VOID REDUCTION STRATEGY FOR BOTTOM TERMINATION COMPONENTS (BTC) USING FLUX COATED PREFORMS.

Anna Lifton, Jerry Sidone, Paul Salerno, Oscar Khaselev and Mike Marczi
Alpha Assembly Solution,
South Plainfield, NJ USA

Klaus Weigl, Gerhard Martl
Rohde-und-Schwarz-Str. Memmingen Germany

ABSTRACT
As power density in semiconductors rises year-over-year, increased efficiency and reliability of Bottom Terminated Components (BTC) packages like QFN, LCS, QFP, and DPAK are becoming much more difficult to manage using traditional soldering techniques. The most notable method for thermal management of BTCs is to increase the efficiency of the thermal path through the bulk solder by decreasing the voids in the solder joint. The most recent surge in increased performance has driven many manufacturers to adjust their void requirements under BTCs from less than 25% to less than 15% or even 10% in many cases.

Both the increased demand on the solder material performance and the ineffectiveness of traditional methods for addressing voiding have the market looking for new technology that can provide economical, reliable and repeatable results. There are several different approaches to reduce voiding: solder paste chemistry modification, stencil design, reflow profile optimization, and adding solder preforms to increase solder volume. No one approach has proven to provide an all-inclusive solution.

Most recent work has demonstrated that using a unique void reduction technology (VRT) can significantly reduce voiding consistently and effectively. A collaboration between three companies representing solder materials (Alpha Assembly Solutions), power semiconductor component manufacturer, and an OEM of specialized test and measurement equipment (Rohde & Schwarz) worked together to investigate the effectiveness of solder preforms at reducing voiding under BTCs. The effects of factors such as component type and size, finish on PCB, preform types, stencil design, reflow profile and atmosphere, were studied using lead-free, low voiding, SAC305 solder paste and preforms.

Key words: bottom termination components; preforms in paste; voiding; tape and reel preforms; flux coated preforms.

INTRODUCTION
Void reduction in both leaded (QFP, DPAK) and non-leaded power components (QFN, LCS) is becoming significantly more important as power density continually increases and component packages are getting smaller. These power components typically contain a thermal pad that is soldered to the printed circuit board (PCB) for increasing thermal and electrical performance. Thermal vias are commonly placed within the PCB to aid in heat dissipation. Additionally, low voiding is important for decreasing the current path of the circuit to maximize high speed and RF performances (1). This study was initiated in response to the markets increasing demand for higher power density components that require low voiding solder joints as a means of optimizing the thermal and electrical performance of the package.

IPC 7093 specification acknowledges that one of the key concerns with bottom termination components (BTC) such as QFN's is achieving the solder volume required for a high reliability solder joint (2). Leveraging the use of a solder preform combined with solder paste, stencil design, and application knowhow are critical factors in determining voiding in these types of components. The study presented seeks to understand the factors that can contribute to voiding such as PCB pad finish, reflow profile, reflow atmosphere, via configuration, component type, and ultimately solder design. These efforts contribute to developing a solution that maximizes solder volume while minimizing voiding to generate a high reliability solder joint under bottom termination components.

EXPERIMENTAL PROCEDURE
A full factorial DOE was designed based on key factors contributing to voiding under bottom termination components. The use of a solder preform was investigated compared to a SOLDER PASTE ONLY benchmark sample. The key factors in this DOE were identified and selected by subject matter experts from a global leader in semiconductor manufacturing, an OEM of specialized test and measurement equipment for radio communications, and solder manufacturer (Alpha Assembly Solutions).

A custom single layer 1.6mm thick PCB test vehicle was designed specifically for this investigation that encompassed numerous variables that can contribute to voiding in bottom termination components. A single layer PCB design was chosen so that other factors (i.e. multilayer board and ground planes) would not influence the key factors being addressed in this study. QFN, QFP, LCS and DPAK (**Figure 1**.) component of various sizes and pin configurations were among the variables addressed and further defined in **Table 1**.

There were 2 types of test boards generated: one with an Immersion tin (ImmSn) plating and another with an Immersion silver (ImmAg) plating.

