The dissipation factor is expressed as tan δ (the tangent value of loss angle δ ). The dissipation is directly related to the resistive power loss in a laminate. Therefore, for an electronic circuit operating at a high power loss, it is desirable to use laminates with a low dissipation factor. The value of the dissipation factors for various combinations of fillers and resins are:

| | |
|---|---|
| Paper phenolic laminates | 0.02–0.08 |
| Glass epoxy laminates | 0.01–0.03 |
| Glass PTFE laminates | 0.0008–0.005 |

The dissipation factor of a laminate varies with the frequency, temperature and moisture absorbed as follows:

- Increase in frequency results in decrease in the dissipation factor.
- Increase in temperature results in increase in the dissipation factor.
- Increase in moisture constant results in proportional rise in the dissipation factor.

This implies that the dissipation factor given in the data sheet must be related to the condition under which it has been determined.

### 6.3.5 Insulation Resistance

This is the ratio of the voltage applied to the current flowing in the base laminate. Although the absolute value of insulation resistance is initially important, the change in resistance under a specified environmental condition is usually more significant. Insulator resistance varies with the environmental conditions and the process techniques of the test samples. Therefore, during testing for the insulation resistance, the test specimen should be subjected to the same environment as would be available in the final application. Insulation resistance is composed of both the volume and surface resistance in a copper clad laminate.

### 6.3.6 Surface Resistivity

This is the resistance to electrical leakage current along the surface of an insulating material. This depends upon surface humidity, cleanliness, finish, temperature, and environmental conditions, among other things.

The surface resistance between two points on the surface on any insulation material is the ratio of the dc potential applied between the two points to the total current between them. This is measured by using a three electrode circular system as shown in Figure 6.7. The electrodes are formed by completely removing the metal foil by etching but leaving the foil outlines on the specimen to form the edges of the electrodes. The guard

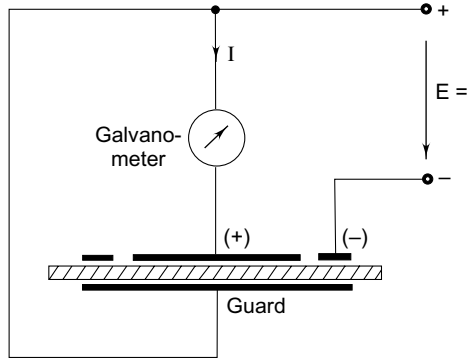



**Fig. 6.7** Schematic electrode arrangement for measuring surface resistivity

electrodes on the opposite, kept at positive (+) potential, help to avoid stray currents passing through the laminate. Measurements are made by applying 500 V dc voltage with a Megohm meter.

Surface resistivity also indirectly depends upon the chemical composition of the dielectric material. The material which has a high moisture absorption property results in a reduction of surface resistivity as is evident from Figure. 6.8. The effect of humidity on the surface resistivity of glass epoxy have been found to decrease logarithmically with an increase in humidity at approximately the rate of one decade per 20 per cent humidity change.

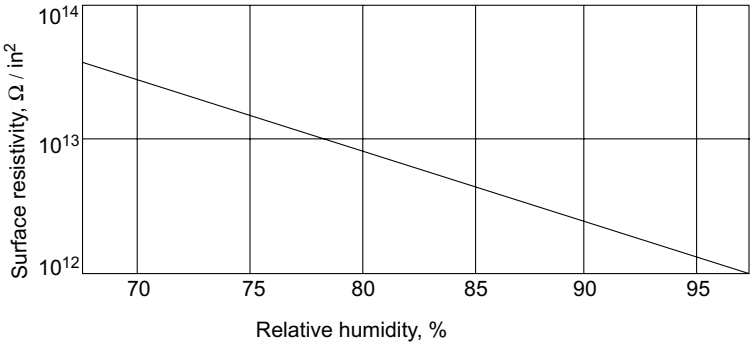



**Fig. 6.8** Variation of surface resistivity with relative humidity for glass epoxy surface

## 6.3.7 Volume Resistivity

This is the measured resistance to leakage current through the body of an insulating material. In other words, volume resistance is the ratio of the dc potential applied to electrodes embedded in a material to the current between them. It is usually expressed in ohm-centimeter.

The volume resistance is again measured by using the three electrode method as shown in Figure 6.9. The volume resistivity is governed by:

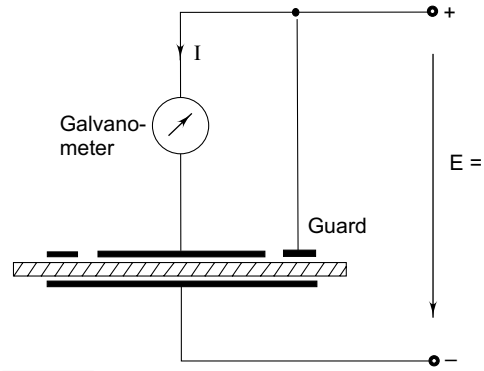



**Fig. 6.9** Schematic electrode arrangement for measuring volume resistivity

$$\text{Volume Resistivity} = \frac{R \times A}{t} \ (\Omega \text{ cm}),$$

where

R = resistance measured (Ω)

A = area of guarded electrode ($cm^2$)

t = thickness of sample (cm)

Volume resistivity is influenced by factors such as the chemical nature of the material, temperature and moisture absorbed in the sample. In general, it falls rapidly with increasing temperature. Volume resistivity is one of the most important electrical properties of a laminate as it is related to its moisture absorption property. Laminates in which the volume resistivity does not change with the moisture, like PTFE are preferred for high frequency applications.

