

EPOXY FLUX MATERIAL AND PROCESS FOR ENHANCING ELECTRICAL INTERCONNECTIONS

Neil Poole, Ph.D., Elvira Vasquez, and Brian J. Toleno, Ph.D.
Henkel Electronic Materials, LLC
Irvine, CA, USA
neil.poole@henkel.com

ABSTRACT

There are two main drivers that are causing electronic device manufacturers to look into methods other than solder paste to form electrical interconnection on area array devices. The first driver is the move to smaller and smaller pitch. On hand-held devices it is very common to see 0.5mm and 0.4mm pitch CSPs, with 0.3mm pitch WLCSPs becoming more prevalent. While there are solder paste materials that can be used to print these fine features, these materials (and the accompanying stencil thickness) are not always suitable for the other components on the assembly. The other driver is the stacking of CSPs. Package on package (PoP) process has been well studied and documented over the past few years [3 – 5], here once again, printing solder paste for the second level interconnect is not practical. In both cases there have been studies looking at tacky flux and/or dipping solder paste in order to form the solder joints [1,2, & 6]. Both of these methods can be used to produce good solder joints, but due to the end nature of these devices these solder joints typically need to be enhanced against drop and vibration by the use of an additional underfill process. In this paper we outline the material and the processes used to produce devices with a novel epoxy based fluxing system. This material provides the wetting and activity to create a solder joint as well as providing some reliability enhancement due to the epoxy adhesive portion without the use of harmful solvents. In addition, we will also discuss the process capability of this material with respect to repeatability.

Key words: Epoxy Flux, Underfill, Soldering

INTRODUCTION

Designed to offer process efficiency, epoxy flux materials deliver a fluxing component that enables solder joint formation as well as an epoxy system that offers added device protection by encapsulating individual bumps. Because epoxy fluxes are cured during the reflow process, they offer an in-line alternative to other underfill mechanisms and eliminate the need for a dedicated dispensing system and the time required to dispense and cure [1,2,&6]. These new systems can also be formulated to provide application flexibility so they can be screen printed, dipped, jetted or dispensed as required. While there are certainly other fluxing – or no-flow – underfill materials that offer in-line processing, none deliver the process ability of epoxy fluxes. No-flow underfill encapsulants, for example, have been used in both semiconductor packaging and PCB

assembly and, although process efficient, there can be challenges with performance and reliability[1,2]. Using the no-flow technique, material is applied to the substrate prior to component or die placement and then is cured during reflow. However, since moisture outgassing from the substrates and packages into the no-flow material, causing voids. Epoxy fluxes, on the other hand, only encapsulate individual spheres or bumps and, therefore, leave channels underneath the device that allow any volatile gasses from the substrate to escape, while still providing solder joint protection.

While PoP devices offer improved efficiency by maximizing PCB or substrate real estate, there are challenges with the second-level assembly of these packages. The bottom level package assembly is very straightforward and follows standard surface-mount procedures. The top level package, however, presents some assembly hurdles to overcome. First, many of these stacked packages experience warpage problems whereby the bottom package may warp downward and the top package may warp upward. This may result in stretched or broken solder joints. Second, the assembly method of the top package presents challenges related to stress reduction and long term reliability. The most commonly employed attachment method for the level two package is a tacky flux dip where the spheres are dipped into a tacky flux prior to component placement. This offers the flux action necessary to form the solder joint during reflow but device support and protection can be less than adequate. Early evaluations, however, indicate that epoxy flux materials offer the top level device support and reliability enhancement required for these new packages.

Finally, the material needs to be formulated such that it has a wide enough process window to be used in several production lines with minimal adjustments and provide repeatable deposition. This paper will focus on the dip transfer method. In this process it is important for consistent, repeatable transfer of the material from the dip tray to the component over 8+ hours. In addition, the material should be formulated to perform similarly in multiple reflow profiles, providing the same performance under each condition. Finally, the material should be free of harmful solvents that can impact the tray life and/or be harmful to the operators.

The epoxy flux material needs to combine the properties of a fluxing material (oxide removal, wetting, etc.) and that of an underfill system (adhesion, thermal cure, etc.) [Figure 1]. The chemistries used, obviously, must be compatible with one another. In this paper we will explore the robustness of the application process, looking at optimum transfer processes and the repeatability of that process. In addition, we will evaluate the reliability enhancement provided by the use of this material. Rather than infer these properties from material property tests, we test the materials on actual components and perform the reliability testing on test vehicles designed to closely mimic electronic devices in the field. We will also present data on the performance of the materials with respect to other reliability performance such as solder extrusion, separation, voiding, etc.