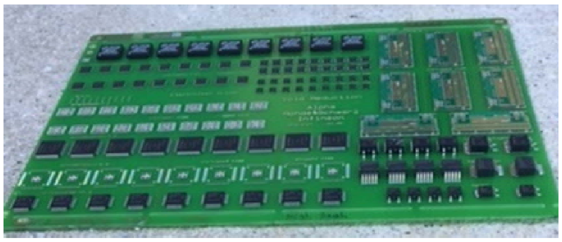


Figure 1. Image of the PCB test vehicle (TV) and some of the components used in this DOE.

Table 1. Components Details

Type	Pin	ID	# of Comp. per TV	Exposed Ground Pad (LxW, mm)
QFP	128	QFP 128	9	7 x 6.4
QFP	64	QFP 64	9	5x5
QFN	32	QFN 32	18	3.6x3.6
LCS	20	LCS 20	18	2.1x2.1
LCS	48	LCS 48	18	5.4x5.4
DPAK	2	DPAK 2	6	8.5 x 7.55
DPAK	5	DPAK 5	6	8.5 x 7.55
DPAK	2	DPAK 2 Sm	6	6.4 x 5.8

The test board also addressed via design including through hole via, no via, and plugged via configurations under the QFN, QFP, and LCS components. The through hole via had a 0.3mm diameter with and 0.5mm diameter resist on top and bottom. The plugged via maintained the same 0.3mm diameter hole and depth of 0.4mm with 0.7mm diameter resist on top and bottom. Vias were configured in a pattern as indicated in **Figure 2** below

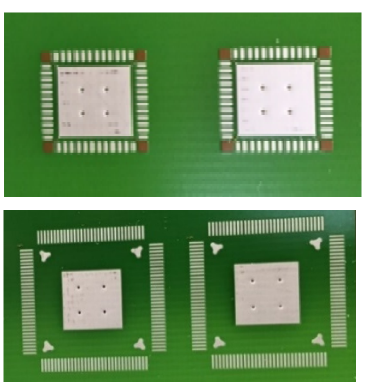


Figure 2. Via design and configuration on the test vehicle (TV)

The investigation also addressed reflow profile and reflow atmosphere. A low voiding SAC305, type 4 solder paste was used for this study with solidus temperature of 217°C and liquidus temperature 220°C. Thermocouples were strategically placed on the QFN32, QFN64, and TO263 component locations on the test vehicle. Proven straight ramp and high soak reflow profiles were evaluated as shown in Figure 3 and 4. The straight ramp profile increased at a rate of 1°C/s until reaching liquidus temperature of 220°C. The test vehicle was subjected to 65 seconds above liquidus (TAL) with peak temperature on the test vehicle reaching 240°C. The high soak reflow profile increased temperature at a rate of 1°C/s up to 150°C before slowing to a rate of 0.5°C/s up to 200°C to allow more time for the flux to activate the surfaces.

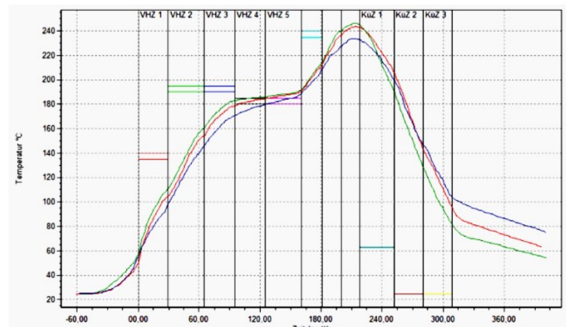


Figure 3. Straight Ramp Reflow Profile

The high soak profile subjected the test vehicle to 50 seconds above liquidus (220°C) with a peak temperature of 240°C on the test vehicle. Finally, both Air and Nitrogen reflow atmospheres were evaluated in this investigation to further understand the effect of voiding under bottom termination components.

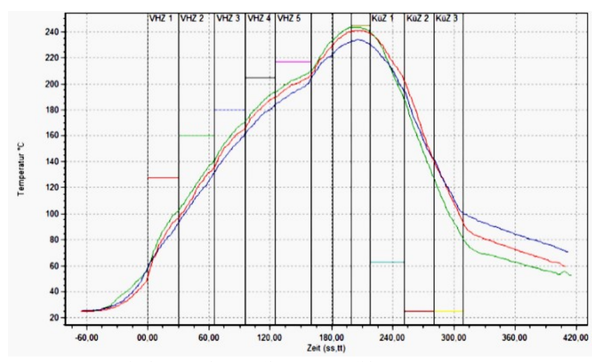


Figure 4. High Soak Reflow Profile

The focus of the investigation involved the use of the micro-flux coated solder preform to increase solder volume relative to fluxing agent and reduce voiding. The use of a SAC305 micro-flux coated solder preform in conjunction with paste was benchmarked against a SOLDER PASTE ONLY test vehicle for each of the configurations summarized below in **Table 2.** Four replicate boards of each iteration were processed in order to ensure statistically viable data.

