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An Evaluation on the Mechanical and Conductive Performance of Electrically Conductive Film Adhesives with Glass Fabric Carriers

Weiyu Zhang,* Yuan Zhao, Zhongwei Liu, and Stone Cheng

Abstract—**Conductive assembly film adhesives are extensively employed in medical, telecom, aerospace, and defense systems. Glass fabric cloth is frequently utilized as the carrier in many film adhesives to enhance handling and processability during electronic device assembly. Furthermore, practical applications have shown that film adhesives with glass fabric carriers can bond adherends with severely mismatched coefficients of thermal expansion. However, the impact of embedding glass fabric on the overall performance of assembly films has not been systematically investigated. To address this gap in knowledge, a study was conducted to compare the performance of electrically conductive film adhesives with and without the glass fabric carriers. The study focused on the mechanical performance of the film adhesives, including lap shear strength, tensile modulus, and the ability to manage applications with mismatched coefficients of thermal expansion. Additionally, the study assessed the impact of the carrier on the electrical and thermal conductivity of the film adhesives. Overall, this integrated assessment provides insights into the effectiveness of the glass fabric carrier on the performance of film adhesives.**

Keywords—**Assembly film adhesives, RF power devices, thermal management**

Introduction

Electrically conductive assembly film adhesives (ECFAs) are a type of advanced adhesive materials that have gained significant attention in recent years due to their ability to provide both high electrical/thermal conductivity and reliable mechanical bonding in various applications [1-4]. Different from conductive die attach film (CDAF), which is within micrometer thickness and used to bond die within mm^2 size to provide adhesion and conductivity, the assembly film is usually used for second level assembly. In a typical scenario, highly complex printed circuit board (with a dimension of in.^{2}) is mounted to a heat sink to effectively dissipate heat with a conductive assembly film adhesive. Unlike CDAF, of which high thermal conductivity up to 100 W/m-k can be achieved from the sintering effect of silver fillers under high-temperature curing condition such as 200°C for a certain amount of time, the complexity and sensitivity of a printed circuit board (PCB) board limit the curing condition of assembly films preferably under 150°C, where sintering effect is unlikely to happen to yield high thermal conductivity. Most of the current conductive assembly films in the market provide a thermal conductivity less than 10 W/m-k. With the rapid development of highly functional electronics, heat management becomes more vital, which leads to a demand on the development of conductive assembly films with higher thermal conductivity. In this case, glass fabric (GF), commonly used as a carrier in the mid layer of a composite film (Fig. 1) to improve processability, mechanical performance, and thermal compatibility of the film adhesive [5, 6], become a barrier of heat transfer through the films. Since both the mechanical performance and electrical/thermal conductivity of ECFAs are critical parameters that could determine their suitability for various applications in electronics and aerospace industries [7, 8], there is a need to investigate the effects of GF carriers on the overall performance of ECFAs. This information is crucial for the development and optimization of ECFAs, as well as for the end users to select products for different applications. However, there have been few discussions probing this topic so far.

In this article, a systematic evaluation was conducted to compare the performances of three ECFA products with and without the integration of a GF carrier. The article not only covers the mechanical properties such as glass transition temperatures, storage modulus, and thermal compatibility but also includes the electrical/thermal conductivity as well as bonding strength of the assembly film adhesives. The results of this study will provide valuable insights to ECFAs for both product developers and application engineers.

Three film adhesives were chosen as the test vehicles to conduct the experiments. Table I shows some of the key aspects of the composite film adhesives in this study that play a role in the mechanical and conductive performance. All of the selected products are epoxy films containing silver as the filler particles. For each product, two versions of films were prepared, one without carrier as the control with a total thickness of 4 mil, and the other integrated with a GF carrier with a total thickness of 5 mil. The carrier-integrated film adhesives were prepared by hot laminating a 1-mil epoxy-impregnated GF between two layers of 2-mil film adhesive, resulting in a 5-mil composite film adhesive. The carrier material comprises ∼20% by volume in all the GF-integrated samples. The curing condition of the samples is 150°C for 1 h with certain pressures applied.

