Effects of Environmental Exposure on the Performance of Electrically Conductive Film Adhesives for RF Grounding Applications*

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Abstract

As more power is driven through active devices, the integrity of materials used to make the electrically conductive interfaces are becoming ever more critical to the performance of RF radar systems. A variety of technologies including thermal grease, solder and adhesive materials have been used to achieve this interface. In many applications, the use of conductive film adhesives are employed to take advantage of key benefits of the materials such as consistent and uniform bondline control, high electrical conductivity, and lower processing temperatures. This paper will compare the performance of an electrically conductive film adhesive widely used over the last twenty years in the electronics industry with that of a newly developed film designed to provide greater resistance to environmental exposure.

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

1. Introduction

The development of RF devices with significantly improved RF output powers has led to increased requirements on the performance of materials used in assembly. Maintaining a consistent and reliable RF grounding path is critical for these current and future assemblies. Historically, electrically conductive interfaces have been used for RF grounding assembly applications due to their performance and processing advantages. Multiple technologies including solder, thermal grease and conductive film adhesives are found in the current market. Compared to other traditional technologies, conductive film adhesives offer unique features and benefits. Their highly electrical conductivity enables superior grounding function, similar to solder, and superior to thermal grease. In addition, the well controlled interface thickness and B-stageable characteristic offer 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 electrically conductive interfaces to provide reliable bonding; not only at room temperature, but also at elevated temperatures. Most of the applications also require that the conductive interface maintain stable

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bonding even under harsh environmental aging. However, traditional conductive film adhesives lose adhesion when exposed to higher temperatures, which makes them less than ideal for many high temperature applications. For many industries and applications, however, there is an increasing demand for high temperature resistance materials – a demand which has driven materials specialists to develop high temperature-resistant conductive interface materials to meet these new thermal requirements and allow electrical devices to operate at high frequency.

This paper examines the performance of two electrically conductive film adhesives used for grounding applications. The ability of the films to maintain adhesion strength at temperature over a wide range of simulated operating temperatures will be compared, both before and after exposure to various accelerated environmental conditions. Various cure schedules were tested to determine the optimized cure schedule. Room temperature and high temperature lap shear are performed to measure the adhesion strength of the two electrically conductive film adhesives after cure and after both exposure to high temperature aging and 85 ºC/85%RH moisture soak. The paper also examines the electrical performance of the films after exposure to 100 hours in moisture soak.

2. Experimental

2.1 Materials

Two electrically conductive adhesive interface materials were evaluated in parallel to assess their bonding strength (lap shear) at a range of temperatures (25 – 200 ºC). Both materials are considered to be isotropic (i.e. to provide consistent conductivity in all directions) of the bond line. Material A is a long-standing industry-leading military standard 883 – 5011 approved isotropic conductive epoxy film product. Material B is a recently developed isotropic film adhesive designed to provide improved resistance to environmental exposure. Properties presented in the technical data sheets of both materials are found in Table 1.

	Material A	**Material B**
Chemistry	Epoxy	Epoxy
Filler	Silver	Silver
Volume resistivity	< 2 x 10^{-4} ohm-cm	< 5 x 10^{-4} ohm-cm
Cure	30 min @ 150C	60 min @ 150C
Thickness	0.1 mm	0.1mm

Table 1: Typical material properties of Material A and Material B

2.2 Curing kinetics and optimization

Isothermal Differential Scanning Calorimetry (DSC) was used to characterize the time to cure material A and material B at various temperatures. Measurement with a TA Modulated DSC (Model 2920) suggested that both material A and material B were capable of curing at a similar temperature. 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 conversion versus curing time was analyzed using TA software. Additionally, to optimize the curing condition of material B, the adhesion strength was evaluated for a range of cure temperature and time combinations.

2.3 Lap shear adhesion strength evaluation

Chromate etched Aluminum panels (101.6mm X 25.4mm X 1.62mm) were used as bonding surfaces to fabricate lap shear panels for each film to measure the adhesion strength of the two conductive film adhesives. Samples of film measuring 12.7mm X 25.4mm were cured between two Aluminum panels to create a ½" area overlay. Clamps were applied to each sample during cure in order to provide a constant pressure of ~15 psi during cure. The cure schedule is as described in Table 2. The tensile lap shear adhesion strength evaluation was conducted at room temperature and elevated temperatures (75 ºC – 200 ºC).

