

# IPC-4103A

with Amendment 1  
2014 - January

## Specification for Base Materials for High Speed/ High Frequency Applications

Supersedes IPC-4103A  
December 2011

*A standard developed by IPC*

*Association Connecting Electronics Industries*



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IPC-4103A with Amendment 1

# Specification for Base Materials for High Speed/ High Frequency Applications

Developed by the High Speed/High Frequency Base Materials  
Subcommittee (D-23) of the High Speed/High Frequency Committee  
(D-20) of IPC

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Users of this publication are encouraged to participate in the  
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## Acknowledgment

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# Specification for Base Materials for High Speed/High Frequency Applications

## 1 GENERAL

**1.1 Scope** This specification covers the requirements for high speed/high frequency performance plastic substrates to be used for fabrication of printed boards for microstrip, stripline, and high speed digital electrical and electronic circuits. This specification applies to the plastic substrate thickness defined in the specification sheets as measured over the dielectric only. As a general guideline, laminates controlled by this specification usually have a dissipation factor of less than 0.005.

**1.2 Type Designation** The following system identifies clad and unclad plastic laminate and bonding layer materials for conventional and enhanced part number call out. Conventional laminate part numbers reflect traditional specification values, and are consistent with the callouts in Table 1-1. Enhanced laminate part numbering would include the conventional part number in Table 1-1 as well as the enhanced information in Table 1-2. Bonding layer part numbers are covered in Table 1-3.

Table 1-1 provides an example for conventional laminate part numbers where IPC-4103 is referenced as follows: 4103AL001C11500C1/C1AA.

**Table 1-1 Conventional Laminate Example**

| 4103                                             | A                                         | L                                                               | 001                                | C                                            |
|--------------------------------------------------|-------------------------------------------|-----------------------------------------------------------------|------------------------------------|----------------------------------------------|
| Specification Number                             | Specification Revision                    | Material Designator<br>(see 1.2.1)                              | Specification Sheet<br>(see 1.2.1) | Dielectric Permittivity Range<br>(see 1.2.2) |
| 1                                                | 1500                                      | C1/C1                                                           | A                                  | A                                            |
| Dielectric Permittivity Tolerance<br>(see 1.2.3) | Nominal Laminate Thickness<br>(see 1.2.4) | Metal Cladding Type and Nominal Weight/Thickness<br>(see 1.2.7) | Thickness Tolerance<br>(see 1.2.5) | Metal Foil Indentations<br>(see 1.2.6)       |

Table 1-2 provides an example for enhanced laminate part numbers where IPC-4103 is referenced. In addition to the conventional Table 1-2, the following designators could be used to define an enhanced material part number such as: 4103AL001C11500C1/C1AAX1A1A.

**Table 1-2 Enhanced Laminate Example**

| X                             | 1                              | A                     | 1                      | A                             |
|-------------------------------|--------------------------------|-----------------------|------------------------|-------------------------------|
| Test Frequency<br>(see 1.2.8) | Dielectric Loss<br>(see 1.2.9) | Resin<br>(see 1.2.10) | Filler<br>(see 1.2.11) | Reinforcement<br>(see 1.2.12) |

Table 1-3 provides an example for bonding layer part numbers where IPC-4103 is referenced as follows: 4103AB520CE1080BRCSCVC1.

**Table 1-3 Bonding Layer Example**

| 4103                               | A                                   | B                                  | 520                                       | C                                            |
|------------------------------------|-------------------------------------|------------------------------------|-------------------------------------------|----------------------------------------------|
| Specification Number               | Specification Revision              | Material Designator<br>(see 1.2.1) | Specification Sheet<br>(see 1.2.1)        | Dielectric Permittivity Range<br>(see 1.2.2) |
| E                                  | 1080                                | B                                  | RC                                        | SC                                           |
| Reinforcement Type<br>(see 1.2.13) | Reinforcement Style<br>(see 1.2.13) | Resin System<br>(see 1.2.10)       | Resin Content Test Method<br>(see 1.2.14) | Flow Parameter<br>(see 1.2.14)               |
| VC                                 | 1                                   |                                    |                                           |                                              |
| Optional Test<br>(see 1.2.14)      | Filler<br>(see 1.2.11)              |                                    |                                           |                                              |

## 1.2.1 Specification Sheets

**1.2.1.1 Legacy Specification Sheets** At the end of this document is a series of specification sheets. Specification sheets 1 through 17 are defined as legacy specification sheets. Only legacy sheets outline requirements for both laminate and bonding layers for each product grade. The specification sheets are organized by a specific reinforcement type, resin system, and/or construction and are provided with a Specification Sheet Number for ordering purposes. The laminate and bonding layer requirements for materials of the like composition are on the same specification sheet for convenience. Material Designator “L” indicates laminate material and Material Designator “B” indicates bonding layer material, as shown in the above designation examples. A bonding layer may be a thermoplastic or thermoset film, reinforced thermoplastic, or thermoset prepreg. Legacy specification sheets **shall** be frozen and any new materials will be submitted under the new format.

**1.2.1.2 New Format Specification Sheets** This applies to specification sheets that are in the 200 Series and 500 Series. On these specification sheets, the Dk, Df, and descriptions are mandatory requirements. Based on other criteria (e.g., CTE, Td, moisture absorption, thermal conductivity), the number of potential specification sheets in the 200 Series and 500 Series could equal 150. Desiring to minimize the number of specification sheets while simplifying the specification sheet system, a “loose/tight” specification sheet concept was created for this revision of IPC-4103; one for which laminate suppliers could use to certify their materials, while OEMs could use to find materials. “Loose/tight” specification sheets provide both “tight” mandatory requirements (Dk, Df, description) as well as “loose” requirements (e.g., thermal conductivity, moisture absorption) that can be certified to or called out on the fabrication drawings. Low loss and higher loss tangent materials have been merged into the same grouping. Hence, fewer specification sheets are required. The same classification logic works for bonding layers in the 500 Series.

Each OEM can specify materials to whatever level they require. The conventional part number can be used to call out the basic material electrical parameters, or the enhanced part number can be used to call out a particular material and/or resin system. The specification sheets can become all-inclusive or exclusively restrictive, in essence, “loose/tight.”

**1.2.2 Dielectric Permittivity Range** The nominal permittivity range is identified in the header of each specification sheet. Nominal permittivity values are identified by letter designation (A, B, C, D, E, F or X) as indicated on the applicable specification sheet.

