

## Epoxy Flux ó A Low Cost High Reliability Approach for PoP Assembly

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### ABSTRACT

Package on package (PoP) is a packaging that rapidly prevails in mobile devices of the electronic industry, due to its flexibility in combining memory and processor into one component with a reasonably low profile. However, similar to BGA, the solder joints of assembled PoP are prone to cracking upon dropping onto the floor, thus needing reinforcement by underfilling. The underfilling process needs an underfill material plus additional dispensing equipment, dispensing and flowing steps, and subsequent time-consuming curing. Furthermore, underfilled PoP suffers solder extrusion upon rework, particularly when reworking at the opposite side of the board right underneath the PoP. Epoxy flux is a new material developed to address the issues described above. It is a liquid epoxy with fluxing power, and it is compatible with solder paste. Applied by a dipping process, epoxy flux can be used at the mounting of bottom package and top package. First, the bottom package is dipped in a film of epoxy flux, and then placed onto the footprint pad on a PCB with or without solder paste. Then, the top package is dipped in epoxy flux and placed on top of the bottom package. The PCB with a stacked PoP is subsequently reflowed in the oven together with other surface mount components placed on printed solder paste. Epoxy flux combines soldering and reinforcement into one single process. With a controlled pick up flux volume, a venting channel is formed, allowing outgassing at reflow. The low stress characteristics of epoxy flux prevents the formation of solder extrusion. Overall, epoxy flux provides a low cost and high reliability solution for PoP assembly.

Key Words: Epoxy flux, Package on Package, PoP, assembly, reliability, soldering

### INTRODUCTION

Package on package (PoP) is a packaging that rapidly prevails in mobile devices of the electronic industry, due to its flexibility in combining memory and processor into one component with a reasonably low profile. However, similar to BGA, the solder joints of

assembled PoP are prone to cracking upon dropping onto the floor, thus needing reinforcement by underfilling. The conventional SMT one-pass assembly process for PoP is shown in Fig. 1. Here the bottom package is placed onto solder paste printed on PCB, followed by placement of a fluxed top package.

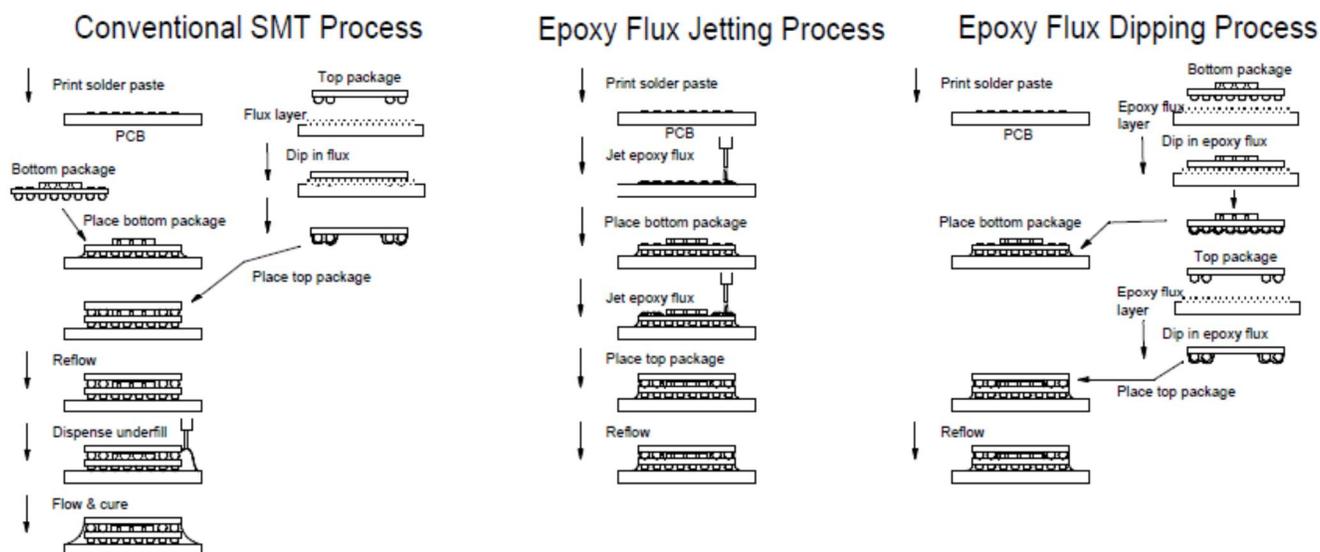


Figure 1. Comparison of various PoP assembly processes

The stacked devices are then reflowed, followed by underfilling. The underfilling process needs an underfill material plus additional dispensing equipment, dispensing and flowing steps, and subsequent time-consuming curing. Furthermore, underfilled PoP suffers solder extrusion upon rework, particularly when reworking at the opposite side of the board right underneath the PoP. Epoxy flux is a new material developed to address the issues described above [1, 2]. The concept of material design, methods of deposition of the materials, and performance are presented and discussed in this work.