Cure Condition	
Material A	Material B
2 hr @ 125 ºC	1 hr @ 125 ºC
	2 hr @ 125 ºC
	4 hr @ 125 ºC
	0.5hr@ 150 ºC
	1 hr @ 150 ºC
	2 hr @ 150 ºC

Table 2: Cure conditions examined for Material A and Material B

2.4 Environmental Exposure

Adhesion strength (lap shear) was also examined after harsh environment aging, both at room temperature and at the elevated temperature (from 75 ºC to 200 ºC). Lap shear samples were prepared per the description in section 2.3. After curing material A with the recommended cure schedule and Material B with the optimized cure schedule, sets of parts for each film were put into different environmental chambers, including: 1) 85°C/85%RH for 500hrs, and 2) continuous high temperature aging at 200°Cfor 250 hours.

2.5 Electrical Performance

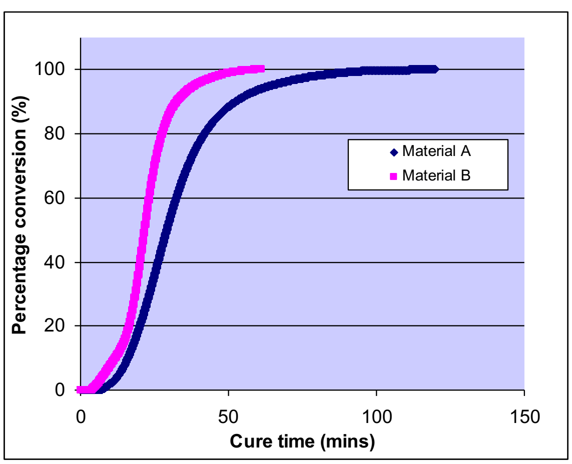
A chemically resistant Electroless Nickel Immersion Gold (ENIG) layer measuring 4 microns was deposited on the surface of an aluminum lap shear panel. The resulting type II surface finish met the chemically resistant, oxide free, high electrically conductive surface required by Mil-G-45204 for military applications [2]. The conductive film adhesives were used to bond two 12.7mm X 25.4mm X 1.62mm coupons together. Cured samples were placed into a moisture rich environment at elevated temperature (85 ºC/85%RH) for 100 hours. Bond Joint Resistance (BJR) was measured under direct current (DC) through the coupon/film/coupon joint before and after exposure.

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 ºC isothermal. In contrast, Film A required approximately twice as long (~120 minutes) to reach full conversion.

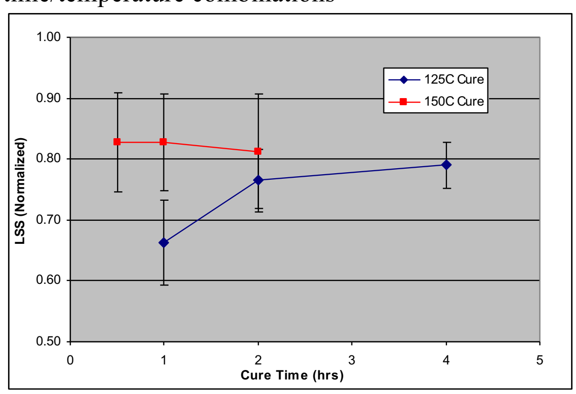
Figure 2 Percentage conversion of Material A and Material B vs. curing time at 125°C isothermal



3.2 Cure Optimization

Previous studies of material B [3] showed that although the cure schedule of 1 hr at 125 ºC was sufficient to produce relatively good adhesion strength and resistance to environmental exposure, optimization of the cure schedule may not be complete. Lap shear panels assembled using material B and cured to a variety of time/temperature combinations were measured for adhesion performance. The room temperature adhesion strength results are shown in figure 3 on a normalized scale. Cure time at 125 ºC was shown to be a significant factor as the adhesion strength of Material B continued to improve with additional time. Samples cured at 125 ºC for 4 hours showed 20% improvement in the room temperature adhesion strength. Cure time at 150 ºC was shown not to be as significant a factor. The room temperature adhesion strength of samples of material B cured at 150 ºC was not significantly impacted by cure time. Less than a 2% difference was observed in LSS for samples cured at 150 ºC for 0.5 to 2 hours. Samples cured at 150 ºC showed a relative improvement in adhesion strength of ~10% over samples cured at 125 ºC. Based on these results an optimized cure schedule of 1 hr at 150 ºC was selected for Matierial B.