**1.2.3 Dielectric Permittivity Tolerance** The permittivity tolerance is identified by a number designation (1, 2, 3, 4, 5, or X). See 3.11.1.1 and Table 3-8.

**1.2.4 Nominal Laminate Thickness** The nominal thickness is identified by four digits. For all substrates covered by this document, thickness is specified or measured over the dielectric (see 3.8.4.2). For metric specification, the first digit represents whole millimeters, the second represents tenths of millimeters, etc. For orders requiring Imperial units, the four digits indicate the thickness in ten-thousandths of an inch. In the example shown in 1.2, 1500 is designated for the English usage of 0590 when using Imperial units.

**1.2.5 Thickness Tolerance, Laminate** The class of thickness tolerance for laminate base material is identified by either A, B, C, D, or X as agreed between user and supplier (AABUS) (see 3.8.4.2 and Table 3-5).

**1.2.6 Metal Foil Indentations** The class of surface quality is identified by letter designation (A, B, C, D, or X (AABUS)). See 3.8.3.1.1.

**1.2.7 Metal Cladding Type and Nominal Weight or Thickness of Metal Cladding** The type and nominal weight or thickness of the metallic cladding for laminate base material is identified by five designators, with the first and fourth designators indicating type of cladding, the third designator being a slash mark to differentiate sides of the base material, and the second and fifth designators indicating the nominal weight or thickness of the metallic cladding.

### Example:

For a laminate clad one side with 1 oz/ft<sup>2</sup> electrodeposited copper foil grade 1 and the other with 1/2 oz/ft<sup>2</sup> electrodeposited double treated copper, as in the example of 1.2, the designator is: C1/DH

For a laminate clad only one side with 1 oz/ft<sup>2</sup> wrought copper foil grade 5 the designator is: A1/U0

For a laminate clad one side with 1/2 oz/ft<sup>2</sup> wrought copper foil grade 5 and the other side with 0.125 in thick aluminum alloy 6061 the designator is: AH/RX. In this case, the ordering document will have to specify the 0.125 in thick aluminum alloy 6061.

**1.2.7.1 Metallic Cladding Designators** The types of metallic cladding and the designators representing them include:

- A. Copper, wrought, rolled (IPC-4562, Grade 5)
- B. Copper, rolled (treated)
- C. Copper, electrodeposited (IPC-4562, Grade 1)
- D. Copper, electrodeposited, double treated (IPC-4562, Grade 1)
- G. Copper, electrodeposited, high ductility (IPC-4562, Grade 2)
- H. Copper, electrodeposited, high temperature elongation (IPC-4562, Grade 3)
- K. Copper, wrought, light cold rolled (IPC-4562, Grade 6)
- L. Copper, wrought, annealed (IPC-4562, Grade 7)
- M. Copper, wrought, rolled, low temperature annealable (IPC-4562, Grade 8)
- N. Nickel
- O. Unclad
- P. Copper, electrodeposited, high temperature elongation, double treated (IPC-4562, Grade 3)
- R. Copper, reverse treated electrodeposited (IPC-4562, Grade 1)
- S. Copper, reverse treated electrodeposited, high temperature elongation (IPC-4562, Grade 3)
- T. Copper, copper foil parameters as dictated by contract or purchase order
- U. Aluminum
- X. As agreed between user and supplier (AABUS)
- Y. Copper Invar Copper
- Z. Copper, electrodeposited, high temperature elongation, double-treated (IPC-4562, Grade 3) for buried capacitance applications

**Note:** Except for types D, N, O, P, U and Z, all foils have integral metal/metal oxide treatments for adhesion on one side, and that side is placed against the substrate. Type T may or may not have treatments.

**1.2.7.2 Copper Foil Weights and Thickness** The weight or thickness of copper foil and the designators for all metal claddings are listed in Table 1-4.

**Table 1-4 Copper Foil Weights and Thickness (Taken From IPC-4562)**

| Foil Designation | Common Industry Terminology | Metric                          |                        | English                            |                                      |                                         |
|------------------|-----------------------------|---------------------------------|------------------------|------------------------------------|--------------------------------------|-----------------------------------------|
|                  |                             | Area Weight (g/m <sup>2</sup> ) | Nominal Thickness (µm) | Area Weight (oz/ft. <sup>2</sup> ) | Area Weight (g/254 in <sup>2</sup> ) | Nominal Thickness (10 <sup>-3</sup> in) |
| E                | 5 µm                        | 45.1                            | 5.1                    | 0.148                              | 7.4                                  | 0.20                                    |
| Q                | 9 µm                        | 75.9                            | 8.5                    | 0.249                              | 12.5                                 | 0.34                                    |
| T                | 12 µm                       | 106.8                           | 12.0                   | 0.350                              | 17.5                                 | 0.47                                    |
| H                | 1/2 oz                      | 152.5                           | 17.1                   | 0.500                              | 25.0                                 | 0.68                                    |
| M                | 3/4 oz                      | 228.8                           | 25.7                   | 0.750                              | 37.5                                 | 1.01                                    |
| 1                | 1 oz                        | 305.0                           | 34.3                   | 1                                  | 50.0                                 | 1.35                                    |
| 2                | 2 oz                        | 610.0                           | 68.6                   | 2                                  | 100.0                                | 2.70                                    |
| 3                | 3 oz                        | 915.0                           | 102.9                  | 3                                  | 150.0                                | 4.05                                    |
| 4                | 4 oz                        | 1220.0                          | 137.2                  | 4                                  | 200.0                                | 5.40                                    |
| 5                | 5 oz                        | 1525.0                          | 171.5                  | 5                                  | 250.0                                | 6.75                                    |
| 6                | 6 oz                        | 1830.0                          | 205.7                  | 6                                  | 300.0                                | 8.10                                    |
| 7                | 7oz                         | 2135.0                          | 240.0                  | 7                                  | 350.0                                | 9.45                                    |
| 10               | 10 oz                       | 3050.0                          | 342.9                  | 10                                 | 500.0                                | 13.50                                   |
| 14               | 14 oz                       | 4270.0                          | 480.1                  | 14                                 | 700.0                                | 18.90                                   |

For nominal weights not listed in this table the nominal thickness is calculated as follows:

Thickness (10<sup>-3</sup> in) = 1.35 x Area Wt. (oz/ft.<sup>2</sup>).

