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Reliability Assessment of CSP Underfill Methods

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Abstract
The miniaturization trend in electronics has proliferated the use of Chip Scale Packages (CSPs) in electronics assembly. CSPs used in portable devices are subjected to harsh mechanical and thermal conditions and underfill provides a dramatic improvement in their thermo-mechanical reliability. This paper provides a comparison of thermo-mechanical reliability performance of CSPs underfilled using different methods such as capillary underfill and corner-fill. The evaluation is based on drop test, liquid-to-liquid thermal shock (LLTS) and air-to-air thermal cycling (AATC).

Key Words: CSP, Underfill, and corner-fill.

Introduction
High speed, miniaturization, low weight and low cost are the performance measures for today's electronics systems[1]. These requirements are making component, board and system packaging more complex each year. Fine pitch BGAs and CSPs provide a potential solution where low weight and small size are requirements and are used in portable devices[2]. High reliability is a requirement for handheld electronic devices. These products are subjected to harsh conditions such as thermal extremes, mechanical shocks and vibration. The high standoff in CSPs provides good thermal reliability. However, the solder joints are susceptible to failures due to shock and vibration. Underfill couples the CSP to the substrate, compensates for the difference in relative displacement of CSP and substrate during drop shock, and thus dramatically improves reliability[3]. Underfill also compensates for the CTE mismatch in the assembly and improves the thermal reliability of CSPs.

CSPs are typically underfilled using capillary or no-flow underfills. However, the substrates used in handheld devices, due to their miniaturization, are densely populated. These boards may have connectors near the CSPs. Underfills tend to flow into the leads causing underfill starvation underneath the CSP, ultimately leading to voids[4]. Passive devices, depending on their orientation are also known to cause similar problems. Sometimes these boards have vias, which may cause underfill bleeding[5]. Capillary and no-flow underfills require lengthy substrate dehydration to prevent void formation. These problems can be alleviated by using a process called "Corner-Fill". In this method, a high viscosity underfill is dispensed near the corner of the CSP after reflow. The CSPs bumps experience high stresses during thermal cycling due the CTE mismatch. Maximum stress is experienced by the corner bumps due to the DNP effect. The corner-fill process couples the CSP corners to the board and redistributes the stresses over a larger area. The coupling of the CSP to the board also reduces the relative displacement between the CSP and board reducing the failure rate during drop shock testing.

In this research effort, an alternative underfill technique called corner-fill is evaluated. The reliability of corner-filled CSPs is compared to CSPs with capillary underfill and no underfill based on drop shock, LLTS and AATC tests.

Test Vehicle Description
The test vehicle was a four-layered FR4 printed circuit board (PCB). The dimensions of the board were 6"x3"x0.031". The test vehicle was designed for 10 mm CSP on one side and 7 mm CSP on the other. The CSP was the 84 I/O Amkor CABGA with a peripheral bump layout. The solder ball pitch was 0.5 mm and the ball diameter was 0.4 mm. The CSP had daisy chains for measurement of electrical continuity. The attachment pads were 10 mil non solder mask defined (NSMD) with electroless nickel/gold surface finish.

Assembly Process
The CSPs were assembled using a Siemens Siplace F5 placement machine. The solder bumps were dipped in 65 µm thick film of Cookson RMA376EH-LV no-clean flux. Figure 1 below shows the reflow profile used for the assembly. The boards were reflowed in air.

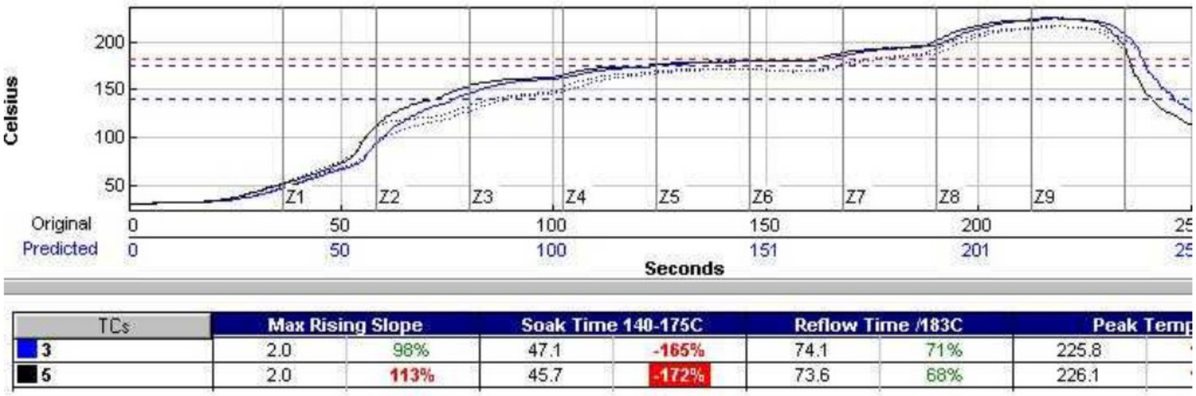

Figure 1 - Reflow Profile

Corner-fill Process

In the corner-fill underfill process, the underfill material was dispensed at the corners of the CSP. Figure 2 shows the dispense pattern for the corner-fill process.

The corner-fill process was performed using the Cookson Staychip HEL 27 underfill. The viscosity of a corner-fill material is higher than a conventional underfill. The material is not meant to flow under the CSP, but has to flow partially in the gap. It has to adhere to the underside of the corners and the sides of the CSP. Figure 3 shows the images of the CSP after the corner-fill process.

The underfilling was performed using a Cookson Camalot 1818 dispenser using a 21-gage needle. The underfill was cured for 30 min at 150°C.

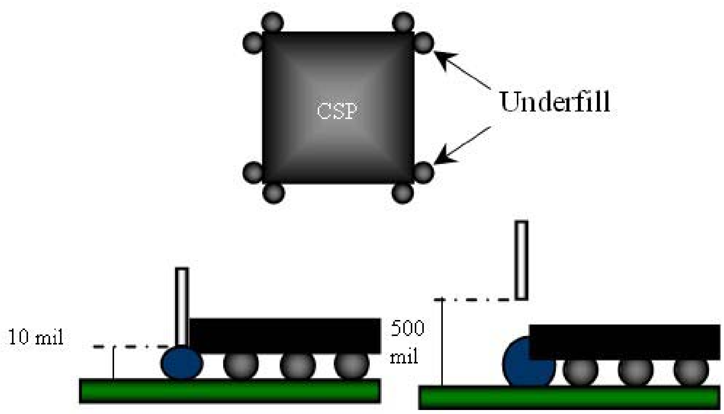

Figure 2 - Corner-Fill Dispense Process

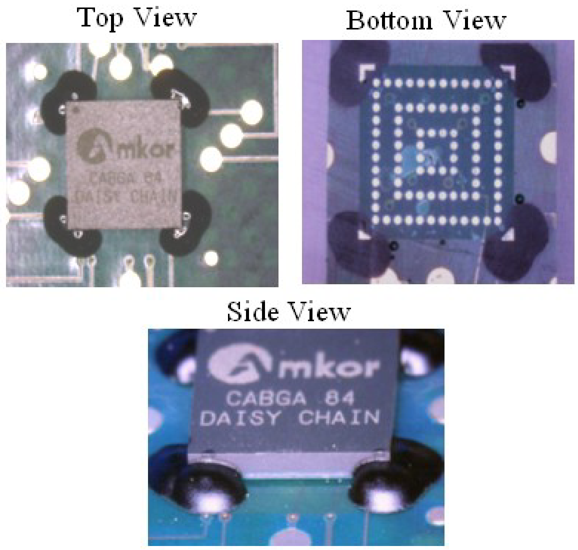

Figure 3 - CSP after Corner-Fill Process

Capillary Underfill

In capillary underfill process, the underfill fills the entire gap between the CSP and the board. The Cookson Staychip 3090 underfill was used for capillary underfill. The underfill was performed using a Camalot 1818 with a 21 gage needle with a dispense gap of 20 mil. The boards were dehydrated for 8 hours at 125°C prior to dispensing. Dispensing was done by using an “L” pass with a board temperature of 100°C.

Reliability Testing

The CSPs, which are used in portable devices, are subjected to harsh thermal and mechanical stresses. The CSP assemblies were subjected to drop shock, LLTS and AATC thermal cycling tests.

Drop Shock Test

The CSP boards were dropped from a height of about 6 feet through a 3” wide pipe. The boards were dropped along the length and the edge of impact was interchanged after every drop in order to evenly distribute the impact shock evenly for all CSPs and prevent damage of the FR4 material. The CSPs were checked for continuity after every drop and a 10% increase in resistance was considered a failure. Figure 4 shows the comparison of drop shock reliability of the non-underfilled, corner-filled and capillary underfilled CSPs after 100 drops.

The non-underfilled CSPs failed much earlier than the corner-filled CSPs. After 100 drops, 50% of the CSPs had failed, whereas there were no failures for the capillary underfilled CSPs. Figure 5 compares the 1st and 50% failures for the assemblies.

Figure 5 shows that the corner-filled assemblies show more than 2X improvement in the drop chock reliability of the CSPs. The failed CSPs were cross-sectioned to characterize the failure modes. Figures 6a and 6b show the cross-sections for the non-underfilled and corner-filled CSPs.

The predominant failure for both non-underfilled and corner-filled CSPs was solder joint crack on the board side. This is expected since the board side interface of the solder joint would be subjected to the maximum stress during drop shock testing due to the difference in relative displacements of the board and the component.

