Stress Management Via Low Modulus Urethane Adhesives For Electronic Applications

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The mismatch of the thermal expansion coefficients of various components and substrates to be bonded has long been a cause for cracking and delamination problems. These problems are especially evident in devices/assemblies containing ceramic, glass, or other fragile materials that will fracture during the stress buildup from thermal cycling.

The electronics industry has relied primarily on silicone-based systems to resolve stress-related problems. Although silicones have demonstrated success in relieving stress, their inherently poor adhesion and release agent characteristics have created additional costly handling steps for production operations such as:

- application of a primer required to improve adhesion,
- extensive masking procedures to avoid silicone "contamination" of areas where the bonding of other adhesives or coatings is critical,
- demasking procedures, and
- solder dewet problems for subsequent process steps.

Advancements in urethane technology have led to the development of adhesives and encapsulants that approach the cleanliness and operating temperature range of silicones, yet display superiority in the following areas:

- substrate adhesion — primer not always required,
- long-term low temperature performance,
- moisture resistance in thin cross sections,
- abrasion resistance, and
- overall physical strength (tensile/elongation/tear strength).

Introduction

This article discusses how low modulus urethane adhesives have been used to resolve stress and heat management problems while displaying improved handling and processing qualities over silicones.

The demand for more sophisticated and reliable electronic devices and assemblies has presented increasingly more difficult problems for materials and design technologists as well as for manufacturing engineers. Problems relating to thermal and stress management have become major concerns as these devices/assemblies are required to perform many more electronic functions in a more confined space.

To complicate matters, these devices/assemblies are hybrid in nature and require the use of different materials that must interface with each other during operational life. The generation of heat from both internal (for example, biased condition) and external sources cause these varied materials to expand at widely different rates. The coefficients of thermal rates expansion of materials typically used in the manufacture of state-of-the-art electronic devices and assemblies are as follows:

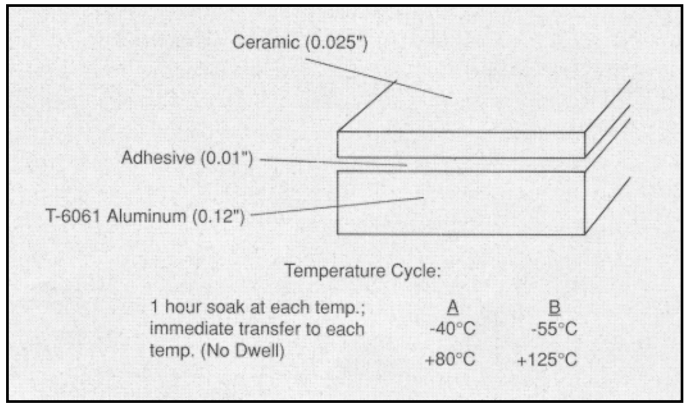


Figure 1, a qualitative way to screen for stress absorbing adhesives by bonding materials with gross mismatches in CTE.

CTE (XY) of various materials (typical values)

Material	**CTE (in/in/°C) x 10^{-6}**
epoxy laminate	18-20
Al_2O_3 ceramic	5-6
Solder	24-26
Glass	3-5
fused quartz	0.5-1
aluminum	23-25
copper	18-20 70%
epoxy adhesive (below Tg)*	25-35
70% silicone adhesive (above Tg)*	140-155
70% urethane adhesive (above Tg)*	140-155

**each is 70% filled*

At the interfacial surfaces of these materials, significant forces and stresses build up as these materials expand and contract (in effect, push and pull on each other) at grossly different rates. Obviously, something has to give, and the stresses are relieved through distortion, cracking, and fatigue. The challenge for the design engineer is to minimize or absorb the forces of stress to greatly reduce the possibility of cracking and related failures.

Design Considerations

In order to properly design a hybrid system, one must review the application and consider the following, which is not an all-inclusive list:

- Temperature excursion limits (ΔT),
- T-cycle vs. T-shock,
- operational and test conditions,
- materials/components required,
- dimensional limitations,
- atmospheric or vacuum environments,
- heat buildup and dissipation,
- areas of stress buildup and relief,
- production oriented,
- processing steps and times, and
- electrica1 1y insulating/electrically conductive.