### 6.3.8 Dielectric Breakdown

Dielectric breakdown is the disruptive discharge measured between two electrodes inserted in the laminate on 25.4 mm centres perpendicular to the lamination. The test is carried out in oil in a similar manner as is done for measurement of the dielectric strength. The data on 1.59 mm thick material is given in Table 6.4.

**Table 6.4** Dielectric Breakdown Data

| Sr. No. | Material | KV |
|---|---|---|
| 1. | XXX PC and FR-2 | 15 |
| 2. | FR-3 and FR-6 | 30 |
| 3. | CEM-1, CEM-3, G-10, G-11 Fr-4, FR-5 | 40 |
| 4. | GT and GX | 20 |



## 6.4 Types of Laminates

### 6.4.1 Phenolic Laminates

Phenolic laminates make use of phenolic resins, which consist of a solution of the reaction product of phenol and formaldehyde in a solvent. The phenolic resins are reinforced with paper fillers and the copper foil is pressed to the base material. Hence, they are also called as 'paper phenolic copper clad laminates'.

The first laminate based on phenolic resins was probably the well-known bakelized fabric. It is made from cloth and resin which is dissolved in a suitable solvent to form a solution used to impregnate the cloth. The cloth is cut into sheets, stacked in a pile and placed between two heated plates of a laminating process. The combined action of the temperature and pressure causes the resin to melt and flow to form a single mass. At the end of the lamination cycle, a strong rigid laminate is obtained.

Phenolic cloth has now been virtually replaced by phenolic paper. The laminate grade classification as per NEMA is X, XX and XXX, which means a content of phenolic resin of about 35, 45 or 55 per cent respectively, the remainder being paper and other fillers and additives. Out of these laminates, X and XX have rather poor characteristics and are seldom used. Further modification of the XXX materials gives XXP and XXXPC grades, where P means punchable and PC is cold punchable. Their properties are summarized below.

- *Grade XX*: Paper-based phenolic, fair electrical properties, good mechanical properties, not recommended for punching and little abrasive action to drills.
- *Grade XXP:* Similar to XX, but can be punched at high temperatures (200 to 250 degrees F)
- *Grade XXX*: More resin than XX, better electrical and mechanical properties and recommended for use in radio frequencies.
- *Grade XXXP:* Same as XXP, but with more resin, recommended for most general purpose applications.
- *Grade XXXPC*: Same as XXXP but can be cold punched (70-120 degrees F), has higher insulation resistance, has lower water absorption and is good for high-humidity applications.

Phenolic laminates offer good punchability and ease of fabrication. They are also have relatively low cost and therefore, have the largest commercial use. One of the drawbacks of the paper phenolics is their poor arc resistance and higher water absorption property as compared to epoxy laminates. Figure 6.10 shows the impact of moisture on the surface resistivity of paper phenolic laminates.

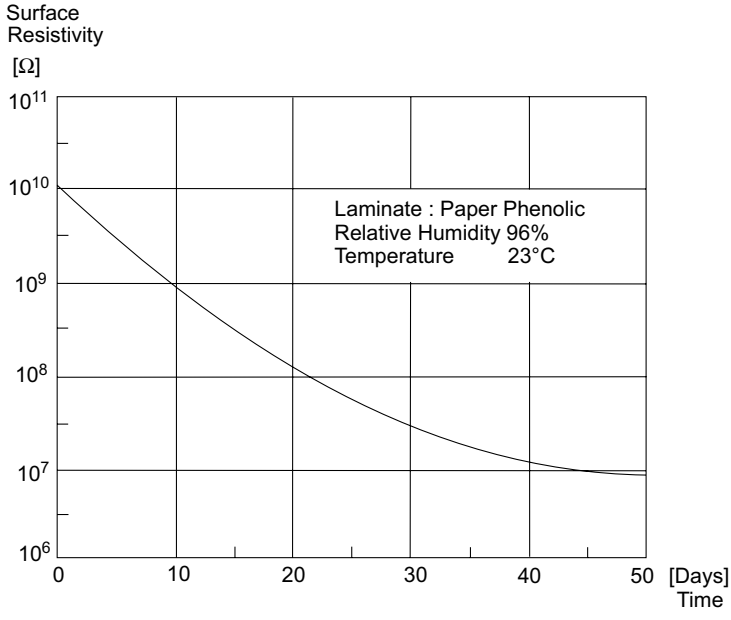



**Fig. 6.10** Impact of moisture on surface resistivity of paper phenolic laminates (redrawn after Bosshart, 1983)

### 6.4.2 Epoxy Laminates

The base material is reinforced with glass fibre or paper fibre as filler and epoxy resin and the copper foil is pressed over it to get copper clad laminates. Hence they are called 'glass epoxy copper clad laminates' or 'paper epoxy copper clad laminates' depending upon the type of filler used. During lamination, the epoxy resin is cured by means of heat, pressure and the action of an added catalyst. The final product is a thermosetting resin which is neither feasible nor soluble. They withstand all chemicals, with the exception of oxidizing acids and are almost indestructible, except at high temperatures. Some of the special properties of epoxy resins are that they:

- Show very low shrinkage during cure;
- Are tough materials;
- Form an outstanding adhesion bond;
- Exhibit high mechanical strength;
- Have extremely high alkali resistance or even excellent acid and solvent resistance;
- Exhibit good electrical properties over a wide range of temperatures and frequencies; they are excellent insulating materials and have high dielectric strength; and
- Demonstrate excellent moisture barriers and low water absorption.

