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Evaluation of Thermally Conductive Adhesives as Staking Compounds during the Assembly of Spacecraft Electronics

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Abstract

A market survey was made of available thermally conductive adhesives and an experimental evaluation has been performed of the impact of thermally conductive adhesives on the thermal fatigue of solder joints when used as staking compounds. Two adhesives were evaluated in the experimental part: one epoxy system, EPO-TEK 930, and one silicone system, CV-2946. A polyimide/glass board mounted with ceramic quad flat packages was used as test vehicle.

Reliability verification was executed according to ESA requirements. No observable effect on the fatigue of the solder joints was seen for either of the two adhesives when applied as staking compounds beneath components. The extent of coarsening of grain structure and cracking of solder joints was the same for solder joints to components without staking compound as for components with staking compound.

1 Introduction

Excessive heat generated by power dissipation in components may threaten the reliability of spacecraft electronic assemblies and in such cases a high heat extraction is needed. In vacuum, forced air cooling is not possible. Therefore, if the heat dissipation through the component lead terminations and by radiation is not large enough, it will be necessary to apply thermally conductive adhesives (staking compounds) between the component packages and the printed circuit board on which they are mounted. However, since these adhesives usually have coefficients of thermal expansion (CTE) that differ from other materials used on printed-board assemblies, they may induce stresses that cause thermal fatigue of solder joints. Not just the CTE is important in this respect. Hardness of the adhesives also is important since a harder adhesive is more prone to transfer the stress.

This work consists of a market survey of available thermally conductive adhesives, testing to establish their suitability to operate under vacuum, and an experimental evaluation of their impact on the thermal fatigue of solder joints when used as staking compounds.

2 Market Survey

Information about thermally conductive adhesives has been collected from the following manufacturers: Ablestik [1], AI Technology Inc. [2], Dexter Corporation [3], Dow Corning Corporation [4], Emerson & Cuming [5], Epoxy Technology [6], Loctite Corporation [7], NuSil Technology [8], Thermoset [9], and Wacker-Chemie GmbH [10]. Data for adhesives from these companies are given in Appendix A. Only materials with a thermal conductivity of at least 1 W/mK have been included.

3 Adhesives Selected for the Experimental Part

Originally, three adhesives were selected for evaluation of their impact on thermal fatigue of solder joints when used as staking compounds: EPO-TEK 930 from Epoxy Technology, CV-2946 from NuSil Technology, and Multimat M-4030LD from Multicore (originally developed by DIEMAT as DM4030LD). Since it turned out that it was impossible to use Multimat M-4030LD as a staking compound, this material was excluded from the evaluations.

EPO-TEK 930 is a two-part, thermally conductive epoxy system made with boron nitride particles as filler. The filler particles are specified to have a size of less than 300 μm. EPO-TEK 930 can be cured at low temperatures (80 to 120°C). It has a specified thermal conductivity of 4.1 W/mK. A modified version, EPO-TEK 930-1, with a much finer particle size filler (<30μm) is available, but it has a thermal conductivity of only about 2 W/mK.

CV-2946 is a two-part silicone material containing boron nitride as filler. It cures at room temperature, but can also be cured at elevated temperatures up to 150°C. The thermal conductivity is specified to be 3.8 W/mK.

Multimat M-4030LD is a paste containing silver flakes, thermoplastic particulates and an organic vehicle system. The paste forms a void-free adhesive layer with very high thermal conductivity (15 W/mK) when processed at 150 to 200°C. At high temperatures, the polymer particles soften and flow forming a silver-polymeric network. The adhesive can be reworked at 120°C.

Outgassing properties, coefficient of thermal expansion, thermal conductivity, and hardness of the chosen products were tested.

3.1 Outgassing under Vacuum

The outgassing properties were tested according to ESA PSS-01-702 [11] and the complete report from the test can be found in Reference 12. The aim of the test is to determine the amounts of outgassing products. For the test, materials are submitted to a humid climate (65 ± 5% relative humidity, 20 ± 1°C, 24 h) for water uptake. Then they are subjected to thermal vacuum (125°C for 24 h). Finally, they are again submitted to the humid climate. Additionally, in the vacuum chamber cooled "collector plates" are mounted directly above the heated cups with the materials. These plates collect some of the outgassing species. The following properties were measured:

TML – Total Mass Loss is the difference of mass directly before and after vacuum test (shows the amount of outgassing products in percentage of initial mass). The acceptance limit is <1.0%.

RML – Recovery Mass Loss is the difference between initial mass and mass after reclimating (shows the amount of non-water products).

WVR – Water Vapour Remaining is the water uptake.

CVCM – Collected Volatile Condensable Material is the mass gain of collector plates divided by the initial mass of the material. The acceptance limit is <0.1%.

Ten cubes with a side of 2 ± 0.2 mm were analysed for each material. The results from the test are compiled in Table 1. Both tested materials passed with values well below the acceptance limits. The outgassing of CV-2946 can be attributed mainly to water vapour.

Table 1. Summary of outgassing test results

Property	Material	
	CV-2946	EPO-TEK 930
TML		
Mean value	0.36%	0.01%
Std. Deviation	0.02%	0.00%
RML		
Mean value	0.08%	0.01%
Std. Deviation	0.01%	0.00%
WVR		
Mean value	0.28%	0.01%
Std. Deviation	0.02%	0.00%
CVCM		
Mean value	0.00%	0.00%
Std. Deviation	0.01%	0.00%

3.2 Coefficient of Thermal Expansion

The CTE was measured using a Thermo-Mechanical Analyser (TMA) for temperatures between -50°C and +150°C [13]. The test was performed per ASTM E-831-93. Test samples consisted of two cubes for each material with a side of about 4 mm. The CV-2946 samples were tested twice and the EPO-TEK 930 samples three times to determine any changes in the expansion of the test material after the first heating run.

The results for CV-2946 are given in Table 2. This material expanded in a very linear manner. In Table 3, the results for EPO-TEK 930 are shown. During the first heating of this material, the T_g was superimposed by a further curing or by other thermal relaxations. This was gone when the material was re-tested.

Table 2. Results from CTE test runs on two samples of CV-2946

Sample	CTE –50 to 150°C (μm/m°C)
Sample 1 first run	222
Sample 1 second run	217
Average value of Sample 1	219.5
Sample 2 first run	201
Sample 2 second run	199
Average value of Sample 2	200
Average value of Samples 1 and 2	209.75

Table 3. Results from CTE test runs on two samples of EPO-TEK 930

Sample	CTE -50 to 50°C (μm/m°C)	CTE 100 to 150°C (μm/m°C)	Averaged CTE -50 to 150°C (μm/m°C)	T_g region
Sample 1 first run	25.8	73.6	57.6	60-90°C
Sample 1 second run	26.4	90.6	41.4	75-100°C
Sample 1 third run	26.1	93.7	41.0	75-100°C
Average value of Sample 1, runs 2 and 3	26.25	92.15	41.20	75-100°C
Sample 2 first run	27.0	77.1	41.20	60-90°C
Sample 2 second run	26.5	88.5	40.7	75-100°C
Sample 2 third run	26.2	90.9	41.2	75-100°C
Average value of Sample 2, runs 2 and 3	26.35	89.70	40.95	75-100°C
Average value of Samples 1 and 2	26.30	90.93	41.08	75-100°C

3.3 Thermal Conductivity

The thermal conductivity was measured using a "guarded heat flow" method [12]. Test samples were prepared as discs with a diameter of 50 ± 0.1 mm and a thickness of 5.0 ± 0.1 mm. The thermal conductivity was measured at -55, -25, 0, 25, 50 and 75°C. The results are compiled in Table 4. It can be noted that the measured thermal conductivity for CV-2946 is considerably lower than the specified value of 3.8 W/mK from the manufacturer of the material.

Table 4. Results of thermal conductivity tests

T (°C)	Measured values k (W/mK)	
	CV-2946	EPO-TEK 930
-55	1.96	3.96
-25	1.90	3.76
0	1.81	4.03
25	1.71	4.22
50	1.57	4,27
75	1.50	4,18

3.4 Hardness

The hardness of the two materials was evaluated with a Shore A hardness tester from Teclock Corporation [14]. The measuring procedure followed the guidelines of ISO 868. The readings were taken 15 seconds after the probe was put in firm contact with the test specimens. Test samples consisted of one cube for each material with a side of about 4 mm. Twelve measurements were performed on each sample.

EPO-TEK 930 had a hardness of 98.3 with standard deviation of 0.8 and CV-2946 had a hardness of 75.4 with a standard deviation of 1.0.

4 Impact on Thermal Fatigue of Solder Joints – Reliability Verification

4.1 Experimental Work

Test Boards and Components

The impact of staking compounds on the thermal fatigue of solder joints was evaluated using test vehicles consisting of ceramic Quad Flat Packs (QFPs) soldered to polyimide/glass boards. The printed boards were one-sided, 160 mm x 233 mm, and 1.6 mm thick. The layout of the printed board is shown in Figure 1. A hole with 4.0 mm diameter was drilled under each QFP to facilitate the application of staking compounds using a syringe. There were also drilled holes with a diameter of 2.0 mm for fixing the boards to a shaker during a vibration test. The surface finish of the boards was fused tin/lead. No solder mask was applied to the boards. The boards were manufactured by Printca AS, Denmark, per ESA PSS-01-710 [15].

