Substrate Attach Epoxies

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Increased in-house experience with insulative adhesives used to attach ceramic to gold-plated Kovar and ceramic to ceramic initiated a confidence study. A specific program was undertaken to tie together industrially available data and our own data. These data particularly concerned four widely used substrate-attach epoxies: Ablebond 660-3, Ablebond 450, Epo-Tex H-74 and Scotchcast 281. Selection of these epoxies resulted from in-house use and availability as well as customer/vendor recommendation.

ADHESIVES may be classified into two broad categories: (1) insulative and (2) conductive. Of these, only the insulative type is discussed herein; more specifically, substrate-attach, insulative epoxies. In general, reliability problems can result unless epoxies which are chemically and physically compatible with components, active devices, processes and metal surfaces are used. Generation and collection of data in support of an epoxy to attach ceramic to gold plated Kovar and ceramic to ceramic are reported in this study.

Test Procedure

The primary concern of these exercises was to compile a satisfactory data base for the selection of a substrate-attach epoxy. Objectives of the program included:

1. Finding a satisfactory substrate mounting epoxy and method for mounting same
2. Identifying potential failure modes
3. Establishing reliability criteria for substrate mounting other than the solder-alloy method.

Realization of these objectives required test methods that related to in-house processing and testing after and during the epoxy attaching step. The following tests were used to evaluate the listed parameters.

Test	Parameter
Constant Acceleration	Tensile Strength
Mechanical Shock (other than Y axis)	Lap Shear
Temp. Cycling	Thermal Expansion Characteristics
Hot Plate Heat Soak	Hi-temp Stress as in TC bonding or during Rework

Enumerated below are the tests performed and methods used.

Cleaning Procedure

Use the following procedure to clean packages and substrates prior to bonding/mounting.

1. Place package face down or to the side in acetone for 60 ± 10 seconds.
2. Drain package.
3. Place in an isopropyl alcohol container for 15 ± 5 seconds; use ultrasonics.
4. Drain package.
5. Place in isopropyl alcohol vapors for 15 ± 5 seconds in position to allow liquid to drip off active surfaces.
6. Withdraw from vapors slowly, allowing to dry.
7. Cover units and transport to oven.
8. Dry units at 125°C ± 10°C for 10 minutes, uncovered.
9. Maintain cover on units between this clean and any heat operation of 150°C or more.

Lap Shear Test

1. Mix epoxy under test according to manufacturer's published recommendations.
2. Apply epoxy to edges of two 2.54 cm x 1.27 cm x .05 cm substrates cleaned per above until .5 cm of the edge is covered. Connect as shown in Fig. 1.
3. Apply epoxy under test to one edge of a 2.54 cm x 1.27 cm x .5 cm substrate cleaned as described above. Position on Au plated Kovar lid as shown in Fig. 2.
4. After curing epoxy per manufacturer's specification, mount bonded pieces in pull tester.
5. Pull at .085 cm/sec until destruction. Make note of pull value in kilograms (1 pound = .4536 kgs).
6. Convert to kg/m² by multiplying value by 3.86 x 10^5.

Tensile Shear Test

The centrifuge evaluation is to be accomplished by testing assembled hybrid units at constant accelerations of 5K g, 10K g, 15K g and 20K g before and during

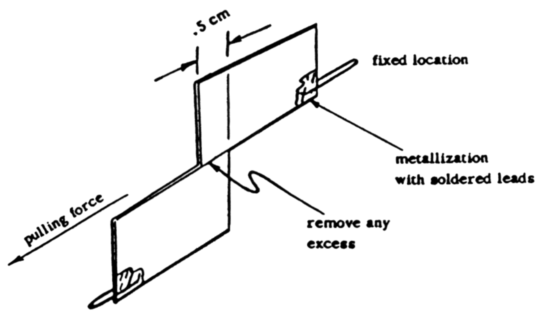

Fig. 1—Arrangement for Step 2 of Lap Shear Test.

thermal degradation until destruction. Each unit shall be weighted as follows: 1.58 cm x 1.58 cm flatpack (1.27 cm x 1.27 cm x .064 cm substrate) = 1.00 gram. 1.91 cm x 1.91 cm flatpack (1.58 cm x 1.58 cm x .064 cm substrate) = 1.44 grams.