Table 2. Assemblies configuration details.

ID	PCB finish	Reflow Profile	Atmosphere
1	ImmSn	High Soak	Air
2		High Soak	Nitrogen
3		St. Ramp	Air
4		St. Ramp	Nitrogen
5	ImmAg	High Soak	Air
6		High Soak	Nitrogen
7		St. Ramp	Air
8		St. Ramp	Nitrogen

Close to 4,000 data points were generated combining 90 components on each test vehicle and four replicates of each configuration. The SOLDER PASTE ONLY benchmark samples were printed in a window pane configuration commonly used in the industry for void reduction and shown in **Figure 5**.

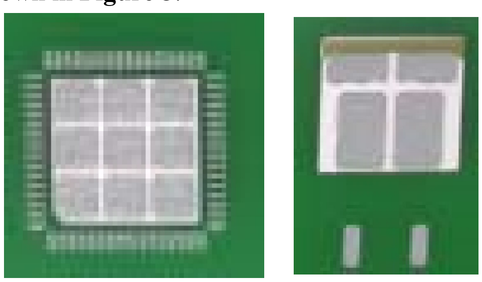


Figure 5. Solder Paste Print Configuration (Examples of window pane solder prints on QFP and DPAK components used in benchmark samples)

The design of a solder preform to allow intimate contact with the thermal pad of the component and increase solder volume played a significant role in the results presented in this investigation. **Figure 6** represents an example of the use of SOLDER PASTE ONLY in window pane format on a QFP where mechanical stack-up issues on the component and reflow characteristics of solder paste make it difficult to achieve good solder volume and voiding despite use of a step-up stencil.

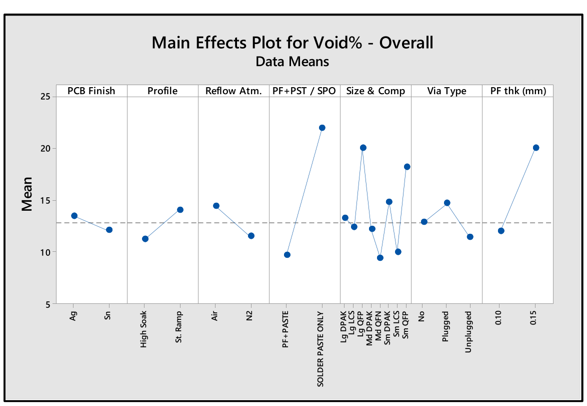


Figure 6. Solder Paste Print design for QFN.

Trials were conducted at Rohde & Schwarz using a fully automated in-line system Use of such a world-class facility helped to maintain control and ensure consistent process repeatability among test vehicles. An EKRA X5 printer was used to print 5 mil thick paste layouts on both the SOLDER PASTE ONLY and solder paste and preform configurations under investigation. Paste was printed at a 65° squeegee angle at a rate of 30mm/s and 80N pressure using a 5mil stencil. Components and solder preforms were placed from tape & reel using a Siemens Siplace X2 with Twin-head and 2N force. Samples were then inspected for skew prior to reflow in an SMT Quattro Peak L Plus belt driven reflow oven per the reflow profiles defined in **Figure 3 and 4**. Finally, upon reflow, every component was subjected to X-ray voiding analysis capturing its largest single void size and total void percent under the thermal pad.

RESULTS AND DISCUSSION.

The void data was analyzed using Minitab and Excel. The Main Effects % Void – Overall plot in Figure 7. Below indicated the following:

* The lowest voids percentage was achieved with a high soak reflow profile, nitrogen reflow atmosphere, using ImmSn plated boards with through hole vias and micro-flux coated solder preforms combined with solder paste on the pads.

