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# EVALUATION OF HIGH RELIABILITY REWORKABLE EDGE BOND ADHESIVES FOR BGA APPLICATIONS

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**ABSTRACT**
Reworkable edge bond adhesives are finding increasing utility in high reliability and harsh environment applications. The ASICs and FPGAs often used in these systems typically require designs incorporating large BGAs or ceramic BGAs. For these high reliability and harsh environment applications, these packages typically require underfill to achieve the needed thermal cycle, mechanical shock and vibration reliability. Moreover, these applications often incorporate high dollar value printed circuit boards (on the order of thousands or tens of thousands of dollars per PCB) hence the need to rework these assemblies and maintain the integrity of the PCB and high dollar value BGAs. This further complicates the underfill requirements with a reworkablity component. Reworkable underfills introduce a number of process issues that can result in significant variability in reliability performance. In contrast, edge bond adhesives provide a high reliability solution with substantial benefits over underfills.

This paper presents a study of new high performance reworkable edge bond materials designed to improve the reliability of large area BGAs and ceramic BGAs assemblies while maintaining good reworkablity. Four reworkable edge bond materials (commercially available) were studied. Test vehicles included 12mm BGAs with plans to expand the study to include ceramic BGAs and large area BGAs. Process development was also conducted on the edge bond process to determine optimum process conditions. For edge bond processing, establishing an edge bond that maximizes bond area without encapsulating the solder balls is key to achieving high reliability. The reliability testing protocol used included board level thermal cycling (-40 to 125 °C) and random vibration testing (3 G, 10 – 1000 Hz).

Key words: Reworkable, Edge Bond, Adhesive, BGA, Large Area BGA

## INTRODUCTION
Edge bond adhesives are an innovative solution for providing high reliability with a substantially easier process. Edge bond adhesives eliminate the plaguing concerns of flux selection, flux-underfill compatibility, underfill voiding, underfill flow time, underfill delamination, and solder extrusion into underfill voids during thermal and power cycling.

Edge bonding refers to a technique in which high adhesion, adhesives are dispensed along the corner edges of a component such as a BGA, CSP, WLCSP, BTN, etc. Edge bonding is done with and without partial encapsulation of the solder balls in area array components. This study focused on thixotropic edge bond adhesives which do not gap flow or partially encapsulate the solder balls. Figure 1 shows an example of edge bonding of the CTBGA228 component. Figure 2 shows a planar cross section of a CTBGA228 with edge bond near the solder joint to board interface. Notice with this edge bond approach that the material does not flow under the BGA and encapsulate the solder joints in any way. Partial encapsulation of the solder joints can lead to stress concentrations on the solder joints and premature fatigue failure of the solder.