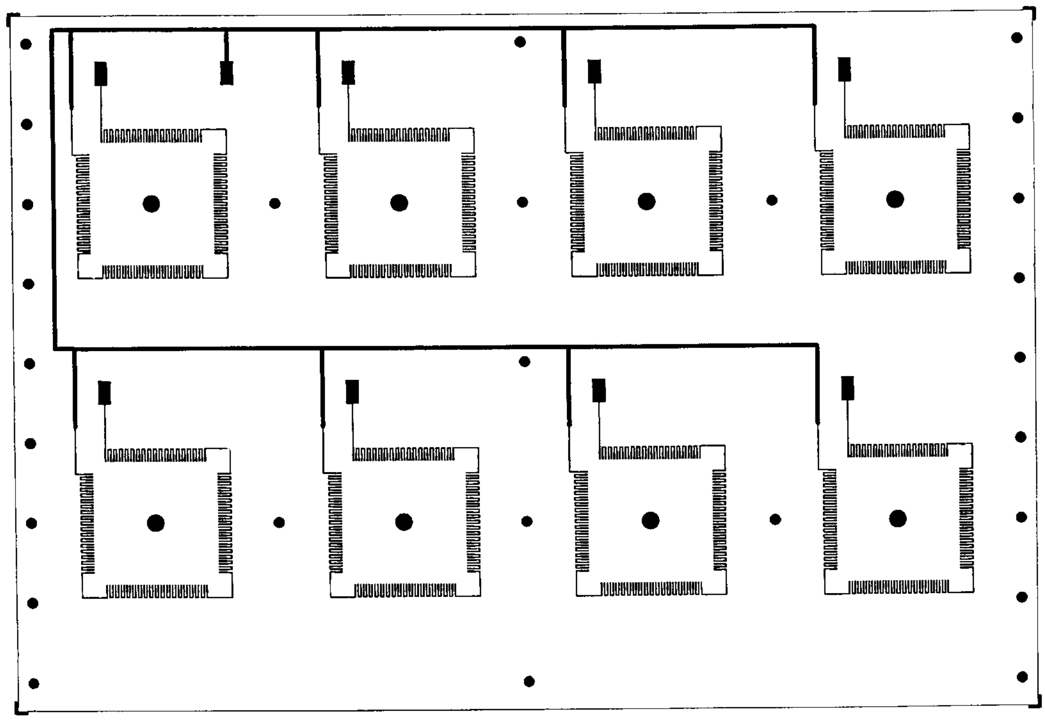

Figure 1. Layout of the printed board used for the evaluations

Ceramic Quad Flat Packs with 144 I/Os and a body size of 28 mm x 28 mm x 3.5 mm supplied by TopLine were used for the tests. The QFPs had an Alloy 42 leadframe and solder-plated gull wing leads with 0.65 mm pitch. Figure 2 shows the form of the leads. The leads were daisy chain interconnected in order to facilitate continuous monitoring of the integrity of the solder joints during thermal testing. Mounted on the board, the QFPs had a stand-off of about 0.3 mm

The leads to the components as received had very poor and varying coplanarity. Most components had a coplanarity of about 200 µm but the worst had a coplanarity of up to 400 µm (Fig. 3). Some leads on some components were also bent in the x-y plane

(Fig. 4). The leads on the components with poor planarity and bent leads were corrected manually.

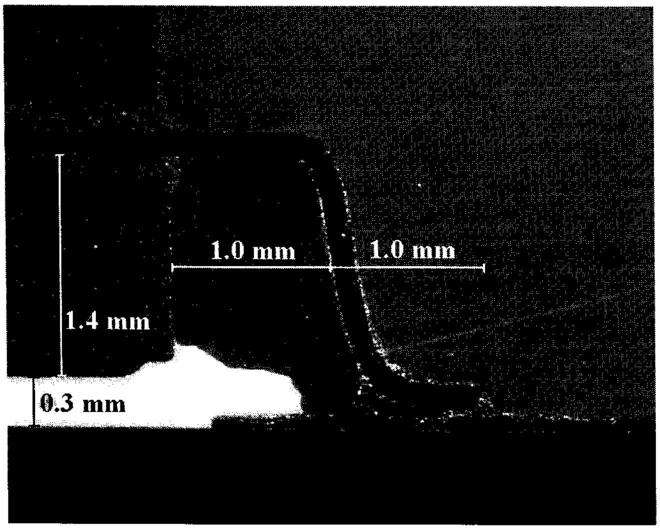

Figure 2. Stand-off and form of leads to the QFP components

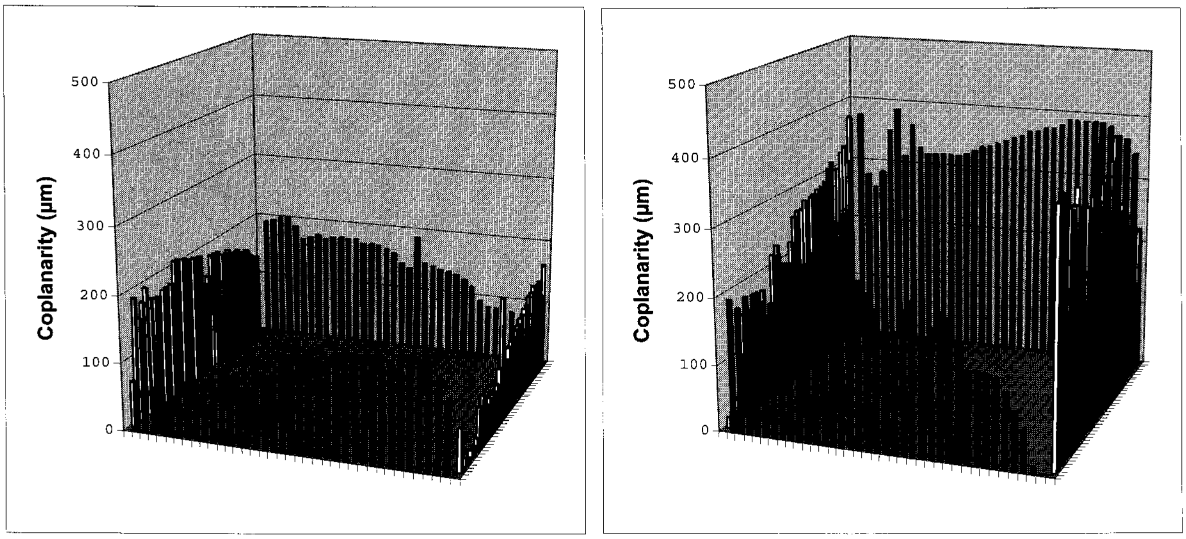

Figure 3. Planarity distribution of leads for a component with typical coplanarity (left) and a component with very poor coplanarity (right)

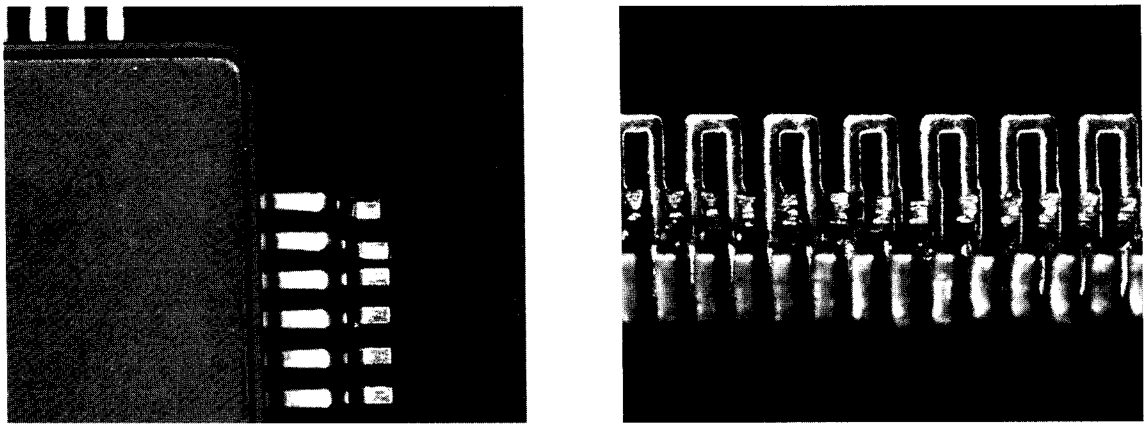

Figure 4. Deviation of leads in the x-y plane for components with bent leads

Assembly and Soldering of Test Vehicles

The printed boards were baked at 125°C for 4 hours prior to screen-printing an RMA solder paste from Alpha Metals, Cleanline UP78T (62Sn/36Pb/2Ag). It was printed on the test boards using a stencil of stainless steel with a thickness of 150 µm. Due to the poor planarity of the leads on the components, Kapton tape had to be applied as a temporary solder mask to the connectors connecting the solder lands to prevent the solder from flowing out on them increasing the risk for open joints.

The components were mounted on the boards using a Zevac soldering and desoldering machine DRS 24. Reflow soldering was performed in a Heller 1500 W convection oven. The reflow profile used is shown in Figure 5.

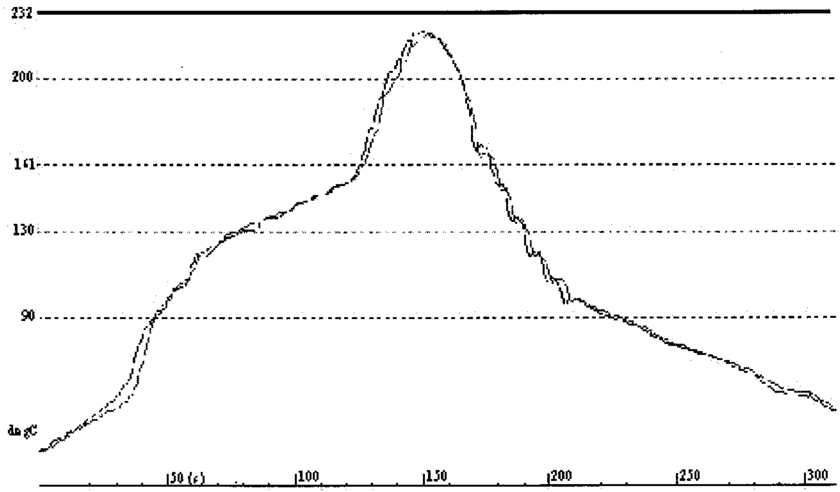

Figure 5. Temperature profile when soldering the test specimens, recorded for two leads, one at the corner and one at the middle of a row of leads

No bridges were formed between leads. However, due to the poor planarity of the leads on the QFPs, open joints occurred on about half of the components, 1 to 15 open joints per component with an average of 5.6 opens. The positions of the open joints were noted and they were then reworked.

The soldered and reworked boards were then cleaned in Zestron LP at 50°C for 10 min using ultrasonic agitation. Zestron LP consists of a blend of di(propylene glycol) ethyl ether and propylene glycol dialkyl ether with a boiling point of 160-220°C. After cleaning, the boards were first washed with isopropanol followed by deionised water and then once more with isopropanol. Finally, the boards were blown dry with nitrogen.

Application of Staking Compounds

Each staking compound was applied under all components on one test board, i.e. in total eight QFPs. The material was applied through the drilled holes under the components, using a syringe. It was applied until the material became visible at the periphery of the component. The distance from the corners of the components into the adhesive materials was 3-5 mm. That is, about 85-90% of the space beneath the components was filled with material as shown in Figures 6 and 7.

