliness of the coated assemblies should be maintained to avoid fungus growth on residues; for example, finger prints might encourage fungus growth. Fungus resistance may be tested using IPC-TM-650, 2.6.1.1.

4.12.21 UV Stability If the hardware will be exposed to ultraviolet radiation, such as outdoor use or space applications, the encapsulation should not be degraded or measurably altered by exposure to UV light. Some encapsulations have additives that absorb UV light before it can degrade the polymer structure. These additives are most often called UV inhibitors. Darkening, yellowing, or discoloration of the encapsulation after exposure to extended UV light is normal. The detrimental effect of UV exposure on the encapsulation would be demonstrated by embrittlement, cracking, crazing, etc.

Some encapsulations may be stable in outdoor use applications, but not vacuum stable, and thus not suitable for space applications. Other encapsulations may be unstable in outdoor use applications, but stable in the absence of oxygen and thus suitable for space applications. This signifies the importance of considering the entire environment in which the device will reside.

4.12.22 Radiation Resistance Material properties affected by radiation in space (nuclear particles and electromagnetic radiation) are mechanical (tensile strength, elasticity, elongation, hardness, etc.), thermal and optical properties.

Polymeric substances exhibit a wide variety of radiation effects that are irreversible. The radiation stability of a polymer is dependent upon the chemical structure of the material because radiation induced excitation is localized to specific chemical bond. Addition of energy absorbing aromatic rings to the chemical structure of the polymer greatly increases radiation stability of the polymer. In general, polymers containing aromatic rings (benzene) are more resistant than those not containing it.

Depending on the chemical type of encapsulation used, radiation can lead to chain scission or increased cross-linking, with chain scission being typified by a softening or tackiness to the encapsulation and cross-linking leading to a more rigid and brittle encapsulation. When the polymer backbone of an encapsulation is altered by these mechanisms, the physical and electrical properties can change, affecting hardware reliability. Radiation resistance needs to be considered for hardware that will encounter high-energy radiation, such as from nuclear reactors, x-ray equipment, all space-related hardware, medical sterilization etc.

4.12.23 Outgassing Some encapsulation materials contain plasticizer agents, especially elastomers, thermoplastics, and other flexible materials. Over the course of time, under certain conditions, the encapsulations may emit these agents, becoming more brittle in the process, as well as possibly contaminating nearby surfaces with the outgassing products. In addition to these agents, some encapsulations contain unreacted low molecular weight species that may also outgas under certain conditions. Some encapsulations outgas significantly, making them unsuitable for space applications. The vacuum of space tends to pull the agents out faster and causes outgassing. Outgassing species may cause problems where optical clarity is paramount in systems with lenses, mirrors and viewing ports. Outgassing resistance is also important where unsealed relays, switches or separable connectors are used. Outgassing products such as cyclics, low molecular weight species and fluorescent chemicals added to the encapsulation materials may form insulating deposit on electrical contacts, possibly causing electrical failure. Outgassing can also be a health concern in a closed environment such as onboard ship if the encapsulation materials contain materials that can form a toxic gas during outgassing, in particular if the item is exposed to a fire.

ASTM E-595 or NASA equivalent specifications may be used to screen materials for outgassing. To avoid outgassing, care should be taken to ensure complete cure has occurred.

5 Rework and Repair

Most encapsulated items cannot be easily repaired, and therefore, are considered “throw-away” items. However, some minor repair of imperfections on the surface of the encapsulation, or to fill visible voids is possible.

5.1 Removal Methods Complete and partial removal methods of the encapsulation from assemblies can be accomplished with techniques such as chemical solvent stripping, mechanical abrasion removal, micro-abrasive media removal, dry ice abrasion, thermal degradation, excimer laser and plasma stripping.
5.1.1 Chemical

The chemical removal techniques involve swelling the encapsulation with a solvent to chemically break down the encapsulation and to reduce the adhesion between the encapsulation and the board sufficiently to float the encapsulation. This technique is applicable to large areas or the entire board. One problem with partial encapsulation removal is the diffusion of liquid into areas other than the area to be removed. The compatibility of solvent should be verified with the assembly prior to use. Either dipping or spraying the solvent onto the encapsulation can be used to remove it. A supersonic spray cleaner may be used to remove the encapsulation in localized areas of the assembly. Use of chemical strippers should be limited because they can be corrosive and difficult to clean, especially if they get into non-hermetically sealed components.

AR encapsulation is the simplest to remove via solvent submersion. The solvent softens the encapsulation and allows removal by additional swabbing or light abrasion with a scraping tool being careful not to damage the substrate. Some encapsulation may be dissolved fully into the solvent solution and swabbing may not be necessary. After removal the area is neutralized via ample rinsing with deionized or distilled water and then heated in an oven 82°C to 93°C [180°F to 200°F] dependent on the substrate’s resistance to temperature). The heating is best performed in a vacuum oven 100 Torr [30 lbs gauge pressure or 1.934 PSI] for approximately one-hour to assist in pulling off any contaminants.

5.1.2 Mechanical Abrasion

This involves rotating disks, grinders and cutting tools. Caution needs to be exercised to prevent removal of substrate material below the encapsulation level and subsequent underlying structure damage. Mechanical methods also include surgical incisions, which are made directly on the solder joints. This method is usually used in conjunction with solder extraction of the solder fillet through the excised incision.

5.1.3 Media Blasting

Media blasting utilizes high velocity abrasive media directed through a nozzle to locally abrade the encapsulation. Media includes plastic pellets, glass beads and ground walnut shell particles. Most systems are designed to control electrostatic discharge from the rapid movement of the high velocity abrasive media.

Users are cautioned that significant ESD damage may occur to ESDS sensitive items in event the machine used does not have built-in ESD controls, or otherwise, in the event the controls fail or the humidity drops below 30%. It is recommended that the voltage generated at the nozzle dispensing the power be verified as within an acceptable range during each daily use of the machine.

5.1.4 Dry Ice Abrasion

Micro-sized carbon dioxide pellets are blasted at localized areas of encapsulation to be removed. With this technique the encapsulation would be removed by impact coupled to low temperature encapsulation embrittlement and fracture.

5.1.5 Thermal Degradation

Thermal degradation involves the use of a heat source to melt the encapsulation, for those encapsulating materials that can be removed by heating. Since high temperatures may be required for some encapsulating material care needs to be taken to prevent damage to components and the PCB.

Once heat is applied, the encapsulation can be softened and charred to facilitate in the removal of the required areas using a localized hot air jet or hot-knife at 300 – 400°C. The encapsulation can be chirped or flaked off the substrates with minor surface abrasion. After removing the encapsulation the substrate must be solvent cleaned with IPA and neutralized prior to re-encapsulation.

5.1.6 Laser

This is an elaborate method of laser ablation removal. The systems are expensive and are generally used for small-localized areas of encapsulation removal on microelectronic assemblies.

When electromagnetic radiation is absorbed by organic polymers, the polymer molecules become excited (heated). When the radiation beam has enough power to heat the polymer sufficiently to produce a vapor pressure then the polymer is volatilized. If the photon energy \( E = \hbar c/\lambda \) is sufficient to break chemical bonds, volatile compounds are produced. Thus laser radiation can remove encapsulation from assemblies by two mechanisms:

- Encapsulation melting and vaporization and
- Chemical photo-degradation of the encapsulation.

Adequate radiation exposure time is required to complete the encapsulation removal from the desired area by either mechanism. Less laser beam power is required for photo-degradation than for ablation. Ultraviolet lasers are required for photo-degradation whereas other lasers are used for melting and vaporization. By focusing the laser radiation beam, small encapsulation areas can be removed. Further upon sweeping the beam the entire encapsulation can be removed by either process. With either technique, care must be taken to ensure no damage to the PCB and its electronic components.

5.1.7 Plasma

This methods requires a vacuum system, an electromagnetic radiation source, and a gas supply. Either radio-frequency (103-109 Hz) or microwave frequency (109-1012 Hz) sources can be used. Plasma etching mechanisms are divided into four categories:

- Sputtering mechanism
- Chemical mechanism
- Ion enhanced energetic mechanism
- Ion enhanced inhibitor mechanism
In the sputtering mechanism ions mechanically eject encapsulation material at low pressure whereas thermalized neutral gaseous radicals react with encapsulation material to form volatile products in the chemical mechanism. The ion enhanced energetic mechanism is characterized by little or no intrinsic surface reaction with neutral radicals until energetic ions increase the reactivity of the encapsulation producing chemical reactions which form volatile molecules from the encapsulation. By depositing an inhibitor to exclude etchant in working areas, small localized areas can be etched by the ion energetic mechanism.

The plasma etching processes are characterized by rate, selectivity, uniformity and surface quality. The electromagnetic source variables are:
- Electric field to number density
- Product of number density and characteristic reactor length
- Generator frequency, number density product
- Reactor shape and aspect ratios. Gas pressure directly influences the etching mechanisms.

If this method is used, caution should be taken to avoid damage to the assembly, the PCB, and the components.

5.1.8 Combination Rework Methods In many cases, combinations of the above methods of removal would provide the most efficient and effective method of encapsulation removal. Each rework situation is different and consultation with the material supplier is needed to determine the most suitable method(s) of encapsulation removal for a particular encapsulation type or chemistry.

5.2 Cleaning after Stripping An encapsulation stripping operation most often involves exposure to solvents, which soften or dissolve organic polymers. If these materials are left on the substrate, which is also an organic polymer system, the stripping agent does not know where to stop. Often, these materials contain halides or other materials which can also attack metals, resulting in corrosion or metal migration on the assembly. Some of the solvents used are conductive and if not completely neutralized or remove, can result in short-circuits. Therefore, it is critical to completely remove these materials from the item being stripped.

The cleaning method used depends greatly on the assembly involved and its susceptibility to the cleaning agents or solvents, and on whether the stripping operation was global or removal from only a limited area.

The manufacturer of the stripping agents can provide information on the best way to neutralize or remove their chemical materials. In most cases, deionized water can be used as a primary rinsing agent to reduce the amount of the stripping agent, and most encapsulations are not affected by deionized water. It is recommended that swabbing the stripped area with isopropyl alcohol NOT be used. This only tends to re-distribute the detrimental materials, rather than remove them. However, deionized water combined with an IPA rinse may be needed in some cases to ensure complete removal of both polar and non-polar contamination. The critical endpoint of the cleaning is to get a substrate that is clean, dry, and ready for re-encapsulation.

Removal of Type UR encapsulation using certain chemical stripper gel or stripper solvents may leave conductive residues. It is recommended that the assembly be cleaned with a combination of polar and non-polar solvents under a pressure wash/rinse/dry cycle to ensure complete removal of any potentially harmful residues from the encapsulation stripping process.

If the board has been globally stripped, then rinsing and cleaning becomes easier. Rinsing with deionized water is recommended to knock most of the stripping agent from the board. If you have access to an ionic cleanliness tester, you can measure the amount of residual ionic contamination, as well as providing a mild cleaning action. If this option is used, check the assembly to make sure that it is not water or isopropanol intolerant.

5.3 Re-Encapsulation It is often necessary to remove a defective component(s), from a previously coated and cured assembly to facilitate repair.

Once the previous encapsulation has been removed and the defective device has been successfully removed and replaced, the site must be cleaned of residual solder fluxes and other contamination and of most importance if chemical removal methods were used. After cleaning, the assembly must be allowed to dry or dried by using hot air.

The degree of wetting and adhesion characteristics over the old encapsulation may vary with chemistry. In some cases an adhesion promoter or mechanical abrasion may be required to treat the new surfaces and the demarcation sites of the intact encapsulation. Once any adhesion promoter is applied and cured, or abrasion technique is completed, the rework site is ready for re-encapsulation. It is important that the same or compatible encapsulation chemistry be used for re-coat. The encapsulation material can be applied by a brush or syringe to the rework area and be allowed to slightly overlap the original encapsulation edges. For large re-coat sites, the methods used to originally encapsulate the assembly may be used. The encapsulation material is then cured, inspected and is ready for service. Users are urged to check with the material suppliers to confirm the recommended removal and rework techniques and any recommended adhesion promoters.

Caution – Normally, different types of encapsulation should not be intermixed on the same assembly unless the user has determined that they are compatible with each other. For example, repairing an assembly (e.g. replacement of a part that is encapsulated), that
originally had Type AR encapsulation applied, using Type UR encapsulation, may cause inadequate adhesion between the two different encapsulation types since the solvents in the Type UR encapsulation can react (i.e. dissolve) with the Type AR encapsulation and result in delamination between the coated areas.

