

Characterization Of Some Commercial Thermally-Cured Potting Materials

Ilknur Baylakoglu, Craig Hillman and Micheal Pecht

CALCE Electronic Products and Systems Center

1103 Engineering Lab Building

University of Maryland

College Park, MD 20742

Abstract

This paper discusses potting materials and their properties including glass transition temperature (T_g), coefficient of thermal expansion (CTE), elastic modulus (E) and extractable ion content of potting material. Their measurement and importance to device reliability are discussed. Measurement methods are explained and compared. The characteristic of commercially available thermally cured potting materials was examined and the significance of different characteristic parameters was discussed. Understanding of the factors affecting these material properties will provide process and design engineers to obtain optimum performance from potting materials and become cognizant of the potential reliability changes that can occur from changes in the beginning of manufacturing processing. The examined potting materials were Emerson and Cuming--Stycast 2651-40 FR, Insulcast--3258LIP and Cytec--Conapoxy FR-1403.

Introduction

A potting material is a multi-component mixture of an encapsulating resin with various types of additives. Polymeric resins (such as epoxies, silicones, polyurethanes, etc.) are usually used as potting materials. Potting involves insertion the electronic component or assembly within a container, filling the container with a liquid resin, and then curing the material as an integral part of the component. Potting compounds can either be mixed and dispensed for encapsulation at the point of use or acquired as a premixed, frozen formulation. The liquid potting material is turned into a solid plastic by a chemical reaction. There are two types of systems, a two-part and a one-part. The two part systems have the resin and the hardener separate since, when they are mixed, the hardening reaction starts. In one-part system the hardener is relatively inactive when mixed with the resin and heat or UV light start the reaction.

To decrease the cost of potting process, first the potting device process requirements to be specified in a manner that potting compound equipment and method work together. If conveyor production line selected, the number of devices to be potted per minute and the space available will determine if they are potting one or multiple devices at a time. The length of the conveyor, its speed the time to travel to the end of the conveyor can be calculated. Oven type (IR or convection) can be selected depending on gel time¹ of the potting compound. In batch process hand pouring the potting compound or machine meter-mix-dispensing can be used.

Potting is used to protect circuit boards and components from moisture, high / low temperatures and physical or

electrical stress. Potting is also provides heat dissipation, flame retardance and cushioning from shock. If potting does not exist, the electronic components may fail due to vibration, electrical faults, heat or other environmental conditions, which exist in electronic applications. Proper application of potting material provides even distribution of heat to eliminate extreme thermal conditions in and around the power handling components. Potting also provides additional electrical insulation between the components and from point to point on the printed circuit board, and also protects against arcing or electrical breakdown, and also can tolerate vibrations. Printed circuit boards that have components that generates high amounts of heat present problems when they are potted. For example high-density power converter may fail because of capacitor cracking through costly losses. The power converter is once under application stress, temperature cycling in use can cause cracking of the chip capacitor due to thermal coefficient of expansion difference between the component and circuit board material. So use of hard-set thermally conductive potting compounds wound up these issues

Because of a low viscosity requirement for room temperature application, potting compounds contain relatively low filler loading level and have high coefficient of thermal expansion. The requisite properties of potting compounds include low viscosity and long pot-life (working life)²; exothermic and fast cure at low temperatures, good adhesion to all package components, resistant to filler settling, high purity, good thermal and moisture stability, low thermo mechanical stress, and good electrical insulating properties [5].

In selection of potting formulation operating temperature range, materials of construction, casting volume and process limitations, substrate material, cure rate or pot life, desired rigidity or hardness, components and existing process parameters have to be considered. It is most desirable to formulate a potting compound with a CTE to match that of the material it is being bonded to. For example the low CTE components cause difficulty to encapsulate due to CTE mismatch with the potting system. In order to reduce the stresses in the potted device the CTE of the potting material must closely match the components.

The CTE of all potting compounds are higher than the parts being potted. So, designers are worried about the coefficient of thermal expansion of the potting compound and focused on CTE of potting compound in order to reduce stress on the device being embedded and to prevent cracking on thermal cycling. In the selection of potting compound, it is necessary to consider not only the CTE property but also other factors that also affect the stress such as; shrinkage, the

¹ Gel time is the time after mixing when the materials become a continuous mass. Gel point is the temperature at which the sample experiences an abrupt reduction in flow characteristics due to gelation.

² Pot-life is the period of time during which a reacting thermosetting plastic or rubber composition remains suitable for its intended purpose after mixing with reaction-initiating ingredients i.e., pourable for a liquid, trowelable for paste.

temperature at gel, operating temperature extremes of the part, flexibility of the potting compound and the T_g of the potting compound.

During the gelation, potting compounds shrink and this shrinkage put added stress on to the part. Slow hardening of the potting compound can minimize the amount of shrinkage and the stress it brings. If hardening resin system is fast, the shrinkage is higher due to the exothermic heat given off during hardening and the reaction speeds up when the temperature is raised further increases the speed of hardening and cause more shrinkage. Lowering the hardening temperature to minimize exotherm³ and slow the reaction reduce the shrinkage to allow orderly flow in to shrinking areas. And also reducing the mass of the potting compound will develop less exotherm and will cause less shrinkage. Long gel time potting compounds, which have more filler, reduce the fast hardening and give less shrinkage. To reduce the stress, it is preferred to gel the potting material at the lowest temperature. In addition, the flexibility of the potting compound reduces the stress on the components.