Where 1.35 is a factor determined from the density of copper foil assumed to be 8.93 g/cm<sup>3</sup> [5.16 oz/in<sup>3</sup>]. This factor is within 1% for all densities from 8.81 g/cm<sup>3</sup> to 8.99 g/cm<sup>3</sup>.

For any alloy or other metals outside this density range the appropriate factor must be used to calculate the foil thickness.

For double-sided bond treated foils, the nominal area weight **shall** be increased by 4.58 g/m<sup>2</sup> [0.75 g/254 in<sup>2</sup> or 0.0150 oz/ft.<sup>2</sup>] to the values in Table 1-1 to determine the upper tolerance limits.

**Caution:** Values in the table are not representative of mechanical thickness of the foil. An allowance for the roughness of the treated side must be added to all values.

**1.2.8 Test Frequency** The test frequency in Hertz, as indicated on each individual specification sheet. For specification sheets 200 and above, the test frequency **shall** be either A, B or X.

**1.2.9 Dielectric Loss Tangent** For specification sheets 1 through 17, dielectric loss tangent is specified as a maximum. For specification sheets 200 and above, the dielectric is specified as either enhanced (1), conventional (2), or AABUS (X). Enhanced is a lower loss tangent value than conventional as called out on each specification sheet.

**1.2.10 Resin** Resin systems on specification sheets 1 through 17 are called out on the headers. In specification sheets 200 and above the resin system is specified as A, B, C, D, E, F, or X.

**1.2.11 Filler** Filler designation on specification sheets 1 through 17 is called out on the headers. In specification sheets 200 and above the filler designation is specified as 1, 2, 3, or X.

**1.2.12 Reinforcement** Reinforcement type on specification sheets 1 through 17 is called out on the headers. In specification sheets 200 and above the reinforcement type is specified as A, B, C, D, or X.

**1.2.13 Bonding Layer Reinforcement Style** The reinforcement type and style of the bonding layer is indicated by five digits based on the chemical type and style. Typical examples of reinforcement designators are shown below:

“E0106” represents E-glass reinforcement style 106 per IPC-4412.

“S0313” represents S-glass reinforcement style 313 per IPC-SG-141.

“A3080” represents aramid reinforcement style 3080 per IPC-A-142.

“Q0525” represents quartz reinforcement style 525 per IPC-QF-143.

Reinforcement properties such as thickness, construction, and weight are established in accordance with the reinforcement style designations of the appropriate material specification. If the bonding layer does not have a reinforcement, use “00000” (five zeros) in this field.

**1.2.14 Bonding Layer Parameters** A variety of test procedures can be used to specify and determine fitness for the use of bonding layers in multilayer board applications.

Table 1-5 outlines some of the available tests to characterize a bonding layer material. All the tests may not be applicable to all bonding layers. The specification for a bonding layer may consist of one test method from Column A, one test method from Column B and one method from Column C as shown in Table 1-5 with the corresponding designators. If no test method is chosen for any column, zero-zero (00) **shall** be the designator. The choice of the test methods **shall** be AABUS and supplied as part of the ordering information. The nominal value and tolerances for the individual tests **shall** be AABUS.

**Table 1-5 Bonding Layer Testing Parameters**

| Column A<br>Resin Content Method | Column B<br>Flow Parameter Method | Column C<br>Optional Bonding Layer Method |
|----------------------------------|-----------------------------------|-------------------------------------------|
| RC – Percent Resin Content       | MF – Percent Resin Flow           | VC – Volatile Content                     |
| TW – Treated Weight              | SC – Scaled Flow                  | DY – Dicy Inspection                      |
| 00 – None specified              | NF – No Flow                      | GT – Gel Time                             |
|                                  | RE – Rheology Flow                | CT – Conductivity, Thermal                |
|                                  | PC – Percent Cure                 | CE – Conductivity, Electrical             |
|                                  | DH – Delta H                      | 00 – None Specified                       |
|                                  | 00 – None Specified               |                                           |

**1.2.15 Color** Unless otherwise specified, all laminates and bonding layers are supplied in the natural (undyed/unpigmented) color. If the user requires another color, it **shall** be specified on the purchase order.

**1.2.15.1 Contrast Agents** Contrast agents, which may be added to a natural color resin system to enhance processing, such as tinting agents for contrast in automatic optical inspection, **shall not** adversely affect the performance, properties, or functionality of the laminate or bonding layer and **shall** be considered as the natural color.

**1.3 Dimensions and Tolerances** All dimensions and tolerances specified herein are applicable only to the end product. Dimensions are expressed in millimeters unless otherwise specified. Reference information is shown in parentheses.

**1.4 Interpretation** “**Shall**,” the imperative form of the verb, is used throughout this standard whenever a requirement is intended to express a provision that is mandatory. Deviation from a “**shall**” requirement may be considered if sufficient data is supplied to justify the exception.

The words “should” and “may” are used whenever it is necessary to express non-mandatory provisions. “Will” is used to express a declaration of purpose.

To assist the reader, the word “**shall**” is presented in bold characters.

**1.5 Terms and Definitions** The definitions of all terms used herein **shall** be in accordance with IPC-T-50 and as defined in 1.5.1

**1.5.1 As Agreed Between User and Supplier (AABUS)** Indicates additional or alternate requirements to be decided between the user and supplier in the procurement documentation. Examples include contractual requirements, modifications to purchase documentation and information on the drawing. Agreements can be used to define test methods, conditions, frequencies, categories or acceptance criteria within a test, if not already established.

**1.6 Revision Level Changes** Changes that were incorporated in the current revision of this specification are indicated throughout by gray shading of the relevant subsection(s). Changes to a figure or table are indicated by gray shading of the figure or table header.

## 2 APPLICABLE DOCUMENTS

The following is a list of applicable documents referenced in the specification. The current revision at the time of order **shall** be used as a part of this specification unless AABUS.

