Table 22.7 Continued

		Testing			
Variation	Acceptable By CCIL/MCIL	Bond strength	Delamination and blistering	Flame	UL 796 reference
(without affecting minimum build-up)[c]					
NOTE If Dissimilar material(s), additional testing is required per 17.5.3 and 17.6 unless the dissimilar material combination has previously been investigated.					
[a] If Dissimilar material(s), additional testing is required per 17.5.3 and 17.6. [b] The board minimum buildup thickness shall not be reduced below the minimum established thickness for the laminate. [d] The board minimum individual laminate sheet thickness and/or prepreg sheet thickness shall not be reduced below the minimum established thickness for the individual sheets.					

Table 22.8
Test Program for Revised Laminating Process – Multilayer PWB

	Testing			
Variation	Bond strength	Delamination and blistering	Flame	UL 796 reference
Increasing laminating pressure		X		12.1.6(e)
Increasing laminating temperature and/or time	X	X	X	12.1.6(e)
Decreasing laminating pressure, temperature or time		No testing		

Table 22.9
Test Program for the Addition of Embedded Capacitors and Resistors in Multilayer Constructions

Variation		Testing				
Embedded component construction	Examples of technology used by industry	Evaluated per Non-reinforced Dielectric Materials and Other Materials Requiring Mechanical Support section of UL 746E	Delamination and blistering	Flammability	Dissimilar material thermal cycling	UL 796 reference
Adding embedded capacitors						
Screen printed	• $BaTiO_3$ in epoxy photo - dielectric • $BaTiO_3$ in polyimide	X	X	X	X	15, 17.5.3, and 17.8.1
Thin film inorganic dielecrtrics ≤1 mic and ceramic paste	• SiO_2 • Al_2O_3 • TiO_2 • $BaTiO_3$	–	X	–	–	15, 17.8.1
Adding embedded resistors						

Table 22.9 Continued on Next Page

Table 22.9 Continued

Variation		Testing				
Embedded component construction	Examples of technology used by industry	Evaluated per Non-reinforced Dielectric Materials and Other Materials Requiring Mechanical Support section of UL 746E	Delamination and blistering	Flammability	Dissimilar material thermal cycling	UL 796 reference
Etching thin film[a]	• Nickel/ phosphorus • Nickel/ chromium • Platinum alloy	–	X	–	–	15, 17.8.1
Plated	• Nickel Phosphide					
Screen printed	• Polymer thick films • Ceramic paste • Conductive paste					

NOTES –

1 – All embedded components are limited to internal board use only. Additional testing may be required for embedded components on the external surface of the board (see 15.6).

2 – The above test program assumes the printed wiring board will be used in rigid end use applications only. Additional testing is required for flexible end use applications (see Standard for Flexible Materials Interconnect Constructions, UL 796F).

[a] Embedded resistor materials supplied on a copper clad core laminate shall have previously had the CCL with the resistor material applied evaluated to the applicable requirements in Standard for Polymeric Materials – Industrial Laminates, Filament Wound Tubing, Vulcanized Fibre, and Materials Used in Printed Wiring Boards, UL 746E, in the section for Ultrathin Laminate and Prepreg Test Program, or in the section for Non-reinforced Dielectric Materials and Other Materials Required Mechanical Support, for Relative Thermal Index (RTI) and Performance Profile Indexing properties if the printed wiring board is to be evaluated for a Maximum Operating Temperature (MOT) and Direct Support (DSR).

Table 22.10
Test Program for Revising HDI Constructions

HDI PWB Construction Variation	Testing			
	Vertical flame test, 34.2	Bond strength/ delamination, 34.3	HDI thermal cycling, 34.3.2	UL 796 reference
Addition of alternate singlelayer core of same UL/ANSI – acceptable by CCIL/MCIL	No testing			16.2, Section 19
Addition of alternate multilayer core package of same UL/ANSI – acceptable by CCIL/MCIL	–	Delam only	–	Table 22.7, Section 19
Decrease the core minimum build-up thickness	X	X	X	Section 19
Decrease the HDI material minimum thickness	X	X	X	Section 19, 34.1.2
Increase the HDI material maximum thickness	X	–	–	Section 19, 34.1.2