* QFP and DPAK packages produced the highest voiding % overall, while the LCS and QFN packages demonstrated the lowest voiding %.
* Through hole and no vias produced the least amount of voiding overall. Vias were not used under the DPAK components, thus the mean values may be skewed a bit.
* The solder paste and preform (PF+Paste) configurations had the most impact on overall voiding.
* Two preform thicknesses were chosen based on whether the components were leaded or non-leaded packages. The components that implemented the 0.15mm thick preform (DPAK and QFP) tended to void more than components using a 0.10mm thick preform.

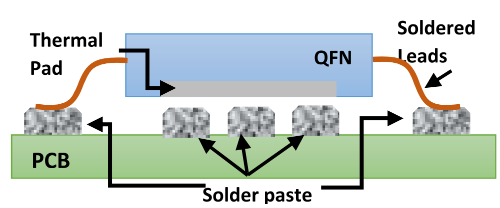


Figure 7. The Main Effects % Void – Overall plot

The remainder of the analysis will gage the factors influencing void percentage while using the solder paste configuration as the basis of the analysis. The Main Effects plot for a SOLDER PASTE ONLY (SPO) configuration is shown in **Figure 8**. The void % average for the contributing factors resulted in approximately 22% average voiding overall. Reflow atmosphere had very little impact on the voiding results. The High soak profile, ImmSn plated pads and through hole vias marginally drove to lesser voiding, while plugged vias were most problematic of the three. The QFP packages tended to void the most.

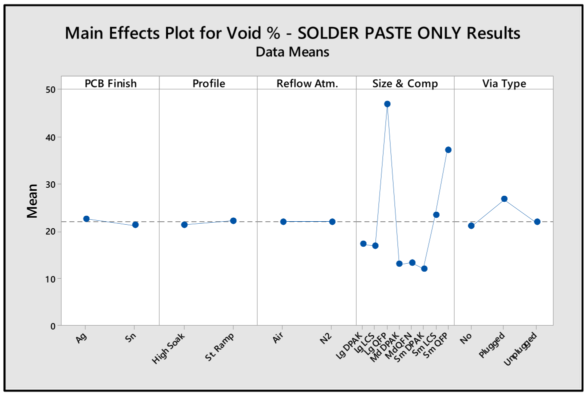


Figure 8. The Main Effects for SOLDER PASTE ONLY configuration

The Main effects plot for the PREFORM AND PASTE (PF+Paste) configuration is shown in **Figure 9.** At an average of 9%, the overall average void% fell below the SPO configuration by more than two times. Unlike the SPO configuration, the primary contributor to voiding in the PF+Paste configuration was the reflow atmosphere.

A similar study was conducted back in 2012 to understand the effects of micro-flux coated solder preforms and voiding under bottom termination components. Since then advancements in flux development has improved void performance significantly. One of the outputs from the previous voiding study (3) stated that a higher preform-to-paste volume ratio on the pad contributed to lower voiding in nitrogen. Since the micro-flux coated preform makes up the bulk of the solder volume on the pad, there is less solder paste needed resulting in less volatiles to outgas. Still in this study (although impressive) the low voiding preform in an Air reflow struggled to match the results of the Nitrogen reflow. The natural oxidation that takes place in air continues to challenge low voiding results, relatively.

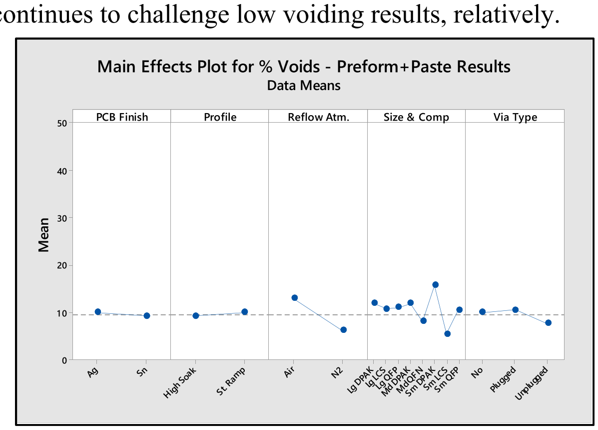


Figure 9. The Main Effects for PREFORM AND PASTE (PF+Paste) configuration

A boxplot of the overall void results as a function of PREFORM AND PASTE and SOLDER PASTE ONLY configurations is shown in **Figure 10**.

It indicates that all packages provided significantly lower voiding when reflowed in nitrogen using the PF+Paste configuration. Even in Air, the PF-Paste configuration showed overall better voiding than the SPO configurations.