### 2.1 IPC<sup>1</sup>

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

**IPC-SG-141** Specification for Finished Fabric Woven from “S” Glass for Printed Boards

**IPC-A-142** Specification for Finished Fabric Woven from Aramid for Printed Boards

**IPC-QF-143** Specification for Finished Fabric Woven from Quartz (Pure Fused Silica) for Printed Boards

**IPC-CF-152** Composite Metallic Materials Specification for Printed Wiring Boards

**IPC-TM-650** Test Methods Manual<sup>2</sup>

2.1.5 Surface Examination, Unclad and Metal-Clad Material

2.1.9 Surface Scratch Examination Metal-Clad Foil

2.1.10 Visual Inspection for Undissolved Dicyandiamide

2.2.18 Determination of Thickness of Laminates by Mechanical Measurement

2.2.19.1 Length, Width and Perpendicularity of Laminate and Bonding film Panels

2.3.1.1 Chemical Cleaning of Metal-Clad Laminates

2.3.4.2 Chemical Resistance of Laminates, Prepreg and Coated Foil Products, by Solvent Exposure

2.3.4.3 Chemical Resistance of Core Materials to Methylene Chloride

2.3.6 Etching, Ammonium Persulfate Method

2.3.7 Etching, Ferric Chloride Method

2.3.7.1 Cupric Chloride Etching Method

2.3.10 Flammability of Laminate

2.3.16 Resin Content of Prepreg by Burn-Off

2.3.16.1 Resin Content of Prepreg by Treated Weight

2.3.16.2 Treated Weight of Prepreg

1. [www.ipc.org](http://www.ipc.org)

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

- 2.3.17 Resin Flow Percent of Prepreg
- 2.3.18 Gel Time, Prepreg Materials
- 2.3.19 Volatile Content of Prepreg
- 2.4.4 Flexural Strength of Laminates (at Ambient Temperature)
- 2.4.8 Peel Strength of Metallic Clad Laminates
- 2.4.8.2 Peel Strength of Metallic Clad Laminates at Elevated Temperature (Hot Fluid Method)
- 2.4.8.3 Peel Strength of Metallic Clad Laminates at Elevated Temperature (Hot Air Method)
- 2.4.13.1 Thermal Stress of Laminates
- 2.4.22.1 Bow and Twist, Laminate
- 2.4.24 Glass Transition Temperature and Z-Axis Thermal Expansion by TMA
- 2.4.25 Glass Transition Temperature and Cure Factor by DSC  
**Note:** Test Method 2.4.25 also describes the delta glass transition temperature test ( $\Delta T_g$ )
- 2.4.38 Prepreg Scaled Flow Testing
- 2.4.39 Dimensional Stability, Glass Reinforced Thin Laminates
- 2.4.41 Coefficient of Linear Thermal Expansion of Electrical Insulating Materials
- 2.4.41.1 Coefficient of Thermal Expansion by the Vitreous Silica (Quartz) Dilatometer Method
- 2.5.5.3 Permittivity (Dielectric Constant) and Loss Tangent (Dissipation Factor) of Materials (Two Fluid Cell Method)
- 2.5.5.5 Stripline Test for Permittivity (Dielectric Constant and Dissipation Factor) at X-Band
- 2.5.5.6 Non-Destructive Full Sheet Resonance Test for Permittivity of Clad Laminates
- 2.5.6 Dielectric Strength of Rigid Printed Wiring Material
- 2.5.6.2 Electric Strength of Printed Wiring Material
- 2.5.17.1 Volume and Surface Resistivity of Dielectric Materials
- 2.6.1 Fungus Resistance, Printed Wiring Materials
- 2.6.2.1 Water Absorption, Metal-Clad Plastic Laminates

**IPC-QL-653** Qualification of Facilities that Inspect/Test Printed Boards, Components, and Materials

**IPC-1730** Laminator's Qualification Profile

**IPC-4412** Specification for Finished Fabric Woven from "E" Glass for Printed Boards

**IPC-4562** Metal Foil for Printed Wiring Applications

**IPC-4563** Resin Coated Copper Foil for Printed Boards Guidelines

**IPC-9191** General Guidelines for Implementation of Statistical Process Control (SPC)

## 2.2 Joint Industry Standards<sup>3</sup>

**J-STD-003** Solderability Test Methods For Printed Wiring Boards

## 2.3 National Conference of Standards Laboratories<sup>4</sup>

**ANSI/NCSL Z540-1-1994** American National Standard for Calibration - Calibration Laboratories & Measuring and Test Equipment - General Requirements

## 2.4 Federal Specifications<sup>5</sup>

**QQ-A-250** Aluminum and Aluminum Alloy Plate Sheet

3. [www.ipc.org](http://www.ipc.org)

4. [www.ansi.org](http://www.ansi.org)

5. [www.sae.org](http://www.sae.org)

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**QQ-B-626** Brass, Leaded and Unleaded Rod, Shapes, Forgings and Flat Product with Finished Edges (Bar, Flat Wire and Strip)

## 2.5 ASTM<sup>6</sup>

**ASTM B152** Standard Specification for Copper Sheet, Strip, Plate and Rolled Bar

**ASTM D635 - 10** Standard Test Method for Rate of Burning and/or Extent and Time of Burning of Plastics in a Horizontal Position

**ASTM D3801 - 00** Standard Test Method for Measuring the Comparative Burning Characteristics of Solid Plastics in a Vertical Position

## 2.6 International Standards<sup>7</sup>

**ISO 10012-1** Quality Assurance Requirements for Measuring Equipment, Part 1 - Metrological Confirmation System for Measuring Equipment

## 2.7 MIL Specification<sup>8</sup>

**MIL-Y-1140** Military Standard: Yarn, Cord, Sleeving, Cloth, and Tape-Glass

## 2.8 International Electrotechnical Commission (IEC)<sup>9</sup>

**IEC 60695-11-10** Test flames - 50 W horizontal and vertical flame test methods

# 3 REQUIREMENTS

**3.1 General** 3.1.1 through 3.1.12 define aspects of quality assessment and quality conformance testing used throughout this document.

**3.1.1 Qualification Assessment** Qualification Assessment is a form of risk reduction between a buyer and a source for laminates and bonding layers. The laminator **shall** produce an assessment of its capabilities and sources of verification for the buyer to evaluate. The buyer must then review this assessment and determine whether the information and verification provided constitutes an acceptable level of risk. The more verification of self-declaration parameters provided, the lower the risk factor associated with utilizing a new laminator. There is no minimum level of Qualification Assessment Verification required by this standard, and it is between the buyer and laminator to determine the extent of verification applicable to their requirements. If the risk assessment is determined to be unacceptably high, increasing the verification requirements may reduce the risk. The cost associated with reducing this risk varies with the type of verification that is determined to be necessary.

**3.1.2 Quality Conformance Testing** Quality Conformance testing is performed on a regular basis following qualification testing as determined by the Manufacturer's Quality System. This is done to demonstrate that the supplier is continually meeting the finished product requirements of this specification and the applicable specification sheet for each base material. In the absence of a documented Manufacturer's Quality System, the conformance testing **shall** be conducted in accordance with the frequency as specified in Table 3-3 for laminates and Table 3-4 for bonding films.