5.4 Environmental, Health and Safety Rework and Repair Considerations Any rework and repair method brings health and safety concerns to the user. Common hazards associated with encapsulation rework and repair operations are inhalation of stripping and/or encapsulation chemicals and skin irritation caused by them, cut or score caused by the abrasion tools and media, and burns caused by the thermal parting tool. It is suggested that gloves and other appropriate protective gear should be used when reworking or repairing encapsulation on PCAs. Consult with in-house health and safety professionals, if available.

6 End Use Environment
End use environment is a vital consideration while selecting an encapsulation. How and where a product is going to be used determines what properties the encapsulation materials are required to possess. Any encapsulation should be thoroughly evaluated for end use environment compatibility. Encapsulation manufacturers may be contacted for specific data on considerations that are not listed in the material data sheet.

A few examples of end use environments for encapsulation are discussed below.

6.1 Outdoor Environment If a product is built for outdoor use and the assemblies are not hermetically sealed, encapsulation will be exposed to the following conditions.

6.1.1 Ultraviolet (UV) Radiation Ultraviolet is an electromagnetic ray with a frequency just outside the visible light spectrum. Ultraviolet radiation is found in sunlight. It is scattered by the atmosphere to a greater degree than is visible light. Hence, even if the encapsulation is not directly exposed under sunlight, it will still be susceptible to UV radiation. UV stability shall be a requirement for the selection of encapsulation to ensure it performs in an outdoor environment.

6.1.2 Humidity Products for outdoor application are subjected to various degrees of humidity. In temperate and warm climate zones, 30 to 60% of the time the relative humidity of the outdoor environment is higher than 80% when the atmospheric temperature is above 0°C. Depending on the degree of humidity exposure, hydrolytic stability and adequate level of permeability shall be the requirements for the selection of encapsulation. Corrosion resistance, which is a function of permeability, may also be required.

6.1.3 Pollutant Gases Atmospheric pollutant gases typically consist of oxides of nitrogen and sulfur (NOx and SOx) which are byproducts of the burning of fossil fuel. These pollutants generate numerous ionic and hygroscopic microscopic compounds that absorb moisture and react among each other and transform into corrosive vapor on the surface of the encapsulation. Resistance to pollutant gases and nitrogen and sulfur derivative acids shall be a requirement for the selection of encapsulation if air pollution is a concern in the end use environment.

6.1.4 Ozone Ozone (O3) is a very reactive gas. It has a short life expectancy when it comes into contact with other materials. It is capable of reacting with many forms of organics, including polymers and elastomers. Most polymers (e.g. encapsulation) have additives to prevent direct attacks from ozone. Check with the encapsulation manufacturer for ozone resistance if high reliability is expected from a coated assembly operating in an outdoor environment.

When moisture, organic compounds and other reactive gases are combined with ozone a wide variety of chemical reactions can occur. Some of them are capable of causing a break down in polymeric chains and or cross linkage.

6.1.5 Acid Rain Acid rain is a byproduct of combustion effluent and other VOCs (Volatile Organic Compounds) released into the air. A complex series of chemical reactions begin when these gases are combined with moisture and ultra-violet light. Ozone (O3), sulfates (SOx) and nitrates (NOx) are the primary acidic constituents of “acid rain” (pH < 5.0).

Because the amount of acid depends on exposure to sunlight (UV), moisture, and warm temperatures there is more acid generated in the summer then in the winter. The harder and longer the rainfall the less the amount of acid it contains as it is "washed" or "scavenged" from the air. Fog, drizzle, and mist may also be extremely acidic.

Resistance to corrosion, specifically resistance to nitrogen and sulfur derivative acids shall be a requirement for the selection of encapsulation if air pollution and acid rain is a concern in the end use environment.

6.1.6 Marine and Coastal Environment Populated coastal environments are capable of causing damage to electronic circuitry. Man-made pollutants combined with suspended sea salt and high humidity can create very conductive and acidic atmospheres. pH factors as low as 1.7 have been measured in fogs in southern California.

Suspended aerosols/particulates can be generally grouped into four categories; organic acids, marine substances, soot carbon, and
inorganic salt. All these particles could become nuclei to absorb moisture and to further combine and react with other particles.

Hydrolytic stability, low permeability, acid resistance and moderate level of abrasion resistance are requirements for the selection of encapsulation for applications in marine and coastal environments.

6.1.6.1 Salt water Salt spray, mist, and suspended crystals may disrupt unprotected circuitry and may corrode the metals in circuitry. The corrosive effects may be greatly reduced at a distance of 2 - 5 miles inland from the shore. The presence of microscopic amounts of salt may create intermittent operation depending on temperature and humidity. Humid environments provide the aqueous layers necessary for chemical attacks to the encapsulations and circuits.

6.1.6.2 Fresh water Fresh water has fewer suspended materials (including salt) than salt water. Again, because of the higher levels of humidity an aqueous layer may be present.

6.2 Automotive
Electronic devices intended for automotive applications are exposed to severe service environments. They are exposed to wide temperature extremes, many types of fluids, and random vibrations. Automotive application environments are generally classified by temperature. Table 6-1 indicates the temperature classifications generally recognized by the automotive industry, and the intended application. The lower temperature limit of these applications is -40°C

<table>
<thead>
<tr>
<th>Industry Class</th>
<th>Application Description</th>
<th>Upper Temperature Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Passenger Compartment</td>
<td>85°C</td>
</tr>
<tr>
<td></td>
<td>Door Interior Headliner</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Trunk Interior</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>Engine Compartment</td>
<td>105°C</td>
</tr>
<tr>
<td></td>
<td>(Non-engine, -transmission Mounted)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chassis-mounted (Not Exposed to Heat Source) Areas Exposed to Direct Sunlight (Dashboard, Rear Deck, etc.)</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>Engine compartment</td>
<td>125°C</td>
</tr>
<tr>
<td></td>
<td>(Engine-mounted, Away from Exhaust Manifold)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Firewall-mounted (Not exposed to catalytic converter)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chassis-mounted (Exposed to Heat source)</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>Engine Compartment</td>
<td>150°C</td>
</tr>
<tr>
<td></td>
<td>(Engine-mounted, Near Exhaust Manifold)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Firewall-mounted (Exposed to Catalytic Converter)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transmission- / Differential- mounted</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Internal to Bell Housing</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>Brake System</td>
<td>175°C</td>
</tr>
<tr>
<td></td>
<td>(Exposure to Oil/Hydraulic</td>
<td></td>
</tr>
</tbody>
</table>
Besides the requirements of various thermal properties, including flammability, according to the temperature classification, resistance to fuel and engine fluids is a general requirement for all automotive applications. Abrasion resistance is required for assemblies in the vicinity of moving parts and in the engine compartment; flexibility may be required in some applications. For applications exposed to open air, UV stability, hydrolytic stability and low moisture permeability is required.

6.3 Avionics Environment Typical requirements for the encapsulation used in an avionics environment include: resistance to fuel and engine fluids, low flammability and permeability, and good thermal and hydrolytic stability. Specific requirements may include abrasion resistance and non-outgassing, depending on the applications. There are several avionics environmental distinctions, which must be treated separately.

6.3.1 Aircraft on the ground Ambient ramp air temperatures may range from -50°F to +172°F. Any moisture that collects on the surface will be contaminated by existing air pollutants plus materials that have deposited on the surface of the PCA. Cleaning and servicing of the aircraft will generate numerous pollutants from fumes, spills and leaks. Some of these sources are cleaning solutions, fuel vapors, hydraulic fluids, anti-corrosion sprays, solvents, paint fumes, and paint stripper fumes.

6.3.2 Equipment Outside the Pressure Containment Compartment During Operations The following changes will occur in a matter of minutes during the operation of this equipment:
- Temperature changes form +175°F at ground level to -59°F at altitude
- High humidity at ground level to very low/freezing conditions at altitude
- 14 psi at ground level to 1 psi at altitude.

Condensation may form under these conditions, especially on descent because the equipment has been 'cold soaked' at operating altitudes. Frequent transition of temperature and pressure can affect the driving forces of penetration and vapor absorption of contaminants.

6.3.3 Equipment Inside the Pressure Containment Compartment During Operations During the hot summer months sudden temperature changes (20°C or more per second) may occur when the aircraft air conditioning system is turned on. Exposure to blowing condensation will occur when this cold air encounters the warm moist ambient air. During cold weather operations the reverse actions may occur except the condensation may form on the assemblies, depending on the humidity of the warm air. Pressure changes may occur from 14 psi to approximately 7 psi.

Airborne particles will gradually build up on the surface of assemblies. Any condensation, spills or leaks may be potential threats to assemblies.

6.4 Space Environment Radiation in space comes from multiple sources – geomagnetically trapped corpuscular radiation of the Van Allen belts, auroral radiation, cosmic radiation, and solar flares. Most radiation experiments are performed under ambient atmosphere conditions but it is believed that effects of radiation (Section 10.15) in vacuum are not as severe as in air due to the lack of oxygen and its role in polymer degradation.

Besides radiation resistance, the encapsulation selected for space environment shall not outgas in a vacuum environment. Specific requirements of the encapsulation are dependent on the application of the assemblies; high reliability is generally expected.

6.5 Medical Environment In a medical environment, encapsulation may be in contact with body fluids, radiation and sterilization media at various temperature ranges. Extremely tight isolation and dimensional tolerances may be required for some medical devices. A special category of medical applications is devices that are implanted in the body cavity that are in long term, intimate contact with body fluids and tissues, which require bilateral compatibility of the encapsulation.

6.6 Geothermal Environment The geothermal exploration industry requires protection of electronic devices in the presence of a “down hole” environment. This environment may include high temperature (220°C), high humidity (RH 100%), salt water, crude oil, natural gas, sulfur compounds, caustic high pH solutions, etc.

The encapsulation selected for geothermal applications shall be resistant to hydrocarbon, acid and alkaline, less permeable to gas and liquid, thermally stable over a wide range of temperature, and dependent on the product, resistant to abrasion.
7.1 Failure Mechanism Failures of assemblies can be attributed to physical failures or defects of the encapsulation during continuous operation and in its intended usage environment. High modulus encapsulating materials are known to cause cracking in the glass component bodies. Failures of encapsulation could be the result of inappropriate selection of encapsulation for its intended functions and operating conditions, or improper processing of the encapsulation. If the application and curing procedures were not performed correctly, there may be incomplete development of desired film properties. Even if they may not result in observable faults during inspection, these factors may compromise the long term reliability of the assemblies.

On the other hand, failures of encapsulation could also be indications of contamination and defects on the solder mask or substrate. The failure mechanisms of the encapsulation and the conditions of the whole assembly need to be evaluated during failure analysis.

7.1.1 Wear/Abrasion Improper handling, storage or shipping can cause unnecessary contact with coated surfaces. This can result in scratches, scrapes, dents, creases and marred surfaces that can become areas of concentrated stress or contamination ingress. Breakdown of the encapsulation may be an indication of a design flaw. Design consideration must be given to prevent contact of the encapsulation with other objects in the unit, such as wiring, cases, attaching hardware, or any moveable objects. Internal forced air-cooling can create problems if the airflow is not controlled to prevent venturi type situations. In these cases, an area of high velocity air can rapidly erode encapsulations due to dust particles.

7.1.2 Loss of Transparency/Discoloration Loss of transparency and/or discoloration can be caused by excessive exposure to dust or airborne particulates on inherent surface tack, UV light, high temperature, and/or exposure to sulfur or other chemical agents. In some cases, opaque (pigmented) encapsulations may be desired for security purposes.

7.1.3 Cracking Cracks in encapsulations have several different sources. The presence of cracks can limit the useful life of encapsulations. Because they allow contaminates to penetrate the encapsulation and represent a breach of encapsulation integrity, the location, length, and depth of the cracks must be evaluated. It should be noted that most encapsulations are true thermal plastics and as such, cracks that form due to cold temperatures will "disappear" as the temperature increases. Even though the cracks are no longer visible, the polymeric links have been broken and contaminates may have penetrated the encapsulation.

7.1.4 Loss of Adhesion Several factors affect the ability of an encapsulation to adhere to an assembly. These factors include, but are not limited to, cleanliness, compatibility between the encapsulation and other interface material, permeability to moisture, and degree of cure. When moisture permeates into the area between the encapsulation and the substrate, a difference in vapor pressure occurs. Changes in temperature and pressure will then build up the osmotic pressures and force the encapsulation away from the surface. This form of delamination will be most noticeable where the encapsulation covers metals because acids may form when there is contamination on the metal surfaces.