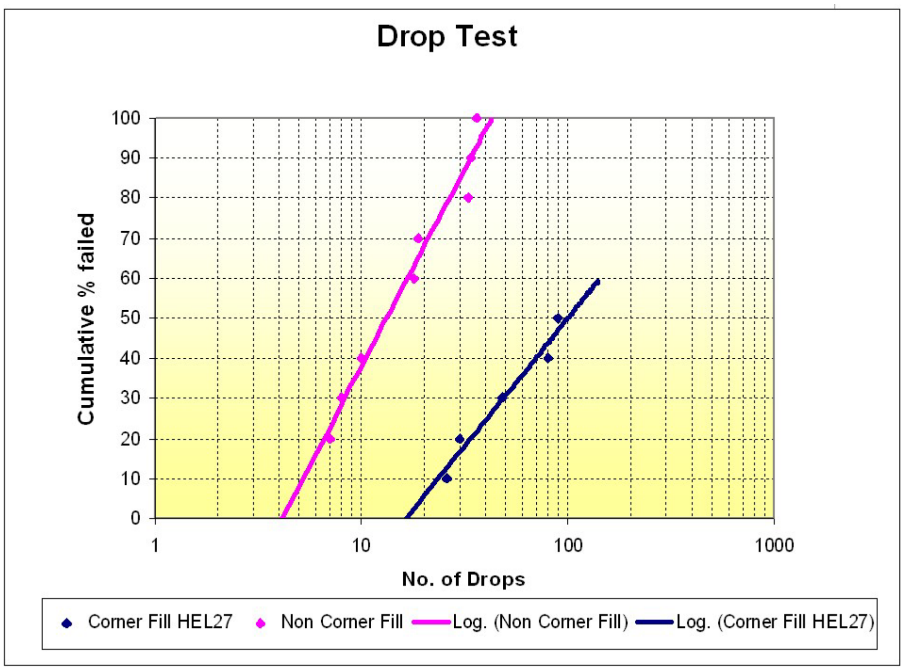

Figure 4 - Drop Shock Reliability

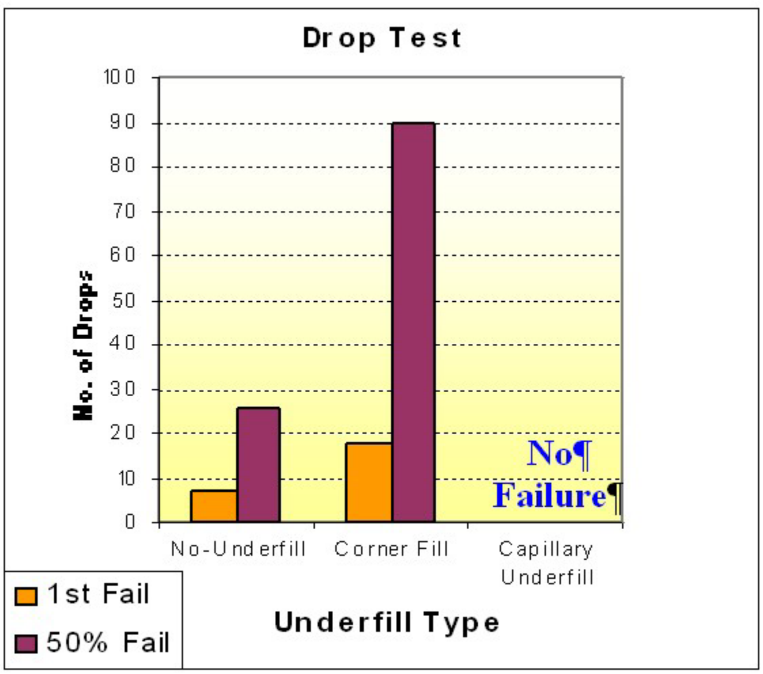

Figure 5 - Drop Shock 1st and 50% Failures

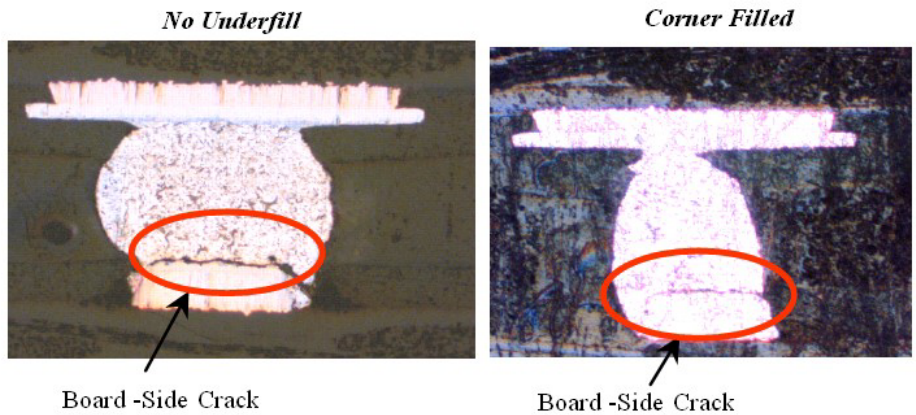

Figure 6 - Failure Mode for Drop Shock Test

Liquid-to-Liquid Thermal Shock Test
The CSP assemblies were subjected to LLTS cycling between -55°C and 125°C with a dwell time of 5 min at each temperature extreme. The total cycle time was 11 min. A 10% increase in the resistance was considered a failure. Figure 7 shows the reliability comparison of the non-underfilled, corner-filled and capillary underfilled CSPs.

There was a significant improvement in the reliability of the CSPs after corner-fill. No failures were seen on the capillary underfilled CSPs even after 4200 cycles. Figure 8 shows the comparison of 1st and 50% failure for non-underfilled and corner-filled CSPs.

Corner-fill provides more than a 2X improvement in the reliability of the CSPs. However, capillary underfill provides the maximum reliability. There were no failures for the capillary underfilled boards even after 4200 cycles. The CSPs were cross-sectioned to determine the failure mechanism. Figure 9 shows the cross-sections for the non-underfilled and corner-filled CSPs.

The failures were through the bulk solder along the component side. This is expected due to the local CTE mismatch on the component side.

