Fill the Void II: An Investigation into Methods of Reducing Voiding

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ABSTRACT

Voids in solder joints plague many electronics manufacturers. Do you have voids in your life? We have good news for you, there are many excellent ways to "Fill the Void." This paper is a continuation of previous work on voiding in which the following variables were studied: water soluble lead-free solder pastes, a variety of stencil designs, and reflow profiles. Quad Flat No-Lead (QFN) component thermal pads were used as the test vehicle. The voiding results were summarized and recommendations were made for reduction of voiding.

In this work several new variables and their effects on voiding were studied. No clean lead-free solder pastes were tested and compared to water soluble lead-free solder pastes. Water soluble solder pastes tend to create more voiding than no clean solder pastes. This is due to the relatively higher volatile content in water soluble solder pastes, and also due to the hygroscopic nature of water soluble solder pastes. The particle size of the solder powder was studied; using IPC type 3, IPC type 4 and IPC type 5 powders. The oxide content of the solder powder increases with decreasing particle size and higher oxide content tends to produce higher voiding levels. Different manufacturers of solder powder were also studied. Solder powder from one manufacturer might lead to higher voiding than from another manufacturer. Finally, the effects of convection reflow were compared to vapor phase reflow with and without vacuum. Convection reflow is commonly used and voiding results from this type of reflow are well documented. Vapor phase reflow is conducted in an oxygen free environment which tends to reduce voiding. Vapor phase systems also lend themselves well to the use of vacuum because the equipment is sealed and vapor tight. Integrating vacuum creates differential pressure between the void and the surrounding atmosphere during the liquid stage which facilitates the escape of the trapped gases. The lowering of the gas pressure outside the solder joints will aid in reduction of voiding.

Reworking solder joints with voids is not an easy task. This typically involves removing the affected components and re-soldering them with the hope that voiding might be reduced. This is a very labor intensive process which can thermally stress nearby components. The possibility of using a vapor phase reflow system with vacuum to rework solder joints with voids was investigated.

In many cases voiding will be reduced only if a combination of mitigation strategies are used. Recommendations for combinations of solder paste, stencil design, reflow profile, and type of reflow are given. The aim of this paper is to help the reader to "Fill the Void."

Key words: voids, solder joints, vapor phase reflow, reflow profile, solder paste, solder powder, stencil design, QFN

INTRODUCTION

Voiding in solder joints is an ongoing issue for electronics manufacturers. Bottom terminated or "no-leaded" devices such as Quad Flat No-Lead devices (QFN) are becoming commonplace. This type of device is vulnerable to voiding due to low standoff heights and relatively large masses of solder paste applied to the pads. QFN thermal pad solder joints are particularly susceptible to voiding and make a good test vehicle for voiding studies.

This study is a continuation of previous work on voiding [1]. In the previous work several parameters were varied and their effects on voiding summarized. Two different water soluble lead-free solder pastes were compared. Dramatically different voiding levels were seen with these solder pastes. Stencil design of QFN thermal pads was varied and differences in voiding levels were seen. Two different convection reflow profiles were used; ramp-to-spike (RTS) and a higher temperature ramp-to-spike (RTS-HT). Differences in voiding were noted and these differences varied based on the solder paste used. The size of the largest voids was also analyzed with respect to the variables. The voiding levels for all of these variables were compared and contrasted using statistical analysis techniques. The previous work was concluded with some recommendations to help the reader "Fill the Void".

This investigation into methods of reducing voiding included a much expanded set of variables. These variables were tested with respect to their effects on voiding and are listed below.

- Water soluble lead free solder pastes: A, B, E
- No clean lead free solder pastes: C, D
- Solder powder size: IPC Types 3, 4, 5
- Solder powder manufacturers: I and G
- Stencil design: cross hatch (U9), cross hatch rotated 45 degrees (U10), 5-dot (U11), diagonal stripe (U12)
- Surface finish on the circuit boards: Electroless nickel immersion gold (ENIG), Organic surface protectant (OSP)
- Convection reflow profiles: RTS, RTS-HT, RTS (2 times), RSS (ramp soak spike), RTS-N2 (nitrogen)
- Vapor phase reflow with and without vacuum: VP, VP-V1, VP-V2, VP-V3
- Vapor phase reflow with vacuum as rework method for existing voids

In most cases these variables were changed in linear fashion rather than in a matrix type design of experiment. For example, in order to study the effects of solder powder size on voiding, one solder paste flux was used with all three solder powder sizes. All other variables were held constant. The voiding results for all three sizes of solder powder were compared to each other.

Analysis of the voiding data was done using statistical analysis techniques. Box and whisker plots were used to show the data populations. Tukey-Kramer honest significant difference (HSD) testing was used to determine if the data sets were significantly different. Conclusions were drawn for each set of variables, and from these conclusions a set of recommendations were made to help the reader "Fill the Void."

METHODOLOGY

Materials

The circuit board used for this experimentation is shown below (Figure 1). This circuit board is made of FR4 material, etched copper pads, and ENIG surface finish. One experiment was run with OSP surface finish for comparison to ENIG.

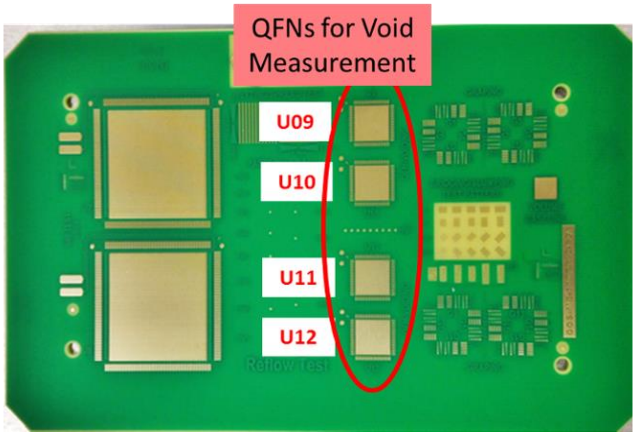


Figure 1 –Test Circuit Board for Voiding

The QFN thermal pads (U9, U10, U11, U12) were used for void measurements. The QFNs used were dummy components with 68 perimeter leads on a 0.5 mm pitch, a 10 mm body size, and a tin finish (Figure 2).

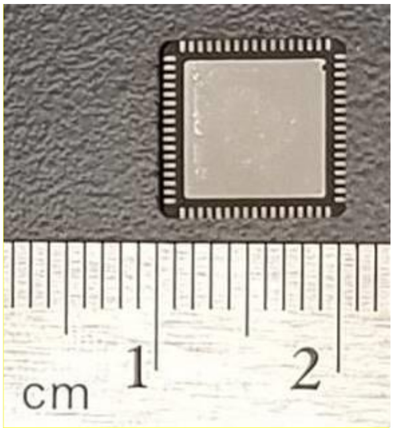


Figure 2 – QFN Dummy Component

The stencil design was varied for each QFN thermal pad location (Figure 3). In each case the solder paste coverage was approximately 65% of the thermal pad area.

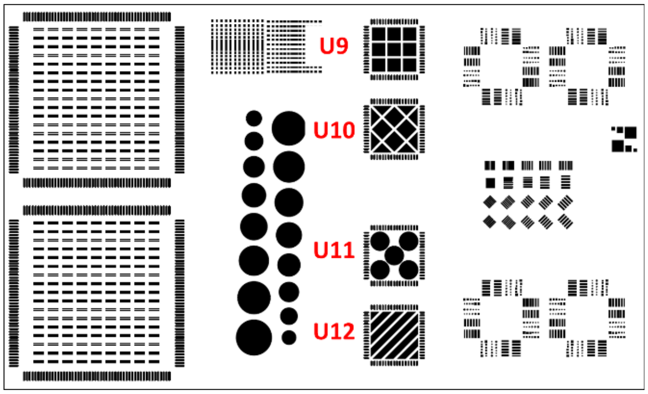


Figure 3 – Stencil Design for QFN Thermal Pads

The stencil design effects on voiding were discussed in the previous work [1]. The data from the previous work will be summarized in this paper for reference.