### MATERIAL DESIGN

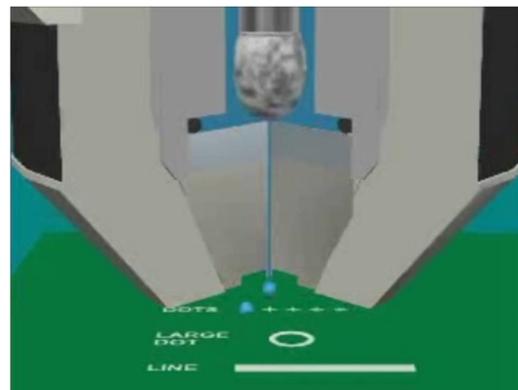
Epoxy flux is a thermoset flux system. It provides fluxing power upon reflow at temperature above the melting temperature of solder, thus allowing the formation of solder joints. It can also cure to form thermoset flux residue around the solder joint thus providing mechanical reinforcement. When epoxy flux is applied to fill the gap between packages of PoP or between bottom package and PCB, it practically functions as an underfill in terms of reinforcement.

### PROCESS DESIGN

There are several ways of applying epoxy flux for PoP assembly, including jetting, dipping, as well as printing. Jetting and dipping are more flexible, with processes shown in Fig. 1.

#### Epoxy Flux Jetting

The schematic of one jetting device is shown in Fig. 2, with the jetting dot size information of several commercial machines shown in Table 1. In the jetting



**Figure 2.** Schematic of one jetting device.

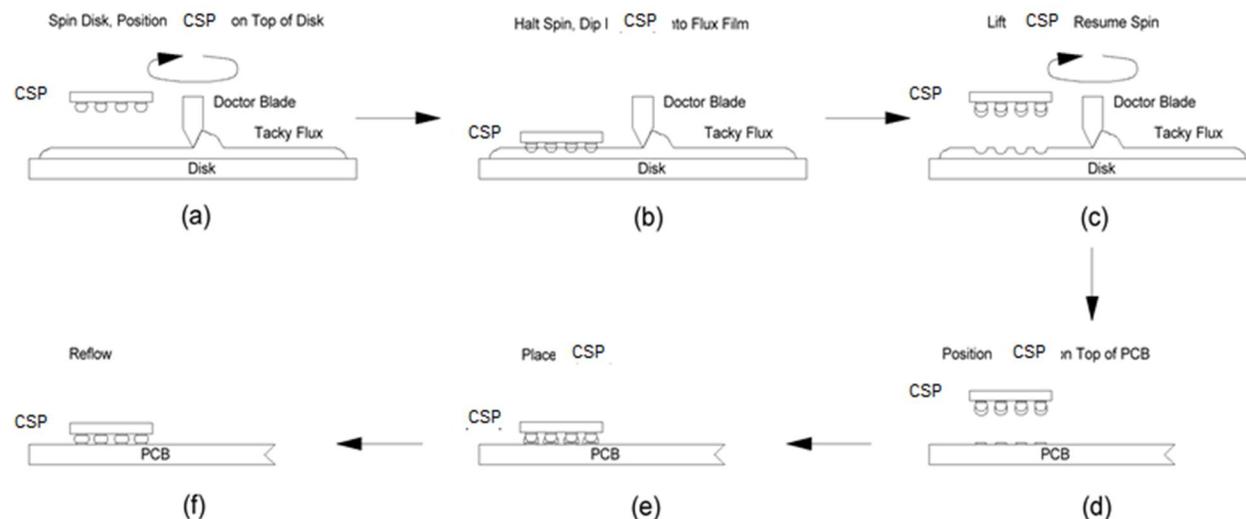
**Table 1.** Feature of several commercial Jetting devices.