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Henkel Corporation, One Henkel Way, Rocky Hill, CT 06067
*Corresponding author; email: weiyu.zhang@henkel.com

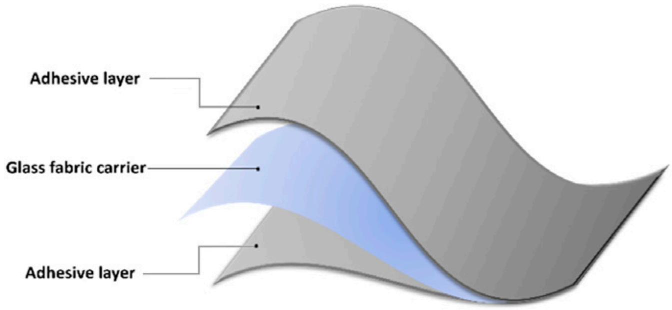

Fig. 1. Assembly film adhesive with GF.

Table I
Film Adhesive Products Chosen for the Evaluation

ID[a]	Silver loading	Hardener	Multifunctional resin	Degree of xlinking
1	Medium low	Tertiary amine based	No	Low
2	Medium	Primary amine based	No	Medium
3	Medium high	Tertiary amine based	Yes	Medium

[a]Films 1 and 2 are commercial products. Film 3 is under development.

Results and Discussion

A. Tensile Modulus

Tensile modulus E' reflects the ability of the adhesive to withstand deformation under mechanical stress, and it is closely related to the stiffness and mechanical strength of the adhesive layer [9]. Here, dynamic mechanical analysis (DMA) was conducted to measure the tensile modulus of the cured adhesives (Fig. 2) from $-50°C$ to $200°C$. Table II summarizes the tensile modulus of the materials at both $25°C$ and $150°C$, as well as the ratio of E' at $150°C$ relative to $25°C$.

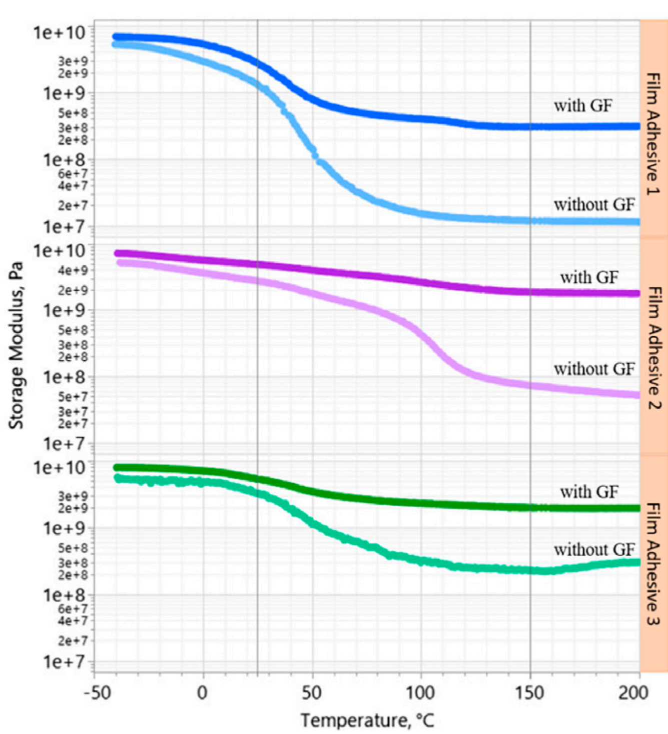

Fig. 2. Comparison of tensile modulus of three film adhesives with versus without GF carrier.

Table II
Dynamic Mechanical Analysis Summary

Film	GF	$E'_{,25°C}$ (Pa)	$E'_{,150°C}$ (Pa)	$E'_{,150°C}/E'_{,25°C}$
1	Without	1.3×10^9	1.2×10^7	0.0092
	With	2.8×10^9	3.0×10^8	0.11
2	Without	2.7×10^9	7.2×10^7	0.027
	With	4.9×10^9	1.9×10^9	0.39
3	Without	3.3×10^9	2.3×10^8	0.070
	With	5.3×10^9	2.0×10^9	0.38

The DMA results indicate that, for all three film adhesives

1. films with a GF carrier have a higher tensile modulus than the same sample but without a carrier.
2. films with a GF carrier maintain a relatively higher tensile modulus after the materials transition from the glassy state to the rubbery state.