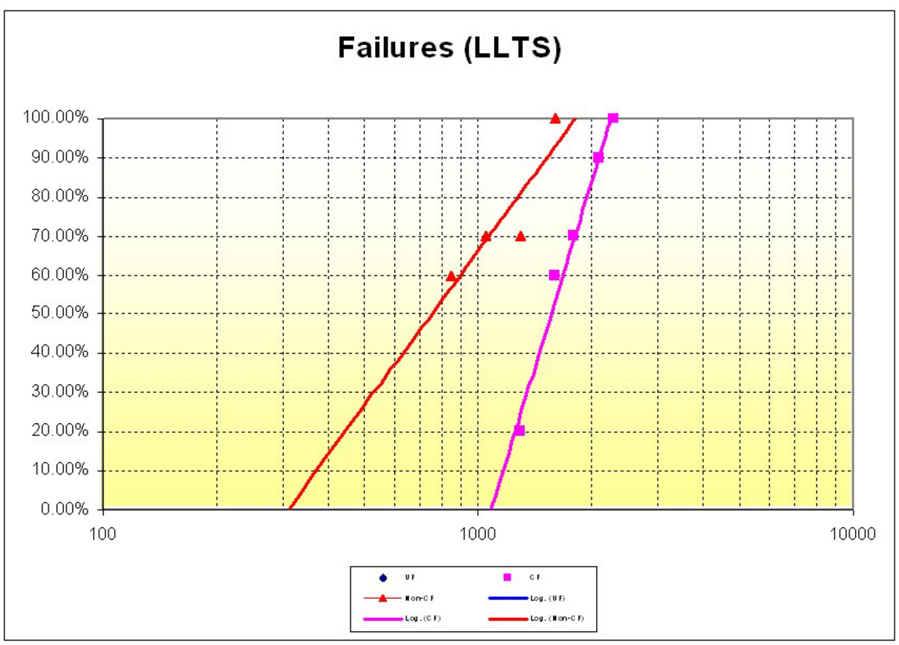

Figure 7 - LLTS Reliability

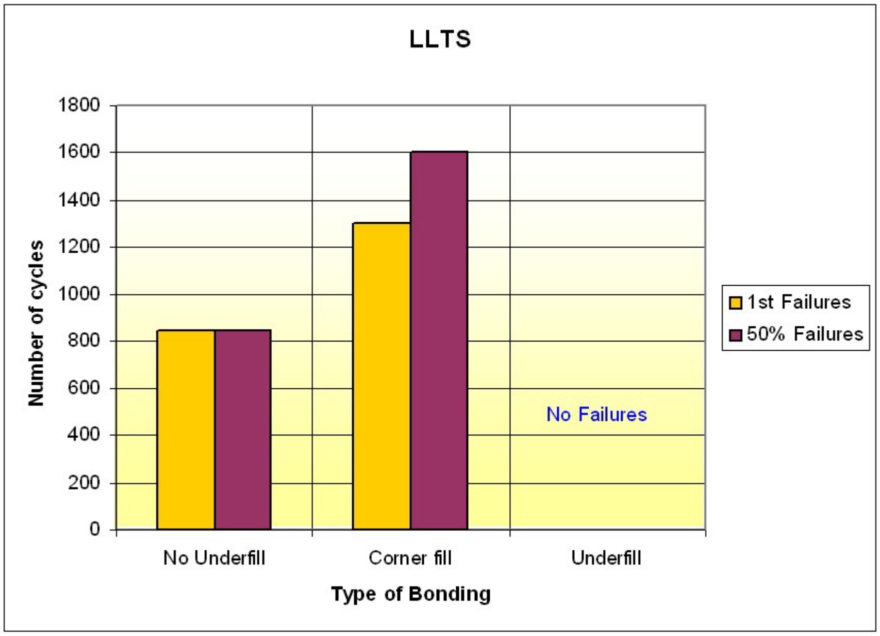

Figure 8 - LLTS 1st and 50% Failures

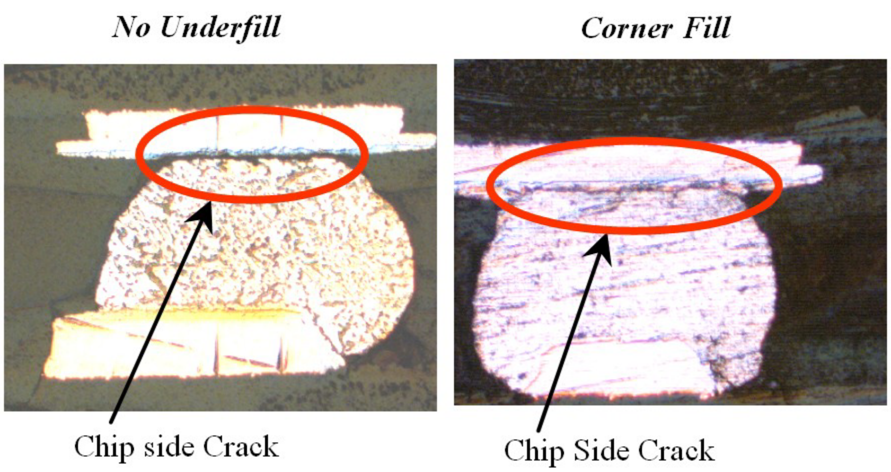

Figure 9 - Failure Mode for LLTS Test

Air-to-Air-Thermal Cycling Test

The CSP assemblies were subjected to AATC between -55°C and 125°C with a dwell time of 20 min at each temperature extreme. The total cycle time was 42 min. A 10% increase in the resistance was considered as a failure. Figure 10 shows the reliability comparison of the non-underfilled, corner-filled and capillary underfilled CSPs.

There was an improvement in the reliability of the CSPs after corner-fill. No failures were seen on the capillary underfilled CSPs even after 1700 cycles. Figure 11 shows the comparison of 1st and 50% failure for non-underfilled and corner-filled CSPs.

Corner-fill provides more than a 2X improvement in the reliability of the CSPs. However, capillary underfill provides the maximum reliability. There were no failures for the capillary underfilled boards even after 1700 cycles. The CSPs were cross-sectioned to determine the predominant failure mechanism. Figure 12 shows the cross-sections for the non-underfilled and corner-filled CSPs.

Solder joint crack on the component side was observed.

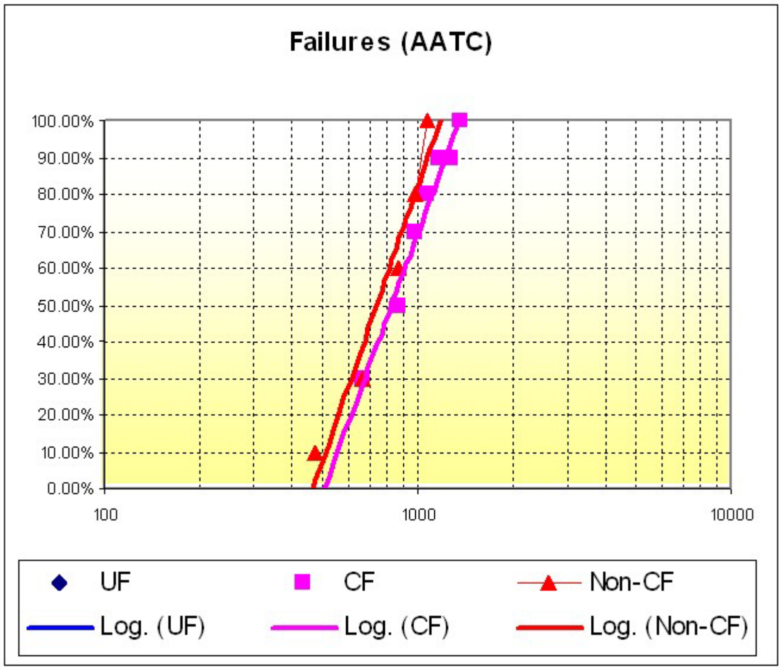

Figure 10 - AATC Reliability

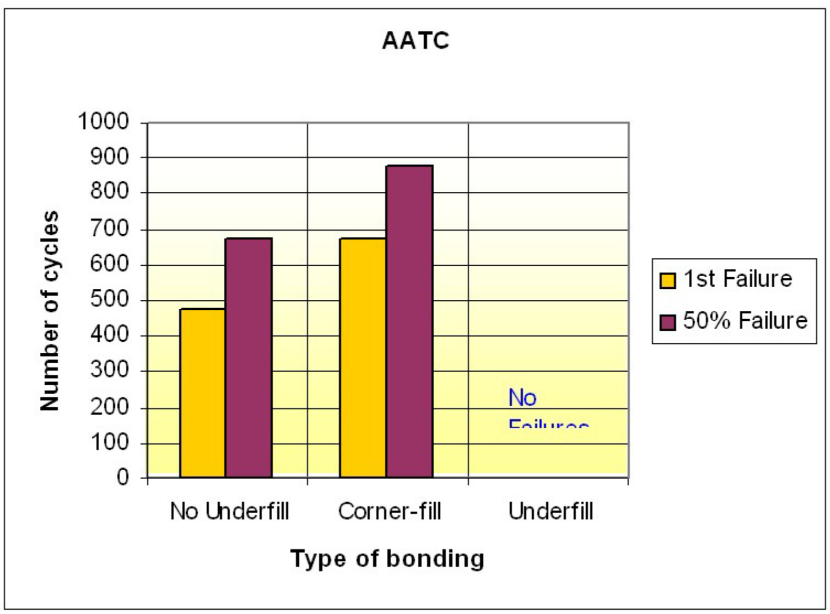

Figure 11 - AATC 1st and 50% Failures

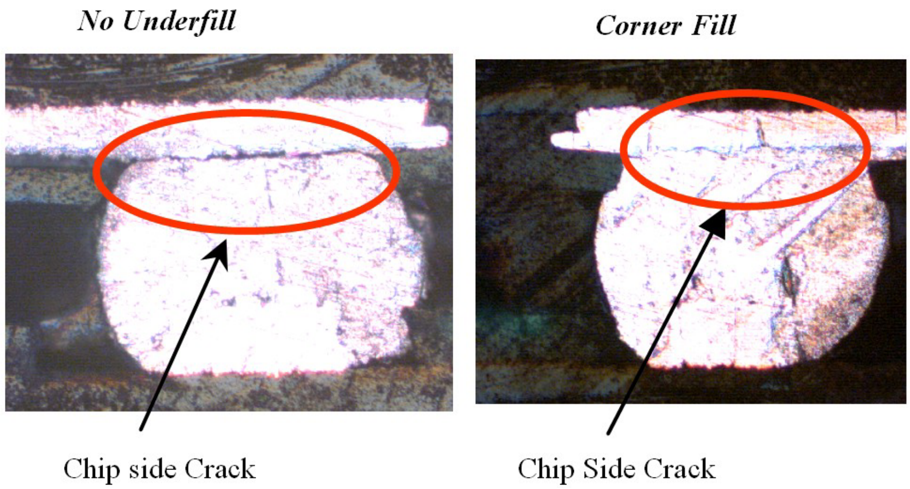

Figure 12 - Failure Mode for AATC Test

Conclusion

The thermal and mechanical reliability was assessed for CSPs underfilled with different techniques using drop shock, thermal shock and thermal cycling. Capillary underfill imparts the highest reliability to the CSPs for thermal and mechanical stresses. In cases, where capillary underfill is not viable due to board layout, corner-filling technique can be used. Corner filling showed about 2X increase in the thermal and mechanical reliability as compared to non-underfilled CSPs. However, proper material selection is necessary for the success of corner-fill process.

Acknowledgement

The authors would like to thank Guoyun Tian and the staff of CAVE Program, Auburn University for their assistance in assembly of the test vehicles.

Refernces

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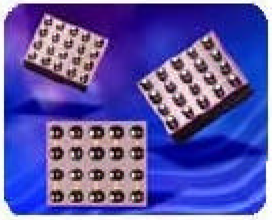
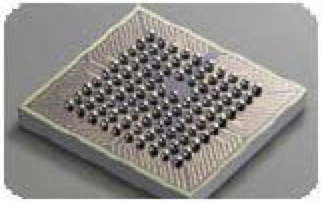
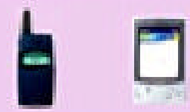
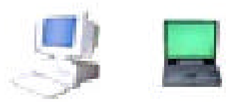
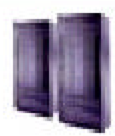
Reliability assessment of CSP underfill techniques

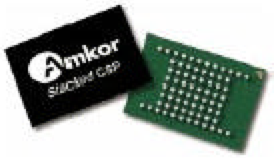
Senthil Rajiv Kanagavel

Chip Scale Packages





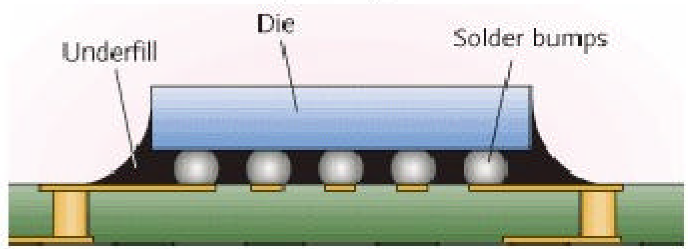
Target Markets	Applications	Semiconductor Devices
Wireless & Portable		Flash SRAM DSP RF
Computing		RDRAM DDR SDRAM
Consumer		RDRAM DDR SDRAM
Networking		RDRAM DDR SDRAM