**3.1.3 Manufacturers Quality System** The Manufacturer's Quality System is an organized entity within the laminator's operation that administers the documentation system, steering committee, lines of responsibilities, etc., as described in IPC-9191.

**3.1.4 Process Control Testing** Testing performed for the purpose of nominalizing the critical steps of the manufacturers' internal process.

6. [www.astm.org](http://www.astm.org)

7. [www.iso.org](http://www.iso.org)

8. [www.everyspec.com/MIL-SPECS](http://www.everyspec.com/MIL-SPECS)

9. [www.iec.ch](http://www.iec.ch)

**3.1.5 Self Declaration** The first level of Qualification Assessment is Self Declaration. A completed IPC-1730 contains a profile of a manufacturer's site capability, processing and test equipment, technology specifics, quality program, manufacturing history, company information, and data verification sources. Self Declaration is the laminator's view of its products and process capabilities to meet the customer's requirements, the requirements of the standard, and the applicable associated specification sheet(s) (see 3.3).

**3.1.6 Quality Assessment Data** The data contained in the Self Declaration is compiled and analyzed for performance characteristics of laminates or bonding films. The performance data may be based on information from a variety of both internal and external sources.

**3.1.7 Sample Qualification** Verification by Sample Qualification signifies that a manufacturer was capable of producing a product with a given set of parameters at a point in time when the Qualification sample was manufactured. Sample Qualification Testing of laminate and bonding layer performance characteristics **shall** be performed at a facility that has demonstrated compliance with IPC-QL-653.

**3.1.8 Production Data** Production data is normal performance data from manufacturing runs generated as a quality assurance function. This data can be compiled, analyzed, and reported as support for product compliance to this standard by the laminator.

**3.1.9 Customer Test Data** Customer test data is normal performance data generated at incoming inspection by the customer. This data can be compiled, analyzed, and reported as support for product compliance to this standard by the laminator.

**3.1.10 Internal Assessment** Internal assessments consist of periodic supplier verification of data contained in the Quality Profile section of the Self Declaration.

**3.1.11 Individual Customer Audit** The Individual Customer Audit is an evaluation of the laminator's facility to compare the current Management Quality System versus the Self Declaration and the requirements of this document. The analysis, summary, and necessary corrective actions, at the discretion of the customer, may become part of the laminator's Self Declaration.

**3.1.12 Independent Third Party Assessment** Assessments are performed by a third party assessor, which is generally procedural in nature. Examples of third party assessors are ISO Registrars, Malcolm Baldrige, Underwriters' Laboratories, Canadian Standards Agency, IECQ, DSCC, etc.

**3.2 Specification Sheets** The individual item requirements **shall** be as specified herein and in accordance with the applicable specification sheets. Where there is no specification sheet available, the individual requirements **shall** be as specified in complementary documents such as master drawings or ordering data sheets (see 6.2).

**3.3 Manufacturers Quality Profile** Suppliers of laminates and bonding layers **shall** assess their manufacturing capability and complete the Laminator Qualification Profile IPC-1730. The laminator **shall** maintain an up to date IPC-1730 document available for review by users. The IPC-1730 **shall** be reviewed and updated on a minimum two year basis. The Laminator's Qualification Profile **shall** be made available for review upon request.

**3.4 Qualification Testing** Laminate and bonding layer materials furnished under this specification **shall** be qualified as described in Table 3-3 for laminates and Table 3-4 for bonding layers. The supplier **shall** retain on file supporting data that the materials meet the requirements of this specification using the test methods described herein. Qualification testing **shall** be performed to demonstrate the supplier's ability to meet all of the requirements of each applicable specification sheet for each base material. Materials listed on a Qualified Products List (QPL) for MIL-S-13949 as of 30 November 1998 are considered to be qualified to the extent of the original qualification and provided the test information is available for review.

**3.5 Verification of Manufacturer's Quality System** The verification of the Manufacturer's Quality System, as outlined in the Self Declaration in IPC-1730, may be conducted to reduce risk to the buyer. The verification may be accomplished via several methods, including Internal Assessment, Individual Customer Audit, and/or Third Party Assessment.

**3.6 Conflict** In the event of conflict, the following order of precedence **shall** apply:

- 1) Purchase order

- 2) Master drawing (see 6.2.1 item D or 6.2.2 item D)
- 3) This specification (specification sheets take precedence over body of text)
- 4) Applicable documents (see section 2)

### 3.7 Materials

**3.7.1 Metal Cladding** Metal cladding **shall** meet the requirements of IPC-4562, IPC-4563, IPC-CF-152, or AABUS. For alternate metal claddings not covered by industry standards, requirements **shall** be AABUS.

**3.7.2 Reinforcement Fabric** Construction of the reinforcement fabrics, if used, **shall** be in accordance with IPC-4412 or MIL-Y-1140. For alternate reinforcement types not covered by industry standards, requirements **shall** be AABUS.

**3.7.2.1 Other Reinforcement Types** Constructions utilizing reinforcement other than woven glass **shall** be as called out in the applicable specification sheet.

**3.7.3 Resin System** Resin systems used to produce laminate and bonding layer materials under this specification **shall** be as specified in the individual specification sheets (see 1.2.1). For alternate resin systems not covered by industry standards, requirements **shall** be AABUS.

**3.7.4 Fillers** Fillers are used in certain systems as called out in the applicable specification sheet. For alternate fillers not covered by industry standards, requirements **shall** be AABUS.

**3.8 General Requirements/Acceptability** Substrates **shall** be considered acceptable if it meets the requirements listed below, or AABUS. The specification sheets indicate specification limits for the substrate on either side of double sided substrate. Requirements only apply to the working area defined in paragraph 3.8.1 unless otherwise specified.

**Note:** When tests are performed by the procuring activity, the bonding layer should be properly stored and should be tested as soon as possible after receipt (not to exceed five (5) days).

### 3.8.1 Fabricated Sheets and Panels

**3.8.1.1 Fabricated Laminate Sheet Material** A substrate sheet **shall** be any size as laminated by the material vendor. The working area of a substrate sheet is considered to be the area inside a 25 mm [0.984 in] border around the perimeter of the sheet after trimming.