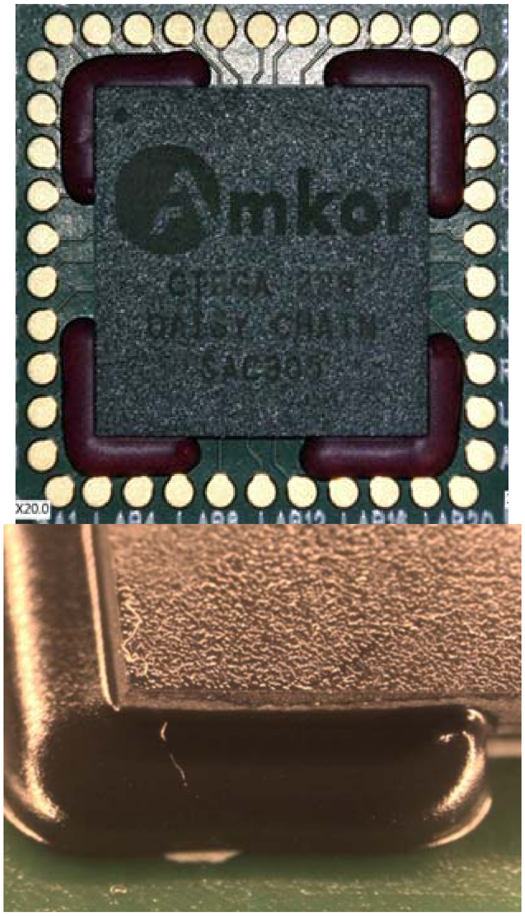


**Figure 1:** Edge Bonding of the CTBGA228

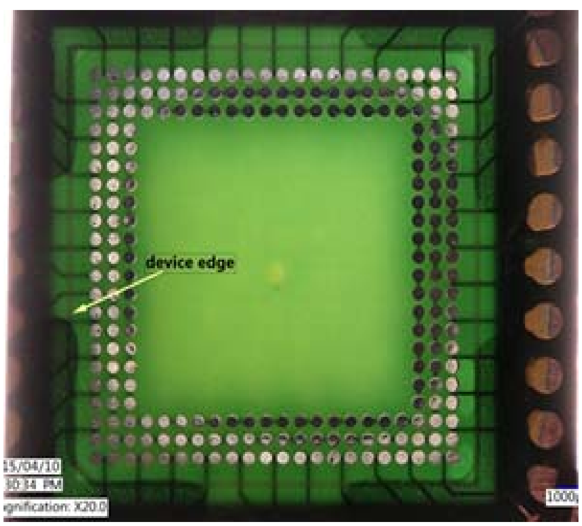
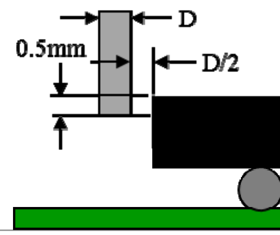
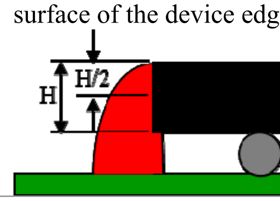



**Figure 2:** Planar Cross Section of Edge Bonded CTBGA228

Processing edge bond adhesives differs from traditional underfill processing. It is a considerably simpler process and often results in reduced cycle times. Key process parameters of the edge bond process are given in Table 1.

**Table 1:** Key Process Parameters for Edge Bonding

| Process Parameter | Description and Range |
|---|---|
| **Needle Size** | • Range: 25~20 gauge<br>• Used for this Development: 25 gauge<br>• Type: Plastic Luer Lock with Metal Needle Tip |
| **Needle Height** | • Range: Above the device edge midpoint, or 0 to 0.5mm below the device top surface<br>• Used for this Development: 0.5mm below the top surface of the device |
| **Needle Edge Spacing** | • Range: Half to three quarters of the needle outer diameter (D)<br>• Used for this Development: D/2, half of the needle diameter<br> |
| **Dispense Needle Speed** | • Range: 1 to 4 mm/second<br>• Typical Values:<br>• 2.5 mm/sec for 8x13mm BGA<br>• 1.5 mm/sec for 11x11mm BGA<br>• 2.2 mm/sec for 27x27mm BGA<br>• 3.5 mm/sec for 12x12mm CTBGA228 |
| **Dispense Valve Type** | • Positive Displacement Auger Valve |
| **Valve Back Pressure** | • Range: 20 to 60 psi<br>• Used for this Development: 45 psi |
| **Bonding Height At Corners and Edges** | • Range: Above the half of the device edge, and below the top surface of the device edge<br>• Used for this Development: Below the top surface of the device edge<br> |
| | (Continued on next page) |

<table>
<tr><td>Bonding Length At Edges</td><td>
<ul>
<li>Range: 1/4 to 1/3 of the device edge length (L)</li>
<li>Used for this Development:
<ul>
<li>1/3 of the device edge length for VFBGA & CABGA (rectangular & small BGAs)</li>
<li>1/4 of the device edge length for PBGA (larger BGAs)</li>
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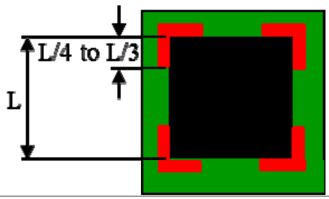

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## EXPERIMENTAL APPROACH

### Test Plan

Four commercial high performance Edge Bond Adhesives, designated as material A, B, C, and D are evaluated in this study. Four criteria are investigated and the test plan for each of them is listed below.