Observation 1 can be attributed to the enhanced effect offered by the glass fibers to the composite, resulting from the higher tensile modulus of GF. This suggests that incorporating ~20% vol. of GF into the silver-filled epoxy films can significantly increase the modulus of the film adhesive. However, as the silver loading and degree of crosslinking in the film grew (from Film 1 to Film 3), the tensile modulus of the silver-filled epoxy film increased (Table II). It can be observed that the impact of GF on the modulus of the composite film decreased, e.g., from 115% for Film 1, 81% for Film 2, 61% for Film 3 in terms of the tensile modulus increase brought by GF at room temperature (RT). This reduction can be explained by the lowered proportion of GF by weight relative to the silver, a much stiffer material, leading to a dilution effect. The contribution of GF to the overall modulus became relatively smaller in films with higher silver loading and crosslinking density.

Observation 2 can be explained by the reinforcement effect brought by the GF, which is a rigid and stiff material over a broad temperature range, providing excellent reinforcement to the composite film. As the temperature increased, the silver-epoxy

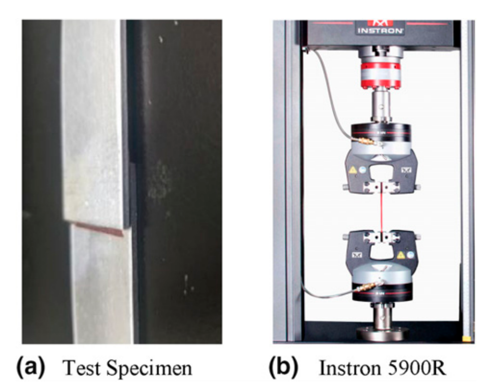

Fig. 3. Lap shear test specimen and equipment. (a) Test specimen. (b) Instron 5900R.

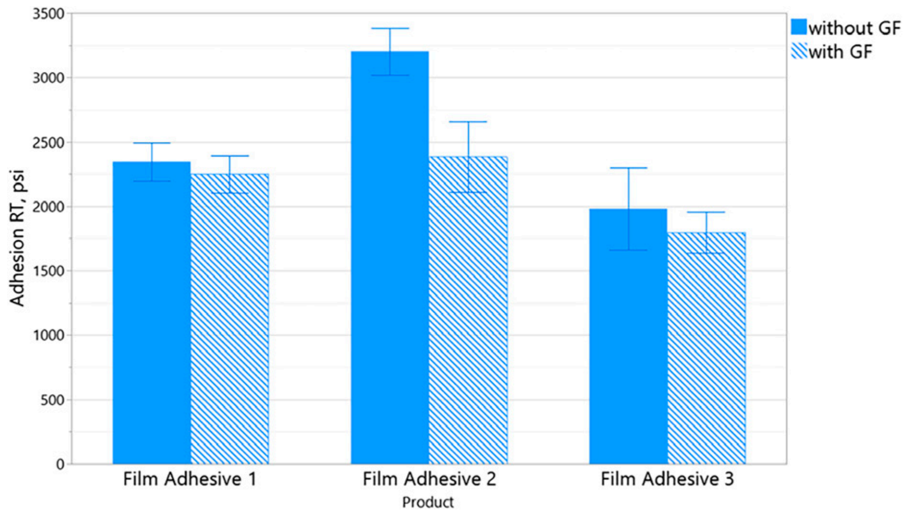

Fig. 4. Lap shear strength of film adhesives with versus without GF carrier at ambient temperature.

composite films went through a transition from a glassy state to a rubbery state, the polymer chains gain more mobility, resulting in a decrease in stiffness and modulus (Fig. 2, films without GF). This transition was leveraged by the retained stiffness of GF in GF films, which effectively decreased the drop of modulus at elevated temperature (Fig. 2, films with GF). Another factor that may contribute to this phenomenon is load transfer. The rigid GF efficiently transfers mechanical loads throughout the silver-epoxy composite, aiding in stress distribution and preventing localized deformations [10, 11]. This load transfer mechanism is particularly crucial at elevated temperatures, where the diminished stiffness of the polymer matrix is observed under mechanical stress. What was also observed was that as the silver loading increased from Film 1 to Film 3, modulus drop at higher temperature was less obvious for both films without GF and films with GF (Table II, $E'_{,150^\circ C}/E'_{,25^\circ C}$), owing to the enhanced stiffness brought by more silver in the matrix.