For each application, the requirements for most of the previously stated concerns will have been specified for the design engineer at the onset of the project. When designing for stress management, the key concern is the extreme temperature limits (ΔT) that the assembly will endure during operation and/or testing. Simply stated, the ΔT is the major driving force for most of the dynamics leading to stress buildup within the assembly. Minor sources of stress may result from handling, assembly, and mechanical shock.

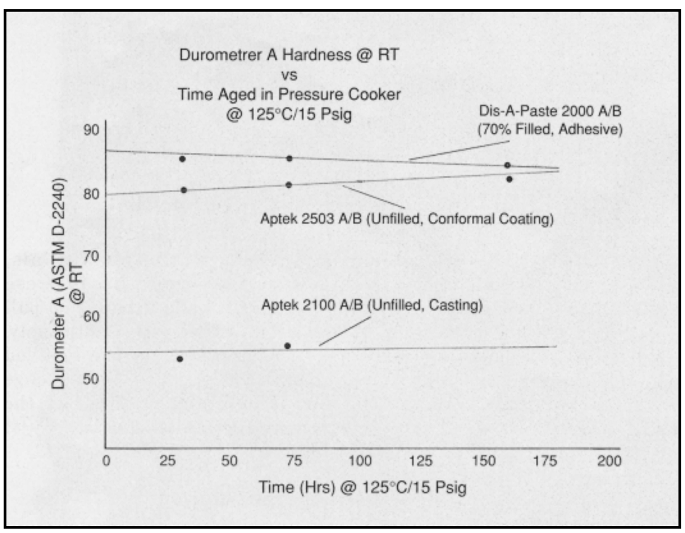
Stress Absorbers

However, there are other considerations besides thermal expansion properties that should be analyzed when resolving stress-related problems. Since it is virtually impossible to perfectly match up the CTEs of all the materials that contact each other, an alternative design strategy is to utilize a “stress absorber”.

Stress absorbers are low-modulus, high-elongation materials typically used as adhesives or encapsulants at junctions of high stress. They absorb stresses mainly by taking up the thermodynamically-caused deflection of the adjoining substrates during thermal cycling. They, in essence, “uncouple” the bonded substrates, allowing for more freedom to move without much constraint. At the same time, the adhesive/encapsulant itself must not impart stress back to the substrates or cracking/failure will result. Therefore, the modulus of elasticity, the elongation, and the bond line thickness are important considerations for selecting and using an absorber.

Raytheon, EDL, Sudbury, Mass.,[1] has developed a simple, qualitative way to screen for stress-absorbing adhesives by bonding materials with gross mismatches in CTE, as shown in figure 1. Failures are drastic and typically occur at the low temperature limit within the first one or two cycles. The results show that for a 'constant bond line thickness, ceramic substrate will crack at -55°C when the adhesive's ability to elongate is significantly reduced and the modulus of elasticity is increased such that the adhesive layer can no longer retard the deflection of the ceramic beyond failure, It was observed that when the low temperature test limit was decreased from -40° to -55°C, some adhesives that had passed then began to fail, This indicated that the modulus of the adhesive changed significantly causing excess deflection, stress, and ultimately cracking of the ceramic.

Quantitative results will be discussed later for a specific application involving multilayer glass-coated ceramic boards bonded to metal lead frames. It is also important for a stress absorber to possess a glass transition temperature (Tg) below the low temperature test limit so that no major thermal mechanical changes within the absorber will occur during temperature cycling of the device. If the stress absorber itself goes through a glass transition phase during testing/ operation, it will change drastically in its own CTE, and the ability for it to cushion the stresses will be impaired. As temperature goes down, elastic modules go up, and elongation also decreases, resulting in a less effective stress absorber.



Graph 1, the data of Durometer A hardness us. time in a pressure cooker at 125°C /15 psig for three electronic grade urethane systems.

Urethane Technology

Stress absorbers for the most part have been derived from silicone technology because of its flexibility, purity, moisture resistance, and high and low temperature capability. Initially, urethane technology was not used due to poor reversion resistance performance (under high heat and humidity environments) and to a limited operating temperature range.

However, advancements in urethane technology (especially polyether-based systems) have clearly demonstrated that reversion resistance is no longer a problem. Graph 1 displays the data of Durometer A hardness vs. time in a pressure cooker at 125° C/15 psig for three electronic grade urethane systems, which illustrates the excellent hydrolytic stability of urethanes.