At glass transition temperature (T_g) the potting compound becomes more brittle and harder. Lower glass transition temperature means less stress since the potting compound is not get hard at the wide range of application temperatures so it can remain flexible and deform rather than putting pressure on the part. Lower T_g materials such as polyurethane urethane and silicone provide safer unbroken solder bonds.

Several important failure modes of electronic devices and assemblies are the result of electro-chemical reactions. These reactions are driven by an externally applied or naturally occurring electro-motive force, which causes corrosion. Every electro-chemical reaction requires a complete circuit path to operate. The circuit paths involved in most failure producing electro-chemical reactions include metallic components and moisture, which bridges between these metals. Since the metals exhibit very low values of resistance as compared with the moisture, the resistivity of this moisture becomes the rate-controlling variable. The conductivity of water is a strong function of its ionic content. The presence of even minute quantities of water-soluble compounds can drastically reduce the resistivity of moisture films, which form on the surface of a material. If this material serves as an insulator between two conductors of an electro-chemical circuit, the result is a significant increase in the reaction rate. This is the reason why thorough cleaning of electronic components and assemblies is essential to their long-term reliability. Not all residues produce the same drop in resistivity. The most damaging are ionic compounds, which are highly soluble in water (such as halides). Presence of such contaminants can even lead to the attraction and accumulation of water beyond the levels, which would be expected. The most benign residues are hydrophobic in nature, and contain no mobile ions.

Corrosion is a time-dependent wearout failure process; the rate of corrosion depends on the component materials, the availability of an electrolyte, the concentration of ionic contaminants, the geometry of the metallic elements, and the

³ High exotherm epoxies release large amounts of heat when they begin to harden.

local electric field. Common forms of corrosion are uniform chemical, galvanic, and pitting [7]. Generally, all three types are accelerated by elevated temperatures [5]. The presence of halides, such as chloride and bromide, at high levels in electronic packaging materials has been shown to have an accelerating effect on the occurrence of electrochemical migration (ECM). This effect has been seen at various packaging levels. Studies have shown that the time-to-failure in plastic encapsulated materials can be directly related to the chloride content in the epoxy-molding compound (EMC) [7]. Very little chloride is required to cause considerable damage to the chip. In anodic corrosion the metal acting as the anode undergoes oxidation and produces metal ions. Anodic corrosion of aluminum metallization is frequently observed in chloride contamination. Unfortunately, chloride ions are common among the chemicals used in processing electronic components; chloride ions are a by-product of the epoxide resin chemistry of encapsulation compounds, and can be carried as a trace impurity [7]. For circuit card assemblies (CCAs) the most prevalent metal is copper. Corrosion in CCAs can produce failures at multiple sites. Copper, which is used in most PWB designs, is extremely susceptible to corrosion from chlorides and sulfides. In addition, copper oxidizes relatively quickly. Surface corrosion can increase surface film resistance and produce by-products that accelerate wear. Another corrosion failure risk in PWBs is the reduction of insulation resistance between adjacent conductors. Insulation resistance is lost by the formation of conductive bridges, and corrosion plays a significant role in this area. Failure under this condition is may be attributed to dendrite growth or conductive filament formation [11].

Some of the very crucial information is often missing in the manufacturer data sheets. For example: The datasheet of Emerson and Cuming--Stycast 2651-40 FR gives the value of 56ppm/°C for CTE, but T_g , modulus and extractable ion content values have not been given. However, Insulcast--3258LIP's data sheet gives CTE value as 3.5ppm/°C, and ionic chloride as less than 50ppm, but, neither modulus nor T_g have been given. The datasheet of Cytec--Conapoxy FR-1403 does not have any CTE, T_g , E or extractable ion content values. This research effort aimed to develop a comprehension of the some characteristic properties of potting materials.

The Measurement Techniques

The properties of the materials were measured by using thermal analysis instruments such as Thermal Mechanical Analyzer (TMA), Differential Scanning Calorimeter (DSC), Dynamic Mechanical Analyzer (DMA) and extractable ion content was determined by, High Performance Liquid Ion Chromatography (HPLC).

The potting materials selected for this study are:

1. **CONAPOXY FR-1403** is a two component, low exotherm, flame retardant, long pot life epoxy potting and casting system. It is recommended by the manufacturer for encapsulation of strain sensitive devices. Its system is appropriate for potting and encapsulating of electrical/electronic devices such as modules, transformers, and coils. Manufacturer is Cytec.

2. **STYCAST 2651-40 FR** is a general purpose, dielectric grade epoxy encapsulant, designed for the general purpose potting of most electrical devices especially those that require flame retardancy. Manufacturer is Emerson and Cuming.
3. **INSULCAST 3258LIP** is an epoxy potting and encapsulating compound displaying good electrical properties, high hardness and adhesion. Manufacturer is Insulcast.