Next we will examine the key factors' influence on voiding from a component basis.

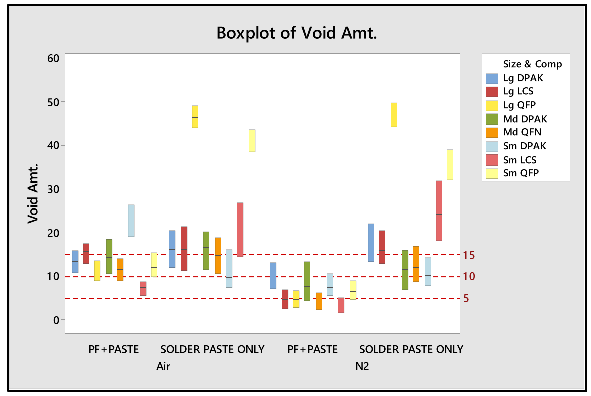
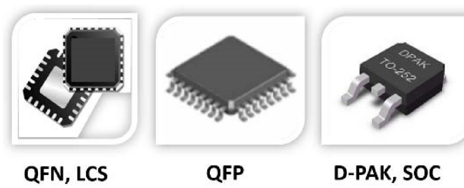


Figure 10. The overall void results as a function of PREFORM/PASTE and SOLDER PASTE ONLY configurations



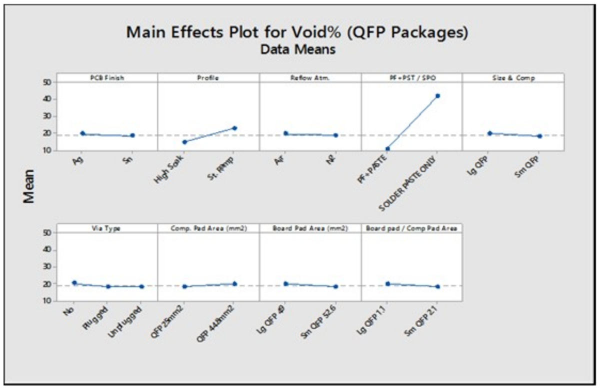
QFP Package (Small, Medium and Large Pads) Results

The void results on the QFP packages are shown in **Figures 11**. A thicker preform (0.15mm) was used to compensate for the extra standoff inherent in the gull wing type leads. The most problematic issue in the field with QFP components is generating enough solder volume under the thermal pad to make a reliable solder joint. Lack of solder volume is one of the primary contributors to higher voiding in QFPs. In many instances a step stencil is employed to generate more solder volume but in turn produces more outgassing due to the increased flux amount. Solder preforms are a natural way to increase solder volume without significantly increasing the flux.

In these samples the board pad area to component pad area differed significantly between the two components. The LG QFP board pad size was ~1:1 to the component pad size and the SM QFP's board pad size was twice the size of the component pad. This factor did not contribute significantly to the results.

The PF+Paste configuration when reflowed in a nitrogen atmosphere significantly reduced voiding to between 5% and 10%. While the configuration did not perform as well when reflowed in air, the overall results showed that a PREFORM AND PASTE configuration provided significantly less voiding than a traditional SOLDER PASTE ONLY window pane pattern.

A high soak profile contributed positively to the results. In a high soak profile, the flux on the preform has more time to interact with the bottom surface of the component producing better wetting surface than quickly ramping to peak.



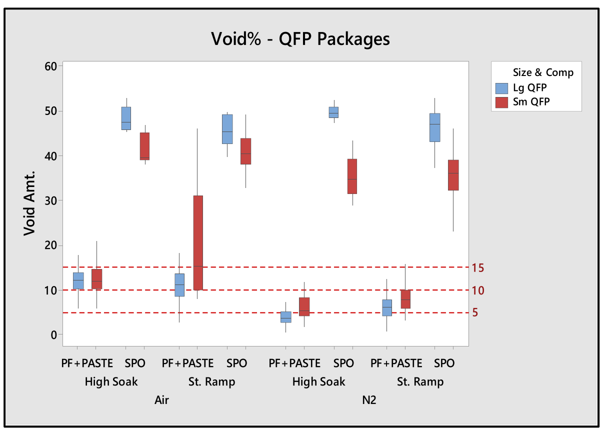
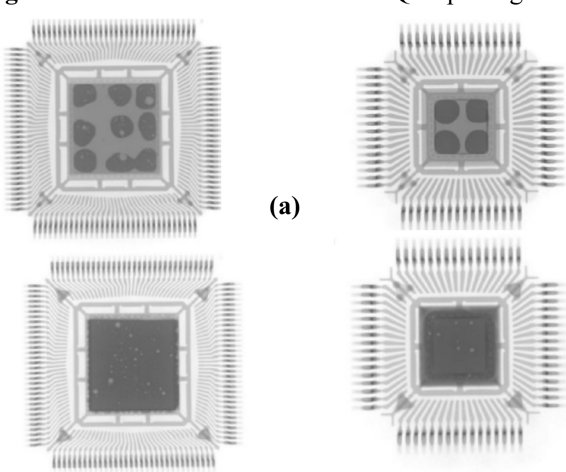