Based on the above observations, it can be inferred that the tensile modulus of the GF-film adhesives is influenced by the properties of both adhesive and the carrier material. It is interesting to know that if this significantly increased, tensile modulus can improve bonding strength at elevated temperatures.

B. Lap Shear Strength

Lap shear strength is one of the best indicators of the bonding strength of adhesives. Lap shear panels made of Chromate-etched aluminum panels ($101.6 \times 25.4 \times 1.62$ mm^2) were assembled to measure the film's adhesion strength. Samples of film adhesives measuring 12.7×25.4 mm^2 were cured between two aluminum panels to create a $1/2''$ long-bonding area (Fig. 3a). The film adhesives were cured at 150°C for 1 h. The lap shear strength tests were conducted with Instron 5900R (Fig. 3b) at RT. The same set of samples were prepared and tested at 150°C as the lap shear

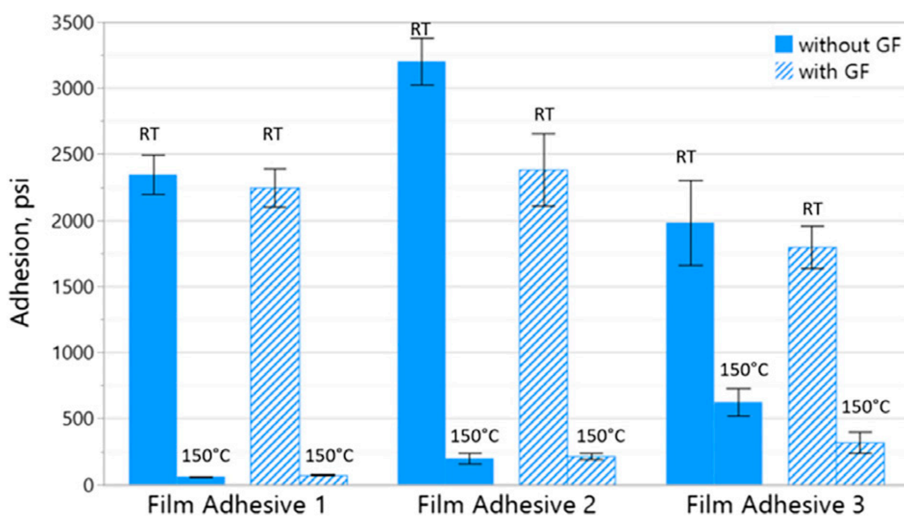

Fig. 5. Lap shear strength of film adhesives with versus without GF carrier at ambient temperature and 150°C.

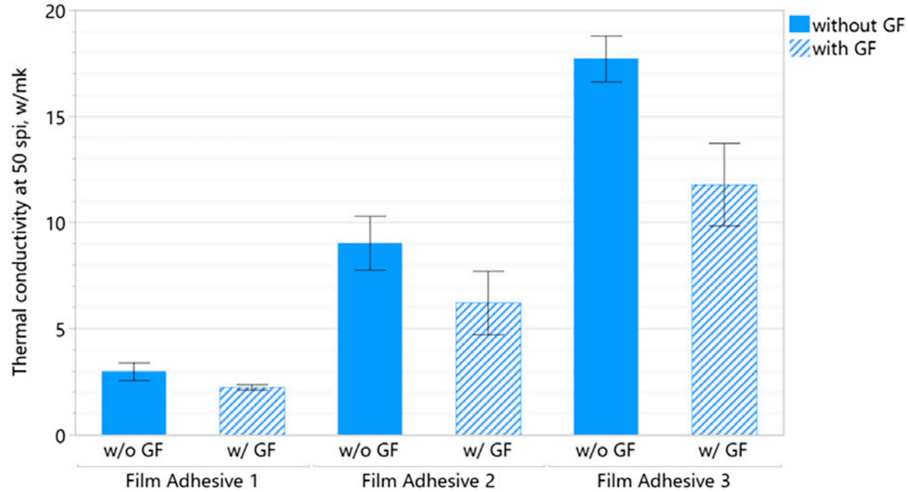

Fig. 6. Comparison of thermal conductivity of the three film adhesives with versus without a GF carrier.

strength under an elevated temperature is an indicator for high-temperature stability for structural adhesive [12].