Adhesion properties are important to the final product appearance and function. An encapsulation that does not adhere completely to the assembly does not protect that assembly. Improper adhesion can lead to blistering, peeling, cracking, mealing, and pop-corning of the encapsulation, especially during thermal and humidity cycling conditions. The risk for adhesion failure is enhanced by the inelasticity of the encapsulation when exposed to mechanical tension.

The adhesion requirement is defined by the agreement between the encapsulation manufacturer, applicator and the end user. The end user and applicator should determine what level of adhesion produces a functional assembly and what test(s), if any, shall be used to determine that sufficient adhesion has been achieved and maintained through environmental conditioning. Adhesion of encapsulation
can be tested using ASTM 3359 Method B. This test may not be applicable to certain encapsulation types.

7.1.5 Bubbles The presence of bubbles in an encapsulation is a factor of air entrapment, outgassing, mixing and/or application methods. In many cases, this phenomenon cannot be overcome. Bubbles are generally acceptable when their size is less than 50% of the distance between conductors at the location and they do not expose conductor, bridge of lands or adjacent conductor surfaces.

7.1.6 Blistering Blistering is generally a precursor to delamination with one slight difference. It can occur in the encapsulation as well as at the surface encapsulation interface. When blistering occurs in the encapsulation this usually results in a hole or divot in the encapsulation. In any event blistering is a serious problem and must be corrected immediately. Blistering is the result of the same situations which cause delamination and must be addressed in the same manner.

7.1.7 Charring Charring usually occurs due to overheating although it can also result from a severe chemical reaction. Reworking, using solder, excessive exposure to UV light, corona discharge, combustion and component overheating are main causes of this problem. Because many forms of contaminants, including carbon, are captured in the encapsulation material and the polymeric links have been damaged, the charred encapsulation must be replaced.

7.1.8 Degradation Degradation is primarily an aging problem due to the types of environmental conditions encountered by encapsulation materials. It is a combination of temperature, moisture, chemicals, abrasion and vibration. Encapsulations will only withstand a certain amount of abuse from the environment before noticeable effects to circuitry operation begin to occur. The nature and amount of harsh conditions each type of encapsulation can handle is variable. The resulting effects to the circuitry will also vary.

7.1.9 Chemical Attack Incompatibility with chemicals in the operating or end use environment may damage the integrity of the encapsulation. Some chemicals react violently with encapsulation, causing immediate failure of the encapsulations, either damaging the assembly at the same time, or leaving the assembly unprotected from other potential threats. Other chemicals may permeate encapsulations and gradually alter the matrix of the polymers, leaving the encapsulations at a weakened state, prone to thermal or mechanical failures.

7.2 Accelerated Testing In general, the long term reliability cannot be determined in “real-time” conditions. Evaluating long term reliability is usually accomplished by a combination of accelerated environmental test conditions and large number of endurance cycles after which the encapsulation is physically examined using a number of various analytical diagnostic techniques. The encapsulation integrity would be evaluated by conducting visual or microscopic examinations as well as electrical measurements before, during and/or after exposure to assess percent change. Once electrical failure is identified, it may be correlated to some type of physical evidence that indicates the encapsulation integrity or adhesion has been impacted. This practice is sometimes referred to as accelerated environmental testing. The data generated by using these types of procedures is generally empirical and specific to the performance of the particular encapsulation and the type of assembly being evaluated.

Accelerated life cycle testing, based on expected end use environments, performed on prototype boards and production samples, are capable of demonstrating long term reliability. Reliability testing can help to determine the probability of failure in the field, but not the absolute lifetime of the products.

7.2.1 Test Parameters Unfortunately there are several difficulties with establishing parameters for accelerated testing. Often times, acceleration factors between a set of stress conditions (e.g. temperature cycling from 0 to 100) and mean time between failure (MTBF) are difficult to obtain with precision. Many statistical tools and models are available in order to aid the user in correlating failure in a test chamber to probability of failure in the field.

The complex synergistic reactions that occur in the field are difficult to duplicate in a test chamber. Therefore the best methodology is to employ a set of test conditions that best emulate the end use environment. For example, the accelerated aging test plan for an assembly that is employed under the hood of a car should include a high temperature condition (as part of a thermal cycle or as a high-temperature soak) as well as vibration. Whereas a consumer electronic product that sits in an office environment does not need to see high temperature conditions or vibration as part of its reliability test plan.

7.2.2 Examples of Tests A number of different tests are available to measure the reliability of an encapsulated assembly. Not every assembly needs to be tested using every condition. A suggested list of test conditions is provided below.

- Temperature and humidity test
- Thermal cycling
- Thermal shock (liquid to liquid, air to air)
- Highly accelerated stress test (HAST)
- Highly accelerated life test (HALT)
- Vibration
- Salt Fog Endurance
- High temperature operating life (HTOL)
- Moisture and insulation resistance
Dielectric Withstanding Voltage

Flexibility

Chemical Resistance

Several standards are available that can guide the user in determining a set of test conditions and parameters (e.g. JEDEC, IPC, ASTM, etc.).

7.3 Bibliography


8 Equipment Considerations

8.1 Mixing The two most common methods of mixing two component formulations are static and dynamic mixing. Static mixing is satisfactory for most materials. Dynamic mixing or spinning element mixing is used on formulations that require more shear than is available through static mixing.

8.1.1 Static Mix Sometimes referred to as “in-line mixers”, a disposable device composed of alternating spiral mixing elements inserted inside a plastic tube. Static mixers are also available in metal but are not as common in potting applications. The spiraling alternating elements within the tube creates a mixing action between the fluids as they pass between these elements, resulting in properly mixed material at the exit of the tube. Higher system fluid pressures are required to force the material through the mix tube than with dynamic mixers.

8.1.2 Dynamic Mixing Dynamic mixers fall into two categories, Spinning Element Mixers and Pin Mixers. These mixers are used with formulations that require additional shear or cannot be satisfactorily blended using static mixing.

8.1.3 Spinning Mixers Spinning element mixers are similar in design to static mixers with the exception that the element is spun within the housing using either a pneumatic or electric drive motor. The mixing chamber is typically a disposable item.

8.1.4 Pin Mixers Pin mixers are constructed of a metal shaft through which a series of metal pins are pressed at right angles to the axis of the shaft. The mixing chamber is also metal. These mixers provide higher shear than spinning element mixers. Since Pin Mixers are not disposable, they need to be flushed periodically using either a solvent or the non-reactive component of the formulation.

8.2 Dispensing

8.2.1 Highly Filled Materials Some filled materials have a tendency to settle out of suspension and need to be agitated before use. The degree or rate of settling is dependent on the type of filler and the viscosity of material in which it is suspended. The formulator can advise on the settling rate over time and whether agitation is required. Slow speed less than 200 rpm is typical to avoid whipping and the introduction of air. Package size and storage position can also have an impact on highly filled materials and the degree of filler settle-out.

8.2.2 Abrasivity of Fillers The degree of abrasivity of a filler material can impact the long term performance of meter/mix equipment, and can result in more frequent preventive maintenance schedules. Fillers are rated for hardness using the Moh’s scale which ranges from 1 to 10 with 1 being soft (i.e. talc) and 10 being hard (i.e. diamond). Particle (mesh) size also influences material characteristics.
8.3.3 Filler Selection Selection of a filler as it relates to equipment considerations. Fillers are used to extend the volume of a compound, reduce cost or modify thermal, physical and electrical properties and to modify thixotropy. If a less abrasive type will provide the necessary properties, the impact on long term maintenance costs can be positively affected. See figure 8-2.

8.3.4 Maintenance Considerations As noted above, highly filled abrasive formulations can require more frequent PM schedules. If using a highly filled product, consideration should be given to inventorying of high wear components so as to reduce unnecessary downtime. In most cases, wetted seals will constitute the most frequent preventive maintenance item. Machine vendors typically provide a spare parts list that includes these items, as well as any other recommended inventory components.

8.3.5 Polyurethanes Containing Isocyanates Isocyanates react with moisture which can result in the formation of abrasive precipitate, typically first seen on exposed surfaces (i.e. cylinder rods, pump shafts, tank inner walls, etc.). Care should be taken to keep exposed surfaces clean and lubricated to prevent buildup of isocyanate deposits. Bulk supply containers should be blanketed with dry nitrogen and should use a desiccant to dry incoming air.
8.3.6 Displacement System Size Larger displacement metering systems provide longer life cycles when compared to smaller systems at the same usage rates (reduced friction over a given volume).

9 Design Considerations in P&E

9.1 Intended Function in the End Use Environment It is critical to understand what the end-use environment and life expectancy of an electronic device will be. If materials are chosen that cannot withstand the temperatures, moisture levels, shock and vibration associated with its working environment, then the device will not perform as intended.

9.2 Residual Stress Effects on Components As P&E compounds react, they may expand or contract during the cure process. The residual stresses formed during shrinkage or expansion can damage fragile components, such as glass bodied diodes, or may alter the functionality of a component by inducing stress on the package, such as oscillators. Some components, such as very low level wire wound inductors, are constructed from very fine wires, which can be destroyed by material movement during cure.

9.3 Sleeving Sleeving is generally done to protect a sensitive device or component from CTE mismatch. It involves the use of a tube, pad or interposer to take up the differences in stress associated with operating temperatures or vibration. Glass diodes for instance can easily crack unless a stress relieving device of some type is surrounding the component.

9.4 LEDs Light emitting diodes are designed to be seen in most applications. Placing potting materials over the LED lens can prevent the transmission of light. If using potting materials for protection purposes, the optical clarity and refraction properties of the material need to be considered. In the case of surface mount or die mounted LEDs, many optical grade potting materials are used as part of the LED device “package” in the manufacture of the component. In these cases, the refractive index is well matched to the application when used to create the lens or component body.

9.5 Inappropriate Uses of P&E Materials The most common inappropriate use of potting materials is to provide mechanical support. Potting materials should never be used as a substitute for hardware or as an adhesive.

9.6 Part Geometries The geometry of an electronic device needs to be considered when choosing a potting material. Component stand-off height, density and the use of stacked PCA’s will dictate the most reliable viscosity material that needs to be used. If the viscosity is too high, it will not flow under and around components thus creating entrapped air and voids that could eventually trap water vapor. Using a viscosity that is too low can cause the potting material to migrate or wick into unwanted areas such as potentiometers, unsealed relays and connector housings creating problems with insertion force mating and electrical contact.

10 Enclosure Considerations

10.1 Component Density Component density or how “stuffed” an enclosure is can cause considerations for the potting material’s ability to flow and eliminate voids. Careful choice of the potting viscosity needs to be considered depending on the level of density within the enclosure.

10.2 Clearances Clearances within an enclosure, if too tight, can cause air entrapment of the potting material. This can lead to voids and spaces that water vapor could eventually migrate into, causing electrical shorts or other problems. When applicable, consideration should be given to the appropriate clearance for the required insulation resistance and thermal ratings of the potting material. See figure 10-1.
10.3 Vent Holes Vent holes are common to many enclosures so they can allow heat to dissipate from heat generating components, allow water to drain and to maintain a well-ventilated enclosure depending on the end-use environment. If a vent hole is designed into an enclosure, there is generally a reason for it. The user is encouraged to determine if potting over a vent hole should be done. In some applications, the liquid potting material can drain out of the vent hole creating a mess on the exterior of the enclosure which will require some level of rework. Vent holes can also create problems for encapsulant applications which employ vacuum degassing of the liquid potting material as it will be sucked out through the holes under vacuum.

10.4 Surface Texture / Surface Energy of Enclosures / Substrates Surface energy or texture of the interior aspect of an enclosure can either enhance or jeopardize the adhesion integrity of the potting material. A loss of adhesion to the interior walls of an enclosure can cause a separation of the potting material and create a space for moisture and water vapor to collect. Mechanical abrasion, plasma treatments, or the use of a primer will reduce that effect.

11 Preparation for P&E

11.1 Material Storage Vendor instructions from their published technical data sheet should be followed to ensure proper product performance. In almost all cases the vendors recommended storage guidelines can also be found on the package label. Basic guidelines will include a storage temperature range to be maintained and a general environment statement such as “store in a cool and dry area” followed by any specific concerns such as “avoid direct sun light” or something else specific to that product’s chemical make-up. Some of these products can have special storage requirements. These should be considered, such as for refrigeration or specific fire containment.