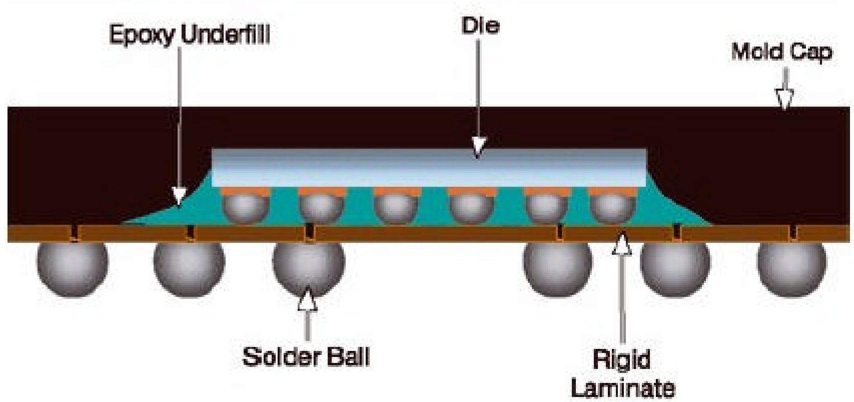
Chip Scale Package Vs. Flip Chip

- ***Compared to Flip Chips, CSPs have:***
  - Higher Stand off
    - Low Strain
  - Low CTE Mismatch
    - Low strain
- ***Hence CSPs have better thermal reliability than flip chips***

Flip Chip



CSP

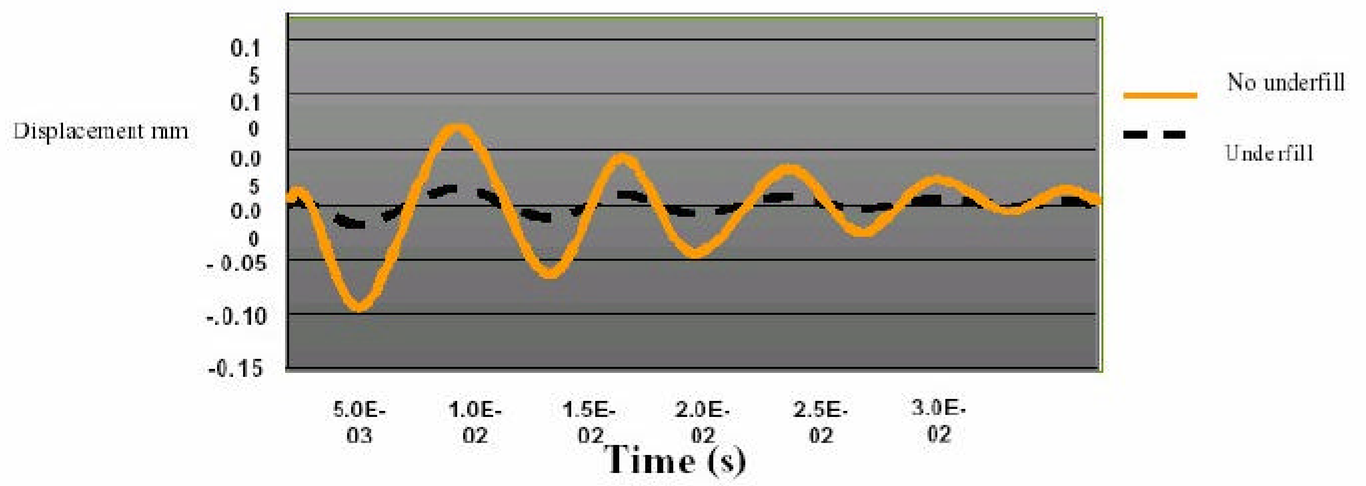


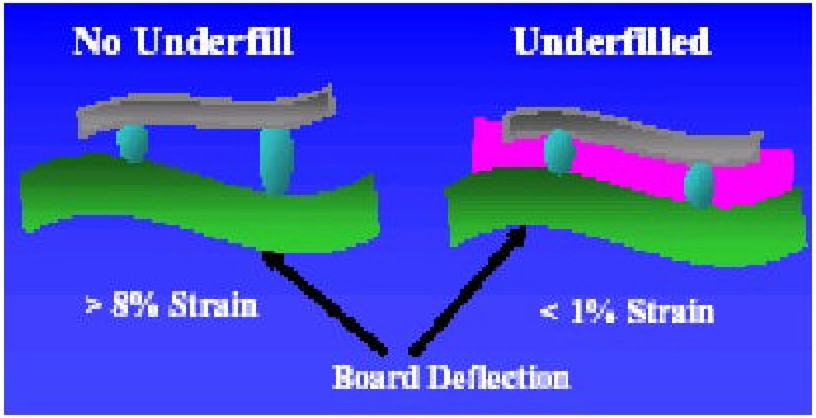
Mechanical Reliability of CSPs

- CSPs used in handheld electronic devices are subjected to harsh service conditions

- CSPs in handheld devices are subjected to:
  - ***Impact shock***
  - ***Vibrations***

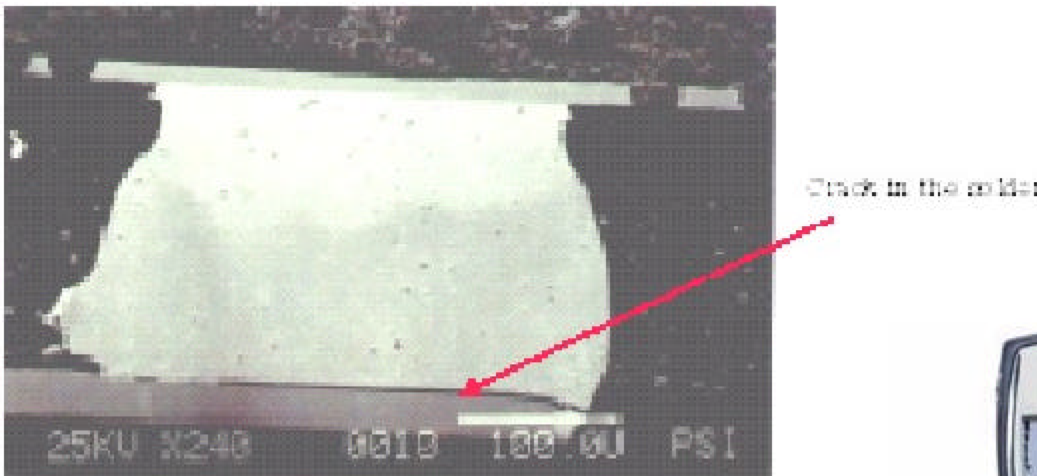
Relative Displacement between CSP and PCB due to Impact





Source:"**When to Underfill Chip Scale Packages, Design Considerations for Portable Electronic Applications", S.** Adamson and Horatio Quinones

CSP Failure due to Impact Shock



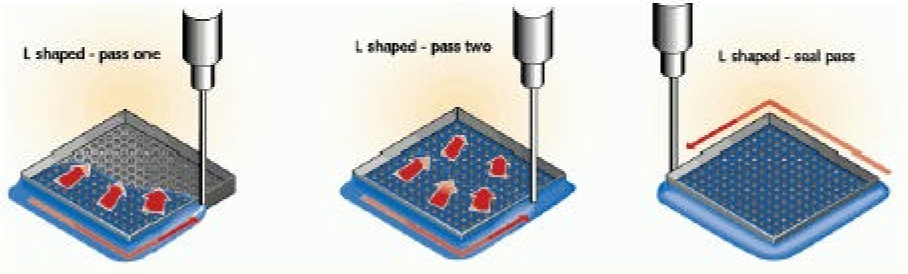
CSP Assembly Parameters

- Device: CABGA
- Test Vehicle: Cookson CSP Test Vehicle
- Placement using Siemens Placement machine
- Flux dipping using Cookson Tack flux
- Flux thickness of 65 micron (2.6 mil) used
- Reflowed using 220 C peak standard eutectic profile

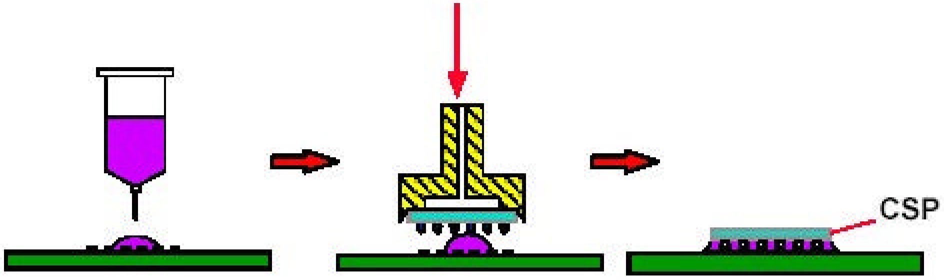
Underfill for CSP Mechanical Reliability

Typical CSP Underfill Processes

Capillary Underfill

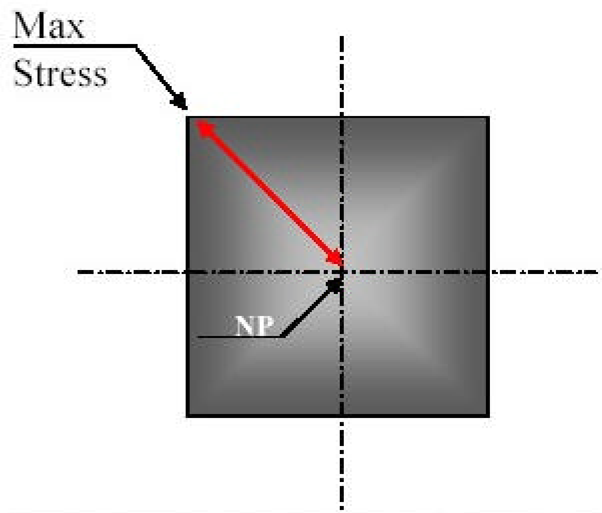


No-flow underfill



Corner-Fill / Partial Underfill

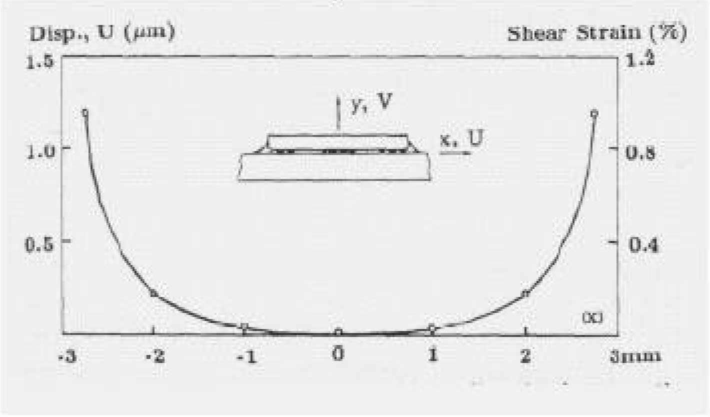
Alternative CSP underfill technique



DNP Effect

$$\text{Shear Strain} = \frac{\text{DNP} \times \Delta\,\text{CTE}}{\text{Stand off Height}}$$