Figure 11. The overall void results of QFP package



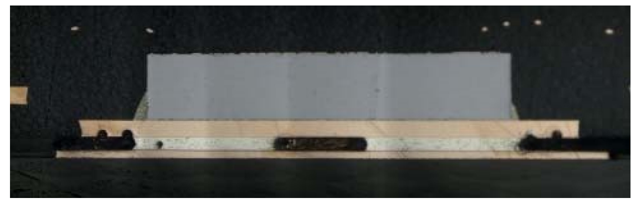
(a)

(b)

Figure 12 X-Ray images of the QFP components showing a difference in pad coverage (a) assembly built with SOLDER PASTE ONLY and (b) PREFORM AND PASTE

One of the main contributors to reducing voiding under QFPs was increasing the solder volume (**Figure 12**). In the PF+Paste configuration an increase in metal volume from the preform produced sufficient volume of solder to generate well-formed fillets and good pad coverage (**Figure 13**).

A high soak profile contributed positively to the results. In a high soak profile, the flux on the preform has more time to interact with the bottom surface of the component producing better wetting surface than quickly ramping to peak



(a)

(b)

Figure 13. Optical images of the cross sectioned QFP components showing a difference in formed fillet and pad coverage (a) assembly built with SOLDER PASTE ONLY and (b) PREFORM AND PASTE

QFN and LCS Packages (Small, Medium and Large Pads) Results

QFN and LCS packages are very similar relative to the thermal pad. They are by definition bottom termination components in that both their thermal pad and signal leads terminate under the body of the component. **Figure 14** summarize the results of these component packages. A combination of PF+Paste, High Soak Profile in a Nitrogen atmosphere provide excellent voiding results to sub 5%. The PF+Paste configuration had the most impact on voiding. A high soak profile contributed positively to the void results whether in Air or Nitrogen atmospheres. Plugged vias contributed to higher void results which is consistent will all the results thus far.

Similar to the QFP packages, it was observed during X-Ray analysis that assemblies built with PF+Paste configuration, had a greater consistency in voiding and pad coverage from one component to another. Void distribution was much tighter for the PF+Paste configurations compare to SOLDER PASTE ONLY (SPO) configuration. Those differences could be clearly observed in **Figure 15** and **16**.