1. Mix epoxy under test per manufacturer's specification.
2. Apply layer 25 microns thick to area in base of flatpack equal to .95A$_s$. (A$_s$ = area of substrate.)
   (a). Clean all flatpacks and substrates under test as described above.
   (b). Abrade base of metal flatpack using 30,000 kg/m² pressure on S.S. White #1 Al_2O_3 powder in air abrasive apparatus.
3. Cure per manufacturer's recommendation.
4. Loosely tape lid to flatpack. *Do not solder or otherwise seal lid shut.*
5. Perform constant acceleration tests at 5000, 10,000, 15,000 and 20,000 g's. Allow one minute dwell at selected g-loading rate.
6. Store units in 150°C oven between acceleration tests. Tests are to be performed each 168 hours until destruction of all test units (or until pre-determined time has elapsed).

Bonding Temperature Test

1. Prepare flatpacks and substrates as in tensile shear test. Centrifuge all units to 20K g before beginning test.
2. Place units under test without lids on hot plate at 350°C ± 5°C for 25 ± 1 minutes.
3. Centrifuge to 10 and 20K g (1 minute dwell). Check for loosened substrates.
4. This evaluation shall be rated as either accept or fail.

Temperature Cycling Test

1. Prepare flatpacks and substrates as in tensile shear test. Centrifuge all units to 20K g before beginning test.
2. Place units in temp cycle chamber for 100 cycles. Cycle according to MIL-STD-883, Method 1010, Condition C.
3. Check for loosened substrates.
4. Centrifuge to 10 and 20K g; check for loosened substrates.

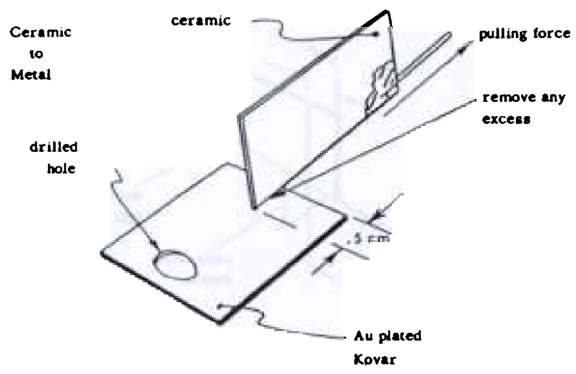

Fig. 2—Arrangement for Step 3 of Lap Shear Test.

5. This test will be evaluated on an accept-fail basis only.

Test Results

Lap Shear Test (Al_2O_3 attach to Al_2O_3)

Material	Shear Strength (kg/m² × 10⁶)	
Epo-Tek H-74	1.25	
	1.88 (Hi)	
	1.08	Ave: 1.12 × 10⁶ kg/m²
	.74	
	.66 (Lo)	
Ablebond 660-3	1.68 (Lo)	
	2.99	
	2.83	Ave: 2.60 × 10⁶ kg/m²
	3.23 (Hi)	
	2.27	
Ablebond 450	1.13	
	.90 (Lo)	
	1.39 (Hi)	Ave: 1.10 × 10⁶ kg/m²
	.94	
	1.13	
Scotchcast 281	.59	
	.53 (Lo)	
	.72 (Hi)	Ave: 6.22 × 10⁵ kg/m²
	.72 (Hi)	
	.55	

Lap Shear Test (Al_2O_3 attach to Au/Kovar Package)

Material	Shear Strength (kg/m² x 10⁶)	
Epo-Tek H-74	.29 (Lo)	
	.29 (Lo)	
	.55 (Hi)	Ave: 4.03 × 10⁵ kg/m²
	.51	
	.37	
Ablebond 450	.55	
	.49	
	.72	Ave: 6.02 × 10⁵ kg/m²
	.39 (Lo)	
	.86 (Hi)	
Ablebond 660-3	2.17 (Hi)	
	1.80 (Lo)	
	1.84	Ave: 1.99 × 10⁶ kg/m²
	2.01	
	2.15	
Scotchcast 281	1.27 (Lo)	
	1.99	
	1.84	Ave: 1.80 × 10⁶ kg/m²
	2.35 (Hi)	
	1.56	

Tensile Shear Test (All tested OK at beginning of test)

Legend: (C/M) = Al_2O_3 attached to Au/Kovar
(C/C) = Al_2O_3 to Al_2O_3
A = Accept, R = Reject; loosened substrate (Parenthetical value × 1000 = K g centrifuge value.)

