Characterization of CEM-1 Boards

DfR Staff

9000 Virginia Manor Rd Ste 290, Beltsville MD 20705 | Phone: (301) 474-0607 | Fax: (866) 247-9457 | www.dfrsolutions.com

Abstract

One of the more common substrates used in low-cost electronic packaging is composite epoxy material (CEM) laminate. This paper presents some of the key thermo-hygro-mechanical properties of CEM laminates used in printed circuit board fabrication.

Introduction

CEM laminates are defined by material composition with some minimum performance specifications [1]. NEMA[1] grade CEM-1 laminates are composed of a cellulose paper core, sandwiched between two layers/plies of continuous woven glass fabric, infiltrated with a flame resistant epoxy resin binder (Figures 1-4). NEMA grade CEM-3 laminates are similar, but with a chopped glass fiber core.

Figure 1 (50x): Optical cross-sectional view of a CEM substrate showing the inner core sandwiched by resin-filled woven glass fibers.

[1] National Electrical Manufacturers Association, Rosslyn, VA

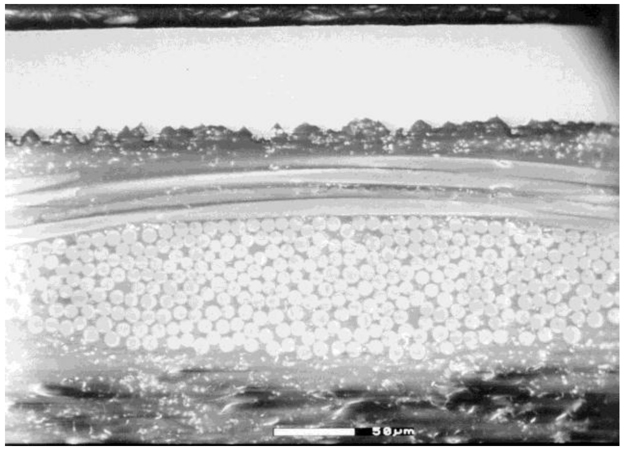

Figure 2 (295x): SEM cross-sectional image showing the solder side (with copper layer) of the CEM substrate.

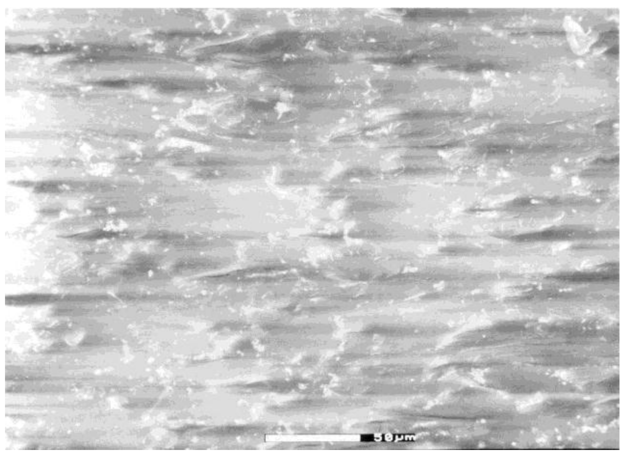

Figure 3 (320x): SEM cross-sectional view showing an enlarged image of the inner core of the CEM substrate.

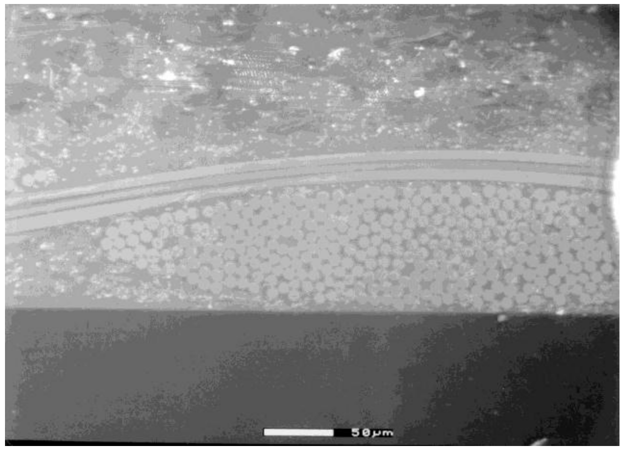

Figure 4 (255x): SEM cross-sectional image showing the component side (no copper layer) of the CEM substrate.