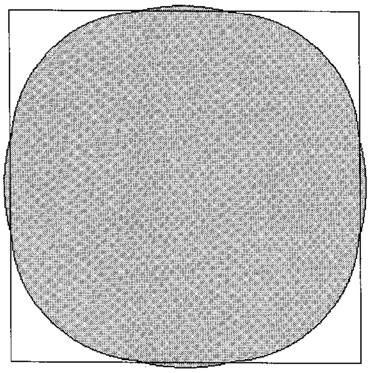

Figure 6. Drawing showing typical distribution of adhesive beneath the body of the components

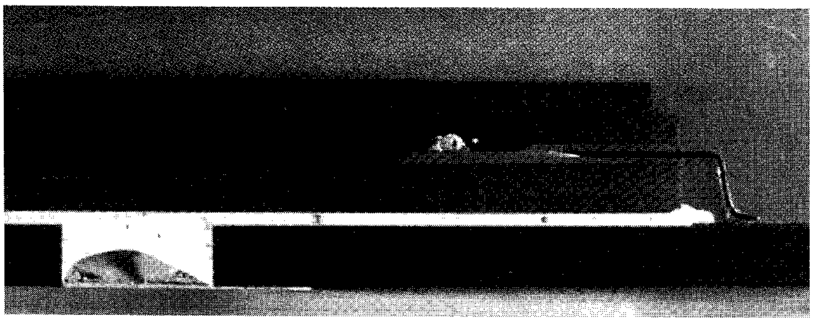

Figure 7. Cross-section of component showing applied adhesive and the drilled hole through which the material was applied

EPO-TEK 930

The two parts were thoroughly mixed, 100 parts per weight of Part A to 3.3 parts per weight of Part B. However, it turned out that EPO-TEK 930 contained filler particles that were considerably larger than the stated size of less than 300 μm (Fig. 8). Since the stand-off for the component was about 300 μm, it was not possible to apply the material, as delivered, under the components. Therefore, Part A, which contained the particles, was ground using a mortar before mixing the two parts. Air entrapped during mixing was removed by applying vacuum (50 mbar) for about 30 minutes.

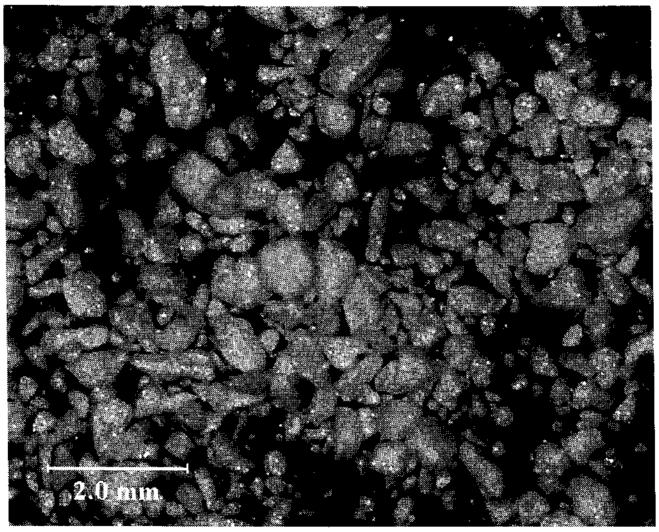

Figure 8. Size distribution of filler particles in EPO-TEK 930

After grinding of Part A and mixing, the material could be applied under the components, with some difficulties. Curing was done at 80°C for 45 minutes. After curing, the material was in good contact with both the component and the board surfaces (Fig. 9).

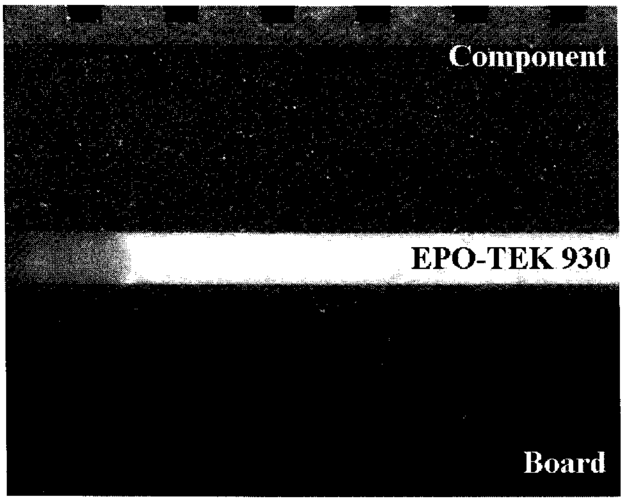

Figure 9. Microsection showing EPO-TEK fillet close to a corner of the component

CV-2946

Fifteen parts of base were thoroughly mixed with 1 part curing agent. The mixed material was de-aerated in the same way as EPO-TEK 930.

The CV-2946 material was easy to apply. Curing was performed at 65°C for 4 hours. This material also had good contact with both component and board surfaces (Fig. 10).

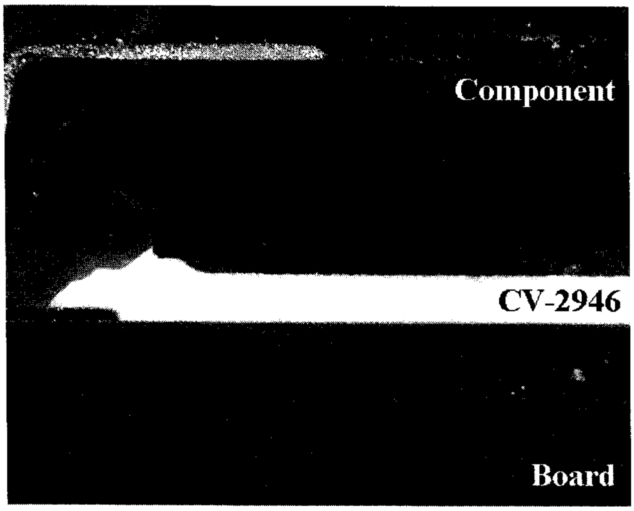

Figure 10. Microsection showing CV-2946 fillet at component edge

Multimat M-4030LD

The material was thoroughly stirred in the jar in which it was delivered and was then de-aerated at about 100 mbar for 30 min to remove air bubbles.

It was very easy to apply under the components. After application of the material, the test board was first heated in an oven at 85°C for 150 min in order to drive off the solvent. Thereafter, the temperature was increased to 175°C during a period of 20 min and the test board was then kept at this temperature for 30 min.

Due to high solvent contents, 9 – 13% by weight, the material shrinks during the heating process. This shrinkage resulted in formation of voids and a gap between the material and the board at some locations and between the material and the component at other locations (Fig.11). Since such a gap makes the material useless as a staking compound, this material was excluded from the evaluation of the impact on solder-joint fatigue.

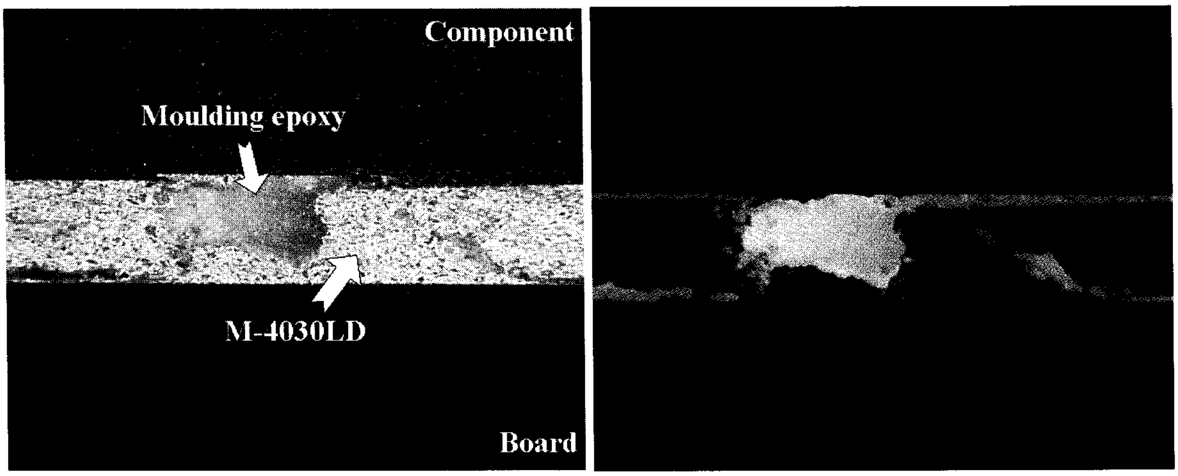

Figure 11. Microsection showing voids and gaps formed when drying Multimat M-4030LD. The sample was moulded in epoxy with fluorescent agent. The photograph to the left is taken with ordinary light and the photograph to the right is taken with UV light

Reliability Verification Methods

The impact of staking compounds on the fatigue of solder joints was evaluated by a combined temperature cycling/vibration test. To simulate true conditions as much as possible, the test was started with 100 thermal cycles followed by the vibration test and then another 900 thermal cycles. The idea was that vibration testing may have a much larger impact on crack propagation than on crack initiation. Since testing prior to launching could initiate cracks, the purpose of the first 100 thermal cycles is to simulate such testing.

A test board equipped with components without any applied staking compound was used as reference board.

Thermal-Cycling Test

Temperature cycling was performed per ECSS-Q-70-08A, Section 13.2 [16]. An air-circulating oven, Heraeus HT 7015-10/S, was used for the test. The temperature was cycled between –55 and +100°C with a temperature ramp of 10°C/min and a soak time of 15 min at each temperature extreme. The actual temperature profile measured for a corner lead to a component is shown in Figure 12.

