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IPC-TM-650
TEST METHODS MANUAL

Number	
2.6.26	
Subject	
DC Current Induced Thermal Cycling Test	
Date	Revision
5/14	**A**
Originating Task Group	
PTV Reliability Test Methods (6-10c)	

1 Scope These methods determine the physical endurance of representative coupons of printed boards to a series of high temperature excursions from ambient. The temperature excursions cause thermo-mechanical fatigue of the electrical interconnect structures.

The test coupon is resistance heated by passing DC current through the coupon to bring the temperature of the copper to a designated temperature. Switching the current on and off creates thermal cycles between room temperature and the designated temperature within the sample. The laminate and surrounding materials are heated to different extents depending on the thermal conductivity of the materials. The thermal cycling can accelerate latent interconnect anomalies to failure.

The number of cycles achieved permits a quantitative assessment of the performance.

1.1 Method A Description Method A uses a coupon with two or more independent electrical nets. The designation for these nets is either a power net (P) or a sense net (S). Each electrical net consists of plated barrels and conductors (internal and external). DC current is passed through one electrical net to heat the coupon to a designated temperature. When the electrical net is at the designated temperature, the DC current is turned off and cooling fans are turned on to cool the coupons to ambient temperature. One heating and cooling sequence represents a thermal cycle. Thermal cycling is continued to either a set number of cycles or a failure. Temperature coefficient of resistance (TCR) is estimated by proprietary algorithms.

A failure is based on a percentage change in the bulk resistance of the coupon at the designated test temperature. The percentage change is measured independently for each electrical net being tested. When the percentage change is exceeded, the test is stopped for the coupon.

1.2 Method B Description Method B uses a coupon with one electrical net. The net consists of via structures connected by external and/or internal circuit lines in a daisy chain. DC current is passed through the electrical net to heat the coupon to a designated temperature. When the electrical net is at the designated temperature, the DC current is turned off and a cooling fan is turned on to cool the coupons to ambient temperature. One heating and cooling sequence represents a thermal cycle. Thermal cycling is continued to either a set number of cycles or a failure. Temperature coefficient of resistance (TCR) is measured.

A failure is based on a percentage change in the bulk resistance of the coupon at the designated test temperature. The percentage change is measured independently for each electrical net being tested. When the percentage change is exceeded, the test is stopped for the coupon.

2 Applicable Documents

2.1 IPC[1]

IPC-MDP-650 Method Development Packet

IPC-TM-650 Test Methods Manual[2]

2.1.1 Microsectioning

2.5.35 Capacitance of Printed Board Substrates After Exposure to Assembly, Rework, and/or Reliability Tests. (At the time of publication of this test method, 2.5.35 is in development.)