Epoxy resins are usually combined with high quality reinforcing material such as glass cloth and composite material, and exhibit exceptionally high mechanical strength and excellent electrical properties.

### 6.4.3 Glass Cloth Laminates

The glass cloth is used for the manufacture of epoxy resin reinforced glass cloth laminates. G-10, G-11, FR4 and FR5 types are some of the glass cloth laminates available. The glass fibres or filaments are usually 9.6 microns (0.38 mil) in diameter, are bunched together and twisted to form thread and are woven from silk fibre in the silk industry. The threads are of different types. The mesh of the cloth is indicated by the number of threads provided per linear inch. 1.6 mm thick laminates contain eight glass cloth layers and if a hole of 1mm diameter is drilled, it cuts about 10,000 filaments. The glass fibre in the holewall will have about 20,000 ends. Spiak and Valiquette (1994) describe the trends in the laminate industry for better and faster materials. Table 6.5 gives the physical characteristics of laminate materials.

The most widely used and industries' standard base material for PCB fabrication is woven-glass-cloth-reinforced epoxy or FR-4 with a 135 °C Tg. The dielectric constant is approximately 4.4 and propagation delay is approximately 178 ps/in. These laminates are constructed on one or multiple piles of epoxy resin impregnated woven glass cloth. FR-4 is the most widely used material because its properties satisfy the electrical and mechanical needs of most applications. They exhibit high mechanical strength and machinability, consistent drilling properties, thermal stability and V-O fire resistant. Designed for single- and double-sided boards, they provide a combination of processing

flexibility and finished board performance needed for many SMT applications. However, demands for the following high performance (Guiles, 1998) requirements has necessitated the development of new materials:

- Boards with special thermal requirements, i.e. those handling high concentration of power in small areas;
- Large or high layer count boards that are complex to manufacture; includes boards with complex etched patterns requiring precise registration;
- Boards requiring controlled thermal expansion characteristics due to special assembly technologies (flip chip, chip-on-board) or enhanced reliability needs;
- Boards with special or tightened electrical requirements, especially those requiring a low dielectric constant for low propagation delay, lower cross-talk and higher clock rates, and a low dissipation factor for low attenuation, better signal integrity, higher clock rates, and lower power consumption in portable electronics.

**Table 6.5** Physical Characteristics of Laminate Materials (after Lucas, 1993)

| Material type | Tg °C | Dielectric constant | | Propagation delay ps\in | Per cent of $H_2O$ | Copper peel strength | |
|---|---|---|---|---|---|---|---|
| | | Resin | w/E-glass | | absorption | lb/in.$^2$ @ 25°C | Lb/in.$^2$@ 200°C |
| Standard FR-4 | 135 | 3.6 | 4.4 | 178 | 0.11 | 11.0 | 5.7 |
| High-performance FR-4 | 180 | 2.9–3.6 | 3.9–4.4 | 168 | 0.04–0.20 | 9.0–11.0 | 7.5–7.9 |
| Polyimide | 220 | 3.4 | 4.3 | 176 | 0.35 | 8.5 | 8.0 |
| BT | 195 | 3.1 | 4.0 | 170 | 0.40 | 8.7 | 5.2 |
| Cyanate ester | 240 | 2.8 | 3.7 | 163 | 0.39 | 8.0 | 6.3 |
| Silicon Carbon | 190 | 2.6 | 3.4 | 156 | 0.02 | 5.0 | 5.0 |
| PTFE | 16 | 2.1 | 2.5 | 134 | 0.01 | 10.0 | 8.0 |

An important physical characteristic of the laminates is the amount of Z expansion occurring when a circuit board, and subsequently an assembly, are exposed first to a series of excursions to

solder temperature and then to life cycles from ambient to operating temperature. The detrimental effect of Z dimension expansion is the work-hardening of the copper cylinder (plated through-hole). From a laminate perspective, the lower the Z expansion, the lower the overall work-hardening and the greater the life expectancy of the electronic assembly (Lucas, 1993).

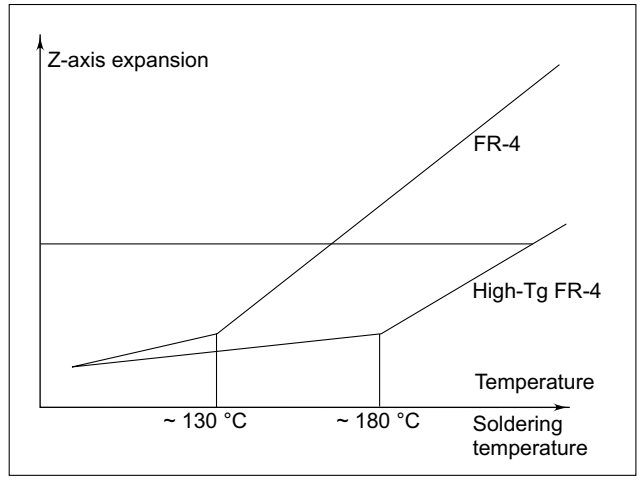



**Fig. 6.11** Z-axis expansion of FR-4 and high Tg FR-4 as soldering temperature increases (after Ehrler, 2002)

Ehrler (2002) examines the properties of various epoxy materials and reinforcements, which are responsible for the development of new materials with improved electrical and thermo-mechanical performance of printed circuit boards. As shown in Figure 6.11, it usually results in improved through-hole reliability due to the enlarged range below the Tg with lower Z-axis expansion in the range upto the soldering temperature. This is usually achieved by increasing cross-linking of the material. High-Tg (180 °C) FR-4 materials with associated reduction in Z expansion have better dimensional stability, which is important for complex PCBs because the cores do not require heating much above the Tg, as conventional FR-4 would require. This i smproves the laminate's resistance to stress-related defects and increases product life expectancy. This high performance FR-4 laminates with standard E-glass reinforcement have a dielectric constant as low as 3.9 and propagation delay as low as 168 ps/in. However, the thermal stability of some high-Tg FR-4 resins does not match that of conventional FR-4 and they have lower copper peel strength.