Another significant advancement for urethanes has been in the expansion of the operating temperature range of

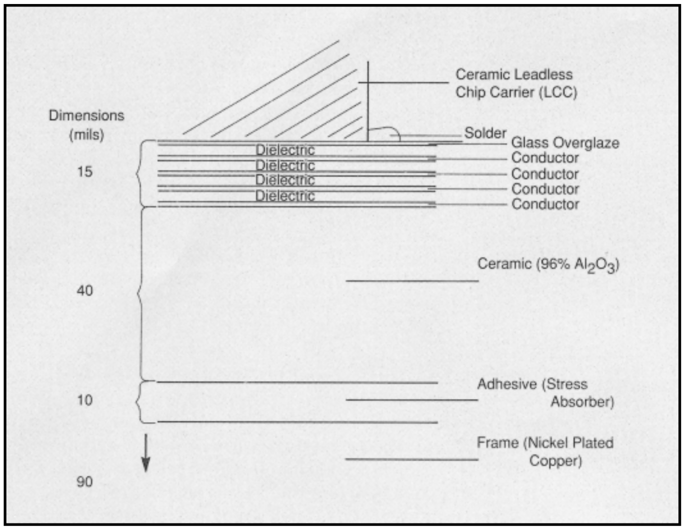


Figure 2, basic construction characteristics of an assembled ceramic multilayer minimum 10 mil bond line of adhesive is interconnect board.

-70° to +115° C, which is more than sufficient for most electrical/electronic applications.

Low temperature performance has become an increasingly important design consideration, and it is important to evaluate the effect of cold environment on components and materials. Research has shown that for some type of silicones during long-term exposure to cold temperatures (either above or below the Tg), a phenomenon called crystalline contraction can occur. During this condition, the silicone shrinks and its modulus of elasticity increases significantly over time. Raytheon **EDL** Div. test data[2] for a dimethyl silicone-based elastomer showed the following dramatic results:

Soak time @ -60°C (hrs.)	**Modulus of elasticity @ -60° C (psi)**
2	300
24	30,000
48	60,000

Urethanes, on the other hand, have demonstrated good success in remaining stable during long-term low temperature conditioning.

Application

The following is a military grade electronic application of an assembled ceramic multilayer interconnect board (MIB) bonded to a nickel-plated copper frame with a low modulus, stress-absorbing adhesive. A detailed discussion of how the empirical data was generated and how it compared favorably to computer-aided design models was published and presented this year by F.L. Liotine, Jr., Raytheon Submarine Signal Div.[3]

Figure 2 illustrates the basic construction characteristics of the assembly. Notice the similarity between this application and the adhesive screening test discussed earlier and depicted in figure 1. The only difference is that the ceramic substrate is now constrained by the multiple layer of metallic and glass depositions and the soldered-on components. These constraints will enhance the ability of the assembly to crack under the deflection caused by ΔT. In fact, the modulus of rupture of the unconstrained ceramic is reported to be approximately 50,000 psi, requiring 30 mils deflection to crack. The glass overglaze (for example, the weakest layer) will crack at approximately 15,000 psi and 10 to 11 mils deflection.

Other design parameters that must be considered before selecting the proper stress-absorbing adhesive are a ΔT = 120°C (-55° + 65°C) and thermal conductivity ≥ (16 x 10^{-4} cal)(cm)/(sec)$(cm)^2$(°C). To meet the thermal conductivity requirement, the adhesive must be filled 60, to 70 percent PEW. However, this will cause an increase in modulus and a decrease in elongation, thus adversely affecting the absorbance capability. There are not many adhesives available to fit this application.

Considerable time and resources were spent to find an adhesive and resolve the cracking problem. Extensive empirical and computer-generated data concluded that in order to avoid glass cracking, a required, and the most important adhesive property to monitor is modulus of elasticity at -55°C. It was determined that modulus values greater than 2,200 psi will cause excess deflection and ultimate failure. It should be noted that a maximum bond line of 12 mils was required due to restrictions on loss of thermal conductivity and maximum height tolerance for the assembly.