2.6.27 Thermal Stress, Convection Reflow Assembly Simulation

3 Test Specimens A typical daisy chain test coupon for each method is shown in Figure 3-1 and Figure 3-2.

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

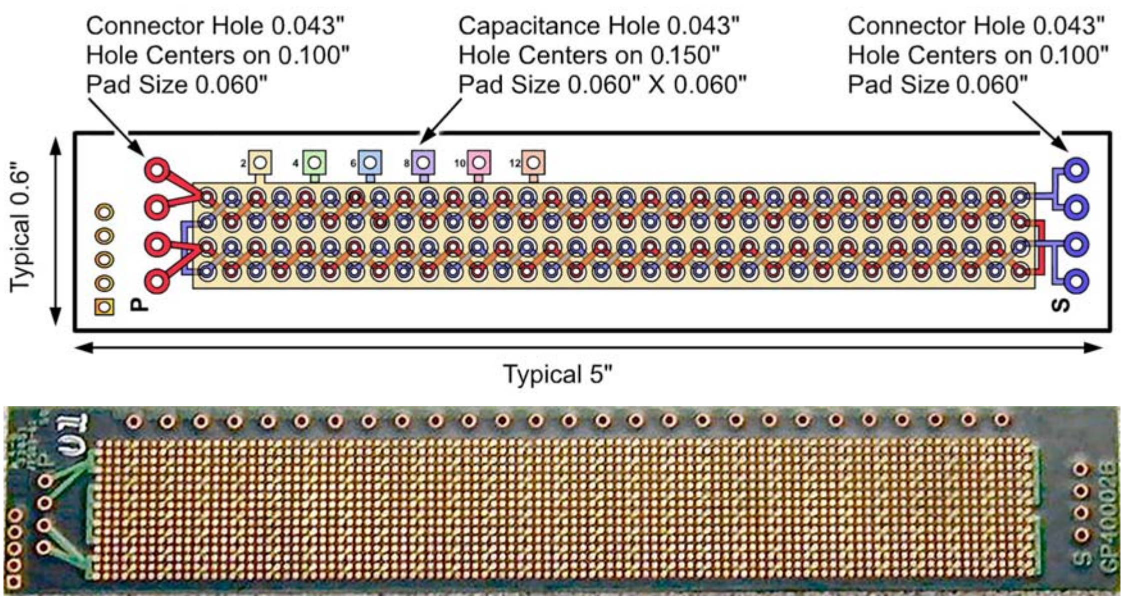

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Figure 3-1 Method A Test Coupon

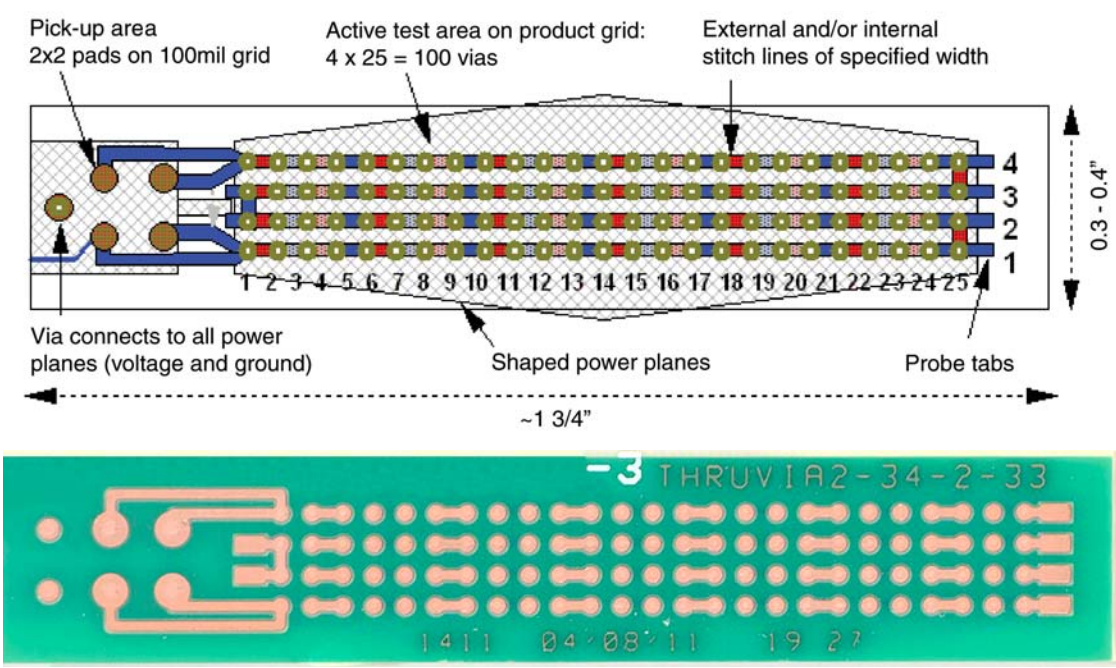

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Figure 3-2 Method B Test Coupon

3.1 Coupon Design Rules Certain designs rules must be applied to achieve thermal uniformity. Electronic design files for coupon construction are available from the equipment supplier or printed board supplier. The resistance values (voltage drops) for each coupon are monitored independently for each electrical net in test, using a four wire measurement technique.

The test coupon(s) is incorporated on the panel to monitor or qualify design, materials, or processes of product and/or reliability assurance.

4 Apparatus or Material At the time of publication of this test method, 4.1 and 4.2 list the only known equipment manufacturers of this test equipment. Equivalent test systems may be used that operate on principles similar to those identified in Method A or B. IPC encourages their submission along with relevant validation test data. This test method will be revised as necessary to include these test systems as this information becomes available.