CSPs are bonded at the corner



Source:"**When to Underfill Chip Scale Packages, Design Considerations for Portable Electronic Applications", S.** Adamson and Horatio Quinones

Corner-Fill Dispensing Parameters

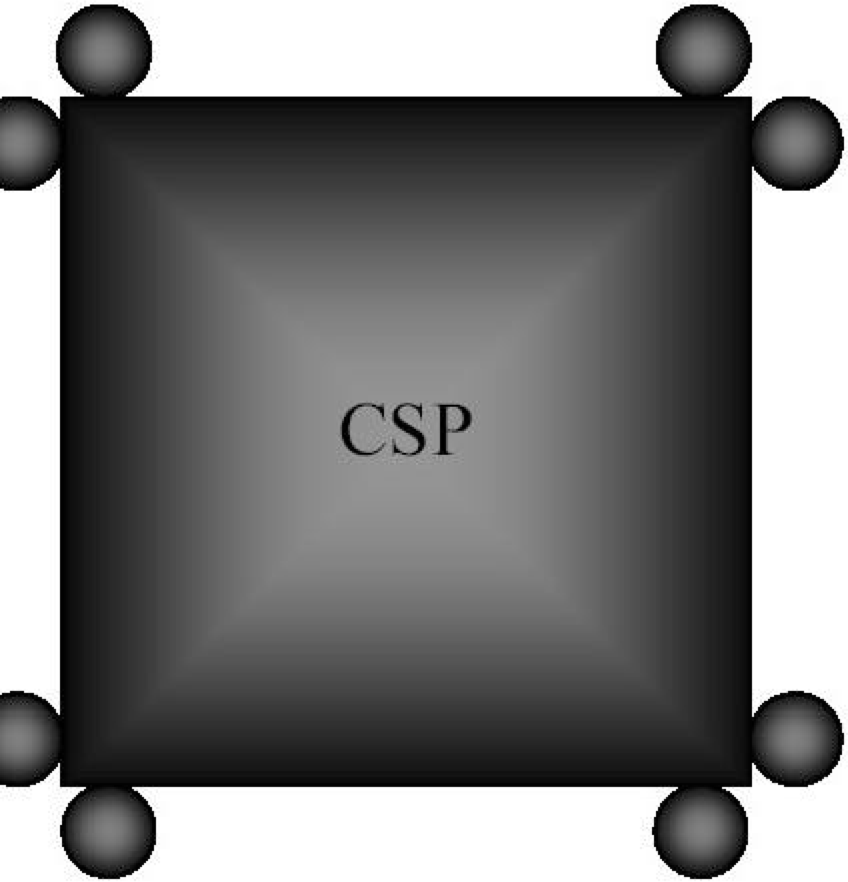
Underfill Properties

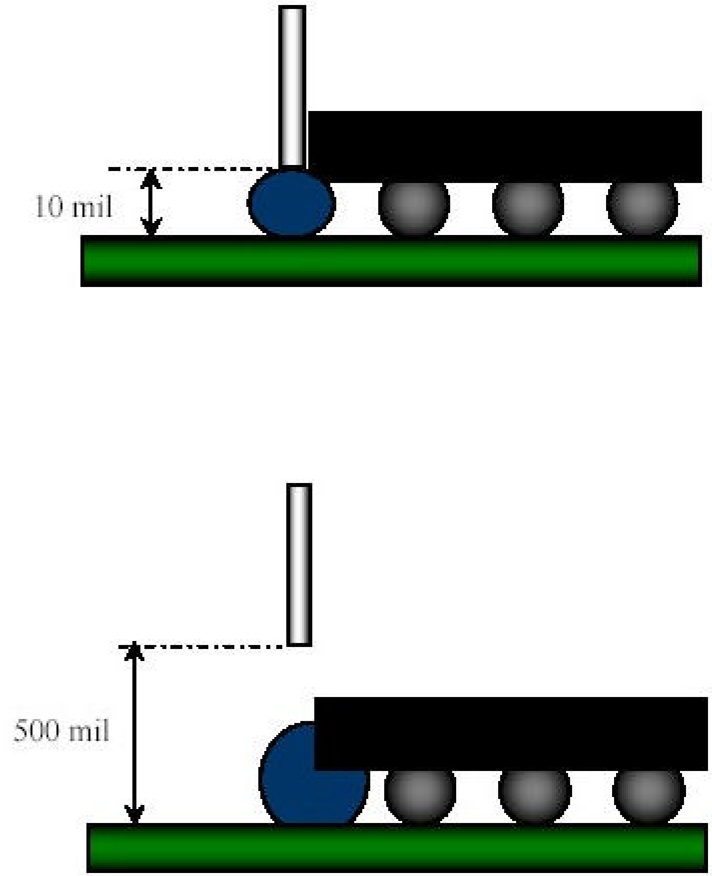
- Material: Corner fill
- Viscosity: 331 Poise @ 1 rpm
- Filler Content: 71%
- T_g: 150 C

Dispense Parameters

- Dispenser: Camalot dispenser
- Needle size = 21 gage
- Shot-size = 300ms
- Gap = 10 mil
- Shift ht up = 0.5in
- Pt dwell = 200ms
- On delay = 150 ms

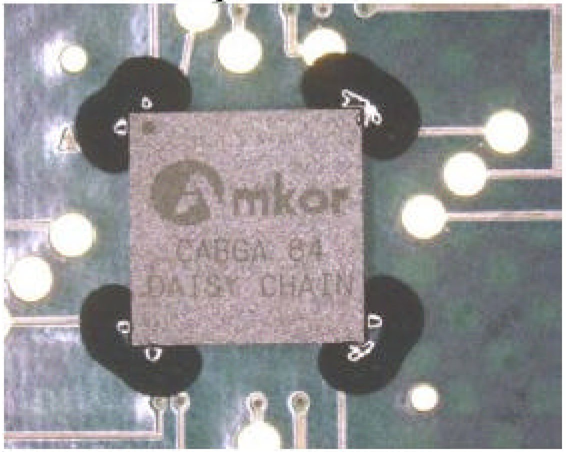
Corner-Fill Dispense Pattern



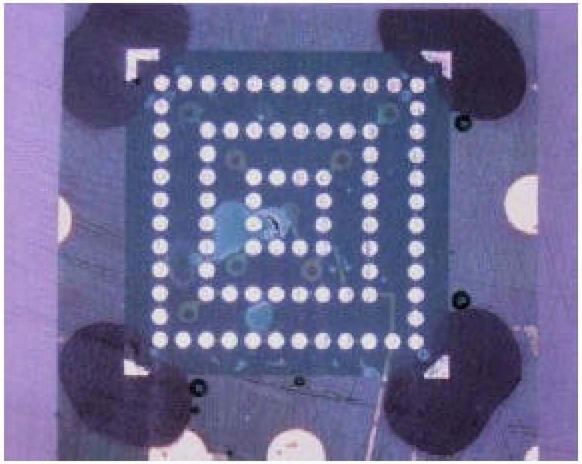


Corner-Fill/ Partial Underfill

Top View



Bottom View



Side View

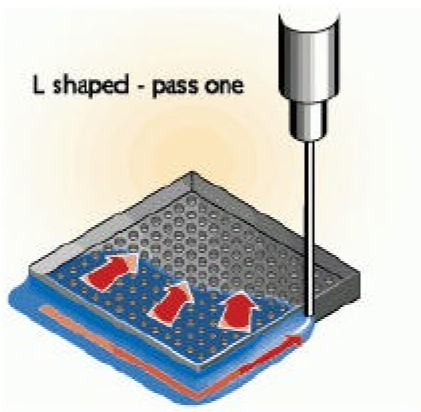
Full Underfill: Dispensing Parameters

Underfill Properties

- Material: CSP Underfill
- Viscosity: 5100 cP
- Filler Content: 55%
- Tg: 150 C
- CTE: 38 ppm/deg C