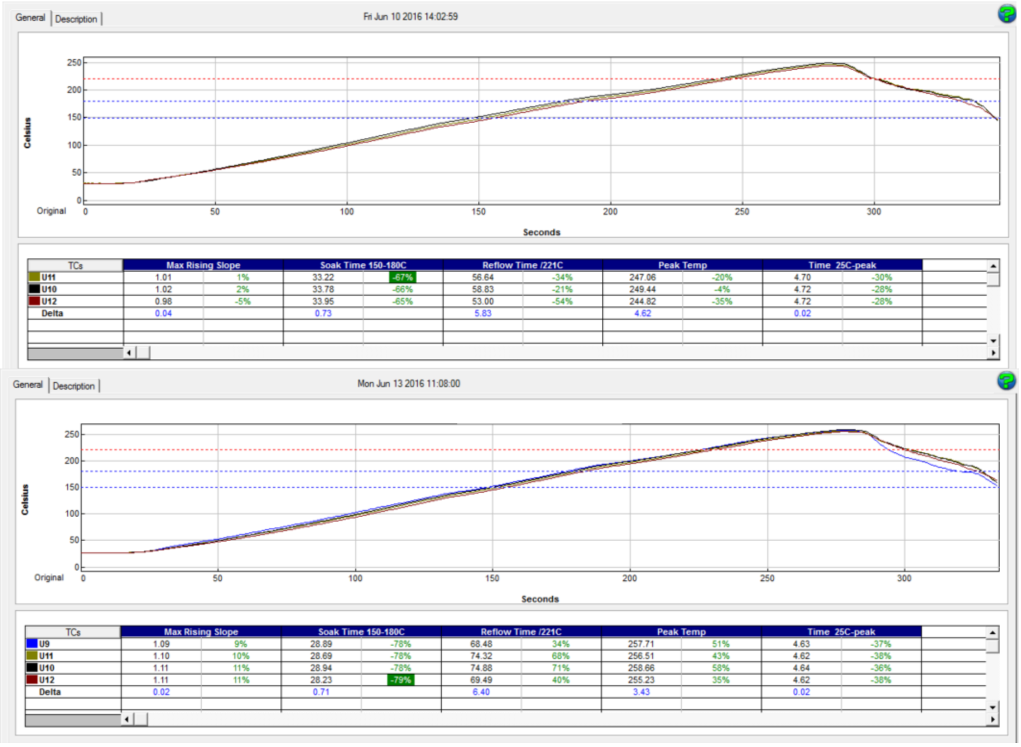
The solder pastes used were varied as shown below (Table 1). Tin (Sn) / Silver (Ag) 3.0% / Copper (Cu) 0.5% (SAC305) alloy was used in all cases.

Table 1 – Solder Pastes Used in Voiding Studies with SAC305 Alloy

Solder Paste Flux Code	Flux Type	IPC Solder Powder Size	Metal Content (% wt)
A	Water soluble – moderate activity	Type 3	88.0
B	Water soluble – high activity	Type 3	88.5
B	Water soluble – high activity	Type 4	88.3
B	Water soluble – high activity	Type 5	88.1
C	No clean	Type 3	88.5
D	No clean – pin testable	Type 3	88.4
E	Water soluble – moderate/low activity	Type 3	89.0

<u>Convection Reflow Profiles</u>

Several different reflow profiles were used in these experiments. The reflow profiles used in the first paper [1] are shown here for reference (Figure 4). These profiles are both linear ramp type. One is a ramp-to-spike (RTS) and the other is a ramp-to-spike with a higher peak temperature and longer reflow time (RTS-HT).

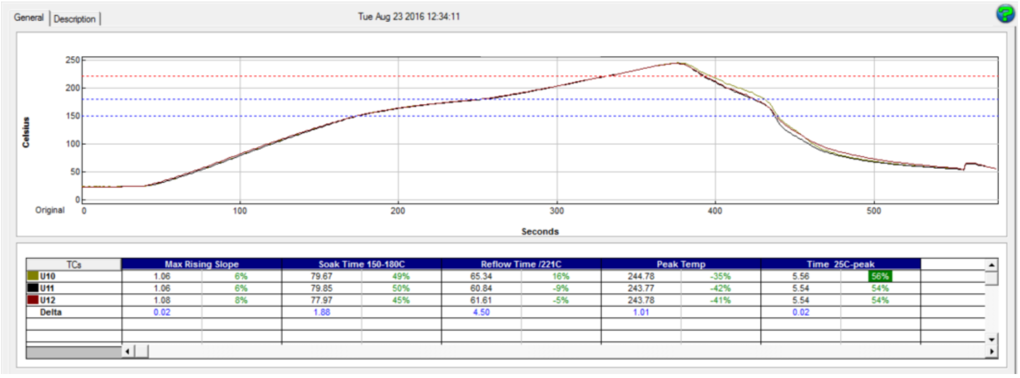


TCs	Max Rising Slope		Soak Time 150-180C		Reflow Time /221C		Peak Temp		Time 25C-peak	
U11	1.01	1%	33.22	-67%	56.64	-34%	247.06	-20%	4.70	-30%
U10	1.02	2%	33.78	-66%	58.83	-21%	249.44	-4%	4.72	-28%
U12	0.98	-5%	33.95	-65%	53.00	-54%	244.82	-35%	4.72	-28%
Delta	0.04		0.73		5.83		4.62		0.02	

TCs	Max Rising Slope		Soak Time 150-180C		Reflow Time /221C		Peak Temp		Time 25C-peak	
U9	1.09	9%	28.89	-78%	68.48	34%	257.71	51%	4.63	-37%
U11	1.10	10%	28.69	-78%	74.32	68%	256.51	43%	4.62	-38%
U10	1.11	11%	28.94	-78%	74.88	71%	258.66	58%	4.64	-36%
U12	1.11	11%	28.23	-79%	69.49	40%	255.23	35%	4.62	-38%
Delta	0.02		0.71		6.40		3.43		0.02	

Figure 4 – RTS Reflow Profile (Top) and RTS-HT Reflow Profile (Bottom)

A ramp-soak-spike (RSS) profile was created with added soak time between 150 and 180 °C (Figure 5).



TCs	Max Rising Slope		Soak Time 150-180C		Reflow Time /221C		Peak Temp		Time 25C-peak	
U10	1.06	6%	79.67	49%	65.34	16%	244.78	-35%	5.56	56%
U11	1.06	6%	79.85	50%	60.84	-9%	243.77	-42%	5.54	54%
U12	1.08	8%	77.97	45%	61.61	-5%	243.78	-41%	5.54	54%
Delta	0.02		1.88		4.50		1.01		0.02	

Figure 5 – Ramp-Soak-Spike (RSS) Reflow Profile

The parameters for each profile are summarized below (Table 2). Reflow in air was done in all cases except for one experiment which was run using a nitrogen atmosphere.

Table 2 – Reflow Profile Parameters

Setting	RTS Profile	RTS-HT Profile	RSS Profile
Ramp rate	0.98 – 1.02 °C/sec	1.09 – 1.10 °C/sec	1.06 – 1.08 °C/sec
Soak time (150-180 °C)	No added soak 33 – 34 sec	No added soak 28 – 29 sec	Soak added 78 – 80 sec
Reflow Time (> 221 °C)	53 – 59 sec	68 – 75 sec	61 – 65 sec
Peak temperature	245 to 249 °C	255 to 259 °C	244 to 245 °C
Profile length (25 °C to peak)	4.70 minutes	4.60 minutes	5.50 minutes

Vapor Phase Reflow

Vapor phase soldering systems feature leading edge technology and provide temperature gradient control in an oxygen free atmosphere, with low peak temperatures (230°C max. lead free) and zero delta T's. Vapor phase reflow systems use a heated fluid (perfluoropolyether, PFPE) which condenses upon the circuit board surface transferring heat to the solder joints through this condensation process. The latent heat transition, from liquid to steam/vapor results in a change of state but not a change in temperature. The absolute maximum temperature any circuit can reach in a vapor phase soldering system is governed by the boiling point of the fluid which is a physical constant. Therefore the temperature gradient of the circuit board is very small as compared to convection reflow systems, and peak temperatures can be held very close to the reflow temperature of the solder alloy used.

