

High Temperature Resistance Conductive Film for RF Grounding Applications

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Abstract

In the defense industry, there is an increasing demand for high temperature resistance materials to address many applications. Historically, conductive film adhesives, thermal grease and solder have been widely used for RF grounding assembly applications. Each technology offers unique features; however conductive films have grown preferentially due to their ability to deliver consistent and void-free bondlines, lower temperature processing, excellent electrical conduction and highly reliable RF ground plane performance – all characteristics that other technologies do not possess. Even the performance of conventional conductive film interfaces requires improvement to mitigate such potential problems as loss of adhesion strength during higher temperature exposure. Because of these requirements in the marketplace, development of a compliant, thermally resistant conductive material that addresses new high temperature requirements and allows Radio Frequency (RF) Transmit/Receive (T/R) modules to operate at high frequency was initiated. This paper examines the latest generation of conductive film and will describe a newly developed high temperature resistance conductive film that offers improved adhesion at elevated temperatures, as compared to conventional conductive films. The results reveal the newly developed high temperature film has effective grounding capability, suitable processing conditions and excellent adhesion performance at high temperatures. The paper will also compare and contrast the cure kinetics, and modulus of the novel high temperature film with traditional conductive film.

Key words: high temperature resistance, conductive film and RF grounding

1. Introduction

Electrically conductive interfaces have been used for RF grounding assembly applications in recent years due to their performance and processing advantages. Multiple technologies are found in the current market, including solder, thermal grease and conductive adhesives. Compared to other traditional technologies, conductive film adhesives offer unique features and benefits. Their high electrical conductivity enables superior grounding function, similar to solder, and superior to thermal grease. In addition, the well controlled interface thickness and high viscosity characteristic offers more predictable and consistent processing during assembly and, therefore, enables uniform and void free bondlines even over a very large attachment area. These materials ensure better RF performance with minimized losses and distortion of high frequency digital signals and maintain low impedance to the ground plane. Compared to solder reflow, conductive

film adhesives have a much lower curing temperature, which makes them suitable for attachment of temperature sensitive components and dramatically reduces thermal stress that results from high temperature processes. Additionally, the strong adhesion of conductive adhesive film materials on different substrates with reasonable flexibility allows reliable bonding over long periods of time between many materials combinations with CTE mismatches. These materials may include metals, ceramics and polymers. Electrically conductive adhesive materials can be die cut into performs according to customer specifications, which confers the benefits of precision, convenience and waste minimization.

With the pace of advanced technology development and the emergence of new performance requirements for the defense and other industries, the trend toward using smaller and more complex assembled electronic devices, increased multilayer integration and higher frequency operation is the

norm rather than the exception. All of these devices require reliable bonding; not only at room temperature, but also at elevated temperatures. Most of the applications also require that the conductive interface maintain stable bonding even under harsh environmental aging. However, standard conductive film adhesives may not have adequate adhesion for high temperature applications. For many industries and applications there is an increasing demand for high temperature resistance materials – a demand which has driven materials specialists to develop new materials to meet these thermal requirements and allow electrical devices to operate at high frequency.

This paper discusses the development of higher temperature capability conductive films for improved mechanical stability. The films' ability to maintain robust adhesion at elevated temperatures will be compared to the adhesion performance of a market-leading conductive film. Room temperature and high temperature lap shear are closely examined under four reliability conditions, including: thermal cycling, high temperature aging, 85°C/85%RH, and solder reflow exposure. The paper also compares and contrasts the curing kinetics and modulus of the novel high temperature film with a market leading conductive film.

2. Experimental

2.1 Materials

Two adhesive interface materials were evaluated in parallel to assess their bonding strength (lap shear) at room temperature and at elevated temperature (100 and 200°C). Both materials are known to provide consistent conductivity in all directions (isotropic) of the bond line. Material A is an industry leading film adhesive certified to MIL – STD 883G, Method 5011. Material B is a newly developed high temperature resistance, isotropic conductive film adhesive. Table 1 highlights general properties of material A and B as stated on the technical data sheets.