Under RT, the results (Fig. 4) showed that the lap shear strength of the conductive film adhesive with a GF carrier was slightly lower than that of the adhesive without a carrier suggesting that the GF may cause more delaminating under mechanical stress due to the resin discontinuity between the film and woven fabric carrier caused by unfavorable wettability.

At 150°C, lap shear strength dropped significantly (Fig. 5) for both film adhesives and the carrier-inserted ones. There was also no indication that the higher tensile modulus associated with the integration of GF could enhance lap shear strength of the film adhesives at the elevated temperatures. The degree of the decrease in lap shear strength at 150°C varies for different film adhesives. Among three products, the new film adhesive (Film 3) showed least drop at 150°C. Despite a lower lap shear strength at RT compared with the other two groups, the new film adhesive exhibited highest hot strength at 150°C for both adhesives with and without a carrier, largely due to the higher degree of crosslinking.

C. *Thermal and Electrical Conductivity*

Thermal conductivity and electrical conductivity are two important properties of conductive adhesives that help to ensure the performance and reliability of electronic devices and other applications where good heat dissipation and electrical connection are needed.

In this article, the thermal performance (*Z* axis) of the film adhesives was evaluated with a laser flash analyzer from NETZSCH. Fig. 6 compares the thermal conductivity of the film adhesives with a GF carrier to the ones without.

As shown in Fig. 6, the thermal conductivity of the film adhesives with the integration of the GF carrier reduced by ~33%. The decrease in thermal conductivity was probably introduced by the insertion of a low thermally conductive material, which is the GF with a thermal conductivity around 0.3 W/m-K, as well as the contact resistance between the film and the GF. The interfacial thermal resistance between the layers can be studied by multilayer laser flash diffusivity measurements in multilayer sample assemblies that simulate the film structure [13], which will be studied in a separate report.

The electrical conductivity of the film adhesives was assessed by measuring their volume resistivity at RT and wetting conditions between layers due to resin content.

Table III summarizes the volume resistivity (ρ) and thermal conductivity (TC) of the film adhesives discussed in this article. There was an overall increase in volume resistivity. The extent of the increase varies among different products, primarily as a result of variations in filler loading and wetting conditions between layers due to resin content.

D. *Capability in Handling Coefficient of Thermal Expansion Mismatched Assemblies*

To assess the ability of the selected film adhesives to handle coefficient of thermal expansion (CTE) mismatched substrates, samples with and without GF were used to bond a copper-cladded FR4 board (CTE around 18 ppm/°C) with a size of 2 × 2 in. on an aluminum plate (CTE around 24 ppm/°C). Bondline thickness of the assembly is 5 mil for GF films and 4 mil for films without a carrier. The assembling processes were exactly the same for all tested specimens. The film adhesives were cured at 150°C for 1 h and then cooled down to

Table III
Summary of Electrical and Thermal Conductivity of the Film Adhesives With Versus Without GF Carrier

ID	GF	ρ at 25°C (Ω·cm)	TC at 25°C, 50 psi (W/m-K)	% Vol. GF
1	Without	6.3×10^{-3}	3	-
	With	1.0×10^{-2}	2	20
2	Without	2.6×10^{-4}	9	-
	With	3.2×10^{-4}	6	20
3	Without	1.3×10^{-4}	17	-
	With	1.5×10^{-4}	12	20