11.2 Substrate Preparation The preparation of the assembly prior to encapsulation is very critical to good wetting, adhesion and subsequent reliability of the assembly. The level and type of soldering residues, handling residues, ionic residues and component mold release agents all play key roles in the success achieved with any encapsulation and/or encapsulation process. The solder mask also has a great impact on how well the adhesion performance of a particular encapsulation material will be.

With the advent of many low residue flux chemistries, (also known as no-clean), cleaning the assembly prior to encapsulation is not normally performed, but sometimes is still necessary. The level of visible and non-visible residues will vary on the type of assembly, physical mass of the components and the solder excursion profile. Base line ionic and corrosive species measurement and periodic confirmation are still recommended and should be within the IPC prescribed limits. Most low residue fluxes may turn “white” after solvent extraction testing for NaCl, as a result of the alcohol in the test solution drying and developing the clear/invisible residues into a white powder. This is an aesthetics issue leading many assemblers not to test at all. The adhesion of encapsulation to these residues is generally very good with all encapsulation. But, how well the residues are adhered to the solder joints should be considered, to reduce the potential for delamination of the cured encapsulation material to the solder joint areas during the life cycle of the assembly.

Water-soluble flux processes require water washing and are generally good candidates for encapsulation because the assemblies are cleaned of many process residues. The critical factor to consider with this type of process is that the assemblies are completely dry, prior to encapsulation.

Vapor degreasing techniques prior to encapsulation operations have been outlawed in many countries due to environmental concerns. The cleanliness of the assembly must still be monitored to insure performance and reliability of the encapsulation materials used. Compatibility of the encapsulation with these process residues should be checked.

11.3 Surface Residues and Impact on P&E

11.3.1 Residual Fluxes Residual solder fluxes (Figure 11-1) can create a variety of issues with any protection chemistry such as conformal coating or P&E. Not only do they make it difficult to obtain adequate adhesion, they can also leave behind corrosive and ionic species. These species can contribute to ECM and pre-mature corrosion with or without the use of protection chemistry. Most potting materials will retard the growth of corrosion but will not prevent it from occurring eventually. Baseline cleanliness level prior to encapsulation or coating should always be determined to insure the user is not “covering over” or burying a potential corrosion cell, which will inevitably lead to circuit failure or intermittent shorts of the PCA.
11.3.2 Adhesives Adhesive residues depending on the adhesive chemistry can typically lead to P&E inhibition or a poisoning of the potting material’s cure mechanism. Simple compatibility checks should be performed so there is no evidence of local or gross inhibition between the adhesive and the potting material. A quick check can be performed by placing the potting material in contact with the adhesive. The evidence of any anomalies may indicate incompatibility.

11.3.3 Primers Primers are typically used to improve and enhance the adhesion of a potting material to a difficult to bond to substrate. Unless they are applied too thick or “over-dosed” they do not pose many issues to the encapsulation process, providing they are cured correctly before the potting material is introduced. In some cases, too much primer can actually create a release agent, thus defeating the purpose of using a primer in the first place. The primer application should be performed per the manufacturer’s recommendations.

To obtain optimal adhesion performance of a silicone encapsulation, a priming step may be required. Optimal adhesion is normally obtained when only a very thin, uniform coat of primer is applied.

Three steps should be considered if priming is required:
1. Preparing the surface - to provide a clean, dry and in some cases reactive surface
2. Applying the primer - to provide a very thin and uniform surface encapsulation
3. Curing the primer - to provide the ideal bonding surface for the silicone

Optimal adhesion is obtained only when the maximum surface area and surface reactivity are made available at the time of primer application. Organic and water-soluble contaminants and loose particulates can reduce the effective surface area available for bonding. Good adhesion can only be obtained when the substrate surface is strong enough to hold a bond.

The primer must evenly coat all available surface area to achieve optimal adhesion. Some surfaces may cause a primer to bead up. Poor surface wet-out like this will result in only spotty/localized adhesion. If the primer beads up when applied, solvents or other additives can be added to the primer to improve wet out. Consult the primer supplier for selection of such additives.

There is a common misconception that can cause considerable problems in the application of a primer; in nearly all cases “more” is definitely not better. Less is best. The best primer performance may be obtained with a cured primer thickness of 0.1 to 10 microns, with optimal adhesion at about 1 micron coverage. Often, this thin application can be best accomplished by wiping the primer on and then immediately wiping it right back off. When applying a primer by dipping or spraying, dilution may be recommended to decrease the primer encapsulation thickness. Over application of most primers will be evidenced not only by poor adhesion, but also by white chalkiness or flakiness on the cured primed surface. Loose material should be brushed off; however, decreased adhesion performance may still be expected.

Maximum adhesion performance is directly related to the extent of the cure of the reactive species in the primer. Primers containing silane-coupling agents begin to react with atmospheric moisture as the solvent carrier evaporates. Ideal adhesion will be obtained during a “window” of extent of primer cure that will be unique to a particular adhesion system, i.e., a given surface, primer and silicone encapsulation. For a given primer, the choice of silicone to be used with it usually has a greater influence on the optimal
extent-of-cure window than does the choice of the surface material. The extent of primer cure is controlled by three main cure conditions: temperature, relative humidity, and time. In most applications, the temperature at which the primer is cured either does not vary severely, or cannot be controlled, as is most often the case with relative humidity. The amount of time that a primer is allowed to cure, however, can usually be more carefully monitored. It is recommended that an evaluation of the effects of cure times on adhesion be carried out to maximize adhesion performance. This can be achieved by allowing the primer to cure at average or normal application conditions for 15, 30, 60, 120, and 240 minutes, and then continuing through the remainder of the normal bonding procedure. Alternatively, primers can be cured for 15 minutes at 72°F, 100°F, 125°F, and 150°F, if the normal primer cure is carried out at the elevated temperatures. Oven atmospheres can often be quite dry. This will slow the cure rate down unless precautions are taken to maintain an adequate relative humidity. To increase the relative humidity in the primer curing area, suggestions include commercial humidifiers, open pans of water (large surface area of water) in the oven, and water misters. It should be noted that water condensed directly onto surfaces to be primed will degrade performance if not removed prior to the primer application.

The optimal cure time established by the above oven curing procedure will be influenced by changes in temperature and humidity. Two general “rules of thumb” are:
1. Cure may be reduced by 50% per every 20°F increase in cure temperature given equal relative humidities (actually 18°F or 10°C = doubling of most reaction rates)
2. Cure times should be approximately doubled per every halving of the relative humidity

There are no sure predictive means to distinguish between adhesion systems that are or are not sensitive to these conditions. Therefore, it is recommended the user determine the primer cure times at conditions that approximate the average and the extremes of the temperature and relative humidity that might be in a given application.

11.3.4 Priming for Acrylics No primer is known to be needed for this encapsulation type.

11.3.5 Priming for Urethane No primer is known to be needed for this encapsulation type.

11.3.6 Priming for Polysulfide For small areas no primer is required. For bonding to Silicones, Fluorosilicones or to achieve a structural bond an adhesion promoter or primer is required.

11.3.7 Plasma Treatment Plasma treatment is the process of placing an assembly in a vacuum chamber and using gaseous plasma to micro-etch away all exposed surfaces. Various gases are used to achieve different etch rates. This process is used as a cleaning and/or surface roughing operation. Because of the process, some areas of the assembly must be masked to prevent unwanted removal and discoloration. Selective plasma treatment may also be used. This process may not be suitable for all applications.

11.3.8 Mechanical Etching Mechanical etching is the process of bombarding an assembly with hard items (e.g. sand or ceramic pieces) to roughen up surfaces. Because of the nature of the process, some areas of the assembly must be masked to prevent damage. This process may not be suitable for all applications. This process is also known as Micro-Abrasive Etching/Removal. Users are cautioned that significant ESD damage may occur to ESDS sensitive items in event the machine used does not have built-in ESD controls, or otherwise, in the event the controls fail or the humidity drops below 30%. It is recommended that the voltage generated at the nozzle dispensing the power be verified as within an acceptable range during each daily use of the machine.

11.4 Masking Masking is the process of temporarily covering and protecting various interconnecting devices from the encapsulation process. These devices can include connectors, adjustable components (such as potentiometers and DIP switches), LED indicators, test points, open relays, mating hardware, and threaded receptacles. The materials used for masking can vary and include: caps, plugs, tapes, latex, and many other removable media. The masking materials should adequately prevent the liquid potting materials from penetrating the intended areas, should be non-corrosive in nature, and should not cause any deleterious effects to the surrounding structures. Once the encapsulation process has been completed and the potting material has solidified, the masking media and any residues need to be removed in their entirety.

11.4.1 Types of Masks In certain instances, masking of assembly or component areas may be required to ensure that the encapsulating compound does not adhere to areas which its presence can create a problem, such as mechanical interface surfaces, electrical contacts, etc. Masks can include plastic boots or covers, a peel-able mask, or masking tape to name a few. Most masks are introduced manually by an operator, although liquid masks can be applied automatically with a dispensing robot. Maskants may leave some form of residue. It is important to evaluate whether this residue can be harmful to your process before implementation.

Be aware that the rear of connectors and via holes can leak encapsulation through.

Encapsulants are designed to ingress under components and so will find their way into a break in your masking. Often using tape and liquid masks together can be the best way to seal areas against dip encapsulation. Create a box with the tape, then seal with the liquid
Caution should be used when using liquid masks. Liquid masks can flow into vias or other holes. Liquid masks are commonly used but must be allowed to dry completely before application of the encapsulation material. Users are cautioned that liquid masking materials that subsequently harden to a rubber-like consistency may cause problems in event they are not completely removed from electrical contacts in connectors, sockets and other similar electrical interface areas. Compatibility should always be verified between the masking material and the encapsulation material.

11.4.1.1 Natural Latex Liquid Masks These masks are a solution of natural latex rubber in water, stabilized by an alkaline component (often ammonia). It is important to make sure that the mask is applied thin enough so that it does not remain liquid on the board for an excessive period of time, as the alkalinity can be damaging in this situation to certain substrates (e.g. Copper). Generally a thickness of less than 2-3 mm is OK.

The alkaline component of the mask can also inhibit the cure of certain catalytic encapsulation products so validation of your mask with the encapsulation material is essential. Heating of the mask can speed up the cure, but avoid heating above 70-80°C as this can begin to degrade the latex resulting in an effect similar to “chewing gum”. This can make the product very hard to de-mask.

11.4.1.2 Synthetic Latex Liquid Masks These masks are a solution of a synthetic polymer in water. They are often used when natural based masks have been shown to inhibit cure of the encapsulation used. Generally, the self-bond strength and ease of use is not comparable to natural products, but they are not necessarily as alkaline and can be lower in odor. Again, heating can speed up the cure, although excessive heat too early can cause bubbles in the mask.

11.4.1.3 Other Liquid Masks There are a variety of other masks available such as heat cure and water-soluble masks. It is not recommended to use a water-soluble mask for encapsulation masking, as they are really more suitable for the soldering process. The heat cure masks can be advantageous in terms of process time. UV curable removable acrylics can also be dispensed and cured as a mask.

11.4.1.4 Tape Masks The tape selected for masking should be non-porous to the encapsulation material and should not produce excessive static when used. Use of static adhesion tapes is not recommended when ESD sensitive components are present. Ideally, use a tape that shows a color or contrast change on contact with the substrate, this allows the detection of breaks in the masking before the board is coated.

11.4.1.5 Boots, Caps, Plugs, etc. Pre-molded boots and polyvinyl caps are commonly used. An advantage of boots, caps and plugs is their ability to be reused.

11.4.2 Manual vs. Automated Masking Manual masking methods typically allow the user to utilize whatever is necessary to protect an interconnect or “keep out” area of the assembly from encapsulation. They include, but are not limited to: molded boots, tapes, caps, plugs, tape dots, latex, UV curable removable acrylics and just about anything else that will do the job effectively.

The critical concerns are preventing leakage and easily removing them after the encapsulation has been applied and cured. All the masking media used must be removed in its entirety and should not cause any deleterious effects to the assembly. Traditional manual methods of masking and de-masking include off-line, batch-type activities done by manual methods. These are typically very labor intensive operations depending on the design layout and complexity of a particular board design. Masking and de-masking operations can sometimes cost more than the encapsulation process itself. Automated masking can include pressure/time dispensers or elaborate XYZ platforms to selectively apply the protective media to the site. Once applied, the masking media must be cured. Most require heat, ambient air or UV curing mechanisms.