Figure 1. Concept of an Epoxy Flux

EXPERIMENTAL

Dip Process Window

The first thing that a good epoxy flux needs to accomplish is to consistently and effectively get onto the parts to be soldered. While there are multiple methods that can be used to accomplish this application, in this paper we will focus on the dip transfer method. In this method, the component to be soldering is dipped into a flux tray that has a thin layer of the epoxy flux material. The component is held in the dip tray for a period of time, then placed onto the substrate [Figure 2].



Figure 2. Images of the dip process

For this process the epoxy flux must have the correct rheology to wet onto the bumps of the package, but not flow off of the bumps prior or during reflow. In addition the material needs to go back to a thin even layer of material after being smoothed with a doctor blade. This rheology must be maintained and consistent even after exposure to air and humidity during one or more shifts in an electronics manufacturing facility. One measure of this process

robustness is to measure the viscosity change over time at temperature, Figure 3. From a process standpoint, the two main factors that affect the amount (and consistency) of the material transfer onto the bumps are the dip depth and the dwell time. In order to determine the transfer efficiency and the process window we used the bottom package of a 14mm x 14mm TMV PoP set with 620 I/O and 0.4mm pitch.

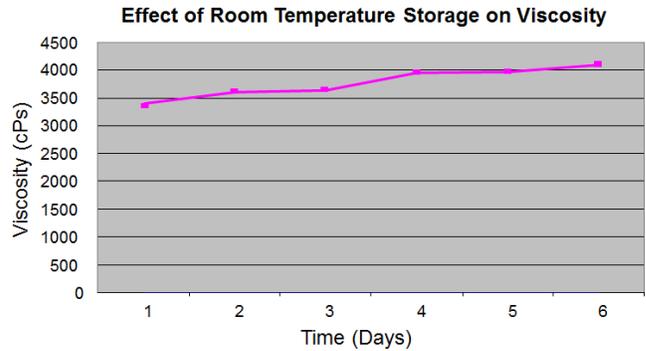


Figure 3. Effect of temperature on viscosity

These parts were dipped at dip depths of 142um to 190um and dwell times of 200ms, 800ms, and 1000ms. The weight of the material transferred was measured and the average of 10 components per data point were collected. From this data a response surface plot was generated in order to highlight the optimum dip depth and dwell time conditions, Figure 4.

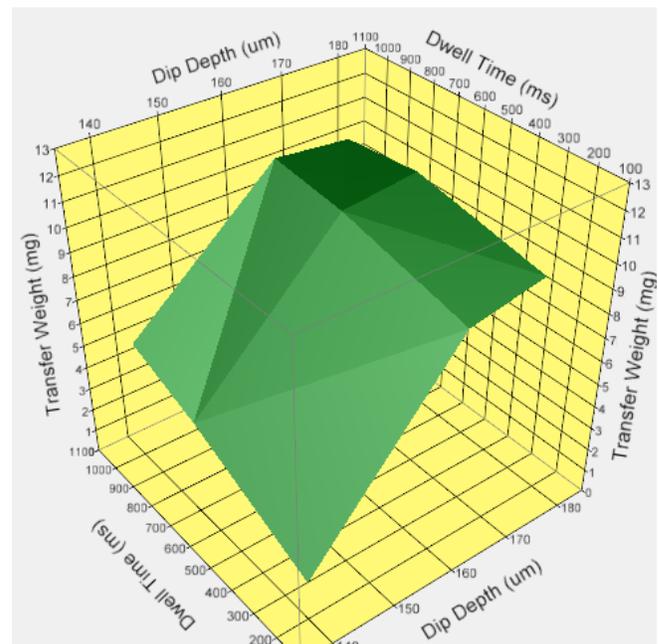


Figure 4. Response Surface Plot Indicating Optimum Dip Process.

This data indicates, for this package, the optimum conditions would be a dip depth of 160um or greater with a dwell time of 800ms or greater. (It should be noted that dipping the component so the bumps are fully immersed and the epoxy flux touches the bottom of the package typically

resulted in the component being difficult to remove from the dip tray due to surface tension and wetting.) These results were further validated by performing a statistical analysis of different dip depths with different dwell times, Figure 5. The data clearly shows a statistically significant difference between dip depth above 165um and those below 165um, which is independent of dwell time.