Vapor phase systems provide process reliability and repeatability exceeding that of standard convection systems. With an external heat source, today's vapor phase soldering systems feature a fully flexible temperature gradient control, with an undisputed thermal profiling capability. All pre-heating and profiling is accomplished in a single sealed process chamber. The temperature gradient control makes for a simpler machine design and a significantly simpler process in an oxygen free environment (Figure 6).

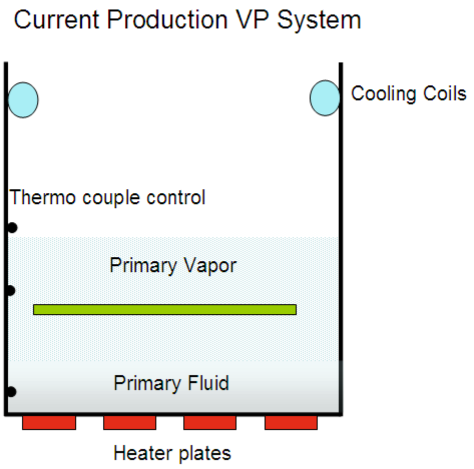


Figure 6 – Vapor Phase Reflow System Uses Heated Vapor (Oxygen Free)

The complete eradication of oxygen from the process allows the flux chemistry to operate in an ideal environment without the need to be concerned about a rear guard action of heated air being blown down on the joints. In standard convection reflow (Figure 7) oxygen from the heated air is continuously oxidizing the solder and the flux medium has to remove the oxide for soldering to take place.

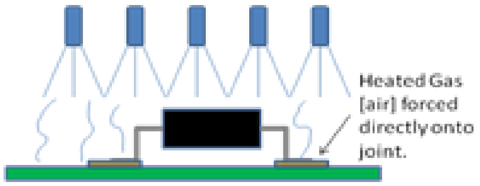


Figure 7 – Convection Reflow System Uses Heated Air

In theory metal oxides contribute to voiding levels. The removal of oxygen from the reflow atmosphere may lead to a reduction in voiding. In an oxygen free environment, flux activation and efficiency is improved and ultimately a possibility to re-engineer paste composition to minimize flux residues and activity levels presents itself.

The vapor phase equipment used in these experiments is shown below (Figure 8). The model that was used had vacuum capability.

Figure 8 – Vapor Phase Equipment

This equipment has four options for vacuum: no vacuum, prevac 1, prevac 2, and main vacuum. These options can be used individually or in combination with each other. Prevac 1 pulls vacuum on the solder paste deposits before any heating takes place in an effort to remove air from the solder paste. Prevac 2 pulls vacuum on the solder paste during ramp up heating but before the solder melts. Main vacuum pulls vacuum on the molten solder deposits to remove entrapped gasses. The main vacuum cycle reduces the pressure by 75 kPa (750 mbar) for two successive steps of about 5 seconds each (Figure 9).

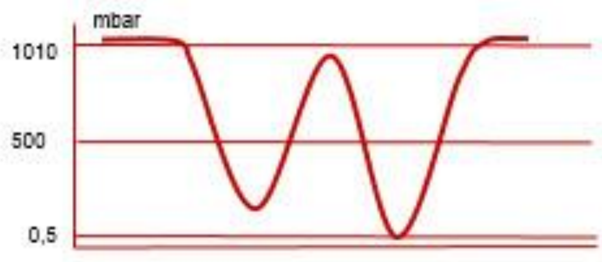


Figure 9 – Vapor Phase Vacuum Cycle

The total time added to the profile when main vacuum is used is roughly 15 seconds. Several combinations of these vacuum cycles were used in this testing and the combinations were renamed with codes. The codes and vacuum combinations are as follows: VP = vapor phase reflow with no vacuum, VP-V1 = main vacuum only, VP-V2 = prevac 1 plus main vacuum, VP-V3 = prevac 1 and prevac 2 plus main vacuum.

The vapor phase reflow profile is shown below (Figure 10). This profile is a ramp-soak-spike type profile.

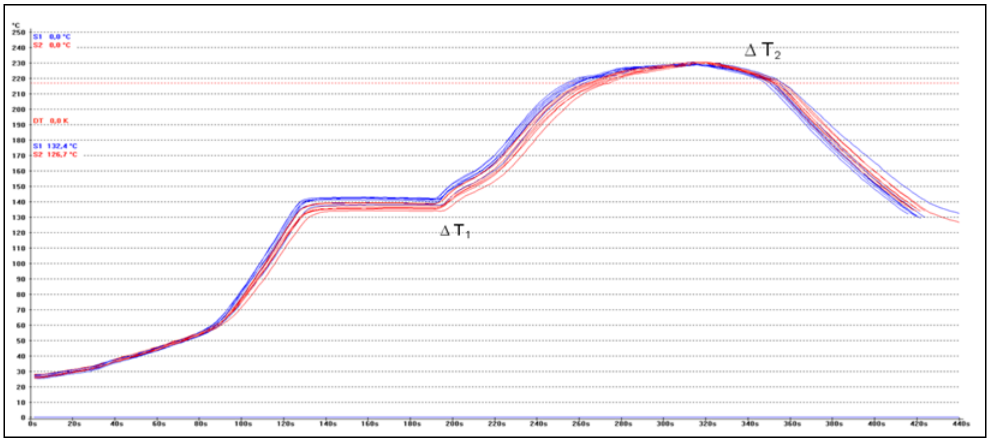


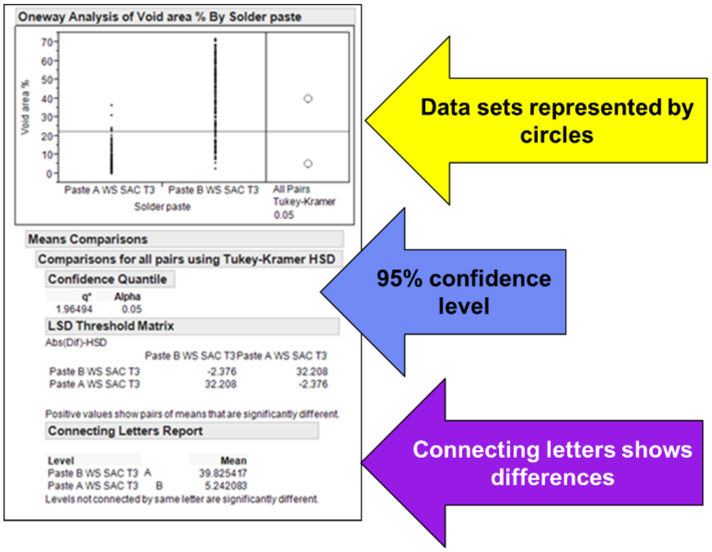
Figure 10 – Vapor Phase Reflow Profile

The soak time from 130 to 145 °C is approximately 80 seconds. The reflow time (> 221 °C) is approximately 70 seconds. The peak temperature is 230 °C. This profile is a typical vapor phase profile and is different than the RSS convection profile.

Experimental Procedure and Statistical Analysis

In most cases 20 circuit boards were run for each variation, but in some cases 30 boards were run. Voiding area was measured for each QFN thermal pad resulting in 4 measurements per circuit board. The total number of measurements for each experimental variation was 80, or in some cases 120. This was done in order to generate statistically significant data.

