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Guidelines for Design, Selection and Application of Conformal Coatings

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Developed by the Conformal Coating Handbook Task Group (5-33c) of
the Cleaning and Coating Committee (5-30) of IPC

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

Contact:

IPC
3000 Lakeside Drive, Suite 309S
Bannockburn, Illinois
60015-1219
Tel 847 615.7100
Fax 847 615.7105



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Cleaning and Coating Committee	Conformal Coating Handbook Task Group	Technical Liaison of the IPC Board of Directors
Chair Doug O. Pauls Rockwell Collins	Co-Chairs Jason M. Keeping Celestica	Bob Neves Microtek Laboratories
Vice Chair Debora L. Obitz Trace Laboratories - Baltimore	and Amy M. Hagnauer Raytheon Company Vice Chair Fonda B. Wu Raytheon Company	
Conformal Coating Handbook Task Group		
Maria D'Aniello, 3M Canada Company	Jawn Swan, Crystal Mark, Inc.	Eric Moffatt, Elzly Technology Corporation
Larry Ennett, 3M Company	Winn Cannon, Cytec Industries Inc.	Graham Naisbitt, Gen3 Systems Limited
Michele Nelson, 3M Company	Rick Jordan, Cytec Industries Inc.	Richard Davidson, Honeywell Aerospace
Douglas Schueller, AbelConn, LLC	David Corbett, Defense Supply Center Columbus	Richard Rumas, Honeywell Canada
Ross Dillman, ACI/EMPF	Lowell Sherman, Defense Supply Center Columbus	Bob Teegarden, Honeywell International - Torrance
Constantino Gonzalez, ACME Training & Consulting	Henry Sanftleben, Delphi Electronics and Safety	Matthew Eveline, HumiSeal Division of Chase Corporation
Greg Alexander, Ascentech, LLC	Kati Yorks, Dow Corning	Jeffrey Sargeant, HumiSeal Division of Chase Corporation
Thomas Cleere, BAE Systems Platform Solutions	Carlos Montemayor, Dow Corning Corporation	John Waryold, HumiSeal Division of Chase Corporation
Joseph Kane, BAE Systems Platform Solutions	Barry Ritchie, Dow Corning Corporation	Michael McLaughlin, IEC Electronics Corp.
Gerald Leslie Bogert, Bechtel Plant Machinery, Inc.	Jonathan Galaska, Dymax Corporation	Mark Northrup, IEC Electronics Corp.
Barbara Kanegsberg, BFK Solutions	Michael Suwe, ELANTAS Beck GmbH	Jagadeesh Radhakrishnan, Intel Corporation
Edward Kanegsberg, BFK Solutions	Robert Phelps, ELANTAS PDG, INC.	Emmanuelle Guene, Inventec Performance Chemicals
Joseph Riendeau, Boeing Research & Development	James Stockhausen, ELANTAS PDG, INC.	Manfred Suppa, Lackwerke Peters GmbH & Co KG
Thomas Crist, CBC Coating, Inc.	Mark Winkeler, ELANTAS PDG, INC.	Vijay Kumar, Lockheed Martin Missile & Fire Control
Jason Keeping, Celestica	Jade Bridges, Electrolube	Sam Polk, Lockheed Martin Missiles & Fire Control
Louis Hart, Compunetics Inc.	Amanda Stuart, Electrolube	
Laura Cote, Continental Automotive Systems	Arthur Perkowski, Electronic Coating Technologies Inc.	
Brian Madsen, Continental Automotive Systems		
Mary Muller, Crane Aerospace & Electronics		



Alisha Amar, Lockheed Martin Space Systems Company	Mradul Mehrotra, Raytheon Missile Systems	Per-Erik Tegehall, Swerea IVF AB
Megan Brecht, Lockheed Martin Space Systems Company	Robert Monier, Raytheon Missile Systems	Rick Carlson, Taiyo America Inc.
Michael Green, Lockheed Martin Space Systems Company	Martin Scionti, Raytheon Missile Systems	Cary Schmidt, Teknetix Inc.
Hue Green, Lockheed Martin Space Systems Company	Nick Webb, Raytheon Missile Systems	Thomas Farrell, Thomas G. Farrell Associates
Dung (Young) Tiet, Lockheed Martin Space Systems Company	Amanda Rickman, Raytheon Systems Company	Renee Michalkiewicz, Trace Laboratories - Baltimore
Dennis Fritz, MacDermid, Inc.	DeAnn Gibbs, Rockwell Collins	Debora Obitz, Trace Laboratories - Baltimore
Albert Mastrangelo, Material Matters International, LLC	Nate Grinvalds, Rockwell Collins	Lee Wilmot, TTM Technologies, Inc.
MaryAnne Mosher, Max Q Systems	Eddie Hofer, Rockwell Collins	Calette Chamness, U.S. Army Aviation & Missile Command
Christopher Hunt, National Physical Laboratory	Douglas Pauls, Rockwell Collins	Bobby Norman, U.S. Army Aviation & Missile Command
Hector Pulido, Nordson ASYMTEK	Debie Vorwald, Rockwell Collins	Sharon Ventress, U.S. Army Aviation & Missile Command
Randy McNutt, Northrop Grumman Corp.	Gordon Sullivan, Royal Adhesives & Sealants	Crystal Vanderpan, UL LLC
Gustavo Arredondo, Para Tech Coating Inc.	Greg Hurst, RSI, Inc.	Andrea Cote, Underwriters Laboratories Inc.
William Yager, Para Tech Coating Inc.	Gaston Hidalgo, Samsung Telecommunications America	Tim Minko, Viasystems Group, Inc.
Richard Litavis, Paradigm Inc.	Yanmei Li, Schlumberger Well Services	Peter Newell, Whirlpool Corporation
Paula Vandenberg, Plasma Ruggedized Solutions	Giovanni Casanova, Schweitzer Engineering Laboratories, Inc	Lionel Fullwood, WKK Distribution Ltd.
Michah Pledger, Pledger Consulting	Greg Simpson, Schweitzer Engineering Laboratories, Inc	Jianfeng Liu, ZTE Corporation
Richard Kraszewski, Plexus Corp.	Stephen Craig, Shin-Etsu Silicones of America, Inc.	Zhe (Jacky) Liu, ZTE Corporation
Kirk Van Dreel, Plexus Corp.	Kim Atkins, Specialized Coating Services	Jiamin Zhang, ZTE Corporation
Amy Hagnauer, Raytheon Company	Lamar Young, Specialty Coating Systems Inc.	John Rohlfing
Bill Vuono, Raytheon Company	Mel Parrish, STI Electronics, Inc.	David Vaughan
Fonda Wu, Raytheon Company		Tom Walker
Lance Brack, Raytheon Missile Systems		

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Guidelines for Design, Selection and Application of Conformal Coatings

1 PREFACE

1.1 Introduction Conformal coatings are used in conjunction with printed circuit assemblies (PCAs). The designer and the users of conformal coatings for electronics applications should be aware of the properties of various types of conformal coatings and their interactions with PCAs to protect the PCAs in the end-use environment for the design-life of the PCA (or beyond). This document has been written to assist the designers and users of conformal coatings in understanding the characteristics of various coating types, as well as the factors that can modify those properties when the coatings are applied. Understanding and accounting for these materials can ensure the reliability and function of electronics.

1.2 Purpose The purpose of this handbook is to assist the individuals who either make choices regarding conformal coating or who work in coating operations. This handbook represents the compiled knowledge and experience of the IPC Conformal Coating Handbook Task Group. It is not enough to understand the properties of the various conformal coatings; the user needs to understand what is to be achieved by applying the conformal coating and how to verify that the desired results have been realized.

1.3 Scope Conformal coating, for the purpose of this document, is defined as a thin, transparent, polymeric coating that is applied to the surfaces of PCAs to provide protection from the end-use environment. Typical coating thickness ranges from 12.5 μm [0.49 mil] to 200 μm [7.9 mil].

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

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

A conformal coating may have several functions depending on the type of application. The most common are:

- a. To inhibit current leakage and short circuit due to humidity and contamination from service environment.
- b. To inhibit corrosion.
- c. To improve fatigue life of solder joints to leadless packages.
- d. To inhibit arcing, corona and St. Elmo's Fire.
- e. To provide mechanical support for small parts that cannot be secured by mechanical means, to prevent damage due to mechanical shock and vibration.

1.4 Classification This standard recognizes that electrical and electronic assemblies are subject to classifications by intended end-item use. Three general end-product classes have been established to reflect differences in producibility, complexity, functional performance requirements and verification (inspection/test) frequency. It should be recognized that there may be overlaps of equipment between classes.

The user is responsible for defining the product class. The product class should be stated in the procurement documentation package.

CLASS 1 General Electronic Products

Includes products suitable for applications where the major requirement is function of the completed assembly.

CLASS 2 Dedicated Service Electronic Products

Includes products where continued performance and extended life is required, and for which uninterrupted service is desired but not critical. Typically the end-use environment would not cause failures.

CLASS 3 High Performance Electronic Products

Includes products where continued high performance or performance-on-demand is critical, equipment downtime cannot be tolerated, end-use environment may be uncommonly harsh, and the equipment must function when required, such as life support or other critical systems.

1.5 Measurement Units and Applications All dimensions and tolerances, as well as other forms of measurement (temperature, weight, etc.) in this standard are expressed in SI (System International) units (with Imperial English equivalent dimensions provided in brackets). Dimensions and tolerances use millimeters as the main form of dimensional expression; micrometers are used when the precision required makes millimeters too cumbersome. Celsius is used to express temperature. Weight is expressed in grams.

1.5.1 Verification of Dimensions Actual measurement of specific part mounting and solder fillet dimensions and determination of percentages are not required except for referee purposes. For the purposes of determining conformance to this specification, all specified limits in this standard are absolute limits as defined in ASTM E29.

Line drawings and illustrations are depicted herein to assist in the interpretation of the written requirements of this standard. Text takes precedence over the figures.

1.6 Order of Precedence The contract always takes precedence over this standard, referenced standards and drawings.

1.6.1 Conflict In the event of conflict between the requirements of this standard and the applicable assembly drawing(s)/documentation, the applicable user approved assembly drawing(s)/documentation govern. In the event of a conflict between the text of this standard and the applicable documents cited herein, the text of this standard takes precedence. In the event of conflict between the requirements of this standard and an assembly drawing(s)/documentation that has not been user approved, this standard governs.

1.7 Appendices Appendices to this Standard are not binding requirements unless separately and specifically required by the applicable contracts, assembly drawing(s), documentation or purchase orders.

1.8 Terms and Definitions Other than those terms listed below, the definitions of terms used in this standard are in accordance with IPC-T-50.

Acetone – A volatile fragrant flammable liquid ketone C_3H_6O used chiefly as a solvent and in organic synthesis.

Adhesion promotion – The chemical process of preparing a surface to enhance its ability to be bonded to another surface, i.e., a layer of conformal coating.

Adhesion failure – The rupture of an adhesive bond such that the separation appears to be at the adhesive-adherent interface.

Anisotropic – Having properties that vary depending on the direction of measurement.

Anthropogenic – Relating to or resulting from the influence of human beings on nature.

ARUR – Abbreviation standing for acrylic resin and urethane resin combination chemistries.

Bridging – Fillet or meniscus formation of coating around the leads of a component caused by capillary action.

Creep – Strain, deformation, or movement of coatings caused by time or temperature.

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

CTE (Coefficient of Thermal Expansion) – Linear dimensional change with respect to an original dimension due to a change in temperature.

Cure – A physical change of state, by solvent removal or cross-linking, whereby a liquid or paste forms a solid.

1) Partial cure = a level of cure that has not yet reached the material's full property profile.

Degradation – Decrease in quality or integrity. Loss of desired physical, chemical, or electrical properties.

Delamination – A separation between a conformal coating layer and the surface it is adhering to.

De-masking – The process of removing or disengaging a maskant film, tape, boot, or plug.

De-wetting – The propensity of the coating material to refuse to wet the surface evenly.

Dielectric constant – The ratio of the capacitance of a configuration of electrodes with a specific material as the dielectric between them to the capacitance of the same electrode configuration with a vacuum or air as the dielectric.

Dielectric strength – The maximum voltage that a dielectric can withstand under specified conditions without resulting in a voltage breakdown, usually expressed as volts per unit dimension.

Dilatometry – The process of measuring expansion.

Dilution – Reduction in viscosity. Can be achieved by mixing a non-reacting, soluble agent into the material.

Dissipation factor – A value that represents the tendency of insulating or dielectric materials to absorb some of the energy in an alternating-current signal.

Diurnal – Occurring every day or having a daily cycle.

Durometer – A measure of the degree of hardness by the resistance to indentation.

EMC – Abbreviation for Electromagnetic Compatibility

EMI (Electromagnetic Interference) – Unwanted radiated electromagnetic energy that couples into electrical conductors.

Emulsion – A stable mixture of two or more immiscible liquids held in suspension by small percentages of emulsifiers.

EOS (Electrical Overstress) – Internal result of an unwanted application of electrical energy that results in damaged components.

ESD (Electrostatic Discharge) – Rapid discharge of electrical energy that was created from electrostatic sources.

Filler – Inert or non-reactive insoluble particles added to a material to modify its solidity, bulk, or other properties.

Fish Eyes – A surface defect to the conformal coating that resembles the eyes of a fish.

Gel time – The amount of time it takes for a coating to solidify into a gel. The gel point is reached when the cross-linking begins to dominate the nature of the coating.

Glass transition temperature (T_g) – The approximate temperature at which a polymer reversibly converts between a relatively brittle condition and a viscous or rubbery condition. This is an important property used to characterize polymeric materials since many of a polymer's properties will change depending on whether it is above or below its T_g .

Hardness – A property that indicates the ability of a material to resist penetration of a specific type of indenter when forced into the material under specified conditions. Indentation hardness is inversely related to the penetration and is dependent on the elastic modulus and viscoelastic behavior of the material. Also known as Durometer.

Heptane – Any of several isometric alkanes C_7H_{16} ; especially the liquid normal isomer occurring in petroleum and used especially as a solvent and in determining octane numbers.

Hybrid – A coating system with more than one principle resin chemistry.

Hydrolytic stability – The degree of resistance of a polymer to permanent property changes from exposure to moisture.

Hydrophobic-Oleophobic Coatings – A coating that repels water and oils.

Impedance – The resistance to the flow of current, represented by an electrical network of combined resistance, capacitance and inductance reaction in a conductor as seen by an AC source or varying time voltage.

Inhibition – The inability for the coating materials to obtain the desired properties at the manufacturers' specified cure time and temperature.

Insulation resistance – A measure of the capability of a material to electrically insulate adjacent conductors from each other.

Masking – The process of applying a temporary film, tape, boot, or plug that prevents the area covered from being coated.

Mealing – A condition in the form of discrete spots or patches that reveals a separation at the interface between a conformal coating and the surface to be coated.

Monomer – A chemical compound that can undergo polymerization.

MSDS (Material Safety Data Sheet) – Provided by the manufacturer, contains relevant properties of the material with regards to safety concerns.

Multi-layering – The process of applying more than one layer of coating to make up the desired thickness.

NBC contamination – Abbreviation for Nuclear, Biological and Chemical agents of contamination.

Oligomer – A polymer or polymer intermediate containing relatively few structural units.

Orange peeling – A surface defect to the conformal coating that resembles the surface or skin of an orange.

Outgassing – The emission of vapors from a processed coating layer when it is exposed to heat or reduced air pressure or both.

Permeability – The ability of molecules of one material to flow through the matrix of another material. The degree of permeability is dependent on the molecular structure of both materials.

Photoresist – A material that is sensitive to portions of the light spectrum and that, when properly exposed, can mask portions of a base metal from exposure with a high degree of integrity.

Polymer – A compound of repeating chemical units that covalently chemically bond to form a higher molecular weight material.

Polymerization – The formation of a matrix of cross-linked long chain molecular structure from short chain monomer molecules.

Polysiloxane – A polymer whose main chemical linkage is repeating units of SiO atoms bonded together.

Pot life – The length of time a material, substance, or product can be left in an open package or dispenser while it meets all applicable requirements and remains suitable for its intended use.

Priming – A surface treatment utilizing a surfactant to promote adhesion of conformal coating.

Repair – The act of restoring the functional capability of a defective article in a manner that precludes compliance of the article with applicable drawings or specifications.