Jetting Design	Drop size
A	30-35 pL (nanograms)
B	20-25 $\mu$ L (micrograms)
C	Largest ( $\sim$ 100 micrograms)

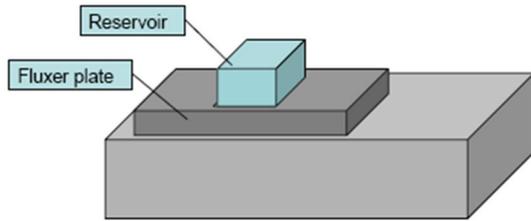
process, epoxy flux is first jetted onto the pads with solder paste already printed, followed by placing the bottom package. Again, epoxy flux is jetted onto the topside of the pads of the bottom package, followed by placing on the top package. This step can be repeated if there is more than one top package. After all of the packages are stacked sequentially, the board is then sent through a reflow oven to complete the soldering and curing simultaneously.

#### Epoxy Flux Dipping

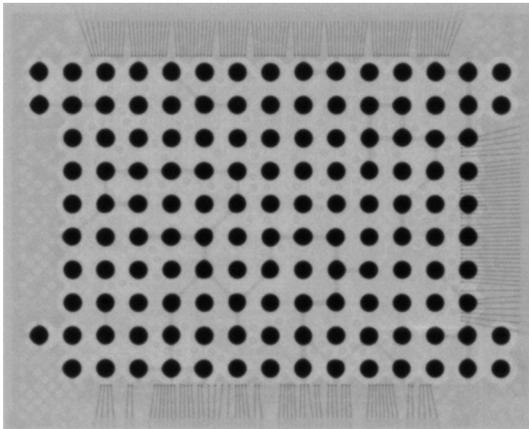
In the dipping process, the packages are predipped into an epoxy flux film prior to placement. The depth of the epoxy flux film can be regulated by a doctor



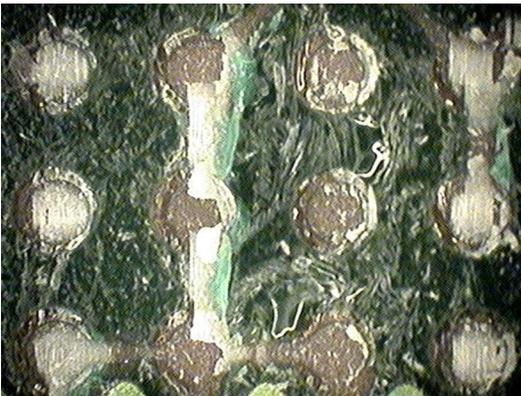
**Figure 3.** Flux dipping process using rotary device with doctor blade for controlling the flux film thickness.



**Figure 4.** Schematic of linear fluxer. The plate slides open to expose cavity [3].



**Figure 5.** X-ray picture of 0.8 mm BGA (10.5 x 13 mm) with SAC305 solder bump, SAC305 solder paste, and epoxy flux.



**Figure 6.** Board surface after BGA in Fig. 5 being sheared off.

blade rotary device, with process illustrated by Fig. 3 or a linear fluxer, as shown in Fig. 4. Typically, the film thickness is set at 80-100% of the solder bump height.

## PERFORMANCE OF EPOXY FLUX

### Solder Wetting

Solder wetting performance of epoxy flux is demonstrated on 0.8 mm BGA (10.5 x 13 mm) with

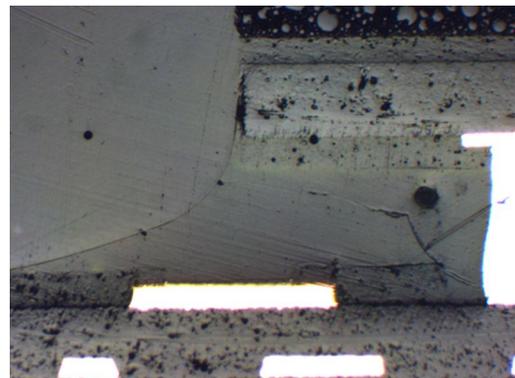
SAC305 solder bump and SAC305 solder paste. Fig. 5 shows the X-ray picture of the joints, with 100% full wetting observed for all solder joints. The shear strength of this BGA is 143lbs, compared with only 113lbs using a conventional flux. Upon shearing, failure of the epoxy fluxed samples occurred on the board side, with copper pads peeled off for some of the joints, as shown in Fig. 6. Apparently, the shear strength of the epoxy flux sample should be greater than 143lbs if pad lifting is avoided.