A. Differential Scanning Calorimeter, DSC

DSC was used to determine the T_g using the measurement of heat flow depending with change in temperature.

DSC measures the amount of energy (heat) absorbed or released by a sample as it is heated, cooled, or held at a constant temperature. The polymer has a higher specific heat above the T_g because at the glassy stage the chemical chains are more mobile and have more effective degrees of freedom. At high temperatures the barriers to rotation about chemical bonds are low enough for the chains to be constantly changing their conformations, and they can easily respond to an applied stress to change the shape of the polymer. For the DSC test potting compounds were prepared by grinding. The sample was heated and holded 2 minutes at 100 °C to evaporate the absorbed moisture and then cooled to room temperature. The grounded and weighed sample was put into an aluminum DSC sample pan and then, heated in the DSC cell at 40 °C/min heating rate from room temperature to 140 °C.

In the DSC, it is assumed that the reversing heat flow is due to changes in the “sensible heat”⁴ and that all kinetic events are reflected in the non-reversing⁵ heat flow. Thus, the reversing heat flow is expected to show an endothermic step change at the glass transition, and the non-reversing heat flow should give a peak whose area would then be the enthalpy relaxation [2]. The T_g is observed as an endothermic stepwise change in the DSC heat flow or heat capacity as in the Figure 1.

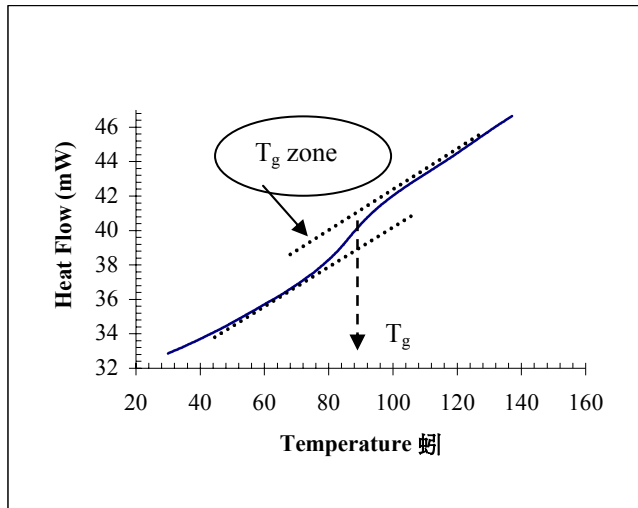


Figure 1. Sample DSC Test data for Stycast 2651-40 FR

B. Thermal Mechanical Analyzer, TMA

TMA is used to measure the dimension change of materials as a function of temperature. TMA measures the dimensional properties (expansion, penetration, coefficients of thermal expansion (CTE)) of materials while heating or cooling or under isothermal conditions is used for the determination of CTE. The TMA CTE measurement procedure consists of heating or cooling the sample on an expansion-calibrated platform and measuring the dimensional change of the sample with an instrumented probe. TMA is particularly useful for the electronics industry, as it helps to ensure that individual components with nearly identical coefficients of thermal expansion can be produced. Since there is a shift to a higher CTE above the T_g due to changes in molecular free volume, the method can also be used to measure the glass transition temperature.

The rectangular samples of each type of potting material were placed in the TMA instrument and were cooled from 150 °C to -10 °C at a cooling rate of 10 °C/min. The slope of the curve is the material's coefficient of thermal expansion (CTE), which increases substantially at temperatures above the T_g . One common method to define the location of the T_g is to use the temperature corresponding to the intersection of the two tangents – as illustrated by the curves in Figure 2.

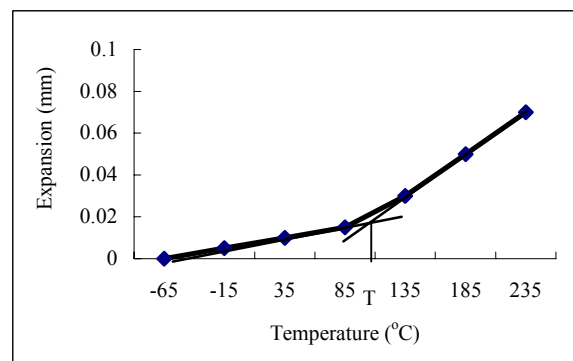


Figure 2. T_g assignment based on change in the CTE of a potting compound

⁴ Sensible heat is defined as the heat energy stored in a substance as a result of an increase in its temperature.

⁵ Reversing heat flow is due to heat capacity, whereas non-reversing heat flow is due to kinetic events such as melting, crystallization, chemical reactions and loss of volatile materials. A "non-reversing" heat flow is a function of temperature and time.

As a polymer approaches the glass transition temperature, the flexural modulus drops, the coefficient of thermal expansion increases, the ionic/molecular mobility increases, and the adhesion strength decreases. An improperly cured compound generally has a high coefficient of thermal expansion, poor adhesion strength, and a lower glass transition temperature because of the reduced cross-link density of the potting compound.