Validation of this test method was performed with the equipment listed in 4.1 and 4.2. Test conditions for the validation are provided in 6.5. If alternate test equipment is used, validation in accordance with IPC-MDP-650 and 6.5 is recommended.

4.1 Method A

4.1.1 This equipment is available from:

PWB Interconnect Solutions Inc. (Canada)
URL: www.pwbcorp.com
Equipment Type: IST

4.1.2 Two (2) four-pin, 2.54 mm [0.1 in] male connector (ITW Pancon MFSS100-4-D or equivalent).

4.1.3 Sn60Pb40, Sn63Pb37, or lead free solder.

4.1.4 Solder flux.

4.1.5 Soldering iron.

4.2 Method B

4.2.1 This equipment is available from:

i3 Electronics (USA)
(formerly Endicott Interconnect Technologies)
URL: www.i3electronics.com
Equipment Type: CITC, CITC-TCR

4.2.2 4-wire multimeter, capable of measuring milliohms

4.2.3 Thermal imaging equipment – optional

5 Procedures

5.1 Sample Selection

5.1.1 Bench top measure the resistance of each net of the coupon with a 4-wire multimeter. A net with an open cannot be tested. A net with a short must be reworked to test the coupon.

5.1.2 Coupon Selection Select coupons for evaluation based upon the test required as described in 5.1.2.1 through 5.1.2.3.

5.1.2.1 Random Sampling A sample chosen without regard to any characteristic of the individual coupons within a population, within one or more lots.

5.1.2.2 Selective Sampling A sample chosen based on the resistance measurements of the sense and power nets. Testing may include high, midrange and low resistance measurements.

5.1.2.3 Comparative Sampling A sample chosen based on the resistance measurements of the sense and power nets. Testing should include similar resistance measurements for the populations being tested.

5.2 Method A Procedure

5.2.1 Single Sense Testing Solder two four-pin male connectors in the 1.02 mm [0.040 in] holes at the left and right edges of the coupon (see Figure 3-1). A solder fillet must be apparent on both sides of the coupon.

5.2.1.1 Dual Sense Testing (Optional) When Dual Sense Testing is required, solder three four-pin male connectors in the 1.02 mm [0.040 in] holes at the edges of the coupon (see Figure 5-1). A solder fillet must be apparent on both sides of the coupon.

NOTE: Dual Sense coupons may be tested using the Single Sense Testing method.

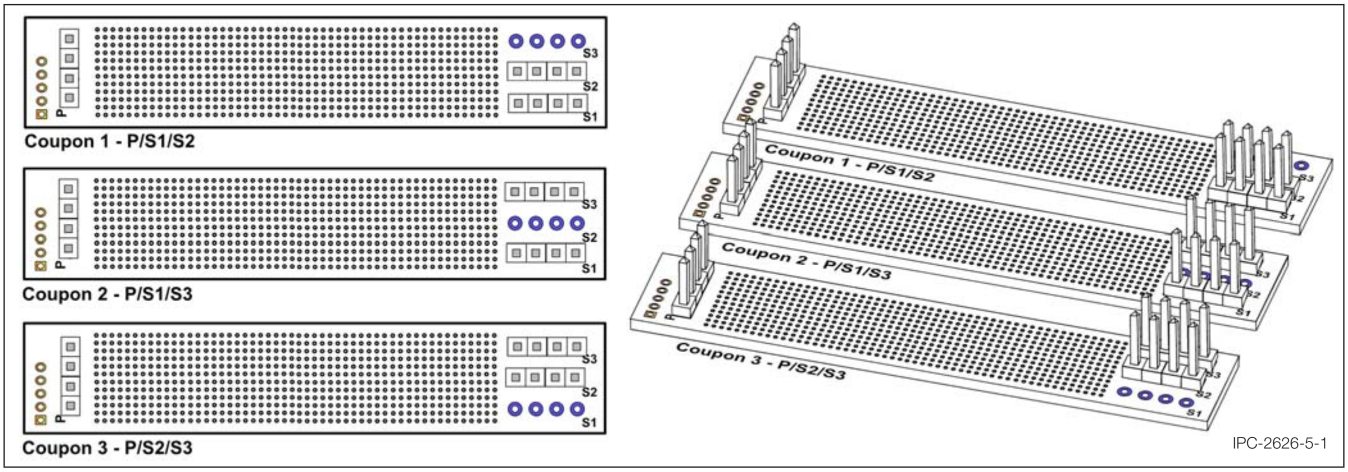

Figure 5-1 Examples of Three Dual Sense IST Test Coupons *(Top-Down View as shown at left and Isometric View as shown at right)*