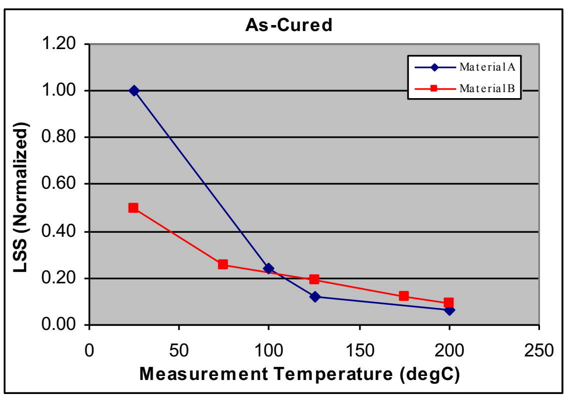
Figure 3. Material B adhesion strength for various cure time/temperature combinations



3.3 Adhesion

Temperature-dependant adhesion strength for both films was measured for optimized cure conditions. Both films were characterized for their ability to maintain adhesion strength at increased measurement temperatures. Figure 3 shows the temperature-dependant adhesion strength of Material A and Material B after cure. Multiple samples were pulled at each temperature from room temperature to 200 ºC to characterize the relationship between adhesion strength and pull temperature. Under the cure conditions selected, Material A was shown to have ~50% better adhesion strength at room temperature than Material B. As the measurement temperature was increased above 100 ºC, the adhesion strength of material A was shown to drop by ~ 80% for as-cured samples. At measurement temperatures above 100 ºC the adhesion strength of material A was shown to change by ~10% more from adhesion strength measured at 100 ºC. As the measurement temperature was increased from room to 100 ºC, the adhesion strength of Material B was shown to decrease by ~50% of the room temperature value. Further increase in the measurement temperature from 100 ºC to 200 ºC yielded a further decrease in adhesion strength of ~10%. This is comparable to previous results using a lower temperature cure condition for material B. A comparison of the temperature dependant adhesion strength performance of Material A and B shows that both have lower adhesion strength, as expected, at elevated temperatures. Material B showed a lower overall % change in adhesion strength over the range of temperatures tested and a higher absolute value at 200 ºC.

Figure 3: Overlay curves of “As-Cured” tensile adhesion strength vs. temperature of adhesive film Material A and Material B

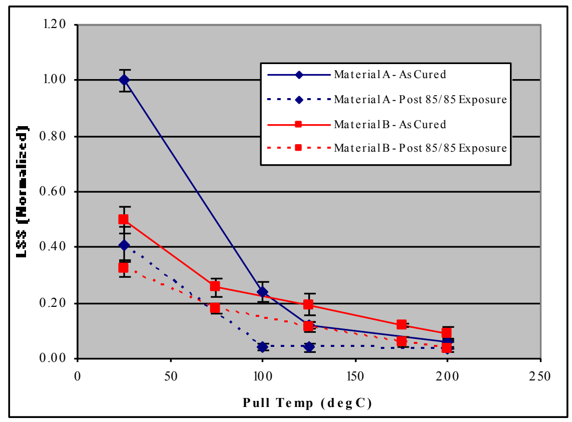


3.4 Exposure to Accelerated Environmental Conditions

3.4.1 Moisture Soak

Temperature-dependent adhesion strength was measured for Material A and Mateiral B after exposure to 500 hours in 85 ºC/85% RH environment. Figure 4 shows room temperature measurements show that after exposure to a moisture rich environment, the adhesion strength of material A was ~60% lower than for the adhesion strength of as-cured samples. As the temperature was increased, post exposure material A samples showed a continued reduction in adhesion strength, reaching minimum levels at 100 ºC. Material B showed a similar, although less dramatic, reduction in adhesion strength at room temperature after exposure to moisture soak. As temperature was increased, however, Material B was shown to have improved adhesion strength performance after moisture soak. At measurement temperatures above 100 ºC, Material B was shown to maintain about 60% of its adhesion strength compared to as-cured Material B samples measured at the same temperatures. Samples of Material B exposed to moisture soak demonstrated similar adhesion strength performance at 125 ºC to As cured samples of material A. At 200 ºC both films were shown to have comparable performance after exposure to moisture soak.