Rework – The act of reprocessing noncomplying articles, through the use of original or alternate equivalent processing, in a manner that assures compliance of the article with applicable drawings or specifications.

RTV (Room Temperature Vulcanizing) – The development of desired dry film properties at room temperature.

Shadowing, coating –

1. A situation that can occur during spray coating of a PCA when components may hide or “shadow” the area underneath them, relative to the spray direction, preventing the surfaces beneath the component from being coated.
2. Also used in reference to curing of coatings by UV rays when components may hide or “shadow” the area underneath, not allowing it to be exposed and cured by the UV rays.

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

Shrinkage – Reduction in volume as a wet, freshly applied layer dries/cures into a coating film with desired properties.

Solids content – The proportion of “resin” or polymer material to the solvent carrier.

Spectroscopy – The production and investigation of spectra, or the process of using a spectroscope or spectrometer.

Stripping – The process of eroding a material by chemical reaction. Stripping agents can be used to remove certain types of conformal coating for the purpose of rework or repair.

Surface tension – The natural, inward, molecular-attraction force that inhibits the spread of a liquid at its interface with a solid material.

Thermoplastic – A plastic that can be repeatedly softened and reshaped, without any significant change in inherent properties, by exposure to heat and hardened by cooling.

Thermoset – A plastic that undergoes a chemical reaction when exposed to elevated temperatures that leads to it having a relatively infusible or crosslinked state that cannot be softened or reshaped by subsequent heating.

Toluene – A liquid aromatic hydrocarbon C_7H_8 that resembles benzene but is less volatile, flammable and toxic and is used as a solvent in organic synthesis. Also known as Methyl Benzene.

Transfer efficiency – The ratio of volume dispensed to the desired volume of coating materials on the PCA

Vesication – The formation of blisters at the interface between a semi-permeable polymer film coating and another material caused by an osmotic effect from the interaction of water soluble matter with moisture.

Viscosity – A fluid's resistance to flow.

VOC (Volatile organic compound) – Regulated compounds containing carbon that have measurable vapor pressures.

Wetting – The formation of a relatively uniform and adherent film of materials on a surface.

Withstand voltage – See dielectric strength.

Young's modulus – Modulus of elasticity. A measure of the flexibility of a material. The lower the modulus, the more flexible the material.

2 APPLICABLE DOCUMENTS

The following documents are listed for reference only. This handbook does not attempt to explain these documents. The following documents of the issue currently in effect form a part of this specification to the extent specified herein.

2.1 ASTM International Standards¹

ASTM B244 Standard Test Method for Measurement of Thickness of Anodic Coatings on Aluminum and of Other Nonconductive Coatings on Nonmagnetic Basis Metals with Eddy-Current Instruments

ASTM D570 Standard Test Method for Water Absorption of Plastics

ASTM D635 Rate of Burning or Extent and Time of Burning of Self-Supporting Plastics in a Horizontal Position

ASTM D1005 Standard Test Method for Measurement of Dry-Film Thickness of Organic Coatings Using Micrometers

ASTM D1212 Standard Test Methods for Measurement of Wet Film Thickness of Organic Coatings

ASTM D2578 Wetting Tension of Polyethylene and Polypropylene Films

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 D5725 Standard Test Method for Surface Wettability and Absorbency of Sheeted Materials Using an Automated Contact Angle Tester

ASTM D6132 Standard Test Method for Nondestructive Measurement of Dry Film Thickness of Applied Organic Coatings Using an Ultrasonic Gage

ASTM D7334 Standard Test Method for Measurement of the Surface Tension of Solid Coatings, Substrates and Pigments using Contact Angle Measurements

ASTM E29 Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

ASTM E96 Standard Test Methods for Water Vapor Transmission of Materials

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

ASTM F22 Standard Test Method for Hydrophobic Surface Films by the Water-Break Test

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

ASTM G21 Standard Practice for Determining Resistance of Synthetic Polymeric Materials to Fungi

ASTM G151 Standard Practice for Exposing Nonmetallic Materials in Accelerated Test Devices that Use Laboratory Light Sources

ASTM G154 Standard Practice for Operating Fluorescent Light Apparatus for UV Exposure of Nonmetallic Materials

ASTM G155 Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials

2.2 Federal Aviation Regulations (FAR)²

FAR §25.853 and Appendix F FAA material flammability tests

1. Note: revision dates of the ASTM International standards are not included in their listing here. Please refer to the current revision.

2. www.faa.gov

2.3 IPC Standards³

IPC-HDBK-001 Handbook & Guide to Supplement J-STD-001

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

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

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

IPC-A-610 Acceptability of Electronics Assemblies

IPC-TM-650 Test Methods Manual⁴

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)

2.4.1.6 Adhesion, Polymer Coating

2.6.1.1 Fungus Resistance - Conformal Coating

2.6.3 Moisture and Insulation Resistance, Printed Boards

2.6.3.1 Solder Mask - Moisture and Insulation Resistance

2.6.3.4 Moisture and Insulation Resistance - Conformal Coating

2.6.7.1 Thermal Shock - Conformal Coating

2.6.11.1 Hydrolytic Stability - Conformal Coating

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

IPC-SM-840 Qualification and Performance of Permanent Solder Mask

IPC-HDBK-850 Guidelines for Design, Selection and Application of Potting and Encapsulation Materials Used for Electronics Circuit Board Assembly

IPC-1331 Volunteer Safety Standard for Electrically Heated Process Equipment

IPC-2221 Generic Standard on Printed Board Design

IPC-6012 Qualification and Performance Specification for Rigid Printed Boards

IPC-7093 Design and Assembly Process Implementation for Bottom Termination Components

IPC-7095 Design and Assembly Process Implementation for BGAs

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

2.4 Joint Industry Standard⁵

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

J-STD-004 Requirements for Soldering Fluxes

2.5 Military Standards⁶

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

MIL-STD-454 Standard General Requirements for Electronic Equipment

MIL-STD-810 Environmental Engineering Considerations and Laboratory Tests

3. www.ipc.org

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

5. www.ipc.org

6. www.dscc.dla.mil

MIL-HDBK-454 General Guidelines for Electronic Equipment

MIL-F-13927 Fungus Resistance Test: Automotive Components

MIL-I-46058 Insulating Compound, Electrical (For Coating Printed Circuit Assemblies)

2.6 Underwriters Laboratories⁷

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

UL746C Polymeric Materials - Use in Electrical Equipment Evaluations

UL508 Industrial Control Equipment

UL508A Industrial Control Panels

2.7 International Standards

2.7.1 European Standards^{8,9}

British Defense Standard 59-47 Conformal Coatings for Panels Printed Circuit and Panels Electronic Circuit

EN 60204-1 Safety of Machinery - Electrical Equipment of Machines - Part 1 General Requirements

EN 61086 (BS) Specification for Coatings for Loaded Printed Wire Boards [Conformal Coatings]

EN ISO 2360 Non-Conductive Coatings on Non-Magnetic Electrically Conductive Basis Materials - Measurement of Coating Thickness - Amplitude-Sensitive Eddy Current Method

DIN 600687-2-10 Electrical Engineering; Environmental Testing Procedures Test J And Guidance: Mold Growth

EU 98/37EC Directive of the European Parliament and of the Council on Approximation of the Laws of Member States Relating to Machinery

EN ISO 2808 Paints and Varnishes

2.7.2 IEC Standards¹⁰

IEC 61086 Specification for Coatings for Loaded Printed Wire Boards [Conformal Coatings]

IEC 61086-2-14 Environmental Testing - Part 2-14: Tests - Test N: Change of Temperature

IEC 61086-2-30 Environmental Testing - Part 2-30: Tests - Test Db: Damp Heat, cyclic (12 +12h cycle)

IEC 61086-2-38 Environmental Testing - Part 2-38: Tests - Test Z/AD: Composite Temperature/Humidity Cyclic Testing

2.7.3 Japanese Standards¹¹

JSA JIS Z 2911 Methods of Test for Fungus Resistance

2.8 US OSHA¹²

US OSHA 1910.106 Flammable Liquids

US OSHA 1910.107 Spray Finishing using Flammable and Combustible Materials

US OSHA 1910.134 Respiratory Protection

US OSHA 1910.1200 Hazard Communication

2.9 RTCA, Inc. Standards¹³

RTCA DO-160 Environmental Conditions and Test Procedures for Airborne Equipment

7. www.ul.com

8. www.dstan.mod.uk

9. www.iec.ch

10. www.jisa.or.jp

11. www.osha.gov

12. www.rtca.org

13. www.nfpa.org

2.10 NFPA Standards¹⁴

NFPA 33 Standard for Spray Application Using Flammable & Combustible Liquids

NFPA 35 Standard for the Manufacture of Organic Coatings

NFPA 79 Electrical Code for Industrial Equipment

NFPA 496 Purged & Pressurized Enclosures for Electrical Equipment

2.11 B11 Standards¹⁵

ANSI B11.1 Safety of Machinery

2.12 FM Global Standards¹⁶

FM Class 3600 Approval Standard for Electrical Equipment for use in Hazardous (Classified) Locations - General Requirements

FM Class 3620 Approval Standard for Purged and Pressurized Electrical Equipment for Hazardous (Classified) Locations

FM Class 3810 Approval Standard for Electrical Equipment for Measurement, Control and Laboratory Use

2.13 SEMI Standards¹⁷

SEMI S8-0308 Safety Guidelines for Ergonomic Engineering of Semiconductors Manufacturing Equipment

SEMI S2-0310e Environmental, Health, and Safety Guideline for Semiconductor Manufacturing Equipment

SEMI S14-0309 Safety Guidelines for Fire Risk Assessment and Mitigation for Semiconductor Manufacturing Equipment

2.14 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 conformal coated, or a text document which contains requirements and processes that conformal coatings shall meet in the “applied” condition. Specifically directed to the assembly and fabrication of hardware, these requirements are usually based on electrical output, physical performance and life cycle reliability of an assembly in an end-use environment. Since each assembly is unique in its functional and electrical responses, conformal coatings have to be selected for usage based on their ability to perform as a protective coating without deleterious effects upon electronic circuit elements over the assemblies performance and life cycle requirements while also meeting the material property and compatibility of the conformal coating to the assembly substrate surfaces.

2.15 The Nature of MIL-I-46058 and IPC-CC-830 For conformal coatings, the two primary specifications that the reader needs to understand are MIL-I-46058 and IPC-CC-830. Mil-I-46058 was originally designed to qualify a conformal coating using various test methods and minimum values. These tests were established based on industry standards using typical generic materials available at that time. In early 1960, the Department of Defense at Fort Monmouth, New Jersey, was responsible for the initial development and issuing of the specification. There have been seven amendments of the specification since the original, each revising and modifying various tests.

Many individuals do not understand the nature of IPC-CC-830 or MIL-I-46058 and consequently they are often misused as specifications.

IPC-CC-830 and MIL-I-46058 are both material qualification specifications. The two documents are virtually identical. The IPC committees in charge of IPC-CC-830 have striven to keep the two documents this way so that coating manufacturers would not have to do two qualification batteries as the tests in MIL-I-46058 were deemed to be acceptable for basic material qualification. For this reason, the IPC committees have not sought to significantly change or modernize IPC-CC-830 at the time of this standard's publication.

14. www.b11standards.com

15. osha.europa.eu

16. www.fmglobal.com

17. www.semi.org

Both of these documents specify a series of tests for conformal coating materials, on standard substrates, with defined minimum acceptability criteria. The tests specified in these documents are those chosen by the military and high-performance segment of the electronics industry to examine the most critical elements of conformal coatings.

Passing these tests is no guarantee that the conformal coating will work in any given application and does not assure that the coating is “good.” Nor does it mean that not qualifying to this specification indicates that the coating is “bad.” These two specifications merely set a minimum set of criteria for a coating to be considered for military or high-performance application. The onus is, and has always been, on the OEM to determine if a coating is adequate for the end item application for the end use environment.

The proper use of these two standards is for material qualification, **NOT** material performance, **NOR** coating methodologies or techniques. Example: *Conformal coating shall be qualified to MIL-I-46058, Type AR.*

It is left to performance standards, such J-STD-001, or to individual customer requirements to define performance requirements for conformal coating on electronic assemblies.

Therefore, an incorrect call out of these documents relates to linking either MIL-I-46058 or IPC-CC-830 to performance on product. Example: *Coating shall be applied and cured per IPC-CC-830.*

It is also important to understand that MIL-I-46058 was declared “Inactive for New Designs” in 1995. Legally, this means that the reference to MIL-I-46058 should not have been used on any new design or design drawing starting in 1995. There have been no technical updates or revision efforts to this document since 1995. So, it can legitimately be asked, “Why this document is still relevant to the industry today?”

To understand why this military specification is still used, it is necessary to first understand the concept of the Qualified Products List or QPL. Example: QPL-46058 (<http://www.dsccl.dla.mil/programs/qmlqpl/QPLdetail.asp?QPL=46058>) for conformal coatings qualified to MIL-I-46058. Most defense contracts specified that any conformal coating used on military or government hardware had to appear on QPL-46058.

In the past, the government would serve both as a repository of material qualification data as well as an auditor or overseer of the independent laboratories or captive test labs that were generating the qualification data. Each year, a DoD Quality Assurance Representative (QAR) was required to visit and qualify each test laboratory and certify their ability as well as witness the actual tests as they are being performed. If a test material was found to pass the required minimums by a qualified laboratory, then that product would be listed on the publicly available QPL for that specification. MIL-I-46058 also required yearly recertification of coatings or every two years for long term tests such as hydrolytic stability.

With this understood, the reason why MIL-I-46058 is still in use 18 years after being declared inactive for new design lies in three areas: (1) popular misconception; (2) the logistical framework of the U.S. defense manufacturing network; and (3) qualification requirements imposed upon coating vendors.

- a. The popular misconception, especially within the defense or high performance electronics industry, is that if a coating appears on the QPL, then it must be “good.” Some expert in the government must have reviewed the data sometime and found the coating to be “acceptable.” Therefore, I don’t have to spend time or money qualifying a new coating because the government has already done so.
- b. The second reason lies purely in inertia. The defense establishment, while not as big as it was in the 1990s, is still a very large entity with tens of thousands of contracts setup where a QPL is a required contractual item. Consequently, the government maintains QPL-46058. The current custodian of the specification and QPL is the Defense Supply Center - Columbus (DSCC). In addition, many countries outside of the United States, who may not have access to the necessary resources or expertise to develop their own coating specifications, have used the US military specifications as guidance on materials and acceptable manufacturing practices.
- c. The third reason is closely linked to the second. Defense manufacturers continue to require coating vendors to perform qualification to MIL-I-46058, and meet the re-certification requirements of the standard in order to do business with them.

It is important to understand the ramification of these items.

- a. The government, due to cutbacks over the years, no longer sends out auditors to determine the qualifications or accuracy of the test data generated. This change occurred sometime in 1999, with the DoD relying on self-certification. In 2000 the DOD stated that this spec is not to be used for new designs.
- b. DSCC has become only a custodian of the test data and of the QPL. Test reports are submitted by the coating vendor, but are not independently verified by the government. In most cases, the data is generated by independent test labs that do such tests routinely and the data is still accurate but there is no government validation of the data.

assumes happens. There is practically no difference between a vendor claiming MIL-I-46058 (with supporting reports) and a QPL-46058 listing.

- c. There is not now, nor has there ever been, a guarantee that a QPL listed coating will work on your product, for your application, for your design life, for your end use environment. That is, and has always been, the duty of the original equipment manufacturer (OEM). The only advantage gained by the QPL is that some of the basic material evaluation tests have already been done.
- d. Military specifications, like their commercial counterparts, are formed from military and commercial working groups of experts. To remain relevant and applicable, they must constantly be revised and updated by knowledgeable people to keep pace with technological developments and improvements in material science. MIL-I-46058 has had no such input or changes since the late 1980s. By perpetuation of the QPL framework, an OEM essentially ties their performance to 1980s technology.
- e. In some cases, the Department of Defense cancelled without replacement their material qualification specification, and adopted the industry standard. An example was the cancellation of MIL-F-14256 and adoption of IPC-J-STD-004. The defense industrial complex tends to fight such changes as commercial specifications do not use QPL structures. However, just as the industry adapted to the change to IPC-J-STD-004, it could similarly do so for conformal coatings.