**3.8.1.2 Fabricated Laminate Panels Material** A fabricated panel **shall** be any size cut from a full sheet. The working area of a fabricated panel is considered to be the area inside a 13 mm [0.5 in] border around the perimeter of the panel.

**3.8.1.3 Fabricated Bonding Layer Panels** Fabricated panels are cut-to-size pieces of a bonding layer. The working area **shall** be the area excluding a 15 mm [0.591 in] border.

**3.8.1.4 Fabricated Bonding Layer Rolls** Bonding layer rolls are continuous lengths of a bonding layer that are rolled for the purposes of inventory and custom fabrication by the user. The working area of the bonding layer **shall** exclude the outer 25 mm [0.984 in] edge. No more than 5% of the nominal roll length **shall** be unsuitable for panel fabrication, which includes splices, areas sampled for testing, and non-splice breaks in the continuous length of the bonding layer. The length of the roll may be compensated to replace that bonding layer unsuitable for panel fabrication AABUS.

### 3.8.2 Inspection Lot

**3.8.2.1 Inspection Lot Laminate** An inspection lot **shall** meet the following criteria:

- a) Material covered by a single specification sheet and the same metal cladding type.
- b) One press load or 200 sheets, whichever is greater. The 200 sheets must be comprised of consecutive press loads of the same specification sheet and the same metal cladding type.

**3.8.2.2 Inspection Lot Bonding Layer** An inspection lot of a bonding layer **shall** be one master roll of reinforcement as provided by the supplier or one master roll of a non-reinforced film. Splices provided by the reinforcement supplier are not considered to be a change in the master roll. Each master roll **shall** be inspected at the beginning and at the end as a minimum. A significant parameter change to the impregnation process **shall** require an additional inspection point.

**3.8.2.3 Preparation of Samples** Unless otherwise specified herein, samples and test specimens **shall** be prepared in accordance with standard in-house procedures. If a referee method is required, it **shall** be AABUS.

**3.8.2.4 Etching Process and Etching Removal for Copper Clad Specimens** Unless otherwise specified, any standard procedure may be used. However, IPC-TM-650, Methods 2.3.6, 2.3.7, or 2.3.7.1 **shall** be used as a referee.

**3.8.2.5 Standard Laboratory Conditions** Unless otherwise specified herein, all inspections **shall** be performed in accordance with the test and laboratory conditions specified in IPC-QL-653.

### 3.8.3 Visual Properties

**3.8.3.1 Laminate Visual Properties** The specimen **shall** be tested in accordance with Table 3-3 for laminates. Unless otherwise specified, the working area of the specimen **shall** be examined with normal or corrected 20/20 vision. Visual inspection may be carried out under ambient temperature and humidity conditions.

**3.8.3.1.1 Metal Foil Indentations** Indentations **shall** be located visually using 20/20 vision. The longest dimension of each foil indentation in a specimen **shall** be measured with a suitable reticle on a minimum 4X magnifier, with referee inspections at 10X. The point value system described in Table 3-1 **shall** be used to determine point count for any 300 x 300 mm [11.81 x 11.81 in] area.

**Table 3-1 Point Value System for Metal Foil Indentations**

| Longest Dimension                     | Point Value |
|---------------------------------------|-------------|
| 0.13 to 0.25 mm [0.005 to 0.009 in]   | 1           |
| 0.26 to 0.50 mm [0.0102 to 0.0197 in] | 2           |
| 0.51 to 0.75 mm [0.0200 to 0.0295 in] | 4           |
| 0.76 to 1.00 mm [0.0299 to 0.0394 in] | 7           |
| >1.00 mm [0.0394 in]                  | 30          |

Class of metal foil indentations **shall** be as specified (see 1.2.6 and 6.2.1 item F). The class **shall** be determined by a point count when examined in accordance with point value versus longest dimension chart shown below and the provisions below.

There **shall** be no adherent material in an indentation nor exposure of base laminate. Indentations with a depth of less than 0.013 mm [0.00051 in] **shall not** be included in the point count. Requirements for foil indentations do not apply to copper that has been treated on both sides, nor to the exterior 25 mm [0.984 in] border on full-size sheets and 13 mm [0.512 in] border on cut panels. Class A applies, unless otherwise specified. The point count allowance for each grade **shall** be prorated for inspection areas less than 300 x 300 mm [11.81 x 11.81 in] but **shall not** be reduced to less than half.

**Class A** The total point count **shall** be 29 maximum for any 300 x 300 mm [11.81 x 11.81 in] area. Fiber indentations over 6.4 mm [0.252 in] long **shall not** exceed two in any 300 x 300 mm [11.81 x 11.81 in] area.

**Class B** The total point count **shall** be 17 maximum for any 300 x 300 mm [11.81 x 11.81 in] area. Fiber indentations over 6.4 mm [0.252 in] long **shall not** exceed one in any 300 x 300 mm [11.81 x 11.81 in] area.

**Class C** The total point count **shall** be 5 maximum for any 300 x 300 mm [11.81 x 11.81 in] area. There **shall** be no foil indentations with a maximum dimension 0.50 mm [0.0197 in].

**Class D** The total point count **shall** be 0 (zero) for any 300 x 300 mm [11.81 x 11.81 in] area. Foil indentations  $\geq 125 \mu\text{m}$  [ $\geq 0.0049$  in] **shall not** be acceptable. Resin spots **shall** be 0 (zero) as inspected with normal or corrected 20/20 vision. If Class D is specified, other quality related features are also required of this quality class per IPC-4562.

**Class X** Requirements **shall** be AABUS (see 6.1.1 item J).

**3.8.3.1.2 Wrinkles** There **shall** be no metal-clad wrinkles, as seen under normal or corrected 20/20 vision of the sheet or panel.

**3.8.3.1.3 Scratches** Scratches are not permitted where any part of the defect is  $\geq 20\%$  of the nominal foil thickness (for example 3.4  $\mu\text{m}$  [133.9  $\mu\text{in}$ ] for 17  $\mu\text{m}$  [669.3  $\mu\text{in}$ ] copper) or occur more than five scratches per 300 x 300 mm [11.81 x 11.81 in]. Any scratch with a depth of less than 5% of the nominal foil thickness **shall not** be counted regardless of length. The maximum allowable scratch length is 100 mm [3.94 in] for any scratch with a depth  $>5\%$  and  $<20\%$  of the nominal foil thickness.

**3.8.3.1.4 Appearance of NonClad Surfaces** The plastic surface on the non-clad side of base materials **shall** be as produced by the curing or lamination process.