5.2.2 Position the coupons at each test head by attaching male to female connectors.

5.2.3 Baseline Performance (Optional) Establish a performance baseline by completing two Method A cycles and then stop the test at the end of the cooling cycle.

5.2.4 Capacitance Test (Optional) If required, the capacitance test **shall** be performed per IPC-TM-650, Method 2.5.35.

5.2.5 Assembly Precondition (Optional) Assembly preconditioning is recommended to simulate the assembly environment to which the printed boards are exposed (see 6.1).

5.2.6 Unless otherwise specified by the user, test all via types and materials per the default test condition in accordance with Table 5-1. For testing of samples containing microvia structures, use the microvia test condition. For testing of samples containing polyimide materials, use the polyimide test condition.

5.2.7 Pre-Cycling Test Sequence The following paragraphs detail the sequence for a single coupon, however this sequence is done at all test heads simultaneously. The ambient resistance, resistance at test temperature, rejection resistance, and current are calculated for each coupon and displayed on the PC monitor.

Table 5-1 Method A Typical Test Conditions

Test Condition	Number of Samples	Test Temperatures	Failure Threshold (Resistance Change)[1]	Number of Cycles	Data Collection Frequency (Cycles)	Precycle Time Window (seconds)	Compensation
Default	6	150 °C	10%	250	25	3	Calculated
Polyimide	6	AABUS	10%	250	25	3	Calculated
Microvias[2]	6	190 °C	10%	250	25	3	None
Polyimide Microvias[2]	6	AABUS	10%	250	25	5	None
Survivability Testing	6	230 °C	10%	10	1	5	None
	6	245 °C	10%	10	1	5	None
	6	260 °C	10%	10	1	5	None

Note 1. For Dual Sense Testing, both the ''Cycle Using'' and the ''Cycle Failing On'' fields on the Method A test equipment **shall** be set to 'both sense circuits.'
Note 2. Power on the microvia or heating trace net.

5.2.7.1 Ambient Resistance The auto ranging multimeter measures the ambient resistance (voltage drop) of the net that heats the coupon with DC current.

5.2.7.2 Resistance at Test Temperature The system software calculates and displays the resistance at the test temperature. The available stress testing range is from 50 - 270 °C [122 - 518 °F]. The equation used to calculate the target resistance is as follows:

Target Resistance = Rrm x (1 + αT [Th - Trm])

where:

αT = Estimated thermal coefficient of resistance for the interconnect
Rrm = Resistance of coupon at ambient temperature
Th = Test temperature
Trm = Ambient Temperature (approximately 25 °C [77 °F])

5.2.7.3 Failure Threshold The system software calculates and displays the resistance change. This is adjustable from a 1% to a 100% increase. The typical failure threshold value is a 10% change in resistance. The equation to calculate the failure threshold is as follows:

Failure Threshold = (RT1 x Rr) + RT1

where:

Failure Threshold is in resistance
RT1 = Resistance of coupon at test temperature for Cycle 1
Rr = Resistance change (typically 10%)

5.2.7.4 Current The system selects an initial current based on the ambient resistance of the coupon and the current table. The current tables are derived from software libraries on the Method A test equipment. During the pre-cycling sequence, the initial current is adjusted for each coupon to assure the test temperature resistance is achieved in three minutes ± precycle time window (see 5.2.7.5).

NOTE: Additional equations/algorithms used by Method A that establish the initial current selection for pre-cycling, relative to the relationship of coupon interconnect resistance αT, coupon construction and stress test temperature to be achieved are considered proprietary at this time.