Lin (2003) describes the properties of the NPLD series material which posses the desirable characteristic of high Tg (200), low Dk (3.5-3.9) and low Df (0.038-0.01). The material provides with improved thermal dielectric and moisture resistance performance and is best suited for use in the Giga-hertz frequency range application.

### 6.4.4 Prepreg Material [B-Stage]

Epoxy resins are widely used in the manufacture of B stage or prepreg material. When two monomers of epichlorohydrin and bisphenol-A are mixed together, a polymer is obtained. This polymer is called B Stage resin, which melts and is soluble in some solvents. The resin is mixed with fillers like paper or glass cloth to get B stage epoxy resin material and are used in manufacturing multi-layer laminates.

They have some characteristics like chemical and solvent resistance and low Z-axis expansion at high temperatures.

### 6.4.5 PTFE (Polytetrafluoroethylene) Laminates

Polytetrafluoroethylene is a thermoplastic material. When reinforced with glass, it results in a laminate which offers several advantages, particularly when used for high frequency (RF) and microwave applications. The thickness distribution in a composite material consisting of resin and glass fabric affects the uniformity of the dielectric constant and the dielectric loss factor. With microwave PCBs being mainly active components, variations of the dielectric characteristics inevitably lead to performance losses. The PTFE woven glass fabric base materials have an exact thickness distribution across the entire manufacturing sheet 1220 mm × 914 mm (48" × 36") as 0.020" ± 0.0015" without any taper towards the edges of a sheet. In addition, PTFE laminates have a low dielectric constant and a low dissipation factor under a wide temperature, humidity and frequency range.

The molecular structure of PTFE is responsible for an extremely low moisture absorption of < 0.02 % of the base material. Thermoplastics undergo a chemical as well as a phase change when they are heated. Their molecules form a three-dimensional cross-linked network. Once they are heated and formed, they cannot be re-heated and re-formed. Microwave laminates made from thermoset resin systems exhibit significantly higher values. The influence of moisture in degrading the electrical behaviour of the laminates, particularly on the impedance, is well understood. PTFE therefore offers very high electrical strength having electrical insulation under severe environmental conditions. Therefore, besides their use in RF and microwave applications, PTFE laminates are often used where high insulation resistance under humid conditions has to be maintained. Typical examples are input stages of high impedance/low current measuring instruments and amplifiers.

A further advantage of PTFE is the higher inter-laminar bond strength and the resultant copper peel strength. Higher peel strength is required during re-work of the assemblies, when conductors are partially exposed to very high temperatures. PTFE/woven glass materials exhibit a minimum peel strength value of 1.8 N/mm (10 lbs/in) even with 0.5 oz/ft$^2$ (17.5 μm) copper foil.

PTFE laminates meet the required class of the flammability UL-94, V-0 without using any flame retardant. Microwave base materials based on thermoset resins mostly require flame retardants degrading other performance parameters such as peel strength or do not meet V-0 for the thinnest material thickness. This is a definite advantage of PTFE-based laminates.

Besides using woven glass as the filler with PTFE, ceramic-filled PTFE laminate has also been developed which is not only low in cost but its use as RF microwave PCB substrate is now well established. The laminate is used for double-sided strip line PCB construction and multi-layer application. The various types of epoxy laminates are:

- NEMA-FR3-flame resistant paper epoxy;
- General purpose glass epoxy G-10, temperature-resistant glass epoxy G-11;
- Fire retardant glass epoxy FR-4; and
- Fire-and temperature-resistant glass epoxy Fr-5.

Flame-retardency is achieved by substituting some functional groups of the resin with halogens like chlorine or bromine.

### 6.4.6 Polyester Laminates (Mylar Lamination)

Polyesters are solutions of unsaturated polyester resin in copolymerizable monomers such as styrene. Glass fibre as filler is used to reinforce the polyester. This is pressed with copper foil to get mylar laminations. The commercially available grade of laminates is FR-6 of NEMA. They are usually of glossy colours such as white or red and are relatively cheap. Their electrical properties resemble those of XXXPC laminates and mechanical properties are fair. Their dimensional stability and water resistance are also good. After soldering, the warp and twist can be considerable.

### 6.4.7 Silicone Laminates

These are made of silicone resins with glass reinforcements. They have good resistance to chemicals and to heat; and are used in the range of 175 °C to 400 °C depending upon their type. It is difficult to obtain a good bond between copper foil and base material in the silicone resin system. Even though the electrical properties of these laminates are very good, their usage is limited because of high cost.

### 6.4.8 Melamine Laminates

Melamine resins can be combined with a variety of reinforced fillers such as glass fibre to produce melamine laminates. They offer very high surface hardness and high arc resistance. However, their main disadvantage is their poor dimensional stability, particularly with cyclic variations of humidity.