Tukey Kramer honest significant difference (HSD) testing was done on the data sets to compare and contrast the data. Tukey Kramer HSD analysis determines whether multiple data sets are significantly different, or statistically similar. This test is similar to Student's t-test used to compare means. The output of the Tukey Kramer HSD test is a chart that shows the data sets, several data calculations and reports (Figure 11).



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Oneway Analysis of Void area % By Solder paste

Means Comparisons
Comparisons for all pairs using Tukey-Kramer HSD
Confidence Quantile
       q*     Alpha
  1.96494      0.05
LSD Threshold Matrix
Abs(Dif)-HSD
                         Paste B WS SAC T3Paste A WS SAC T3
Paste B WS SAC T3                   -2.376           32.208
Paste A WS SAC T3                   32.208           -2.376

Positive values show pairs of means that are significantly different.
Connecting Letters Report

Level                         Mean
Paste B WS SAC T3  A     39.825417
Paste A WS SAC T3    B    5.242083
Levels not connected by same letter are significantly different.
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Data sets represented by circles

95% confidence level

Connecting letters shows differences

Figure 11 – Explanation of Tukey Kramer HSD Report

The top part of the Tukey Kramer HSD analysis shows scatter plots and circles that represent the data sets. If the circles overlap, then the data sets are not significantly different. If the circles do not overlap, then the data sets are significantly different. The center part of the Tukey Kramer HSD analysis contains a variety of data calculations. The confidence level for this testing is 95% which means that we can say with 95% assurance whether the data sets are statistically similar or different. The bottom part of the Tukey Kramer HSD analysis is a Connecting letters report. Letters are assigned to the data sets in order of means with the highest mean at the top. If the letters are the same then the data sets are not significantly different. If the letters are different then the data sets are significantly different. In some cases, data sets are assigned multiple letters. This indicates that a data set is statistically similar to multiple other data sets. For example, in Figure 11 above, "Paste B WS SAC T3" has a letter code of A and "Paste A WS SAC T3" has a letter code of B. That means these two solder pastes generated significantly different voiding. In this example Paste B generated higher voiding than Paste A.

RESULTS AND DISCUSSION

The results of the voiding investigations are broken out below by variable. The results for each comparison are discussed within each section below.

Solder Paste Effects on Voiding

Solder paste flux has a dramatic effect on voiding. Some solder pastes show a tendency to generate low voiding while others generate higher voiding. Voiding by solder paste is shown below for the RTS profile and SAC305 Type 3 solder powder (Figure 12).

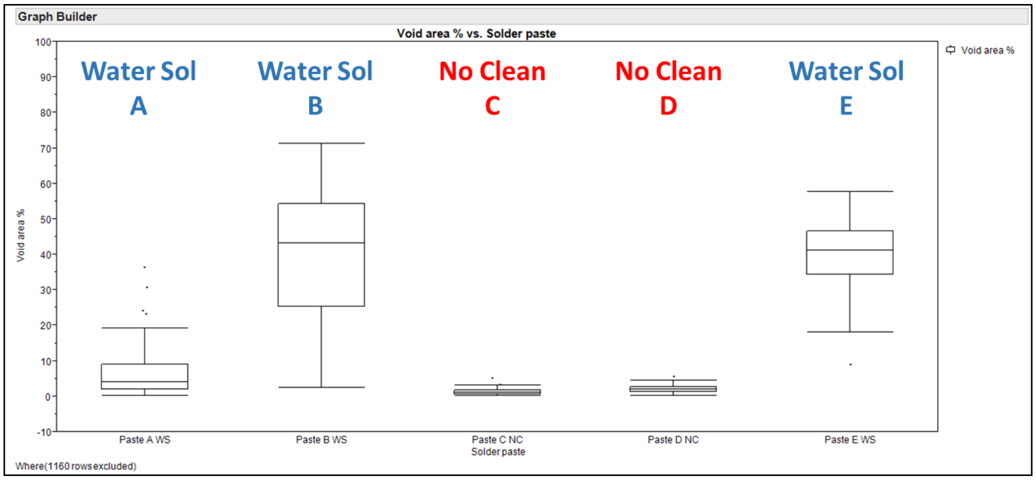
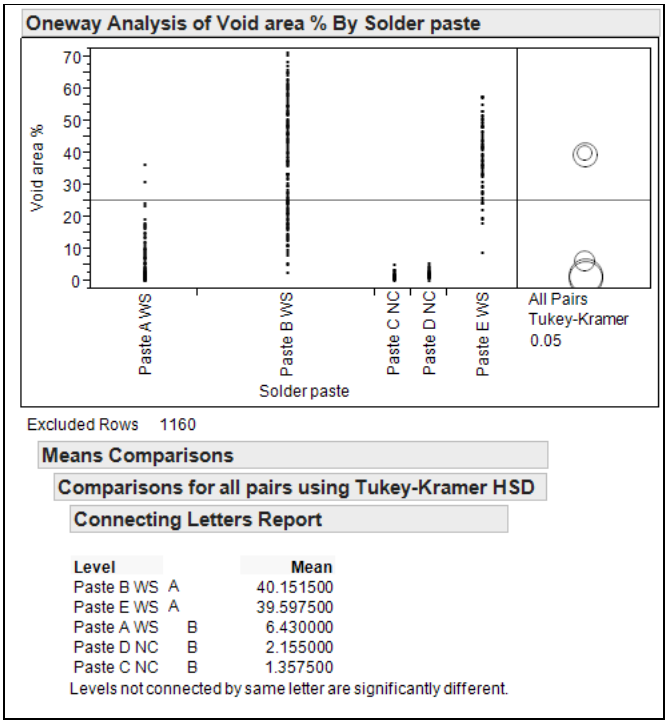


Figure 12 – Voiding by Solder Paste, RTS Profile, SAC T3

Water soluble solder paste A generated lower voiding than both of the other water soluble solder pastes B and E. Voiding levels from solder pastes B and E have similar median values, but the range for paste E is much narrower than for paste B. Voiding for both no clean solder pastes C and D is much lower than all of the water soluble solder pastes. Tukey Kramer HSD analysis below shows the statistical comparison of these data sets (Figure 13).



Excluded Rows 1160

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Connecting Letters Report

Level			Mean
Paste B WS	A		40.151500
Paste E WS	A		39.597500
Paste A WS		B	6.430000
Paste D NC		B	2.155000
Paste C NC		B	1.357500

Levels not connected by same letter are significantly different.

Figure 13 – Tukey Kramer HSD Analysis for Voiding by Solder Paste

Voiding from solder pastes A, D and C are significantly lower than both solder pastes B and E. The voiding levels from solder pastes A, D, and C are similar to each other. Voiding from solder pastes B and E are similar to each other.

Voiding from the no clean solder pastes was much lower than the water soluble solder pastes. The void area y-axis was changed to a 0 to 10% scale to show the differences in these no clean solder pastes (Figure 14).