11.5 Preheats Preheating a substrate prior to encapsulation can drive out many types of volatile species. However, an oven profile which is too hot or too long can also cause many process residues to outgas or be driven out of the PCB substrate and component bodies, creating more trouble than when the user started. Proper oven profiling should be performed to determine the proper heat and duration, given the mass of the part. Preheating a part prior to encapsulation can also help with the flow characteristics of the potting material. The viscosity of the potting material will temporarily be reduced as it comes into contact with the hot parts. In some applications, the potting material itself is preheated. This not only temporarily reduces the viscosity and improves flow, but can also provide a head start for the cure mechanism, depending on the potting chemistry being used. Any preheating of the liquid potting material will reduce pot life.

11.6 Molds and Containers

11.6.1 Waxes Waxes are used as a temporary housing when a part is being cast.

11.6.2 Porous Containers Sometime used as a mold to allow ambient moisture and oxygen to permeate through the material, such as paper mache or other porous, chemically permeable materials.
11.6.3 Mold Release Agents Typically used to facilitate the removal of the part from the mold without affecting the chemistry.

11.6.3.1 On the Mold Material that is applied to the interior aspect of the mold.

11.6.3.2 On the Components In the component fabrication process, release agent residues used to facilitate removal of the component from the mold can cause a variety of problems once attached to the printed circuit board.

11.7 Mixing and Preparing Materials

11.7.1 Hand mixing (Cups) Cup holding materials which are mixed before application. See figure 11-2.

![Figure 11-2 Mix cup with 2-part, unmixed epoxy](image)

11.7.1.1 Craft Sticks Wooden craft sticks or tongue depressors are suitable for non-critical mixing of many potting materials by hand. They should be selected with consideration for the type and amount of material being mixed. They are inexpensive and can easily be disposed of after mixing. Caution should be exercised when using wood products, i.e., splinters, moisture, etc.

11.7.1.2 Metal Spatulas These are preferred for mixing higher viscosity or larger volumes of material by hand because of their durability. They are sturdy and can be re-used after cleaning. They are strongly preferred over wooden sticks for mixing polyurethanes or any moisture sensitive material, which can absorb moisture from the wood. See Figure 11-3 & 11-4.

![Figure 11-3 Mixing Spatulas](image)
11.7.1.3 **Hand Mixing (Static Mixing Tubes / Bi-packs)** Using a bi-pack or side-by-side cartridge with attached static mix tube has the advantage of eliminating the problematic mixing stage as the material is dispensed already mixed. Proper selection of the static mix tube is critical to getting a uniform mixture. Many mix tube designs are available with varying mix tube lengths, mix element shapes, numbers of mix elements, multiple stage mix tubes, diameter, etc. Material is pushed out of the cartridge using either manual or pneumatic dispense guns, similar to a caulk gun. Any appearance of swirls, striations, uneven hardness on cure, or tackiness most likely indicates incorrect mix tube selection. This is especially a concern when there are large differences in viscosity between the two components or the mix ratio difference is large (i.e. 4:1, 10:1). Multiple stage mix tubes may be needed to increase back pressure and prevent one component from shooting through the mix tube without adequate mixing. One drawback to this type of dispensing is the amount of material that is lost in the mix tube that cannot be used. This can be significant with larger mix tubes. Users are encouraged to check with the material supplier for the appropriate size tube. See figure 11-5

11.7.1.4 **Other Issues** Many types of containers can be used for hand mixing. Glass beakers, metal paint cans, plastic cups or pails and paper cups are some examples of containers. When using paper cups, avoid cups with wax coatings, especially when working with warm resins as the wax can melt off and get into the potting material. Paper cups should be avoided if possible when mixing polyurethanes due to potential moisture issues. When using plastic containers caution should be used with regard to material and expected exotherm temperatures to avoid softening or melting of the plastic.

When mixing by hand, the sides and bottom of the container should be repeatedly and thoroughly scraped to ensure proper mixture of the components. The amount of mixing required will depend on how vigorously the material is mixed and the amount of material involved but a minimum mix time of 1-2 minutes is recommended. Fast setting systems are best dispensed through a static mix tube rather than by hand mixing. Subsequent decanting to a secondary clean container for final mixing is recommended.

11.7.2 **Automated Mixing on the Fly**

11.7.2.1 **Small Volume** Automated mixing is best suited to high volume dispensing due to the amount of time and material involved
in properly setting up the dispense equipment. The advantage is the improved consistency achieved from one part to the next. For small volumes, the potting material components are normally stored in separate, small containers or pots. These pots may also have provisions for heating and/or agitating the material. The potting material is pumped from the pots to the metering system. The metering system delivers the A and B materials, at the proper ratio, to the mix head. Often manual control, such as a foot pedal, is used to control the dispensing. Usually the amount of material dispensed is controlled to a specific “shot” size. Controls on small volume machines can vary significantly.

11.7.2.2 Bulk Volume Similar in many ways to small volume dispensing. Here the potting material may be pumped from large pots or directly from pails, drums or bulk containers. Larger machines typically are more sophisticated and often have the capability to control the mix ratio, shot size, dispense rate, component and dispense temperatures, line and dispense pressures, and even adjust dispense rate during the filling process. Proper selection of the pumps and equipment material is critical to getting repeatable and reliable performance. Equipment suppliers will determine the proper design based on the characteristics of the potting material selected. While automated equipment can provide excellent consistency when producing large volumes of parts, equipment manufacturers or experienced equipment technicians should be consulted when setting up and maintaining this equipment in order to establish the optimum dispense conditions and to properly adjust dispense pressures, temperatures, and other variables that can affect the quality and consistency of the dispensed material. See figure 11-6

![Bulk Reservoirs](image)

11.7.3 Proper Mix Ratio Improper mix ratio is the primary cause of potting failures next to poor mix. Periodically checking mix ratio is one of the most critical steps to producing consistent parts. This must be done regardless of the sophistication of the dispense machine and controls. The preferred method for checking the mix ratio is by weight. It is possible to measure weight much more accurately than volume. Techniques vary depending on the equipment involved but it is best to dispense several shots of the potting material into separate containers for each component and weigh them. The proper ratio should be specified by the manufacturer of the potting material and they should be able to recommend an acceptable range. Many systems, especially polyurethanes, need to be kept in a tight range or they will not cure properly. Some epoxy and silicone systems can be mixed within a wide range and still cure.

11.7.4 Vacuum Degassing of Mixed Materials Degassing 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 11-7
11.7.4.1 **Before Dispensing** Most potting materials are degassed by the manufacturer as part of their normal processing to remove the air incorporated during mixing, so additional degassing is normally not needed. When the components are mixed by hand however, some air will be re-introduced and may need to be removed prior to dispensing. This can be done in a small vacuum chamber or bell jar. It may be desirable to have a method of stirring the material while under vacuum to assist in removing the air as some systems release air less efficiently than others. It is recommended that vacuum be pulled on the material for a period of time (at least 5 minutes or as the material manufacturer recommends) after the foam “breaks” or collapses on itself. Common vacuum levels are 20-25 Hg. There may be a limit to how long material can be degassed after mixing for fast setting products before the viscosity becomes too high to use. Material dispensed through a static mix tube, if required, should be degassed before going through the tube.

On meter/mix equipment, bulk tanks are often used to supply the system. In some instances, it may be desirable to vacuum degas the A and B components separately in the tanks. The need is often predicated on how easily the materials will give up air bubbles after filling and left under ambient conditions which, in turn, are dependent on the viscosity of the material. It may also be necessary with wide ratio materials (i.e., 10:1 or greater) where the presence of any air in the components can create significant ratio delivery anomalies and improper mix. Filling the tanks after a work shift will often provide enough time for air bubbles to evacuate. At viscosities greater than ~30 – 40 K centipoise, air bubbles may not evacuate readily and may require the use of vacuum to facilitate the process. After vacuum degassing, some materials, if left at ambient for too long a period of time, can reabsorb air into the components of the liquid.

In subsequent Vacuum Encapsulation applications, the absence of air in the mixed material is critical to the success of the encapsulation process. Degassing of the A and B materials in the bulk supply before introducing it into the meter/mix system is absolutely mandatory.

When degassing materials in bulk containers, sufficient room needs to be provided for expansion. A rule of thumb is to provide the same volume for expansion as the loaded volume in the vessel. Degassing times may take as little as 5 minutes with low viscosity materials, or up to 20 minutes or more with higher viscosities. Actual time is dependent on the specific material. A simple method to check the progress of the degassing process is to open the vessel after a trial period and note the liquid film left on the sidewall of the tank (the height of the expansion). Using a paint stick or other flat device, “skive” a path down through the film, then replace the lid of the vessel and repeat the degassing process. Subsequent inspection will tell how much degassing has taken place based on the height of the film left in the skived area.

12 **Dispensing**

12.1 **Pouring** This method simply “pours” the potting material into the housing. The viscosity of the potting material and the void space geometry of the product will dictate if the material will give up air bubbles or if a vacuum step will be needed. If a vacuum step is needed, care needs to be taken not to overfill the cavity. The entrapped voids in the part can cause the potting material to expand, rise and breach the part enclosure under vacuum. Weighing the part before and after potting is a simple and effective quality tool to ensure air entrapment has not occurred.

12.1.1 **Positive Displacement Piston Metering.** These are typically specialized systems which have the capability to meter and mix the two parts on the fly. By using a ram, piston pump or tank pressure, the material is fed into a set of metering cylinders or chambers. The metering pistons are linked to displace the material, on ratio, into the mixing device or external static mixing tube.

12.1.2 **Injection Molding** This process employs a die which is part specific. The potting material is generally heated and then injected into a mold, which is also heated and water cooled. Once injected the material cures rapidly at which time the mold is opened and the mold injected part is ejected as a solid.

12.1.3 **Dipping** Some parts can be submerged into a vessel of mixed potting material. The size of the vessel should commensurate with the size of the part. Viscosity and work time or pot life needs to be considered so flow characteristics can be allowed to migrate.
under and around small parts. Due to gravity, there may always be a “drip” or “sag” associated with this method. See figure 12-1.

Figure 12-1 Dip coating an assembly

12.1.4 Brushing This method is typically not suitable for potting materials unless only small areas of the assembly are being encapsulated.

12.1.5 Spraying This method is not practical with the higher viscosity potting materials. However, in some cases diluted potting materials can be sprayed but work time and viscosity are critical factors. This method does not allow a significant amount of film build, resulting in thin layers of protection.

12.1.6 Dispensing Under Vacuum. Vacuum potting or encapsulation provides improved impregnation in difficult void space geometries (i.e., around pins, under circuit boards) and ensures void free encapsulation. It is critical to the potting of high voltage products to avoid corona effect. Parts are loaded either singly or in trays into a vacuum chamber. A fluid line of mixed, degassed material is fed through a bulkhead connector into the chamber, terminating at a shut off valve, typically a pinch valve. Vacuum is pulled on the chamber to a given level, at which time the potting process begins. Depending on the configuration of the part, a series of shots may need to be taken so as not to cause excessive expansion. After the dispensing cycle has been completed, the parts go through a “soak” cycle which provides sufficient time for complete saturation of the potting material within the parts. The vacuum chamber is then vented to atmosphere and the parts are removed.

12.2 After Dispensing Vacuum degassing may be needed after dispensing to remove any air introduced by the filling process as well as to assist in removing air trapped under boards or around and under various components. The optimum vacuum cycle (time, pressure) will need to be determined for each application and will be affected by the potting system viscosity, reactivity, air release properties and part geometries. When degassing material after it is dispensed, consideration must be given to the available head space in the potted unit so that there is sufficient room for expansion of the potting material during degassing such that it does not spill over the sides of the unit.

12.2.1 Degassing the Assembly It is recommended to pull a vacuum on a potted assembly immediately after dispensing the potting material into the housing. This assists in trapped air evacuation, which if left in the part can cause voids and create spaces for moisture and water to collect. Typically 20-25 inches of Hg vacuum is needed with most assemblies for some period of time, typically 5 to 10 minutes.

12.2.2 Wait Periods and Exotherms Exothermic chemical reactions can generate extremely high amounts of heat once mixed. The larger the bulk of material being used the higher the heat generation. This needs to be understood for each specific application to insure exothermic temperatures do not impact heat sensitive devices or parts used within the assembly. Safety aspects need to be considered. Dispense temperatures can also affect exotherm.

13 Cure Mechanisms Depending on the chemistry of the encapsulation, cure mechanisms can be categorized as follows. Some materials employ dual cure to ensure complete cure of all the material applied on an assembly.

13.1 Heat Cure This method typically uses a thermal excursion to initiate or accelerate the cure mechanism. Typical heat ranges from 100C to 150C. Just prior to polymerization of the polymer or potting material, there will be a drop in viscosity. 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 parts or assembly needs to “ramp up” to temperature before the potting material will begin to solidify. In extreme cases of thermal exposure the overall system may increase in hardness.