### Cross-Section

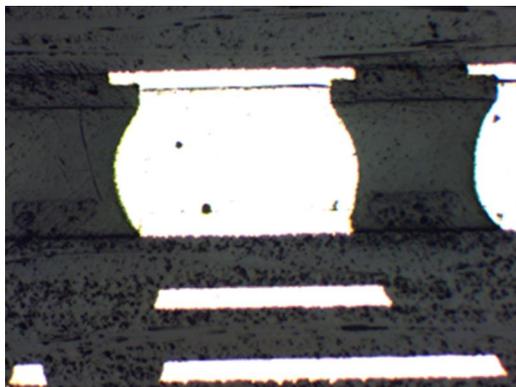
The Cross-sectional view of assembled 0.5 mm pitch BGA (7 x 7 mm) assembled with SAC305 ball, SAC305 solder paste, and epoxy flux is shown in Fig. 7. The close-up views of this device are shown in Fig. 8 to Fig. 10. The fillet shown in Fig. 8 indicates the space under the package is well filled. Solder joints formed with the BGA exhibiting full wetting, as shown in Fig. 9. Fig. 10 shows a vacancy in epoxy flux between two solder joints. This vacancy is characteristic of epoxy flux, and is designed as a venting channel. Without this venting channel, outgassing from the PCB substrate and packages caused by Pb-free reflow temperature often causes bubbling within the fully sealed liquid epoxy layer under the package, and consequently resulting in drifting or tilting of packages. This venting channel is typically designed to be less than 5% of the interface area, and is distributed randomly.



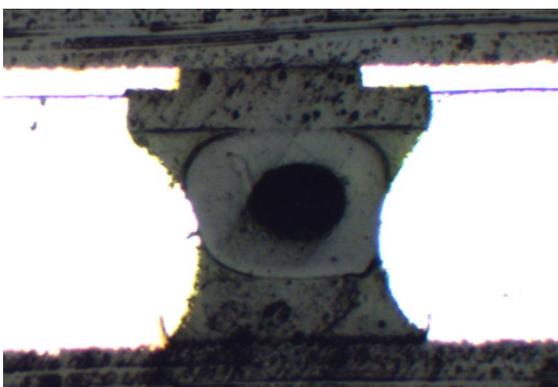
**Figure 7.** Cross-section of 0.5 mm pitch BGA (7x7 mm) assembled with epoxy flux.



**Figure 8.** Fillet of epoxy fluxed sample shown in Fig.



**Figure 9.** Cross-section of solder joint for BGA shown in Fig. 7.



**Figure 10.** Venting channel between solder joints.

**Table 2.** Reliability of epoxy fluxes versus conventional flux for 0.3 mm pitch CSP, size: 2.67 mm x 2.67 mm, I/O: 81

Tests	Conventional Solder Paste	Epoxy Flux A	Epoxy Flux B
Chip shear test, lbs.	19.2 ± 0.1	24.0 ± 4.3	36.5 ± 1.3 (+80% typical)
Drop test (drop # to fail)	80, 80, 90, 90	150, 180, 210	220, 220, 230, 240, 250, 290, 300, 320
Thermal cycling test (-55 ~ 125 °C)	168, 168, 168	719, 897, 897, 1098	870, 1089, 1498, 1843

### Reliability

Reliability of the epoxy flux system can be demonstrated with the data shown in Table 2 for 0.3 mm pitch CSP, size: 2.67 mm x 2.67 mm, I/O: 81, using SAC305 ball and SAC305 paste. Epoxy flux shows more than 60% higher shear strength than conventional flux, and are several times higher in drop numbers to failure. The thermal cycling test results show all epoxy fluxes last more than 1000 cycles for the cycling condition -55 to 125°C.