5.2.7.5 Pre-Cycling Pre-cycling is initiated by the application of the selected current to the coupon; the computer monitors the coupon's performance throughout a 30 second and 60 second cycle. The resistance level is monitored and the current is adjusted based on the resistance reading. These short duration tests adjust the current to prevent the coupon heating rate being too fast on the first pre-cycle. The computer monitors and records the coupon's performance on the first pre-cycle. If at the end of the first pre-cycle, the coupon achieves the specified resistance level in three minutes ± precycle time window, it will be accepted for subsequent stress testing. If the resistance value was not achieved in this time frame, the coupon will automatically be pre-cycled again with a revised or compensated current. The system will retest using revised conditions until all coupons are accepted or rejected for stress testing.

NOTE: The equation(s)/algorithms used by Method A to compensate the DC current are considered proprietary at the time of publication of this method revision.

5.2.7.6 Forced air cooling is commenced after each precycle to cool the coupons to ambient temperature.

5.2.7.7 The system automatically records and saves all information regarding the pre-cycling conditions for subsequent stress testing.

5.2.8 Stress Cycle Test Sequence The following paragraphs detail the sequence for a single coupon; however this sequence is done at all test heads simultaneously.

5.2.8.1 When the pre-cycle sequence is complete, the Method A stress test is initiated by applying the same DC current level established for each individual coupon during the pre-cycle operation for three minutes. The computer monitors and records the relative changes in resistance of the plated barrel and internal connections throughout the heating cycle.

5.2.8.2 The three minutes of heating is followed by forced air cooling. Cooling time is a function of overall thickness and construction of the coupon. The computer monitors and records the coupon's performance throughout the cooling cycle.

5.2.8.3 The individual coupons are placed on the tester and are continually thermal cycled using their customized heating and cooling conditions until the rejection criteria is achieved or the maximum number of cycles is completed.

5.2.8.4 The coupon's resistance "delta" (the variance from resistance of coupon at test temperature for Cycle 2) increases (positively) as failure inception occurs. The rate of change in the delta is indicative of the mechanical change (failure) within the barrel and/or internal connections.

5.2.8.5 When an individual coupon delta reaches the rejection resistance, Method A stress cycle testing is stopped for the coupon. The rejection criteria provides for early intervention so failure analysis activities can try to find the root cause for the failure with minimal collateral damage from the stress cycle.

5.2.8.6 The heating and cooling resistance data is compiled for each coupon's performance throughout the stress testing. The system software provides a download file to graph the coupon's performance. Data is compiled to create graphs of each coupon's performance throughout stress testing.

5.2.8.7 The data is tabulated into a test report for analysis.

5.2.8.7.1 Tabulation of Results for Single Sense Testing The test data should be organized to provide the following:

- Test Coupon Description
- Test Parameters
- Sample ID
- Power Circuit (P) Cycles to Failure or End of Test
- Power Circuit Percent Change
- Sense Circuit (S) Cycles to Failure or End of Test
- Sense Circuit Percent Change
- Disposition of Test Results

5.2.8.7.2 Tabulation of Results for Dual Sense Testing The test data should be organized to provide the same data as described in 5.2.8.7.1 with the addition of the following:

- Sense Circuit (S1,S2) Cycles to Failure or End of Test
- Sense Circuit (S1,S2) Percent Change

5.2.8.8 The resistance data for the coupons are plotted on resistance graphs to indicate how damage is accumulated over the test cycles.

5.2.8.9 Microsection (Optional) An appropriate number of coupons are selected for microsection review. A small current is placed on the failing circuit and observed under a thermal camera (see 6.2 and Figure 6-1). The most damaged interconnection is selected for microscopic review.

5.2.8.10 Review all the tabulated data for a determination of the disposition of the coupons.

5.3 Method B Procedure

5.3.1 Unless otherwise specified by the user, the default test condition **shall** be Tin/Lead Reflow in accordance with Table 5-2.

5.3.2 Assembly Precondition (Optional) See Table 5-2 Note 1. See also 6.1.

5.3.3 Temperature Coefficient of Resistance Test Sequence The TCR is calculated once for each unique coupon type or cell. Once determined, that TCR is used for Method B testing of all coupons of that type or cell. Examples of elements that can affect the TCR and therefore define a coupon type/cell are: via structure (thru holes vs. buried vias vs. microvias, etc.), via diameter, via length, total board thickness, laminate/resin material, plating chemistry, type of via fill, and surface finish.