Dispense Parameters

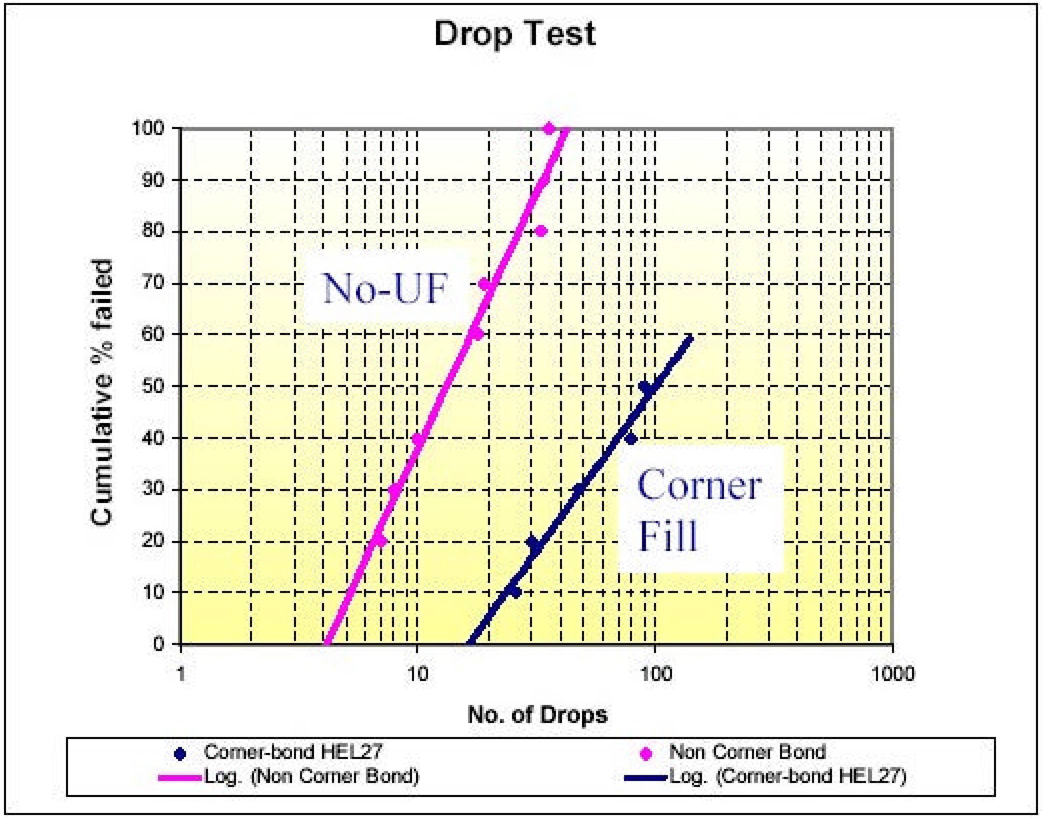
- Dispenser: Camalot Dispenser
- Needle size = 23 gage
- Line Speed
  - Main Pass: 0.1 "/sec
  - Fillet Pass: 0.3"/sec
- Dispense Gap = 20 mil



Drop Shock Test

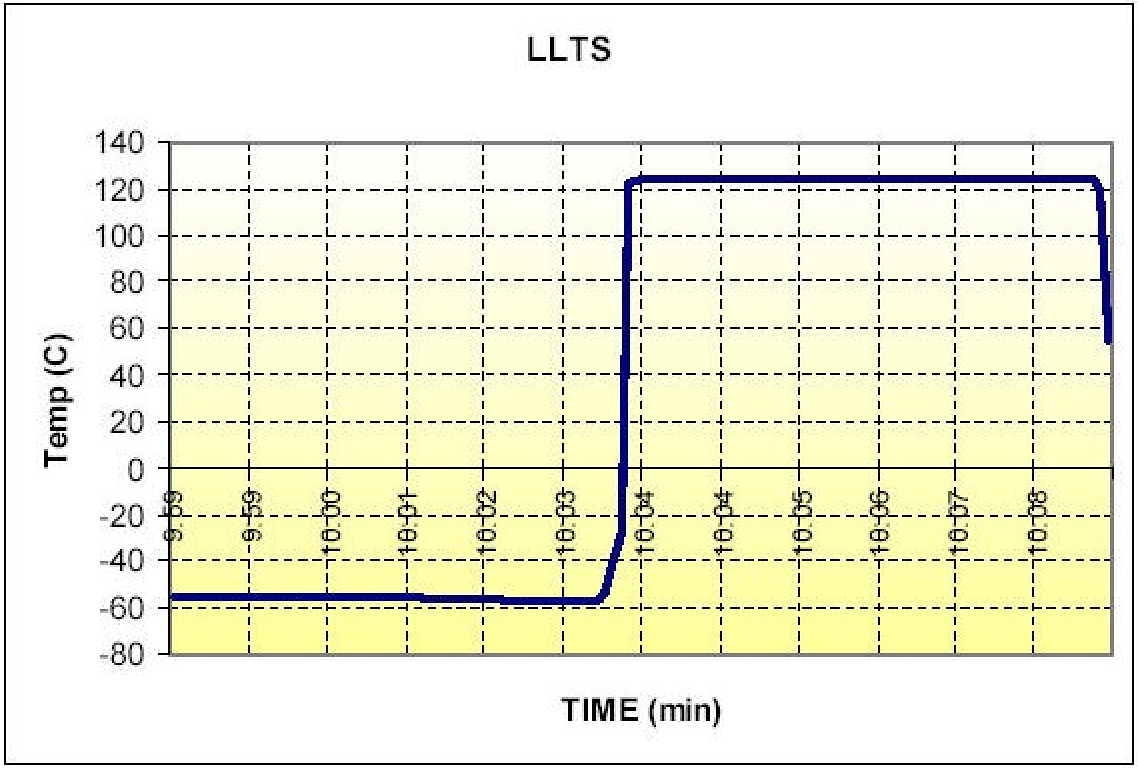
- Drop Height of 6 feet
- Free fall through a hollow tube
- Alternate edge of impact
- Resistance values checked after every drop
- Failure is a ±10% increase in initial resistance

Drop Shock Reliability



No failure for fully underfilled CSPs with CSP Underfill after 100 drops

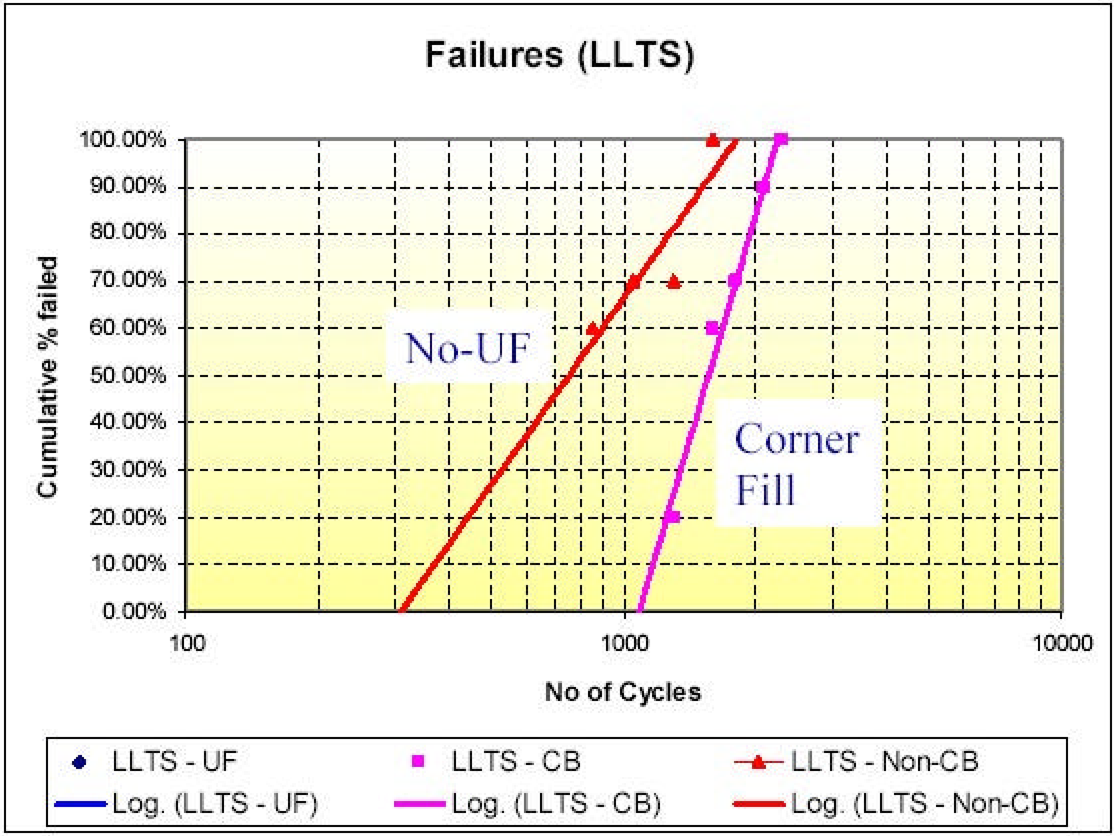
Liquid to Liquid Thermal Shock



-55 °C to 125 °C , 5 min dwell for each temp, 5 sec transfer time

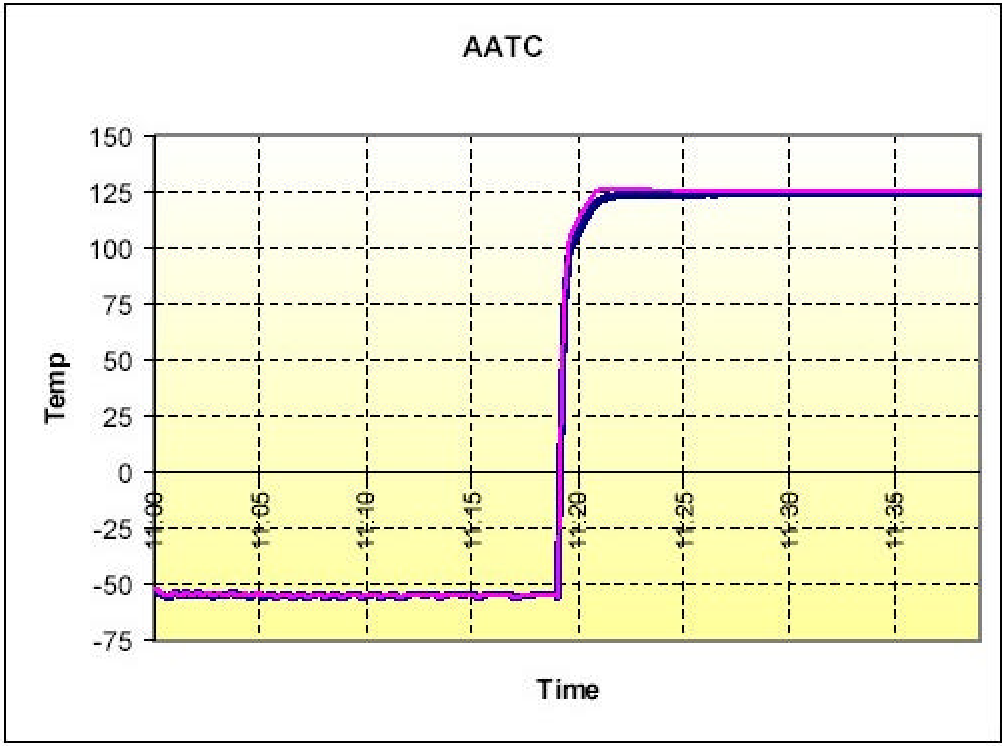
$\pm$10% of initial resistance value constitutes a failure

