The benefits of conformal coatings

To coat, or not to coat…

Jim Stockhausen
ELANTAS PDG, Inc.
Ohio Valley SMTA
September 18, 2013
What is a Conformal Coating?
What is not a Conformal Coating?
What is a Conformal Coating?

A specially formulated, polymeric coating applied at low coatweights to printed circuit boards to provide protection from their end-use environment.
What is a Conformal Coating?

A specially formulated, polymeric coating applied at low coatweights to printed circuit boards to provide protection from their end-use environment.

Common Functions:

- Inhibit current leakage due to environmental contamination
- Inhibit corrosion
- Improve fatigue resistance of solder joints
- Inhibit arcing, corona discharge, etc.
- Provide mechanical support and vibration resistance
- **Provide resistance to fluids and humidity**
Why are conformal coatings used?
Why are conformal coatings used?

Reliability
Reliability – definitions:

“Reliability is the ability to function under specific conditions, for a specified period of time, without failure.”
Reliability – definitions:

“Reliability is the ability to function under specific conditions, for a specified period of time, without failure.”

“An attribute of any system that consistently produces the same results, preferably meeting or exceeding its specifications”
Why are conformal coatings used?

- Historically, high reliability was driven by military and aerospace applications
- Reliability has become a ‘must have’ for today’s electronic devices
- The drive for enhanced functionality and miniaturization continues to raise the bar for PCB reliability
- Board protection via Conformal Coating reduces premature failure:
  - Reliability is improved
  - Customer satisfaction is enhanced
- The cost argument for conformal coatings can be a simple one
Why are conformal coatings used?

Reliability – example:

Automotive radio board
- Apply conformal coating:
  - 100mm x 150mm x 0.1mm = 1.5cm³
  - Coating materials = $0.08
  - Labor to apply = $0.05
  - Approximate total: $0.13 / board
Why are conformal coatings used?

Reliability – example:

Automotive radio board

Without Conformal Coating:
1 field failure = $170 to replace the radio
($80 radio + $90 labor)

Conformal Coating costs equate to one field failure in 1300 boards

Does not consider the impact of field failure on customer relationships & brand image
## Conformal Coatings
### Applications & challenges

<table>
<thead>
<tr>
<th>Application</th>
<th>Challenges to circuit board performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automotive</td>
<td>Gasoline, engine/brake fluids, temperature cycles</td>
</tr>
<tr>
<td>Industrial</td>
<td>Water, humidity, detergents, chemicals</td>
</tr>
<tr>
<td>Military</td>
<td>Dust, abrasion, temperature, chemicals</td>
</tr>
<tr>
<td>Aerospace</td>
<td>Temperature, pressurization/depressurization cycles; fluid/moisture resistance</td>
</tr>
<tr>
<td>Medical</td>
<td>Fluid/moisture resistance; critical need for continuous performance</td>
</tr>
</tbody>
</table>
Conformal Coating
Material Breakout by lbs sold

Polyurethane: 24%
Silicone: 35%
Acrylic: 7%
Epoxy: 4%
Others: 30%

$/lb

<table>
<thead>
<tr>
<th>Material</th>
<th>$/lb</th>
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<tbody>
<tr>
<td>Polyurethane</td>
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<tr>
<td>Acrylate</td>
<td>$4 - $9</td>
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<tr>
<td>Silicone</td>
<td>$20 - $30</td>
</tr>
<tr>
<td>Parylene</td>
<td>$200 - $400</td>
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</table>
Conformal Coating
Material breakout by end-use application
Common types of Conformal Coatings
Common types of Conformal Coatings

- Acrylics (Type AR)
- Urethanes (Type UR)
- Epoxies (Type ER)
- Silicones (Type SR)
- Poly(paraxylylene) (Type XY)

Typically applied at 1-5 mil thickness

- IPC Conformal Coating Task Group is beginning to address “specialty” coatings for IPC-CC-830 Rev C
Common types of Conformal Coatings

- Acrylics (AR)

  Easy to use and re-work

  Very common in market place – cost effective

  Typically “one part” coatings – resin and carrier solvent
Common types of Conformal Coatings