C. Dynamic Mechanical Analyzer, DMA

DMA was used to obtain the elastic modulus of the molding material at room temperature (25°C). Dynamic mechanical analysis can be used to analyze both elastic and viscous material response simultaneously. In this type of test, a motor is used to apply a sinusoidal strain to a material (either tension, bending, or shear) and the resulting stress is measured with a force-measuring transducer. The force is then electronically separated into two components, an elastic stress and a viscous stress. The elastic stress of the material is the component of the measured stress that is in phase with the applied strain, and the viscous stress is the component of the stress that is in phase with the strain rate, or 90° out of phase with the strain. Thus, both the strain amplitude and strain rate dependence of E can be measured, gaining information on both the elastic and viscous properties of materials. Elastic modulus is actually more of an indicator of the rigidity of a material than the strength. It is the basis for simple linear engineering calculations, for example, in determining the stiffness of a plastic part.

The elastic modulus of the potting materials was obtained at 25°C by using 3-point bend tests on the DMA at different strain percentages and different initial loads. The selection of the test method was based on the relative stiffness of the test specimens compared to that of the test load frame. The optimum experimental setup was found to be 0.02% strain and 50% initial load for the materials to be tested.

D. High Performance Liquid Chromatograph (HPLC)

HPLC was used to measure the ion concentration of extraction solution of potting materials.

Chromatographic processes can be defined as separation techniques involving mass-transfer between stationary (common name for the column packing material in any type of chromatography) and mobile (liquid media that continuously flows through the column and carries the analytes). HPLC utilizes a liquid mobile phase to separate the components of a mixture. These components (or analytes) are first dissolved in a solvent, and then forced to flow through a chromatographic column under a high pressure. In the column, the mixture is resolved into its components. Figure 3 shows the sample chromatogram for the Dionex600, IonPac AS4A-SC Column with 1.8mM Na₂CO₃ /1.7 mM NaHCO₃, which was used in these experiments.

Extractable ion content was determined based upon test guidelines defined in MIL-STD-883, Method 5011. The first step was to ensure cleanliness of the experimental setup. Extraction flasks were prepared by pouring 20 ml of nitric acid and an equal amount of deionized water and agitating the solution. After agitation, the solution was allowed to stand for

15 minutes before the flasks were rinsed ten times with deionized water. The flasks were then fitted with condensers and refluxed for approximately 24 hours. The boiled water was discarded and the flasks were filled with fresh deionized water. The water was boiled for a few hours or until 2/3 of the water evaporates. Flasks were then allowed to air dry upside down.

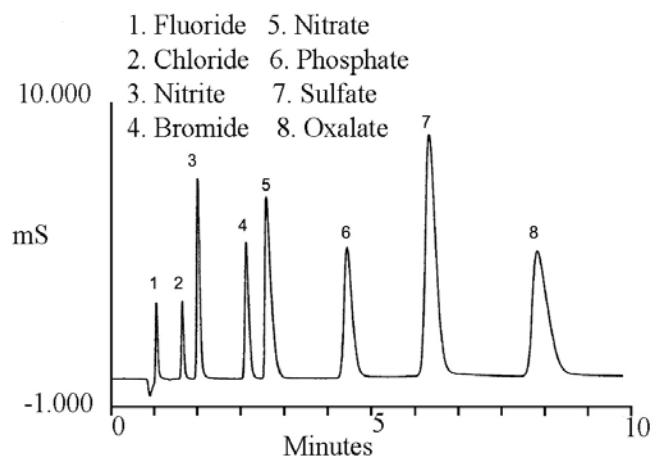


Figure 3. Sample chromatogram for HPLC IC IonPac AS4A-SC Analytical Column with eluent: 1.8 mM Na₂CO₃ /1.7 mM NaHCO₃

Before extraction, samples are required in powder form. For powder samples, three 1±0.01 g⁶ samples were prepared from each potting compound by grinding. The ground samples were added to 250 ml extraction flasks subjected to the cleaning process described above. The weight of the cured sample in each flask was recorded to the nearest milligram. 50.00±0.01 g of deionized water with a resistance of at least 18 megaohms was added to each flask. The prepared flask was refluxed for 20.0±0.5 hours at 100°C. An extraction temperature at least 20°C higher than the maximum applications temperature is needed to assure good reliability [10]. After allowing the solution to cool to room temperature, the extracts were analyzed by taking 0.1 ml of the extract solution and injecting it into the ion chromatograph injector port. The chromatograph was calibrated with 0.5 ppm, 1 ppm and 1.5 ppm Cl standard solution.

Results and Discussion

Results from DSC measuring T_g are shown in Table 1.

Table 1: Glass transition measurement results from DSC

Potting Material	T _g DSC (°C)
CONAPOXY FR-1403	51
STYCAST 2651-40 FR	85
INSULCAST 3258LIP	72

⁶ MIL-STD-883 recommends 3-gram samples. CALCE has found that 1-gram samples can be sufficient when grinding of samples can be difficult due to the sample's high hardness.