Table 22.10 Continued on Next Page

Table 22.10 Continued

HDI PWB Construction Variation	Testing			
	Vertical flame test, 34.2	Bond strength/ delamination, 34.3	HDI thermal cycling, 34.3.2	UL 796 reference
Increase the HDI material maximum number of layers	X	X	X	Section 19, 34.1.2
Intermixing of different HDI materials	X	X	X	17.6, Section 19, 34.1.2
Addition of prepreg as HDI material with limited build-up thickness	See Section 17 and Table 22.7.			19.1

PERFORMANCE

23 Test Samples

23.1 A complete set of samples shall be provided as scheduled in Table 23.1.

Table 23.1
Samples for Initial Investigation

	References
A. Basic set of samples (See Figure 10.1)	
1. Shall represent all of production.	8.1
2. Base shall be of minimum thickness.	9.1.4
3. Midboard conductor shall include minimum width.	10.7.1
4. Edge conductor shall be of minimum width.	10.8.1
5. Process shall be at highest temperature and time limits using the selected etchant.	12.1.1
6. Shall contain representative plating.	10.12.1
7. Shall contain plated contact fingers and/or through-holes if applicable.	
B. Extra set of samples (added to A)	
1. For each different base manufacturer.[a]	9.1.1, 9.1.2, 16.2.1, 17.8.1
2. For each different grade or family of base material.[a]	9.1.1, 9.1.2, 16.2.1, 17.8.1
3. For each base-material cladding process.	10.6.1
4. For each copper weight range.	10.6.3
5. For a change in any process where the temperature on the surface of the board exceeds 100°C (212°F) or the maximum operating temperature of the printed wiring board, whichever is greater.	12.1.6
C. Sets of 20 samples for flammability tests – See the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94.	27.2.1
NOTE – If fully representative, a sample is not prohibited from combining one or more items.	
[a] Samples may not be required. See 16.2.1.	

23.2 A representative conductor pattern for a test sample is shown in Figure 10.1 and Figure 10.3. Annex A includes examples of sample construction cross sections. Figure A.2 – Figure A.8 are examples of the typical Flammability sample construction cross sections. Figure A.9 – Figure A.15 are examples of the typical Bond Strength and Delamination sample construction cross sections. Figure A.1 cross sections "b" and "c" are referenced in these figures to help explain the multilayer constructions.

23.3 A test sample is not prohibited from employing conductors on more than one side. See Section 16, Singlelayer Printed Wiring Boards, and Section 17, Multilayer Printed Wiring Boards.

23.4 A sample is to be tested without mounted components, such as capacitors and resistors. If embedded components are included in the board construction, they should be included in the test sample.

23.5 The construction of samples of molded boards shall simulate actual construction for 3-dimensional boards.

23.6 The construction of multilayer Bond Strength and Delamination and Blistering samples shall be as follows:

a) The thinnest individual sheets of laminate and prepreg shall be included. The minimum bonding layer thickness shall be included in contact with any internal conductive layers that may not be the maximum metal weight. The internal conductor of maximum metal weight shall be in contact with the necessary thickness of prepreg sheets to have good layer registration without inside delamination or air entrapment.

b) The Bond Strength and Delamination conductor test pattern shown in Figure 10.1 shall be included in the internal patterned conductor layers and on both the external patterned conductor layers. The internal patterns shall mirror the external conductor pattern. Internal conductor widths are to vary as needed for the metal weights or thicknesses employed but shall not be narrower than the external conductor width.

c) The largest unpierced conductor area to be used in production shall be included on the external and internal conductor layers.

d) At least one internal patterned conductor layer shall contain the maximum metal weight used in production. If the maximum internal metal weight cannot be accommodated by the minimum multilayer construction build up described in 17.5, a second set of Bond Strength and Delamination test samples shall be provided. The first set of samples shall contain the maximum internal metal weight that can be accommodated by the minimum multilayer build-up described in 17.5. The second set of Bond Strength and Delamination test samples shall contain the minimum multilayer build up construction that can accommodate the absolute maximum internal metal weight to be used in production.

e) The external conductor layers shall consist of the minimum metal weight used in production. If the initial minimum external metal weight is less than 33 μ (1 oz/ft^2), the conductors shall be plated up to 33 μ (1 oz/ft^2) to aid the bond strength pull. When external metal weights heavier than 102 μ (3 oz/ft^2) are used in production, an additional set of samples fabricated with the maximum external metal weight to be used in production shall be provided.

f) Each generic laminate material layer shall be in contact with each generic prepreg material layer. The total build up of the multilayer laminate Bond Strength and Delamination samples shall not exceed the minimum production thickness plus the thickness of two or the minimum number of internal patterned conductor layers, whichever is greater. If constructed as shown in Figure A.1 "c", each prepreg layer shall be subjected to Bond Strength testing as shown in Section 28.

g) Chromic/sulfuric etchant shall be considered representative of all etchants. Any other acidic or alkaline etchant shall be considered representative of all etchants except chromic/sulfuric.