### 6.4.9 Polyamide Laminates

Polyamide is reinforced with filler like woven glass fabric, or aramide fibre or quartz fibre to form laminates with good electrical and mechanical properties, higher copper bond strength, good heat resistance and low Z-axis expansion. They find use in demanding military and aerospace applications and in special multi-layer circuits. They, however, have poor peel strength, which can result in lifted copper conductors after soldering at high temperatures.

### 6.4.10 Teflon Laminates

Teflon is reinforced with glass fibre to get a laminate of low dielectric constant and it is used in Radio Frequency (RF) applications with small leadless components. Due to the high co-efficient of thermal expansion, teflon laminates have limited use.

### 6.4.11 Mixed Dielectric Laminates

Mixed dielectric laminates are becoming popular in today's microwave and high-speed digital PCBs.

One such material is Speedboard C prepreg, which can be used as a prepreg or an outer-layer HDI dielectric for critical signal routing, while using low cost FR-4 for non-critical layers in multi-layer PCBs provides a good solution for these applications. Speedboard prepreg is used as a low loss HDI dielectric that improves the performance of the controlled impedance high speed digital, RF and microwave PCBs by making them thinner, lighter and faster. The product is comprised of expanded polyterafluoroethylene (ePTFE) that has been impregnated with a modified BT resin. The air space inside the ePTFE is replaced with resin and the ePTFE membrane becomes the carrier or delivery system for the resin. The conformable ePTFE toughens the dielectric, improving reliability and enabling excellent surface planarization for high density fine lines and space.

Speedboard C material features a low dielectric constant of 2.6 and a low loss tangent of 0.00036 that is stable over frequency and temperature. It utilizes standard thermoset processing as opposed to fusion processing. The material is manufactured by M/s W.L Gore and Associates Inc. Newark, DE. Additional information may be obtained from the company's website at www.gore.com.



## 6.5 Evaluation of Laminates

### 6.5.1 Laminate Testing

Tests for laminates are described in many publications such as IEC Publication 249, NEMA and ASTM standards MIL-P-13949, BS4584 [UK] and DIN 40802 [Germany]. Generally, electrical and mechanical design, and the particular fabrication process will demand that the final material has certain features and controls. Some of the methods most commonly used today to evaluate the laminates are described in the following sections.

### 6.5.2 Surface and Appearance

Surface and appearance standards are probably the most difficult tests to define adequately. Laminates generally get rejected for pits and dents in the copper surface. Most laminators advocate that surface and appearance standards must be applied only on the finished boards. Some users of laminate require copper surface standards only on certain critical areas, such as the areas for tips inserted into edge connectors. In those cases, the user usually specifies the laminators with an overlay of the critical copper areas to be inspected on each sheet of material before it is shipped. Thus, the surface standard is applied only to areas that are pertinent to the finished board. With more than 90 per cent of the copper being ultimately removed, the change of pit or dent affecting a critical area is quite small.

#### Dimensional Stability

Copper pits and dents are defined in the surface standards wherein the specification defines the longest permissible dimension of a pit or dent and supplies point values for rating all pits and dents. As per the MIL-P-13949 standard, the defect dimensions and the point values are given as follows:

| Defect dimension (mm) | Point-Value |
|---|---|
| 0.13 --- 0.25 | 1 |
| 0.28 --- 0.51 | 2 |
| 0.53 --- 0.76 | 4 |
| 0.79 --- 1.02 | 7 |
| over 1.02 | 30 |

The sum of points for all defects within the inspected area must be less than 30 per 645 $mm^2$. Scratches are permitted that have a depth of less than 140 µm or a maximum of 20 per cent of the foil thickness.

### Colour

Colour variation of the laminate can take place from lot to lot due to variation in colour of the batches of resin, types of paper used or due to variation of alloy coating on the copper. Generally, a set of samples that illustrate the preferred colour extremes are established.

## 6.5.3 Water Absorption

Water absorption of a laminate must be as low as possible. If it is high, the electrical characteristics of the laminate will change considerably as a result of humidity or of the absorbed liquid during PCB manufacture. Absorbed water can also cause outgassing during soldering or promote blistering of a heated laminate.

The amount of water absorbed by a sample of specified size, when immersed in distilled water for a specified period at a specified temperature, is taken as a measure of water absorption. Usually, three specimens of 50 mm × 50 mm are taken and subjected to immersion in distilled water at 20 °C for twenty-four hours. The average value of water absorbed in milligrams represents the water absorption.

Alternatively, the gain in weight expressed as a percentage of increase over the initial weight can also be taken as a measure of water absorption. A 76.2 × 25.4 mm piece of the laminate is chemically etched to remove the copper and then dried by heating it at 107 °C for one hour. After cooling, it is weighed and immersed in distilled water at 25 °C for twenty-four hours. It is then surface dried and weighed again. The increase in weight as a percentage of the initial weight must not exceed the valves shown in Table 6.6.

**Table 6.6** Water Absorption Limits

| **Material** | **Thickness** | | |
|---|---|---|---|
| | 0.79 mm | 1.59 mm | 3.17 mm |
| XXXP,XXXPC,FR-2 and FR-3 | 1.00 | 0.65 | 0.50 |
| G-10, G-11, FR-4 and FR-5 | 0.80 | 0.35 | 0.20 |

### 6.5.4 Punchability and Machinability

Punchability is the most desirable mechanical property of copper clad laminates. Good punchability, in simple terms, means that when the laminate is punched, there is no cracking of the board, there is no lifting of the copper around the punched hole, the edges are smooth and there is smoothness inside the holes. These properties are possible if the laminates are dimensionally stable and free of warp and twist.