Epo-Tek H-74

	173 Hrs	240 Hrs	402 Hrs	570 Hrs	738 Hrs	906 Hrs	1074 Hrs	1242 Hrs
(C/M)	R(5)	—	—	—	—	—	—	—
(C/M)	R(20)	—	—	—	—	—	—	—
(C/M)	A	R(5)	—	—	—	—	—	—
(C/M)	A	R(15)	—	—	—	—	—	—
(C/C)	A	A	A	A	A	A	A	A
(C/C)	A	A	A	A	A	A	A	A
(C/C)	A	A	A	A	A	A	A	A
(C/C)	A	A	A	A	A	A	A	A

Ablebond 450

	173 Hrs	240 Hrs	402 Hrs	570 Hrs	738 Hrs	906 Hrs	1074 Hrs	1242 Hrs
(C/M)	A	A	R(10)	—	—	—	—	—
(C/M)	A	R(5)	—	—	—	—	—	—
(C/M)	A	R(15)	—	—	—	—	—	—
(C/M)	A	R(10)	—	—	—	—	—	—
(C/C)	A	A	A	A	A	A	A	A
(C/C)	A	A	A	A	A	A	A	A
(C/C)	A	A	A	A	A	A	A	A

Ablebond 660-3

	173 Hrs	240 Hrs	402 Hrs	570 Hrs	738 Hrs	906 Hrs	1074 Hrs	1242 Hrs
(C/M)	A	A	A	A	A	A	A	A
(C/M)	A	A	A	R(15)	—	—	—	—
(C/M)	A	A	A	A	A	A	R(15)	—
(C/M)	A	A	A	R(20)	—	—	—	—
(C/C)	A	A	A	A	A	A	A	A
(C/C)	A	A	A	A	A	A	A	A
(C/C)	A	A	A	A	A	A	A	A
(C/C)	A	A	A	A	A	A	A	A

Scotchcast 281

	173 Hrs	240 Hrs	402 Hrs	570 Hrs	738 Hrs	906 Hrs	1074 Hrs	1242 Hrs
(C/M)	A	A	A	A	A	A	A	A
(C/M)	A	A	A	A	A	A	A	A
(C/M)	A	A	A	A	R(20)	—	—	—
(C/M)	A	A	A	A	A	A	A	A
(C/C)	A	A	A	A	A	A	A	A
(C/C)	A	A	A	A	A	A	A	A
(C/C)	A	A	A	A	A	A	A	A
(C/C)	A	A	A	A	A	A	A	A

Bonding Temperature Test

Epo-Tek H-74		Ablebond 660-3	
(C/C)	A	(C/C)	A
(C/C)	A	(C/C)	A
(C/C)	A	(C/C)	F(20)
(C/C)	A	(C/C)	F(20)
(C/M)	F(10)	(C/M)	F(10)
(C/M)	F(10)	(C/M)	F(10)
(C/M)	F(10)	(C/M)	F(10)
(C/M)	F(10)	(C/M)	F(20)

Ablebond 450		Scotchcast 281	
(C/C)	A	(C/C)	A
(C/C)	A	(C/C)	A
(C/C)	F(20)	(C/C)	A
(C/C)	F(20)	(C/C)	A
(C/M)	F(10)	(C/M)	F(10)
(C/M)	F(20)	(C/M)	F(20)
(C/M)	F(20)	(C/M)	F(20)
(C/M)	F(20)	(C/M)	F(20)

Discussion

Ordinarily, high reliability hybrids are not subjected to stresses other than Y_1 except on impact. However, at the suggestion of one customer, the lap shear test was devised to determine resistance to an X- direction force. Due to the surface roughness of the alumina in the package and on the substrate it was felt that Al_2O_3-Al_2O_3 attachment would test the cohesive strength of the material while the Al_2O_3-Au/Kovar bond would only exhibit the adhesive capability of the epoxy to the metal flatpack. This did not prove entirely true. The epoxy did, in the case of metal-to-ceramic, free itself from the metal. The ceramic-to-ceramic bonds were randomly severed both at the substrate and package (same test specimen).