2.2 Curing kinetics

Curing kinetics of two conductive film adhesives (materials A and B) were characterized by isothermal Differential Scanning Calorimetry (DSC) using a TA Modulated DSC (Model 2920). To avoid mass loss, a hermetically sealed pan was used and the sample weight was measured before and after the experiment. The percentage of cure versus curing time was analyzed using TA software.

Table 1 General material information

	Material	
	A	B
Chemistry	Epoxy	Epoxy
Filler	Silver	Silver
Volume Resistivity	$< 2 \times 10^{-4}$ Ohm-cm	$< 5 \times 10^{-4}$ Ohm-cm
Cure Schedule	125°C, 120 mins	125°C, 60 min
Thickness	0.1 mm	0.1 mm

2.3 Dynamic mechanical properties

Dynamic mechanical analysis (DMA) is a useful evaluation of viscoelastic properties of polymer. DMA scans were carried out in a temperature range from room temperature to 250°C at a heating rate of 3°C/min at 1Hz with a constant strain of 10µm. A tensile film clamping geometry was used with a film sample size of 16.5mm X 6.5mm X 0.1mm. Both conductive film materials A and B cured according to the cure schedule listed in Table 1. The data for storage modulus, loss modulus, and loss tangent were obtained through DMA analysis.

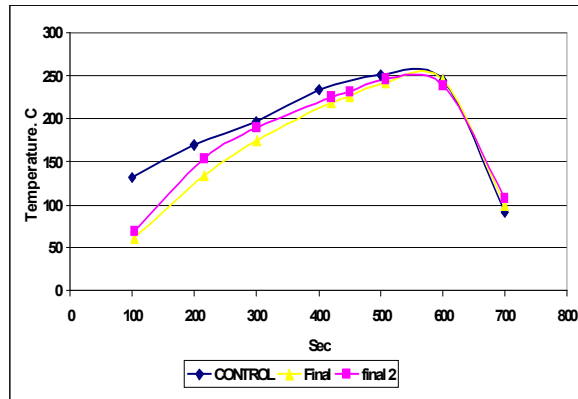
2.4 Adhesion evaluation (Lap shear)

The lap shear adhesion strength of the two isotropic conductive film adhesives were evaluated in parallel after curing each adhesive film between two aluminum panels (101.6mm X 25.4mm X 1.62mm) with a 25.4mm X 25.4mm overlay area. Two clamps were applied on each side of the bonding areas (~15 psi on bonding area of 1"x1") during curing. The cure schedule is as described in Table 1. The tensile lap shear adhesion strength evaluation was conducted at room temperature and elevated temperatures (100°C and 200°C).

2.5 Reliability testing

Adhesion strength (lap shear) was also examined after harsh environment aging, both at room temperature and the elevated temperature (100°C and 200 °C). The sample preparation is the same as described in section 2.4. After curing, the parts were put into different environmental chambers, which include: 1) thermal cycling (-40 to 150°C) 250 cycles 2) high temperature aging (200°C) for 250 hours 3) 85°C/85%RH moisture soak for 500hrs, and 4) 10 passes of solder reflow exposure as illustrated by the reflow profiles shown in Figure 1.

Figure 1 Standard 260°C Reflow Profile for Surface Mount Assembly

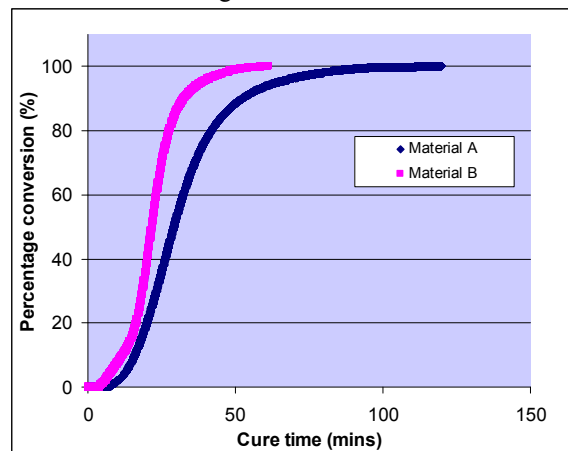


3. Results and discussion

3.1 Curing kinetic analysis

Isothermal DSC was performed on samples of Material A and Material B as described in section 2.2. The percent conversion as measured by DSC is shown in Figure 2. Full conversion of the film is achieved once exothermic behavior of the cure reaction is complete. Film B reached full conversion within 1 hour at a 125 °C isothermal. In contrast, Film A required approximately twice as long (~120 minutes) to reach full conversion.