Manufacturers should be consulted on the recommended drilling speeds and feeds prior to performing any machining operations. Sectioning the board often helps in evaluating the type of the hole being obtained and is particularly important on plated through-applications. Often, sectioning will show that the material has been heated by drilling to such an extent that the surface is smooth and not palatable, is smeared with resin, or is so roughened that glass fibres protrude and will inhibit continuous plated through-holes.

Punchability can be measured in a die that simulates the conditions used in the fabrication process. Various hole sizes, spacing and configurations are incorporated in the test die. Careful physical inspection and sectioning of the holes will indicate the types of punching being obtained. The material must be carefully inspected to ensure that no cracking occurs and that there is no lifting of copper around the hole. Many paper base grade laminates will tend to vary in punchability from lot to lot. So care must be taken to measure a wide range of sample panels.

A preferred test for measuring the punchability of a laminate is defined in the German standard DIN 53488. The test entails punching square holes at exact spacing on a strip of laminate measuring 120 mm $\times$ 15 mm and visually inspecting to determine the minimum spacing between two adjacent holes which do not crack or chip. The punchability of the sample is expressed in points from 1 (optimum punchability) to 4 (low punchability) as a function of the minimum unbroken spacing and the laminate thickness. The test is particularly useful in comparing different laminates.

### 6.5.5 Peel Strength

Peel strength indicates the measure of adhesion of copper to the base material. The basic test pattern for testing peel strength or copper bond strength specified in MIL-P-13949 and by NEMA standards is illustrated in Figure 6.12. The pattern is processed by the same fabrication technique as in the user's final process, with the exception of exposure to various plating solutions or solder which will also be tested. When testing for peel strength, the specimen should be mounted on a flat, horizontal surface. The wide copper end of each trace is peeled back approximately 25 mm so that the line of peel is perpendicular to the edge of the specimen. The end of the peeled strip is then gripped by a clamp, which is attached to a force indicator or tensile tester adjusted to compensate for the weight of the clamp, and connecting chain. The minimum load of the force indicator is recorded. The ratio of the recorded force F to the conductor width is the *peel strength.* This is usually expressed in pounds per inch of width or in grams per millimeter of width.

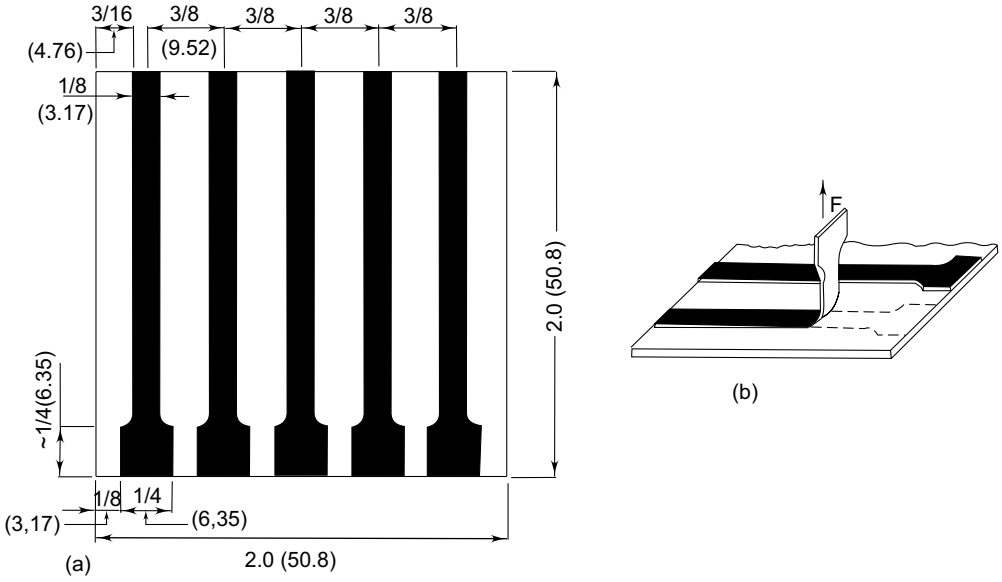



**Fig. 6.12** Peel strength test (a) NEMA test sample (b) the test is performed by applying a force 'F' to a conductor

For the most commonly used laminates, the minimum peel strength for 1 oz/ft$^2$ copper thickness is 0.143 kg/mm. The peel strength value varies with the thickness of copper. For example, for a 2 oz/ft$^2$ copper foil, the minimum peel strength required is 0.1756/mm for XXXP, XXXPC, FR-3, FR-4, FR-5 and 0.1964 kg/mm for G-10 and G-11.

### 6.5.6 Bond Strength

Bond strength is a measure of the adhesion of a conductor pad to the base material. It is an important parameter as the conductor de-lamination in most cases starts from a pad. Bond strength can be measured on a finished PCB or on a test pattern. For doing so, a specimen of the laminate is drilled as recommended, with at least 10 holes of 50 mil (1.27 mm) diameter, spaced about 10 mm. Around each hole, a 2.54 mm conductor pad is made by printing and etching the sample. It should be seen that land centres are not offset by more than 4 mils (0.1 mm) from the hole centre. The specimen is then assembled by using staples of AWG 20 tinned copper wire. The specimen is soldered according to standard operating parameters on a wave soldering machine. The lead projections on the solder side are pulled vertically to the laminate and the values which cause pad removal are recorded. Figure 6.13 shows an arrangement for carrying out the bond strength test. The average value from at least eight tests should not be less than:

4.0 kg [8.8 lb] for XXXP, XXXPC and FR-2; and

8.0 kg [17.7 lb] for G-10, G-11, FR-4 and FR-5

and the minimum value should not be less than 70 per cent of the average.