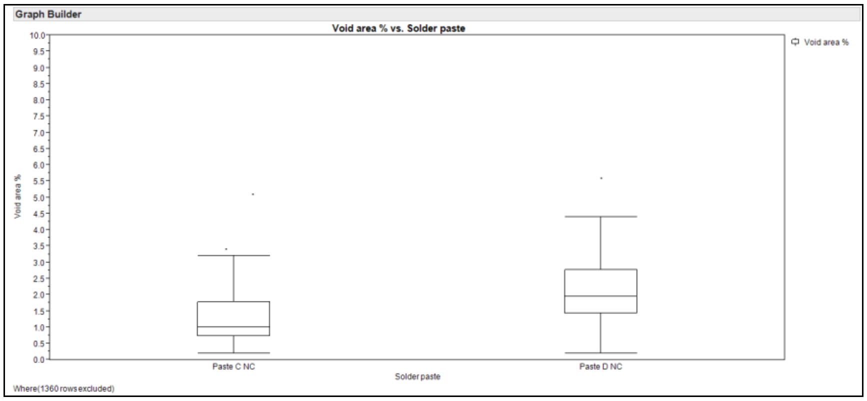
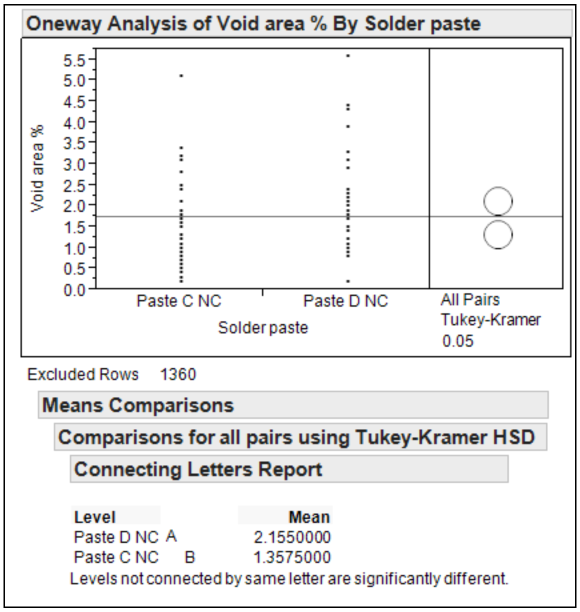


Figure 14 – Voiding by No Clean Solder Paste, RTS Profile, SAC T3

Solder paste D voiding is significantly higher than solder paste C as shown by Tukey Kramer analysis (Figure 15).



Excluded Rows 1360

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Connecting Letters Report

Level			Mean
Paste D NC	A		2.1550000
Paste C NC		B	1.3575000

Levels not connected by same letter are significantly different.

Figure 15 – Tukey Kramer HSD Analysis for No Clean Solder Paste Voiding

<u>Solder Powder Size and Manufacturer Effects on Voiding</u>

Solder paste B was made with three different solder powder sizes: IPC types 3, 4 and 5. The voiding levels for these three solder pastes with the RTS profile are shown below (Figure 16).

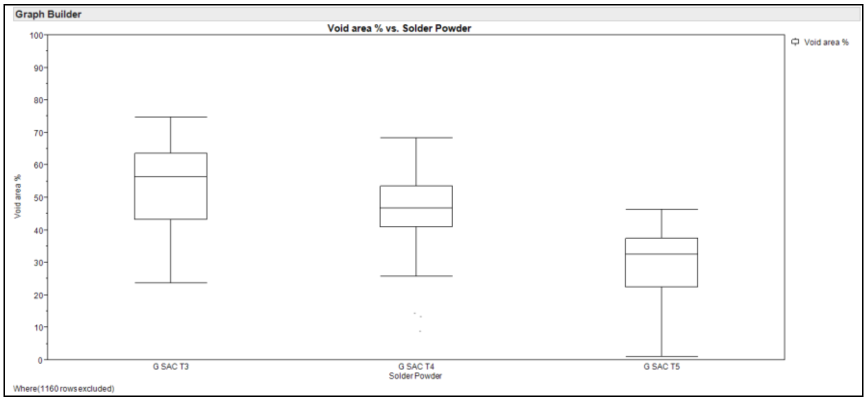
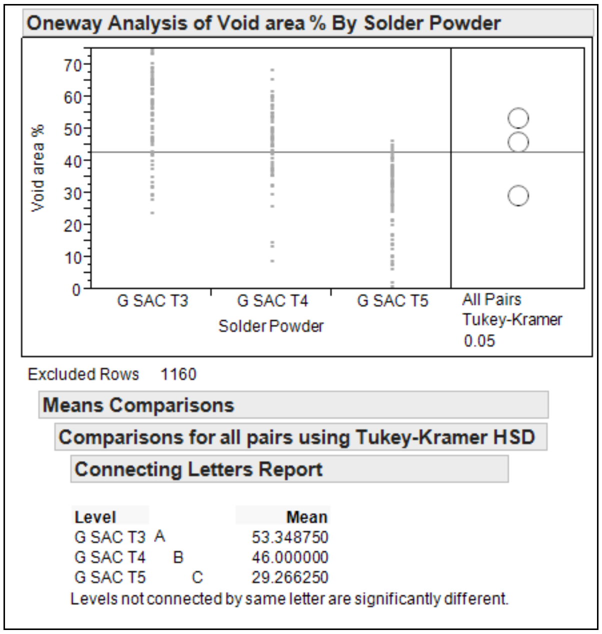


Figure 16 – Voiding by Solder Powder Size, Paste B, RTS Profile

Voiding levels decreased with decreasing solder powder size (T3 > T4 > T5). Tukey Kramer analysis (Figure 17) shows that these voiding results are significantly different.



Excluded Rows 1160

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Connecting Letters Report

Level				Mean
G SAC T3	A			53.348750
G SAC T4		B		46.000000
G SAC T5			C	29.266250

Levels not connected by same letter are significantly different.

Figure 17 – Tukey Kramer HSD Analysis for Voiding by Solder Powder Size

This is the opposite of what was expected. Total oxide levels on the solder powder increase with decreasing particle size for a given mass of solder powder. This is due to the fact that surface area increases as particle size decreases. Metal oxides are thought to contribute to voiding, therefore in theory type 4 and 5 solder powders should produce higher voiding than type 3 solder powder. Further investigation is required to explain this trend.

SAC305 type 3 solder powder from two different manufacturers (I and G) was used to make solder paste B. The RTS profile was used and the voiding results are shown below (Figure 18).

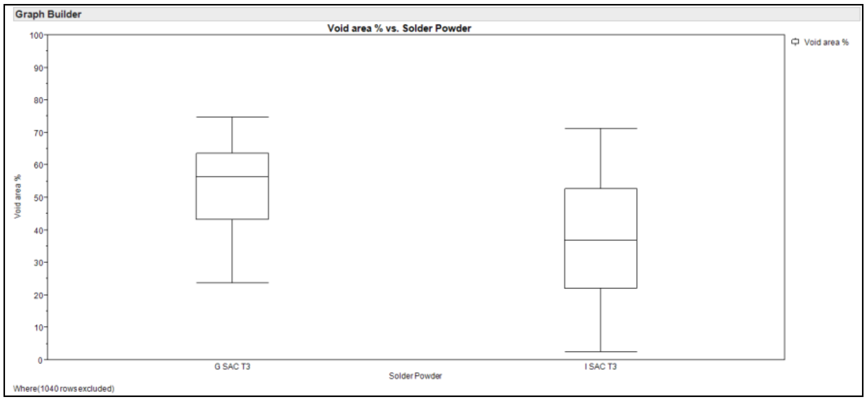
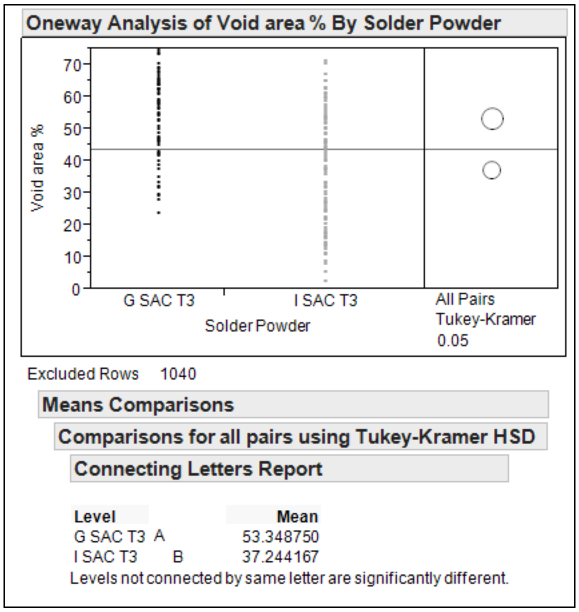


Figure 18 – Voiding by Solder Powder Manufacturer, Paste B, RTS Profile

The voiding for solder powder manufacturer I is lower than for manufacturer G, but the range of voiding is wider. These results are statistically significant as shown by Tukey Kramer analysis (Figure 19).