Figure 2 Percentage conversion of Material A and Material B vs. curing time at 125°C isothermal



3.2 Dynamic mechanical analysis

Storage and Loss modulus were measured as a function of temperature using DMA. Material A was shown to experience a significant decrease in both storage and loss modulus at approximately 100°C (Figure 3 and 4). The temperature at which this transition occurs is near the glass transition (T_g)

of Material A (approximately 90°C). Storage and Loss modulus measurements of Material B show a much flatter response to increasing temperature. This reflects a higher T_g of the resin chains which should correlate to improved temperature resistance performance.

Figure 3 Overlay curves of storage modulus vs. temperature of conductive Material A and Material B

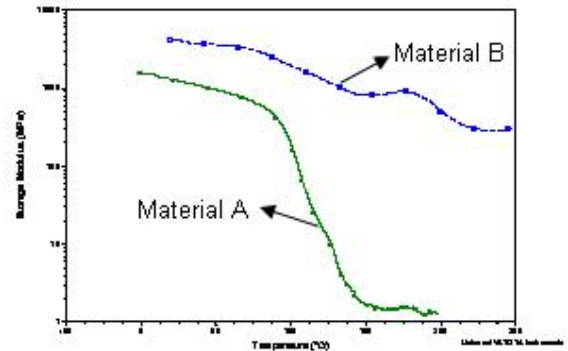


Figure 4 Overlay curves of loss modulus vs. temperature of conductive Material A and Material B

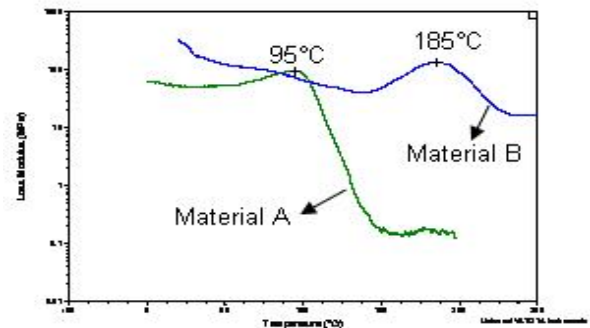
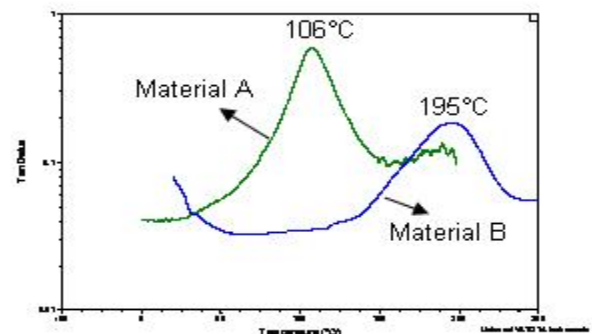


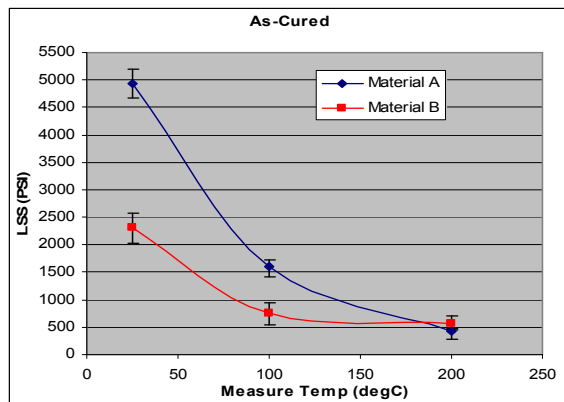
Figure 5 Overlay curves of $\tan \delta$ vs. temperature of conductive Material A and Material B