The thermal, mechanical, chemical, and electrical properties of CEM substrates can vary depending upon the type of epoxy resin used by the manufacturer, and the fiber selected for reinforcement of the surface layers. An example of this variation in CEM laminate types can be seen in Table 1. This range in material properties can necessitate characterization of the CEM substrate received from the vendor before eventual use.

Test Parameters	ASTM D709-92	Manufacturer A	Manufacturer B	Manufacturer C
Flexural Strength (GPa)	0.24	0.33	0.38	--
Flexural Modulus (GPa)	--	15.9	--	--
Moisture Absorption (%)	0.30	0.25	0.17	<0.1
Permittivity	5.0	4.6	4.5	--
Dielectric Breakdown (kV)	40	40	60	>60
CTE X-axis (ppm/°C)	--	13	13	24
CTE Y-axis (ppm/°C)	--	16	16	18
CTE Z-axis (ppm/°C)	--	--	275	250
Tg (°C)	--	--	95	130

Table 1: Properties of selected commercially available CEM laminates

Experimental Procedure

Precise values for mechanical and thermal properties are critical when accessing reliability implications, especially for integrated components or systems. For example, knowledge of the exact T_g, will allow users to operate up to a maximum temperature before any dramatic changes in modulus or CTE are encountered. Equipment necessary to evaluate these properties include: thermo-mechanical analyzers (TMA), dynamic mechanical analyzers (DMA), and differential scanning calorimeters (DSC).

Elastic Modulus

The elastic modulus of a CEM-1 substrate was measured using dynamic mechanical analysis[2]. After the specimens were placed in a three-point bending fixture, a load was applied sinusoidally at a frequency between 1 and 100 Hertz with a maximum strain of 0.01%. The deflection behavior of the specimen as a function of load and frequency allowed the machine to calculate an elastic (storage) modulus and a viscous (loss) modulus. Since the measured loss modulus was one to two orders of magnitude less than the storage modulus, the CEM substrates are approximately elastic. Thus, the storage modulus measured at 10 Hz was selected as the elastic modulus.

The modulus of the CEM-1 laminate was measured before and after saturation with moisture. Saturated conditions were induced by exposing the CEM laminate material to 95% RH at 25 °C for 72 hours. Previous experiments for these laminates show that there is very little or no increase in weight due to moisture accumulation after 72 hours at these conditions. The elastic modulus of CEM specimens was measured over a temperature range of 35 °C to 105 °C.

Glass Transition Temperature (T_g)

Measurement of the glass transition temperature (T_g) provides information necessary to determine approximate manufacturing and use temperatures. Below the T_g, the CEM-1 laminate is rigid and is able to mechanically support various components and devices. Above the T_g, the epoxy resin becomes viscoelastic due to the breakdown of intermolecular secondary bonding.

The glass transition temperature was measured using a Differential Scanning Calorimeter (DSC)[3]. In the DSC, two pans, one empty and one containing CEM-1 material, are heated such that their temperature difference is zero. The heat added to (or taken from) the pan containing CEM-1 relative to the reference pan is recorded as a function of temperature. The T_g is identified by a sharp absorption of energy by the CEM-1 substrate, resulting in a corresponding strong endothermic peak in the heating curve.

Coefficient of Thermal Expansion (CTE)

Measuring the coefficient of thermal expansion (CTE) allows a designer to determine the mechanical compatibility of CEM-1 substrate with mounted electronic components. A CTE much

[2] RSA-II, Rheometrics Scientific, Piscataway, NJ
[3] Pyris 1, Perkin Elmer, Norwalk, CT

greater than or less than the CTE of devices connected to the laminate can result in the occurrence of stress-dependent failure mechanisms, such as fatigue or creep. CTE also can limit the maximum use temperature, as the epoxy resin used as a matrix in CEM-1 undergoes a rapid increase in CTE above the glass transition temperature.

The CTE was measured using a Thermo-Mechanical Analyzer (TMA)[4]. In the TMA, a glass probe is placed in direct contact with the sample. Changes in the dimension of the sample are recorded by a transducer, which is connected to the glass probe. The CTE was measured over a temperature range of 20 to 200°C, at a temperature ramp rate of 5°C per minute. The probe force was set at 2mN to maintain physical contact with the sample without inhibiting thermal expansion.