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

13.2 Heat Accelerable Some room temperature curing may be accelerated by the application of heat. The acceleration of moisture cure encapsulations may require additional humidity. Consult the material supplier for the specific conditions for acceleration.

13.3 Vacuum Bake This method employs both heat and vacuum at the same time which helps to evacuate trapped air or bubbles during the cure cycle. See figure 13-1.

![Figure 13-1 Example of an oven capable of Vacuum Degassing](image)

13.4 Under Pressure Some assemblies will use pressure during cure to force potting material into intricate spaces within the housing. This can be done with and without the addition of heat.

13.5 Humidity Forced humidity although not very common, can be useful for moisture cured RTV materials (room temperature vulcanizing). The general rule of thumb for RTV chemistries is \( \frac{1}{4} \)” depth of cure for every seven days at ambient Rh, because the Rh needs to permeate through the potting material. RTV’s should not be used in excessive depths exceeding \( \frac{1}{4} \) inch.

13.6 Room Temperature Cure Many two-part potting chemistries can cure at ambient room temperature. This cure system is
considered “free”, as there is no cost associated with curing the material. Room temperature cure is a relatively slow process. The encapsulation is cured in an ambient environment. Solvent based encapsulations must be subjected to room temperature cure to evaporate the solvent prior to any other cure to prevent entrapped solvent. Some encapsulations may be accelerated by the application of mild heat and/or humidity.

13.7 UV/Visible Light This method employs the use of high intensity light as the initiating cure source. It is useful for immobilizing the surface of the potting material very quickly. Due to potential for shadowing, light curing should be used only applications where the entire potting area may be exposed to light or when a secondary cure mechanism is incorporated into the chemistry and process. Visible light sensitive materials will cure deeper than those that are sensitive only to UV. Higher intensity light will generally provide a faster cure. Various high intensity light sources are designed to deliver the proper wavelengths. Insufficient light exposure results in incomplete cure, while excess exposure can scorch the material surface and begin degrading the material. Most UV curable encapsulation contains a secondary cure mechanism to cure encapsulation material that migrates under devices that will not absorb the UV energy. The secondary mechanisms for the photo-initiator modified encapsulations can be ambient moisture for the silicones (SR), and catalyzed, heat, aerobic, or ambient moisture for the organic AR, ER, UR, and materials. Aerobic UV chemistries are not totally effective depending on the fillet formation thickness and the ability for ambient air to diffuse through and penetrate the encapsulation fillet. The wavelength, intensity and duration of the UV source should be verified with the appropriate material supplier.

Add Photograph/Illustration here (Galaska @ Dymax)

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

13.9 Cure Process Considerations Characteristics of “cured” encapsulation are provided in the material supplier’s technical data sheet. If the recommended curing conditions of the supplier are not strictly followed, end results will vary. Cure is defined as completion of chemical reaction and full development of properties. Adhesion is typically the last property to develop. This may be several hours to several days depending on the encapsulation chemistry. Consult the material suppliers for cure schedules. If final testing and or “burn in” are anticipated after the encapsulation operation, the time taken for the chosen material to reach optimum properties needs to be considered.

13.10 Cure By-Products Some encapsulation materials can produce by-products as a result of the curing chemistry employed. Some silicones may produce methanol in small amounts and others evolve cyclics, which can produce a micro-layer of silica on or near mechanical relays and read/write heads. Because so many chemistries are available, the user should contact the encapsulation supplier to understand what by-products and volatiles will be produced as a result of a particular product chemistry. For products that do form a by-product you should verify what the by-product is and utilize only materials with a non-corrosive by-product. Many silicones used as encapsulation may liberate methanol as a by-product and this is considered a neutral-cure or non-corrosive product. Products to avoid in encapsulation applications are acetoxy-cure silicones since they liberate acetic acid.

13.10.1 Exotherm Catalyzed materials or materials that contain two parts can usually generate exothermic heat as part of the curing reaction. Material mixed in large bulk (>1 liter), can reach very high exothermic temperatures if not used within the pot life and left to cure in large quantities. It should never be left in fluid delivery systems or reservoirs past the recommended pot life. This should also be verified with the material supplier.

13.11 Shrinkage Unlike the thinner conformal coatings, shrinkage during encapsulation is normally not a problem as long as the encapsulated item contains the minimum amount of material specified on the assembly drawing/documentation.

13.12 Premature Surface Cure/Solvent Entrapment Due to the highly competitive nature of electronics manufacturing, processes are always monitored for methods to save costs. Reducing the cure/dry cycle is one of the simplest ways to speed production. Unfortunately, this effort to save money, no matter what it costs, can create serious reliability problems.

Rapid curing can cause a "skin" to form on the surface of encapsulations that will prevent the thinners/solvents from evaporating. This can result in bubbles/voids in the encapsulation as well as preventing the cross-linking of polymeric chains for certain types of materials. Some solvents can attack the substrate or solder masks when left exposed over extended times. Other thinners, such as water, can attract and dissolve ionic contaminates.

Solvent/thinner entrapment can also occur if the encapsulation completely underfills the space between the component and substrate preventing evaporation. This can lead to problems that are not visible unless the component is removed. Any proposed changes to a successful encapsulation and curing operation should be thoroughly tested before being implemented into production.
13.13 Exceeding Cure Recommendations While under-curing an encapsulation may lead to an incomplete development of film properties, over-curing may lead to some adverse effects on the performance of encapsulation. Depending on the chemistry and cure mechanism, exceeding the cure schedule and conditions recommended by the material supplier may lead to embrittlement, discoloration, formation of ripple, decomposition, etc.

14 Application Process Monitoring The monitoring of the encapsulation process should be sufficient to guarantee consistent and reliable application and cure of these materials. The encapsulation process is usually the last assembly step in the electronic assembly process and a mistake here could be significant. Therefore, the encapsulation and cure process should be monitored and documented to insure and demonstrate reliable yields.

14.1 Inspection Guidelines Once an assembly has been encapsulated, it is important to inspect, or evaluate the success of the process. Most often, a visual inspection is employed. During inspection an operator may be evaluating a variety of criteria.

Inspection can be done before and/or after curing has taken place. This will depend on your specific process and the ease of rework and repair of your encapsulation.

Visual inspection is not as common in selective or robotic applications due to the large number of assemblies encapsulated in the production. In these applications, automatic quality control options are available. Presence sensors can verify that encapsulation has been placed on the assembly. This cannot, however confirm, uniformity, or placement aside from a particular spot. Flow meters can verify the volume of encapsulation that has been applied to each assembly, while preventing out of tolerance parts from continuing in the process.

14.2 Monitoring a P&E Process

14.2.1 Workmanship Workmanship of the encapsulation application process needs to be evaluated to ensure that the applied encapsulation fulfills the specified requirements. Regardless of the application method, the applied encapsulation shall not exhibit dewetting behavior. The cured encapsulation must meet the accept/reject criteria of IPC J-STD-001. If de-masking is included in the process, workmanship of the de-masking step needs to be examined to ensure that masking residue and degradation of the encapsulation or the board or the assembly is minimized. Forms of degradation include lifting of materials from substrate, peeling, cracking, lifting of edges, physical damage to the substrate and/or components.

14.2.2 Oven Profiling This involves the use of temperature measuring devices or thermocouples to determine the temperatures generated within the oven or thermal tunnel environment. In the case of thermal tunnels which are multi-zoned, monitoring devices, such as a thermal data monitoring device, can be passed through the oven. The data monitoring device is capable of plotting the specific temperatures in each zone. In the case of stationary circulating ovens or convection ovens, measurements should be taken in multiple locations because each oven can have hot and cold areas.

Add Illustration here depicting a mole

14.2.3 Volumetric Shot Size This feature is available on automated equipment in which data acquisition can be used to measure and plot shot size.

Add Photograph/Illustration here (obtain one from Assymtec)

14.2.4 Weight This is by far the most accurate and reproducible measurement for determining how much potting material is contained within an assembly. Any reduction in pre-established weights for a given assembly would indicate trapped air or voids within the part. Changes in specific gravities of individual components as well as mix ratio anomalies can also affect differences in weight. Figure 14-1 is a scale capable of measuring the weight of a potting sample.

Figure 14-1 Scale
14.2.5 Hardness Also known as durometer, this measurement dictates the given hardness or penetration value for a particular cured potting material. Any change in the mean value would indicate that the mix ratio is off or the cure cycle/process is incomplete.

15 Environmental, Health and Safety Processing Considerations

There are several safety guidelines that should be followed during all parts of the encapsulation process. First and foremost is basic cleanliness and caution. All work areas should be kept reasonably neat, spills should be cleaned up immediately, food or drink should never be in work areas, and eye protection should be worn at all times in the manufacturing environment. Also, material safety data sheets (MSDS) should be available for all encapsulations, solvents, strippers, etc. used in the encapsulation process. These MSDSs should be located in an area which is accessible to individuals working with the chemicals and materials contained therein. Anyone working with a particular encapsulation, solvent, etc. should review the MSDS on site and be sure to follow the safety protocols listed for that particular material.

Any application method brings health and safety concerns to the user. Manual operations must address operator issues even more seriously, as the employee will have direct contact with the spray process. Common hazards associated with encapsulation applications are inhalation/ventilation and skin irritation. Proper ventilation in the area where encapsulation are applied, cured, and re-worked is very important. Also, most encapsulants are irritants and contact with skin should be avoided. It is suggested that gloves and other appropriate protective gear should be used when handling encapsulation. Consult with in-house health and safety professionals, if available. See Appendix A for an example of a P & E material MSDS

15.1 Environmental Health & Safety Viscosity Adjustment Refer to your local authorities for regulatory requirements on solvent used in viscosity adjustment.

15.2 Curing Ventilation Considerations Cure chemistry of some encapsulating products involve the emission of harmful by-products. Special care is required to protect workers from exposure to such fumes. Adequate ventilation should be used during this process. When employing ultra-violet curing methods, care should be taken to avoid eye and skin exposure to the UV energy.

15.3 Workplace Considerations When working or having contact with chemicals, such as the encapsulating materials, workers need to be familiar with products in order to prevent any risk that could damage health or environment.

A safe practice requires the use of safety equipment suitably designed to prevent contact with hazardous substances. Manufacturers’ material safety data sheet will identify the proper personal protective equipment requirements for routine handling and spills.

15.6 Exotherms Dependent on Volume of Material Curing reaction of some encapsulating products has an exothermic character. When the product cures some amount of energy in the form of heat is released. As a result of this, the temperature of the product and part can increase several degrees. Temperature increment is proportional to the volume of material reacting. The larger the volume of product the higher the temperature reached. In some cases, temperature can go up more than 80 °C (175 °F). Special attention must be observed in order to prevent excessive exposure to high temperature for the operator or electronic component encapsulated with such material.

16 Inhibition

Inhibition is defined as the inability for the encapsulation materials to obtain the optimum properties at the manufacturers specified time and temperature.

Inhibition is caused by the contamination of the catalyst in heat-cure (addition-cure) encapsulation with 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.

There are certain situations, however, where the cure reaction cannot proceed normally. These conditions occur when materials called inhibitors are present. In the presence of such an inhibitor, the cure in the immediate vicinity of the inhibiting material is poor. In this inhibited area the encapsulation remains in its liquid state even though the cure schedule has been completed. This potting material will remain liquid regardless of any subsequent attempts to convert it to a solid. There are different levels of inhibition. Encapsulations that cure by a free radical mechanism may be subject to inhibition. Encapsulation formulations that derive their free radicals from UV photoinitiators or organic peroxides are examples. In the presence of atmospheric oxygen, reactive radicals react preferentially with oxygen to form inactive, non-propagating, alkyl peroxy radicals. The most common signs of oxygen inhibition are a tacky surface or uncured material on the surface after cure. Increasing the UV intensity and/or cure temperature usually will solve the problem. With proper cure conditions, reactive radicals form much faster than oxygen can diffuse into the thin film, and complete cure occurs. Alternatively, curing under an inert gas will eliminate oxygen inhibition.

Inhibition is often confused with improper mixing of two component materials. The user should ensure that it is a true inhibition problem and not a mixing problem.
16.1 Interfacial Inhibition  Interfacial inhibition occurs at the interface between the substrate and the encapsulation. 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 encapsulation, e.g. primer and changing the cure system.

