Highly Accelerated Thermal Shock (HATS™) Testing for PCB Hole Reliability

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Outline

- Acknowledgements
- History of Thermal Shock
- MIL-STD and IPC Test Methods
- Experimental Background
- Delphi Standards
- HATS™ Test System
- Comparison Data
- Final Thoughts
Acknowledgements

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Albuquerque, NM
History of Thermal Shock

- Thermal shock testing has been around for a long time
- Thermal shock tests have been used to determine PCB & PCA reliability
- Air-to-air methods have longest history in thermal shock
- Significant disadvantages in cost and time
  - Costly to run dual-chamber and liquid systems (electricity or liquid nitrogen)
  - Air-to-air methods take a very long time
History of Thermal Shock

- Reliability models based upon coefficient of thermal expansion (CTE) of the device under test (DUT)
- Difference in thermal extremes (delta T) determines overall expansion of DUT
  - Example: -40 to +145C is an 185C delta T
- Dual-chamber air-to-air methods require difficult sample fixturing and wiring
- Monitoring typically infrequent
  - Finding glitches almost impossible
MIL-STD-202G, Method 107

- Originated in the late 1950’s
  - Test method last updated in 1984
- Contains both air-to-air & liquid-to-liquid parameters
- Based upon two chamber model
  - Hot & cold for either air or liquid
- Dwell time based upon mass of samples tested
  - Time conservatively estimated for sample to reach equilibrium
- Most methods are built upon this standard
MIL-STD-202G, Method 107

- Transition time between chambers is less than 5 minutes
- Air-to-air methods
  - Lots of thermal mass in transfer cage used to move DUT between temperature zones
  - Low heat transfer rate to DUT
- Liquid-to-liquid methods
  - High heat transfer rate to DUT
  - Difficult to move samples between liquids
  - Liquids are volatile & very expensive
Method 107, Air-to-Air

<table>
<thead>
<tr>
<th>Category</th>
<th>Lower Temperature (°C)</th>
<th>Upper Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>-55</td>
<td>85</td>
</tr>
<tr>
<td>B</td>
<td>-65</td>
<td>125</td>
</tr>
<tr>
<td>C</td>
<td>-65</td>
<td>200</td>
</tr>
<tr>
<td>D</td>
<td>-65</td>
<td>350</td>
</tr>
<tr>
<td>E</td>
<td>-65</td>
<td>500</td>
</tr>
<tr>
<td>F</td>
<td>-65</td>
<td>150</td>
</tr>
</tbody>
</table>

### Air-to-Air Categories

<table>
<thead>
<tr>
<th>Mass (g)</th>
<th>Dwell Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 28</td>
<td>15</td>
</tr>
<tr>
<td>28 to 136</td>
<td>30</td>
</tr>
<tr>
<td>136 to 1,360</td>
<td>60</td>
</tr>
<tr>
<td>1,360 to 13,600</td>
<td>120</td>
</tr>
<tr>
<td>13,600 to 136,000</td>
<td>240</td>
</tr>
<tr>
<td>&gt; 136,000</td>
<td>480</td>
</tr>
</tbody>
</table>

### Air-to-Air Dwell Times
Method 107, Liquid to Liquid

<table>
<thead>
<tr>
<th>Category</th>
<th>Lower Temperature (C)</th>
<th>Upper Temperature (C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>BB</td>
<td>-65</td>
<td>125</td>
</tr>
<tr>
<td>CC</td>
<td>-65</td>
<td>150</td>
</tr>
<tr>
<td>DD</td>
<td>-65</td>
<td>200</td>
</tr>
</tbody>
</table>

**Liquid-to-liquid Categories**

<table>
<thead>
<tr>
<th>Mass (g)</th>
<th>Dwell Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1.4</td>
<td>0.5</td>
</tr>
<tr>
<td>1.4 to 14</td>
<td>2</td>
</tr>
<tr>
<td>14 to 140</td>
<td>5</td>
</tr>
</tbody>
</table>

**Liquid-to-liquid Dwell Times**
IPC-TM-650, TM 2.6.7 Series

- 2.6.7A: Thermal Shock and Continuity - Printed Board
- 2.6.7.1: Thermal Shock - Polymer Solder Mask Coatings
- 2.6.7.1A: Thermal Shock - Conformal Coating
- 2.6.7.2A: Thermal Shock, Continuity and Microsection - Printed Board
- 2.6.7.3: Thermal Shock - Solder Mask
IPC-TM-650, TM 2.6.7 Series