2.16 The Relation of MIL-I-46058 and IPC-CC-830 to Performance Specifications With the understanding above, that MIL-I-46058 and IPC-CC-830 are only for material qualification testing, it is important to understand the use of conformal coating in relation to performance specifications. A performance specification, whether military, commercial, or OEM-specific, indicates what performance a conformal coating must provide to be considered as acceptable. Examples include:

- a. Conformal coating shall protect exposed metallic circuitry against 250 hours of salt fog testing when tested per Procedure X.
- b. Conformal coating shall not blister or delaminate from the substrate when subjected to 48 hours of thermal cycling per Profile X.

Such specifications also indicate unacceptable coating conditions (defects), which relate to coating application and curing methods. Examples include:

- a. Conformal coating shall not contain foreign objects or debris (FOD) when examined at 4X magnification.
- b. Conformal coating shall not contain pinholes or fisheyes when viewed at 4X under black light illumination.

J-STD-001 is the primary IPC performance specification for electronic assemblies, with conformal coating performance outlined in Section 10 of that specification.

IPC-A-610 is a workmanship standard which gives visual guidance on acceptable and unacceptable coating conditions, giving examples of pinholes, inadequate coverage, fisheyes, etc. As such, it is not considered to be a performance specification and should not be used as such.

Table 2-1 compares how the J-STD-001 and the IPC-A-610 compare when dealing with conformal coating criteria.

OEM generated performance specifications vary widely in the industry and which industry segment is involved. Aerospace, automotive, industrial controls, telecommunications, etc., will all have performance requirements that differ, depending on the end use application and design life of the product. However, the performance specification should always list the following elements:

- a. What the coating is expected to do.
- b. For what period of time.
- c. After what accelerated test methodology.
- d. A definition of what constitutes a defect or coating failure.

**Table 2-1 The Relation of IPC-A-610 and J-STD-001 to Acceptance Standards
Conformal Coating Criteria Comparison (IPC-A-610E vs. J-STD-001E)**

IPC-A-610E (Ref: 10.8.2; Accept Criteria)	J-STD-001E (Ref: 10.1.2.2)	Comments:
Completely cured and homogenous.	Be Completely cured and homogenous.	Same, no conflict.
Coating only in those areas where coating is required.	Cover only in those areas specified on the assembly drawing(s)/documentation.	Same, no conflict.
Loss of adhesion adjacent to masking.	No masking area specific criteria.	Potential conflict. (Tolerance around masking area as agreed between user & supplier) without this tolerance deltas may arise.
No bridging of adjacent lands or conductive surfaces from: • Loss of adhesion (mealing) • Voids or bubbles *Dewetting • Cracks • Ripples • Fisheyes or orange peel Entrapped material does not violate minimum electrical clearance between components, lands or conductive surfaces.	Be free of blisters, or breaks that could affect the operations of the assembly or sealing properties of the conformal coating. Be free of cracks, crazing, voids, bubbles, mealing, peeling, wrinkles or foreign material which expose component conductors, printed circuit conductors, (including ground planes) or other conductors or violates design electrical clearance.	Exposed conductive surfaces vs. sealing properties. (No definition of a sealing property is present, potential conflict) without this definition deltas may arise. Essentially the same, no conflict.

3 ENVIRONMENTAL, HEALTH AND SAFETY (EHS) REQUIREMENTS

The application of a conformal coating to a printed circuit board assembly (PCA) typically involves spraying, brushing or otherwise applying a solution in which the conformal coating resin can be dissolved in a solvent onto the assembly. Applying conformal coatings by spraying is subject to the 1910.107 *Spray Finishing using Flammable and Combustible Materials* standard of US OSHA. The solvent then evaporates/volatilizes leaving the resin coating on the PCA. This conformal coating process involves the following EHS issues:

- Employee exposure to the solvent or resin.
- Fire safety considerations when the solvent is flammable or combustible.
- Air emissions from the volatilized solvent (e.g., VOCs, HAPs, etc.).
- Waste management from used brushes or other applicators, spray gun cleanup mixtures, unused coating solution and used masking tape.
- Material content declaration (MCD) requirements.
- Greenhouse gas (GHG) reporting.
- Equipment design and construction.

Each of these EHS issues must be addressed for compliant conformal coating operations both internally and externally with all applicable regulatory agencies

3.1 Employee Exposure to Conformal Coating Materials/Ingredients Other than water, most conformal coating solvents are non-halogenated organic solvents that have established hygienic exposure limits for workers exposed to these materials. Examples of these permissible exposure limits (PELs) are contained in Table 3-1.

NOTE: The industry results above are current with the writing of this document, but should be validated by users for their current requirements and standards.

Some solvents like chlorobenzotrifluoride and propylene glycol methyl ether acetate (PGMEA) have no established hygienic limits.

The primary method of achieving safe and compliant exposure levels for employees using these coatings is ventilation both local and general. Industrial hygiene (IH) testing is required to determine employee exposure to these materials. Particular attention must be paid to the isocyanate compounds (e.g., TDI, MDI) material in urethane coatings due to its extremely low exposure limit. IH results above the adopted PEL or ceiling limit will require improvements in local ventilation or, if no engineering controls are possible, that spray coating employees wear air purifying respirators. Wearing a respirator is not

Table 3-1 Permissible Exposure Limits (PELs)

Material/Ingredient	8-hour PEL	Coating Used
Ethyl benzene	100 ppm	Epoxy and urethane
Isobutyl acetate	150 ppm	Acrylic
Isopropyl alcohol	400 ppm	Acrylic
Methanol	200 ppm	Acrylic
Toluene ¹	200 ppm	Urethane
Toluene diisocyanate (TDI)	0.005 ppm	Urethane
Xylene	100 ppm	Epoxy

1. Ceiling limit = 300 ppm. In CA 10 ppm and 150 ppm

compliance to several US OSHA requirements in their 1910.134 *Respiratory Protection* standard including medical clearance to wear a respirator (134(e)), along with annual fit testing (134(f)), required training (134(k)) and respirator maintenance (134(h)).

In addition to airborne concentrations of coating solvents, Printed Board (PB) and PCA manufacturers must also ensure that coating employees wear the appropriate personnel protective equipment (PPE), e.g., glasses or goggles, gloves, apron, etc., to prevent skin contact with these solvents. Users of conformal coatings must also be aware that coating materials can cause skin sensitization from repeated contact. This is another reason to ensure that required PPE is worn at all times, and that proper PPE donning and doffing procedures are followed. Users should also note that used PPE is a waste stream that requires proper management. In addition to the above, PPE and filters for area intake should be maintained on a proper schedule.

3.1.1 Hazard Communication The health hazards (both acute and chronic) and physical hazards of all materials must be clearly communicated to all employees that work with each material. Historically, this information was provided in both material safety data sheets (MSDSs) and associated container labels. Container labeling typically used either the Hazardous Material Identification System (HMIS) or the National Fire Protection Association (NFPA) labels that used a three color and 0-4 rating system to quickly convey material hazards. Appendix N contains descriptions of these labeling systems.

In 2002, the United Nations adopted its standard on the Transport of Dangerous Goods and the Globally Harmonized System of Classification and Labeling of Chemicals. Many nations then adopted the GHS standard including Japan in 2006; the European Union, Korea, Singapore, Taiwan and Vietnam in 2008; Brazil, China, Indonesia, Russia, South Africa and SOLAS in 2009; and Australia and Mexico in 2011. The GHS standard replaces MSDSs with Safety Data Sheets (SDSs) having a fixed format, and establishes a standard classification for each hazard and labeling template using pictograms, signal words and hazard statements. The US adoption of the GHS system by US OSHA in March 2012 requires that all employee training be completed by December 2015 and full compliance with all adopted GHS requirements by June 2016.

3.1.1.1 GHS Safety Data Sheet (SDS) The GHS SDS contains 16 sections in a standardized order. Appendix P shows the breakdown of these sections. Note that US OSHA does not enforce section 12 (ecological), 13 (disposal) and 14 (transport) information requirements of the GHS SDS.

3.1.1.2 GHS Hazard Classification The GHS standard establishes hazard category on a 1-4 scale for each type of hazard (health, physical and environmental). Unfortunately for US users that are familiar with the HMIS and NFPA hazard rating systems, the GHS hazard categories are reverse of both the HMIS and NFPA ratings. An example of this difference is the ratings for flammable liquids in Table 3-2.

Table 3-2 Ratings for Flammable Liquids

Flash Point	-7 °C [<20 °F]	-7 to 38 °C [20-100 °F]	38-60 °C [100-140 °F]	60-66 °C [140-150 °F]	66-93 °C [150-200 °F]
GHS	Category 1 or 2	Category 1 or 2	Category 1 or 2	Category 1 or 2	None for >200F
OSHA	Flammable	Flammable	Combustible	Combustible	Combustible
NFPA	4	3	2	2	2 (>200 is 1)
HMIS	4	3	2	2	2

Other hazard categories per the GHS standard are shown in Appendix O.

3.1.1.3 GHS Container Labels Once the hazard category has been established based on a chemical's physical properties, the GHS standardized container labels must contain the following information per Appendix O of the US OSHA Hazard Communication standard 1910.1200:

"C.2 The label for each hazardous chemical that is classified shall include the signal word, hazard statement(s), pictogram(s) and precautionary statement(s) specified in C.4 for each hazard class and associated hazard category, except as provided for in C.2.1 through C.2.4."

3.1.2 Other Employee Exposure Issues

3.1.2.1 Rework There are four primary modes of conformal coating rework:

- a. Chemical Stripping
- b. Thermal Stripping
- c. Abrasive Blasting
- d. Mechanical removal

Each of these methods has potential impacts on the health and safety of rework operators.

3.1.2.1.1 Chemical Stripping Conformal coating stripping by chemical methods often requires solvents with strong smells and potential health hazards. Some stripping agents are known or suspected carcinogens. Exposures to such agents are limited as shown in 3.1 for some materials. Many agents are caustic and will attack the skin and other membranes. Chemical stripping should always be done in an area where ventilation is good, preferably in a method which exhausts vapors, such as a fume hood. Consult the Safety Data Sheet (SDS) for recommended personal protective equipment (PPE) required if local ventilation cannot control employee exposure to established hygienic standards. Chemically resistant gloves and safety glasses are required. Many of the stripping solvents are flammable and so care should be taken to keep these materials away from point ignition sources and must be stored in flammable cabinets. Used stripping solvent and stripped coatings are generally disposed of as hazardous wastes, and so protective measures have to be taken when handling these wastes.

3.1.2.1.2 Thermal Stripping Thermal stripping of conformal coating is often accomplished by heated blades or streams of heated air, often 200-300 °C [392-572 °F]. Thermal protection measures must be taken to avoid burning the skin. Thermal gloves and safety glasses are recommended. In addition, the high temperatures involved can cause the conformal coating to pyrolyze or burn. The decomposition products released can be respiratory hazards and irritants to eyes and may have an established exposure standard. Thermal stripping should be used in conjunction with fume extraction equipment.

3.1.2.1.3 Abrasive Blasting Abrasive removal of conformal coating is very similar to "sand-blasting," but which uses more refined media. The velocity of the blast media particles can be quite high and would damage skin easily. Care must be taken to avoid contact with the stream of particles. Abrasive blasting is also a "dusty" form of coating removal, and is most often done in a glove-box form of containment. Care must be taken to avoid inhalation of the blast media particles as well as the particles of removed coating. Exposure to "particles not otherwise regulated" is limited by US OSHA to 15 mg/m³ total and 5 mg/m³ respirable.

3.1.2.1.4 Mechanical Removal Mechanical removal of conformal coating is accomplished with bladed instruments, such as scalpels or with rotary mills. The primary hazard for bladed instruments is the danger of cutting the skin. Fixtures to hold the assembly and Kevlar gloves are recommended. The primary hazard for rotary devices is airborne particles and inhalation of such particulate matter. Safety glasses and dust respirators are recommended for such actions if local ventilation is infeasible to limit employee exposure to airborne contaminants.

Industrial hygienists, familiar with local rules and regulations, should be consulted for more information on worker protective measures.

3.2 Fire Safety Requirements As the example list of solvents in Table 3-2 shows, many conformal coating solvents are either flammable (flash point below 37.8 °C [100 °F]) or combustible (flash point at/above 37.8 °C [100 °F]). As such, conformal coating operations present a fire hazard in the facility where the coating operations are located. Before installing such a coating operation, the design should be reviewed and approved by the facility's property protection insurance carrier. Many property protection carriers will evaluate accordingly to FM 7-14 data sheet recommended test standards for installations like spray booths, including storage requirements for flammable and combustible liquids in fire-resistant cabinets.

install and operate conformal coating operations to adopted fire prevention standards will not only risk employee safety, but will pose a business interruption hazard to the facility and higher property protection insurance costs to that facility.

In addition to property protection insurance carrier approval, the US OSHA 1910.106 covers the storage and use of flammable liquids. Further, most local fire departments require notification or approval to store flammable liquids on-site and annual inventory submittals like the California Hazardous Materials Business Plan (HMBP). Users of conformal coatings should verify local fire department requirements for coating solutions.

NOTE: US assemblers that utilize spraying to apply conformal coatings should be aware of the fire prevention requirements in US OSHA's spray finishing regulations such as the 1910.107(g)(2) requirement that all spraying areas must be kept as free as possible of combustible residue buildup, including daily cleaning if necessary. Hence, the overspray on both sides and floors of spray booths must be kept clean.

3.3 Air Emissions / Permitting The ventilation of conformal coating workplaces, specifically exhausts, contains the source of the vast majority of volatile organic compound (VOC) emissions from PCA facilities. Such emissions are regulated in most locations, with the primary requirements being either state or local rules on emitting VOCs. The application of such emission rules is based on the 24 hour/day x 365 days/year, or 8760 hours/year operation potential to emit (PTE). Such PTE limits are often expressed as tons/year (TPY). Therefore, hourly emission rate x 8760/2000, or 4.38 = TPY.

VOC emission regulations are also set as pounds of VOC per gallon of coating applied. This approach often limits the volume (gallons) of coating used in a day, week or year. Both the TPY and gallons/unit of time limits require that conformal coating users must quantify and know the exhaust usage rate for conformal coating operations or annual purchase amounts.

In addition to VOC emission limits, many air control districts like California's AB2588 Hot Spots rules, or Connecticut's 22a-174-29 Hazardous Air Pollutants (HAPs) have regulations that address the emission of certain VOCs that are designated as toxic air contaminants (TACs). The permitting of such TAC VOCs is based on an air dispersion analysis of the solvent in the emission stack and what resulting property line concentration would be. TAC regulations establish either a maximum allowable stack concentration (MASC) or a property line concentration for the TAC emitted. Toluene and xylene are two examples of VOCs that are also TACs and must be analyzed for both air emission requirements.

3.4 Solid Waste Management The main waste stream from conformal coating is generally the mixture that results from cleaning the tooling and its container of the coating last applied. Such waste may be generated several times per day as pot life is exceeded or if different coatings are applied. Tooling cleaning solvent waste can be minimized by utilizing an on-site solvent reclaim unit that recovers virtually all of the cleaning solvent and minimizes solvent in the waste coating solids that remain. A similar waste stream can be unused or out-of-date coating solution. Such wastes are typically classified as flammable wastes (US EPA waste code D001). Note that the EPA definition of a flammable waste is a waste with a flash point below 37 °C [100 °F]. This threshold would capture some combustible solvents as defined by US OSHA.

In addition to waste tooling cleaning mixtures and unused or out-of-date coating solutions, conformal coating wastes include empty solution containers (potentially includes aerosol cans), used filters, brushes, PPE gloves, respirator masks, etc., used PCA masking tape, and also peelable spray booth wall coating.

Each waste stream must be analyzed to ascertain whether or not it meets the criteria of a hazardous waste, or a non-hazardous solid waste. All such waste determinations must be documented and reviewed annually to ensure accuracy. Some states classify any process waste as a state waste even though such wastes do not meet any hazardous waste criteria.

3.5 Material Content Declaration (MCD) Regulations Many legal entities have adopted regulations and directives that ban or restrict certain substances in electronic products and components. In the European Union, these include Restriction of Hazardous Substances (RoHS), Waste Electrical and Electronic Equipment (WEEE), End of Life Vehicles (ELV), Registration, Evaluation, Authorization and Restriction of Chemicals (REACH), and Energy using Products (EuP). Other countries have adopted related laws or regulations to control substances of concern or recycle the waste, such as China's PoHS, *Administrative measures on the control of pollution caused by electronic information products* and Korea's *Act for Resource recycling of electrical and Electronic Equipment and Vehicles*. Conformal coating is an homogenous material used in electrical and electronic equipment or automobiles and is covered by these regulations. Conformal coatings must meet the requirements of different countries where the components or products are manufactured or sold.