16.2 Mild Inhibition  Mild inhibition is most often observed when the encapsulation 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 encapsulation, e.g. primer, or by the addition of cure accelerator.

16.3 Gross Inhibition  Gross inhibition exists when the inhibited area remains in its liquid state even though the cure schedule has been completed. Options for overcoming gross inhibition include changing the substrate or selecting a non-addition cure encapsulation, e.g. moisture cure encapsulation.

16.4 Location of Inhibition  Inhibition sometimes occurs on the exposed surface while it is curing in a contaminated oven. In these cases, the atmosphere within the oven contains sufficient curing agent or catalyst leftover from a previous product to cause inhibition of the surface of the heat-cure encapsulation. Solutions to this problem are to heat the oven at its maximum temperature for eight hours to remove residual volatile inhibiting materials or use a dedicated oven.

Residuals left on the assembly are another potential source of inhibition. In most cases it is not the material from which the substrate is made that has caused the inhibition. But rather, residuals left from other materials that have been processed on the assembly or from residual oils remaining on the substrate surface such as greases, mold release agents, or hand lotions. These same considerations apply to other tools used in the processing of the encapsulation. Equipment such as funnels, dispense tubes, hoses, seals and gaskets will sometimes pick up and retain residuals. They should be scrupulously cleaned or replaced before being used with heat-cure encapsulation.

16.5 Causes of Inhibition  The most common causes of inhibition are sulfur or sulfur-containing chemical compounds, amines and certain other nitrogen-containing chemical compounds, acidic materials (usually organic acids) and organotin Room Temperature Vulcanizing (RTV) silicone rubber catalysts. Exceptions to sulfur or nitrogen compounds that inhibit heat-cure encapsulation are certain flexible polyurethanes. They are commonly contained in some gloves, finger cots, masks, sleeving, solder masks, certain fluxes, mold release agents, process hoses, gaskets, O-rings and other rubber products, hand cream, uncured epoxy and urethane. As stated before, organic acids are inhibitors. The reaction byproduct of the peroxide catalyst in many heat-vulcanized rubber stocks is an organic acid. Thus, if the rubber has not been properly post-cured, it is possible that acid will remain and cause inhibition. This problem is particularly acute with hot-air-vulcanizable silicone rubber because the acid formed during its vulcanization has a much lower volatility than the acid byproducts of other silicone rubbers. As a consequence, longer post-cures are needed with hot-air-vulcanizable silicone rubber.

16.6 Compatibility Check List  These materials and components shown in Table 16-1 were evaluated using a heat-curing product. It is believed that other heat-cure encapsulation will act similarly. The user should verify the compatibility of encapsulation/board combinations prior to the final selection of the encapsulation.

Table 16-1 Material Compatibility

<table>
<thead>
<tr>
<th>Polyvinylchloride, plasticized</th>
<th>Hot-air-vulcanizable silicone rubber</th>
<th>Sulfur Compounds:</th>
<th>Nitrogen compounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy, amine-cured</td>
<td>Neoprene rubber</td>
<td>Thiols</td>
<td>Amines</td>
</tr>
<tr>
<td>Polysulfide MIL-S-8516</td>
<td>Buna N rubber</td>
<td>Sulfides</td>
<td>Amides</td>
</tr>
<tr>
<td>Cellophane tape</td>
<td>GRS rubber</td>
<td>Sulfates</td>
<td>Imides</td>
</tr>
<tr>
<td>Masking tape</td>
<td>Natural rubber</td>
<td>Sulfites</td>
<td>Azides</td>
</tr>
<tr>
<td>Vinyl electric tape</td>
<td>Acid core solder flux</td>
<td></td>
<td>Thioreas</td>
</tr>
<tr>
<td>Latex vacuum tubing</td>
<td></td>
<td>Rosin core solder flux</td>
<td></td>
</tr>
</tbody>
</table>

16.7 Adhesion  Several factors affect the ability of an encapsulation to adhere to an assembly. These factors include, but are not limited to, cleanliness, compatibility between the encapsulation and other interface materials, and degree of cure. Adhesion properties are important to the final product appearance and function. An encapsulation that does not adhere completely to the assembly is not protecting that assembly. Improper adhesion can lead to moisture ingress, blistering, peeling, cracking, mealing, and pop-corning of
the encapsulation, especially during thermal cycling and heat/humidity treatment. The adhesion requirement is defined by the agreement between the applicator and the end user. The end user and applicator should determine what level of adhesion produces a functional assembly and what test(s), if any, shall be used to determine that sufficient adhesion has been achieved and maintained through any tests or environmental conditioning. The risk for adhesion failure is not only affected by the strength of adhesion but also by the elasticity of the encapsulation. An encapsulation with high elasticity is less prone to adhesion failure when exposed to mechanical tension than an encapsulation with low elasticity.

16.8 Solder Mask/Substrate Compatibility of the solder mask and substrate with the encapsulation of choice is essential in order to produce a high quality assembly. Adhesion of the encapsulation to the solder mask is central to the compatibility issue. The large numbers of solder mask, substrate, and encapsulation combinations make a detailed list here impractical. The end-users should discuss the compatibility criteria of the encapsulation with the encapsulation supplier. Qualification of a given system including solder mask, encapsulation materials and process parameters should be completed prior to the implementation of these materials.

16.9 Components Poor adhesion/de-wetting of encapsulation to component and component leads can be a problem. In some cases the problem can be remedied with a change in application method, allowing better penetration of the encapsulation in between fine-pitch leads, etc. Some components may have material on their surface that can inhibit encapsulation adhesion, such as mold release agents, wax, polysiloxanes (silicones) and marking inks. Component cleanliness is also an important factor in encapsulation adhesion. If localized delamination occurs, it is the responsibility of the users to determine acceptability.

16.10 Surface Finishes One of the areas on a PCA that an encapsulation has to adhere to is the surface finish of the PCB. Surface finish is the material on metallized areas of the exterior PCB layer. Previous generations of these areas on a PCB were the remaining copper after etching and other PCB processing prior to reflowing tin/lead (Sn/Pb). Newer technologies have resulted in alternate materials to Sn/Pb being used as the finish on the PCB prior to assembly processing. These materials include, but are not limited to, bare copper, immersion tin, immersion silver, immersion gold, electrolytic or electrolyless nickel combined with gold and/or palladium, organic soldering preservative (OSP), and other similar types of alloys. It should be noted that if these materials are on areas of the PCB where a solder joint is formed, then the processing usually will modify these finish materials. Most of these modifications are the conventional assembly processing using hot air Sn63/Pb37 eutectic solder leveling or reflow methods. However, because the surface finish may contain a different metal or organic material prior to assembly processing, the resulting intermetallic in the solder joint may contain trace elements of the board surface finish. It is this type of condition and other areas of the PCB with finishes not changed by assembly processing that need to be evaluated for encapsulation compatibility. In many cases, these conditions may necessitate conducting a qualification test using a representative PCB sample before approving the intended encapsulation as “acceptable for use”.

16.11 Cleanliness The single most common deterrent to encapsulation adhesion is surface contamination. The presence of ionic residues, oily materials, and particulates on board surfaces and components can result in corrosion, insulation breakdown, poor adhesion and subsequently, failure of the encapsulation. Ionic contamination may cause mealing or vesication of the encapsulation. Oily materials and particulates will not allow most encapsulation to adhere to the surface/substrate leading to peeling. A thorough cleaning and drying process is the best method available to minimize the adhesion problems due to residues. Even when using low-residue fluxes/no-clean processes it is very important that the assemblies do not exhibit any of the flux residues. Small traces of flux residues left on the assembly due to improper cleaning and volatilization of the flux chemistries can lead to poor adhesion of the encapsulation or inhibition. The cleaning process is also a factor. When using alternative cleaning methods and chemistries, such as hydrocarbons, terpenes, esters, etc. caution must be observed with respect to residual solvents. These residual solvents can cause outgassing at elevated temperatures resulting in adhesion problems such as blisters and vesication. When using aqueous cleaning methodologies proper drying is essential. Encapsulation may have poor adhesion due to the presence of any residual water on the assembly.

Level of cleanliness should be determined between assembler and the end user. The IPC-CH-65 may prove to be a useful guide for this determination.

16.12 Interlayer Adhesion If encapsulation is applied in different layers (i.e., multiple applications of the material are required) the degree of adhesion between layers and the degree of wetting on previously applied layers is dependent on the type of chemistry and material selected. Some chemistry needs to be cured completely before the next layer is applied whereas some chemistries would not adhere to itself while wet. It is not a common practice to utilize surface treatments between layers for a multilayer encapsulation process.

For rework and repair, when a new layer of encapsulation is applied over an old layer, the degree of wetting and adhesion may be influenced by the relative surface tension, the condition (cleanliness, wear and tear) of the old layer, and the compatibility with the encapsulation removal method (residues of stripping agent, thermal degraded encapsulation, abraded surface, etc). Adhesion promoters or surface treatments may be used to enhance adhesion. Defining the process for re-encapsulation should be considered as part of the encapsulation process.

17 Potting / Coating over Encapsulants
17.1 **Mixed Hardness Systems** This can be done when using extremely hard potting materials such as epoxy and is done to reduce the stress on sensitive or delicate devices or components by providing a “buffer” material as a stress relieving layer.

17.2 **Interlayer Adhesion** Many potting chemistries do not adhere to themselves very well. In these cases, a use of a primer or mechanically roughening the surface may enhance the intra-layer adhesion. In some cases, interlayer adhesion may be improved by dispensing the second layer on the semi-cured first layer (B-stage).

17.3 **Compatibility with Process Materials** It is important when reading the following section, to recognize that all potting seal in as well as out. In order to successfully apply a potting material to a PWA, compatibility of the potting with various materials on the PWA during the application and curing processes need to be considered. This includes compatibility with board or component surfaces, solder masks, common contaminants such as flux residues, and chemicals such as plasticizer, defoamer, conformal coatings and mold release agent.

This can be employed when a potting material’s cure system is sensitive or poisoned (inhibition) by the residues contained on the PC board. For instance a moisture cure conformal coating can be used to create a protective boundary between the inhibiting agent and the potting material.

**PCA Residues of which to be aware:**

1. Adhesives
2. Human agents – perspiration, acids and/or oils
3. Lanolin from hands
4. Mold release agents
5. Oils
6. Silicones
7. Surfactants
8. Others depending on the process your supplier is using and the process you are using.
9. Housing machine oils or uncured materials
10. Flux
11. Post-cleaning PCA by-products
12. Consumable perishables
13. Some alcohols

It is suggested that pre-production products be processed prior to the validation of actual production.

18 **Materials Related to Lead Free Processing that Affect P&E**

18.1 **Materials that Leach from Substrates at Higher Temperature** Lead-free or reduced-lead solder alloys employ fluxes that react at much higher temperatures. The higher temperatures can drive out various species from the solder mask, component bodies, flux residues, and mold release agents used to fabricate the devices. These species can sometimes interfere with the potting materials cure chemistry causing incomplete cure or gross inhibition.

18.2 **Changes in Surface Energy of Substrates** The higher temperatures associated with the lead-free soldering technologies can alter or change the surface energy of the electronic substrates and devices being encapsulated. In addition, the elevated temperatures can cause other components from the substrate or component bodies to leach. This can result in poor “wetting” characteristics and loss of adhesion.

*Add Photograph/Illustration here (may get some from APEX-Expo 2011 NPL technical paper)*

18.3 **Glycols from Solder Masks** Glycols from solder mask agents can interfere with adhesion and are generally very hygroscopic in nature. This can lead to moisture absorption and entrapment at the interface of the PC board and the potting material allowing moisture molecules to collect in the space. They can wreak havoc on the electrical performance of some devices and cause premature corrosion and ECM. High moisture content can cause some chemistries to foam.

18.4 **Flux / Paste residues are More Aggressive** Some residual acid species in the flux can interfere with some types of cure mechanisms. This can result in localized inhibition or gross inhibition where none of the potting material can cure. High residual acid content can also increase ionic content.

19 **Rework and Repair Processes**

The rework process for potting and encapsulation can be a very challenging operation. If a PCB and/or the components are to be replaced during the life of the product, then the encapsulation removal and application procedures must be considered during the
product design stage. The first consideration should be the post rework/repair performance as critical or non-critical. This is due to
the potential that a re-coated encapsulation seldom (if ever) seals the surface as well as the original encapsulation. See Chapter 14
of this Handbook for more discussion on rework and repair.