- IPC methods are based upon the “MIL-STD” methods
- Small distinctions between methods for product technology
- Geared specifically to PCB’s and related materials
- Upper temperature is set to be below glass transition temperature (Tg) of laminate materials
Experimental Background

- Objective – compare different thermal shock test methodologies
- Delphi test panels fabricated by 3 different PCB manufacturers
- 6-layer 0.031-inch CAT process capability panels
  - CAT via formation modules (used for Delphi and HATS™ test)
  - IST coupons
- Comparison testing
  - Delphi air-to-air cycle (-40 to +145°C)
  - Modified IST cycle (+25 to +170°C)
  - HATS™ cycle (Delphi temperature cycle)
CAT Process Capability Panel

10.5 x 7.25 inch, 6-layer 0.031-inch thick panel
Test Panel Pre-Conditioning

- Panels subjected to 6 cycles of assembly pre-conditioning temperature profile
  - 2 minute preheat from +25 to +183°C
  - 1 minute dwell between +183 to +215°C
  - 3 minute cool-down
- Panels retested to determine any changes in coupon via net resistance
  - No significant changes were found
Delphi Standards

- 25 minute dwell at each temperature extreme
- Less than 5 minute transfer between extremes
- 1000 cycles $\rightarrow$ 41.7 days... (a long time)
- Temperature extremes and delta T based upon end product use
- Use of periodic resistance measurement to monitor reliability
  - Periodic monitoring misses actual failure point
- Delphi uses custom boards with different hole technologies
## Delphi Application Specific Requirements

<table>
<thead>
<tr>
<th>Class</th>
<th>Cycle</th>
<th>Operating Temperature</th>
<th>Typical Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>-40 to 105C</td>
<td>85C</td>
<td>Passenger compartment</td>
</tr>
<tr>
<td>B</td>
<td>-40 to 125C</td>
<td>105C</td>
<td>Underhood Off-engine</td>
</tr>
<tr>
<td>C</td>
<td>-40 to 145C</td>
<td>125C</td>
<td>Underhood On-engine</td>
</tr>
<tr>
<td>D</td>
<td>-40 to 165C</td>
<td>145C</td>
<td>High performance/Chip-on-board/High dissipation components</td>
</tr>
</tbody>
</table>
HATS™ Test System

- **Highly Accelerated Thermal Shock (HATS™)**
- Partnership – Conductor Analysis Technologies & Microtek Labs
  - New company – Integrated Reliability Test Systems, Inc.
- Air-to-air methodology with stationary coupons
  - Single chamber, high volume airflow with large heat transfer capacity
  - 36 coupons (144 nets) per chamber load
- Thermal specifications
  - Temperature range: -60 to +160°C
  - Air transition time: 30 seconds (-60 to +160°C)
  - Air Stability: ± 2°C
- Data acquisition
  - Mode: 4-wire resistance
  - Accuracy: 2% of resistance value
  - Precision: 2% resistance CoV
  - Speed: 10 readings per second
HATS™ Test System

- Sample sizes ranging from
  - 0.5 inch x 1.0 inch (smallest)
  - 1.0 inch x 2.0 inch (largest)
- Cycles times for a -40 to 145°C cycle
  - 0.031” coupons approximately 7 minutes
    - 500 cycles in 2.5 days
  - 0.125” coupons approximately 10 minutes
    - 500 cycles in 3.5 days
- Capable of simulating test temperatures of current induced (CITC or IST) test methodologies
HATS™ System
Online Coupon Generator

- www.HATS-Tester.com
- Gerber files immediately emailed
- 4 independent nets per coupon
- Nets can be “Through”, “Blind”, “Buried” or “Stacked”
- Parameters for each net
  - Hole size
  - Land size
  - Grid size
  - Interconnect sequences
  - Include/exclude teardrops
  - Include/exclude non-functional lands
  - Include/exclude soldermask coverage
  - Include/exclude ground planes
HATS™ Test Coupons

1.0 x 0.5 inch Coupon

1.0 x 1.0 inch Coupon

2.0 x 1.0 inch Coupon
HATS™ Test Data

Net 1 Resistance Percent Change by Cycle Graph

10% Resistance Change Graph

Cycle Number

Change in Resistance (%)

Cycles to Failure

Hole/Land Diameter (mils)