5.3.3.1 Temperature Coefficient of Resistance Determine the TCR of each unique coupon type or cell using the average value from 2 to 4 coupon samples. Attach coupons to each quick connect test fixture and close the oven door. A

Table 5-2 Method B Typical Test Conditions

Test Condition	Number of Samples	Test Temperature[1]	Failure Threshold (Resistance Change)[2]	Number of Cycles	Data Collection Frequency	Temperature Ramp Rate	Dwell at Test Temperature
Tin/Lead Reflow (Default)	8	23 to 220 °C [73 to 428 °F]	5% per cycle or 10% from first cycle	10	1 second intervals	3°C / second	40 seconds
Lead-Free Reflow	8	23 to 245 °C [73 to 473 °F]	5% per cycle or 10% from first cycle	10	1 second intervals	3°C / second	40 seconds

Note 1. These default test conditions represents assembly conditions, and therefore assembly preconditioning is not required. The available temperature test range is from 23 to 300 °C [73 to 572 °F] to any number of cycles.

Note 2. See 5.3.5.

computer controls the oven temperature through a range of temperatures from 23 °C to 260 °C [73 to 500 °F]. The computer monitors and records the equilibrium resistance for each temperature. The equation used to calculate the TCR for each tested coupon is as follows:

$$TCR(T) = \frac{(Rh - Rrm)}{(Th - Trm) \times Rrm}$$

where:

TCR(T) = Calculated TCR for the coupon as a function of intended Method B Test Temperature T
Th = Temperature of coupon at oven temperature
Rh = Resistance of coupon at oven temperature
Rrm = Resistance of coupon at ambient temperature
Trm = Ambient Temperature (approximately 23 °C [73 °F])

5.3.4 Stress Cycle Definition The system calculates and displays the coupon test temperature with the following equation:

$$T = Trm + \frac{(R - Rrm)}{(Rrm \times TCR(T))}$$

where:

TCR(T) = Measured thermal coefficient of resistance for this type/cell of coupons (see 5.3.3.1)
Rrm = Resistance of coupon at ambient temperature measured at start of each cycle
T = Coupon test temperature calculated at 1 second intervals
R = Coupon resistance measured at 1 second intervals
Trm = Ambient temperature measured at each cycle (approximately 23 °C [73 °F])

Alternately, this equation may be expressed in terms of the target resistance that is equivalent to the targeted high temperature for that coupon and cycle, as follows:

Target Resistance = Rrm x (1 + TCR(Th)[Th - Trm])

where:

Th = Target high test temperature

5.3.5 Failure Threshold Three different failure criteria or a combination of these three may be used for a Method B cycle as shown below. Refer to definitions for the variable names and the equation for Target Resistance in 5.3.3.

1) R-high. During any single cycle, R exceeds target value by more than R1% (default R1 = 5%) anytime during cycle, that is,

   R-high failure threshold: R > Target Resistance x (1 + R1).

2) R-low. During any single cycle, the final Rrm(n) after cooling is greater than Rrm(n-1) of the previous cycle by more than R2% (default R2 = 5%), that is

   R-low failure threshold: Rrm(n) Rrm(n-1) x (1 + R2).

3) R-delta. Coupon is failed at cycle n if the final Rrm(n) after cooling is equal to or greater than R3% (default R3=10%) change from Rrm(0) at the start of test prior to cycle 1.

   R-delta Failure Threshold: Rrm(n) > Rrm(0) x (1 + R3).

5.3.6 Stress Cycle Test Sequence The following paragraphs detail the sequence for a single coupon; however this sequence is done at all test heads simultaneously.

5.3.6.1 Stress test coupons are placed in the table top test fixture. The test fixture includes a cooling fan and quick connect housings for the test coupons.

5.3.6.2 The Method B test system uses the TCR and associated equation (see 5.3.3) to heat the coupon with DC current (variable level determined in 1 second intervals) to the prescribed ramp rate and high test temperature. The computer also monitors and records the relative changes in resistance of the plated barrel throughout the heating cycle.