In most cases the encapsulation process is used to protect the electronic assembly from moisture, harsh environments and an array
of various contaminants. Removing the potting material will depend on the chemistry employed and the degree of encapsulation.
The user is encouraged to check with the material supplier to determine which methods are best suited for removing that particular
chemistry. In many cases, removing the potting material in its entirety may prove to be impractical. For local areas or component
replacement, a combination of thermal degradation, solvent stripping and mechanical removal techniques may be required.
Salvaging of the entire assembly may be impossible. Keep in mind that whatever solvent or techniques is used to remove the
potting material may also attack the underlying substrates on the assembly. It is recommended that a removal and rework process
be considered early on in the design process. If it is likely that repair and rework will be needed then the user should consider a re-
enterable potting material.

19.1 De-masking When de-masking, caution should be observed to avoid any degradation of the encapsulation, assembly, or board.
Forms of degradation include lifting of materials from substrate, peeling, cracking, lifting of edges, physical damage to the substrate
and/or components. Careful scoring may minimize degradation.

19.2 Rework and Repair Procedures The IPC-7711/7721 – provides step-by-step procedures for the removal, rework, and repair
of coatings and encapsulations.
- Identification of Chemistry
- Solvent Method
- Peeling Method
- Thermal Method
- Grinding/Scraping Method
- Micro-Blasting Method

19.3 ESD/EOS Controls
Refer to section IPC 7711/7721, 2.2.1 for information about Electrical Overstress (EOS) damage prevention.
Refer to section IPC 7711/7721, 2.2.2 for information about Electrostatic Discharge (ESD) damage prevention.

20 Regulations

There may be other international or local regulations which are not listed here. These are common regulations which will effect most
geographical locations.

20.1 RoHS The Restriction of Hazardous Substances regulation was created as a function of the lead-free process initiative. This
directive, adopted by the European Union, looks for the restriction or elimination of the use of hazardous materials for any new
electrical and electronic component. Included in the list of hazardous materials trying to eliminate are: lead, mercury, cadmium,
hexavalent chromium, poly-brominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE), in quantities exceeding
maximum concentration values allowed. Any encapsulating product used or introduced to the European Union for any kind of
electrical or electronic application needs to be in compliance with this regulation. For more information please visit www.rohs.eu

20.2 REACH The Registration, Evaluation, Authorization and Restriction of Chemical substances (REACH) is a regulation adopted
by the European Union with the aim to find possible substitution of dangerous chemicals when suitable alternatives have been
identified. Likewise, this directive tries to better identify chemical substances used in the European Union to assess hazards and risks
of these substances, and to identify and implement the risk management measures to protect humans and the environment.

20.3 TSCA Under the toxic substances control act (TSCA) U.S. chemical manufacturers, importers, processors, and distributors
requires to immediately notify the Environmental Protection Agency (EPA) of any chemical substances that are identified as
potential risk of injury to health or the environment. Especially oriented to ban and eliminate the production, importation, use, and
disposal of specific chemicals including polychlorinated biphenyls (PCBs), asbestos, radon and lead- based paint. For more
information please consult: www.epa.gov

APENDIX A
MSDS

Below is a typical listing for a Material Safety Data Sheet. Please see explanations at the bottom of each section.

1. PRODUCT AND COMPANY IDENTIFICATION (This information generally used for emergency information to contact the
manufacturer)
24 Hour Emergency Telephone:
2. HAZARDS IDENTIFICATION POTENTIAL (This information generally used for emergency information and potential health effects)

HEALTH EFFECTS Acute Effects
Eye: Skin: Inhalation:
Oral:
Prolonged/Repeated Exposure Effects
Skin: Inhalation: Oral:
Signs and Symptoms of Overexposure
Medical Conditions Aggravated by Exposure

The above listed potential effects of overexposure are based on actual data, results of studies performed upon similar compositions,

3. COMPOSITION/INFORMATION ON INGREDIENTS (This information generally used for contained ingredients and chemical composition.)

CAS Number Wt % Component Name
Trade Secret

4. FIRST AID MEASURES (This information generally used for first aid measures.)

Eye:
Skin: Inhalation: Oral:

5. FIRE FIGHTING MEASURES (This information generally used for firefighting measures.)

Flash Point:
Auto ignition Temperature: Flammability
Limits in Air: Extinguishing Media:
Unsuitable Extinguishing Media:

Dry chemical.
Unusual Fire Hazards:

6. ACCIDENTAL RELEASE MEASURES (This information generally used for spill, containment and clean-up measures)

Containment/Clean up:

7. HANDLING AND STORAGE (This information generally used for typical handling and storage recommendations.)

8. EXPOSURE CONTROLS / PERSONAL PROTECTION (This information generally used for exposure limits, recommended personal protection and typical exposure limits.)

Component Exposure Limits
CAS Number Component Name
Exposure Limits
Trade Secret
TWA 5 ppm, STEL 10 ppm.

Engineering Controls
Local Ventilation: Recommended.
General Ventilation: Recommended.

Personal Protective Equipment for Routine Handling
Eyes:
Use proper protection
Skin:
Suitable Gloves: Inhalation:
Suitable Respirator:

**Personal Protective Equipment for Spills** *(This information generally used to determine the physical and chemical properties of the material.)*

Eyes:
Skin: Inhalation/Suitable Respirator:
Precautionary Measures:

9. **PHYSICAL AND CHEMICAL PROPERTIES**
Physical Form:
Color: Specific Gravity @ 25°C: Viscosity:
Freezing/Melting Point: Boiling Point:
Vapor Pressure @ 25°C: Vapor Density:
Solubility in Water:
pH:
Volatile Content:
Flash Point: closed cup or open cup
Auto ignition Temperature: Flammability
Limits in Air:
Note: The above information is not intended for use in preparing product specifications.

10. **STABILITY AND REACTIVITY** *(This information generally used to determine the stability and reactivity of the material.)*
Chemical Stability:
Hazardous Polymerization: Conditions to Avoid: Materials to Avoid:
Hazardous Decomposition Products

11. **TOXICOLOGICAL INFORMATION** *(This information used to determine potential toxicological information.)*
Component Toxicology Information
Special Hazard Information on Components
Mutagens CAS Number Wt %
Component Name Trade Secret

12. **ECOLOGICAL INFORMATION Environmental** *(This information generally used to determine ecological and environmental information and impact.)*
Fate and Distribution

Environmental Effects
Complete information is not yet available.

Fate and Effects in Waste Water Treatment Plants

13. **DISPOSAL CONSIDERATIONS RCRA Hazard** *(This information generally used to determine disposal information and considerations.)*
Class
When a decision is made to discard this material, as received, is it classified as a hazardous waste?
Characteristic Waste: Reactive: Example:
D003
State or local laws may impose additional regulatory requirements regarding disposal.

14. **TRANSPORT INFORMATION** *(This information generally used to determine transport and shipment regulation information and restrictions.)*

**DOT Road Shipment Information (49 CFR 172.101)**
Not subject to DOT.

**Ocean Shipment (IMDG)** Not subject to IMDG code.

**Air Shipment (IATA)**
Not subject to IATA regulations.
15. REGULATORY INFORMATION
(This information generally used to determine regulatory and local compliance information.)
TSCA Status: All chemical substances in this material are included on or exempted from listing on the TSCA Inventory of Chemical Substances.

EPA SARA Title III Chemical Listings
Section 302 Extremely Hazardous Substances (40 CFR 355):
Section 304 CERCLA Hazardous Substances (40 CFR 302): Section
311/312 Hazard Class (40 CFR 370):
Acute:
Chronic: Fire: Pressure:
Reactive:
Section 313 Toxic Chemicals (40 CFR 372):

Supplemental State Compliance Information
California
Massachusetts
No ingredient regulated by MA Right-to-Know Law present.
New Jersey CAS Number
Wt %
Component Name Pennsylvania
CAS Number
Wt %
Component Name

16. OTHER INFORMATION
(This information generally used for additional information pertinent to the specific material not categorized within the standard MSDS format.)

Prepared by:
(This information generally assigns the owner and/or author of the data contained in the MSDS.)

Appendix B
B.1 Reference documents The following documents are listed for reference only. This handbook does not attempt to explain these documents.

AFNOR NF EN 60664-3 (AFNOR - Association Francaise de Normalisation) Insulation Coordination for Equipment Within Low-Voltage Systems – Part; Use of Coating, Potting or Molding for Protection Against Pollution
DIN 65064 Aerospace (KSC - NASA - KSC - Kennedy Space Center) – Potting Compounds for Care and Edge Filling or Sandwich Structures – Technical Specification
KSC-SPEC-E0029 (KSC - NASA - KSC - Kennedy Space Center) Compound, Potting and Molding, Elastomers, Specification
MIL-C-47224B (MI - Aviation and Missile Command) Compound Molding, Transfer, Epoxy Resin, Single- Component
MIL-I-16923H (SH - Naval Sea Systems Command (Ship Systems) Insulating Compound, Electrical, Embedding, Epoxy
MIL-I-46865B (SH - Naval Sea Systems Command (Ship Systems) Insulating Compound, Electrical, Epoxy, Colloidal Silica Fill for Potting and Encapsulation
MIL-M-24041C (SH - Naval Sea Systems Command (Ship Systems) Molding and Potting Compound, Chemically Cured, Polyurethane
MIL-P-46872A Potting and Molding of Cable Assemblies (not for new design)
MIL-P-70661 (AR - U.S. Army Tank - Automotive Command, Armament Research Development and Engineering Center) Potted Circuit Card Assembly for Tow-2-E6 Probe and SNA Assembly
MIL-C-47002A (MI - Aviation and Missile Command) Coating, Polyurethane, Single Component System.
MIL-P-47099A (MI - Aviation and Missile Command) Polyurethane Foam, Polyether Type, Rigid for Packaging and Encapsulation of Electronic Components.
MIL-R-47025A (MI - Aviation and Missile Command) Resin, Casting, Fire Retardant, Epoxy Base.
(Placeholder for GFKORR document)
MIL-HDBK 691B (get a copy)

SAE AMS 3358B  Silicone Potting Compound, Elastomeric 2-Part, General Purpose
SAE AMS 3361B  Silicone Potting Compound, elastomeric, two-part, general purpose.
SAE AMS 3362C  Silicone Rubber Compound Room Temperature Vulcanizing, 15,000 cPoise Viscosity, Durometer 35-55
SAE AMS 3363D  Silicone Rubber Compound, Room Temperature Vulcanize 50,000 cPoise Viscosity, Durometer 30-45
SAE AMS 3364C  Silicone Rubber Compound Room Temperature Vulcanizing
SAE AMS 3364C  Silicone Rubber Compound Room Temperature Vulcanizing, Short Application Life.
SAE AMS 3368  Silicone Resin, Elastomeric, Transparent Elevated Temperature Cure.
SAE AMS 3370A  Silicone Resin, Elastomeric, Transparent Room Temperature Cure.
SAE AMS 3372A  Silicone Resin, Elastomeric, High Shear Strength, Elevated Temperature Cure.
SAE AMS 3373/1A  Compound, Silicone Rubber, Insulating and Sealing, Oil and Reversion Resistant, Low Viscosity, Room Temperature Cure.
SAE AMS 3373B  Compound, Silicone Rubber, Insulating and Sealing.
SAE AMS 3375A  Adhesive Sealant, Fluorosilicone, Aromatic Fuel Resistant, One-Part Room Temperature Vulcanizing.
SAE AMS 3375B  Adhesive Sealant, Fluorosilicone, Aromatic, Fuel Resistant, One-Part Room Temperature Vulcanizing.
SAE AMS 3571B  Resin, Polyether Urethane (EU) Casting Flexible, Solid, Unfilled FSC-9320.

DELPHI DX300439  Silicone Potting – Ultraviolet and Moisture Cure.

ASTM D570  Standard Test Method for Water Absorption of Plastics
ASTM D2440  Standard Test Method for Rubber Property – Durometer Hardness
ASTM C 603  Standard Test Method for Extrusion Rate and Application Life of Elastomeric Sealants
ASTM D635  Rate of Burning and/or Extent and Time of Burning of Self-Supporting Plastics in A Horizontal Position
ASTM D3359  Standard Test Methods for Measuring Adhesion by Tape Test
ASTM D3833  Standard Test Method for Water Vapor Transmission of Pressure Sensitive Tapes
ASTM E96  Standard Test Methods for Water Vapor Transmission of Materials
ASTM F1249  Standard Test Method for Water Vapor Transmission Rate Through Plastic Film and Sheeting Using Modulated Infrared Sensor
ASTM D 1763  Standard Specification for Epoxy Resins

FAR §25.853 and Appendix F  FAA material flammability tests