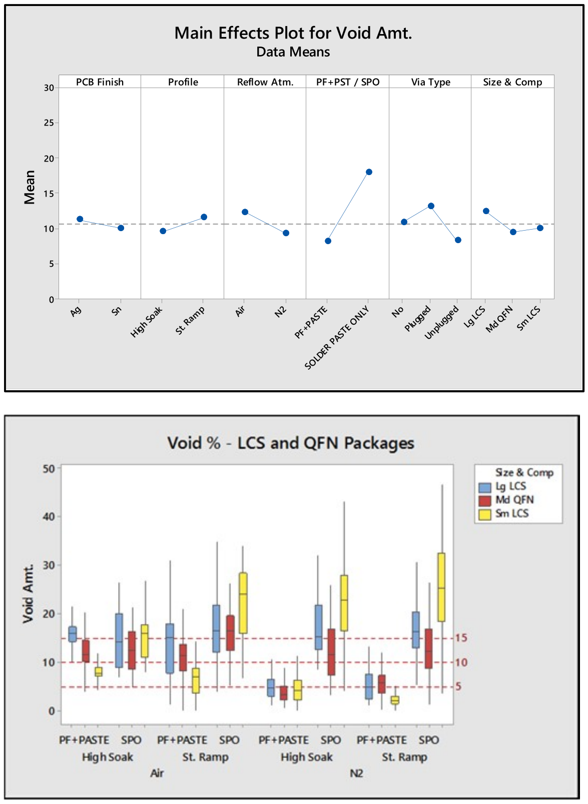


Figure 14. The overall void results of QFN and LCS package

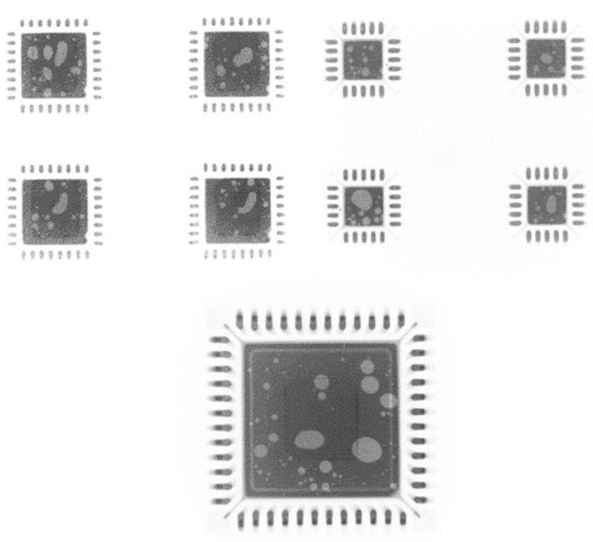


Figure 15. X-Ray images of the QFN and LCS components assemblies built with SOLDER PASTE ONLY showing variation in voiding levels from one component to another.

Some of the assemblies were metallographically prepared for microstructural evaluation. Interfacial reaction between component thermal pad and solder as well as solder and board pad was examined. Uniform and continuous IMC (Inter Metallica Compound) layer as formed at all interfaces, Acceptable solder joints were built using both configurations (SPO and PF+Paste). SEM images of the cross sectioned assemblies solder paste assembly only (SPO) (Figure 16) and PF+Paste configuration (Figure 17) show well-formed IMC layers.

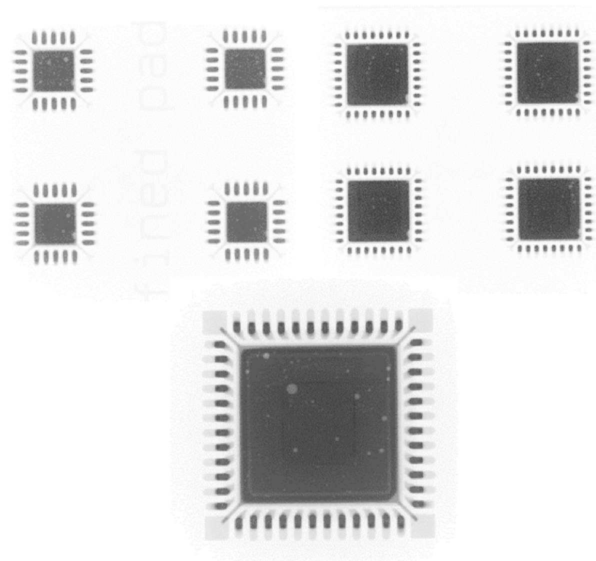


Figure 16. X-Ray images of the QFN and LCS components assemblies built with PREFORM AND PASTE showing variation in voiding levels from one component to another.

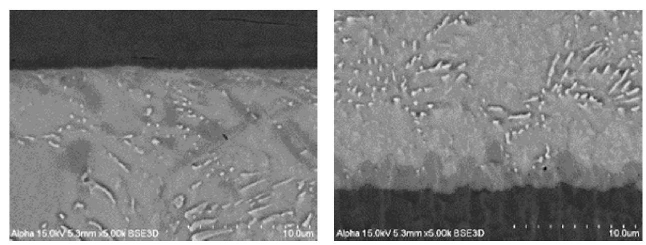


Figure 16. SEM images of the interfacial reaction of the assemblies built using SOLDER PASTE ONLY (SPO).