### Compatibility with Solder Paste

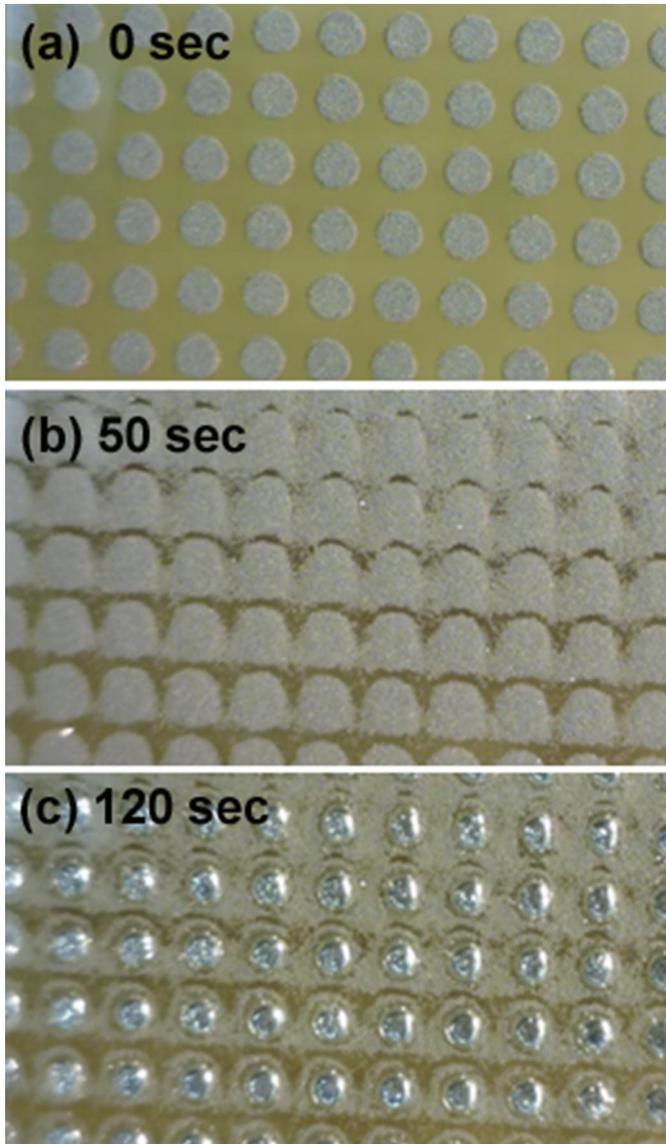
At assembly of the PoP, since the bottom package has solder bumps, printing solder paste on PCB pads is not critical for the successful assembly of the bottom package. However, at times, open between bottom package and PCB may be the result of excessive thermal warpage. Under this condition, printing solder paste becomes essential for minimizing opens.

As all solder pastes contain significant amounts of solvents, burn off of the volatiles of solder paste embedded in the liquid epoxy flux under the bottom package becomes a very challenging task. Furthermore, the powder of solder paste soaked in liquid epoxy is also prone to ooze out and form bridging and numerous solder balls.

Fig. 11 shows a simulated test for solder paste under the BGA and embedded in liquid epoxy flux. Here the SAC305 solder paste was printed onto PCB pads, and then covered by liquid epoxy flux A. A glass slide was placed on top of the solder paste/epoxy flux to mimic the body of a BGA. This sandwiched PCB was then placed on a hot plate with a surface temperature of 250°C. Fig. 11(a), (b), and (c) represent the view at 0 second, 50 seconds, and 120 seconds on hot plate. The solder paste immensely diffused away from the printed dots at 50 seconds, and never coalesced back to form proper solder bumps after 120 seconds.

Fig. 12 shows the same experiment using the same SAC305 solder paste but embedded in epoxy flux B. Here the solder paste remained as one integral body the entire time for each printed dot.

Results above show that a properly formulated epoxy flux can allow for a satisfactory coalescence of solder paste without suffering solder balling or bridging.