3.5.1 EU RoHS/WEEE/ELV

- a. Directive 2002/95/EC of the European Parliament and of the Council on the Restriction of the use of certain Hazardous Substance in electrical and electronic equipment (RoHS Directive)

- b. Directive 2002/96/EC on Waste Electrical and Electronic Equipment (WEEE Directive)
- c. Directive 2000/53/EC of the European Parliament and of the Council on End-of-Life Vehicles (ELV Directive)

The RoHS Directive seeks to reduce the concentration of six hazardous substances in electrical and electronic equipment (EEE) articles to 1000PPM (by weight) for lead, mercury, hexavalent chromium, Polybrominated biphenyls (PBB) and Polybrominated diphenyl ether (PBDE) and 100PPM (by weight) for cadmium in EEE. The ELV Directive limits concentrations of four metals in motor vehicles to 1000PPM (by weight) for lead, mercury, hexavalent chromium, and 100PPM (by weight) for cadmium.

Both the WEEE and ELV directives specify the minimum recycling requirements for waste electrical and electronic equipment and vehicles at end-of life to minimize the impact of waste on the environment. According to WEEE, producers should meet the related recovery requirements by 10 different EEE categories. According to ELV, no later than January 1, 2015, for all end-of life vehicles, the reuse and recovery shall be increased to a minimum of 95% by an average weight per vehicle and year. Within the same time limit, the reuse and recycling shall be increased to a minimum of 85% by an average weight per vehicle and year.

If the conformal coating is used in electrical and electronic equipment or vehicles which are sold to EU market and covered by RoHS, ELV or WEEE, it must meet those requirements.

3.5.2 REACH European Union Regulation (EC) No 1907/2006, Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) entered into force on June 1, 2007. The regulation requires that all substances manufactured or imported into the EU/EEA on their own, in preparations, or released from articles during their normal use must be registered if certain criteria are met. Substances contained in articles and are not released during normal use are exempt from this registration requirement.

In addition, REACH establishes substances of very high concern (SVHCs) that if contained in articles, must be declared and safe use information must be provided to customers and consumers of such articles. The list of the chemicals identified as candidate SVHC classification under REACH is adopted and published by the European Chemicals Agency (ECHA). These SVHCs can be found at the website: http://echa.europa.eu/chem_data/authorisation_process/candidate_list_table_en.asp

As of December, 2011, ECHA has adopted seven lists of substances as candidate SVHCs, making the total adopted 74. In addition, 20 other substances were published for public comment for potential listing as SVHCs on December 21, 2011. The ECHA adoption process under Annex XIV for REACH (Authorization list), can be found at the website: http://echa.europa.eu/chem_data/authorisation_process/annex_xiv_rec_en.asp

PCA manufacturers must consider in addition to all raw materials used in manufacturing PCAs, but also packaging materials as potential sources of SVHCs.

When conformal coating suppliers submit data sheets for the substances in the conformal coating product to PCA manufacturers, the material data sheet should only represent the coating material, and not the solvent(s), as solvent(s) volatilize and are not included in the final product coating.

All manufacturers who ship into the EU must recognize that the REACH SVHC requirements apply equally to the packaging used to ship product as they do to the product itself. In addition to EU REACH SVHC requirements for packaging, for example, the SVHC cobalt dichloride in humidity indicator cards (HICs) is an issue that requires either a change to a different chemical substance, or provision of safe handling instructions with the traditional HICs if SVHC thresholds are met.

Beyond SVHCs, wood packaging is subject to disinfection requirements established by the FAO International Standard for Phytosanitary Measures No 15 on *Guidelines for regulating wood packaging material in international trade*. For more information reference <http://www.fao.org/DOCREP/006/Y4838E/y4838e00.htm>. The USDA has adopted such standards at 7CFR 319.40-3 on wood packaging material treatment requirements. Reference <http://edocket.access.gpo.gov/2007/E7-10559.htm>.

3.5.3 The ISPM15 Mark Wood packaging material entering the EU must carry the ISPM15 mark, which has the universally recognizable, non-language specific IPPC logo and 3 codes (country, producer and treatment measure applied). For debarked wood, the letters “DB” should also be on the mark. The mark allows for easy verification that the wood meets the necessary requirements during inspection at the point of export or import. Markings should be legible, visible, permanent and non-transferable.

3.5.4 Regulations or Laws in Other Countries

3.5.4.1 Regulation in Norway *Prohibition on Certain Hazardous Substances in Consumer Products* (PoHS) entered into force in Norway on January 1, 2008. It covers almost all consumer products, not only electrical and electronic equipment.

but also clothes, bags, buildings, toys, etc. Eighteen substances of concern are restricted in PoHS, including Hexabromocyclododecane (HBCDD), Tetrabromobisphenol A (TBBPA), C14-C17 medium-chained chlorinated paraffin (MCCP), Arsenic (As), Lead (Pb), Cadmium (Cd), Tributyl tin compounds (TBT), Tributyl tin compounds (TPT), Di(2-ethylhexyl)phthalate (DEHP), Pentachlorophenol, musk xylene, musk ketone, Ditallowdimethylammonium Cation (DTDMAC), Dimethyldioctadecylammonium chloride/Disterayldimethylammonium chloride (DODMAC/DSDMAC), Dihydrogenated Tallow Dimethylammonium Chloride (DHTDMAC), Bisphenol A (BPA), Perfluorooctanoic acid PFOA and Triclosan. The concentration of these substances varies and for some like TBBPA (1%) are much higher than 1000 ppm.

3.5.4.2 Regulation in Japan Modified law for Promotion of Effective Utilization of Resources and related regulations (J-Moss) entered into force in Japan on July 1, 2006. According to these regulations, substances of concern (SoC) used in electrical and electronic equipment are restricted. The SoCs limited in J-Moss are the same as RoHS. The concentrations of 1000PPM (by weight) for lead, mercury, hexavalent, chromium, PBB, PBDE and 100PPM (by weight) for cadmium are allowed. If the concentration of the SoC is higher than the limitation, it should be marked with an Orange label. The detailed information is specified in JIS C0950 – *The marking for presence of the specific chemical substances for electrical and electronic equipment*.

3.5.4.3 Regulation in China *Administrative measures on the control of pollution caused by electronic information products* entered into force in China on March 1, 2007. Eleven categories of electronic products are covered. *Administrative by-law on recycling of waste of electronic products* entered into force on January 1, 2011. It specifies the general principle, responsibility, monitor and management and legal responsibility on waste of electronic products.

3.5.5 Material Content Declaration Reporting Systems In order to facilitate the exchange of material content and material content legislation compliance, the electronics industry association IPC adopted a reporting standard IPC-1750 series for electrical and electronic component material content reporting and RoHS compliance certification. The latest version of the material declaration standard 1752A was adopted February 2012. Users can access the three standards at <http://www.ipc.org/ContentPage.aspx?pageid=Materials-Declaration>

Due to national and international environmental legislation (for example the EU Directive on End-of life vehicles, hazardous material legislation etc.), every supplier of a product may be responsible for the product for its entire life (operations, use, removal, disposal etc.). In addition to this, the suppliers will have to provide information about the materials used in the product in order to deconstruct the commonly used materials, in addition to classifying levels of danger related to the materials. This requires a detailed knowledge about the composition of the materials used.

Based on such requirements, International Material Data System (IMDS) and China automotive material data system (CAMDS) have been established. These allow the automobile manufacturers and parts suppliers to standardize the process and to enable efficient data collection. So far most of automotive manufacturers are using IMDS to collect the required data from suppliers and CAMDS as a data collection system is used in China.

3.5.5.1 IMDS International Material Data System (IMDS) is the automotive industry material data system. It is widely used by many automotive OEMs and many cascading tiers of part suppliers and material manufacturers. Automotive parts and materials are to be reported using IMDS. See <http://www.mdsystem.com>.

Currently, IMDS uses Global Automotive Declarable Substance List (GADSL) as its default substance list. This substance list allows the IMDS user to set up a management system for dangerous substances for his products to query the current status. The detail GADSL list can be found at <http://www.gadsl.org/>.

GADSL defines the following terms: “P” - Prohibited in all applications; “D/P” - Prohibited in some applications and declarable in all other cases; and “D” - Substance must be reported if the threshold limits are exceeded, however the substance is not prohibited for use in automotive parts.

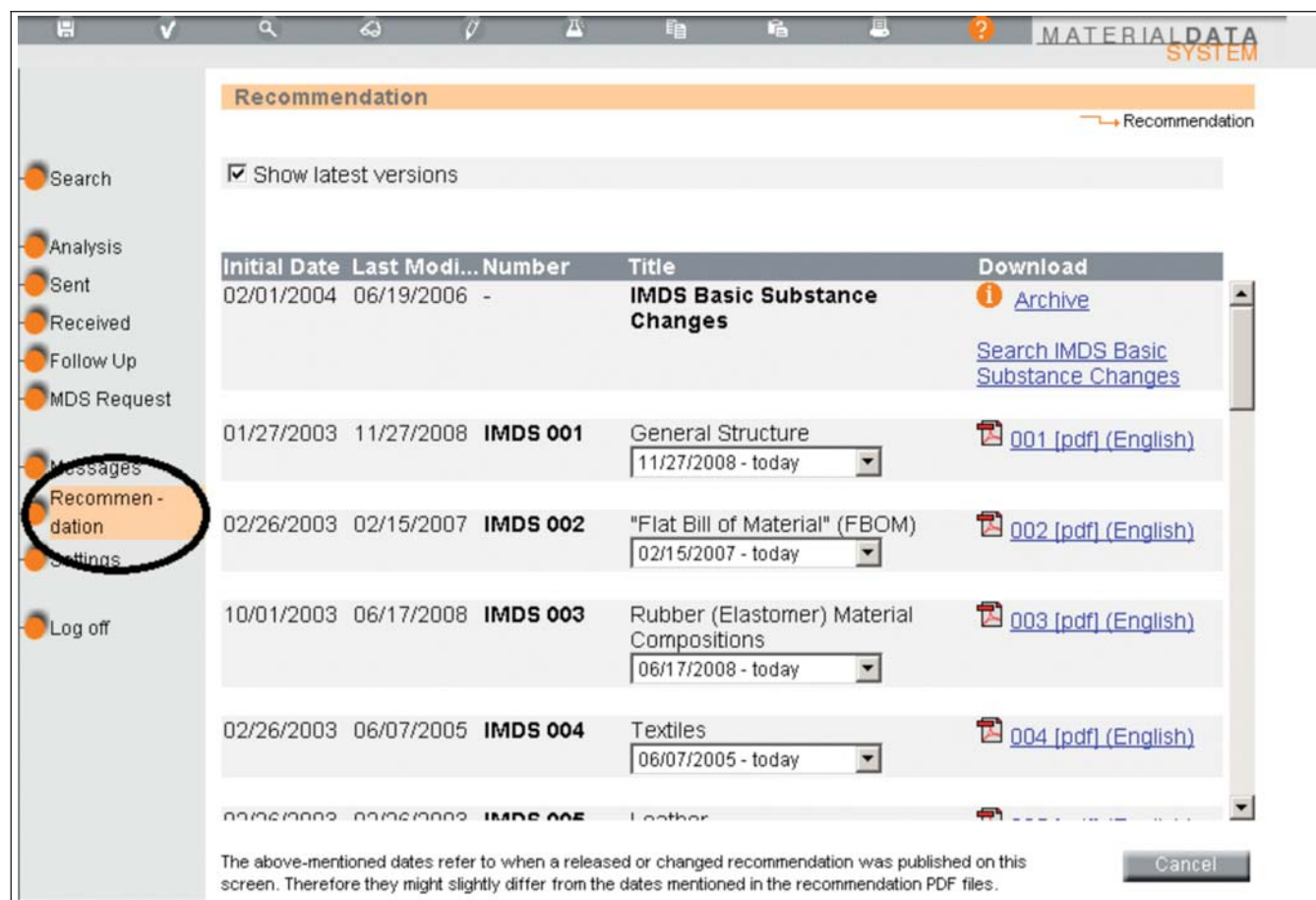
In IMDS, the relevant substance should be clearly declared if it is in REACH SVHC list, and the GADSL category, See Figure 3-1.

The screenshot displays the MATERIAL DATA SYSTEM interface. On the left is a navigation menu with options: Menu, Search, MDS, Ingredients (highlighted), Recycle information, Supplier data, Recipient data, and Log off. The main area is titled 'Ingredients' and shows a tree structure for 'MA-ADHESIVE 79257319 / 2 (Node ID 79257353)'. The tree includes 'MA-ADHESIVE', 'Silicone - MQ', and 'Polydimethyl-siloxane'. A dropdown menu is set to 'GADSL'. On the right, a 'Details' panel lists various attributes for the selected substance. A black oval highlights the 'GADSL category' and 'REACH-SVHC' fields.

Details	
Type	Basic Substance
Name	Polydimethyl-siloxane
Einecs-No.	-
EU-Index	-
CAS-No.	9016-00-6
GADSL category	Poly(oxy(dimethylsilylene))
REACH-SVHC	No
Synonyms	Dimethyl silicone Dimethicone
Confidential	No
Portion	Rest 98 [%]

Figure 3-1 GADSL and REACH SVHC Reported in IMDS

If a conformal coating supplier is requested to use IMDS to submit its material data sheet to its customer, it should follow IMDS reporting requirements. There are some recommendations available after logging into the system, see Figure 3-2.



MATERIAL DATA SYSTEM

Recommendation

☒ Show latest versions

Initial Date	Last Modified	Number	Title	Download
02/01/2004	06/19/2006	-	IMDS Basic Substance Changes	Archive Search IMDS Basic Substance Changes
01/27/2003	11/27/2008	IMDS 001	General Structure 11/27/2008 - today	001 [pdf] (English)
02/26/2003	02/15/2007	IMDS 002	"Flat Bill of Material" (FBOM) 02/15/2007 - today	002 [pdf] (English)
10/01/2003	06/17/2008	IMDS 003	Rubber (Elastomer) Material Compositions 06/17/2008 - today	003 [pdf] (English)
02/26/2003	06/07/2005	IMDS 004	Textiles 06/07/2005 - today	004 [pdf] (English)
02/26/2003	02/26/2003	IMDS 005	Leather	005 [pdf] (English)

The above-mentioned dates refer to when a released or changed recommendation was published on this screen. Therefore they might slightly differ from the dates mentioned in the recommendation PDF files.

[Cancel](#)

Figure 3-2 Recommendations Link

3.5.5.2 CAMDS China Automotive Material Data System (CAMDS) is a material report system for OEMs in China. It is similar to IMDS. It was officially released on July 11, 2009. The website of CAMDS is <http://www.camds.org/camds/login.action>. Automotive manufacturers in China will use this system to collect SoC data from suppliers. CAMDS also uses Global Automotive Declarable Substance List (GADSL) as its default substance list. In CAMDS, the relevant substance should be clearly declared if it is in the GADSL category (see Figure 3-3).

The screenshot displays the CAMDS web application. The title bar reads '中国汽车材料数据系统' (China Automotive Material Data System) and 'China Automotive Material Data'. A 'No Message' button and an 'Exit' button are in the top right. The left sidebar contains a 'Main Menu' with 'Main Menu', 'MDS', 'Ingredients', 'Supplier Information', and 'Recipient data'. The 'MDS' section is expanded, showing a tree view of materials. Under 'X6CrNi19 9', a list of elements is shown: 锰 (Manganese), 镍 (Nickel), 硅 (Silicon), 碳 (Carbon), 铬 (Chromium), 硫 (Sulfur), 磷 (Phosphorus), and 铁 (Iron). The '镍' (Nickel) entry is selected. The main area is titled 'view MDS' and 'view Material Data'. It shows a 'Detail' tab with the following information:

Type	Basic Substance
Chinese Name	镍
English Name	Nickel
CAS No.:	7440-02-0
EU-Index	028-002-00-7
Einecs	231-111-4
Synonym 1	
GADSL	D
Confidential	☐
Proportion	☒ From 8.5 To 10.5 [%] ☐ Fixed 0 [%] ☐ Rest 0[%]

The 'GADSL' field is circled in black, indicating its importance in the reporting process.