- Acrylics (AR)
  - Pros:
    - Economical
    - Ease of removal for rework/repair
    - Simple drying process
    - High fluorescence under black light
    - Ease of viscosity adjustment
    - Can self-heal at higher temperatures
  - Cons:
    - High VOC contents for solvent-borne coatings
    - Poor chemical resistance
    - Flammability of solvent-borne coatings
    - Tends to wick into areas where coatings should not go
    - Can get soft/tacky at higher temperatures (>80°C)
Common types of Conformal Coatings

- **Urethanes (UR)**
  
  Good humidity resistance
  
  Good dielectric properties
  
  Flexible, durable coating
  
  One-part: urethane resin in carrier solvent
  
  Two-part: Part A (resin) and Part B (hardener/catalyst)
Common types of Conformal Coatings

-Urethanes (UR)
  - Pros:
    - Good dielectric properties
    - Good moisture resistance to vapor
    - Good solvent resistance
    - Abrasion resistance
    - Somewhat reworkable
  - Cons:
    - Moisture can impact cure rate and cured properties
    - Long post-cure time to reach full properties
    - Potential to stress components during temperature cycling
    - Yellows with age
Common types of Conformal Coatings

- **Urethane acrylates (AR/UR)**

  Typically UV curable with secondary cure for shadow areas

  100% solids

  Typically thicker coating thicknesses (4-6 mil)

  Classified according to the dominant resin present
  - if a coating is 51% acrylic/49% urethane, classified as Type AR
Common types of Conformal Coatings

-Urethane acrylates (UR/AR)
  - Pros:
    - High throughput with UV curable coatings
    - High solids / low VOC’s
    - Good adhesion and flexibility across with temperature range
    - Good chemical resistance
  
- Cons:
  - Can require capital investment for UV cure equipment
  - Rework can be difficult to rework due to solvent resistance
  - Typically thicker coating thickness
Common types of Conformal Coatings

- Epoxies (ER)

Two part formulations Part A (resin) and Part B (hardener/catalyst)

Reasonable humidity resistance

Tough, hard coatings
Common types of Conformal Coatings

-Epoxies (ER)
  - Pros:
    - Useful to 150°C
    - Very good abrasion resistance
    - Good dielectric properties
    - Very good chemical resistance
  - Cons:
    - Rigid; can crack in vibration or thermal cycling
    - Can shrink, causing stress on components/diodes
    - Handling two-part formulations; limited pot life
    - Extremely difficult to rework
Common types of Conformal Coatings

- Silicones (SR)

Excellent for temperature extremes and cycling

Good humidity resistance

Flexible, resilient coating

\[
\begin{align*}
\text{CH}_3 & \quad \text{Si} & \quad \text{O} \\
\text{Si} & \quad \text{O} & \quad \text{CH}_3
\end{align*}
\]
Common types of Conformal Coatings

-Silicones (SR)
  - Pros:
    - Stable over wide temperature range (-40°C to 200°C)
    - Flexible; provides vibration dampening
    - Good moisture resistance (especially liquid water)
    - Good UV/sunlight resistance
    - High dielectric strength
    - Good chemical and heat resistance
  - Cons:
    - Low abrasion resistance
    - Potential for contamination with other processes
    - Can have outgassing
    - Rework/repair is very difficult
### Other types of Conformal Coatings

<table>
<thead>
<tr>
<th>Type of coating</th>
<th>Advantages/disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poly para xyylene (Parylene) (XY)</td>
<td>Uniform coverage with no pinholing; chemically inert / requires vacuum deposition; very expensive</td>
</tr>
<tr>
<td>Hotmelt</td>
<td>Ease of application and rework; very good moisture protection / thick coatweights; limitations at high temperatures</td>
</tr>
<tr>
<td>Fluoro polymers</td>
<td>Excellent moisture repellency / little mechanical support or vibration resistance</td>
</tr>
<tr>
<td>Synthetic rubber</td>
<td>Good moisture protection; ease of rework / low solvent resistance</td>
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</table>
Comparison of common Conformal Coatings

Performance Summary

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Acrylic</th>
<th>Epoxy</th>
<th>Urethane</th>
<th>Silicone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short Term Humidity Resistance</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
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<tr>
<td>Long Term Humidity Resistance</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>3</td>
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<tr>
<td>Abrasion Resistance</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>4</td>
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<tr>
<td>Mechanical Strength</td>
<td>3</td>
<td>1</td>
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<td>2</td>
</tr>
<tr>
<td>Temperature Resistance</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
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</table>