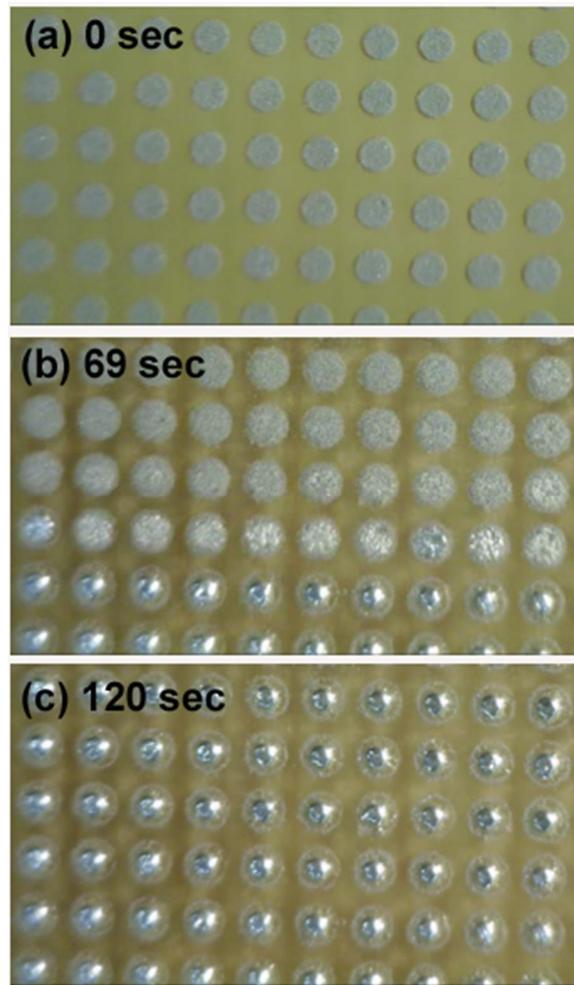
**Figure 11.** SAC305 solder paste with epoxy flux A under glass slide placed on hot plate at 250°C.

SIR Performance

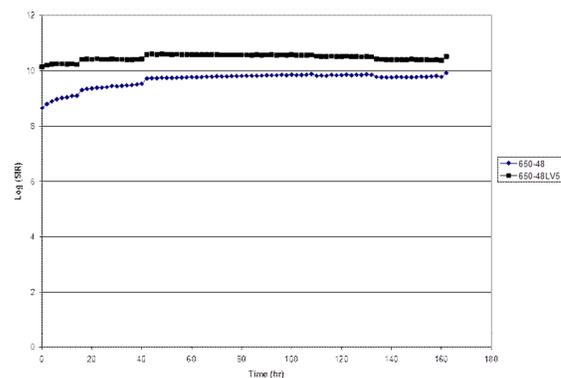
Being a thermoset system, epoxy flux is destined as a no-clean material, hence has to meet surface insulation resistance requirements without cleaning. Fig. 13 demonstrates that the IPC SIR requirement, greater than 100 mega ohms at 168 hours per J-STD-004, is easily met by one epoxy flux material.

Reflow Window

Epoxy fluxes can be designed to be very robust in terms of reflow windows. Table 3 shows the electrical continuity for daisy-chained BGAs assembled under various reflow profiles with two



**Figure 12.** SAC305 solder paste with epoxy flux B under glass slide placed on hot plate at 250°C.



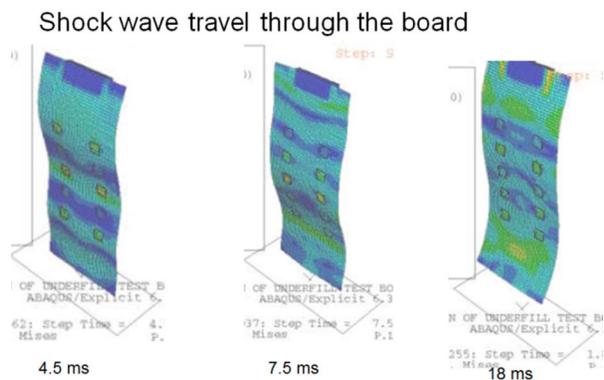
**Figure 13.** SIR performance of one epoxy flux per J-STD-004 procedure.

epoxy fluxes. Successful solder joint formation was achieved at a very broad reflow profile range.

**Table 3.** Electrical continuity of BGA assembled using two epoxy fluxes reflowed at various profiles.

Profile #	Time to peak temperature, min	Peak temperature, °C	TAL, sec	Continuity w/Epoxy Flux C	Continuity w/Epoxy Flux D
1	4	230	59	Good	Good
2	4	237	70	Good	Good
3	4	245	80	Good	Good
4	6	237	nd	Good	Good
5	3	237	nd	Good	Good
6	2.5	237	nd	Good	Good

Note: nd – not detectable



**Figure 14.** Printed circuit board experiencing shock wave traveling through upon drop [4].

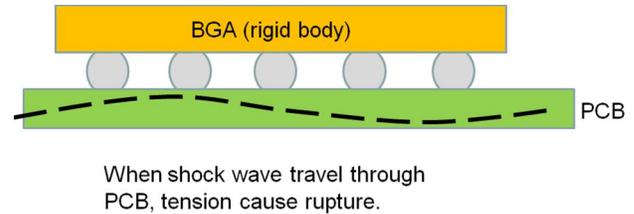
#### Physical Properties

The physical properties of a representative epoxy flux are listed below. The low T<sub>g</sub> property is considered crucial for avoiding the solder extrusion phenomenon at reflow or thermal cycling.