**NOTE:** Visible surface anomalies are a class of cosmetic defect resulting from the effects of high lamination temperatures on certain organic materials that are an inherent part of the manufacturing process. These materials are present in the laminates only to the extent that they are necessary for the manufacture of the materials, and cannot be entirely eliminated. Extensive work has been done to determine if these particles have any effect on the performance of the laminates, particularly regarding electrical performance, and no relationship has ever been established. Various grades of High Performance Laminates manufactured are a composite of ceramic particles, PTFE resin, and glass. Such materials are typically white or off-white in color. Certain dark-colored materials (foreign inclusions) are process-inherent and may be deemed acceptable.

**3.8.3.1.5 Surface Finish of Foil after Curing Except for Double Treat** Unless otherwise specified (see 6.2.1), discoloration of the copper surface as a result of the curing or lamination process **shall** be acceptable.

**3.8.3.1.6 Surface and Subsurface Imperfections** The etched panels **shall** be inspected to verify that no subsurface imperfections in excess of those shown below are present. The panels **shall** be inspected using an optical apparatus or aid that provides a minimum magnification of 4X. Referee magnification **shall** be accomplished at 10X. Lighting conditions of inspection **shall** be appropriate to the type, grade and thickness being inspected or AABUS.

Surface and subsurface imperfections (such as weave texture, resin saturation, scorching, voids, and foreign inclusions) **shall** be acceptable provided the imperfections meet the following:

- The reinforcement fiber is not cut or exposed.
- No more than 1.0% of the board area on each side **shall** be affected.
- White spots are allowable on woven and non-woven glass (PTFE).
- The imperfections do not propagate as a result of thermal stress.
- The foreign inclusions are translucent.
- Voids are  $<0.075$  mm [0.0029 in] in the longest dimension and do not occur in void clusters any more than two spots per 300 x 300 mm [11.81 x 11.81 in] inspected.

Surface and subsurface nonconductive stains, logos, and discolorations in the dielectric **shall** be acceptable provided the material is not functionally degraded by the discoloration.

**3.8.3.2 Bonding Layer and Prepreg Layer Visual Inspection** The specimen **shall** be tested in accordance with Table 3-4 for bonding layers. Visual inspection is conducted with normal or corrected 20/20 vision.

**3.8.3.2.1 Inclusions** Metallic inclusions are not acceptable. Opaque foreign matter other than fibers **shall not** exceed 0.50 mm [0.019 in]. Opaque foreign inclusions  $<0.13$  mm [0.005 in] **shall not** be counted. Opaque foreign inclusions between 0.50 mm [0.019 in] and 0.13 mm [0.005 in] inclusive **shall** average no more than two spots per 300 mm x 300 mm [11.81 in x 11.81 in] inspected.

**3.8.3.2.2 Impregnation/Coating Imperfections** Imperfections in impregnation or coating **shall** be acceptable provided the criteria are met as shown below:

- a) Overall bonding layer thickness increases from reinforcement imperfections is maximum 99%.
- b) Dewetted areas (measured in at least two dimensions) are maximum 2.3 mm [0.0906 in].
- c) Pin-holed areas are maximum 0.65 mm [0.0256 in].
- d) Reinforcement distortion maximum (variation in pick line) per 300 mm [11.81 in] distance is 25 mm [0.984 in].
- e) Creases with exposed reinforcement are maximum  $<15$  mm [ $<0.591$  in].



- f) Silver streaks, cigar voids (non-wetted fibers) are not present.
- g) Brown streaks (binder marks) are AABUS.

**3.8.4 Dimensional** Length, width, thickness, and other dimensional characteristics **shall** be measured with equipment capable of accuracy to verify the requirements of this specification.

**3.8.4.1 Length and Width** When tested in accordance with Table 3-3 and Table 3-4 as applicable, the material **shall** meet the length and width requirements specified below.

**3.8.4.1.1 Length and Width, Laminate** Length and width **shall** be as specified on the procurement document (see 6.2). Unless specific dimensions are specified, standard size metal clad substrates from which test specimens have been cut **shall** be acceptable. Permissible variations from the specified length or width **shall** be as specified in Table 3-2. Adjacent edges must be perpendicular within 0.15 mm [0.006 in] per inch.

**Table 3-2 Permissible Variation in Length and Width of Laminates**

| Fabricated Panel (<6 FT <sup>2</sup> ) |                                    |                       | Substrated Sheet (>6 FT <sup>2</sup> )      |
|----------------------------------------|------------------------------------|-----------------------|---------------------------------------------|
| <304.8 mm [12 in]                      | 304.8 to 609.6 mm<br>[12 to 24 in] | >609.6 mm [24 in]     | All Edges                                   |
| ± 0.80 mm [± 0.031 in]                 | ± 1.60 mm [± 0.062 in]             | ± 3.2 mm [± 0.125 in] | + 25.0 mm [+ 1.0 in]<br>- 0.0 mm [- 0.0 in] |

**3.8.4.1.2 Length and Width, Bonding Layers** The length and width of bonding layer sheets **shall** be as specified in the procurement document (see 6.2.2 item H). The permissible variations from the specified length or width **shall** be AABUS. Adjacent edges **shall** be perpendicular within 0.13 mm [0.005 in] per 25 mm [0.984 in].

**3.8.4.1.3 Bonding Layer Roll Width** For bonding layer base materials the width of the rolls **shall** be as specified in the procurement document (see 6.2.2 item H). The width of the material **shall** be within +6.4/-0.0 mm [+0.250/-0.0 in] of the specified value.

**3.8.4.1.4 Bonding Layer Roll Length** The length of the bonding layer rolls **shall** be as specified in the procurement document (see 6.2.2 item H). The length **shall** be within ± 1% of the value specified.

### 3.8.4.2 Thickness

**3.8.4.2.1 Thickness Class Laminates** For Class A, B, C, D, materials, the thickness of the laminate base material without the metal cladding **shall** be measured in accordance with IPC TM-650, Method 2.2.18 (see Figure 3-1).