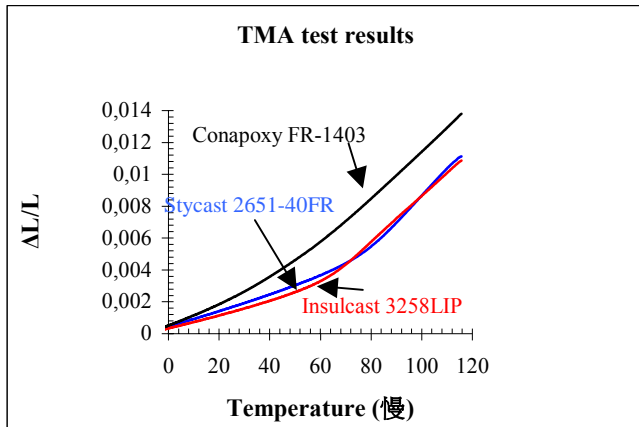


Figure 4. TMA test results of potting materials for T_g and CTE assignment

Table 2: The T_g and CTE measurement results from TMA

Material Parameter	CONAPOXY FR-1403	STYCAST 2651-40 FR	INSULCAST 3258LIP
T_g (°C)(TMA)	50	75	59
T_g (°C)(DSC)	51	85	72
CTE (PPM/°C) BELOW T_g	75	54	48
CTE (PPM/°C) ABOVE T_g	148	153	148
Elastic Modulus (GPa)	4.5	10	10
Chloride Concentration in Solid (ppm)	400-544	85-88	88-118

High filler loadings, high cross link densities, and other thermo molecular processes can mask the shift in heat capacity due to the T_g and make the transition difficult or impossible to identify with DSC[12]. Conapoxy Fr-1403 has nearly 70% filler according to its datasheet, such as, aluminum hydroxide, kaolin, carbon black and tris-chloroethyl phosphate as flame retardant and coloring agents. Due to the high filler content of the material, DSC results may not be right to use for this material. We however, find any uniform trend between the DSC and TMA results, and that gives us confidence on the TMA results.

Results from TMA measuring T_g and CTE are plotted in Figure 4 and also displayed in Table 2. All potting materials show the T_g in the range of 50-85 °C. TMA and DSC test results show that, Conapoxy FR-1403 has the lowest T_g and highest CTE below T_g . It is low viscosity, flame retardant (UL94V-O), low shrinkage, and low exotherm, with a 60-minute work life according to its manufacturer product data sheet. Conapoxy's high CTE expectation is validated because of its low viscosity.

The CTE of all potting compounds are higher than the parts being potted. Potting of boards with surface mount components on them present a special problem. Serious CTE mismatches happen when the surface mount technology (SMT) PC board is exposed to lower than room temperatures. The

CTE of potting compounds is higher than the PC board so, the potting compound shrinks more than the PCB and presses on the surface mount component. When the temperature is below the T_g of the potting compound, the potting becomes harder and produces more pressure to the component until it breaks the solder connection.

The solution to this problem is to use low T_g potting compounds or use a very low CTE material and other modifications. The most convenient solution is to use the low T_g potting compounds like urethane and silicone for low stress potting. These materials are soft and have low modulus and low strength high elongation so they do not produce much stress on the part. If the T_g is low then the stress level will stay low even as the temperature goes to lower values. Epoxy, acrylics and polyesters have high T_g and are so hard at the lower temperatures they break the solder connection. The lowest T_g epoxy today is -22°C. The type of urethane which is most effective is Poly BD which have T_g s in the -50°C range.

T_g and CTE, they both are usually quoted and accepted as single numerical values, different methods of measurement and sample preparation will provide varying data for the same material. Even within the same sample, the glass transition occurs within a range of temperatures and not as a single point. Factors such as intrachain stiffness, polar forces, and comonomer compatibility can affect the length of the glass transition region [3]. Thermal expansion coefficients are affected by polymer chain stiffness, packing, cure shrinkage and filler interactions [4].

The T_g measured by DSC is higher than the T_g measured by TMA. This difference can be explained by how DSC and TMA measure T_g and how T_g value is not a true temperature, but a temperature range where the secondary chemical bonds start to weaken.

DSC measures changes in the heat flow in a material. It can detect heat absorbed or emanated during transitions in the material structure, such as T_g . However, it primarily identifies the onset and conclusion of these transitions. The T_g is often identified as the halfway point in this transition. TMA measures the actual change in physical thickness of sample as it is heated or cooled. In many materials, there is a fairly distinct change in CTE that occurs at or around a certain temperature, and it is that change we can readily see on a graph and call T_g .

Because the two methods are measuring different properties, they will not necessarily give the same T_g 's. As a general industry practice, T_g 's measured by DSC will be higher than T_g 's measured by TMA. The difference is often estimated at approximately 5°C – 10°C [6]. Taking this into account, the T_g 's measured by TMA and DSC show a high degree of correlation.