Rating: 1 = best
## Comparison of common Conformal Coatings

### Performance Summary

<table>
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<tr>
<th>Attribute</th>
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<th>Epoxy</th>
<th>Urethane</th>
<th>Silicone</th>
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<tr>
<td>Acid resistance</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
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<tr>
<td>Alkali resistance</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>3</td>
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<tr>
<td>Organic solvent resistance</td>
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<td>1</td>
<td>2</td>
<td>3</td>
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<tr>
<td>Repairability</td>
<td>1</td>
<td>4</td>
<td>3</td>
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<td>Cost</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

Rating: 1 = best
Simplified chemistry selection for common Conformal Coatings

Temperature Range

-40°C to +125°C

Solvent / Chemical Resistant

Yes

Epoxy

Urethane

No

Acrylic

-60°C to +200°C

Silicone

ELANTAS
Electrical Insulation
The importance of a clean board
Cleaning before coating
Effects of Contamination & Defects

Contamination on the board before coating can lead to:

- Poor adhesion of the coating to the substrate
- Interference with cure of the coating
- Trapping ionic or conductive materials under coating

This can lead to:

- Bubbling, blistering and lifting of the coating
- Discoloration
- Corrosion
- Arcing
- Current leakage

*For optimum long term performance & reliability, clean & dry boards before conformal coating*
Conformal Coatings
Methods of application

Brushing
Pros:
• Low capital investment
• No masking required
• Good for rework/touch-up

Cons:
• Inconsistent thickness / high variability in coating
• Difficult to control voids and bubbles
• Very dependent on operator technique
Conformal Coatings
Methods of application

**Dipping**
Pros:
• Good for low volume throughput
• Good for coverage on complex shapes/parts within assembly

Cons:
• Ambient conditions (temperature, humidity) impact coating quality
• Masking and preparation required
• Dipping bath must be kept free of contamination
Conformal Coatings
Methods of application

Spray - manual

Pros:
• Low capital investment
• Simple process
• Can coat complicated board designs

Cons:
• Hard to contain overspray, resulting in waste and emissions
• Difficult to control coating thickness
• May require multiple coat/cure cycles to reach desired coating
• Masking required
Conformal Coatings
Methods of application

Spray - automated

Pros:
• Uniform coating
• High throughput
• Material savings
• Little/no masking required
• Range of application methods

Cons:
• Capital investment required
• Programming, maintenance required
Optimizing Conformal Coatings results

For each board / coating combination, optimum application conditions vary.

**Example: Bectron PL 4122-40E**

- Airless process; using nozzle 71 or 74
- moisture and temperature levels very important
- adjust height and pressure to optimize coating

<table>
<thead>
<tr>
<th>Nozzle (cone)</th>
<th>71</th>
<th>74</th>
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<tbody>
<tr>
<td>Height (distance)</td>
<td>8-12 mm</td>
<td>8-12 mm</td>
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<tr>
<td>Pressure</td>
<td>14-20 PSI</td>
<td>28-35 PSI</td>
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<tr>
<td>Band size (width)</td>
<td>10-20 mm</td>
<td>5-12 mm</td>
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<tr>
<td>Speed</td>
<td>380-450 mm/s</td>
<td>380-450 mm/s</td>
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<tr>
<td>Temperature</td>
<td>23-25 C</td>
<td>23-25 C</td>
</tr>
<tr>
<td>Layer thickness (dry)</td>
<td>30 µ</td>
<td>30 µ</td>
</tr>
</tbody>
</table>
Optimizing Conformal Coating results
Bectron® MR 3406 adopted for use with ASYMTEK coater

Nordson ASYMTEK with Melting resin tank

min. 200 - 400µm thickness
Selective Conformal Coating System
for selectively applying coating Bectron® MR 3406
Curing / Drying Conformal Coatings
Principle Curing / Drying Processes

- Drying / solvent evaporation

- Heat

- RT (Moisture / Two-Part)

- Combined UV / Secondary cure
  - UV / Heat
  - UV / Moisture
  - UV / Two-Part
Curing / Drying of Conformal Coatings
Solvent Evaporation
- Typical of acrylic coatings
- Simple and cost effective approach