23.7 The construction of multilayer flammability samples shown in Figure A.1 "b" or Figure A.1 "c" shall be as follows:

a) The build-up shall include the thinnest individual base material and bonding sheets. The build-up thickness shall be the minimum total thickness that would result from two or the minimum number of etched conductive layers of the minimum internal metal weight. The flammability sample build up shall be the same build up as the Bond Strength and Delamination samples – the same individual sheet thickness, quantity and position in the buildup of the laminate and bonding sheets/prepreg plies – minus the copper. If the PWB is being evaluated for “Flammability Only,” the construction of the samples shall represent actual production printed wiring boards.

b) Each generic base material layer shall be in contact with each generic bonding layer and be an external surface layer. Each bonding layer that will be used as an external layer shall be in contact with each generic base material layer.

c) All metal shall be etched from internal and external surfaces.

d) Chromic/sulfuric etchant shall be considered representative of all etchants. Any other acidic or alkaline etchant shall be considered representative of all etchants except chromic/sulfuric.

24 Data Collection

24.1 The conductor width shall be determined by measuring the contact or interface area of the conductor material to base material. See Figure 24.1. Each of the following conductor widths shall be determined:

a) A midboard conductor having the minimum average width on the sample;

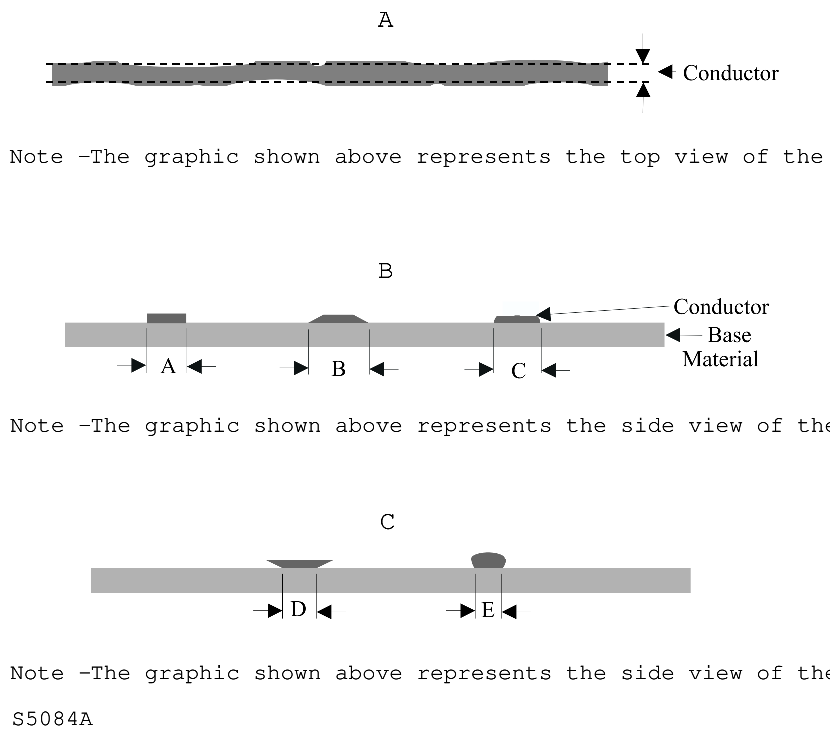
b) A 1.6 mm (0.062 inch) width conductor;

c) An edge conductor having the minimum average width within 0.40 mm (0.015 inch) of the board edge and not sheared at the board edge, except as described in 10.8.1. If the edge conductor does not meet the criteria and/or is not included on the sample, a conductor of other width (d) specified by the fabricator shall be tested; and

d) A midboard/non-edge conductor of "other" width (optional) specified by the fabricator. The "other" width conductor is optional unless the edge conductor does not meet the criteria in 10.8 and/or is not included on the sample test pattern.

Figure 24.1

Measuring Conductor Average Width



24.2 In cases where the contact or interface area of the materials cannot be viewed from above due to the conductor dimensions, (see Figure 24.1C), the average contact or interface area of the separated materials shall be used to measure the conductor average width.