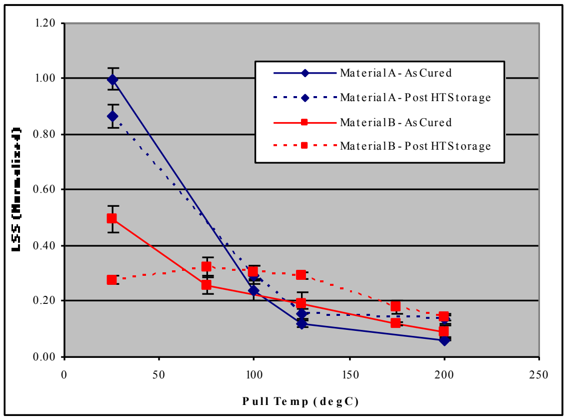
Figure 4: Overlay curves of “As-Cured” and “Post Moisture Soak” tensile adhesion strength vs. temperature of adhesive film Material A and Material B



3.4.2 High Temperature Storage

Cured samples of Material A and Material B were stored in an oven at 200 ºC for 250 hours. After a 24 hour cool down period, the samples were measured for temperature-dependant adhesion performance from room temperature to 200 ºC. Room temperature measurements of as-cured and post exposure samples of material A show minimal effect on adhesion strength (Figure 5). Continued measurements at elevated temperatures for material A show similar performance for both the “As-Cured” and “Post HT Stored” samples with less than 15% difference at any given temperature. After exposure to high temperature storage, room temperature lap shear measurements for material B show a 25% reduction in adhesion strength compared to as-cured material B. As the measurement temperature is increased, the adhesion strength of material B after exposure is shown to improve by as much as 10% at a given temperature. At 200 ºC both material A and material B were shown to have comparable adhesion strength both before and after high temperature storage. Material B’s temperature-dependent lap shear adhesion strength showed less overall change and better stability after prolonged high temperature storage. For both materials, the adhesion strength measured at 200 ºC was higher for samples stored at high temperatures than for the As-Cured samples.

Figure 5: Overlay curves of "As-Cured" and "Post HT Storage" tensile adhesion strength vs. temperature of adhesives Material A and Material B

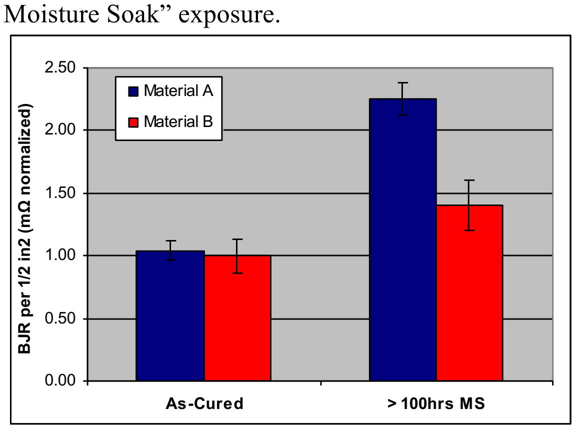


3.5 Electrical Performance

3.5.1 Bond Joint Resistance Measurements

Samples of Material A and Material B were cured between gold plated lap shear panels in order to perform electrical conductivity measurements through the bonded joint. After cure, Bond Joint Resistance (BJR) measurements made on samples of Material A and Material B are shown to be comparable (Figure 6) with less than a 4% difference. The cured samples were then exposed to 100 hrs exposure to 85 ºC/ 85%RH. Post exposure BJR measurements showed an increase in resistance for Material A of approximately 100% while Material B

Figure 6: Comparison of the BJR measurements for Material A and Material B for "As-Cured" and "Post Moisture Soak" exposure.



showed an increase of ~40%. Increased BJR measurements can be attributed to a variety of factors. In most cases it is a function of oxidation, either of the bonding surfaces (i.e. metal oxidation) or of the conductive filler and resins in the adhesive. In this test, all test coupons were plated with a gold finish, so the likelihood of the bonding surfaces oxidizing is negligible. Both Material A and Material B utilize different resin and filler technologies which, based on this test, appear to be reacting differently to moisture soak exposure.

4. Conclusions

This paper examined the behavior of two materials intended for use in RF grounding applications after exposure to a variety of accelerated environmental conditions. Optimization of the cure schedule showed that improved performance was achieved for Material B after use of increased temperature during cure. The lap shear results indicate that both materials show comparable temperature-dependent adhesion results after cure. These results show that Material B is a comparable replacement for Material A in some RF grounding applications where high levels of mechanical stability are required. Exposure to high temperature storage was shown to provide more stable temperature dependant adhesion strength for material B over the range of temperatures tested. As expected, both materials maintained relatively similar levels of temperature-dependent adhesion strength after 250 hrs. of high temperature exposure over the range of temperatures tested. Prolonged moisture soak (85ºC/85%RH) exposure was shown to have less effect on Material B than material A both with regard to mechanical and electrical performance. This suggests that for applications requiring both good resistance to high temperatures and moisture rich environments, Material B may offer better performance.

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