Ablebond 660-3 exhibited excellent resistance to X-direction forces in both the ceramic-to-ceramic and ceramic-to-metal experiments. Further, Scotchcast 281 proved excellent in the lap shear test on ceramic-to-metal parts.

The tensile shear test was the one upon which the largest amount of weight was placed in selecting an epoxy to use at our facility. This was due largely to a "rattler" (substrate loose in package after burn-in and centrifuge testing) problem incurred with metal-bottomed flat packs. At the time we were using Epo-Tek H-74 both on metal and ceramic based flatpacks. Note H-74's very poor showing with Al_2O_3 attached to Au/Kovar (C/M). As a result of our tensile shear testing, Scotchcast 281 proved to be an excellent choice as a substrate-attach epoxy for use with metal-bottomed flatpacks. All epoxies passed the tensile shear test in alumina-bottomed flatpacks. Thus this test did not differentiate the superior epoxy for this application. Consequently, other investigation was necessary.

In addition, the bonding temperature test was run to determine the feasibility of thermocompression bonding repair of assembled hybrids. It is noted that the bonding temperature test was the most rigorous while the temperature cycling test proved the least rigorous of the tests. None of the epoxies withstood the temperatures of TC bonding as a means of circuit rework. We thus concluded that either rework temperatures would have to be lowered or environmental requirements relaxed to have usable circuits after high temp rework. The temperatures experienced in the tensile shear test are in line with gold ultrasonic bonding as a circuit repair method and this type of bonding is suggested when repairing circuits. The temperature cycling test results are offered for information purposes only. The test seemed necessary because of the high coefficient of thermal expansion of Scotchcast 281. The test illustrates that among the epoxies tested no detrimental thermal mismatches occurred in our systems under test.

Conclusions

Two meaningful conclusions were drawn from this work:

1. Epo-Tek H-74 is a fully acceptable substrate material when dealing with ceramic-based flatpacks.
2. Scotchcast 281 (3M Co.) proved superior on Au-bottomed flatpacks.

In all cases of excessive exposure to high temperatures, as in TC wire bonding upon rework, failures occurred in ceramic to Au bonds. Ceramic to ceramic bonds showed fewer failures. However, the results were totally unacceptable. Therefore, rework must be minimized or at least held to very short durations on the bonder platen.

Finally, two epoxies will continue to be used at our facility for the purpose of substrate attachment. Epo-Tek H-74, with its superior thermal conductivity characteristics (See Table I), will be used in ceramic flat-packs. Scotchcast 281 will be used as our substrate to Au attach epoxy and for component mounting on substrates.

Table I—Epoxy Characteristics

Epoxy	Volume Resistivity (Ohm-Cm)	Conductivity Cal/sec-cm-°C x 10^{-3}	Coefficient of Thermal Expansion cm/cm/°C x 10^{-6}	Pot Life (Hrs)	Curing Cycles	Rheology	Shelf Life (Years)
		.903	33.8 (0-40°C)	> 4			
450	3 x 10^{14}	.299	31.1 (−50° to +40°C) 40.2 (+40° to +90°C) 52.0 (+90° to +150°C)	< 8	2 Hours @ 75°C 1 Hour @ 120°C	Flowable Resin: Bisphenol A epoxide. Curing agent: 3° amine Filler: $CaCO_3$	1 Year @ −40°C or colder.
660-3	1 x 10^{14}	.284	53.3 (−50° to +40°C)	> 24	1 Hour @ 125°C	Flowable, non-thixotropic	.5
281	> 10^{14}	.412	83 (73° to 235°C)	> 24	2.5 Hours @ 120°C 7.0 Hours @ 95°C 24 Hours @ 65°C 1 week @ 25°C	Flowable, non-thixotropic	1