Oneway Analysis of Void area % By Solder Powder

Excluded Rows 1040

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Connecting Letters Report

Level			Mean
G SAC T3	A		53.348750
I SAC T3		B	37.244167

Levels not connected by same letter are significantly different.

Figure 19 – Tukey Kramer HSD Analysis for Voiding by Solder Powder Manufacturer

Different solder powder manufacturers may use slightly different processes to make the solder powder. This results in slightly different particle shapes and particle size distributions and potentially different oxide levels, which all have an impact on voiding.

<u>Stencil Design Effects on Voiding</u>

The 4 stencil designs tested showed some differences in voiding. The results of the previous work [1] are summarized below (Figure 20).

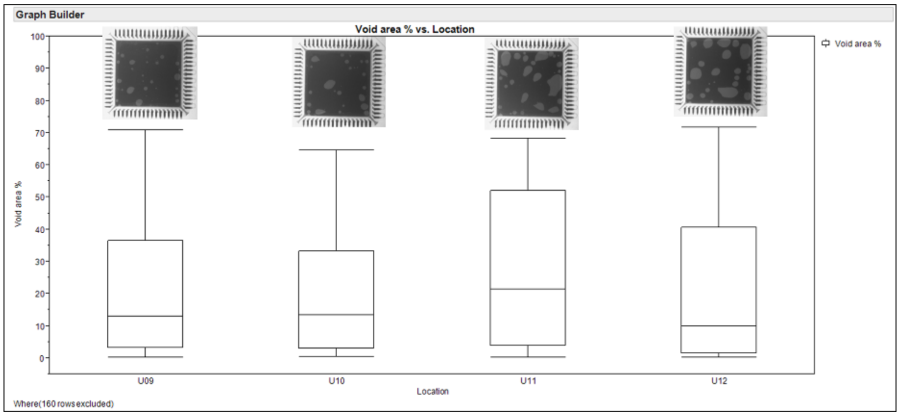
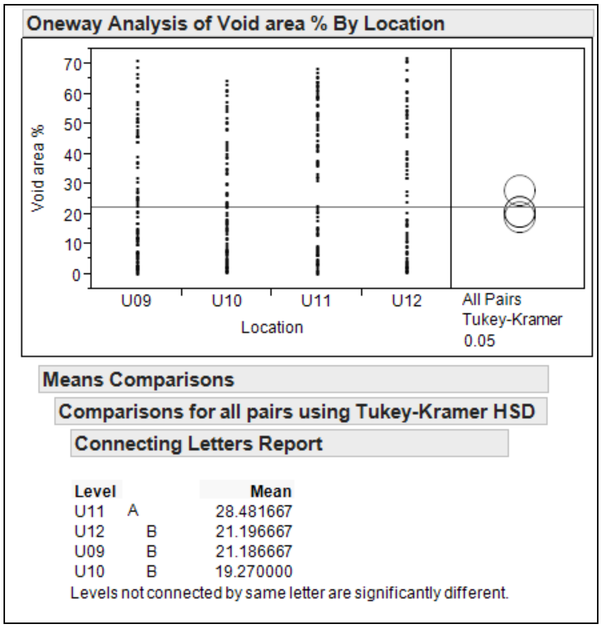


Figure 20 – Voiding by Stencil Design

The 5-dot stencil pattern (U11) showed higher median voiding than the other designs. Tukey Kramer analysis validates this result (Figure 21).



Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Connecting Letters Report

Level			Mean
U11	A		28.481667
U12		B	21.196667
U09		B	21.186667
U10		B	19.270000

Levels not connected by same letter are significantly different.

Figure 21 – Tukey Kramer HSD Analysis for Voiding by Stencil Design

Voiding from the 5-dot pattern (U11) is significantly higher than the other stencil designs used. The other stencil designs all gave statistically similar voiding levels. Additional stencil designs are being considered and will be evaluated in the future.

Surface Finish Impact on Voiding

The ENIG surface finish was used as a default for all testing with the exception of one experiment where OSP surface finish was evaluated. Solder paste B was run on both surface finishes with SAC305 type 3 solder powder and the RTS profile. The voiding levels are shown below (Figure 22).

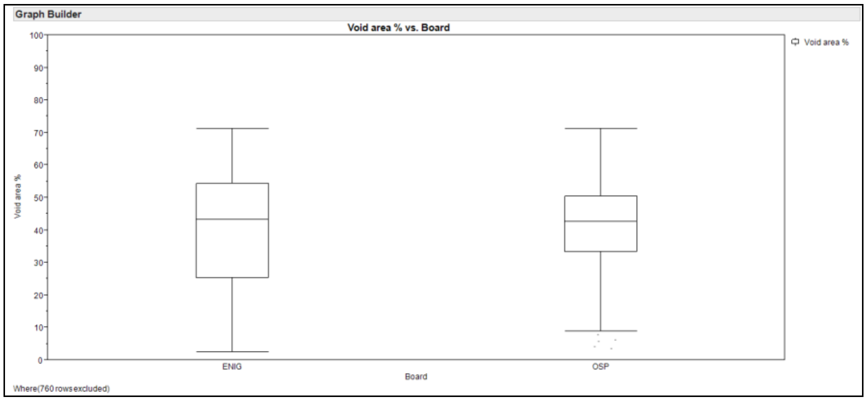
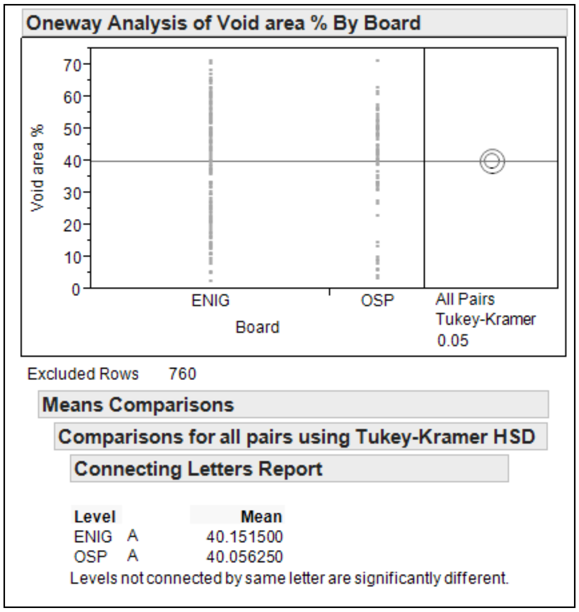


Figure 22 – Voiding Comparison of ENIG versus OSP, Paste B, RTS Profile

In this case there is little difference between the voiding levels on ENIG and OSP surface finishes. Tukey Kramer analysis verifies that these data sets are not significantly different (Figure 23).



Oneway Analysis of Void area % By Board

Excluded Rows 760

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Connecting Letters Report

Level		Mean
ENIG	A	40.151500
OSP	A	40.056250

Levels not connected by same letter are significantly different.

Figure 23 – Tukey Kramer HSD Analysis for Voiding of ENIG versus OSP

This result was unexpected. OSP is thought to generate higher voiding than other surface finishes. OSP is made up of a relatively thick organic layer which can out-gas under reflow conditions. OSP is also difficult to wet limiting spread of solder which can lead to voiding. Solder paste B is known to give excellent wetting on ENIG surfaces but moderate wetting on OSP surfaces, but this did not seem to impact the voiding results. Further investigation is required to determine the impact of surface finishes on voiding.