Absorbed moisture affects the thermo mechanical properties of epoxy materials. It reduces the T_g , the modulus, and the strength, especially at high temperatures [11]. Absorbed moisture behaves as a plasticizing agent and reduces the glass transition temperature (T_g) of the potting compound [1]. The increased CTE mismatch due to reduction in T_g results in a higher stress gradient in the potted device, which in turn may lead to reduced device life. This reliability issue becomes a concern in the case of potted devices that are

exposed to temperatures above the T_g of the potting material. The lowering of the glass transition temperature by the use of moist potting compounds indicates that the final inalterable cross-linked network is different under humid conditions. Moisture absorption also affects the CTE of cured potting compounds. The CTE increase due to the absorbed moisture causes changes in the stress fields in the pot, which can lead to a reduced potting life. For hygroscopic materials intended for high stability structural applications, the CTE increase due to moisture should be systematically determined. In another study performed at CALCE, experiments have determined that T_g can drop with moisture absorption. Therefore, over a period of weeks in high humidity environments, the T_g of the potting material could drop by as much as 10°C . The moisture content of potting compounds during curing has a strong impact on the viscosity, void density, polymerization kinetics, and properties of the cured material.

Results from DMA typical plot of frequency sweep measuring of Conapoxy FR-1403, Insulcast-3258LIP and Stycast-2651-40FR at room temperature is displayed in Figure 5. When elastic modulus dependence on frequency is small, the elastic modulus is reported based on the value at 10 rad/second (Table 3). This often reasonably represents the average values over the entire frequency range. In addition, low frequencies are more sensitive to material structure such as molecular weight and molecular weight distribution. High frequencies measurements provide more accurate information on dynamic behavior such as extrusion and injection molding.

Stycast 2651-40FR and Insulcast 3258LIP have the same elastic modulus; their potting application parameters are expected very similar to each other.

Elastic modulus needs to be high enough to provide mechanical protection and low enough to absorb interfacial strains [10].

High modulus of elasticity (E) of 4 to 10 GPa provides good stress reduction for underfill encapsulants [8]. Stiffness, which is the measure of how much a material deforms when a stress applied, is better for Stycast 2651-40FR and Insulcast 3258LIP, when compared with Conapoxy Fr-1403. The content of stress-relief additives added to Conapoxy Fr-1403 seems be higher to lower the elastic modulus, so Conapoxy Fr-1403 usage in the application of vibration exposed module provides more stress released potting.

Optimum elastic modulus should be selected depending on the application requirements. For example 8.5 GPa has been selected for Chip Scale Packaging for Memory Devices to provide the solder joint reliability be consistent with high resistance to inner lead or bonding pad damages [9].

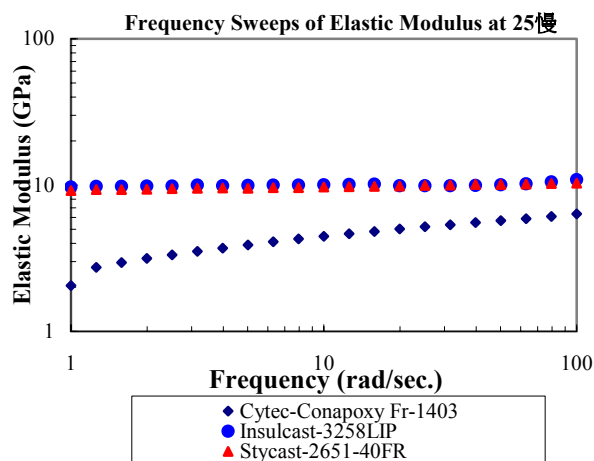


Figure 5: DMA Frequency Sweeps test output for potting material samples

Table 3. Elastic modulus values at 10-rad/sec. frequency in DMA

	Emerson Stycast 2651-40 FR	Insulcast 3258LIP	Conapoxy FR-1403
Elastic Modulus (GPa)	10	10	4.5

Chloride ions are the most significant source of corrosion, readily combining with the most common metals (copper, lead, tin) used in electronics [7].

Table 4 shows the ionic impurity requirements in the polymeric materials per MIL-STD-883.

Table 4: Ionic impurity limits in the cured polymeric material per MIL-STD-883, METHOD 5011

Ion	Maximum Concentration
Fluoride	< 50 ppm
Chloride	< 200 ppm
Sodium	< 50 ppm
Potassium	< 50 ppm

The liquid ion chromatography experiment results for the Chloride ion content of three different type of potting material are shown in the Table 5.

Table 5: Concentration of extractable chloride from potting materials

	Emerson Stycast 2651-40 FR	Insulcast 3258LIP	Cytec Conapoxy FR-1403
Chloride Concentration in Solid (ppm)	85-88	88-118	400-544

The ion concentrations in the extract of the HPLC output (Figures 6, 7 and 8) have been converted to the sample extractable concentrations (solid Cl content) by multiplying by the ratio of the deionized water weight at the end of refluxing (W) to sample weight (S); that is, by (W/S). Sample weight was 1g for all tests.