5.3.6.3 The dwell time at test temperature is followed by forced air cooling. Cooling time is a function of overall thickness and construction of the coupon. The computer monitors and records the coupon's performance throughout the cooling cycle.

5.3.6.4 The individual coupons are continually thermal cycled using their customized heating and cooling conditions until one of the rejection criteria is achieved or the maximum number of cycles is completed.

5.3.6.5 The heating and cooling resistance data is compiled for each coupon's performance throughout the stress testing. The system software provides a download file to graph the coupon's performance. Data is compiled to create graphs of each coupon's performance throughout stress testing.

5.3.7 Graphing and Data Analysis

5.3.7.1 Tabulation of Results Test results are typically reported with the following information:

- Test Coupon Description
- Test Parameters: Temperature(s), ramp rate, dwell

- Sample ID
- Temperature Coefficient of Resistance for each test temperature and ''cell''
- Cycles to fail
- Applicable failure criteria
- Failure point (temperature at fail, hot or cold side of cycle)
- Failure isolation and analysis, if applicable
- Disposition of Test Results

6 Notes

6.1 Assembly Preconditioning – Optional The elevated temperatures of the lead free assembly process impacts the performance of the plated barrels and internal connections. Assembly preconditioning is recommended before the DC current induced thermal cycling. When an individual coupon delta reaches the rejection resistance, stress cycle testing is stopped for the coupon.

6.1.1 Method A The available equipment ranges and typical assembly preconditions are provided in Table 6-1. Attach the power cable at the same location as the Method A stress test.

6.1.2 Method B The Method stress test temperatures are based on the assembly process temperatures (see Table 5-2).

6.1.3 Convection Reflow Assembly Simulation (Method C) The assembly temperatures are based on IPC-TM-650, Method 2.6.27.

6.2 Microsection Evaluation – Optional If detailed failure analysis is desired to determine the exact location of separations and/or cracks, select an appropriate number of coupons for failure analysis. Locate the failure location and microsection to determine the most likely cause of the failure. Microsection of failed coupons **shall** be performed in accordance with IPC-TM-650, Method 2.1.1.

6.2.1 Locate Failure by Thermal Camera Locate the failure by applying a small current to the failing circuit and observe the thermal camera output (see Figure 6-1). The location with the 'hottest' thermal signature is selected for failure analysis.

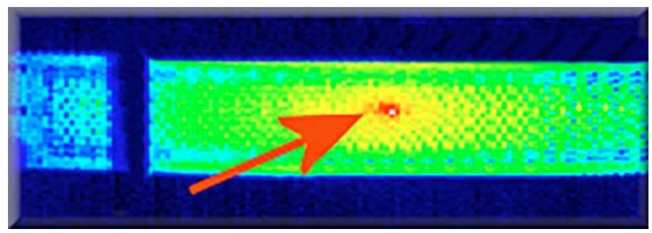

Figure 6-1 Microvia Failure Location

6.2.2 Locate Failure by Hot Plate Locate the failure using a hot plate set at 220 - 250 °C. The hot plate should be covered with Kapton tape or a similar electrical insulator to insulate the coupon from the hot plate surface. Place the coupon on the hot plate and monitor the resistance change using a 4-wire multimeter. The location with the highest resistance or open is selected for failure analysis.

6.2.3 Locate Failure by Resistance Locate the failure using a 4-wire multimeter. Electrical isolate the circuits, PTHs, or conductors by cutting conductors. The location with a high resistance or open is selected for failure analysis.

6.3 Methods Overview Table 6-2 provides an overview of the two methods described in this test method to measure the change of resistance of plated barrels and/or internal connections as they are subjected to thermal cycling.