24.3 The maximum area conductor diameter shall be determined on the sample test pattern. Alternate conductor area diameters shall also be determined if necessary for the test method.

24.4 The external conductor thickness (weight) including foil thickness and plating shall be determined on the sample test pattern. In addition, the external conductor foil and conductor surface plating thickness shall be determined on the sample test pattern to verify the total conductor thickness is appropriate for the bond strength pull.

24.5 For multilayer samples with internal conductor test patterns, the internal conductor thickness (weight) shall be determined for each internal conductor layer.

24.6 The build up thickness of the uncoated flammability sample shall be determined by measuring the sample thickness on the sample. The build up thickness of the bond strength, delamination, conductive paste adhesion, dielectric crossover (withstand), and silver migration test samples shall be determined by measuring the sample thickness where no conductor material resides on the internal and external surfaces of the sample construction.

24.7 The measuring device used to measure the build up thickness and test pattern parameters shall have an accuracy of 10 percent of the measured parameter. Microsection analysis shall be used to determine the external and internal conductor thicknesses and widths.

25 Microsection Analysis

25.1 General

25.1.1 The purpose of the microsection examination is to evaluate and determine compliance of the materials, construction, and test pattern of the printed wiring board with the applicable standard and test method sample coupon construction requirements. The same basic procedures may be used to evaluate other areas of the sample.

25.1.2 Guidelines for preparing microsection samples are described in the Standard Practice for Preparation of Metallographic Specimens, ASTM E 3, and Microsectioning, Manual and Semi or Automatic Method, IPC TM-650 2.1.1.

25.2 Test samples

25.2.1 The microsection samples shall be cut from the printed wiring board or test coupon to include representative areas of the parameters to be measured. This may require multiple microsections. All samples must maintain required traceability. Three common types of cutting tools are diamond saws, routers, and punching dies. Samples shall be cut perpendicular to the evaluation surface with enough clearance to prevent damage to the examination area. The recommended minimum clearance is 2.5 mm (0.1 inch). Depending on the printed wiring board or test coupon design care shall be exercised in choosing a microsection location such that a complete examination can be made.

25.2.2 Samples sizes are generally not more than 12 to 25 mm (0.5 to 1.0 in.) square. The sample height shall be determined for convenience in handling during polishing.

25.2.3 Samples shall be cleaned thoroughly with isopropyl or ethyl alcohol to remove all greases, oils, and residue from the cutting tools. Dry the sample thoroughly. Cleanliness during sample preparation is important for good adhesion of the mounting resin. Poor adhesion of the mounting resin can cause gaps between the sample and the mounting material which make proper examination difficult.

25.2.4 Samples shall be mounted prior to grinding and polishing in a castable resin/potting material. The sample shall stand in the mount ring perpendicular to the base with the surface to be evaluated facing the mounting surface. A release agent may be applied to the plate and mounting rings, as applicable. Clips or tape may be used to support the sample until the potting material is cured, as applicable.

25.2.5 The mounting mold shall be filled with potting material carefully to reduce bubbles in the potting material. Allow samples to cure and remove mount mold.

25.2.6 A description of the basic grinding and polishing steps is outlined in 25.2.7 – 25.2.9.

25.2.7 The samples shall be rough planar ground using using an abrasive medium. ANSI 180 – 240 grit abrasive paper (or equivalent) may be used as a starting grit size using metallographic equipment to remove the sectioning/cutting damage. The sample shall be held firmly in contact with the rotating wheel in a circular path against the rotation of the wheel. Rinse the sample with running water and dry. Wheel speeds of 200 to 300 rpm are generally used during grinding. Rotate the sample 90 degrees planar between successive grit size and grind to remove the scratches from the previous step. The successive grinding time may be three times longer than the previous step. Scratches are grooves in the surface of the sample produced by the abrasive particles in the grinding paper. The surface of the sample shall be flat with one set of unidirectional grinding scratches. Water flow must be maintained for removal of grinding debris and to prevent overheating and damage to the sample.

25.2.8 Continue grinding the samples with fine grit size. ANSI 400 – 1200 grit (or equivalent) may be used in successive order to remove the rough and finer grinding damage/scratches. Less time shall be spent on the larger grit and more time on the smaller grit for better sample quality. The scratch removal can be verified by microscopic inspection between steps. Rinse and dry samples between each step to avoid contamination by grinding particles.