LLTS Testing



No Failures for full underfill after 4200 cycles

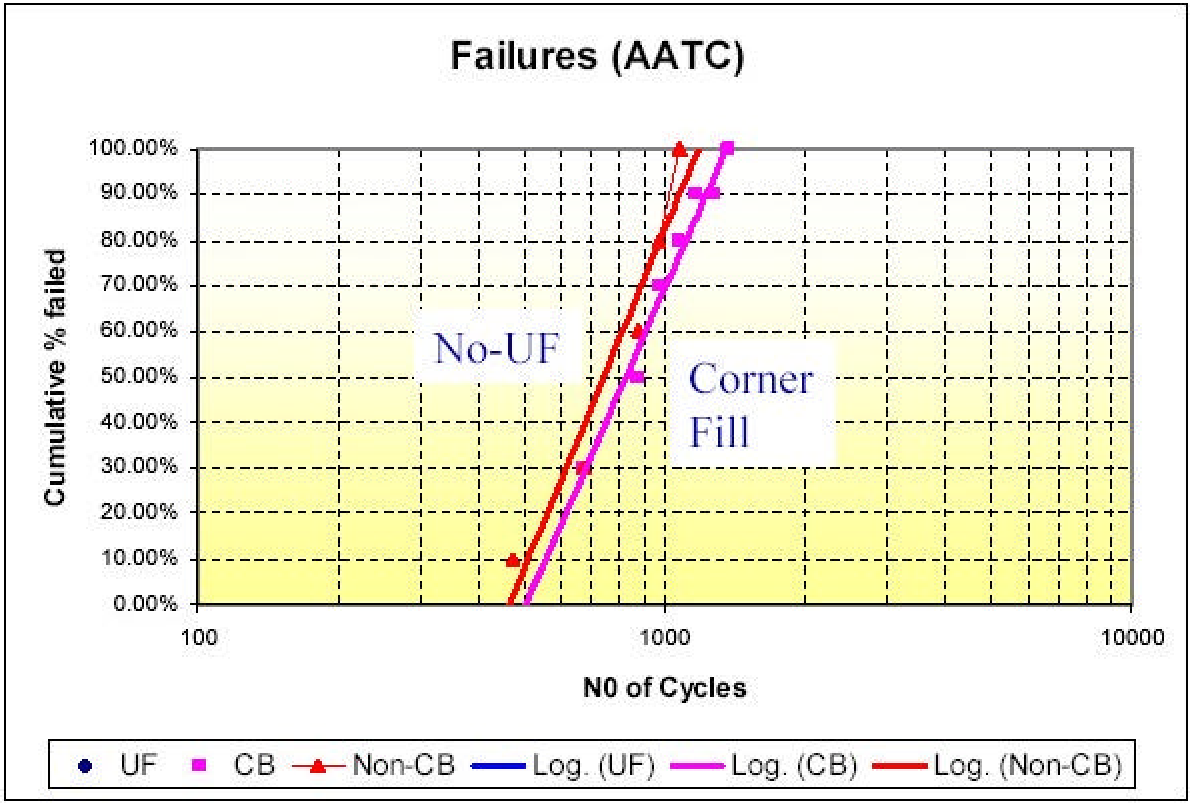
Air to Air Thermal Cycling



-55 ℃ to 125 °C , 20 min dwell for each temp

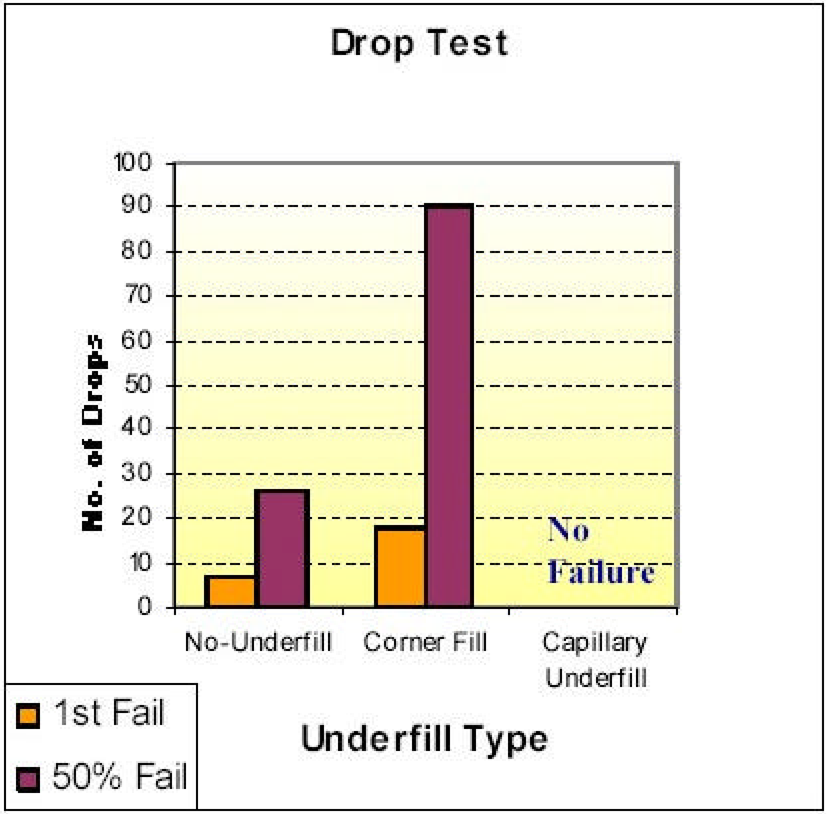
±10% of initial resistance value constitutes a failure

Air to Air Thermal Cycling



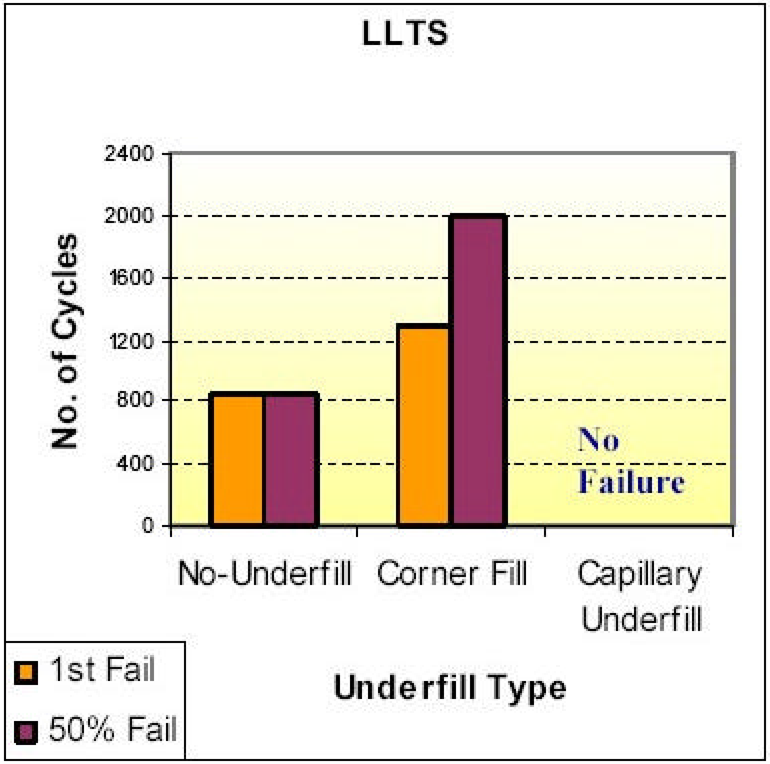
No Failures for full underfill (SC-3090) after 1700 cycles

Comparison of Underfill Methods



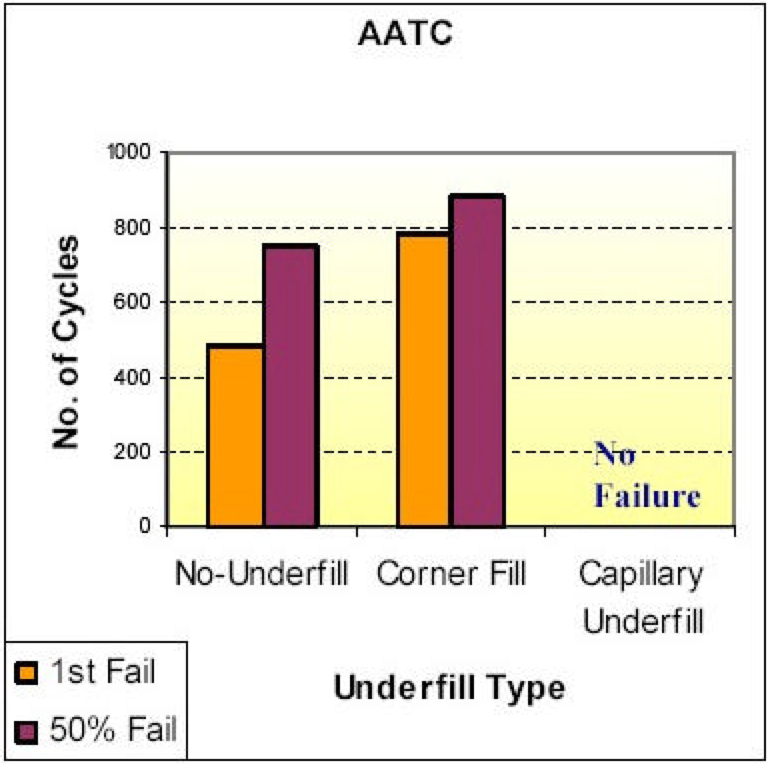
More than 2X Improvement with Corner-Fill