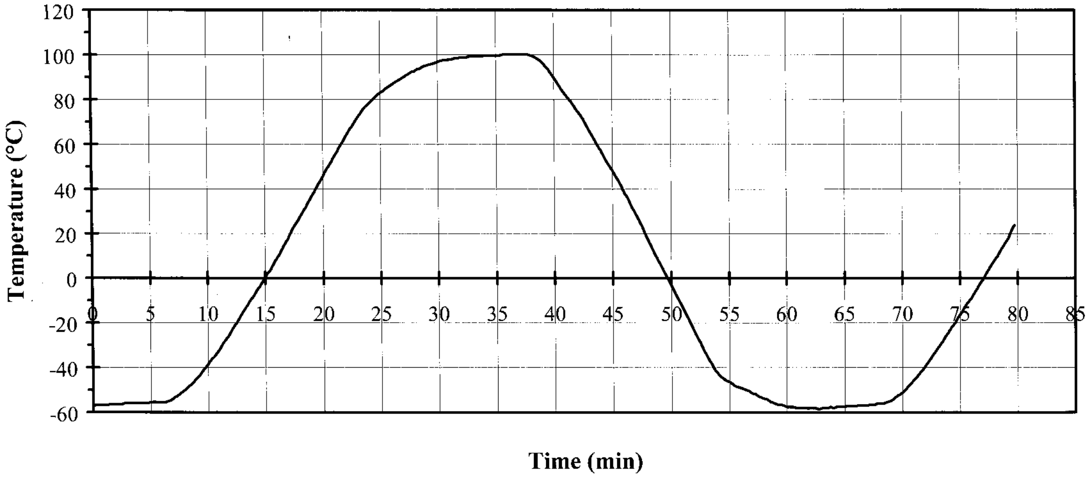

Figure 12. Temperature profile measured for a corner lead to a QFP component during the thermal-cycling test

A high-speed event detector, an Anatek 128IVF, was used for monitoring resistance of the daisy chains *in situ* in the temperature-cycling chamber. The event detector records ultra-short spikes or open circuits in the daisy chains, provided the spikes last at least 1 μs. An open circuit, in this case, was defined as a total daisy-chain resistance above 100 ohms, about five times the measured resistance of the QFP daisy chain prior to the test. The event detector was connected only during the thermal cycling performed after the vibration test.

A failure was defined as the first interruption of electrical continuity that is confirmed by nine additional interruptions within an additional 10% of the cycle life according to the recommendation in IPC-SM-785 [17].

Vibration Test

Sine and random vibration testing was performed using the conditions given in Table 5, which state the minimum severity for vibration testing given in Chapter 13 of ECSS-Q-70-08A [16]. The vibration testing was performed in two axes, one parallel to the long side of the test board and one perpendicular to the test board.

Table 5. Severity levels used for vibration testing

Sine vibration	Frequency range	10-2000 Hz (CPS) at 15 g
	Vibration amplitude	(Peak to peak) 10-70 Hz at 1.5 mm
	Sweep speed	1 octave per minute
	Duration	1 cycle from 10-2000-10 Hz
Random vibration	Frequency range	20-2000 Hz at 15 g (RMS)
	Power spectral density	0.1 g^2/Hz
	Duration	10 min per axis

The test boards were fixed directly to the vibration board using five steel bars as shown in Figure 13. The screws were drawn with a force of 0.25 – 0.27 Nm. Four product response accelerometers were attached to the test boards in the positions shown in Figure 13. The registered responses for the board with EPO-TEK 930 applied beneath the components are given in Figures 14 and 15. The responses were very similar for the board with CV-2946 as staking compound and for the reference board.

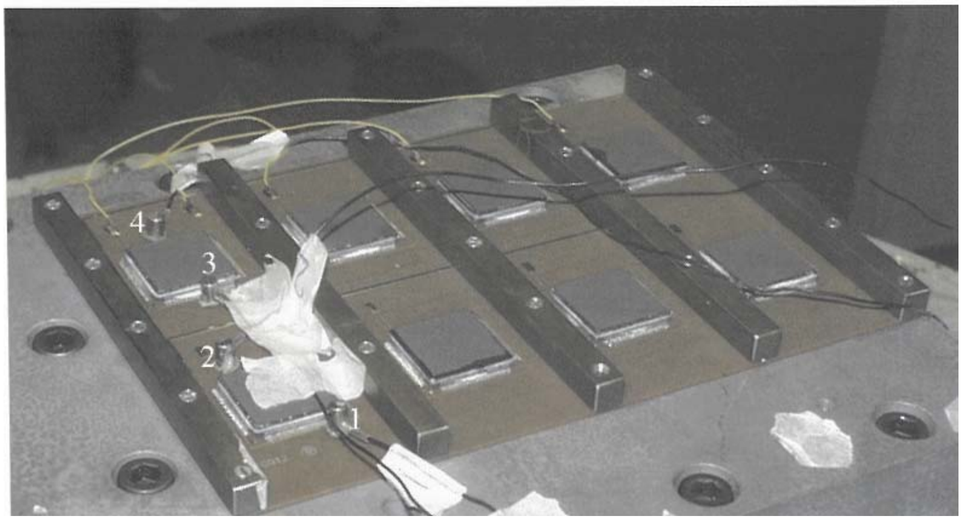

Figure 13. View of test board mounted on the vibration exciter with the four product response accelerometers attached to the test board

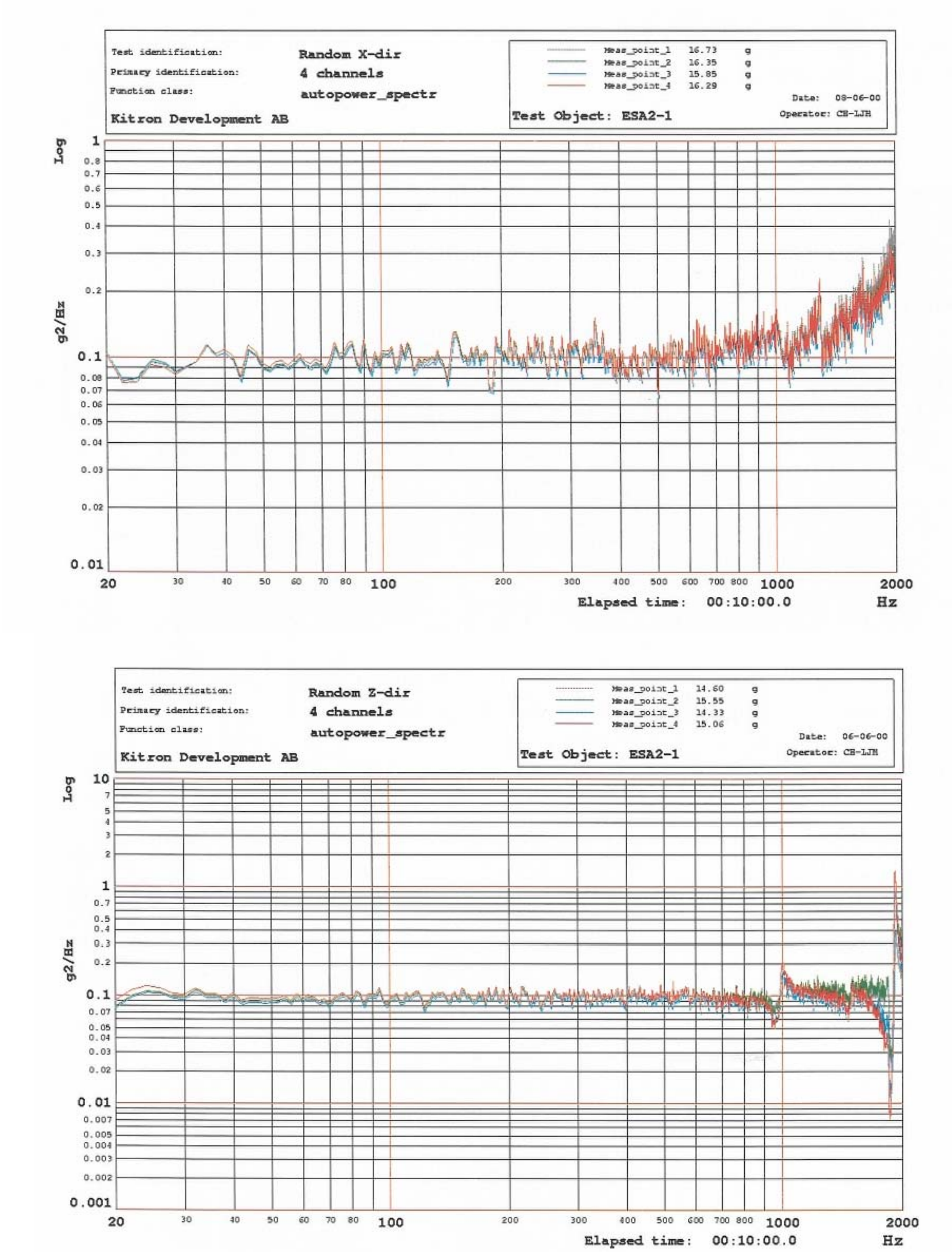

Figure 14. Acceleration spectral density recorded during the random vibration test in the x-direction (upper diagram) and in the z-direction (lower diagram) for the board with EPO-TEK 930 applied beneath the components

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Figure 15. Acceleration recorded during the sine vibration test in the x-direction (upper diagram) and in the z-direction (lower diagram) for the board with EPO-TEK 930 applied beneath the components

4.2 **Results**

Appearance of Solder Joints

The solder joints formed to the QFPs had a smooth shiny surface (Fig. 16). After the reliability verification test, the surface had become quite gritty on all tested boards (Fig. 17).

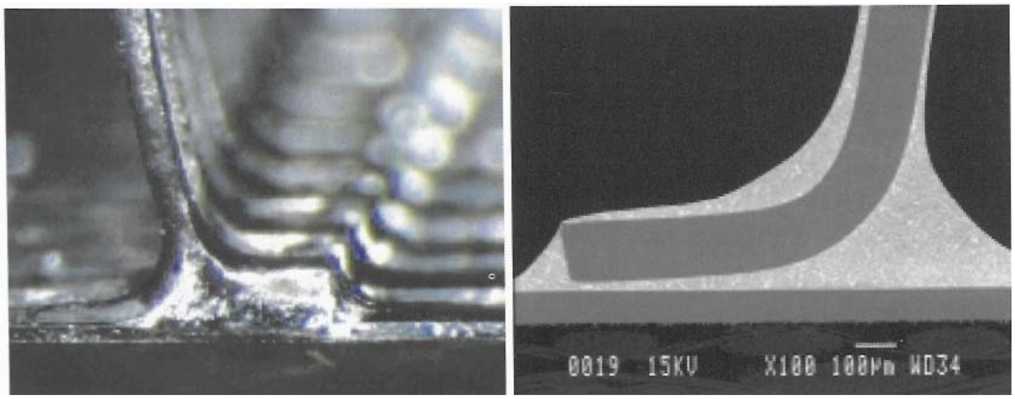

Figure 16. Appearance of as received solder joints before thermal cycling (left), and an SEM photograph of a microsectioned solder joint (right)

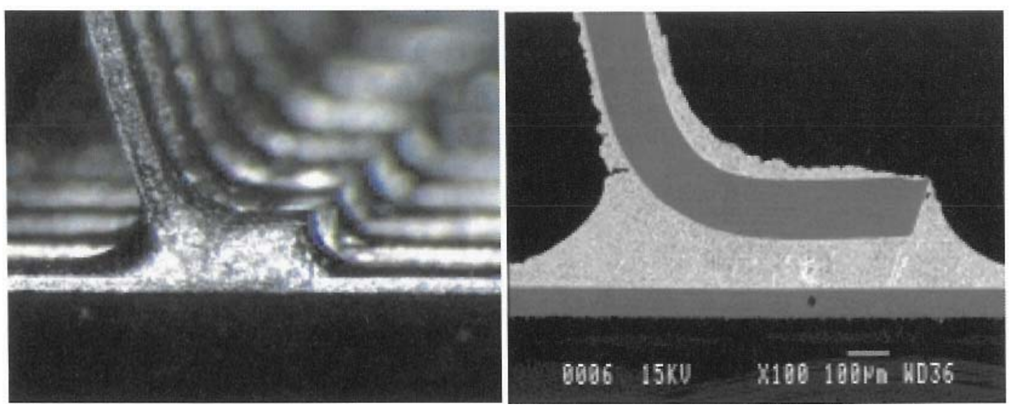

Figure 17. Appearance of solder joints after environmental reliability testing (left), and an SEM photograph of a microsectioned solder joint (right)

Due to the poor planarity of the leads to the components, the geometry of the solder fillets formed varied considerably. Most notably, there was a large variation in lead stand-off. Figure 18 shows the extremes, from almost zero up to about 150 μm (the thickness of the lead). Some lead overhang was also observed for a few joints (Fig. 19).