3.3 Adhesion

Temperature-dependant adhesion strength for both films was measured. Both films were characterized for their ability to maintain adhesion strength as measurement temperature is increased. Figure 6 shows the temperature dependant adhesion strength of Material A and Material B after cure. Multiple samples were pulled at each temperature (25 °C, 100 °C, and 200 °C) in order to understand the relationship between performance and bond line temperature. At room temperature, the “As-Cured” samples of Material A show average adhesion strength more than two times greater than the adhesion strength of Material B measured at 25 °C. As the samples were heated above 25 °C to a steady state bond line temperature of 100 °C, the adhesion strength was measured to be, on average, 1600 psi for Material A and 750 psi Material B, respectively. Again, Figure 6 illustrates that the adhesion strength of Film A at 100 °C is 67% less than the room temperature measurements. Material B also shows similar behavior with a 68% lower adhesion strength measured at 100 °C compared to room temperature data. Adhesion strength measured at 200 °C demonstrates the characteristic behavior of Material A compared to Material B.

Figure 6 Overlay curves of “As-Cured” tensile adhesion strength vs. temperature of conductive Material A and Material B



Adhesion strength was measured for Material A to be less than 500 psi at 200°C, constituting a 90% reduction in adhesion strength from room temperature. Similar examination of adhesion properties for Material B shows strength measured at 200°C greater than 500 psi with reduction from room temperature adhesion strength of 75%. The temperature performance characteristics of Material A suggests that, with increasing temperature, the adhesion strength of Material A will continue to decrease above 200 °C whereas the

adhesion strength of Material B is shown to be more stable at highly elevated temperatures.

3.4 Adhesion after reliability testing

Accelerated life testing plays a critical role in the selection of adhesive products for various applications. These tests were conducted to characterize the behavior of the two films under conditions common for applications in the defense and aerospace markets. Lap shear panels were assembled with samples from each film, cured and placed in various environmental chambers. The adhesion strength was measured as a function of temperature to determine the ability of the material to maintain grounding under extreme temperatures after exposure to environmental aging conditions. Fifteen panels from each film were placed into each of the four exposure conditions 1) Thermal cycling, 2) high temperature aging (200°C) for 250 hours, 3) 85°C/85%RH 4) 10 pass of solder reflow exposure. After completion of each environmental exposure condition, the samples were left out in a lab environment for one day prior to adhesion testing.

3.4.1 Thermal Cycling

As different materials are assembled for microelectronic applications, stress as a result of Coefficient of Thermal Expansion (CTE) mismatch is known to build up at the interfaces. To determine the resistance of materials to both high and low temperatures, as well as the material's ability to withstand cyclic stresses, thermal cycling has long been used by industry to test the reliability of assembled parts. A variety of industry standards, such as Mil-Std 883 (Method 1010) for military and space applications, and JEDEC (JESD22-A104) for commercial electronics define various conditions for thermal cycling tests. Both standards recommend that a minimum of 10 cycles are required for acceptance with 1000 cycles required for qualification. For this study, lap shear adhesion samples assembled using Material A and Material B were exposed to 250 thermal cycles, with temperature range from -40°C to 150 °C. A rate of 6.3 °C/min was set for the transition with a 15 minute dwell at each extreme.

Lap shear adhesion strength for Material A before and after exposure to air to air thermal cycling is shown in Figure 7. The results show negligible difference in behavior after exposure to air to air thermal cycling indicating the film performance is very robust.