- Drying time
  - Requires drying equipment / area
  - Material can flow before drying

- Safety Considerations
  - Flammability
  - VOC’s
  - Requires ventilation

- High Coatweights should be avoided
  - Solvent Entrapment
Curing / Drying of Conformal Coatings

Heat Cure

- Rapid and complete cure
- Requires ovens and floor space
- Cure time
  - Material can flow before crosslinking cures coating
- Temperature sensitive components a concern
- Capital investment & related maintenance required
Curing / Drying of Conformal Coatings
Room Temperature (RT); Moisture Cure

- Simple and cost effective approach

- Cure time
  - Requires racking
  - Work-in-progress while curing
  - Material can flow while liquid

- Speed of cure varies with relative humidity (RH)
Curing / Drying of Conformal Coatings
Combined UV with secondary cure

- Advantages of UV Cure, without shadowing issues

- UV Light Combinations:
  - UV / Heat
  - UV / Moisture
  - UV / Two-Part

- Guarantees fast immobilization and 100% cure

- UV lamps can be retrofitted to production line

- Capital investment & related maintenance
Rework / repair of coated printed circuit boards
Reworking of Conformal Coatings

Frequently, removal of conformal coating to repair or replace a component underneath is required due to:

- Production Problems
- Field Failures
- Component upgrades

Rework requires:

- Removal of coating
- Clean up of exposed area
- Replacement of component
- Clean up
- Re-coat

Usually a manual process
Methods of rework and repair

– Chemical
  • Often require harsh chemicals that may run afoul of local restrictions
  • Usually have to ID the coating first to select suitable solvent
  • Exposure must be tightly controlled
  • Post stripping cleaning is essential

– Abrasion
  • Media blasting in ESD safe equipment – various blast media
  – Suggest wheat starch pellets or soft plastic pellets
  • Becoming the preferred method for military rework depots

– Thermal
  • Often called “burn-through” methods
  • Most often used on urethanes, some health concerns from smoke
  • Don’t do this on acrylics – black, sticky, tar-like goo that stinks to high heaven

– Mechanical (least desirable)
  • Peeling, razor blades, etc.
  • High probability of damage
  – Other: removal with plasma, supercritical CO2, laser ablation

Post removal cleaning is ALWAYS needed prior to recoating
Coating Removal

Acrylics:
- Soak in solvents

Urethanes:
- Soak in solvent, burn through or micro-abrasion

Epoxies:
- Micro-abrasion or soak in m-Pyrol, strong acid or base

Silicones:
- Micro-abrasion / mechanical action or soaking in ‘Silicone Strippers’

Discuss with your coating supplier the best method for rework
Product Qualification

*Making sure the board meets expected performance and reliability requirements*
Product Qualification

Critical to confirm performance and to predict reliability of board

Principle Tests:

- IPC-CC-830
- MIL-I-46058
- Underwriter’s Laboratory
- BMW Group Standard GS 95011-5
- SIR with:  
  - 85RH/85deg C
  - Salt Spray
- Adhesion
- In-house testing regime
### Product Qualification

**IPC-CC-830:**

<table>
<thead>
<tr>
<th>Material Requirements</th>
<th>Method</th>
</tr>
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<tbody>
<tr>
<td>Materials</td>
<td>Visual Inspection</td>
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<tr>
<td>Shelf Life</td>
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<tr>
<td>Cure</td>
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<tr>
<th>Chemical Requirements</th>
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<td>Fourier Transform Infrared Spectroscopy</td>
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<tr>
<th>Physical Requirements</th>
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<td>Viscosity</td>
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<tr>
<td>Appearance</td>
<td>Visual Inspection</td>
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<tr>
<td>Fluorescence</td>
<td>Visual under UV Light</td>
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<tr>
<td>Fungus Resistance</td>
<td>IPC-TM-650 2.6.1.1</td>
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<tr>
<td>Flexibility</td>
<td>IPC-TM-650 2.4.5.1</td>
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<td>Flammability</td>
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<tr>
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<tr>
<td>Moisture &amp; Insulation Resistance</td>
<td>IPC-TM-650 2.6.3.4</td>
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<td>Thermal Shock</td>
<td>IPC-TM-650 2.6.7.1</td>
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<tr>
<td>Temperature &amp; Humidity Ageing (Hydrolytic Stability)</td>
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**Product Qualification**