Initially, only a silicone-based adhesive was approved for this application. However, as Raytheon reports, "Many problems associated with silicone technology as a bonding adhesive are well determined. Contamination from silicone adhesive contributed to both soldering difficulties and conformal coating defects." The company further advised that "both military (SMT-Mil-2000) and commercial guidelines now contain cautionary notes warning against the contact of assemblies and processes with silicones as

Table 1

Material	Modulus of Elasticity (psi)[4] [at RT]	[at -55° C]
Ecosil®1 4952 A/B	415	2227
APTEK®2 95018-3 A/B	139	1593
3M A-30 tape3	90	10,000

Notes:
1. Ecosil® is a registered trademark of Emerson and Cuming, Inc., a W.R. Grace Co.
2. APTEK® is a registered trademark of Aptek Laboratories,Inc.
3. 5 mil double-backed acrylic pressure sensitive tape manufactured by 3M Co.
4. All values are worst case.

Table 2 Stress/Deflection Data @ -55° C; ΔT = -120° C (Computer Generated)			
Material	Bondline Thickness	Maximum Stress (PSI)	Maximum Deflection (mils)
Ecosil 4952	7.5	15,769	10.45
	10	13,483	9.02
APTEK 95018	7.5	12,686	8.59
	10	11,471	7.32
3M A-30 Tape	7.5	28,435	18.18
	10	26,606	16.94

Table 3 Empirical Temperature Cycle[1] Data		
Material	Bondline Thickness	Results
Ecosil 4592	7.5	Cracks2 at larger LCC only
	10	No cracks
	12	No cracks
APTEK 95018	10	No cracks
	12	No cracks

Notes:
1. Temperature cycle +65° to -55° C per Mil-Std-202; 135 cycles.
2. Cracking occurred within first 10 cycles; cracks worsened with additional cycles.

well as other contaminants." Three discussions with manufacturing personnel also have confirmed that silicones require costly labor intensive process steps such as primer application for adhesion, extensive masking procedures to minimize contamination, and extra cleaning procedures to remove unwanted silicone residue.

This situation led to an investigation of alternative materials that would meet the applications requirements yet provide processing and handling improvements. Tables 1, 2, and 3 present data developed by Raytheon, showing that a urethane-based adhesive is capable of exceeding the requirements. In fact, based on the computer data in table 2, it appears that the cold temperature compliancy of the adhesive 95018-3 A/B* will allow for bond line thickness to be reduced to approximately 7.5 mils and still prevent cracking. The computer predicts the silicone system to be marginal at this reduced thickness, and empirical testing shows evidence of cracking at the large ceramic LCCs, as shown in table 3.

An additional manufacturing concern is the need to maintain a uniform bond line thickness over a wide area as some of the ceramic substrates are as large as 4 x 6". This can be a significant problem and source of cracking if sections of the bond line drop below the critical thickness.

Aptek has supplied Raytheon with fully cured sheets of film of their 95018-3 adhesive at a thickness of 0.01" ±0.001'". A thin coat of adhesive is applied (usually with an ink roller) to the top surface of the frame. The cured "gasket" of 95018-3 is positioned onto the wetted frame and the air voids are rolled out. A light coat of adhesive is rolled onto the surface of the gasket and the ceramic positioned on top of that to complete the "sandwich" construction. The assembly is allowed to set at RT for gelation and then placed in an air circulating oven for full cure.

The concept of using thermally conductive C-staged films spacers with an adhesive is not a new one. In fact, current strategic military electronic hardware is being manufactured with these materials with great success in device performance and reliability. This method ensures stress and vibration relief and a very high level of thermal conductivity via the complete filling of air voids with uniform bondline line spacing underneath heat generating components such as ceramic LCC, ceramic flat packs, etc.

Other Applications

In addition to military applications, opportunities for the use of low modulus urethanes for relieving stress in electronic assemblies/devices are increasing. Currently, urethane adhesives and encapsulants are being used or evaluated in the fields of medical electronics, space and communications, and optoelectronics.

Recently, silver-filled urethane adhesives and coatings have demonstrated technical success in applications where high purity, low outgassing, excellent adhesion, flexibility especially at low temperatures, and electrical conductivity are required.

Conclusion

Due to limited adhesion, additional costly processing, and contamination problems, considerable effort has been made to replace silicones. Recent developments and success in electronic applications have shown that low-modulus urethanes are viable and reliable materials to resolve stress management problems.

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