Comparison of Underfill Methods



More than 2X Improvement with Corner Fill

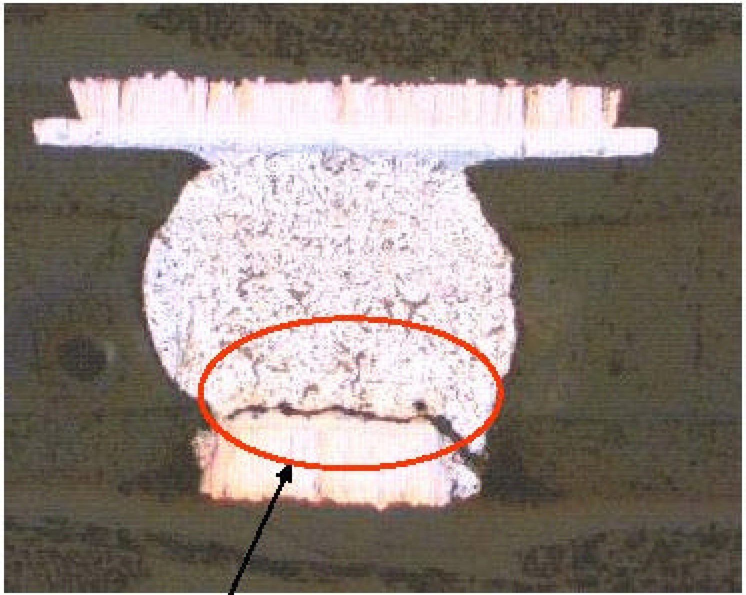
Comparison of Underfill Methods



Improvement with Corner Fill

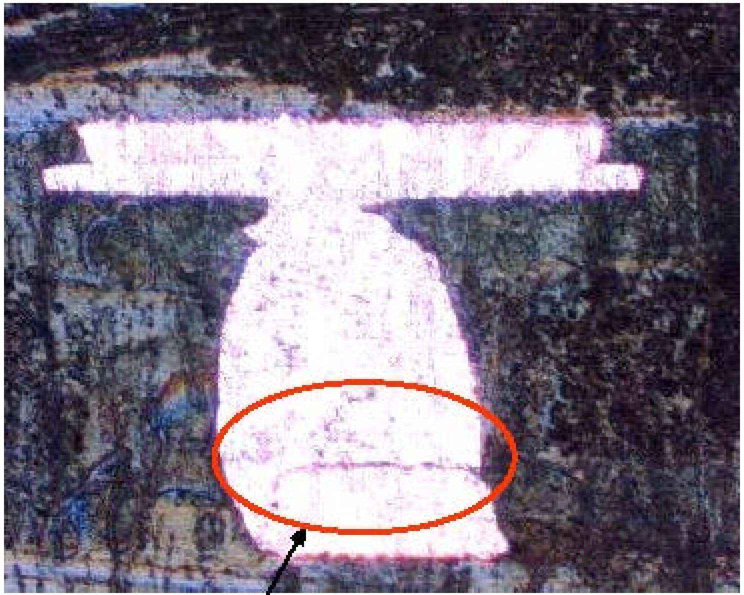
Failure Mode : Drop Test

No Underfill



Board -Side Crack

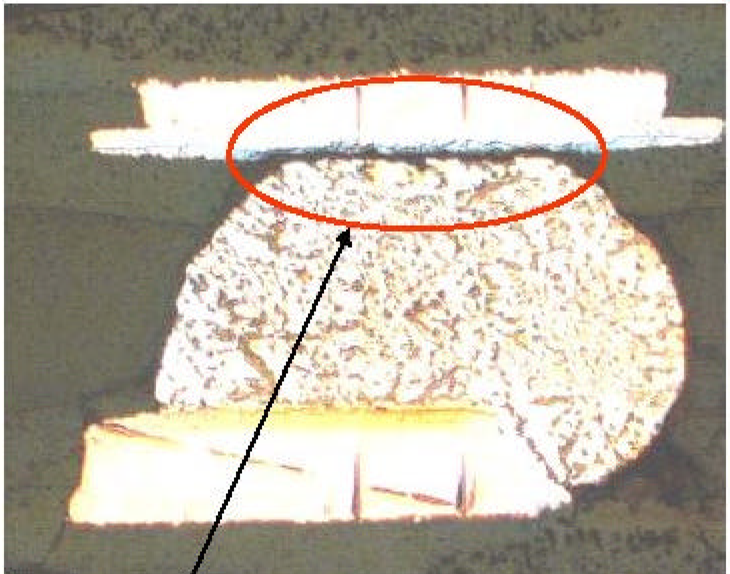
Corner Fill



Board -Side Crack

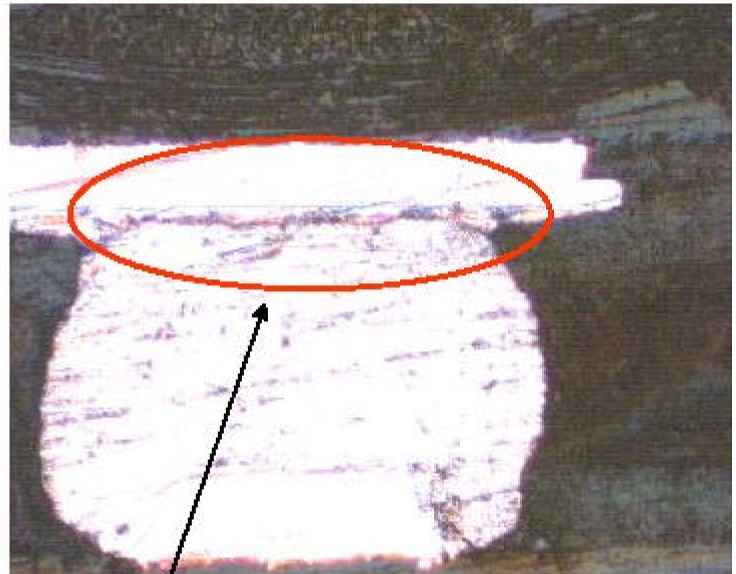
Failure Mode : LLTS Test

No Underfill



Chip side Crack

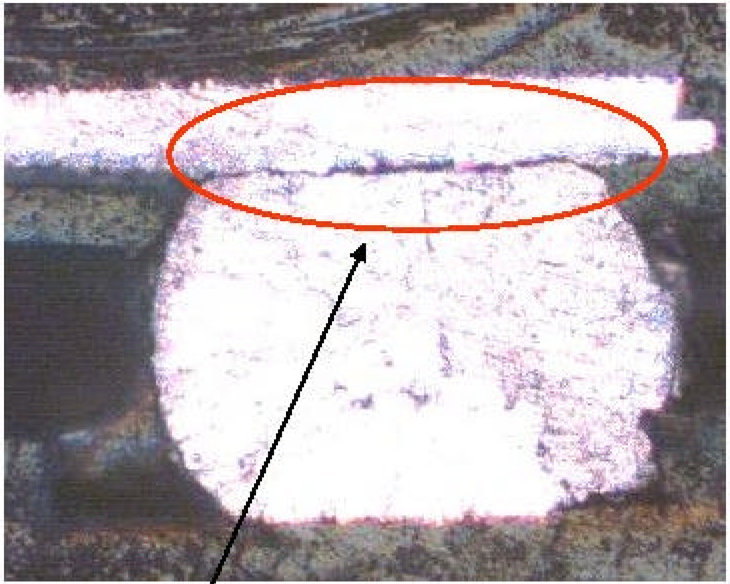
Corner Fill



Chip Side Crack

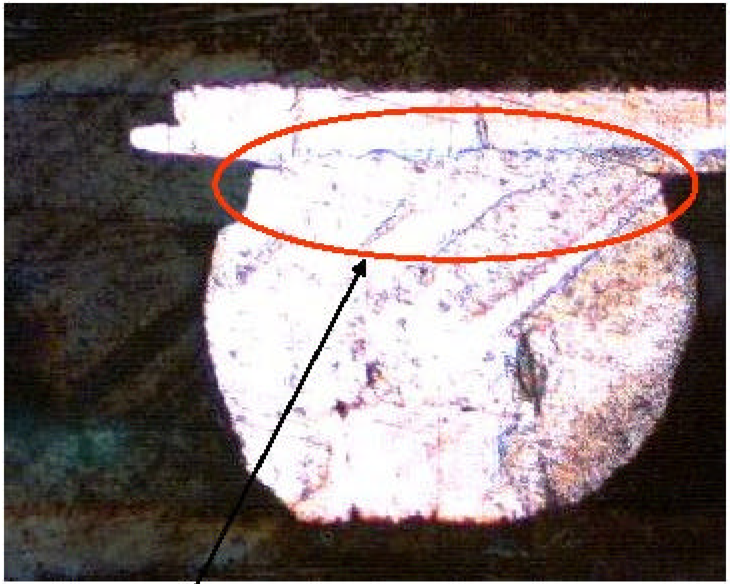
Failure Mode : AATC Test

No Underfill



Chip side Crack

Corner Fill



Chip Side Crack

Conclusions

- The thermal and mechanical reliability was assessed for CSPs underfilled with different techniques using drop shock, thermal shock and thermal cycling.
- Capillary underfill imparts the highest reliability to the CSPs for thermal and mechanical stresses.
- In cases, where capillary underfill is not viable due to board layout, corner-filling technique can be used.
- Corner filling showed about 2X increase in the thermal and mechanical reliability as compared to non-underfilled CSPs