The same test can be used [pulling the lead from the component side] for determining the strength of the solder, provided that the tinned copper wire is highly solderable.

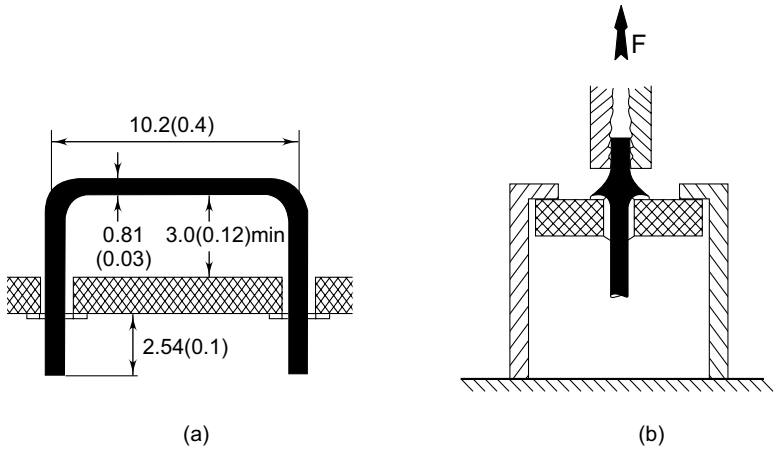



**Fig. 6.13** Arrangement for test for bond strength (a) dimension of the sample (b) test arrangement (redrawn after Leonida, 1983)

### 6.5.7 Solder Resistance

The resistance of the laminate to soldering can be determined by floating a specimen on the surface of molten solder at 260 ± 3 °C (500 ± 5 °F) for a given time, usually from 10 to 60 seconds. The specimen must have conductors and holes (non-plated or PTH) of the same type used on the PCBs to be manufactured. The sample should not be fluxed. In order to prevent wetting by solder, a thin layer of silicone grease or oil is used for this purpose. After floating, the specimen is visually inspected for blistering, haloing, measling, etc.

### 6.5.8 Warp and Twist

Warp is the warpage along the edge of a sheet whereas the twist is the warpage along the diagonal. Excessive warpage or twist can lead to problems at various stages of PCB manufacturing and assembly. The measurement of warp and twist is carried out by taking a square specimen of laminate having a side of 914.4 mm or on a rectangle with the shorter side not less than 610 mm.

By definition, the sample is warped, if the sample, when placed on a flat area, has all its four corners in contact with the supporting plane. For measuring warp, the sample is placed so that all corners contact the supporting plane. Along each side, the maximum deviation from the plane is measured and expressed as a percentage of the length of the side.

Similarly, if at least one corner of the sample does not contact the supporting plane, it is twisted. For measuring twist, the specimen is supported on these corners and the maximum deviation is measured on the triangle internal to the corners. One support is then measured to the unsupported corner and the maximum deviation is measured on the other half of the panel. Twist value is usually expressed as a percentage of the diagonal of the specimen. Warp and twist values are governed by the MIL-P-13949 standard.

### 6.5.9 Flexural Strength

Flexural strength is a measure of the force per unit area, that a laminate strip will be able to withstand without fracture, when supported at ends and the force is applied at the centre. Figure 6.14 shows the testing arrangement for flexural strength.

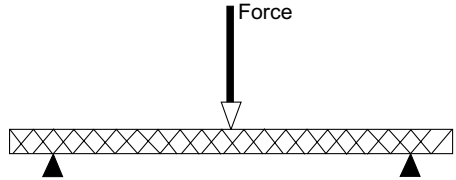



**Fig. 6.14** Testing of flexural strength

The values of flexural strength are not the same in the two directions, i.e. parallel to the length of the filler (lengthwise) and perpendicular to it (cross-wise). For measurement of flexural strength, the specimen is 25 mm wide and at least twenty times the thickness of its length. The span of support is generally sixteen times the thickness. Five specimens, each corresponding to the two directions (lengthwise and cross-wise) are studied. The minimum average of the values in the two directions is taken as the flexural strength.

### 6.5.10 Flammability

The problem of inflammability arising out of the materials used in the industry is a cause for great concern. So, there is a need to make and use more flame-resistant laminates. The standards for testing flammability have been laid out by IEC, NEMA and Underwriters Laboratories (UL).

UL 94 is a general standard for the flammability testing of plastic materials. According to this standard, materials tested for flammability are classified as 94 V-D, 94V-1 94V-2 and 94 HB. The tests are conducted either in horizontal or vertical position. These tests are conducted in a chamber which is free from draught. The sample taken is of 127 mm length and 12.7 mm wide. Before the tests are conducted, the samples are conditioned for forty-eight hours at 23 °C and 50 % RH. The equipment used and test set-up are described in detail in the standard.