Convection Reflow Profile Effect on Voiding

Solder paste B with SAC305 type 3 solder powder was run in every variation of convection reflow profile. In all cases reflow was done in air, except for the last variation which used a nitrogen atmosphere (RTS-N2). The profile variations tested were: ramp-soak-spike (RSS), ramp-to-spike (RTS), RTS-2 is the RTS profile run twice to simulate double sided reflow, ramp-to-spike high temperature (RTS-HT), and RTS-N2 with nitrogen (99% purity). The results are shown below (Figure 24).

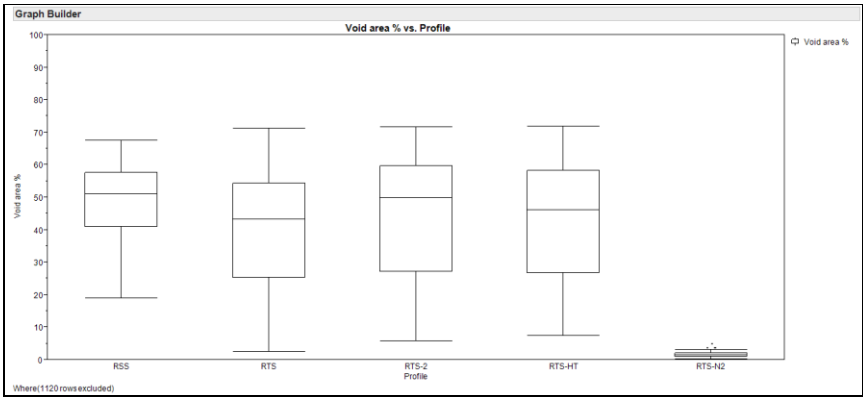
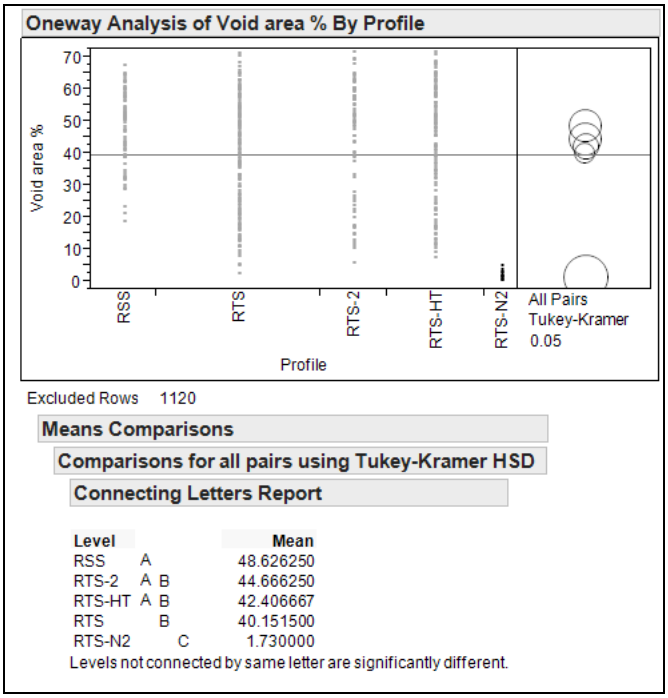


Figure 24 – Voiding by Convection Reflow Profile, Paste B

The RSS profile generated slightly higher voiding than the RTS profile, but similar voiding to the RTS-2 and RTS-HT profiles. The RTS-N2 profile using a nitrogen atmosphere generated extremely low voiding. These results are statistically significant (Figure 25).



Excluded Rows 1120

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Connecting Letters Report

Level				Mean
RSS	A			48.626250
RTS-2	A	B		44.666250
RTS-HT	A	B		42.406667
RTS		B		40.151500
RTS-N2			C	1.730000

Levels not connected by same letter are significantly different.

Figure 25 – Tukey Kramer HSD Analysis for Voiding by Profile

The voiding levels of solder paste B increased significantly when a RSS profile is used, as compared to a RTS profile. Running the RTS profile a 2nd time to simulate double sided reflow did not increase voiding significantly. Use of a nitrogen atmosphere greatly benefitted solder paste B showing a dramatic reduction in voiding.

Vapor Phase Reflow Effects on Voiding

Vapor phase reflow was done with several solder pastes (A, B, and C) made with SAC305 type 3 solder powder. Vapor phase reflow was run with and without the vacuum options (VP-V1, VP-V2, VP-V3). The results are shown below with the RTS convection voiding levels shown for comparison (Figure 26).

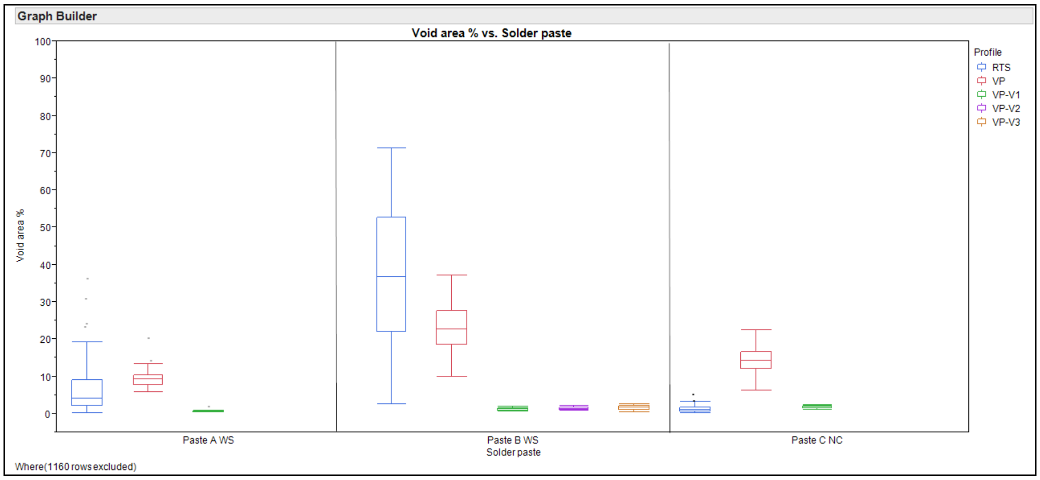
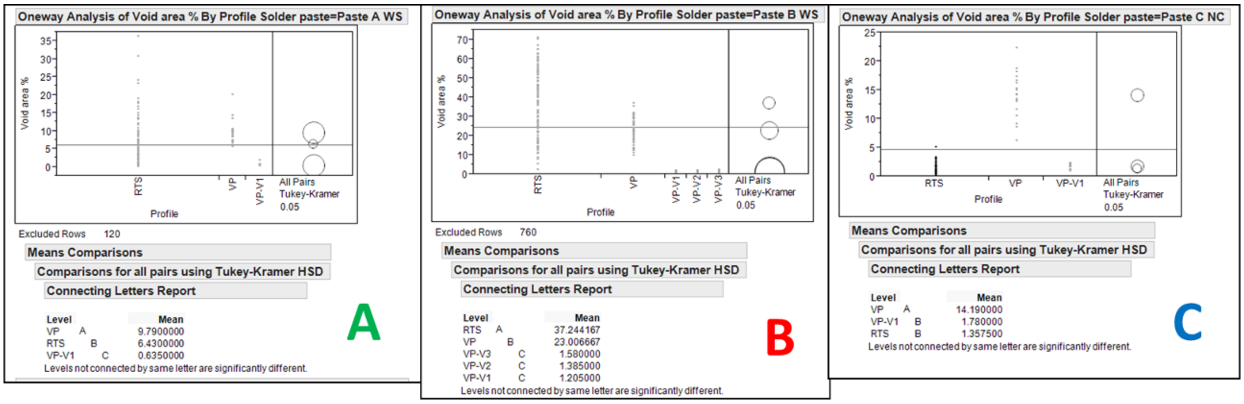


Figure 26 – Voiding for Vapor Phase Reflow versus RTS Convection Reflow for Solder Pastes A, B, C

Tukey Kramer HSD analysis shows some significant differences in the voiding levels (Figure 27).