Figure 7 Overlay curves of adhesion strength for Material A after cure and thermal cycling

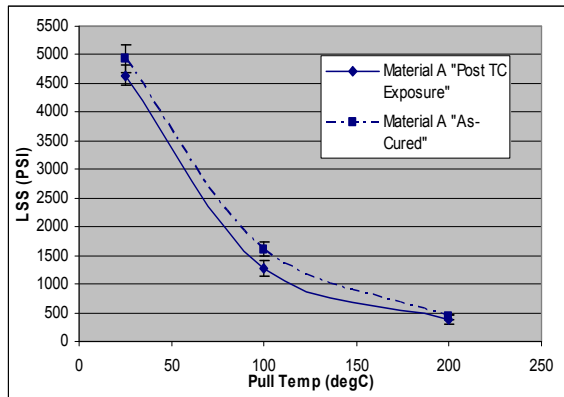
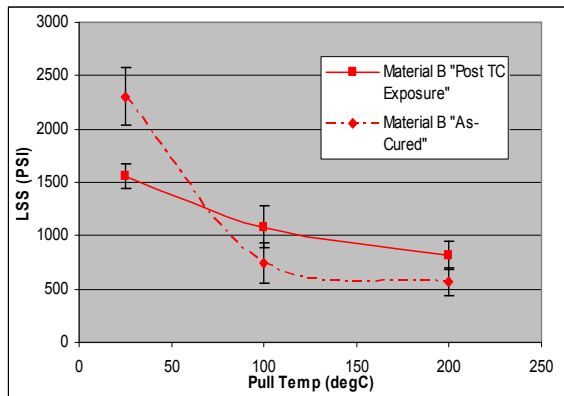


Figure 8 Overlay curves of adhesion strength for Material B after cure and thermal cycling



In contrast, the behavior of Material B after exposure to thermal cycling is shown to differ from samples tested after cure (Figure 8). At room temperature, the thermal cycling exposed samples demonstrated a 30% reduction in adhesion strength. At 100 °C, the post exposure adhesion strength of Material B was measured to be 30% lower than post exposure room temperature measurements but demonstrated a higher level of adhesion strength compared to “As-Cured” samples measured at 100 °C. This trend was also shown to continue at 200 °C with samples exposed to thermal cycling, demonstrating improved adhesion strength as compared to the “As-Cured” samples.

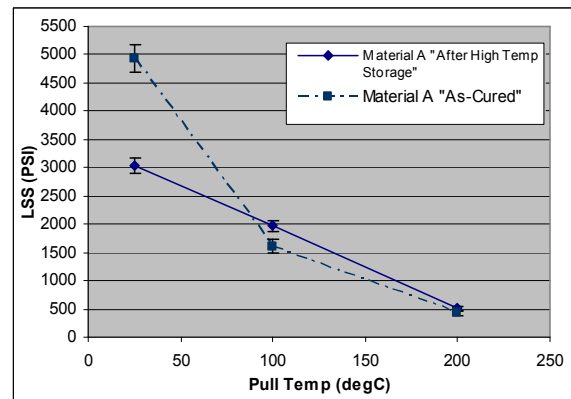
3.4.2 High Temperature Aging

During microelectronic operation, active components dissipate heat as a by-product, resulting in elevated temperature on assemblies. Power devices for millimeter and microwave applications utilize components with operating temperatures commonly above 80 °C. Characterization of adhesive

materials used in assembly of microelectronics must therefore be tested after subjection to high temperature storage. Accelerated aging at higher temperatures can be used to determine the effect of storage at these conditions has on the material, in the absence of applied electrical stresses. Again, industry standards such as Mil-Std 883 (Method 1008) define the test method to be used for High Temperature Storage (HTS). Lap shear panels assembled using Material A and Material B were cured and subjected to a continuous elevated temperature of 200 °C for 250 hours. Under these conditions, the effect of elevated temperature on the material's adhesion strength can be directly measured.

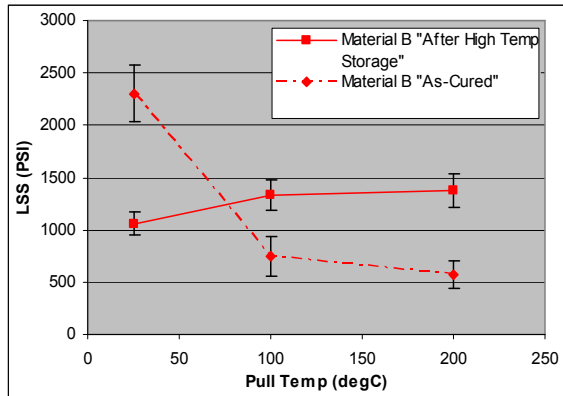
The adhesion strength of Material A after exposure to high temperature storage is shown in Figure 9. At room temperature, the adhesion strength is shown to be 40% lower than that of As-Cured samples. As the measurement temperature is increased, the adhesion strength trend of Material A is further shown to behave similarly for both as-cured and after exposure conditions and as expected for this type of material. Adhesion is maintained at the harshest conditions tested for both conditions.