Swelling due to Moisture Absorption

Epoxy resins used in the production of printed circuit boards (PCBs) are hydrophillic and will thus absorb moisture during normal operation, causing the substrate material to swell. This change in dimensions can lead to the creation of localized stresses. These stresses must be taken into consideration to avoid lower than expected reliability and premature failures.

To measure swelling due to moisture absorption, samples of CEM-1 laminates were baked at 125°C for 48 hours to remove any existing moisture. The samples were then subjected to a humid environment inside a specially modified TMA (see figure 5). The laminates were soaked at 85°C/95%RH to induce a high rate of moisture sorption. Once dimensional changes reached a steady-state value (after 10 hours), which established that the boards were saturated with moisture, the ambient temperature was lowered to 30°C to eliminate the change in dimensions due to thermal expansion. The relative humidity (RH) inside the TMA box was determined using a RH sensor. The corresponding weight gain was measured using a Mettler analytical balance with a resolution of 0.1 mg.

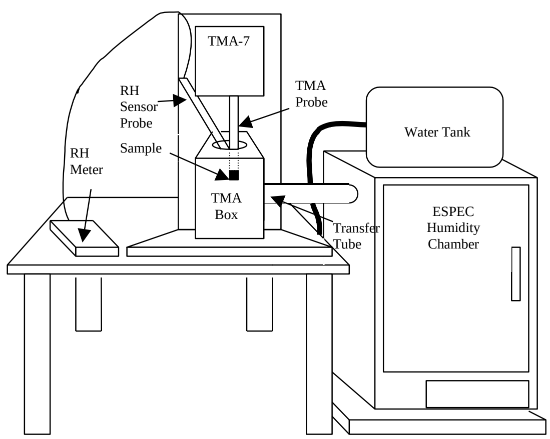

Figure 5: Schematic of the modified TMA equipment setup used to measure swelling of the CEM substrates.

[4] TMA-7, Perkin Elmer, Norwalk, CT

Results

Elastic Modulus

The temperature dependence of the elastic modulus of CEM-1 laminate material, as-received and saturated with moisture, is displayed in Figure 6. The initial values for the as-received and saturated with moisture are 21 and 12 GPa, respectively. In both conditions, the elastic modulus begins to show a decrease in value at approximately 75 °C. The moisture-saturated CEM laminate undergoes a greater drop in elastic modulus with increasing temperature, up to a final temperature of 105 °C. The values for the as-received laminate are similar to those found in other reports on reinforced laminate material [2,3].

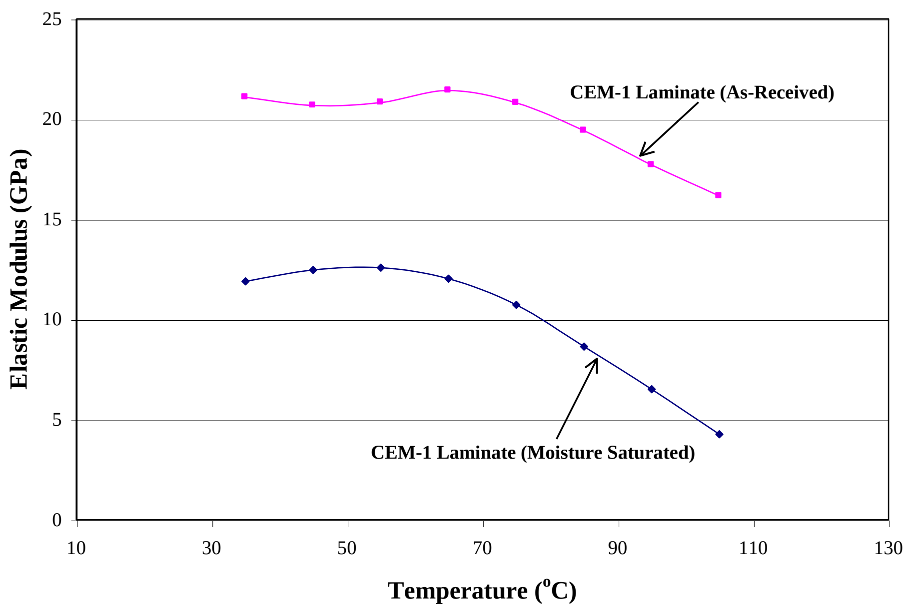

Figure 6: Elastic modulus of CEM-1 substrate material, as-received and after saturation with moisture, as a function of temperature.