Table 6-1 Method A Assembly Preconditioning Test Conditions

Condition	Number of Samples	Test Temperature	Maximum Test Temperature	Resistance Change	Number of Cycles	Precycle Time Window	Compensation
Tin/Lead Reflow	6	230°C [446°F]	240°C [464°F]	10%	6	5 seconds	None
Lead Free Reflow A	6	245°C [473°F]	255°C [491°F]	10%	6	5 seconds	None
Lead Free Reflow B	6	260°C [500°F]	270°C [518°F]	10%	6	5 seconds	None

Table 6-2 Methods Overview

	Method A	Method B
DC Current Applied To	Plated Structure, Conductor, Land and Internal Connections	
Temperature Coefficient of Resistance (TCR)	Estimated	Measured
Assembly Preconditioning[1]	3 minute to temperature 230 °C for tin-lead 245 °C for low temperature lead-free 260 °C for high temperature lead-free Or alternate assembly preconditioning method, such as per IPC-TM-650, Method 2.6.27	3 or 5 °C per second to temperature 220 °C for eutectic tin-lead assembly 245 or 260 °C for lead-free assembly
Test Temperature	150 °C for standard FR4 170 °C for standard polyimide 190 °C for microvias on standard FR4 210 °C for microvias on Polyimide 230 °C for Survivability tin-lead 245 or 260 °C for Survivability lead-free	220 °C for eutectic tin/lead assembly 245 °C for lead-free assembly
Heating Rate or Time	3 minutes maximum Variable based on application	3 or 5 °C per second
Dwell time at maximum temperature	1 second Variable based on application	40 seconds
Failure Threshold	10% increase in resistance over resistance at test temperature	For each cycle, 5% change in resistance for R_{High} or R_{Low}
		10% increase in resistance over resistance at ambient temperature
Cooling Method	Forced ambient air	Forced ambient air
Resistance Monitored	Continuous	Continuous

Note 1. When testing at reflow temperature, assembly preconditioning and test temperature may be combined.

6.4 Optional Testing Instances of optional testing throughout this test method represent tests that have not been validated in accordance with IPC-MDP-650.

6.5 Validation Testing Validation of test machines referenced in 4.1 and 4.2 **shall** test the following key aspects of the test method. The TCR is used to associate resistance values to the test temperature, and the designated test temperature/resistance at the beginning of the thermal cycling test. These validation activities **shall** be done at 2 or more independent test sites that use the test machine. The testing is assessing that there is no statistical difference between independent test machines at a 95% confidence limit on a minimum of 16 test coupons.

6.5.1 Method A

6.5.1.1 Temperature Coefficient of Resistance (TCR) Validation

1. Verify the equipment is calibrated and ready for use.
2. Load coupons into all the test heads on the test machine
3. Record the resistance of the each coupon at 150 °C on the Sense net.
4. Remove the coupons from the test equipment and attach wires to the (4) header pins on the Sense net.
5. Attach thermocouple wires to the laminate surface of each coupon.
6. Place coupons in an oven set at 150 °C.

7. When the thermocouple/ thermometer measures 150 °C, record the resistance of the Sense net with a 4-wire cable and a bench top multi-meter.
8. For validation, compare the resistance readings of the manual measurements in the oven and the test machine for each coupon.

6.5.1.2 Test Temperature/Resistance Validation

1. Verify the equipment is calibrated and ready for use.
2. Load coupons into all test heads on the test machine.
3. Enter the test parameters shown in Table 6-3 (or equivalent) into the test machine.

Table 6-3 Temperature Coefficient of Resistance (TCR) Validation Parameters

Test Parameter	Setting
Maximum # Cycles	5
Data Recorded	1
Test Temperature	150 °C
% Rejection Sense Circuit	10%
% Rejection Power Circuit	10%
Precycle Time	5
Compensation	Calculated

4. For Cycle 2, measure the resistance at 150 °C and at room temperature on the test machine.
5. For validation, compare the resistance measurement at 150 °C between test machines and at room temperature between test machines.

6.5.2 Method B

6.5.2.1 Temperature Coefficient of Resistance (TCR) Validation

1. Label coupons and record 4-wire resistance with bench top multi-meter.
2. Measure the temperature and resistance at the following equilibrium temperatures: 23, 75, 125, 150, 175, 200, and 220 °C. Calculate TCR for test temperature 23-220 °C.
3. For validation, compare the measured TCR values between test machines.

6.5.2.2 Test Temperature/Resistance Validation

1. Run 3 cycles for test temperature 23-220 °C using the mean TCR measured in 6.5.2.1.
2. For Cycle 3, record the calculated temperature T(calc, high) at end of high temperature dwell.
3. For validation, compare the T(calc, high) value between test machines.