□ Material Properties Comparison:
- › Viscosity, Thixotropy, Tg, Modulus, CTE

□ Reworkability:
- › Use the assembled boards and apply 4 edge bond adhesives.
- › Rework the samples for each edge bond, evaluate the reworkability.
- › Rework criteria – see Table 2

□ Thermal Cycle Reliability Test:
- › 2 boards (30 parts)/edge bond, 4 edge bond adhesives.
- › -40°C~125°C, Dwell time: 15 minutes. Total cycle time: 34 minutes
- › Probe the daisy chains every 200 cycles.
- › Per JESD22-A104, test condition G, soak mode 4.

□ Random Vibration Reliability Test:
- › 1 board (15 parts)/edge bond, 4 edge bond adhesives.
- › Per JEDEC JESD22-B103. Service condition 3, 3G peak acceleration, 10 to 1000 Hz, 30 min each axis. Extend vibration testing if needed.

### Test Vehicle

The BGA test vehicle used for the edge bond adhesive evaluation was based on JEDEC standard JESD22-B111, shown in Figure 3. The dimensions of these 8 layer boards are 132mm x 77mm x 1mm. ENIG was used as the surface finish. One board side was designed for thermal cycle reliability test, and the other side was designed for drop reliability test. The layout design for both sides were the same and they used the same solder mask defined SMD pads. The only difference for the drop side is that via-in-pad was adopted and the traces were duplicated on the outer layer and one inner layer to avoid the trace failure during the drop test. There were 15 devices on each side. The devices used in this evaluation were Amkor CTBGA228, as shown in Figure 4. This CTBGA (ChipArray Thin Core Ball Grid Array) daisy chain device has a 0.5mm pitch, and 12mmx12mm body dimension. The ball matrix is 22x22 with a perimeter ball alignment. The solder balls use SAC305 alloy and their diameters are 0.30 ± 0.05mm.

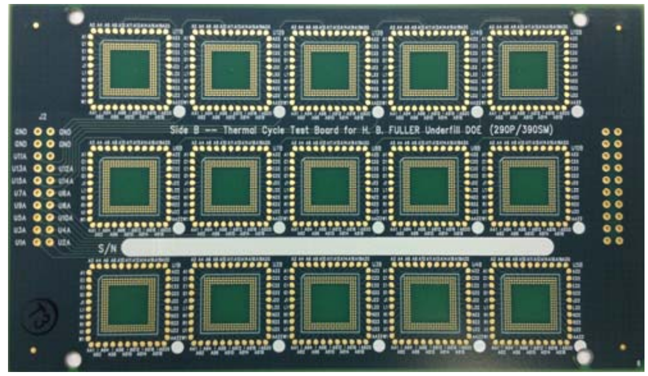


**Figure 3:** Test vehicle for reworkable underfill evaluation


**Figure 4:** Device used in the reworkable underfill evaluation

## RESULTS

### Materials Property Comparison

Some key material property data and process data is give in Table 2. The four materials have a very wide range of viscosities and Tg values ranging from 74 to 120 °C. They also have CTE (α1) values that range from low to moderate.