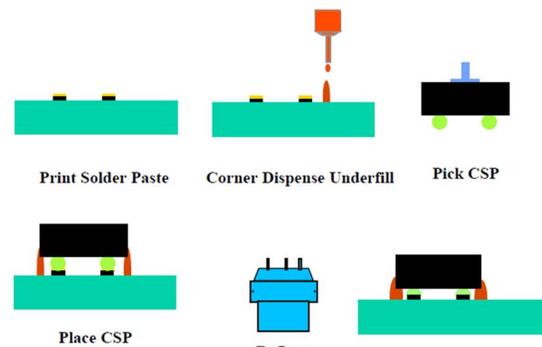
- É T<sub>g</sub> - 56 °C
- É CTE (<T<sub>g</sub>) - 64 ppm
- É Typical Viscosity - 5-7 kcps
- É Shelf life (at -20°C) - 3 month
- É Pot life (at room temp.) - 24 hours
- É SIR (Ohms) - >1.0 E+8 (pass)
- É Reworkable
- É Flux activation temperature - 150 °C

#### FAILURE MODES UPON DROP

Upon drop of portable devices, the printed circuit board experiences a shock wave traveling through it,



**Figure 15.** Schematic of shock wave passing through the board under BGA component.



**Figure 16.** Schematic of corner bonding process [8]

as shown in Fig. 14. When the wave passes through the area under a rigid component such as BGA or PoP, each solder joint experiences compression and tension sequentially, as shown in Fig. 15, and it is the tension which results in joint fracture [5]. The failure modes reported [6] include pad cratering (83.3%), I/O trace fracture (73.3%), board side solder crack (33.3%), daisy chain trace fracture (3.3%), and chip side solder crack (1.7%) in terms of percentage of analyzed components. Study of Srinivas shows the failure rate of bottom joints is higher than top joints for PoP upon drop [7]. Accordingly, the most critical reinforcement desired would be a bonding force holding the board surface and the bottom package body together.

#### POLYMERIC REINFORCEMENT APPROACHES

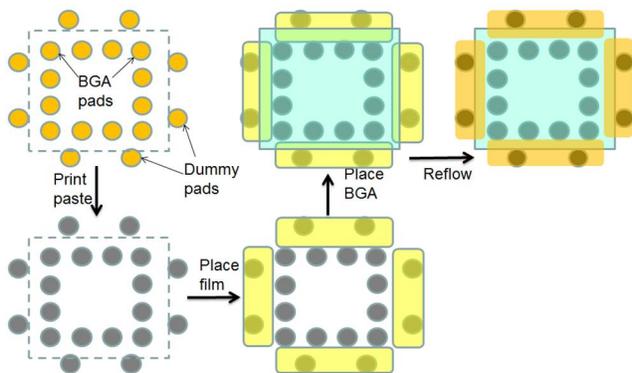
There are several polymeric reinforcement approaches attempted by the industry as introduced schematically below.

##### Corner Bond

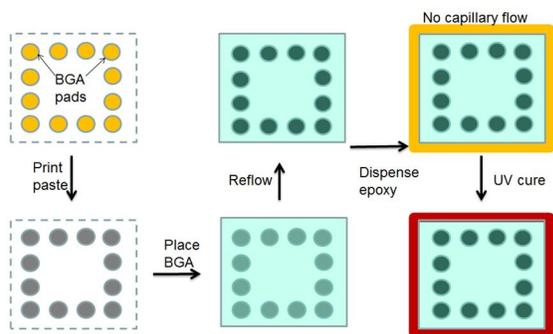
É Pro

Cure at solder paste reflow process. No additional curing step & oven needed.

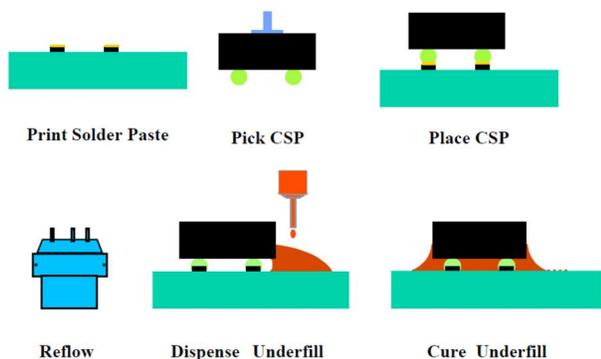
Reinforce BGA to some extent.