25.2.9 Polish the samples to remove the scratches from intermediate steps. Diamond polish is preferred. Smearing of the printed wiring board material or potting material may occur if lubrication levels are too low or if excessive load is used during grinding. Increase or change the lubricant and reduce the applied load to reduce smearing.

25.3 Micro-etching the sample surface

25.3.1 When the required microsection quality has been achieved, the sample shall be etched to allow examination of the copper foil and plating interface.

25.3.2 The etching solution shall be prepared daily and is a mixture of 7 drops Ammonium Hydroxide solution and 9 drops Hydrogen Peroxide solution. The Ammonium Hydroxide solution is a 1:1 ratio solution of reagent grade Ammonium Hydroxide and deionized water. The Hydrogen Peroxide solution is a 1:1 ratio solution of stabilized Hydrogen Peroxide (3 percent by volume) and deionized water.

25.3.3 The etching solution shall be applied for 2 to 3 seconds. If necessary, repeat the application of the etchant 2 to 3 times to show the plating surface. Rinse in running tap or deionized water to remove etchant.

Note: Over etching may obscure the demarcation line between the copper foil and electroplate copper, preventing accurate evaluation. Thin copper foil and special plating processes require the etching time to be modified.

25.4 Material and test pattern parameter examination

25.4.1 The microsection sample shall be evaluated at a minimum 100X magnification with bright field illumination. Foil thickness less than 12.5 mic shall be evaluated at a minimum 200X magnification to confirm thickness.

25.4.2 All parameters required by the standard shall be measured and observed including, but not limited to, overall construction build up thickness, laminate layer thickness, bonding layer thickness, number and thickness of reinforcement layers, conductor thickness (weight), conductor base width, etc.

26 Thermal Stress Test

26.1 Purpose

26.1.1 The thermal stress test is designed to evaluate the physical fatigue of representative samples or production boards exposed to assembly soldering. See Table 26.1 for the test methods to be conditioned using the thermal stress test. There shall be no wrinkling, cracking, blistering, or loosening of any conductor or any delamination in the PWB sample or production board as a result of the thermal stress test.

Table 26.1
Test Methods Requiring Thermal Stress Test

Test	Section
Flammability	27
Bond strength	28
Delamination	29
Conductive paste adhesion	33
HDI thermal cycling bond strength	34

26.2 Apparatus

26.2.1 Thermal stress reflow conditions shall be conducted using the following apparatus:

Reflow Oven – The reflow system shall have adequate environmental controls to maintain the tolerance range and limits in the designated reflow profiles. IR reflow requires attention to the uniformity of temperature across the sample due to the susceptibility of the materials to infrared absorption.

26.2.2 Thermal stress shall be conducted using one of the apparatus specified below for other soldering processes:

a) Convection Oven – Attention shall be directed to maintaining the test temperature, when introducing and removing the samples into and from the oven chamber.

b) Sand Bath – Attention shall be directed to the uniformity of temperature throughout the fluidized bed, and avoid mechanical damage imposed by an inadequately fluidized sand bath. Samples shall be prepared to prevent adhesion of sand. Samples shall not be tested for flammability if sand adheres to the sample.

c) Solder Pot – Attention shall be directed to the samples when removing them from the solder pot so the solder does not join with the conductor traces. Samples shall be prepared so as not to have solder resist or excess solder on conductor traces.

26.3 Procedure

26.3.1 All samples are to be conditioned at 121°C ±2°C (250°F ±3.6°F) for a minimum of 1.5 hours prior to being subjected to thermal stress unless specified otherwise by the PWB fabricator.

26.3.2 Thermal stress shall be conducted within 30 minutes after removal from the 121°C ±2°C (250°F ±3.6°F) oven. If not conducted within 30 minutes, the samples shall be stored in a desiccator to prevent moisture absorption.

26.3.3 All samples shall be subjected to reflow soldering conditions or equivalent process specified by the PWB fabricator. The standardized thermal stress conditions described in Table 26.2 shall be used for this investigation.

Table 26.2
Sample Thermal Stress Standardized Conditions

Assembly process	Maximum peak temp	Dwell time	Cycles
Reflow 260°C, 245°C or 230°C	T1 (default 260C)	IPC TM-650 2.6.27	X (default 6)
Reflow Special	T2	t2 plus profile conditions	X
Wave / Selective soldering	T3	t3	X

Notes:

1 – Default reflow conditions are 260°C peak temperature and 6 cycles. PWB fabricator shall specify alternate conditions if necessary for the thermal stress test.