**MIL-I-46058:**

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<tr>
<td>Materials</td>
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<td>Shelf Life</td>
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<td>Cure</td>
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**Physical Requirements**

<table>
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<th>Metric</th>
<th>Method</th>
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<tr>
<td>Coating Thickness</td>
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<td>Appearance</td>
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<td>Fungus Resistance</td>
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<td>Flexibility</td>
<td>FED-STD-141, Method 141</td>
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<td>Flammability</td>
<td>ASTM D635</td>
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**Electrical Requirements**

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<tr>
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<th>Method</th>
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<tr>
<td>Insulation Resistance</td>
<td>Mil-STD-202, Method 2, Condition B</td>
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<tr>
<td>Dielectric Withstanding Voltage</td>
<td>IPC-TM-650 2.5.7.1</td>
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<tr>
<td>Q (Resonance)</td>
<td>As per 4.8.6 MIL-I-46058</td>
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**Environmental Requirements**

<table>
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<tr>
<th>Metric</th>
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<td>Moisture &amp; Insulation Resistance</td>
<td>Mil-STD-202, Method 106</td>
</tr>
<tr>
<td>Thermal Shock</td>
<td>Mil-STD-202, Method 107</td>
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<tr>
<td>Temperature &amp; Humidity Ageing (Hydrolytic Stability)</td>
<td>FED-STD-141, Method 4061</td>
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</tbody>
</table>
Product Qualification

**IPC-CC-830 vs. MIL-I-46058:**

MIL-I-46058 predates IPC-CC-830

MIL-I-46058 has been phased out, but is still a commonly used standard

MIL-I-46058 is much more common in US

IPC-CC-830B recognizes that any coating “presently qualified to the MIL-I-46058 shall also be recognized as meeting the requirements of IPC-CC-830”
Product Qualification

Underwriter’s Laboratory
UL746C  Polymeric Materials – Use in Electrical Equipment

Section 70 - Conformal Coatings

Tests:  - Voltage Transient Test
        - Dielectric Withstand & Breakdown Test
          Both with  · Environmental Cycling
                     · Humidity Conditioning
                     · Thermal Conditioning
        - UL94*

* not required if substrate is HB classified
Product Qualification

Underwriter’s Laboratory

Flame Retardancy Ratings:

UL94  Flame spread rating to indicate flammability

UL94  HB  Horizontal Burning Test

UL94  V-X Vertical Burn Test

  V-0  Flame Must be out in 10s
       No glow beyond 30s
       No burning material can fall

  V-1  Flame must be out in 30s
       No glow beyond 60s
       No burning material can fall

  V-2  Flame must be out in 30s
       No glow beyond 60s
       Burning material can fall
Surface Insulation Resistance Testing

Very commonly used with a variety of environmental aging:

- 85% Relative Humidity at 85°C
- Temperature and humidity cycling
- Salt spray (followed by temperature and humidity cycling)
- Any of the above with and without load
Product Qualification

Adhesion

Cross Hatch Testing
Product Qualification

Adhesion

Hydraulic Pull off Tester

- Environmentally sealed, one-piece metal enclosure
- Heavy-duty hydraulic pump designed to apply smooth and continuous pressure with 1 single stroke
- USB port for downloading to a computer
- Self-aligning, quick-coupling ensures proper to actuator
- Single-use, self-aligning clips ensure even, consistent pull-offs
- Adhesive (uneven bond-line)
Product Qualification

In-House Testing

Can be a wide variety of tests

Typically - combinations of common tests under specific conditions

Chemical resistance testing often used (especially automotive fluids)

Common for OEM specifications to be passed down to Tier 1’s (e.g. BMW)
Benefits of Conformal Coatings

Summary

Achieving maximum benefits from conformal coating of printed circuit boards requires coordination of:

- Board design
- Cleaning protocol
- Coating selection
- Coating application
- Coating cure
- Product testing
Benefits of Conformal Coatings

Summary

Achieving maximum benefits from conformal coating of printed circuit boards requires coordination of:

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*and a strong team effort along the way*
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_To coat or not to coat? Coat, of course!!_
Thank you for your attention.