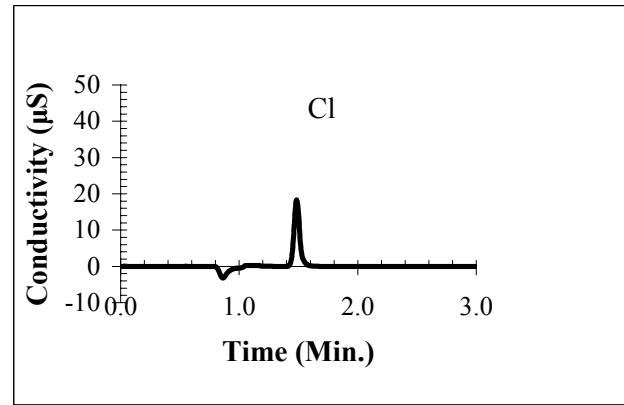


Figure 8. HPLC output for Stycast 2651-40 FR

As it is seen in Table 5, the chloride ion concentration of the Insulcast 3258LIP and Emerson Stycast 2651-40 FR are below 200 ppm limit given by MIL-STD-883, Method 5011, but Conapoxy Fr-1403's Cl content is 2.3 times higher than the limit value 200 ppm. Cl seems to be used as flame retardant agent. No bromide ions were seen in chromatograms of the Emerson Stycast 2651-40 FR, and Conapoxy Fr-1403, however, Insulcast 3258LIP chromatogram shows the evidence of bromide ion. When Insulcast3258LIP and Emerson Stycast 2651-40 FR samples are compared, it is seen that, both show the content of chloride ion, however Insulcast 3258LIP shows higher chloride ion, when compared with Insulcast chromatogram. All things being equal, the Insulcast material is inferior to the Stycast material because it shows a higher chloride concentration and evidence of bromide ions, which can also lead to electrochemical migration.

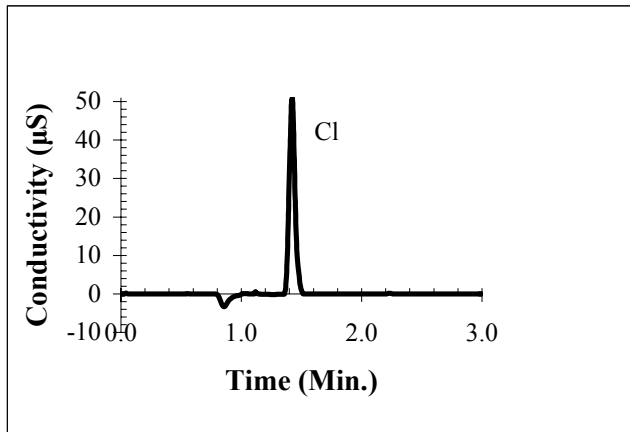


Figure 6. HPLC output for Conapoxy Fr-1403

The rate of release of extractable ions increases above the plastic material's glass transition temperature. Since the corrosive chloride ions become more mobile within a plastic operating above its T_g , this has the practical implication that epoxy-potted devices will be at greater risk for corrosion failures in applications, which require them to operate near or above their T_g [10].

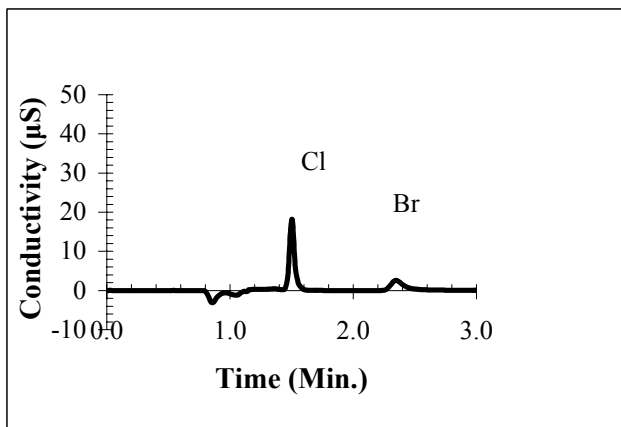


Figure 7. HPLC output for Insulcast 3258LIP

The ingress of moisture and contaminants can cause electrolytic corrosion and electrochemical migration. The rate of these chemical mechanisms is a function of the bias voltage, presence of moisture, temperature, and conductivity of the penetrating electrolyte. Probably the most prevalent and potent ionic contaminant associated with corrosion is chloride. Therefore, precautions need to be taken to minimize or eliminate sources of chloride and other halides.

In the plastic encapsulant material (PEM) industry, measures to avoid corrosion-related failures include selection of molding materials with less than 10 ppm hydrolyzable ionic contamination, formulation of flame retardants with additives to offset bromine content, and reduction of ionic impurities in the encapsulant by use of ion scavengers or ion catchers during the formulation of the encapsulant.

Summary

Because of the investigated characteristics are very similar to each other, the reliability performance of Stycast 2651-40 FR and Insulcast3258LIP are expected nearly same to each other, but Conapoxy Fr-1403 shows the evidence of

extremely high level of CI and almost 1.5 times high CTE values than Stycast 2651-40 FR and Insulcast3258LIP. Because of the low ionic residue content of the Stycast 2651-40 FR and Insulcast3258LIP, their electrical properties are better, and preferred in the high voltage applications, TV transformers, and connectors.