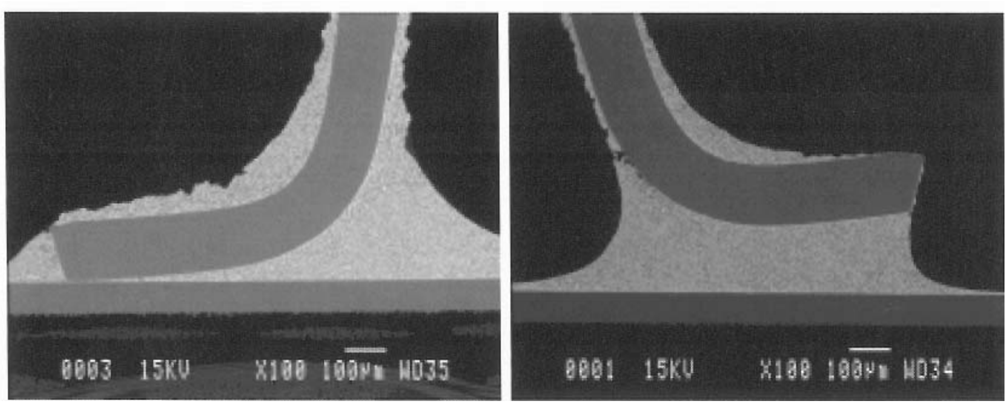

Figure 18. Variation in lead stand-off

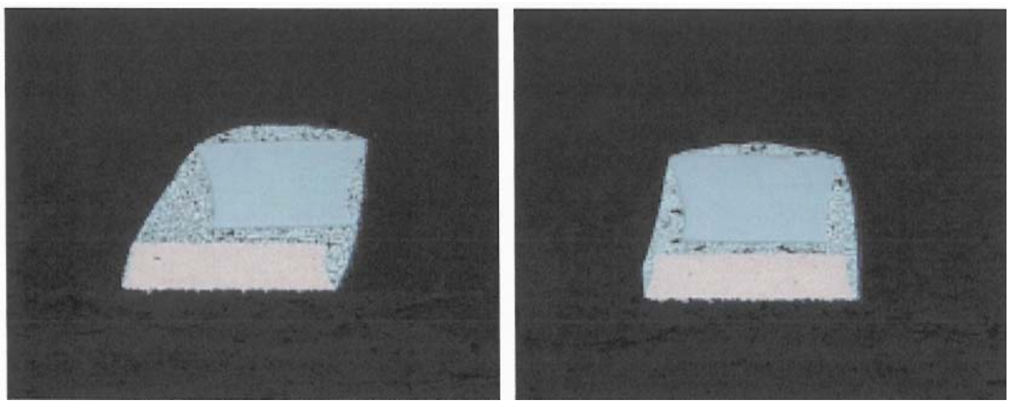

Figure 19. Maximum lead overhang observed (left). In this case, leads close to the lead with overhang were perfectly centred (right)

Integrity of Adhesive Fillets

Both EPO-TEK 930 and CV-2946 still had good contact to component and board surfaces after the reliability testing, indicating good adhesion of these materials. However, moulding in epoxy with a fluorescent agent revealed small cracks in the EPO-TEK 930 material after the reliability test. The cracks were observed at the periphery of the adhesive fillet, extending about 1 mm inward (Fig. 9 and Fig.20). No cracks could be found in the CV-2946 material after testing.

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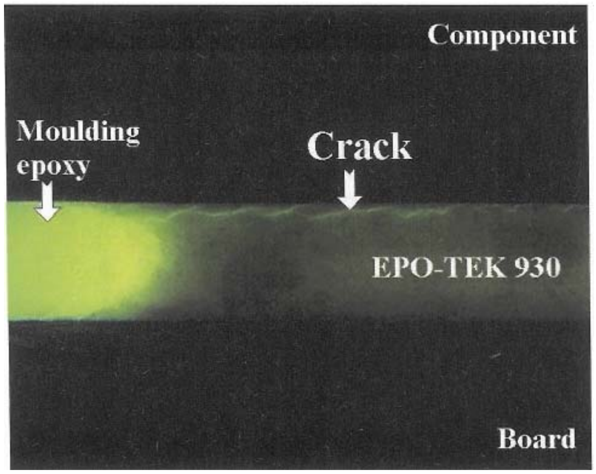

Figure 20. Microsection showing cracks in the EPO-TEK fillet close to a corner of the component formed during reliability testing

Reliability Verification

Electrical Continuity Measurements

Failures were registered for two components during the temperature cycling, one when the measurements were started after the vibration test, i.e. after 100 cycles, and one after 688 cycles. Both components had CV-2946 applied as staking compound. Analysis of the failed components showed that in both cases only one solder joint had failed per component and that the failures were due to bad soldering (Fig. 21). The joint with registered failure when the measurements were started was probably not wetted at all, although there was electrical contact before testing. The joint probably failed after the first temperature cycle. For the joint failing after 688 cycles, which had been reworked, only the toe of the lead had been wetted by the solder.

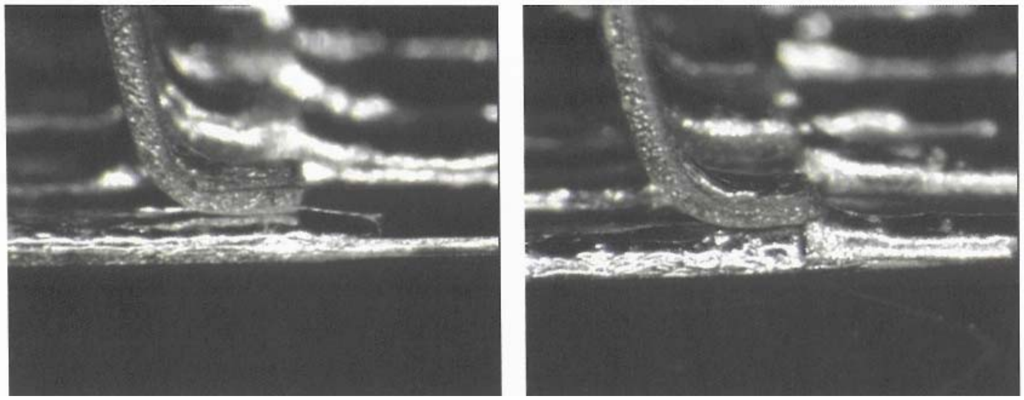

Figure 21. Solder joints with registered opens when the measurements started after 100 cycles (left) and after 688 cycles (right). Both components had CV-2946 applied as staking compound

Microsectioning of Solder Joint

Microsectioning of the solder joints revealed that cracks had started to form at the heel for most of the leads (Figs. 22 - 27). The cracks, all of about the same size, had foilned both at the corners and at the middle of the sides of the components. The occurrences of cracks and their sizes were very similar for the reference components without staking compound, compared to the components with EPO-TEK 930 and CV-2946 as staking compounds.

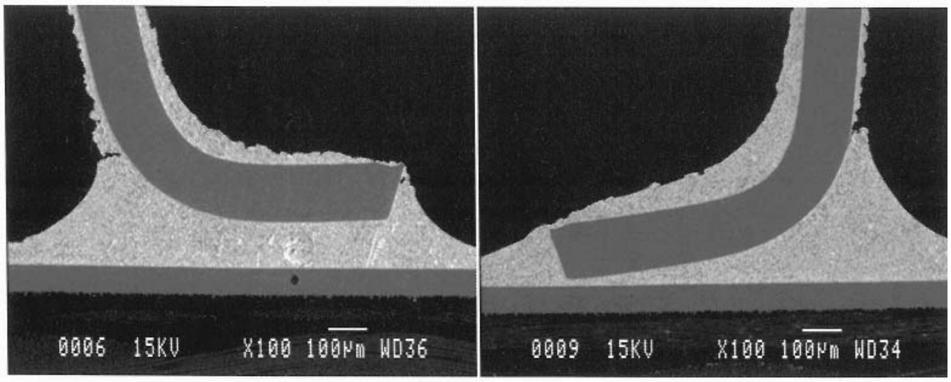

Figure 22. Microsections of corner solder joints on the reference board without staking compound

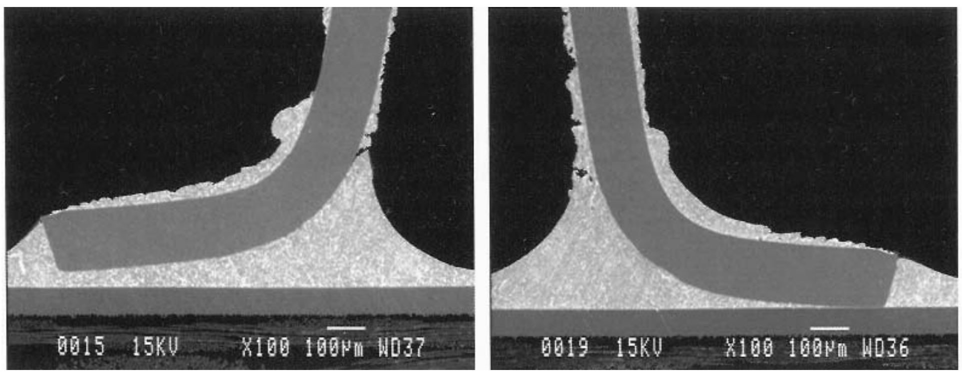

Figure 23. Microsections of centre solder joints on the reference board without staking compound