Figure 3-3 GADSL Reported on CAMDS

Conformal coating as one of the material in automobile parts should be reported by CAMDS according to the customers' requirements.

3.6 Greenhouse Gas (GHG) Reporting Many major electronic manufacturers have subscribed to the GHG emissions reporting of the Carbon Disclosure Project (CDP) (reference www.cdproject.net) for not only their own activities, but also their suppliers through the Supply Chain Leadership Collaboration (SCLC). Such GHG reporting for both investor and public access is based on the reporting criteria established by the GHG Protocol at www.ghgprotocol.org. Most GHG emissions are carbon dioxide from on-site fossil fuel combustion and off-site electricity generation, but also include emissions of methane, nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF₆).

GHG emissions are classified by the GHG Protocol as either Scope 1 (direct emissions from sources owned or controlled by the reporting entity), or Scope 2 (indirect emissions from sources owned or controlled by an entity other than the reporting entity). Scope 1 emissions include all on-site fuel combustion and fuel usage by company owned or leased vehicles. Scope 2 emissions are those from purchased electricity. There are Scope 3 emissions that cover supply chain and product distribution emissions, but are generally smaller and more complex to calculate than Scope 1 and 2 emissions.

Assemblers can utilize a variety of online resources to quantify their GHG emissions. For example, US EPA published the following emission factors in 2004:

Natural gas	116.39 lbs/million BTUs
Distillate fuel oil (1,2&4)	159.66 lbs/million BTUs
Liquified propane gas (LPG)	138.75 lbs/million BTUs
Gasoline	19.37 lbs/gallon
Diesel	22.23 lbs/gallon
LPG	12.70 lbs/gallon

For purchased electricity, US assemblers can utilize a US EPA web site that quantifies average CO₂ emissions per KWH of electricity by zip code at the following URL: <http://www.epa.gov/cleanenergy/energy-and-you/how-clean.html>.

Assemblers in other countries have similar electric utility source emission data. For example, the National Development and Reform Commission of China published electric utility emission factors for seven utilities in 2008.

3.7 Equipment Standards In the electronics industry, the platforms or equipment used for automated conformal coating applications have few specific standards to which they are constructed, given their unique nature. As is the case in many other industries, equipment manufacturers rely on the expertise of organizations that perform testing and industrial risk analysis. Examples of organizations that perform these services include American National Standards Institute (ANSI), Canadian Standards Association (CSA), Factory Mutual (FM), International Organization for Standards (ISO), National Fire Protection Association (NFPA), Technical Inspection Association (TÜV) and Underwriters Laboratory (UL). There are many other country specific organizations that perform similar functions. In general, the objective of equipment certification that these organizations provide helps, when inspection officers, insurance companies or corporate safety personnel; have questions or doubts when having a unique system installed in their facility.

Example 1: In the European Union the entity referred to is the "Notified body" although this is a Directive reference, not a single organization. Their role is defined in one of the CE annexes. The EN ISO 13849 standard on Safety of Machinery is also used for machine design.

Example 2: In Canada, CSA carries out certifications of equipment and is the issuer of industry standards.

International recognition of a certification issued by these organizations is valued as an additional benefit, given the expense and amount of work involved in compliance to the criteria established by the organization that provides the inspection/certification service.

The equipment manufacturing companies and their customers must navigate a wide range of standards and regulations. Equipment should comply with all applicable health and safety standards.

The equipment manufacturers, to a large extent, rely on the third party inspecting and certifying organizations to pinpoint the appropriate standards they want their equipment tested against. This determination depends on a multitude of factors and is part of the certifying process. The manufacturer and the inspector must work closely; first because the work environment and conditions need to be thoroughly conveyed to the certifier in order for them to be able to use the right set of standards for testing. Secondly, the certifier needs to make sure the equipment manufacturer understands the inspection and test process, before it takes place. This ensures the order in which to be prepared to act on the outcome of the inspection.

equipment manufacturer does not want to be overburdened with compliance to standards not relevant to the process. The certifier provides a crucial independent and objective assessment as a third party knowledgeable organization.

It would not be possible to narrow the standards to which the conformal coating equipment is expected to comply due to the variation of each manufacturer's equipment and the different requirements that the equipment should meet according to the geographic location where it will be installed.

The list below is not comprehensive, but just a sample of the standards that testing or inspecting organizations use when called to perform the service.

- a. ANSI B11.0 – Safety of Machinery
- b. 98/37/EC – Machinery Directive
- c. FM CLASS 3600 – Electrical Equipment in Hazardous Locations
- d. FM CLASS 3810 – “Electrical Equipment for Measurement, Control & Laboratory Use
- e. NFPA 33 – Standard for Spray Application Using Flammable & Combustible Liquids
- f. NFPA 496 – Purged & Pressurized Enclosures for Electrical Equipment
- g. SEMI-S8-0308 – Safety Guidelines for Ergonomic Engineering of Semiconductor Manufacturing Equipment
- h. UL 508 – Industrial Control Equipment
- i. EN 60204-1 :2006
- j. FM CLASS 3620 – Purged & Pressurized Electrical Equipment in Hazardous Locations
- k. IPC 1331 – Electrically Heated Process Equipment
- l. NFPA 79 – Electrical Code for Industrial Equipment
- m. SEMI-S2-0310e – EHS Guidelines for Semiconductor Manufacturing Equipment
- n. SEMI-S14-0309 – Safety Guidelines for Fire Risk Assessment and Mitigation for Semiconductor Manufacturing Equipment
- o. UL 508A – Industrial Control Panels

NOTE: Standards are in constant evolution, when using any of them to look at compliance, the newest version should be used.

The standards of choice will depend on the independent interpretation of the working conditions. It's in the machine manufacturer's best interest to make sure these conditions are appropriately understood for the inspection to proceed using the standards that will provide the best balance of safety-health compliance with the least possible modifications to the original machine design.

3.7.1 Factory Mutual Factory Mutual (FM) Research is a not-for-profit scientific research and testing organization, managed by FM Global, an industrial risk insurer, headquartered in Norwood, Massachusetts in the USA. This corporation was founded in 1835 by a group of mill owners to form their own mutual fire insurance company; it now has more than 170 years of loss prevention and testing. Factory Mutual Research works with commercial and industrial clients to solve problems by use of standards, research and product certification. They have helped businesses put safe products into local, national and international markets. FM uses a more independent philosophy when determining which standards to test to when asked to do an evaluation.

In the US, the Department of Labor and Occupational Safety and Health Administration (OSHA) have given FM a status of National Recognized Testing Laboratory (NRTL). This is the same status as organizations such as UL and CSA. FM uses NFPA, ANSI, ASTM, FM and other national and international standards for testing and certifying products.

The FM Approvals division has offices in the US, Europe (France), Singapore, China, Japan and India.

3.7.2 TÜV SÜD Independent TÜV's (Technischer Überwachungsverein, English translation: Technical Inspection Association) were founded in the 1870s by the German steam boiler industry. These regional organizations helped regulate and supervise the safety of steam installations in the interest of public safety. The original TÜV association in Bavaria, “TÜV Bayern” was one of several regional TÜV organizations in Germany. With the advancement of technology, its presence and capabilities quickly expanded. To meet the challenges of progressive deregulation, liberalization, and harmonization of trade practices in Europe TÜV Bayern eventually joined forces with other regional TÜV's to form TÜV Süddeutschland Holding AG, the largest of the “TÜV's.”

The Product Service division of TÜV America Inc. is aligned with TÜV Product Service GmbH in Europe through TÜV Süddeutschland Holding AG. Product Service GmbH performs independent EMC testing /certification medical devices testing and certification and product safety testing. TÜV's testing approach is more accepting of input regarding standards to be considered when doing inspection evaluation.

TÜV Product Service GmbH is a European Union (EU) Competent Body and Notified Body authorized for conformity assessment procedures to many EU Directives. TÜV SÜD has a global reach, claiming over 600 service offices worldwide.

4 CONFORMAL COATING MATERIALS

Conformal coatings are polymeric materials used to protect electronic assemblies from a wide variety of life cycle contaminants. Conformal coatings provide a high degree of insulative protection and can be resistant to many types of solvents and harsh environments encountered in the product life cycle. The coating materials also act to immobilize various types of particulates on the surface of the assembly and function as protective barriers to the various devices on the board.

They are resistant to moisture and humidity, which may reduce the potential of leakage currents, "cross talk," electrochemical migration, dendrite growth and arcing. These issues are becoming more critical with the reduction in component size, pitch, circuitry spacing, laminate thickness and voltage plus the rise in speed (frequency) of signals.

4.1 Coating Types Conformal coatings can be broken down into two liquid families, organic and silicone. The primary traditional classifications are acrylic (AR), epoxy (ER), silicone (SR), urethane (UR) and Parylene (XY). Figure 4-1 illustrates these classifications based on basic resin chemistry type, which is further differentiated into subtypes based on cure mechanism. Appendix A provides a comparison of various product types as a quick guide for the selection of conformal coating.

These systems are primarily made up of monomers, oligomers, de-foaming agents, fillers and wetting agents. Various combinations of each are added to the formulations to adjust the cured and uncured properties. Solvents may be added to adjust application viscosity. Prior to the start of curing process, solvents evaporate ("flash off"), leaving a resin matrix to initiate the cure. The VOC emissions associated with this type of cure created a need for more environmentally acceptable production chemistries and cure mechanisms. Presently solvent-based conformal coating chemistries exist which use VOC-exempt components to comply with these environmental regulations. Refer to Section 3 on Environmental, Health and Safety Considerations.

All resins except for acrylic resins are cured by an irreversible polymerization reaction with varying degree of cross-linking (thermo-set polymers). The cross-linking of the epoxy, urethane and silicone polymers provide very good chemical resistance but also make it difficult to remove the coatings when performing repair work. Some silicone coatings are inherently soft allowing easier removal depending on coating chemistry and thickness. No polymerization reaction is taking place when applying acrylic coatings. Therefore, it is misleading to say that acrylic coatings are cured. They are formed by drying a solution of already formed acrylic polymer chains dissolved in a solvent (thermoplastic polymer). Hence, acrylic coatings are easily dissolved in many organic solvents providing poor chemical resistance but facilitating repair work. Consequently, most acrylic materials are solvent-based.

All, except the Parylenes (XY), have traditionally been solvent-based until environmental issues dictated a need to change. Now, many materials are solvent-free chemistries (100% solids). The ability to ultra violet (UV) cure is commonplace. This new generation of conformal coating materials has also given birth to hybrid coatings that contain two or more systems to achieve superior properties, i.e., ARUR.

Raw materials as well as film properties need to be considered while selecting conformal coating materials. Due to variations in conformal coating chemistry, it is recommended to consult the coating manufacturers or technical data sheet for more information.

See Section 10 for Removal and Repair Methods and Processes

4.1.1 AR – Acrylic Acrylics are easy to apply and the dried film can be removed using the solvent method in Section 10. Spot removal of the coating to repair a solder joint or replace a component can be easily accomplished by localized solvent application. For other removal methods please refer to Section 10.

Acrylics dry rapidly, reaching tack-free condition in a short period of time, are fungus resistant, and provide long pot life. Furthermore, acrylics give off little or no heat during cure eliminating damage to heat-sensitive components, have no further shrinkage once the carrier solvent has evaporated off, and have good humidity resistance. Acrylic coatings exhibit low glass transition temperatures (T_g). Above T_g , the large expansion can result in damaging effects.

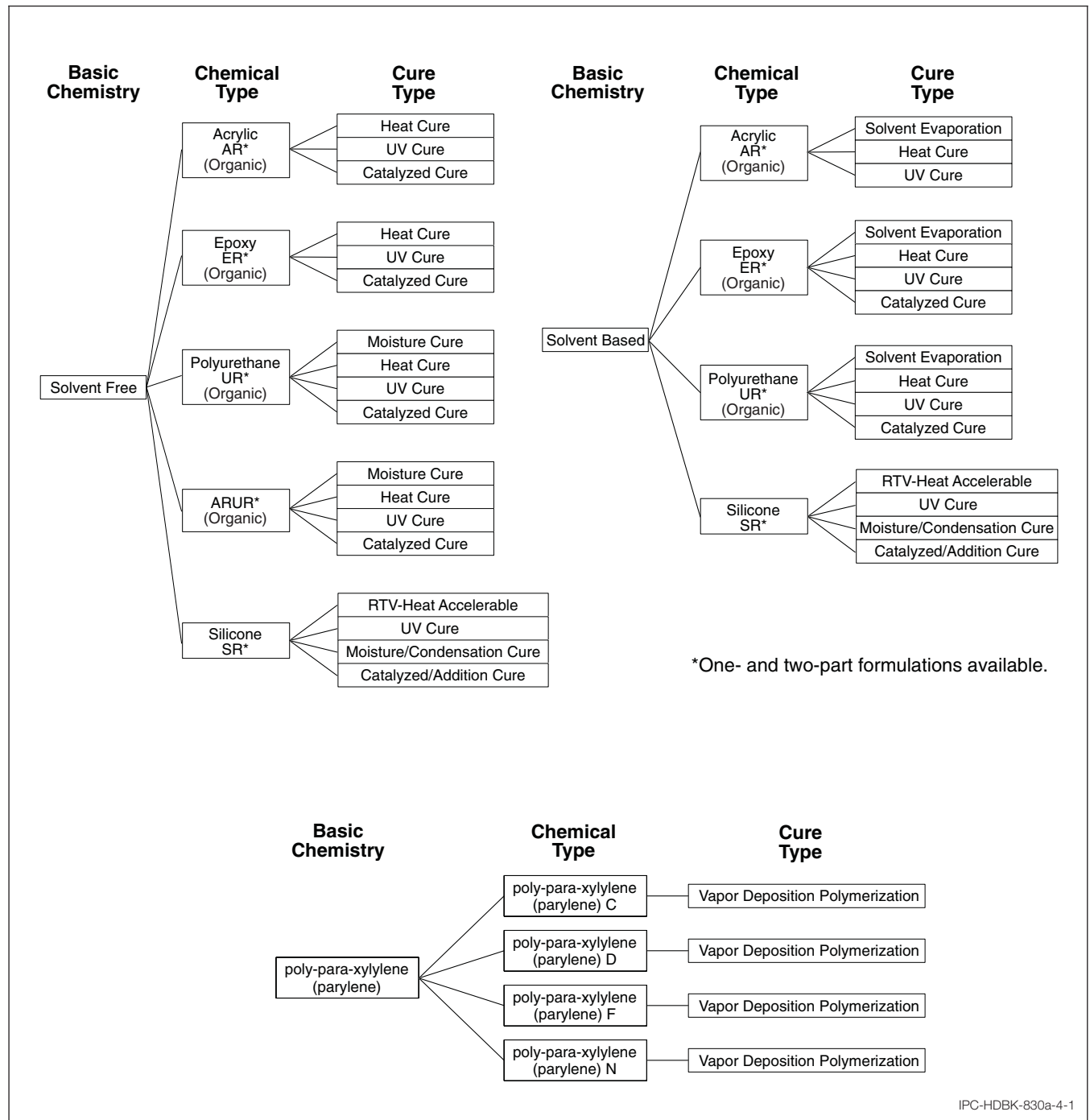


Figure 4-1 Conformal Coating Family Trees

4.1.2 ER – 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 coating may vigorously attack epoxy-potted components as well as printed board laminate materials. Other effective ways to repair a board or replace components are to burn through the epoxy coating with a knife or a soldering iron or use of abrasive media. See Section 10 for other rework methods

When most epoxies are applied, a “buffer” material should be used around fragile components to prevent their damage from film shrinkage during polymerization.

Curing of epoxy systems takes place in up to 3 hours at an elevated temperature or up to 7 days at room temperature.

Two-part epoxies begin to chemically react as soon as they are mixed. Consequently, there is a finite pot life and processing window. The processing properties of the epoxy mixture will change throughout the processing window.

Single part epoxy resin coatings with temperature-activated hardeners are also available. These coatings require cure temperatures higher than 66 °C [150 °F]. Single part UV curable coatings are available which minimizes exposure to these elevated temperatures.

Single part vinyl modified epoxy compounds are available for special applications that require higher thermal performance properties. These compounds are also less brittle.