**Table 2:** Edge Bond Material Properties

| Property | Matl. A | Matl. B | Matl. C | Matl. D |
|---|---|---|---|---|
| **Viscosity (cps) @25 °C** | 114,000 | 90,500 | 350 | 580,000 |
| **Thixotropic Index** | 5.12 | 5.61 | 7.5 | 4.5 |
| **Work Life (Days)** | 1 | 1 | 7 | 12 |
| **Modulus (MPa)** | 8450 | | | 3850 |
| **Tg (°C) (TMA)** | 110 | 120 | 74 | 127 |
| **CTE, α1 (ppm/°C)** | 30 | 57 | | 31 |
| **CTE, α2 (ppm/°C)** | 95 | 105 | | 110 |
| **Cure Conditions** | 130 °C for 8 min | 120 °C for 3min | 150 °C for 90 sec | 130 °C for 8 min |

**Table 3:** Edge Bond Adhesive Reliability for CTBGA Test Vehicle

| Edge Bond | T0 | T100 | T200 | T300 | T400 | T500 | T600 | T700 | T800 | T900 | T1000 | T1200 | T1400 | T1600 | T1800 | T2000 | T2200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Matl. A | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 |
| Matl. B | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 1/30 | 1/30 | 2/30 |
| Matl. C | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | | | |
| Matl. D | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 | 0/30 |

**Reworkablility**

The edge bond adhesives provided excellent reworkability and a considerably simpler rework process compared with reworkable underfills. For thixotropic edge bond adhesives, the components can be locally heated to soften the adhesive allowing it to be removed with a soft wooden spatula. This is typically done at 50 to 100 °C above the edge bond Tg. For large thermal mass assemblies, the PCB assembly may need to be pre-heated to 100 to 150°C to improve reworkability. With the edge bond removed, the component temperature can be raised to solder reflow temperatures and removed. With the adhesive completely removed, no extra shear or torque is required to remove the component as is the case with reworkable underfills significantly simplifying the rework process.

**Thermal Cycle Reliability**

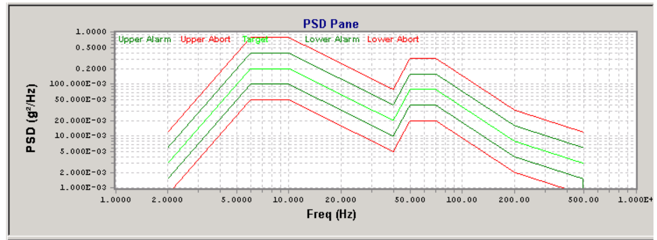
Thermal cycle reliability testing per JESD22-A104 from -40 to 125°C with 15min dwell times was conducted on the four edge bond materials using the CTBGA228 test vehicle. Daisy chain continuity measurements were performance on as processed assemblies and after every 200 cycles. The failure criteria used was daisy chain loops exhibiting 50% increases in resistance from their baseline measurements.

Table 3 shows the thermal cycle reliability performance for the four edge bond materials tested. The table entries indicate the "number of failed components/total number of components tested" (e.g., 0/30 can be read 0 components failed out of 30 components tested).

Material A and D show excellent reliability performance with no failures through 2200 cycles. Matl. C has no failures through 1600 cycles, and it's testing is ongoing. Matls. B also exhibits very good reliability performance with the first failure at 1800 cycles.

**Random Vibration Reliability**

Random vibration reliability testing per JESD22-B103 with a peak acceleration of 3G's, frequency range of 10 to 1000Hz, was conducted on the four edge bond materials using the CTBGA228 test vehicle. Daisy chain continuity measurements were performance on as processed assemblies. Per the JEDEC standard, each board axis (x, y, and z) is subject to a random vibration profile for 30 min. Figure 5 shows the vibration controller profile used for testing. Figure 6 shows the 3 axis fixturing used for the vibration testing. An Analysis Technology event detector was used to track interconnect failures in situ. The failure criteria used was a threshold resistance of 1000 ohms monitored independently on each assembled component in situ.