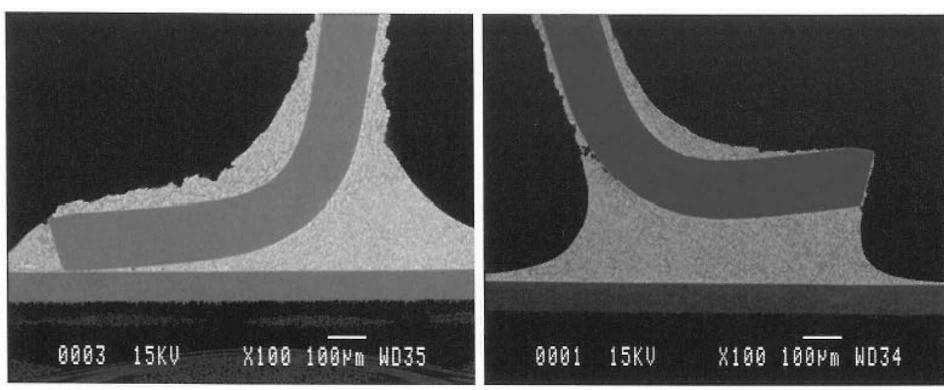

Figure 24. Microsections of corner solder joints on the board with EPO-TEK 930 as staking compound

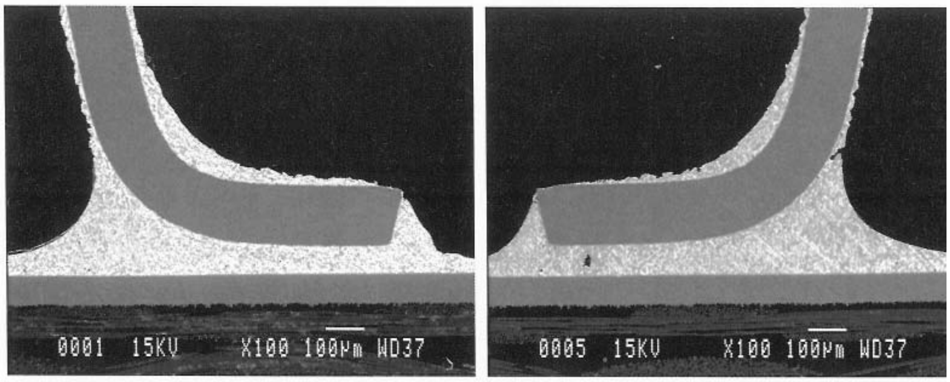

Figure 25. Microsections of centre solder joints on the board with EPO-TEK 930 as staking compound

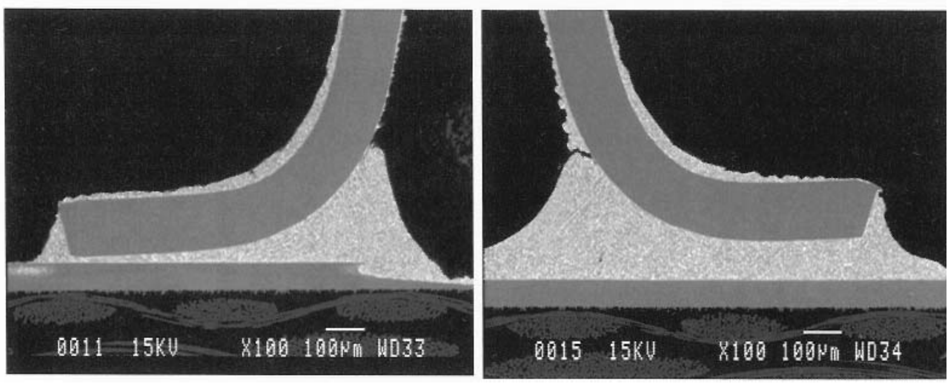

Figure 26. Microsections of corner solder joints on the board with CV-2946 as staking compound

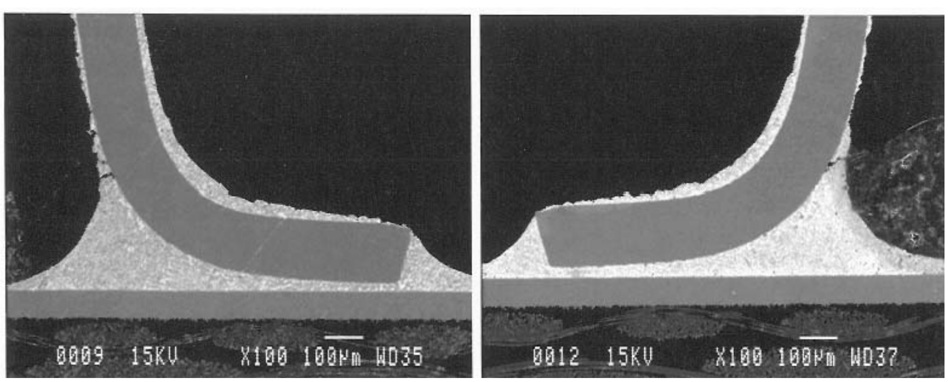

Figure 27. Microsections of centre solder joints on the board with CV-2946 930 as staking compound

A coarsening of the grain structure was observed, especially at the heel of the solder joints where the cracks were initiated. The extent of coarsening was very similar on all test boards, i.e. it was not affected by the application of either of the two staking compounds (Fig. 28).

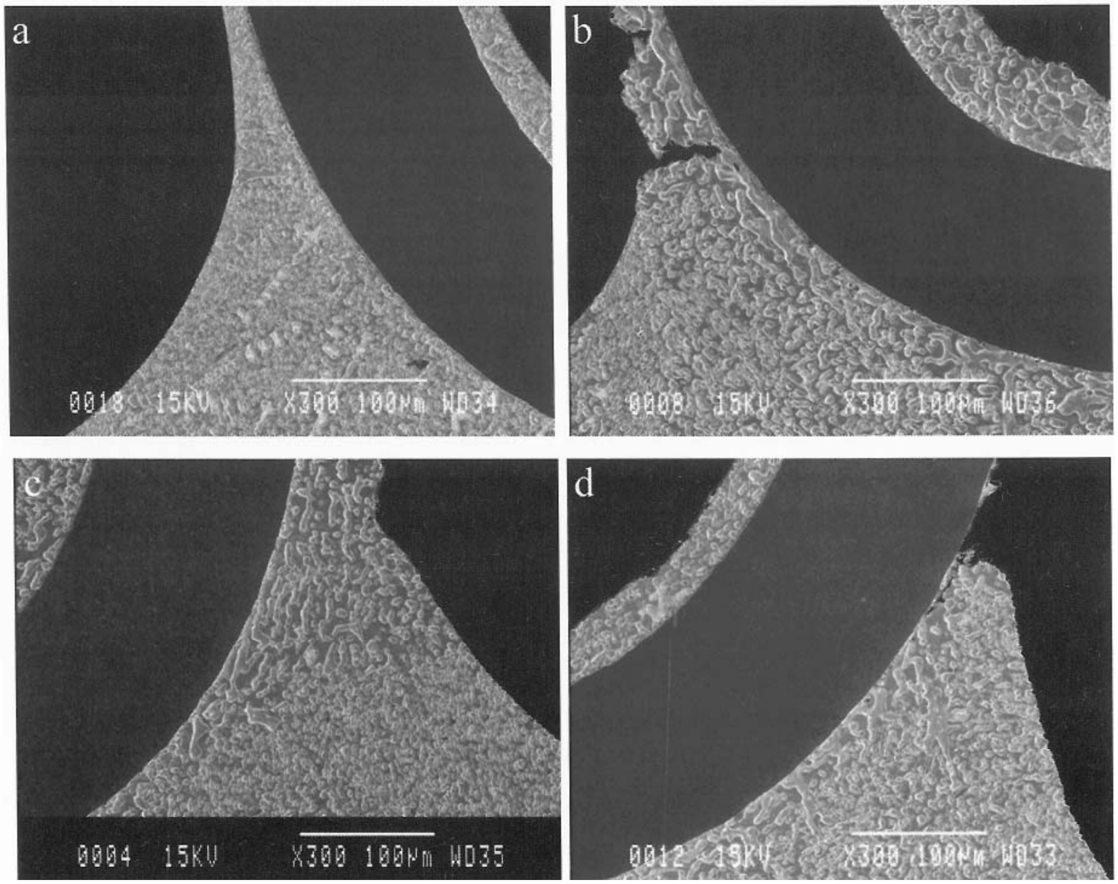

Figure 28. SEMphotographs showing coarsening of the grain structure prior to testing (a) and after testing for components without staking compound (b) and with EPOTEK 930 (c) and CV-2946 (d) as staking compounds

5 Conclusions

(i) Due to the poor coplanarity and bent leads of the test components, the solder joints to the components were far from optimal. Several joints had to be reworked due to open solder joints. Furthermore, some solder joints had lead overhang, which is not acceptable according to the requirements in specification ESA-PSS-O1-738 [18]. Despite these facts, it was considered that the objectives of the investigation could still be achieved using the imperfect test vehicles. In fact, it may make the investigation more adequate since it represents a worst case.

(ii) The results clearly show that the use of EPO-TEK 930 and CV-2946 as staking compounds beneath ceramic QFPs had no observable effect on the fatigue of the solder joints when tested according to ESA-PSS-01-738. The extent of cracking and coarsening of grain structure were the same for solder joints to components without staking compound as for components with staking compound. The observed failures for components with CV-2946 as staking compound can be attributed completely to the poor quality of single solder joints to these components.

(iii) The two-part silicone (CV-2946) is simple to process and apply as a staking compound; however, it was found to have a considerably lower thermal conductivity (1.7 W/mK) at room temperature than specified in the manufacturer's datasheet (3.8 W/mK).

(iv) The epoxy material (EPO-TEK 930) was found to contain particles larger than the 300 µm size specified; these would need to be ground smaller to ensure that the mixed compound can flow into the 0.1 to 0.4 mm stand-off gap between component package and PCB that is required by ESA [18]. Its thermal conductivity was confirmed at 4.2 W/mK.

(v) The Multimat M-4030LD was found to be unsuitable as a staking compound due to its solvent content.