4.1.3 SR – Silicone Silicone coatings are useful materials when components must endure extreme temperature cycling environments such as automotive applications. The useful operating range of these materials can be -45 °C to + 200 °C [-49 ° to +392 °F], with some low temperature materials that are capable of operating down to -110 °C [-166 °F]. Consult the vendor's data sheets for specific material thermal operating temperature range. They provide high humidity resistance along with good thermal endurance, making them desirable for assemblies with heat dissipating components such as power resistors. For high impedance circuitry, silicones offer a low dissipation factor. They are forgiving materials in production because they coat over and adhere to most surfaces found on a printed board and offer good resistance to polar solvents. Cross contamination factors stemming from the use of silicones and the effects on other production processes is no longer a major concern with the solvent-free, low volatility chemistries that are easily handled with proper housekeeping practices. Secondary cure for the UV curable versions is accomplished with a effective ambient moisture mechanism. It should also be considered that high temperature protection may generally demand that the silicone coating be cured at or near to the maximum temperature it is designed to withstand. Silicone coatings can be applied at large thickness (depending on viscosity). Most silicones are relatively soft allowing easier rework and removal. Silicone cure systems include ambient moisture cure and heat cure. Most moisture cure systems can be heat accelerated with mild heat (55-60 °C [131-140 °F]) allowing assemblies to be handleable in 1-2 minutes. Consult the vendor's data sheets for typical cure times and conditions and possible accelerated cure methodologies.

4.1.4 UR – Polyurethane Polyurethane coatings are available as either single or two-component formulations. Both provide good humidity and chemical resistance, plus higher sustained dielectric properties.

Their chemical resistance, however, can be a major drawback since rework can become difficult and costly. To repair or replace a component, refer to Section 10.

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

Single component polyurethanes, while easy to apply, sometimes require days at room temperature to reach full properties. Refer the data sheets for more information.

Two component formulations, on the other hand, reach optimum cure properties at elevated temperatures within hours, with pot lives up to 3 hours.

4.1.5 XY – Parylene The first Parylene (or paraxylylene) was developed by Union Carbide under the trade-mark name of Parylene. Consequently, the industry has come to refer to all Type XY materials as "Parylene."

These are the vacuum deposited XY coatings. Both material characteristics and application technique yield XY conformal coatings that are uniquely different from the liquid applied coating types. The obtained coating film yields consistent thickness with true conformance to the assembly contour and is pinhole and bubble free. The XY film is also characterized by properties such as good dielectric, low thermal expansion, good abrasion resistance and outstanding chemical resistance, among others. This makes XY coating a good choice for protecting circuits against effects from harsh environments, notably high humidity with condensation, intermittent immersion, salt fog, atmospheric pollutants and exposure to aggressive solvents. This type of coating is frequently used in FDA approved devices for medical and biomedical applications. Parylene coatings can be removed by abrasion, conventional surface mount techniques, excimer laser, heat softening, plasma etching and several other methods. Parylene coatings are very effective in high voltage applications, owing to the capability of coating sharp edges.

A fluorinated version is also available that can maintain its properties at temperatures in excess of 400 °C [752 °F], has increased UV stability, and has a lower dielectric constant.

4.2 UV Cure Ultra-violet light (UV) coating curing occurs in seconds rather than in minutes or hours. They have been historically developed for use on flat bare substrates and are of particular benefit for fiber optic filament coating as curing can be effected at speeds of up to 400 ft/min.

Some materials used on assemblies have limited effect because of the shadowing produced by components. On some coating formulations the shadowing effect has been overcome by the use of a secondary cure mechanism.

Historically the reliability of this type of coating was suspect at temperature ranges such as <-55 or $>+130$ °C [<-67 or $>+266$ °F] as they become brittle and less flexible. Current formulations do not tend to exhibit this phenomenon.

4.3 Other Types of Conformal Coatings

4.3.1 Amorphous Fluoropolymer Polytetrafluoroethylene (PTFE) is an amorphous thermoplastic polymer, similar to Teflon®, which does not crystallize with age. Because it has a very low surface energy, it is hydrophobic to water and also repels organic alcohols, ketones, ethers, acids and amines. It is permeable to most common gases and hydrogen chloride vapor as well as aqueous hydrochloric acid and soluble inorganic chlorides. It can be deposited on substrates as vapor, and as solution by spin cast, dip and spray.

When fluoropolymer coatings are used in aerospace environments/applications, electrical properties may degrade due to radiation exposure. Caution should be used when selecting material with these electrical properties.

4.3.2 Fluorocarbon (FC) An alternative to traditional hydrocarbon-based conformal coatings is a fluorochemical coating used as a surface modifier. These hydrophobic-oleophobic coatings provide excellent moisture and environmental protection along with chemical, solvent and corrosion resistance. Due to the low surface energy of these coatings (as low as 11-12 mN/m), water, solvents (such as heptanes, toluene and acetone) and lubricating oils bead up and drain off coated substrates. Typically supplied in fluorocarbon solvents, they are “environmentally sustainable” because they contain no volatile organic compounds (VOCs) and have low global warming potential. Fluorochemical coatings in fluorocarbon solvents are also non-flammable and low in toxicity.

Fluorochemical coatings provide films with excellent adhesion to printed board materials as well as a wide variety of surfaces such as copper, aluminum, ceramic, steel, tin and glass. Delivering anti-wetting, anti-stiction, anti-migration and anti-corrosion properties they are used in many diverse applications. With low thermal expansion, they are an excellent choice for application in consumer and industrial environments that must protect against high humidity, atmospheric pollutants and aggressive solvents.

Processing can be quick and easy being dispensed, dipped, or sprayed. These coatings provide a thin, fast drying layer that can often be applied without masking and can be soldered through for rework. Some fluorochemical coatings exhibit an indefinite pot life as they are fully reacted polymers in solution. Other fluorochemical coatings have been developed with reactive cross-linking chemistry for improved durability. Either way, fluorochemical coatings are resistant to most hydrocarbon solvents and water.

Fluorochemical coatings can provide moisture and environmental protection for a multitude of printed circuit board applications. The low viscosity and low surface tension of these coatings allow them to cover board components thoroughly (based on process design) with a thin film of polymer that maximizes thermal dissipation plus are pin-hole and bubble free when applied to clean substrates. Fluorochemical coatings easily flow into, and coat between, small gaps and layers. Coated films are clear, consistent in thickness with excellent conformance to the board and its components. Choices are available for drying at room temperature for easy processing, reparability and reworkability. Cured versions can provide even higher levels of performance. Durability and abrasion resistance vary with the formulation and the thickness of the applied coating.

Low outgassing, UV traceable and higher solids concentration compositions are available for additional functional performance and processing ease. These coatings can be removed by a variety of methods including cleaning with fluorinated solvents, abrasion, laser, heat softening, plasma etching and other alternatives (see Section 10 Rework, Repair and Restoration).

4.3.3 Perfluoroether For certain applications involving extended exposure to fuels, hydrocarbon oils, hydraulic fluid, non-polar solvents, acids, or bases the use of perfluoroether type coatings could be considered. This polymer is based on a perfluoroether (fluorinated-carbon to oxygen) backbone combined with an addition-curing silicone crosslinker. One-part perfluoroether materials are processed (dispensed/sprayed and cured) in the same manner as heat-cured silicone type coatings. They can be sprayed or dispensed using typical existing equipment and heat cured at 150 °C [302 °F] for 1 hour.

Perfluoroether elastomer provides improved low temperature properties, long-term heat resistance, self-priming adhesion, excellent electrical properties and ionic purity. As a 100% solids (no-solvent) material, it offers processing advantages unmatched by other standard fluoroelastomers. The thermal resistance and low modulus are similar to silicone properties while providing protection from the harshest environments.

4.3.4 Atomic Layer Deposition Encapsulation (ALD-CAP) This process deposits a thin ceramic coating. It is similar to chemical vapor deposition, but is self-limiting, with applied film thickness ranging from 50-500 nm. The applied coating is conformal, tough, flexible, hermetic, and has been shown to contain the growth of tin whiskers. The application process takes place at a minimum of 80 °C, and deposition rates are approximately 1 micron/hour. This material is still in the developmental stage. More information can be found in the following reference: *Tin Whisker Containment with Flexible Ceramic Conformal Coatings*, Jerry Winkler, Clayton Sneider, Stephen Davidson, Randy Lasater and Ofer Sneh,

4.3.5 POSS-Thiol This refers to polyhedral oligomeric silsesquioxanes (POSS). POSS is a hybrid, nano-structured chemical which is nonvolatile and has high temperature stability. The thiol group in the composition forms covalent bonds when reacted with tin. The basic idea is to apply POSS-thiol to the tin plated surface so that POSS-thiol will break down the Sn-oxide layer and create multiple (1013/ cm²) nano-scale openings in the oxide layer so as to relieve the stress caused by the Sn-oxide layer. More information can be obtained from the references below.

1. Tin Whiskers: How to Mitigate and Manage the Risks, Sony Mathew, Michael Osterman, Michael Pecht, Center for Advanced Life Cycle Engineering (CALCE), Tadahiro Shibutani, Qiang Yu, Yokohama National University. Proceedings of 2007 International Symposium on High Density Packaging and Microsystem Integration (HDP'07)
2. Thompson, R. G, Lichtenhan, J. D, and Lee, A, "POSS-thiol Based Mitigation of Sn-Whiskers," Proc. of CALCE International Symposium on Tin Whiskers, College Park, MD, April 24-25, 2007.
3. POSS-Thiol Based Sn Whisker Mitigation, Dr. Raymond Thompson, John Cassimus, Dr. Joe Lichtenhan, Dr. Brian Gregory, Proceedings of 2008 CALCE Symposium on Part Reprocessing, Tin Whisker Mitigation and Printed Wiring Assembly Rework/Repair

4.3.6 Other Coating Types and CC-830 Much of the industry's conformal coating classification terminology comes from MIL-I-46058. IPC-CC-830, which mirrors MIL-I-46058, has the same terminology. Both documents classify conformal coatings into five broad classifications based on the predominant coating chemistry:

- a. Type AR – acrylics
- b. Type UR – urethanes
- c. Type ER – epoxies
- d. Type SR – silicones
- e. Type XY – Parylene

Because MIL-I-46058 is a military standard that is currently inactive for new designs, there are no efforts underway to update these classifications for new coating types, such as fluoropolymers or ceramic materials. The IPC Conformal Coating Task group has decided that the CC-830 needs to mirror the MIL-I-46058 specification.

4.4 The Uses of Conformal Coating This section enables a user to select a conformal coating based on industry experience along with the understanding of pertinent considerations on the potential usages of these conformal coating materials and their complement materials to enable higher product reliability, pending the process selected and harsh environment conditions. It is the responsibility of the user to determine the suitability, via appropriate testing, of the selected coating and application method for a particular end use application.

4.4.1 Proper Selection of Conformal Coating Electronic assemblies are built on insulators. Moisture or dirt can weaken the insulation on the surface of the insulator to such an extent that it no longer functions properly. While the base of the assembly - the laminate - and the protective effect of the solder mask on the actual printed board layout usually can still meet the insulation demands even in inclement conditions, it is a different story with unshielded solder joints and component leads.

Besides the solder joints circumvented by the solder mask there are different potentials applied to the various components on the board which have no protection against atmospheric influences. To shield these potentials, conformal coatings, thick film lacquers or casting compounds can be used, depending on the desired level of protection.

Conformal coatings are developed and formulated in order to protect electronic assemblies from tough environmental conditions, contamination and moisture, in particular, dewing (condensing moisture). The attainable degree of protection depends on the type of polymer used, the application process and the drying/curing conditions of the coating.

The climatic resistance requirements depend on the mechanical or electrical properties. The mechanical or electrical properties of the coating must retain their protective effect across end use application environments (e.g., mission, consumer, etc.).

The potential climatic loads - in terms of ambient parameters or interferences - that can occur while an electronic assembly is being operated are illustrated in Figure 4-2.

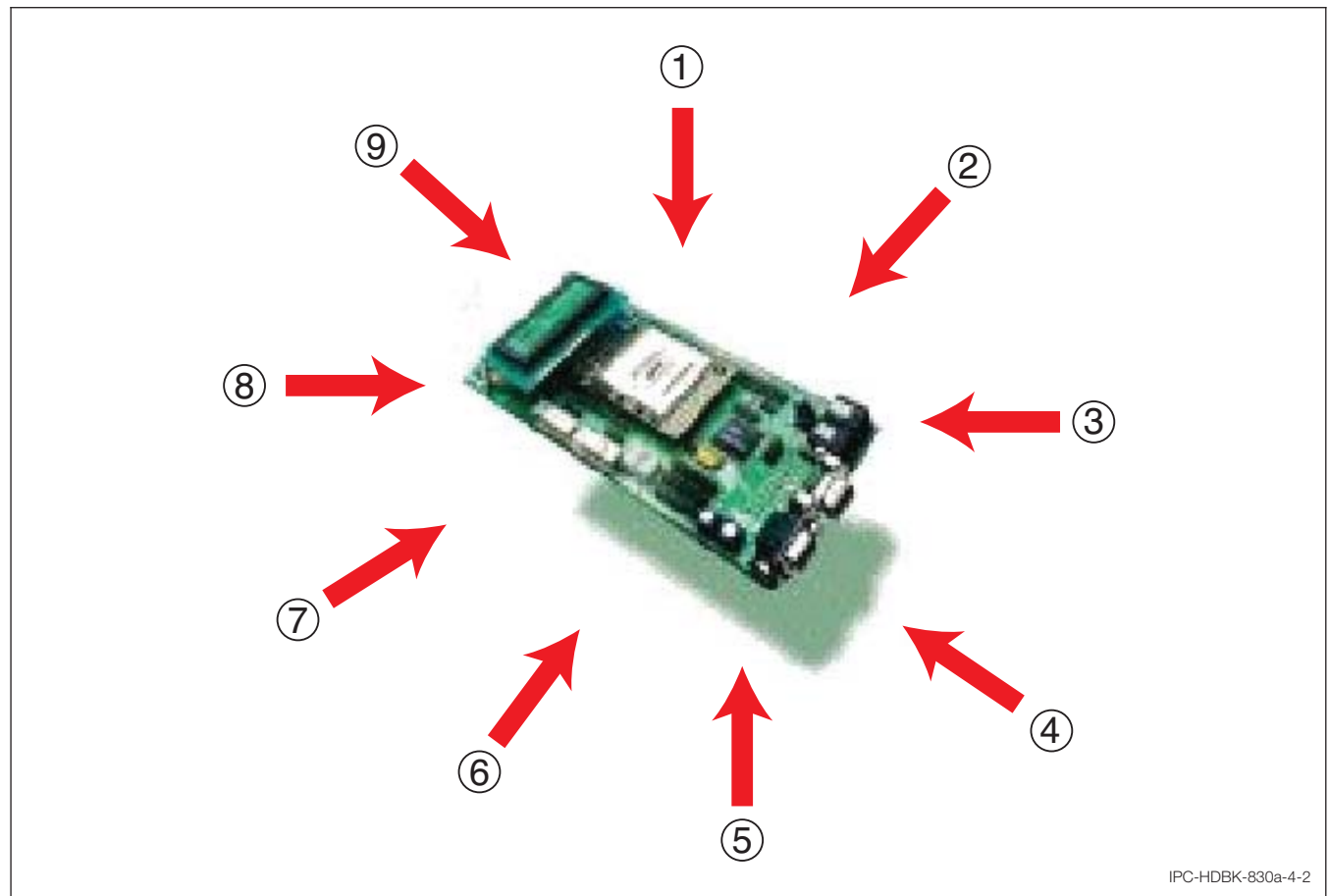


Figure 4-2 Potential Loads During the Operation of an Electronic Assembly

1. Thermal shock
2. Vibration
3. Air humidity
4. Dewing (rain)
5. Contamination (Salts, Dust, Operating media, Fungus)

6. Noxious Gases (NO_x , SO_2 , H_2S ...)
7. Tin Whisker mitigation
8. Air pressure, Air flow
9. Temperature

One of the major demands on an electronic assembly is that it maintains its functionality while considering various surrounding conditions such as when exposed to dewing (condensation), elevated temperature, humidity, etc. High temperature and high humidity is a particularly challenging combination, especially when the temperature fluctuates below the dew point. Suitable products must be chosen based on the material properties to perform in these conditions for the life of the product.

The reliability of a product is for the most part determined as early as the conceptual/ development phase. The critical factors that are responsible for reducing the reliability of an electronic assembly are illustrated in Figure 4-2.