**Table 3-3 Reference Information and Testing Frequency of Laminates<sup>1</sup>**

| Tests                                                | Requirement Paragraph       | Test Method <sup>2</sup>    | Qualification Testing | Conformance Testing | Conformance Testing Frequency | Specimens per Sheet Sampled |
|------------------------------------------------------|-----------------------------|-----------------------------|-----------------------|---------------------|-------------------------------|-----------------------------|
| <b>General</b>                                       |                             |                             |                       |                     |                               |                             |
| Visuals                                              | 3.8.3.1                     | 2.1.5                       | X                     | X                   | Audit <sup>3</sup>            |                             |
| Surface Finishes                                     | 3.8.3.1.1 through 3.8.3.1.6 | 2.1.5<br>2.1.9              |                       | X                   | Audit <sup>3</sup>            |                             |
| Surface/Subsurface Imperfections                     | 3.8.3.1.6                   |                             | X                     | X                   | Lot                           | 3                           |
| Dimensional <sup>9</sup>                             | 3.8.4                       | 2.2.19.1                    | X                     | X                   | Audit <sup>3</sup>            |                             |
| Bow/Twist                                            | 3.8.4.3                     | 2.4.22<br>2.4.22.1          | X                     | X                   | Lot                           | 1                           |
| <b>Physical</b>                                      |                             |                             |                       |                     |                               |                             |
| Peel Strength After Thermal Stress                   | 3.9.1.1.1                   | 2.4.8                       | X                     | X                   | Lot                           | 4 <sup>6</sup>              |
| Peel Strength At Elevated Temperature <sup>4,5</sup> | 3.9.1.1.2                   | 2.4.8<br>2.4.8.2<br>2.4.8.3 | X                     | X                   | 3 Months                      | 4 <sup>6</sup>              |

| Tests                                                            | Requirement Paragraph | Test Method <sup>2</sup>      | Qualification Testing | Conformance Testing | Conformance Testing Frequency | Specimens per Sheet Sampled |
|------------------------------------------------------------------|-----------------------|-------------------------------|-----------------------|---------------------|-------------------------------|-----------------------------|
| Peel Strength After Exposure to Process Solutions <sup>4,5</sup> | 3.9.1.1.3             | 2.4.8                         | X                     | X                   | AABUS                         | 4 <sup>6</sup>              |
| Dimensional Stability <sup>10</sup>                              | 3.9.1.2               | 2.4.39                        | X                     | X                   | 1 Months                      | 3                           |
| Flexural Strength                                                | 3.9.1.3               | 2.4.4                         | X                     | X                   | 12 Months                     | 6 <sup>8</sup>              |
| Conductivity, Thermal                                            | 3.9.2.3.4             | AABUS                         | X                     |                     |                               | AABUS                       |
| <b>Chemical</b>                                                  |                       |                               |                       |                     |                               |                             |
| Flammability                                                     | 3.10.1.1              | UL 94                         | X                     |                     |                               | 3                           |
| Thermal Stress, Etched                                           | 3.10.1.2              | 2.4.13.1                      | X                     | X                   | Lot                           | 2                           |
| Thermal Stress, Unetched                                         | 3.10.1.2              | 2.4.13.1                      | X                     | X                   | Lot                           | 2                           |
| Solderability                                                    | 3.10.1.3              | J STD-003 Edge Dip            | X                     | X                   | 3 Months                      | 3                           |
| Chemical Resistance <sup>4</sup>                                 | 3.10.1.4              | 2.3.4.3                       | X                     | X                   | Lot                           | 1                           |
| Metal Surface Cleanability <sup>4</sup>                          | 3.10.1.5              | 2.3.1.1                       | X                     | X                   | Lot                           | 1                           |
| T <sub>g</sub> <sup>4,5</sup>                                    | 3.10.1.6              | 2.4.24<br>2.4.25              | X                     | X                   | AABUS                         | 1                           |
| Delta T <sub>g</sub> <sup>4,5</sup>                              | 3.10.1.7              | 2.4.25                        | X                     | X                   | AABUS                         | 1                           |
| Average X/Y/Z CTE <sup>4,5</sup>                                 | 3.10.1.8              | 2.4.41<br>2.4.41.1            | X                     | X                   | 1 Month                       | 1                           |
| <b>Electrical</b>                                                |                       |                               |                       |                     |                               |                             |
| Permittivity                                                     | 3.11.1.1              | 2.5.5.3<br>2.5.5.5<br>2.5.5.6 | X                     | X                   | Lot                           | 1                           |
| Loss Tangent                                                     | 3.11.1.2              | 2.5.5.3<br>2.5.5.5            | X                     | X                   | Lot                           | 1                           |
| Volume Resistivity                                               | 3.11.1.3              | 2.5.17.1                      | X                     | X                   | 12 Months                     | 3                           |
| Surface Resistivity                                              | 3.11.1.4              | 2.5.17.1                      | X                     | X                   | 12 Months                     | 3                           |
| Dielectric Breakdown                                             | 3.11.1.5              | 2.5.6                         | X                     | X                   | 3 Months                      | 3 <sup>7</sup>              |
| Electric Strength                                                | 3.11.1.6              | 2.5.6.2                       | X                     | X                   | 3 Months                      | 3                           |
| <b>Environmental</b>                                             |                       |                               |                       |                     |                               |                             |
| Moisture Absorption                                              | 3.12.1.1              | 2.6.2.1                       | X                     | X                   | 3 Months                      | 4                           |
| Fungus Resistance                                                | 3.12.1.2              | 2.6.1                         | X                     |                     |                               | 1                           |

**Note 1.** This Table is applicable for Qualification Testing and where a documented Manufacturer's Quality System is absent for Conformance Testing.

**Note 2.** All methods are from IPC-TM-650 unless otherwise noted.

**Note 3.** The following are audit requirements for visual and dimensional properties.

| Lot Size      | Sample Size | Acceptance Number |
|---------------|-------------|-------------------|
| <50           | 5           | 0                 |
| 51 to 90      | 7           | 0                 |
| 91 to 150     | 11          | 0                 |
| 151 to 280    | 13          | 0                 |
| 281 to 500    | 16          | 0                 |
| 501 to 1,200  | 19          | 0                 |
| 1201 to 3,200 | 23          | 0                 |
| >3201         | 29          | 0                 |

**Note 4.** Optional tests AABUS.

**Note 5.** Note applicable to specific material only.

**Note 6.** One lengthwise and one crosswise specimen for each side - four total for double-sided.

**Note 7.** One additional sample will be prepared for initial voltage reading for step-by-step testing.

**Note 8.** Three lengthwise and three crosswise specimen.

**Note 9.** The supplier shall use a statistical sampling plan to assure conformance to dimensional requirements.

**Note 10.** Nominal value to be AABUS.