The classifications of the various tests are:

*Vertical Burning Test (94V-O, 94V-1, 94V-2).*

- Specimen must extinguish within
  10 seconds (94V-O)
  30 seconds (94-1, 94V-2)

- For each set of five specimens, the specimen should not have a total combustion time exceeding:

  50 seconds (94V-O)

  250 seconds (94V-1, 94 V-2)

- There should be no samples to dip flaming particles that may ignite the dry absorbent surgical cotton below (94V-O, 94V-1). Samples may dip flame particles, while burning briefly.
- After the second flame test, specimen with flaming combustion should not last beyond

  30 seconds (94V-0)

  60 seconds (94-1).

*Horizontal Burning Test: (94 HB):*

- The burning should not exceed 76.2 mm per minutes over a 76.2 mm span.
- Samples must cease to burn before the flame reaches the 102 mm reference mark.

### 6.5.11 Glass Transition Temperature

The glass transition temperature (usually expressed as Tg) is an established indicator of as to how well a laminate resin system would resist softening from heat. At Tg temperature, the resin changes from its glossy state and its molecular bonds begin to weaken enough to cause a change in physical properties (dimensional stability, flexural strength, etc.). FR-4 epoxy shows a Tg of 115-125 °C and polyimide 260-300 °C. Tg, in a way, is an indicator of the amount of expansion that will take place from ambient to solder.

### 6.5.12 Dimensional Stability

The increased circuit density results in the increased need for circuit board dimensional stability. The dimensional stability in X,Y directions is a function of the laminate reinforcement (glass or paper), whereas the thickness expansion 'Z' is generally function of the system or resin matrix.

*Z-expansion:* This is the amount of expansion which occurs in the Z-dimension when a circuit board, and subsequently an assembly, are exposed first to a series of excursions to solder temperature and then to lifecycles from ambient to operating temperature. The detrimental effect of Z-dimension expansion is the work hardening of the copper cylinder (plated through-hole). From a laminate perspective, the lower the Z-expansion, the lower is the overall work-hardening and the greater the life expectancy of the electric assembly. Ideally, if a laminate with a Z-expansion equal to that of the plated through-hole could be created, the stress and the associated work-hardening could be virtually eliminated. On a practical basis, the laminates that meet specified performance requirements are selected. Most selections are made on the basis of the glass transition temperature.

### 6.5.13 Copper Adhesion

This is usually tested by the 'peel strength test'. As the test is destructive, it is not done on the production board. Rather, the supplier is asked to prepare some test specimens with each production batch.



## 6.6 Useful Standards

- *IPC/JPCA4104: Specification for High Density Interconnect (HDI) and Microvia Materials:* Covers various conductive and dielectric materials that can be used for the fabrication of HDI and microvias, also includes qualification and conformance requirements for such materials as photo-imageable dielectric dry films and liquids, epoxy blends and coated foils.
- *IPC-4103: Specification for Base Materials for High Speed/High Frequency Applications*: Includes requirements for high speed/high frequency laminate or bonding layers to be used primarily for the fabrication of rigid or multi-layer printed boards for high speed/high frequency electrical and electronic circuits.
- *IPC-M-107: Standards for Printed Board Materials Manual*: Contains the requirements for the various reinforcements, foils, laminates and prepregs.
- *IPC-4101A: Specification for Base Materials for Rigid and Multi-layer Printed Boards:* Covers the requirements for base material (laminate and prepreg) to be used primarily for electrical and electronic circuits.
- *IPC-4562: Metal Foil for Printed Wiring Applications:* Includes nomenclature and requirements for metal foils used in laminate and PCB fabrication.
- *IPC-CF-148A: Resin-coated Metal for Printed Boards:* Covers the requirements for metal foils coated with a resin or composite of resins on one side, to be used for the fabrication of PCBs, including specification sheets that outline engineering and performance data for resin-coated metal foil, indicating foil material type and resin type.
- I*PC-CF-152B: Composite Metallic Materials Specification for Printed Circuit Boards:* Includes requirements for copper/invar/copper (CIC), copper/molybdenum/copper (CMC) and three-layer composites for use in electronic applications.
- *IPC-TR-482: New Developments in Thin Copper Foils:* A compendium of technical methods and techniques used for evaluating the quality aspects of present and future interconnection product and electronic assemblies; addresses base materials, conductor physical requirements, internal planes, construction, registration, plated-through-holes, component mounting areas, cleaning evaluation, soldermask and printed board electrical requirements.
- *IPC-TR-484: Results of IPC Copper Foil Ductility Round Robin Study:* The test report evaluates ductility of the foils provided by the industry's copper foil vendors.

- *IPC-TR-485: Results of Copper Foil Rupture Strength Test Round Robin Study*: The test report evaluates rupture strength testing as a means of determining the mechanical properties of electrodeposited and rolled copper foil.
- *IPC-4412: Specification for Finished Fabric Woven from "E" Glass for Printed Boards:* Covers the classification and requirements for finished fabrics woven from *E* glass fiber yarns.
- *IPC-4130: Specification and Characterization Methods for Non-woven E Glass Mat:* Defines the nomenclature, definitions and requirements for materials made from non-woven '*E*' glass fibres; includes specification sheets for selecting and purchasing these materials.
- *IPC-4110: Specification and Characterization Methods for Non-woven Cellulose Base Paper for Printed Boards:* Defines the nomenclature, chemical and physical requirements of paper made from cellulose fibres for PCB fabrication.
- *IPC-4411-K: Specification and Characterization Methods for Non-woven Para-aramid Reinforcement:* Includes the nomenclature, definitions and requirements for reinforcement made from non-woven para-aramid fibres.