**Figure 17.** Schematic of Place-N-Bond Underfilm process [9].



**Figure 18.** Schematic of edge-bond, epoxy liquid process.



**Figure 19.** Schematic of capillary flow underfill process [8].

Less promising for preventing crater failure.  
No prebaking needed.  
Often reworkable.

- É Con  
Premature curing due to altered reflow profile can result in difficulty of BGA collapse upon reflow.  
Polymer wicking or smear at placement can interfere with solder paste reflow.

For precision deposition, premium dispensing equipment is needed, & significant increase in cycle time becomes inevitable.  
Cannot reinforce bonding between top and bottom packages.

Place-N-Bond Thermoplastic Underfilm

- É Pro  
No dispensing equipment needed.  
Cure at solder paste reflow process. No additional curing step & oven needed.  
Reinforce BGA to some extent.  
Less promising for preventing crater failure.  
No prebaking needed.  
Often reworkable.

- É Con  
Need dummy pads designed in on PCB, more reserved space required around BGA.  
Film placement may disturb components placed earlier & cause defects.  
Epoxy wicking may interfere solder wetting.  
Cannot reinforce bonding between top and bottom packages.

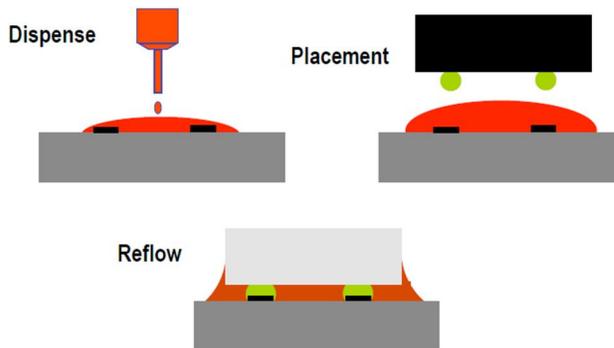
Edge Bond ó Epoxy Liquid Process

- É Pro  
Fast UV cure, no heat cure needed.  
Epoxy won't interfere with soldering.  
Easy inspection.

- É Con  
One more step dispensing needed. Cycle time is unacceptable for high volume, high throughput production.  
For high performance, premium dispensing equipment needed.  
Less promising in preventing crater failure.  
Cannot reinforce bonding between top and bottom packages.

Capillary Flow Underfill

- É Pro  
Mature technology.



**Figure 20.** Schematic of no-flow underfill process [8, 10].

Potential with the highest reinforcement.  
 Promise reduction in both joint & crater failures.

É Con

Requires post reflow underfill dispense, capillary flow & cure. Costs more time & equipment.  
 May require prebake to avoid voiding if there is delay prior to underfilling.  
 Reworkability can be an issue, including components around BGA which were flooded by underfill.

#### No-Flow Underfill

É Pro

Simple dispense process, no flow needed.  
 Cure during solder paste reflow.  
 Significant reinforcement.  
 Promise reduction in both joint & crater failures.  
 Some are reworkable.

É Con

Placement may introduce voids.  
 PCB prebaking may be needed.  
 For large BGA, open & chip drifting or lifting may be the result due to earlier gelling of underfill at the hotter perimeter.  
 Solder wetting may be hampered due to premature gelling upon alternation in reflow profile.  
 No filler allowed.

#### Epoxy Flux

The processes of epoxy flux are shown in Fig. 1 to 4.

É Pro

Only one extra dipping step needed. The simplest process among all polymer reinforcement approaches.  
 No solder wetting interference concern.  
 No PCB prebaking needed due to designed-in venting channel.  
 Significant reinforcement.  
 Promising reduction in both joint & crater failures.  
 Reworkable.  
 Compatible with assembly of BGA & PoP, including PoP stacking.  
 Compatible with solder paste, thus can tolerate warpage at soldering.

É Con

Need epoxy flux bed.  
 Larger nozzle size may be needed for pick & place at dipping step.

#### **SUMMARY**

Among existing polymeric approaches for assembly and reinforcement for PoP, epoxy flux turns out to be the most versatile low cost option. The reliability

enhancement achieved includes mechanical, thermal, and electrical properties.

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