Glass Transition Temperature/Coefficient of Thermal Expansion

The results of T_g measurements are shown in Table 2. The coefficients of thermal expansion of CEM-1 material, both in-plane (XY) and out-of-plane (Z), are displayed in Table 3. A sharp change in the CTE can also be used to identify the T_g. The results of determining the T_g using a change in CTE is compared to the T_g measured by the DSC (Table 2).

Sample No.	T_g (Determined by DSC)	T_g (Determined by CTE)
1	88°C	95°C
2	92°C	95°C
3	91°C	---
4	91°C	---
Average	**91°C**	**95°C**

Table 2: Glass transition temperature (T_g) of CEM-1 substrate material

Sample	CTE (30 to 60 °C)	CTE, T > T_g (100 to 200 °C)
In-Plane (1)	25.9 ppm/ °C	11.2 ppm/ °C
In-Plane (2)	26.5 ppm/ °C	13.1 ppm/ °C
In-Plane (3)	25.6 ppm/ °C	14.4 ppm/ °C
Average In-Plane (XY)	**26.0 ppm/ °C**	**12.9 ppm/ °C**
Out-of-Plane (1)	105.7 ppm/ °C	274.7 ppm/ °C
Out-of-Plane (2)	91.0 ppm/ °C	261.3 ppm/ °C
Average Out-of-Plane (Z)	**98.3 ppm/ °C**	**268.0 ppm/ °C**

Table 3: Coefficients of thermal expansion (CTE) of CEM-1 substrate material

Moisture Absorption

Table 4 displays dimensional changes and swelling coefficient after moisture saturation. Swelling (%), swelling coefficient and moisture content (%) were calculated using the following expressions:

- Swelling (%) = [(Soaked Length - Dry Length) / Dry Length] x 100 (1)
- Moisture Content (%) = [(Soaked Weight - Dry Weight) / Dry Weight] x 100 (2)
- Swelling Coefficient = Swelling % / Moisture Content % (3)

	Swelling			Moisture Content	Swelling Coefficient	
Sample No.	Length (X)	Width (Y)	Thickness (Z)		In-Plane (XY)	Out-of-Plane (Z)
1	0.2 %	0.2 %	4.0 %	3.8 %	0.05	1.05
2	0.3 %	0.6 %	4.7 %	4.0 %	0.11	1.18
3	0.2 %	0.2 %	3.9 %	3.8 %	0.05	1.03
4	0.3 %	0.4 %	4.1 %	3.8 %	0.08	1.08
Average	0.3 %	0.4 %	4.2 %	3.9 %	0.09	1.08

Table 4: Average dimensional change and swelling coefficient of CEM-1 substrate material after moisture saturation.

Discussion

In certain non-critical applications, CEM-1 substrate material can be utilized as a low-cost substitute of FR-4 boards. However, the designer must be aware of the limits of CEM-1 performance, such as an increase in the CTE above the T_g and a marked drop in stiffness at temperatures slightly below the T_g. CEM strength also decreases with increasing thickness (with FR-4, strength is constant). Moisture can act as a plasticizer, reducing the elastic modulus of a CEM-1 board that has been exposed to a humid environment.

In addition, expansion due to increases in the ambient temperature (CTE) or due to moisture sorption (swelling) must be well quantified. This will allow for proper estimation of stresses that will arise due to environmental conditions. Modeling based upon accurate material properties allows for the design of electronic systems that provide acceptable levels of reliability and performance.

5. References

1. ASTM Standard D 709, “Standard Specification for Laminated Thermosetting Materials,” (1992)
2. R. Darveauz, L. Norton, and F. Carney, “Temperature Dependent Mechanical Behavior of Plastic Packaging Materials,” Proceedings of the 45th Electronic Components & Technology Conference, 1995, pp. 1054-58.
3. Substrate Material Testing, CALCE Internal Document, 1992.