Figure 9 Overlay curves of adhesion strength for Material A after 200 °C continuous storage



Adhesion strength measurements of Material B after exposure show vastly different behavior, as compared to measurements of “As-Cured” samples (Figure 10). Room temperature measurements show the adhesion strength of samples exposed to HTS to be 30% lower. At elevated temperatures, samples of Material B stored at 200 °C do not show lower adhesion strength as temperature increases from room temperature. Again, the temperature-dependant adhesion strength results indicate that Film B is capable of maintaining adhesion strength after exposure to high temperature aging.

Figure 10 Overlay curves of adhesion strength for Material B after 200 °C continuous storage

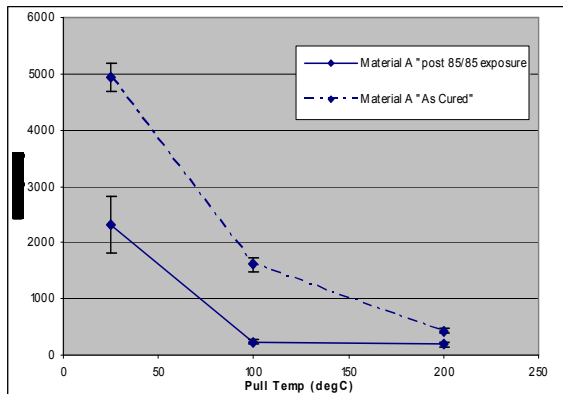


3.4.3 Moisture Soak

When considering adhesive material selection, it is common to use aggressive environmental exposures to characterize mechanical and electrical behavior. Materials are subjected to prolonged exposure to moisture at elevated temperatures to provide a stressed environment to test the robustness of the materials. The adhesion strength performance as a function of temperature of each material was measured after Moisture Sensitivity Level (MSL or moisture soak) exposure.

Figure 11 shows the effect of prolonged exposure to moisture at elevated temperature on Material A. At room temperature, Material A was shown to lose only 50% of its adhesion strength due to exposure to moisture soak.

Figure 11 Overlay curves of “As-Cured” and 85 °C/85% RH – 500hr exposure for conductive Material A

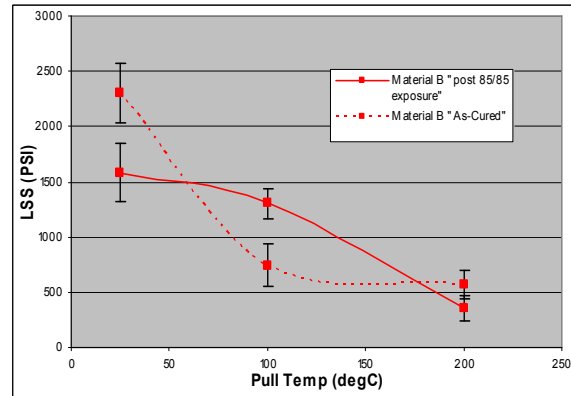


Further results from lap shear adhesion testing at elevated temperatures details the performance of Film A after moisture exposure. Samples of Material A tested at 100 °C and 200 °C yield less adhesion strength than the As-cured

Material A results. The behavior of Material A after exposure to moisture soak shows a similar trend to that of the “As-Cured” samples with continued reduction in adhesion strength for all measurement temperatures

Lap shear adhesion strength results for Material B after exposure to moisture soak are shown in Figure 12. Post moisture soak exposure was shown to be 30% less at room temperature compared to “As-Cured” room temperature adhesion strength for Material B. At a lap shear test temperature of 100 °C, the adhesion strength of Material B was shown to be less than 20% from room temperature samples exposed to high humidity and elevated temperature, and 40% from “As-Cured” samples measured at room temperature.