These critical factors must be looked at closely. First, it is necessary to pinpoint the potential factors that may disrupt later operation and second, it is necessary to simulate them in suitable tests or test cycles. It is equally important to use appropriate acceleration models to test for these factors to warrant their steadfast interpretation and evaluation over the life of the product.

As a rule, under normal circumstances - that is to say between approx. 40 to 70% r.h. - problem-free operation is typical without the need for an additional conformal coating. At a relative humidity of 70% or greater, circuit card failure becomes more likely (see Figure 4-3). The increasing moisture adsorption causes higher leakage currents and leads to potential board failure based on product design. The first signs of dewing (condensation) may also arise because the critical relative humidity of many salts that leads to premature dewing (condensation) is already reached. For a secure operation where dewing is a potential risk it is advisable to apply a protective coating.

0	10	20	30	40	50	60	70	80	90		100
low humidity				medium humidity				high humidity			max. humidity
risk of ESD				problem-free operation				critical operation			special case

Figure 4-3 Effects of 0 to 100% Relative Humidity on the Operation of an Electronic Assembly

The possibility or prescription to apply a protective coating should be addressed as early as possible in the planning phase or incorporated into the design of the assembly. When selecting the components attention must be paid to their coatability; the layout specification for the coating process must also be taken into consideration, e.g., spacing constraints to areas that should not be coated or the arrangement of connectors.

Conventional conformal coatings only form very thin layers to shield the electronics and generally afford adequate protection. If a higher protective effect is required, e.g., because of longer exposure to dewing, either due to climatic stress or the installation position (vertical or horizontal), or a higher mechanical resistance is needed, “thick film lacquers” are a practical solution.

Constructional requirements often requested as “extras” call more for a total encapsulation which can only be achieved by using casting resins or casting compounds. They can be applied in thick layers or even in molded shapes, although they are also more difficult to process.

A conformal coating protects against short-term moisture loads or other forms of contamination. A conformal coating should not and cannot secure the electrical operation of an assembly that is permanently exposed to water.

Electronic assemblies are protected by means of conformal coatings with different formulations and solids contents, depending upon which ink film thicknesses of around 20 to 40 µm [0.78 to 1.57 mil]- or 100 µm [3.93 mil] or more in the case of “thick film lacquers” - can be achieved in one application.

Since these film thicknesses are sufficient for most requirements in practice, it is only necessary to apply a second coat or use a casting resin where a deeper encapsulation or embedding of the components is desired for specialty applications.

Depending on the material used, coatings afford protection against, for example:

- mechanical abrasion
- atmospheric moisture, dewing, hand-sweat and all kinds of chemicals
- mold when used in tropical conditions

Moreover, coatings can improve the electrical insulation between different potentials, for example with respect to:

- ex protection requirements
- high-voltage applications
- insulation at high altitudes

For other types of loads, in particular aggressive industrial atmospheres, exposure to solvents or similar, where a 1-part conformal coating does not offer sufficient resistance, 2-part conformal coatings or casting compounds are used to protect the electronics.

This primary requirement is fulfilled by many materials and consequently insulating materials/compounds can consist of several different substances such as natural resins, plastics, artificial resins and a variety of additives including plasticizers, pigments and filling agents. The electrical properties of an insulator may depend upon the ambient conditions - temperature and humidity. Bearing this in mind, certain restrictions or changes in the electrical resistance towards selected materials - especially water - must be reckoned with.

Furthermore, there is the possibility of impeded insulation properties of the protective coating caused by the standard practice of coating uncleaned assemblies. On uncleaned assemblies a coating exerts an additional immobilization effect on substances that may reduce the insulation capability (fluxing agent residues, process residues, etc.). Appropriate compatibility tests are vital. Potential osmotic activity of process residues can weaken the protective effect of a conformal coating to such a drastic extent that when later operated under stress the functionality cannot be secured.

The “Kärner matrix” can be consulted in this respect, which says that the use of suitable materials is an obligatory - but insufficient - condition to ensure insulation performs satisfactorily. This statement is reflected in Figure 4-4 and was originally used to describe the long-term performance of outdoor insulations, but is just as true to its full extent for the protection of electronic assemblies.

The application of a conformal coating may result in an adequate protection of the assembly in many cases, but a truly secure protective effect can only be achieved if the coating selection and process are supported by corresponding tests and the necessary background knowledge.

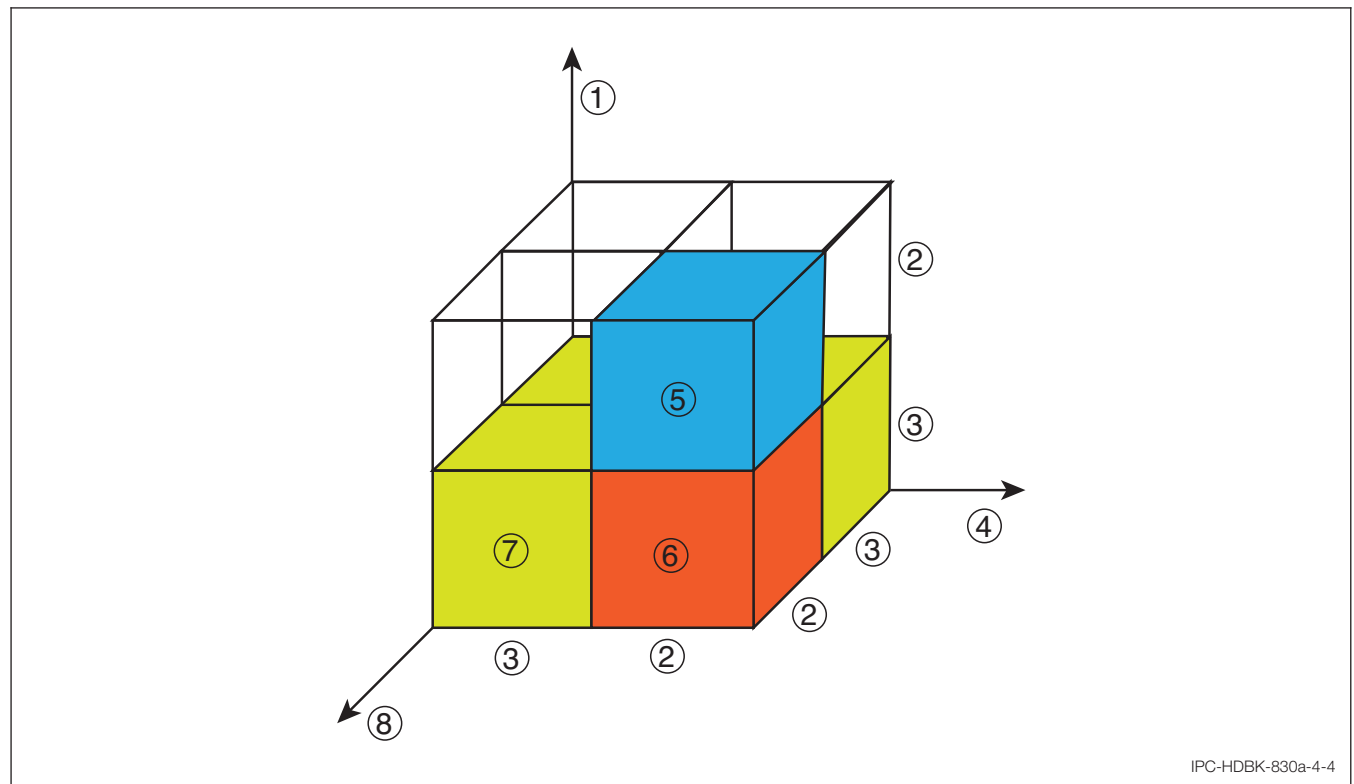


Figure 4-4 The “Kärner matrix” showing the relationship between a material and the electrical insulators made from it.

- 1. Protective effect
- 2. Good
- 3. Poor
- 4. Material
- 5. Know-how required
- 6. Possible
- 7. Normal
- 8. Design

4.4.2 Conformal Coating vs. Potting and Encapsulation Potting and Encapsulation is a very broad topic and is typically used to provide higher level protection chemistries for many applications including anything from toys to high power applications. There is no clear industry-wide definition that would decipher distinct differences between either of the terms. Because of this and the need for the electronics industry to have some form of reference on the topic an assembly task group was formed to address this process. The task group developed IPC-HDBK-850, Guidelines for Design, Selection and Application of Potting and Encapsulation Materials Used for Electronics Circuit Board Assembly.

Potting, referring to the “liquid uncured material” and Encapsulation referring to the “process” of applying the liquid uncured material should be used to make the distinction between the two terms. This process typically yields protection from a multitude of contaminants including: liquids, moisture, insulation, chemical resistance, vibration damping, and so on.

applications where the electronics may be in extremely harsh environments where a conformal coating may not provide the level of protection such as submerged applications. Many potting materials can also provide thermal dissipation depending on the level and type of fillers that are used. Commonly used materials can range in hardness from very soft gels, to harder impenetrable materials such as epoxies, and cure mechanisms can include room temperature polymerization and heat. Ultra-violet and visible light cure mechanisms may be impractical because of the depth of the potting materials that are used which can be up to several inches. UV and visible wavelengths cannot generally penetrate past a certain depth in order to initiate the required reaction to effect polymerization. Often these are used in conjunction with a secondary cure process such as thermal for full polymerization.

Conformal coating should not be used in lieu of encapsulation when the end-use environment dictates a much higher level of protection required for the specific applications. In some cases, conformal coatings can be used in conjunction with or prior to encapsulation. This is to provide additional protection to the PCA or to prevent inhibition (cure poisoning) of the potting material to surface residues. This creates a “barrier layer” that is compatible with the potting material being used at the interface.

Encapsulation/potting usage differs from conformal coating applications since thicknesses of the material are much thicker, particularly if molds are used to fully encapsulate electronics. Therefore, thermo mechanical properties in conjunction with dielectric properties become critical in selecting the appropriate material for the intended application. Coefficient of thermal expansion (CTE), glass transition temperature (T_g) and Modulus are some of the primary properties that need to be reviewed against the hardware assembly of materials’ analogous properties. This is to ensure that there is no potential for failures occurring over the cure and operating temperature envelopes.

Depending on the type and chemistry of the potting material being used, performing rework to the printed board after the encapsulation process has been completed can be challenging if not impossible depending on thickness, geometry and chemistry.

Conformal Coating, Potting and Encapsulation all share the following common functions to some degree:

- a. Inhibit current leakage and short circuit due to humidity and contamination from service environment.
- b. Inhibit corrosion.
- c. Improve fatigue life of solder joints to leadless packages.
- d. Inhibit arcing and corona, in particular for high voltage applications.
- e. Provide mechanical support and to prevent damages due to mechanical shock and vibration.
- f. Provide a mitigation method for the growth of tin-whiskers.

Some key distinctions between them however are as follows:

- a. Conformal coatings are typically applied in thickness less than 8 mils whereas potting and encapsulants are applied >8 mil.
- b. Conformal coatings are clear and applied with the expectation that components details and markings are visible.
- c. Conformal coatings generally lend themselves to rework better than potting and encapsulants.

4.5 Tin Whisker Mitigation As most of the world converts to lead-free manufacturing, the concern over tin whiskers as a reliability hazard has grown due to the emergence of pure tin as a dominate component surface finish. A significant amount of research on tin whisker formation and tin whisker mitigating strategies has been performed in both commercial and defense industries. NASA has a report at the following web link which summarizes the concern well: <http://nepp.nasa.gov/whisker/background/index.htm>.

“Whiskers are elongated single crystals of pure tin that have been reported to grow to more than 10 mm [250 mils] in length (though they are more typically 1 mm or less) and from 0.3 to 10 μ m [0.01 to 0.393 mil] in diameter (typically 1-3 μ m [0.039 to 0.12 mil]). Whiskers grow spontaneously without an applied electric field or moisture (unlike dendrites) and independent of atmospheric pressure (they grow in vacuum). Whiskers may be straight, kinked, hooked, or forked and some are reported to be hollow. Their outer surfaces are usually striated. Whiskers can grow in non-filament types which are sometimes called lumps or flowers. Whisker growth may begin soon after plating. However, initiation of growth may also take years. The unpredictable nature of whisker incubation and subsequent growth is of particular concern to systems requiring long term, reliable operation.”

There is a substantial amount of industry discussion regarding the impact that conformal coating has on tin whiskers. The general industry consensus can be summarized to be as follows:

- a. The electronics industry considers conformal coating as an industry Best Practice tin whisker mitigation protocol.
- b. The conformal coating captures and contains whisker, however, it does not inhibit or stop whiskering.
- c. Many aerospace companies consider conformal coating as one acceptable tin whisker mitigation strategy and it is often employed as one risk mitigation strategy incorporated into a systems risk mitigation approach.

Appendix L provides more details on some useful industry papers related to this topic.

This information has been extracted from an IPC white paper IPC-WP-009 “A Summary of Tin Whisker Research References.”

Conformal Coatings have been able to contain whiskers and prevent whisker breakthrough to contact adjacent electronic leads and connections and thus prevents electrical shorts.

4.6 Fungus Mitigation Many products in the military/aerospace industry have the requirement to be fungus resistant or containing nothing that a fungus would consider as a nutrient material. Historically, fungus and similar biological growths have attacked the constituent materials of electronic assemblies representing a reliability risk. While this requirement is often levied on military/aerospace products, components and materials, not many understand why this requirement exists. There are numerous fungus resistance test methods in existence. This section covers only those relevant to electronic assemblies and associated materials of construction and was written to give an overall background to fungus resistance testing, why such testing is required of high reliability electronic products, and the predominant methods used in the industry.

The use of fungus resistant materials in high performance aviation electronics is often required by military/aerospace customers for the following reasons:

- a. Microorganisms digest organic materials as a normal metabolic process, thus degrading the substrate, reducing surface tension and increasing moisture penetration.
- b. Enzymes and organic acids, produced during metabolism, diffuse out of cells and onto the substrate and cause metal corrosion, glass etching, hardening of grease and other physical and chemical changes to the substrates.
- c. The physical presence of microorganisms produces living bridges across components that may result in electrical failures.
- d. The physical presence of fungi can also cause health problems and produce aesthetically unpleasant situations in which users will reject the equipment.

As with any review of commercial and military standards or specifications, there is a significant difference in the language used or the terms used. The terms “non-nutrient” and “fungus-inert” are identical in that both terms mean that there is nothing in the candidate material that a fungus would consider as “food.” The term “fungus proof” refers to a material that has an active anti-fungal or biocidal agent incorporated into the structure which kills the fungus spores on contact.

4.6.1 Major Fungus Test Methods Numerous military, governmental and industry organizations provide test methods to assess fungus growth. While the language varies from specification to specification, it is clear that there are four primary fungus resistance test methods:

- a. ASTM G21 for many materials such as cast films
- b. IEC 61085 for coatings
- c. DO 160 Section 13.0 for finished electronic hardware for commercial aviation
- d. MIL-STD-810 Method 508.5 for some materials and for finished electronic hardware for military use

Refer to Appendix M for more details discussion of these test methods.

This information has been extracted from an IPC white paper IPC-WP-010 “A Summary of Fungus Resistance Test Methods.”

4.7 Flammability Mitigation There are two primary areas of concern related to the flammability of conformal coating. First during the processing as far as equipment and operator safety when using uncured materials, the second is during the field service of the dried film.

As far as end use, the final cured material should be tested and rated in accordance to MIL-I-46058 or IPC-CC-830. Flammability of cured film on the supported substrate (i.e., FR-4 or G-10) is the ability to support combustion or continue to burn. Various ratings can be used to describe the flammability, such as V-0 or V-1 per UL; and Non-burning or self-extinguishing per MIL-I-46058 or IPC-CC-830. For further descriptions on ratings refer to the applicable specification.

4.7.1 Flammable Liquid Issues Users of conformal coatings must also evaluate other safety factors, such as fire safety considerations and both the acute and chronic health effects of the specific coating chemicals. FM and NFPA regard liquids with a flash point below 37 °C [100 °F] to be flammable, and liquids whose flashpoint is above 37 °C [100 °F] combustible. Flammable liquids pose explosion hazards when their vapors are not properly removed by either local or general ventilation. Users of flammable liquids also must recognize that installations where these liquids are to be used must conform to certain construction standards, such as explosion-proof wiring, switches, motors, etc., (Reference NFPA 35 and OSHA 29 CFR 1910.106). Users of flammable liquids may require the approval of the local fire department, and in some districts, a permit for using of these liquids. Notification may also be required under EPA's Community Right to Know regulations 40 CFR 355.30 (b), 370.21 and 370.25 to report storage and usage of certain chemicals to both the local fire department and emergency planning commission. Regardless of location, users of cleaning equipment and materials must determine the regulations applicable to their particular conditions of use.