6 Acknowledgements

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7 References

1 Ablestik, 20021 Susana Road, Rancho Dominguez, CA 90221, USA, Phone: 310-764-4600, Fax: 310-764-2545, http://www.ablestik.com.

2 AI Technology Inc., 70 Washington Road, Princeton Junction, NJ 08550, USA, Phone: 609-799-9388, Fax: 609-799-9308, www.aitechnology.com.

3 Dexter Corporation, Electronic Materials, 9938 Via Pasar, San Diego, CA 92126, USA, Phone: 858-695-1716, Fax: 858-695-0951, http://www.dexelec.com.

4 Dow Corning Corporation, Box 0994, Midland, MI 48686-0994, USA, Phone: 800-634-9660, http://www.dowcorning.thomasregister.com.

5 Emerson & Cuming, 46 Manning Road, Billerica, MA 01821, USA, Phone: 978-436-9700, Fax: 978-436-9701, www.emersoncuming.com.

6 Epoxy Technology, 14 Fortune Drive, Billerica, MA 01821, USA, Phone: 978-667-3805, Fax: 978-663-9782, http://www.epotek.com.

7 Loctite Corporation, 1001 Trout Brook Crossing, Rocky Hill, CT 06067-3910, USA, Phone: 860-571-5100, Fax: 860-571-5465, http://www.loctite.com.

8 NuSil Technology, 1050 Cindy Lane, Carpinteria, CA 93013, USA, Phone: 805-684-8780, Fax: 805-566-9905, http://www.nusil.com.

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Appendix A: Market Survey of Thermally Conductive Adhesives

Table A1. Summary of general information about thermally conductive adhesives

Product name	Manufacturer	Thermal conductivity (W/mK)	Chemical type (parts)	Filler	Remark
Thermally conductive adhesives					
ME7159	AI Technology Inc	11.4	Epoxy (1)	Diamond	Very flexible. Suitable for mismatched CTE's. Reworkable.
EPO-TEK 930	Epotek	4.1	Epoxy (2)	Boron nitride	
CV 2946	NuSil	3.8	Silicone (2)	Boron nitride	For bonding heat sinks
CV 2948	NuSil	3.8	Silicone (2)	Boron nitride	For bonding heat sinks
ME7158	AI Technology Inc	3.6	Epoxy (1)	Aluminium nitride	Very flexible. Suitable for mismatched CTE's. Reworkable.
T7109	Epotek	3.0	Epoxy (2)	Boron nitride	Substrate attach, heat sinking, die attach. Dispensable
T6081	Epotek	2.5	Epoxy (1)	Boron nitride	NASA approved, substrate attach, heat sinking, die attach
1-4173	Dow Corning	1.90	Silicone (1)	NS*	Bonding integrated substrate, lids and housing, heat sink
ME7155	AI Technology Inc	1.7	Epoxy (1)	Alumina	Very flexible. Suitable for mismatched CTE's. Reworkable.
T6116	Epotek	1.5	Epoxy (1)	Alumina	Substrate attach, heat sinking, die attach. Dispensable
Eccobond 285/Catalyst 9	Emerson & Cuming	1.44	Epoxy (2)	NS*	
Eccobond 285/Catalyst 11	Emerson & Cuming	1.44	Epoxy (2)	NS*	
H65-175MP	Epotek	1.4	Epoxy (1)	Alumina	NASA approved, MIL for use in hybrids
H70E	Epotek	1.4	Epoxy (2)	Alumina	NASA approved
H70E-4	Epotek	1.4	Epoxy (2)	Alumina	Dispensable staking adhesive
Eccobond 281	Emerson & Cuming	1.4	Epoxy (1)	NS*	For bonding components
Eccobond 276	Emerson & Cuming	1.38	Epoxy (2)	NS*	For high temperature
5404	Loctite	1.33 (100°C)	Silicone (1)	Glass beads	Flexible. Bond metallic heat sinks, ceramic ships and circuit board substrates
Abletherm 12-1	Emerson & Cuming	1.3	Silicone (1)	NS*	
Eccobond 282	Emerson & Cuming	1.3	Epoxy (1)	NS*	For bonding metals and ceramics
CV 2943	NuSil	1.25	Silicone (2)	NS*	
CV 2960	NuSil	1.25	Silicone (2)	NS*	
CV 2961	NuSil	1.25	Silicone (2)	NS*	For bonding heat sinks
3873	Loctite	1.25	Acrylic ester (1)	Glass beads	Bonding heat generating devices to thermal speaders

T7110	Epotek	1.25	Epoxy (2)	Alumina?	Substrate attach, heat sinking, die attach. Cryogenic appl.
Eccobond 285/Catalyst 24LV	Emerson & Cuming	1.22	Epoxy (2)	NS*	
3872	Loctite	1.2	Acrylic urethane (1)	Glass beads	UV and heat cured, bonding to heat sink. Repairable
Elastosil RT 675	Wacker-Chemie	1.2	Silicone (2)	NS*	Extreme hardness
H67-MP	Epotek	1.1	Epoxy (1)	Alumina	NASA approved, MIL for use in hybrids, dispensable
H74	Epotek	1.1	Epoxy (2)	Alumina	Dispensable paste, sealing of lid, NASA approved
CV 2942	NuSil	1.05	Silicone (2)	NS*	
H77	Epotek	1.0	Epoxy (2)	Alumina	Dispensable paste, sealing of lid, NASA approved
CV 2942	NuSil	1.0	Silicone (2)	NS*	
Thermally and electrically conductive adhesives					
QMI 5030	Dexter	25	Thermoset/thermoplastic (1)	Silver	Attachment of components
Thermaxx 2600K	Ablestik	20	Thermoset/thermoplastic (1)	Silver	Die and heat sink attach
QMI 4030LD**	Dexter	15	Thermoplastic (1)	Silver	Reworkable
MD-140	Thermoset	13	NS*	Silver	Die attach, dispensable
EG8050	AI Technology Inc	7.9	Epoxy (1 or 2)	Silver	Very flexible. Suitable for mismatched CTE's. Reworkable.
ME8456	AI Technology Inc	7.9	Epoxy (1)	Silver	Very flexible. Suitable for mismatched CTE's. Reworkable.
QMI 4030SR**	Dexter	5	Thermoplastic (1)	Silver	Can replace solder in SMT
Hysol KO111	Dexter	3.7	Epoxy (1)	Silver	Attachment of IC and components to leadframes
QMI 516	Dexter	3.7	BMI	Silver	Hydrophobic
Ablebond 84-1LMIT1	Emerson & Cuming	3.60	NS*	Silver	Chip attach, Screen-printable
Hysol KO110	Dexter	3.5	Epoxy (1)	Silver	Attachment of IC and components to leadframes
Ablebond 8206	Ablestik	3.0	NS*	Silver	Die attach
Ablebond 8207	Ablestik	3.0	NS*	Silver	Die attach
Ablebond 8177	Emerson & Cuming	3.0	Epoxy	Silver	Chip attach, dispensable
QMI 509	Dexter	2.9	BMI	Silver	Hydrophobic
Hysol KO120	Dexter	2.8	Epoxy (1)	Silver	Attachment of IC and components to leadframes
MD-110	Thermoset	2.33	Epoxy (1)	NS*	Die attach
QMI 505MT	Dexter	2.0	BMI	Silver	Hydrophobic
QMI 301	Dexter	1.9	Cyanate ester (1)	Silver	Attacment of IC to cofired ceramic packages
Ablebond 8700E	Ablestik	1.6	Epoxy	Silver	Die attach, dispensable and printable
QMI 518	Dexter	1.5	BMI	Silver	Hydrophobic
QMI 505	Dexter	1.4	BMI	Silver	Hydrophobic

QMI 506	Dexter	1.2	BMI	Silver	Hydrophobic
Encapsulants					
Stycast 2851 KT	Emerson & Cuming	2.78	Epoxy (1)	NS*	Heat sinks can be cast in place
1-4174	Dow Corning	1.90	Silicone (1)	NS*	
H70E-2	Epotek	1.4	Epoxy (2)	Alumina	Dispensable
Circalok 6703	Thermoset	1.3	Silicone (2)	NS*	
Stycast 4954/Catalyst 50	Emerson & Cuming	1.3	Silicone (2)	NS*	
Stycast 2850 FT/Catalyst 11	Emerson & Cuming	1.28	Epoxy (2)	NS*	
Stycast 2850 FT/Catalyst 9	Emerson & Cuming	1.25	Epoxy (2)	NS*	
Stycast 5954 A/B	Emerson & Cuming	1.15	Silicone (2)	NS*	Encapsulation of heat generating devices
920-FL	Epotek	1.1	Epoxy (2)	Alumina	
Stycast 2850 FT/Catalyst 24 LV	Emerson & Cuming	1.02	Epoxy (2)	NS*	
3-6642	Dow Corning	1.00	Silicone (2)	NS*	Repairable, flexible
Stycast 4952	Emerson & Cuming	1.0	Silicone (2)	NS*	
Films					
Ablefilm 5025E	Emerson & Cuming	3.50	Epoxy	Silver	Electrically conductive
Ablefilm ECF550X	Emerson & Cuming	2.1	Epoxy	Silver	Electrically conductive
Ablefilm ECF561E	Emerson & Cuming	1.60	Epoxy	Silver	Electrically conductive, flexible
Ablefilm 563K	Emerson & Cuming	1.10 at 121 C	Epoxy	NS*	For bonding hot devices onto heat sink