Figure 12 Overlay curves of “As-Cured” and 85 °C/85% RH – 500hr exposure for conductive Material B



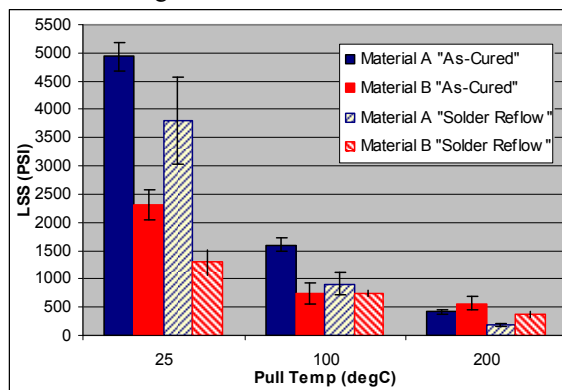
Comparison of the lap shear adhesion results after exposure to humidity at elevated temperatures show similar results for the behavior of Material A and B after moisture exposures. Both Material A and Material B were shown to maintain adhesion after prolonged exposure to a harsh moisture environment. Temperature-dependant adhesion results show Material B to be more resistive to moisture exposure at elevated temperatures than Material A.

3.4.4 Solder Reflow Exposure

Electronics manufacturers routinely subject assemblies to solder reflow to attach components and rework failed devices. With increasing concern over the content of lead in electronic devices, higher temperature lead-free (Pb-free) profiles, such as that shown in figure 1, are common. It is therefore important to characterize the ability of a conductive interface material to withstand exposure to board mounting solder processes. Test conditions can be found in many industry standards such as JEDEC (JESD22-A113 or J-STD-020) and typically require exposure to three reflow cycles.

Measurements of the temperature-dependant behavior of Material A and Material B show similar adhesion strength performance. Exposure to ten Pb-free solder reflow cycles yielded consistent adhesion strength measurement characteristics at all measurement temperatures. Lap shear measurements of "As-Cured" samples of Material A show consistently higher adhesion strength at each measurement temperature than for samples exposed to multiple reflows (Figure 13). As expected, this result is consistent with the performance of Material B, which shows the exposure of the material to solder reflow cycles lowers the adhesion strength for all temperatures measured.

Figure 13 Comparison of As-Cured and Post Reflow adhesion strength for Material A and Material B



Both materials (A and B) were shown provide measurable adhesion strength even after exposure to ten Pb-free reflow cycles. This results highlights the ability of conductive epoxy films to provide robust performance even after exposure to more reflow cycles than is typical in electronics assembly

4. Conclusions

This paper presented performance characteristics of a newly developed high temperature-resistant conductive film (Material B) that offers superior adhesion at elevated temperatures. The curing kinetic study showed that Material B has better processing conditions which offer a lower curing temperature and shorter curing time than standard conductive film (Material A). The lap shear results indicate that Material B provides improved adhesion strength performance at elevated temperatures, even after exposure to harsh environmental conditions. Exposure to thermal cycling was shown to have little effect on the temperature-dependant adhesive strength of Material A. However, Material B was shown to be more resistant to higher temperatures. Additionally,

Material B was shown to provide improved high temperature performance over Material A after exposure to continuous storage at 200 °C. The behavior of both materials (A and B) was compared after exposure to moisture sensitivity level conditions. Again, Material B demonstrated improved performance over Material A at elevated temperatures after exposure. Adhesion strength of both materials was maintained after exposure to multiple Pb-free reflow cycles with Material B yielding slightly higher strength at 200 °C. Increased adhesion strength with increased measurement temperature suggested that further analysis of Material B is necessary. Further testing is necessary to understand the cure requirements of Material B as they relate to high temperature adhesion performance. Follow up studies characterizing temperature-dependant adhesion strength as a function of incremental Pb-free solder reflow exposure should be conducted. In depth analysis of the electrical reliability for both films is necessary and will be included in subsequent studies. These results suggest that Material B is an effective alternative for temperature resistance applications in many industries.