Oneway Analysis of Void area % By Profile Solder paste=Paste A WS

Excluded Rows 120

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Connecting Letters Report

Level				Mean
VP	A			9.7900000
RTS		B		6.4300000
VP-V1			C	0.6350000

Levels not connected by same letter are significantly different.

Oneway Analysis of Void area % By Profile Solder paste=Paste B WS

Excluded Rows 760

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Connecting Letters Report

Level				Mean
RTS	A			37.244167
VP		B		23.006667
VP-V3			C	1.580000
VP-V2			C	1.385000
VP-V1			C	1.205000

Levels not connected by same letter are significantly different.

Oneway Analysis of Void area % By Profile Solder paste=Paste C NC

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Connecting Letters Report

Level			Mean
VP	A		14.190000
VP-V1		B	1.780000
RTS		B	1.357500

Levels not connected by same letter are significantly different.

Figure 27 – Tukey Kramer HSD Analysis for Voiding for Vapor Phase Reflow versus RTS Convection Reflow

Solder paste A gave higher voiding in the vapor phase reflow without vacuum as compared to the RTS convection reflow. Vacuum option V1 significantly reduced the voiding of solder paste A. Solder paste B gave very high voiding in the RTS convection reflow as compared to the voiding levels when run in vapor phase without vacuum. Addition of any of the three vacuum options V1, V2 or V3 reduced the voiding dramatically for solder paste B. Solder paste C showed high voiding in vapor phase without vacuum. Addition of vacuum option V1 reduced the voiding to a similar level as is seen with the RTS convection reflow.

Application of vacuum during reflow has a dramatic effect on voiding which can help overcome the basic voiding tendencies of the solder paste and other factors. One would assume that convection reflow with vacuum would perform similarly to vapor phase with vacuum. Testing would have to be run to validate this assumption.

Vapor phase reflow with vacuum was run in an attempt to rework pre-existing voids. Solder paste B with SAC305 type 3 solder powder was reflowed first in the convection RTS profile and voiding measurements were taken. The same circuit boards were reflowed again in the vapor phase system with vacuum, and void measurements taken (Figure 28).

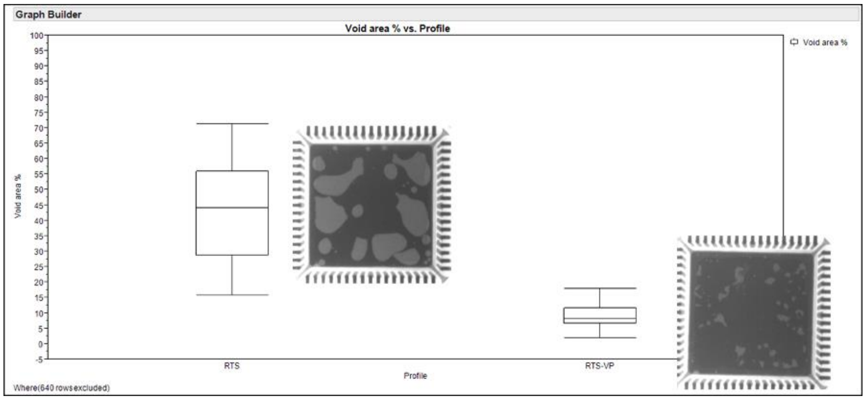
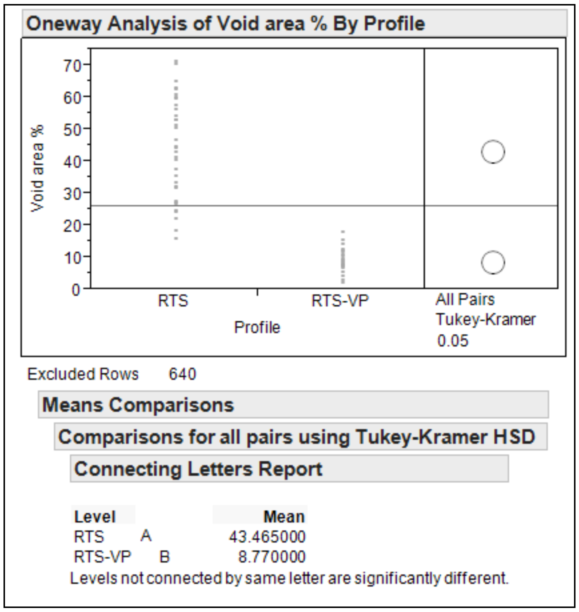


Figure 28 – Void Rework with Vapor Phase with Vacuum

A large reduction in existing voids was seen when vapor phase with vacuum was used to rework the voids. Tukey Kramer analysis shows that this result is significant (Figure 29).



Oneway Analysis of Void area % By Profile

Excluded Rows 640

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Connecting Letters Report

Level		Mean
RTS	A	43.465000
RTS-VP	B	8.770000

Levels not connected by same letter are significantly different.

Figure 29 – Tukey Kramer HSD Analysis for Vapor Phase Rework

This result shows that vapor phase with vacuum can be used as a rework method to reduce voiding. This is an interesting result because rework of soldered components with voids is difficult, is often unsuccessful and can result in thermal damage to the circuit board. Further work would have to be done to ensure the vapor phase with vacuum rework process does not affect solder joint quality and strength.

<u>Recommendations to “Fill the Void”</u>

Based on the data presented in this paper, here are some recommendations.

- Choose a solder paste that gives low voiding in your process.
- Use of smaller solder powder (IPC Type 4 or 5) in your solder paste may reduce voiding.
- Design the stencil to print solder paste in a manner which minimizes voiding. The use of gas escape routes can have an impact on voiding levels.
- Use a reflow profile to minimize voiding with your solder paste. The reflow profile should be tuned to fit each solder paste.
- Consider use of a nitrogen atmosphere with convection reflow because it may reduce voiding.
- Use a reflow system with vacuum to reduce voiding. Vacuum reduces voiding dramatically regardless of solder paste or other factors.
- Rework of soldered components with voids can be accomplished using vapor phase reflow with vacuum.

CONCLUSIONS

Voiding in solder joints is affected by many factors. Solder paste has a dramatic effect on voiding. In general, no clean lead free solder pastes generate lower voiding than water soluble lead free solder pastes. Solder powder size was shown to have an effect on voiding. Voiding tends to decrease with decreasing solder powder size. Solder powder from different manufacturers also has an effect on voiding due to differences in the manufacturing process. Stencil design has an impact on voiding, although this impact can be slight when compared to other factors. ENIG and OSP surface finishes had little affect on the voiding levels with the solder paste used in this evaluation. Reflow profile has a large effect on voiding, and the reflow profile must be tuned to minimize voiding with each solder paste. Vapor phase reflow and convection reflow with nitrogen reduced voiding as compared to convection reflow in air. The use of vapor phase reflows with vacuum gave extremely low voiding levels. It was also shown that vapor phase reflow with vacuum can be used to rework and reduce existing voids in soldered components.

Only some of the factors that influence voiding were studied in this work. There is much more testing to be done. Due to the commonplace use of bottom terminated components, it is clear that voiding will be an issue that many must address. The authors will continue to study factors that influence voiding in an effort to help the reader to “Fill the Void”.

FUTURE WORK

Development of strategies for mitigation of voiding is ongoing and these strategies will be presented in future technical papers. The selection of components used to evaluate voiding will be expanded. Additional stencil designs will be evaluated along with the added components. Solder powder size and oxide content and their impact on voiding will be investigated further. The effect of surface finish on voiding will also be studied with an expanded set of solder pastes. The influence of a nitrogen atmosphere in convection reflow will be investigated further. Voiding levels will be studied over the normal stencil life of solder paste. A combination of mitigation strategies developed could have a dramatic effect on the reduction of voiding.

ACKNOWLEDGEMENTS

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REFERENCES

[1] T. Lentz, G. Smith, “Fill the Void”, Proceedings of SMTA International, 2016.