* NS = Not Specified
** Supplied in Europe by Multicore as Multimat

Table A2. Summary of specific data for thermally conductive adhesives

Product name	Thermal conduct. (W/mK)	Viscosity (mPas)	Gravity (g/cm^3)	Cure schedule (lowest temp./highest temp.)	Hardness (Shore A)	Tg (°C)	CTE (ppm/°C)	TML (%)	RML (%)	CVCM (%)	Use temperature (°C)
Thermally conductive adhesives											
ME7159	11.4	Paste	2.3	8 h @ 80°C / 10 min @ 200°C	80	-25	120	0.23	-	0.031	Up to 150
EPO-TEK 930	4.1	Paste	2.9	45 min @ 80°C / 5 min @ 120°C	88**	90	37/121	0.5	0	0.01	Up to 150
CV 2946	3.8	Paste	1.54	7 d @ 25°C / 15 min @ 10°C	70	NS*	NS*	0.50	-	0.01	- 65° to + 250°C
CV 2948	3.8	Paste	1.54	7 d @ 25°C / 15 min @ 10°C	70	NS*	NS*	0.50	-	0.01	- 115° to + 260°C
ME7158	3.6	Paste	2.3	8 h @ 80°C / 10 min @ 200°C	80	-25	120	0.28	-	0.053	Up to 150
T7109	3.0	11500	NS*	8 h @ 80°C / 10 min @ 150°C	NS*	85	40/120	-	-	-	Up to 175
T6081	2.5	7000-8000	NS*	60 min @ 60°C / 30 min @ 200°C	NS*	225	40/120	-	-	-	Up to 160
1-4173	1.90	58000	2.70	90 min @ 100°C / 20 min @ 150°C	92	NS*	NS*	-	-	-	NS*
ME7155	1.7	Paste	2.3	8 h @ 80°C / 10 min @ 200°C	80	-25	120	0.54	-	0.067	Up to 150
T6116	1.5	13000	NS*	15 min @ 150°C / 1 min @ 175°C	NS*	92	36/110	-	-	-	Up to 175
Eccobond 285/Catalyst 9	1.44	Paste	2.27	16-24 h @ 25°C / 1-2 h @ 65°C	NS*	NS*	NS*	0.29	-	0.00	- 40° to + 130°C
Eccobond 285/Catalyst 11	1.44	Paste	2.27	8-16 h @ 80°C / 30-60 min @ 120°C	NS*	112	29	0.28	-	0.01	- 55° to + 155°C
H65-175MP	1.4	Paste	NS*	60 min @ 180°C	NS*	180	55/165	-	-	-	Up to 175
H70E	1.4	4000-7000	NS*	3 h @ 80°C / 1 min @ 175°C	NS*	>80	45/165	-	-	-	Up to 150
H70E-4	1.4	20000-40000	NS*	3 h @ 80°C / 1 min @ 175°C	NS*	>80	55/185	-	-	-	Up to 150
Eccobond 281	1.4	Paste	2.3	4 h @ 80°C / 15 min @ 180°C	88**		32,4	0.35	-	0.06	- 55° to + 180°C
Eccobond 276	1.38	Paste	2.24	4 h @ 65°C / 20 min @ 150°C	90**	27	55/150	0.38	-	0.01	- 40° to + 230°C
5404	1.33 (100 C)	Paste	2.35	15 min @ 130°C / 10 min @ 150°C	57	-40	/104	-	-	-	NS*
Abletherm 12-1	1.3		2.3	4 h @ 65°C / 20 min @ 150°C	90	12	55/150	-	-	-	Up to 200
Eccobond 282	1.3	Paste	2.3	4 h @ 100°C / 15 min @ 175°C	85**	NS*	NS*	-	-	-	- 40° to + 180°C
CV 2943	1.25	Paste	2.60	7 d @ 25°C	90	NS*	NS*	0.5		0.01	- 115° to + 260°C
CV 2960	1.25	Paste	NS*	7 d @ 25°C / 10 min @ 150°C	50	NS*	NS*	<0.1	<0.02	<0.01	- 65° to + 250°C
CV 2961	1.25	Paste	1.26	7 d @ 25°C / 10 min @ 150°C	50	NS*	NS*	<0.1	<0.02	<0.01	- 115° to + 260°C
3873	1.25	Paste	2.08	Primer activated, 24 h @ 70°C	72**	49	/76	-	-	-	NS*
T7110	1.25	3000	NS*	24 h @ 25°C / 2 h @ 60°C	NS*	70	70/160	-	-	-	Up to 150
Eccobond 285/Catalyst 24LV	1.22	Paste	2.18	8-16 h @ 25°C / 30-60 min @ 65°C	NS*	NS*	NS*	1.00	-	0.00	- 65° to + 105°C

3872	1.2	Paste	2.5	UV + 60 min @ 100°C / 10 min @ 140°C	71**	-33	/90	-	-	-	NS*
Elastosil RT 675	1.2	35000	2.3	24 h @ 25°C / 10 min @ 150°C	80	NS*	160	-	-	-	NS*
H67-MP	1.1	10500-15500	NS*	60 min @ 150°C	NS*	110	55/137	-	-	-	Up to 175
H74	1.1	40000-80000	NS*	12 h @ 50°C / 20 min @ 100°C	NS*	>100	38/127	-	-	-	Up to 150
CV 2942	1.05	Paste	2.42	7 d @ 25°C	90	NS*	NS*	0.5	-	0.01	- 65° to + 250°C
H77	1.0	6000-12000	NS*	60 min @ 150°C	NS*	>90	22/110	-	-	-	Up to 160
CV 2942	1.0	Paste	NS*	4 h @ 65°C / 60 min @ 100°C	90	NS*	NS*	0.5	-	0.01	- 65° to + 250°C
Thermally and electrically conductive adhesives											
QMI 5030***	25	5500	3.60	30 min @ 175°C	NS*	50	74/	-	-	-	NS*
Thermaxx 2600K	20	8100	3.8	30 min @ 100 to 200°C + 15 min @ 200°C	NS*	68	36/	-	-	-	NS*
QMI 4030LD	15	32500	3.42	30 min @ 150°C	NS*	15	28/	-	-	-	NS*
MD-140	13	30000	3,8	5-10 min @ 120°C / 1-3 min @ 180°C	NS*	82	13/32	-	-	-	NS*
EG8050	7.9	Paste	4.0	48 h @ 25°C / 10 min @ 150°C	NS*	-20	120	0.57	-	0.016	Up to 130
ME8456	7.9	Paste	3.5	16 h @ 80°C / 10 min @ 200°C	80	-20	100	0.25	-	0.05	Up to 150
QMI 4030SR***	5	42500	3.07	15 min @ 150°C	NS*	30	30/	-	-	-	NS*
Hysol KO111	3.7	7500	4.2	10 min @ 165°C	NS*	68	57/	-	-	-	NS*
QMI 516	3.7	8000	3.93	15 min @ 150°C	NS*	-33	51/112	-	-	-	NS*
Ablebond 84-1LMIT1	3.60	22000	NS*	2 h @ 120°C / 60 min @ 150°C	NS*	103	50/200	-	-	-	NS*
Hysol KO110	3.5	7000	4.0	10 min @ 165°C	NS*	78	57/	-	-	-	NS*
Ablebond 8206	3.0	13800	NS*	60 min @ 160°C	NS*	63	50/160	-	-	-	NS*
Ablebond 8207	3.0	11000	NS*	60 min @ 160°C	NS*	63	50/160	-	-	-	NS*
Ablebond 8177	3.0	22000	3.91	4 min @ 130°C	NS*	NS*	NS*	-	-	-	NS*
QMI 509	2.9	9000	3.5	15 min @ 150°C	NS*	1	77/168	-	-	-	NS*
Hysol KO120	2.8	7500	3.8	10 min @ 165°C	NS*	99	63/	-	-	-	NS*
MD-110	2.33	150000	2.9	30 min @ 130°C / 15 min @ 150°C	NS*	60	80/250	-	-	-	NS*
QMI 505MT	2.0	10700	3.42	15 min @ 180°C	NS*	-10	72/170	-	-	-	NS*
QMI 301	1.9	11400	3.8	15 min @ 130°C / 10 min @ 150°C	NS*	245	45/85	-	-	-	NS*
Ablebond 8700E	1.6 (2.1 @ 121 C)	18000	NS*	2 h @ 120°C / 60 min @ 175°C	NS*	160	45/120	-	-	-	NS*
QMI 518	1.5	8200	3.08	15 min @ 150°C	NS*	-64	69/152	-	-	-	NS*
QMI 505	1.4	8000	3.13	15 min @ 150°C	NS*	-30	74/166	-	-	-	NS*
QMI 506	1.2	8500	2.97	15 min @ 150°C	NS*	-32	74/177	-	-	-	NS*

Encapsulants											
Stycast 2851 KT	2.78	40000-70000	2.80	1 min @ 120°C / 5 min @ 80°C	94**	NS*	30	0.29	-	0.04	- 55° to + 155°C
1-4174	1.90	58000	2.71	90 min @ 100°C / 20 min @ 150°C	92	NS*	NS*	-	-	-	NS*
H70E-2	1.4	9000-15000	NS*	3 h @ 80°C / 1 min @ 175°C	NS*	>80	46/170	-	-	-	Up to 150
Circalok 6703	1.3	8000	2.00	4 h @ 65°C / 1 h @ 100°C	60	NS*	100	-	-	-	- 55° to + 205°C
Stycast 4954/Catalyst 50	1.3	40000	2.30	16-24 h @ 25°C / 2-4 h @ 65°C	80	NS*	157	0.17	-	0.08	- 65° to + 260°C
Stycast 2850 FT/Catalyst 11	1.28	64000	2.29	8-16 h @ 80°C / 30-60 min @ 120°C	96**	115	31/98	0.29	-	0.02	- 55° to + 155°C
Stycast 2850 FT/Catalyst 9	1.25	58000	2.29	16-24 h @ 25°C / 1-2 h @ 65°C	96**	86	35/99	0.25	-	0.01	- 40° to + 130°C
Stycast 5954 A/B	1.15	35000	2.45	2-7 d @ 25°C / 20 min @ 150°C	85	-120	150	-	-	-	- 65° to + 260°C
920-FL	1.1	5000-13000	NS*	20 min @ 100°C / 5 min @ 150°C	NS*	>90	42/20	-	-	-	up to 150
Stycast 2850 FT/Catalyst 24 LV	1.02	5600	2.19	8-16 h @ 25°C / 30-60 min @ 65°C	92**	68	39/112	0.39	-	0.00	- 65° to + 105°C
3-6642	1.00	5100	2.21	20 min @ 100°C / 5 min @ 150°C	82	NS*	180	-	-	-	- 40° to + 20°C
Stycast 4952	1.0	35000	2.20	16-24 h @ 25°C / 4-6 h @ 65°C	70	NS*	162	-	-	-	- 65° to + 260°C
Films											
Ablefilm 5025E	3.50	-	NS*	2 h @ 125°C / 30 min @ 150°C	NS*	90	65/150	-	-	-	NS*
Ablefilm ECF550X	2.1	-	NS*	2 h @ 125°C / 60 min @ 150°C	NS*	109	40/500	-	-	-	NS*
Ablefilm ECF561E	1.60	-	NS*	2 h @ 125°C / 60 min @ 150°C	NS*	47	100/380	-	-	-	NS*
Ablefilm 563K	1.10 at 121 C	-	NS*	2 h @ 125°C / 30 min @ 150°C	NS*	97	45/500	-	-	-	NS*

* NS = Not specified
** Shore D
*** Supplied in Europe by Multicore as “Multimat”.