4.7.2 Coating Film Flammability Concerns All conformal coatings must be considered to be combustible. There are various industry, military and governmental bodies that provide test requirements based upon end use of the coated product. It is vital that the correct test be used to access the ability coating to survive a specific service environment.

5 DESIGN FOR COATING 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 conformally coated assembly.

In this section, 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 conformal coatings 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 conformal coatings for electronic applications aware of the various factors that affect the protection afforded coated assemblies in the end-use environment for the design-life of the assembly.

5.1 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) 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 IPC-D-279.

The design team can consider the general design guidelines presented in the body of this section as a methodology for achieving its reliability goals. IPC-D-279 contains information that illustrates the general design steps and process flow using concurrent engineering. IPC-D-279 also includes information that illustrates the interactive nature of the design for reliability process.

5.1.1 Defining Reliability Requirements The basic requirements to be defined include but are not limited to:

- a. Years of service.
- b. Failure rates/probabilities as a function of time.
- c. Repair/replacement/upgrade/service/maintenance/warranty strategy.
- d. Life cycle environment(s).
- e. Definition of acceptable performance.
- f. Criticality of function(s).
- g. Available test equipment.
- h. Mean time between maintenance.
- i. Mean time between failures.

5.1.2 Understanding the Product Life Cycle The product life cycle begins at the component level (including the printed board) and continues through and beyond the assembly level. Exposures throughout the life cycle include the assembly/process conditions; the testing, storing, transportation and operating environments.

Test, storage and transportation need to be considered at both component and assembly levels as well as before, during and after the coating process.

5.1.3 Defining the Product Environment For each environment in 5.1.2, it is critical to identify, characterize and quantify all parameters that may affect the performance of the product. These include the humidity and pressure of the environment; the range, rate of change and exposure period to temperature (i.e., temperature cycles encountered during the operation of the product). Some products may also encounter physical vibration and shock during operation. Electrical parameters such as ESD, EOS, EMC, EMI and high voltage exposure should be taken into consideration. Most environments include chemical exposure, either from common factors such as salt spray and fuel, or specific chemicals such as flux, solvents, NBC decontamination, etc. Not to be neglected are radiation from sun light, UV or other specific sources; reactive gases (SO_x , NO_x , H_2S , C_{12} , O_3 , etc.), airborne/surface acids, submicron particles and contamination from dust, oil, or human contact.

When the life environments have been identified and defined, the engineering team is prepared to analyze and select the conformal coating, coating process and test strategies required.

5.1.4 Aerospace Applications Coatings used in Aerospace are often required to operate in severe environments, including high altitudes, jungle, desert, or shipboard. Coatings may provide a barrier against sand and dust, high humidity, fungus and corrosive atmospheres containing sulfur compounds or salt spray. Electronics used in aircraft, missiles and weapons systems are required to operate under severe temperature cycling and vibration. Such environments may also cause mechanical stress on fragile electronic components or other structures, necessitating coatings with a low modulus of elasticity, restricted coefficient of thermal expansion, or other specific physical properties.

Coatings may be required to improve insulation resistance between conductors, especially to reduce the risk of plasma arcing, which increases at higher altitudes as atmospheric pressure decreases. Coatings may need to be applied under components or inside spaces that are not otherwise accessible to standard spray application. However, coatings must be excluded from some surfaces inside mechanical switches, relays, connectors, or anywhere they may cause an open circuit. In addition, coatings have been demonstrated to reduce operating life of solder connections under temperature cycling when deposited under Ball Grid Arrays (BGAs) or other closely-spaced components with bottom terminations (see IPC-7095 and IPC-7093).

Qualification testing on Aerospace assemblies may include thermal shock, combined environments (temperature cycling and vibration), mixed flowing gas, fungus resistance, high humidity, or temperature/altitude. These conditions may exceed the rated or qualified properties of the coating.

5.1.5 Automotive Applications

5.1.5.1 Design and Test Typical reliability demands on automotive electronics are:

- a. Life cycle: 15 to 20 years.
- b. Mileage: 300000 to 600000 km.
- c. Running time: 6000 to 12000 hours.
- d. Parking time: 120000 to 450000 hours.
- e. Drive cycles: 11000 to 110000 trips.
- f. Reliability: >99.5% over the life cycle.

To evaluate the ageing of polymer materials, conformal coatings and pottings within an acceptable timeframe, many different life cycle tests have been developed during which the materials are subjected to increased loads over shortened periods of time. Environmental cycling tests in a variety of combinations are used within and outside the automotive industry. During this cyclic load test, temperature fluctuates between, for example, -40°C [-40°F] and $+80^\circ\text{C}$ [176°F] or $+140^\circ\text{C}$ [284°F]. As a rule, these tests are not only performed parallel to one another but are integrated into a “test tailoring” process. The focal points are:

- a. Environmental tests.
- b. Mechanical tests.
- c. Electrical tests.
- d. High temperature storage.
- e. Combinations of the above.

Typically, “serial tests” are utilized to evaluate the environmental loading of conformal coatings. In particular, combining thermal cycling loads (which may cause damage to the coating such as cracking or delamination) with environmental cycling tests under dewing (moisture condensing) conditions enable a quick conclusion to be drawn on the environmental stability of the coated assembly or coating.

The environmental tests that are most frequently cited in relation to conformal coating or potting are:

- a. Temperature/humidity storage to determine the electrical stability (ageing per Arrhenius or Lawson).
 1. Pressure Cooker Test (PCT).
 2. Highly Accelerated Stress Test (HAST).
 3. Temperature Humidity Bias Test (THB).
- b. Thermal cycling test (TC or TCT) / thermal shock test (transition air-to-air) to determine the electrical and mechanical stability of electronic assemblies (e.g., Coffin-Manson equation for solder joints).
- c. High-temperature storage to determine temperature-related failure mechanisms. (e.g., stress migration, Kirkendall effect, polymer embrittlement).
- d. Accelerated Life Test (ALT).
- e. High Temperature Operating Life (HTOL).
- f. Gross and fine leakage test to determine the imperviousness of housings.
- g. Salt spray or noxious gas exposure.
- h. Burn-in tests to pinpoint premature failures, to determine the life cycle of electrical components (Arrhenius equation, bathtub curve).
- i. Electrical ageing tests to reveal ageing processes such as partial discharge, treeing and electrical surface ageing (inverse power law).

The ALT comprises a long-term high temperature storage test which equates to the HTOL test at component level. The test enables statements to be made on the life cycle based on a significant number of failures on a given number of specimens.

5.1.5.2 Thermal/Environmental Cycling Test Reliability tests on the packaging of integrated circuits for high-temperature electronics in motor vehicles have revealed that none of the technology combinations tested initiated electrical failures after 3000 hours exposure to 150 °C [302 °F] and 1700 hours exposure to 165 °C [329 °F]. The thermo-mechanical loads in a thermal shock cycle from -40 °C [-40 °F] to +150 °C [302 °F] resulted in initial failures on the joints and in particular on the plated-through holes of the PCBs after just 1500 cycles.

There are many different methods to determine the thermal cycling resistance, the most popular are:

- a. Thermal shock test (TST).
- b. Thermal cycling test (TCT).
- c. Power cycle.

The thermal cycling and thermal shock tests are primarily used to assess the packaging of integrated circuits or the stability of copper-plated through holes. In the IST and TCT Comfort 40 tests, electrical measurements are performed on the latter so that any degradation of the copper barrel is registered directly. The “simple” TCT has been superseded in most instances; while it would lead to the same results, the duration of the test is much longer. The case is different when it comes to determining the thermal cycling or thermal shock stability of coating materials. They can fail due to embrittlement, cracking, or delamination that cannot be detected by means of electrical measurements. The time of failure can only be assessed at established intervals with the help of lengthy visual inspections.

In “hard” thermal shock tests (e.g., air-to-air with transition times between the storage temperatures of under 10 seconds), or in the “soft” thermal cycling tests (e.g., with a temperature ramp of 5 °C [9 °F]/min), it is mainly the thermal mismatch that induces mechanical stress. Overall, the tests consider the same basic loads or stress factors, the only difference being the longer test duration for the “soft” thermal cycling method. In contrast, a “soft” thermal cycling test which includes controlled humidity stress is referred to as an environmental (cycling) test. During such a test, the specimens are not only exposed to mechanical stress but also to varying humidities (changing climates).

A change in climate does not only mean the change from day to night, a seasonal climate change, or the short-term high humidity after a thunderstorm, but also a change within a so-called microclimate. In motor vehicles, examples of such a change would be:

- a. A climate change induced by vehicle operation.
- b. Introduction of additional moisture into the passenger compartment.
- c. Dewing after a change in the weather or a visit to the car wash, etc.

Besides potential temperature effects, the temperature can fall below the dew point, leading to the condensation of moisture. Accelerated environmental tests such as THB (85 °C [185 °F]/85% RH) or HAST are suitable to ascertain the sensitivity of an assembly to moisture. However, no dewing occurs at these test conditions. Only special dewing tests supply a quick statement on the functionality of an assembly when it is exposed to dewing during later operation. Normally, dewing is achieved by utilizing the special “ramp mode” function of the environmental chamber, or by placing a correspondingly cooled assembly in damp heat per JASO (Japanese Automotive Standards Organization) standards.

The risk of dewing (or its simulation) is directly connected to changes in the climate (temperature). Examples of typical environmental cycling tests include:

- a. IEC 60068-2-30 Db (damp heat 25/55 °C [77/131 °F]/95% RH cyclic, without frost).
- b. IEC 60068-2-14 Nb (thermal cycling at standard humidity).
- c. IEC 60068-2-38 Z/AD (damp heat -15/65 °C [5/149 °F]/93% RH cyclic, with frost).
- d. IPC-TM-650 Test Methods Manual, 2.6.3.4, Moisture and Insulation Resistance - Conformal Coatings.

However, it must be noted that the test chambers are usually conceived so that no dewing occurs on the specimens. Just heating the chamber with warm air in the standard manner does not guarantee dewing. The test chamber must be equipped with a “dewing function” that enables the separate chamber heating system to be deactivated during the designated heat-up phase. The retarded (delayed) temperature rise of the test specimen will ensure dewing takes place.

5.1.6 High Density Interconnect (HDI) on PBs/Backplanes with Soldered or Press Fit Contacts High Density Interconnect PBs (sometimes referred to as backplane assemblies), with either soldered-in connectors or press-fit contacts in plated thru hole (PTH) vias, are increasingly being designed with conformal coat protection. These assemblies require different design considerations than conventional circuit card assemblies, which are populated and soldered with various types of components, and where coating typically is required only to conform over the various topographies to achieve complete coverage. HDI designs may require more insulative protection, which may entail different coatings, application methods and process parameters.

5.1.6.1 Backplanes A backplane (or “backplane system”) is a circuit card assembly that connects multiple pin-and-socket type interconnects (connectors) in parallel, so that each individual pin of each connector is linked to the same relative pin on all the other connectors, forming a “bus.” It usually consists of a large multi-layer printed board with many connectors, used as a backbone to connect several printed circuit assemblies together to make up a complete electronics system.

While a motherboard may include a backplane, the backplane is actually a separate entity. Unlike a motherboard, a backplane lacks on-board processing power, with the CPU typically mounted on a plug-in card. Backplanes are normally used in preference to cabled systems because of their greater reliability. Cables must be flexed every time that a card is added to or removed from the system, which may lead eventually to mechanical failures. Without this issue, a backplane’s service life may be limited only by the longevity of its connectors. For example, the DIN 41612 connectors used in the VME (Versa Module Europa) bus system can withstand 50 to 500 insertions and removals (or “mating cycles”), depending on their quality.

In some cases, bus expansion cables will extend a computer bus to an external backplane, usually located in an enclosure, to provide more or different slots than the host computer. These cable sets have a transmitter board located in the computer, an expansion board in the remote backplane and a cable between the two.

5.1.6.2 Active and Passive Backplanes Backplanes have grown in complexity from the simple (used in the original PC) or S-100 style where all connectors were connected to a common bus. Because of limitations inherent in the specification for driving slots, backplanes are now offered as passive and active.

Passive backplanes offer no active bus driving circuitry. Any desired arbitration logic is placed on the daughter cards. Active backplanes include chips that buffer the various signals to the slots. The distinction between the two isn’t always clear, but may become important if a whole system is expected to have no single point of failure (SPOF). A passive backplane, even if it is single, is not usually considered a SPOF.

5.1.6.3 Midplane Whereas cards and devices connect to only one side of a backplane, a midplane has cards and devices connected to both sides. This ability to plug cards into either side of a midplane is often useful in larger systems made up primarily of modules attached to the midplane. Midplanes are used in computers, mostly in blade servers, where server blades reside on one side and the peripheral (power, networking and other I/O) and service modules reside on the other. Midplanes are also popular in networking and telecommunications equipment where one side of the chassis accepts system processing cards and the other side accepts network interface cards.

5.1.6.4 Design Considerations The primary consideration must be which circuits require protection, i.e., which surfaces require the insulating properties of the coating. Areas requiring coating must be specified in the design.

5.1.6.5 Soldered-In Vs. Press-Fit Connectors Press-fit attachment eliminates the need for soldering and therefore any potential interactions between solder flux and conformal coatings. Also, because cleaning under connector bodies can be difficult, solderless attachment eliminates any potential for corrosion from entrapped solder flux residues. Press-fit connectors also facilitate application of coating before connector assembly (see 5.1.6.7).

Coating must not be allowed to flow into electrical contacts where it may cause open circuits, so other design considerations include:

- a. Connector mounting (i.e., whether mounted with stand-off or flush to the board).
- b. Free-floating contacts or interference fit contacts passing through the connector body.
- c. Female vs. male contacts.
- d. Environmental sealing at the back side of the connector body (to backplane printed board) or front (mate to PCA) side.

The choice of connector may also drive the selection of a coating material and process (see 5.1.6.6). If a mix of connector types is used, this may necessitate a mix of coating types or a hybrid process, complicating assembly.

5.1.6.6 Coating Selection The coating must provide the requisite electrical/insulative protection without interfering with electrical performance of lower level PCAs. Other considerations include:

- a. Processing properties for the uncured coating will dictate whether coating can be applied where required, and whether it may flow into areas where it is not desired (e.g., inside connectors or into PTH vias).
- b. Coating thickness minimums and maximums to achieve required insulating properties.
- c. Effects of coating thickness on mechanical mounting of parts and components.
- d. Coating compatibility with materials of construction (e.g., whether the solvent carrier could attack markings).
- e. Thermal properties of the cured coating and effects on heat transfer from components during operation.
- f. Thermal expansion properties and potential stress on solder.

5.1.6.7 Coating Application and Handling Coating may be applied before or after connector installation. Attaching the connectors after conformal coating helps ensure any necessary conformal coating coverage underneath the connector body, and facilitates connector replacement if rework or field maintenance is required. Installation after coating is easier with solderless “press-fit” connectors, which have barbs on the leads to bite through any coating material that may have flowed inside plated thru holes.

When connectors are installed on the backplane prior to conformal coating, they must be covered or masked to prevent coating material from intruding into or contaminating connector contacts during the coating process. Mounting surfaces, ground planes and other keep-out areas defined in the design will also require masking.

Hard or brittle coatings can easily flake off if the coated assembly is not protected. Handle completed assemblies carefully to prevent conformal coating from abrading off of protruding component leads or other areas.

5.2 PBs Printed boards (PBs) are one of the major subcomponents of a conformal coated assembly. Other sub-elements of the assembly that are considered in the conformal coating design and selection include, but are not limited to, surface finish, spacing between component leads or printed wiring features, discrete and integrated circuit components, solder joint configuration, etc. However, it is the printed board that is the singular largest feature of the assembly that is conformal coated and therefore has a significant impact in determining which conformal coating and process of application is most appropriate to use. The characteristics of the printed board that need to be considered should include the properties of the dielectric laminate, prepreg adhesive, metallized signal layers, pad pattern for surface mount attach designs, aspect ratio of plated-through holes (PTH) and vias (blind or buried). Therefore, the materials of construction of the printed board are important in determining the appropriate conformal coating and method of application.