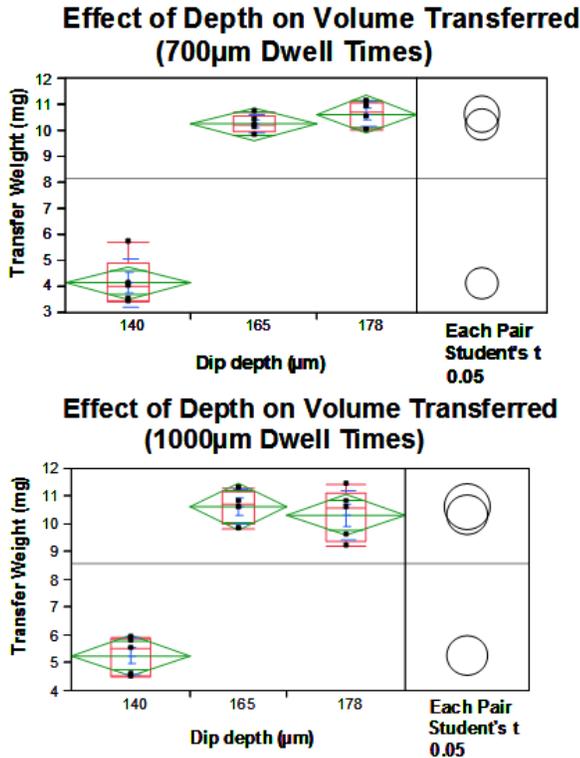


Figure 5. Statistical Comparison of Dip Depth

Furthermore, the dip depth effects the repeatability over different dwell times as well, Figure 6.

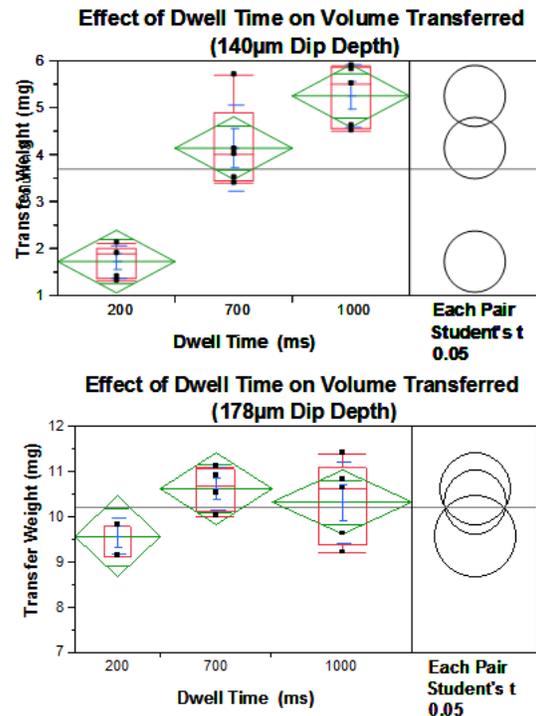


Figure 6. Statistical Comparison of Dip Depth versus Dwell Time

Another confirmation of the material lifetime was conducting using the transfer volume as a metric against time. This would provide information regarding the lifetime of the material on the dip tray and how the transfer efficiency would be affected over time, Figure 7. What we discovered is that the material provided consistent volume transfer over 120 hours, even with a dwell time as low as 200ms (which would not be recommended in HVM, but was used for the purpose of determining process windows).

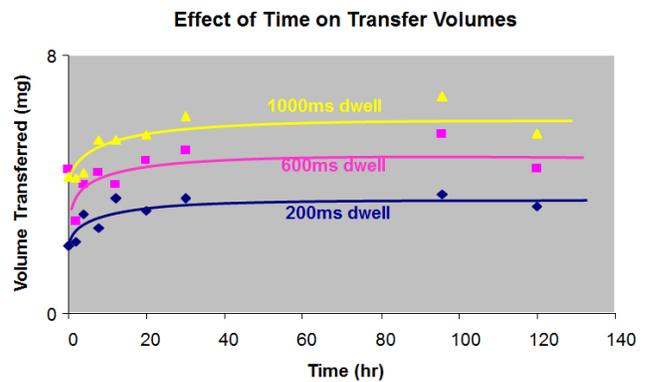


Figure 7. Volume Transfer versus Time

Solder Joint Yield

One of the common concerns with epoxy flux type of materials is the ability to form a solder joint [1-2]. The chemistry is a careful balance between activity and soldering above solder liquidus and curing the epoxy system at elevated temperatures. The material needs to be robust enough to provide repeatable solder joint connections on a

variety of parts, under different dip conditions and reflow profiles. All these studies were conducted with SAC alloy components and Pb-free compatible reflow profiles. Three different parts were tested (Table 1).