| Apply | Frequency (Hz) | Power Spectral Density ($g^2$/Hz) | Calculate | Slope (dB/Oct) | Upper Alarm (dB) | Lower Alarm (dB) | Upper Abort (dB) | Lower Abort (dB) |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 0.003 | Slope | 11.5076 | 3 | -3 | 6 | -6 |
| 2 | 6 | 0.2 | Slope | 0 | 3 | -3 | 6 | -6 |
| 3 | 10 | 0.2 | Slope | -5 | 3 | -3 | 6 | -6 |
| 4 | 40 | 0.02 | Slope | 18.7017 | 3 | -3 | 6 | -6 |
| 5 | 50 | 0.08 | Slope | 0 | 3 | -3 | 6 | -6 |
| 6 | 70 | 0.08 | Slope | -6.60252 | 3 | -3 | 6 | -6 |
| 7 | 200 | 0.008 | Slope | -3.22233 | 3 | -3 | 6 | -6 |
| 8 | 500 | 0.003 | Total Grms | 3.11104 | | | | |

**Figure 5:** Vibration Controller Profile

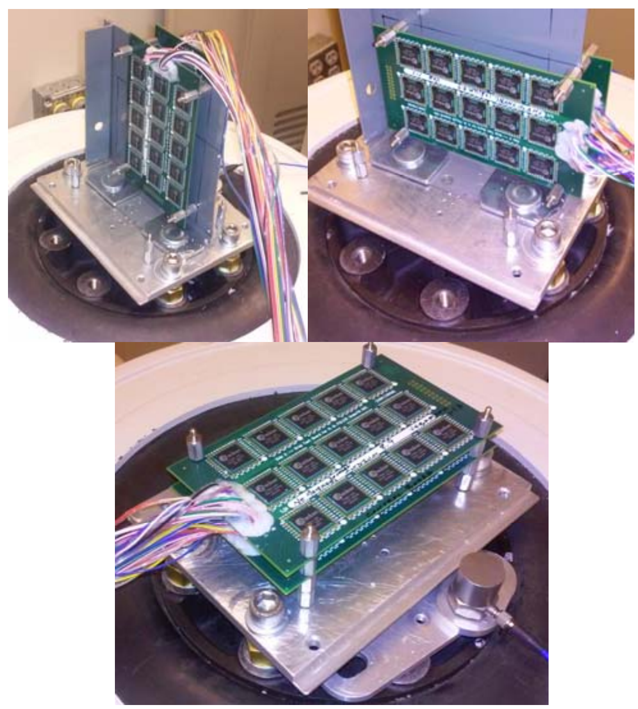


**Figure 6:** Vibration Testing X, Y, and Z Axis Fixturing

The CTBGA test vehicles edge bonded with materials A, B, C, and D all passed 30 min of random vibration on each axis without an event being detected for a total of 90 min of vibration. The next phase of testing will involve random vibration testing to failure with each of the edge bond materials.

## DISCUSSION AND SUMMARY

Edge bond adhesives provide an attractive alternative to traditional reworkable underfills for BGA, CSP, WLCSP and BTN components. Moreover they significantly reduce the complexity of the encapsulation process for reliability improvement. Effectively eliminating typical concerns with underfill processing including flux selection, flux-underfill compatibility, underfill voiding, underfill flow time, underfill delamination, and solder extrusion into underfill voids during thermal and power cycling. The edge bond dispensing process is also considerably easier than underfilling. "L" shaped dispense patterns are used to deposit edge bond on the component corners and anchor them down. The current work focused on processing thixotropic materials having minimal flow under the components thereby mitigating possible stress concentrations due to partial solder ball encapsulation.

New edge bond adhesives have properties tailored to high reliability performance and a variety of applications. Materials with a range of Tg, modulus and CTE values are available. This study used edge bond materials with Tg values ranging from 74 to 124 °C and alpha one CTE values ranging from 30 to 57 ppm/°C. In addition, edge bond adhesives provided excellent reworkability and a considerably simpler rework process compared with reworkable underfills.

The materials tested show excellent to very good performance in thermal cycle testing exceeded 2000 cycles for Matls A and D. Moreover, the materials tested showed robust performance in random vibration testing passing for 90 min with a peak acceleration of 3G.

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