2 – Reflow - The peak temperature (T1) and number of cycles (X) shall be specified.

3 – Reflow Special – Unique conditions defined by PWB fabricator for ramp rate (R1), cooling rate (C1), peak temperature (T2), dwell time (t2) and cycles (X).

4 – Wave / Selective – The peak temperature (T3) and dwell time (t3) shall be specified.

5 – The peak temperature shall be measured on the board surface.

6 – See reflow profile figures referenced in IPC TM-650 2.6.27.

26.3.4 PWBs for use with reflow assembly processes shall be thermally stressed using one of the standardized profile conditions Reflow 260°C, Reflow 245°C, Reflow 230°C or Special Reflow in accordance with IPC TM-650 2.6.27. The thermal stress maximum temperature and maximum cycles shall be specified by the fabricator. The Reflow 260°C profile using six (6) cycles shall be the default thermal stress unless specified otherwise.

26.3.5 PWBs for use with wave solder and/or selective soldering assembly processes shall be thermally stressed using the maximum temperature, maximum time, and maximum cycles specified by the fabricator. One (1) cycle shall be the default unless specified otherwise.

26.4 Retests

26.4.1 A retest is to be performed when a change in thermal stress is desired to increase the temperature, dwell time and/or number of cycles. See assembly soldering process (solder limits), 10.13.

27 Flammability

27.1 General

27.1.1 Flammability classifications of the printed wiring board shall be determined in accordance with the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94. An HB flammability classification can be extended to the printed wiring board without test when the base material used to fabricate the board is flammability classed HB or better.

27.1.2 The flammability classification to be assigned to a printed wiring board can be V-0, V-1, V-2, or HB. The printed wiring board may not receive a better flammability classification than the base material, when coated samples are tested.

27.2 Samples

27.2.1 Samples for vertical flammability testing specified in 27.1 are to be 125 mm (5 inches) long by 13 mm (0.5 inch) wide in the minimum thickness to be used in production. After any cutting operation, care is to be taken to remove all dust and any particles from the surface. The cut edges are to have a smooth finish, and the radius on the corners is not to exceed 1.3 mm.

27.2.2 The samples are to be subjected to the all same production operations as the printed wiring board they represent, except that all of the conductive material is to be removed by etching.

27.2.3 Multilayer flammability test samples are to have all conductive material removed from both internal and external planes.

27.2.4 When a coating, such as solder-resist, antioxidant, or paint, is to be used in production, additional individual sets of samples shall be provided containing the applied coatings.

27.3 Conditioning

27.3.1 Unless the printed wiring board is intended for hand soldering only, the flammability test samples shall be subjected to the thermal stress conditions described in Section 26.

27.3.2 The flammability test samples are to be preconditioned as described in the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94.

Exception: As an alternative to the preconditioning in an oven for 168 ±2 hours at 70 ±2 °C, the test samples can be preconditioned in an air-circulating oven for 24 ±1 hours at 125°C ±2°C.

27.3.3 Once samples are removed from the pre-conditioning environment, samples shall be tested within 30 minutes or the specified time period.

28 Bond Strength

28.1 After thermal stress

28.1.1 Following the test in Section 26, Thermal Stress, for foil-type conductors, the average strength of the bond between the printed wiring and the base material shall not be less than:

a) 0.350 N/mm (2 lbf/inch) of width for each individual conductor, for the average bond strength determined in accordance with 28.2, after being subject to thermal stress; and

b) 0.350 N/mm (2 lbf/inch) of width for each individual conductor, for the average bond strength determined in accordance with 28.3, after being subject to thermal stress and 240- hours (10 day) oven conditioning; or

c) 0.175 N/mm (1 lbf/inch) of width for each individual conductor, for the average bond strength determined in accordance with 28.3, after being subject to thermal stress and 1344-hours (56 day) oven conditioning.

28.2 As received

28.2.1 Four samples constructed as described in Section 23 shall be used to determine the average Bond Strength. The average Bond Strength shall be determined on a minimum of three conductors. Additional conductors of other widths may not be necessary for testing unless requested by the fabricator. A separately formed or plated contact is to be tested unless it is constructed at least 3 times wider than the minimum conductor width on the printed wiring board. Each of the following conductor widths shall be tested:

a) A midboard conductor having the minimum average width on the sample;