Component	Type	Pitch	Size	I/O
A	CSP	0.5mm	12mm sq	228
B	CSP	0.4mm	13mm sq	432
C	TSV PoP	0.4mm	14mm sq	620

These components were tested under a variety of conditions. In all combinations 100% yield was achieved, Table 2. In total, 365 components were built with no opens. The 0.5mm pitch CSP components were used to evaluate the drop test improvement (Figure 8) and thermal cycling improvement (Figure 9). The TMV PoP were evaluated by an OEM and passed their reliability testing, but the results cannot be included here.

Component	Number Parts	Dwell Time (ms)	Dip Depth (um)	Yield (%)
A	3	0	190	100
A	3	250	190	100
A	3	500	190	100
A	45	600	190	100
A	3	750	190	100
A	18	1000	190	100
B	40	600	114	100
B	40	150	127	100
C	210	500 / 800	100 / 175	100

Reliability

One of the driving factors to using epoxy flux is to enhance the reliability of the devices beyond solder alone. The effect on reliability performance was measured on actual components rather than inferred from shear testing or tensile pull testing. For both of these reliability tests component A (0.5mm pitch CSP) was used on a 1.0mm thick PCB, as defined by the JEDEC drop test standard [7]. First we evaluated the drop test improvement as per the JEDEC method [7], Figure 8.

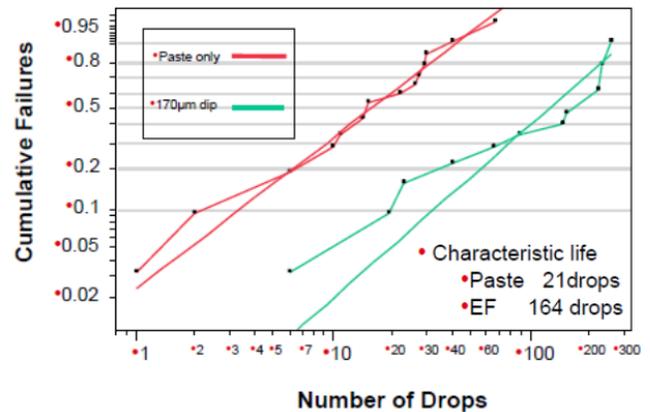


Figure 8. Drop Test Improvement from Epoxy Flux (EF)

Next we evaluated the improvement in thermal cycling performance using the same test vehicle, cycling between -55°C to +125°C, for 1000 cycles (30 minutes per cycle), Figure 9. Unfortunately, there were not enough parts to generate a Weibull plot for the thermal cycling data, so we just compared the number of failures versus cycles. Since the epoxy flux is unfilled, we did not expect an improvement in thermal cycling, but we do observe a slight improvement in the thermal cycling reliability. This is currently being further explored across different packages. Another aspect of the material chemistry that can affect both of these reliability metrics is voiding caused by outgassing. Since this is a solvent-free system, any outgassing would be caused by reaction products during the reflow and cure.

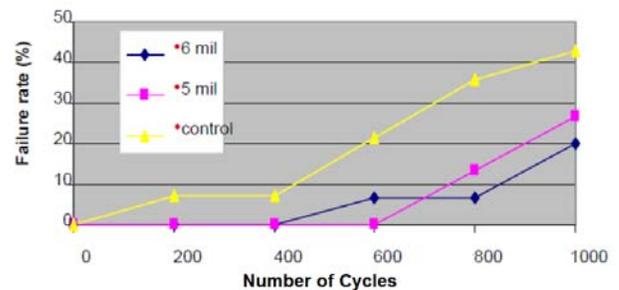


Figure 9. Thermal Cycling Improvement with Epoxy Flux

The first step is to determine if the material itself outgasses during the reflow and cure cycle. To evaluate this aspect a thermo-gravimetric analysis (TGA) methods were used. In this method the weight loss of a material is precisely measured over a thermal profile, and the weight loss as a percent is reported. We used three different temperature profiles. The first was a sharp ramp to 250°C and hold, the second was a single SAC-alloy reflow profile, and the third was the weight loss between the first and second SAC reflow, results in Table 3.