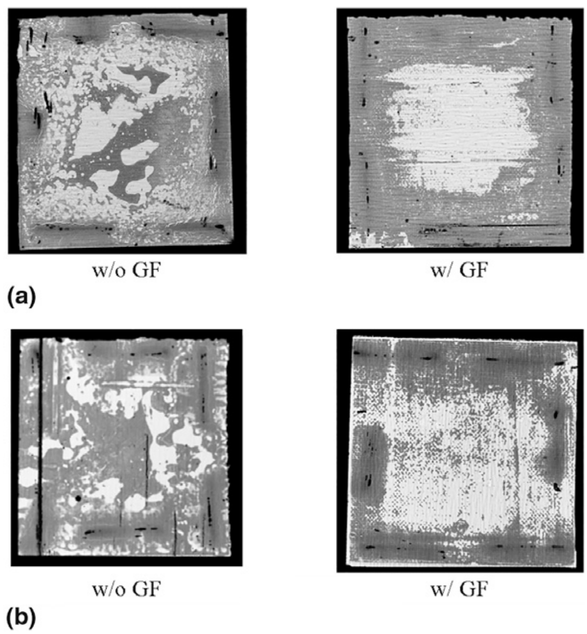

Fig. 7. CSAM images of film adhesives 1 and 2 with and without a GF carrier. (a) Film Adhesive 1. (b) Film Adhesive 2.

ambient temperature. Scanning acoustic microscopy (CSAM) was employed to inspect bondlines for voids/cracking.

Fig. 7 presents CSAM images of bondlines without and with the GF cloth. It is evident that the integration of a GF carrier significantly improved the uniformity of the bondlines and suppressed air entrapment or void formation, which indicates that the integration facilitates material handling and assembly processes. This is quite an attractive characteristic in practice.

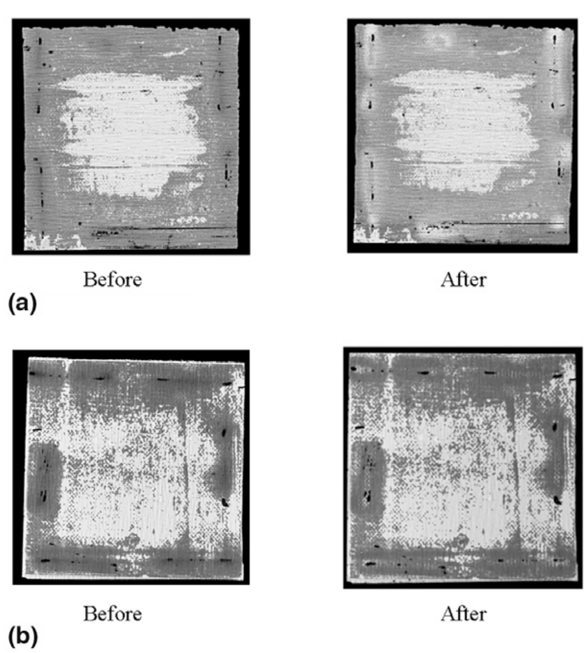

Fig. 8. CSAM images of film adhesives 1 and 2 with GF, before and after thermal shocking test. (a) Film Adhesive 1. (b) Film Adhesive 2.

In addition, more uniform bondlines with less air entrapment or void formation may enhance assembly reliability when exposed to thermal cycling conditions. To verify this, 500 cycles of thermal shocking tests between $-55°C$ and $125°C$ were conducted on the assemblies bonded by the film adhesives with the GF carriers. CSAM were performed again after the thermal cycling tests (Fig. 8). The results indicated that both films with GF carriers exhibited no significant changes after the thermal shock testing, which may indicate that the integration of GF carriers can improve reliability of the CTE-mismatched assemblies.

Conclusions

In summary, the investigation in this study evaluated the impact of GF on the performance of ECFAs. The results indicate that the integration of GF slightly decreased the lap shear strength of the adhesives at RT, and it has little impact on improving lap shear strength at an elevated temperature. Although the carrier significantly reduced the extent of the drop of the tensile modulus during the transition of the material from the glassy to rubbery state, there appeared no direct relationship between the increased tensile modulus and lap shear bonding strength at an elevated temperature. As for thermal performance, the integration of $\sim$20% vol. of GF carrier decreased the thermal conductivity by $\sim$33% for the samples studied in this article. In addition, the integration also led to a slightly lower electrical conductivity. During the CTE mismatch application study, the GF films exhibited improved handling and processability, leading to enhanced bondline uniformity and minimized issues with air entrapment or void formation. Five hundred cycles of thermal shocking tests indicated that no significant changes were observed on assemblies bonded by film adhesives with the integration of the GF carriers.

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