Acknowledgments

The research for this article was performed at the CALCE Electronic Product and Systems Center of the University of Maryland. The center provides a knowledge and resource base to support the development of competitive electronic components, products, and systems. The Center is supported by more than a hundred electronic product and systems companies from all sectors, including telecommunications, computer, avionics, automotive, and semiconductor manufacturers.

The authors would like to thank Manny Arceo (ASCO) for providing materials.

References

- [1] Zheng, Q. and Morgan, R.J., "Synergistic Thermal-Moisture Damage Mechanisms of Epoxies and their Carbon Fiber Composites", *Journal of Composite Materials*, vol. 27, no. 15, 1993, pp. 1465-1478.
- [2] McKenna G. B., "Glass Formation and Glassy Behavior", *Comprehensive Polymer Science*, Booth, C. and Price, C., Eds, Oxford: Pergamon, 1989.
- [3] Roller, Mark B., "The Glass Transition: What's the Point?" *J. Coating Technology*, vol. 54, no. 691, 1982, pp. 33-40.
- [4] Fahmy, A. A. and Raga, A. N., "Thermal-Expansion Behavior of Two-Phase Solids", *J. Appl. Phys.*, vol. 41, 1970, pp. 5108-5111.
- [5] Pecht, M., Nguyen, L.T., and Hakim, E.B., *Plastic-Encapsulated Microelectronics*, New York: John Wiley & Sons, 1995.
- [6] Konarski, M.M., "Effects of Tg and CTE on Semiconductor Encapsulants", Loctite Corporation, Technical Paper. (http://www.loctite.com/electronics_html/Effects_of_Tg_and_CTE_in_Semiconductor_Encapsulants.pdf, March 2001)
- [7] Pecht, J. and Pecht M. *Long-Term Non-Operating Reliability of Electronic Products*, Boca Raton, FL, CRC Press LLC, 1995.
- [8] Babiarz, Alec J., Lewis, Alan R., Ciardella, Robert L., "Automating Underfill For Non-traditional Packages, Secondary CSP underfill Stacked Die, and Underfill, Stacked Die, And No-flow underfill". *Proceedings of Fifth Annual Pan Pacific Microelectronics Symposium*, 25-27 Jan. 2000, pp. 401-406.
- [9] Akiyama Y., Ishimura A., Anjoh I. "Chip Scale Packaging for Memory Devices", *Proceedings. 48th*

Electronic Components and Technology Conference, IEEE; vol. 25, no. 1476, 25-28 May 1998, pp. 477-481.

- [10] Hagge, John K. "ROBOCOTS: A Program to Assure Robust Packaging of Commercial-Off-The-Shelf (COTS) Integrated Circuits", *Proceedings of International Journal of Microcircuits and Electronic Packaging, IPMAPS 2000*, Boston, September 2000 vol. 23, no., 4 pp. 424-434.
- [11] Osterman, M. "Reliability and Performance of Advanced PWB Assemblies" in *"High Performance Printed Circuit Boards"*, Harper, Charles A., editor, McGraw Hill, New York, NY, 1999.
- [12] Sichina, W. J., National Marketing Manager, Perkin Elmer "Characterization of Polymers by TMA", <http://www.thermalinstruments.com/PETech-28.pdf>, December 12, 2001.

Biographies



Ilknur Baylakoglu is a research associate within the CALCE Electronic Products and Systems Center at the University of Maryland. She received her B.S. and M.S. in Chemical Engineering from Middle East Technical University (METU) in Ankara, Turkey. She has worked in printed circuit board (PCB) manufacturing for ten years as senior engineer and manager. Her area of interests includes PCB failure mechanisms, and failure analysis, material characterization, encapsulating materials reliability effect in electronics.



Michael Pecht is the Director of the CALCE Electronic Products and Systems Center at the University of Maryland and a Chair Professor. Dr. Pecht has a BS in Acoustics, a MS in Electrical Engineering and a MS and PhD in Engineering Mechanics from the University of Wisconsin. He is a Professional Engineer, an IEEE Fellow and an ASME Fellow and a Westinghouse Fellow. He has written eleven books on electronics products development, and six books on the electronics industry in Southeast Asia. He served as chief editor of the IEEE Transactions on Reliability for eight years and on the advisory board of IEEE Spectrum. He is currently the chief editor for Microelectronics Reliability International. He serves on the board of advisors for various companies and provides expertise in design, test and reliability assessment of electronics products and systems.

Craig Hillman is a research faculty within the CALCE Electronic Products and Systems Center at the University of Maryland. Dr. Hillman received a B.S. in Metallurgical Engineering and Materials Science and a B.S. in Engineering and Public Policy from Carnegie Mellon University in Pittsburgh, PA. He then received his Ph.D. in Materials at the

University of California-Santa Barbara investigating the effect of architecture and stresses on the strength and reliability of layered materials. Dr. Hillman completed a research fellowship at Cambridge University in Cambridge, England before accepting his current position at CALCE EPSC. He has written a number of papers on reliability and failure analysis of electronic components and printed circuit boards. His area of interests include solder failure mechanisms, the effect of plating variability on strength of solder interconnects, corrosion mechanisms of contacts and connectors, and diode failures at high voltages.