12/22, 13.5/23.5, 14.5/24.5, 16/26
## Delphi/PCQR² Reliability Study

<table>
<thead>
<tr>
<th>Hole (mils)</th>
<th>Land (mils)</th>
<th>Annular Ring (mils)</th>
<th>Aspect Ratio</th>
<th>Interconnect Sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>14</td>
<td>3</td>
<td>3.8:1</td>
<td>1-4-2-5-3-6</td>
</tr>
<tr>
<td>8</td>
<td>20</td>
<td>6</td>
<td>3.8:1</td>
<td>1-4-2-5-3-6</td>
</tr>
<tr>
<td>10</td>
<td>16</td>
<td>3</td>
<td>3.1:1</td>
<td>1-4-2-5-3-6</td>
</tr>
<tr>
<td>10</td>
<td>22</td>
<td>6</td>
<td>3.1:1</td>
<td>1-4-2-5-3-6</td>
</tr>
</tbody>
</table>
Delphi Data

- Manufacturer A
- Manufacturer B
- Manufacturer C
IST Data

Manufacturer A

Manufacturer B

Manufacturer C
HATS™ Data

Manufacturers A, B, and C are shown in the graphs. The graphs illustrate the percentage of failure over cycles for different manufacturers. The data suggests that Manufacturer A has higher failure rates compared to Manufacturers B and C.
Delphi/PCQR² Reliability Study

PCQR² Relative Reliability Comparison

IST - Interconnect Stress Test  TS - Thermal Shock  HATS - Highly Accelerated Thermal Shock

PTV - 8 and 10 mil holes - 31 mil thick board

Cycles

Fab A-IST (11)  Fab B-IST (12)  Fab C-IST (13)
Fab A-TS (48)  Fab B-TS (48)  Fab C-TS (48)
Fab A-TS-CAT (702)  Fab B-TS-CAT (648)  Fab C-TS-CAT (704)
Fab A-HATS (24)  Fab B-HATS (24)  Fab C-HATS (24)

IST - 3 min. cycles - RT to 170°C
TS - 60 min. cycles - -40 to 145°C
HATS - 14 min. cycles - -40°C to 145°C
IPC D-36 PCQR² Adoption of HATS™

- PCQR² committee adopted HATS™ test method for relative reliability data
  - Shortened Delphi Class “C” cycle time for under hood on-engine requirements
  - Uses standard CAT via formation modules from PCQR² test panels
- PCQR² Database relative reliability test cycle
  - 500 cycles or until 10% resistance change
  - -40C to +145C
- www.pcbquality.com
## Test Methodology Differences

<table>
<thead>
<tr>
<th>Attribute</th>
<th>HATS</th>
<th>IST</th>
<th>Dual-Chamber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal exchange</td>
<td>Air-to-air</td>
<td>Current induced</td>
<td>Air-to-air</td>
</tr>
<tr>
<td>Number of coupons per load</td>
<td>36</td>
<td>6</td>
<td>Custom</td>
</tr>
<tr>
<td>Nets per coupon</td>
<td>4</td>
<td>2</td>
<td>Custom</td>
</tr>
<tr>
<td>Total number of nets per load</td>
<td>144</td>
<td>12</td>
<td>Custom</td>
</tr>
<tr>
<td>Typical temperature range (°C)</td>
<td>-60 to +160</td>
<td>+25 to +150</td>
<td>-55 to +160</td>
</tr>
<tr>
<td>Delta T (°C)</td>
<td>220</td>
<td>125</td>
<td>215</td>
</tr>
<tr>
<td>Typical cycle time (minutes)</td>
<td>14</td>
<td>5</td>
<td>60</td>
</tr>
<tr>
<td>Precision 4-wire resistance</td>
<td>Yes</td>
<td>Yes</td>
<td>Difficult</td>
</tr>
</tbody>
</table>
Test Methodology Differences

- HATS™ method provided 4.3 times shorter cycle time than Delphi dual-chamber method
  - Same temperature range and delta T as Delphi Class “C” cycle
  - Uses air as the transfer medium
- IST cycle time was shortest
  - Lowest temperature of IST cycle is 65°C higher than Delphi Class “C” cycle
  - Lower delta T than Delphi method, +145°C vs. +185°C
  - Upper temperature of IST test method
    - Exceeds T_g of many laminate materials
    - 25°C higher than Delphi method
Integrated Reliability Test Systems, Inc.

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