Temp Profile	Weight Loss (%)
250C Peak	2.36
1x Reflow	1.15
2x Reflow	0.77

In all cases the weight loss was well below 3% - therefore only a small amount of material is ejected during the process due to the material alone. The other possible source of outgassing is by-products produced during the removal of the oxides from the solderable surfaces. Figure 10 illustrates the process used and Figure 11 shows two materials and their relative performance.

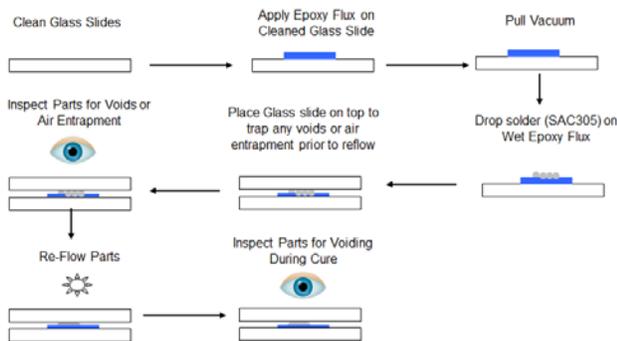
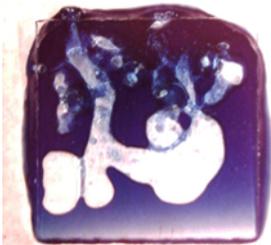


Figure 10. Illustration of Process for Evaluating Voiding in Epoxy Flux

Poor Performer



Current Epoxy Flux

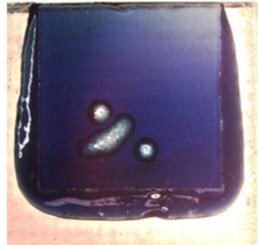


Figure 11. Images of Voiding Improvement of Epoxy Flux on OSP

Since this material is also acting as the flux and will remain on the PCB between bumps and traces we also needed to insure the reliability with respect to surface insulation resistance (SIR). For this test we evaluated both the epoxy flux over the SIR comb traces as well as epoxy flux over solder on the traces. The boards were conditioned with 40°C/90%RH for 168 hours (7 days) and the insulation resistance measured, Figure 12.

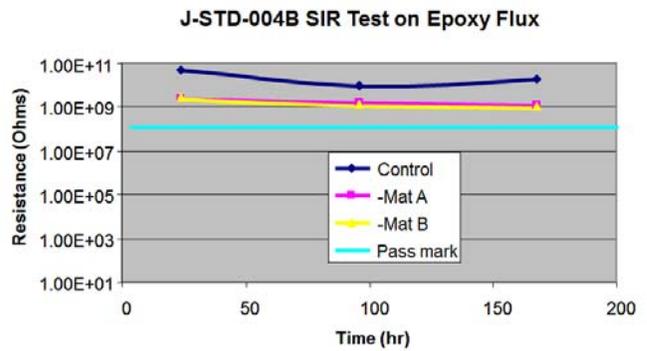


Figure 12. SIR Performance of Epoxy Flux

CONCLUSIONS

The pace of new package development is tremendous. Consumers continue to demand higher functioning, low cost products and manufacturers must keep pace. High volume, high reliability solutions are the only answer for optimization of production environments and new underfill materials technology is enabling these advances.

New package configurations, finer pitches and the need for ever increasing throughput rates are pushing current underfill systems to their limit. Of course, there will always be a place for traditional capillary underfills. But, for stacked packages, large footprint array devices and many other emerging technologies, older materials systems cannot offer the in-line processing advantages in tandem with the reliability required for these new products.

In this paper we have shown the process robustness of new dip processable next-generation epoxy flux systems. This has been demonstrated with multi package builds with 100% yield. These components and test vehicles were then shown to be more reliable with respect to drop and thermal cycling versus solder paste alone.

Next-generation epoxy flux materials, however are providing not only the UPH, performance and reliability required for high-volume manufacturing, but also offer a level of versatility heretofore unavailable. With a dual function flux and underfill in one material, epoxy fluxes have a broad application range for both packaging and board assembly environments. With capability for PoP assembly, large area array device assembly, protection and much more, manufacturing firms can conceivably source one material for production of various products. In this paper we discuss the process window and capability of dipping, similar formulations have been used and applied via dispensing, screen printing, and jetting. This provides unprecedented manufacturing flexibility.

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