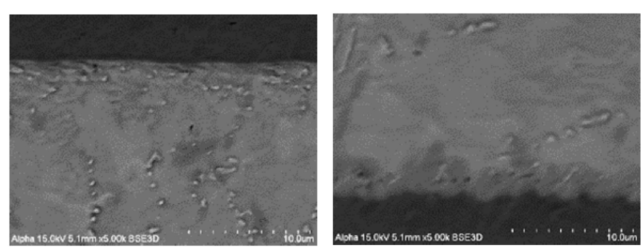


Figure 17. SEM images of the interfacial reaction of the assemblies built using PF+Paste configuration.

DPAK Packages (Small, Medium and Large Pads) Results

The results of the DPAK package trials are shown in **Figures 18.** The average voiding across all the data was about 14%.

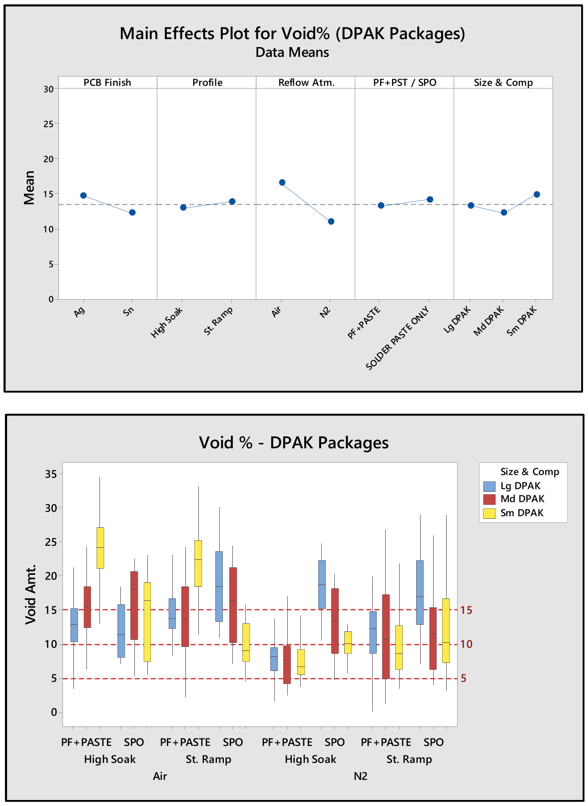


Figure 18. The overall void results of DPAK package

The PF+Paste configuration using a high soak profile and reflowed in Nitrogen produced the most impressive voiding results, averaging between 5%-10% under all 3 package sizes (**Figure 19**). PF+Paste reflowed in Nitrogen presented lower, more consistent voiding overall when compared to Air atmosphere results.

SUMMARY AND CONCLUSIONS.

The work presented demonstrates the advancement of bottom terminated component assembly through the use of solder preform, low voiding microfluxed coated solder preforms and optimized processing parameters.

A significant reduction in voiding was achieved by carefully managing the preform design and flux amount to achieve optimum soldering conditions. Consistent sub-10% voiding can be achieved for various size components. The use of preform in conjunction with microfluxed coating technology ensures low voiding in both air and nitrogen reflow environment. The process generates low residue and ensures high electrochemical reliability. Common finishes used in industry such as immersion Sn and immersion Ag are capable of producing reliable solder joints. Via design is an important factor in BTC assembly and will be discussed in further communications. Lessons learned from critical factors will be discussed in a future communication.

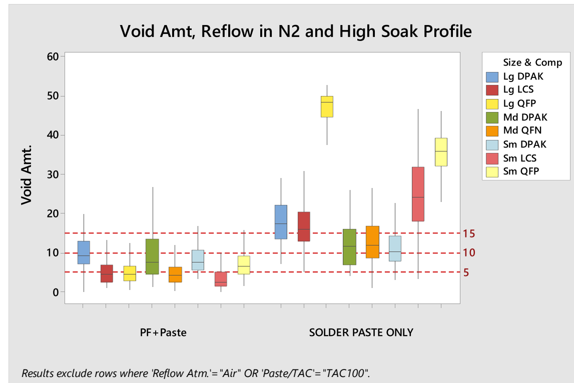


Figure 20. The overall void results comparing PREFORM AND PASTE to SOLDER PASTE ONLY configurations

ACKNOWLEDGEMENT

Authors would like to thank Osman Balkan and Herbert Miller for developing and designing the test vehicle as well as Kevin Smith for valuable input into the DOE design. Alan Plant, Frank Andres, Karen Tellefsen and Westin Bent for process development. Daniele Perico for support during DOE design. Steven Prokopiak and Bogdan Bankiewicz for material development and manufacturing.

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