Fill the Void IX: The Impact of Reflow on Voiding in Solder Joints

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Abstract

Voiding in solder joints remains a concern for manufacturers of printed circuit board assemblies (PCBAs). High voiding levels may lead to electrical, thermal, or mechanical failures. In some cases, challenging void limits are established as a "safety factor" to avoid the potential for failures. These challenging voiding limits create the need for methods of reducing voiding in solder joints.

This paper details continuing work on the impact of reflow on voiding in solder joints. Reflow profiles are easily changed and may influence void behavior. Reflow equipment is more difficult to change but can have a major impact on voiding, e.g. vacuum reflow. Several no-clean SAC305 solder pastes were tested with multiple convection reflow conditions and voiding measured in QFN thermal pads. The PCBAs were reflowed a 2nd time to determine the effects of 2nd reflow on 1st side voiding. This testing was repeated with vacuum reflow. Vacuum reflow was also used after 1st side convection reflow to remove established voids. The results were summarized and recommendations made to "Fill the Void."

Introduction

Voiding in solder joints has been researched for many years, and the limits keep tightening, resulting in a need for methods to reduce voiding. Many solder paste formulations have been developed to reduce voiding potential. Myriad solder paste print and reflow process parameters have been tested with respect to voiding potential. Reflow equipment has been developed with vacuum to reduce voiding in solder joints. When reduction of voiding below the established limits proves difficult, then a combination of void reduction strategies may be employed. This can include modification of PCBA design, change of the printed solder paste volume and location, adjustment of reflow profile parameters and/or equipment, use of solder preforms, and changing the solder paste used in the process. Rework of voids in solder joints is not always effective therefore mitigation strategies focus on prevention of voiding.

This work is a continuation of prior work, in which solder joint voiding was studied for various reflow profiles and multiple no-clean SAC305 solder pastes. In this work, two no-clean SAC305 solder pastes are used that typically show low voiding and relatively higher voiding. Three reflow profiles are used which are intended to vary voiding with the solder pastes. With double-sided SMT processing, voiding in the 1st side solder joints changes during 2nd side PCBA reflow, and so two-pass reflow is further investigated in this work. The influence of vacuum reflow on voiding in solder joints is of interest, and vacuum reflow is used as an option in both 1st and 2nd side reflow. The components and solder joints investigated in this work are MLF68 thermal pad solder joints, and 0.4 mm pitch BGA solder joints. When vacuum is drawn, voids expand in solder joints and can cause bridging between tight pitch solder joints like BGAs. Recommendations are made to reduce voiding and minimize potential bridging in solder joints.

Prior Work

T. Lentz, P. Chonis, and JB. Byers [1] studied methods of reducing voiding in solder joints. Five different solder pastes were tested including three water-soluble SAC305 and two no-clean SAC305 solder pastes. One of the water-soluble solder pastes was tested with various reflow profiles and a ramp-soak-spike (RSS) profile was shown to give statistically higher voiding than a ramp-to-spike (RTS) profile. The voiding was reduced significantly by reflow in vapor phase (oxygen free) for this same water-soluble solder paste. Vacuum applied during reflow further reduced voiding to near zero levels regardless of the reflow profile for this same water-soluble solder paste.

T. Lentz [2] studied the effects of surface finish on solder paste performance including voiding in solder joints. A water-soluble SAC305 solder paste and a no-clean SAC305 solder paste were reflowed in RSS and RTS reflow profiles, and voiding was compared. The no-clean solder paste showed similar voiding levels for both reflow profiles. The water-soluble solder paste gave higher voiding for the RTS profile and lower voiding for the RSS profile. Three PCB surface finishes were tested and they influenced voiding as well.

T. Lentz and G. Smith [3] studied methods for mitigating voiding for bottom terminated components. A low voiding no-clean SAC305 solder paste was used for this work along with 5 reflow profiles, and a host of stencil printed design variations. The reflow profiles varied soak time, reflow time, peak temperature, and overall length. The linear RTS profile gave the lowest overall voiding and was used for the remainder of the work. Stencil design was shown to have a large impact on voiding behavior.

T. Lentz [4] studied the impact of solder alloy on voiding in solder joints. Voiding was studied with the same no-clean solder paste flux and five different alloys including Sn63/Pb37 and Sn/Bi37/X lower temperature alloys. An RTS SAC305 reflow profile was compared to RTS profiles appropriate to the Sn63/Pb37 and Sn/Bi37/X lower temperature alloys. The voiding was reduced for these two alloys when run in the SAC305 profile as opposed to their normal lower temperature reflow profiles.

N. Holle, T. Ewald, U. Welzel [5] gave an overview of voiding in solder joints from an industry perspective. Increasing peak reflow temperature reduced voiding in some cases, but very high peak temperatures do not reduce voiding significantly. It was noted that many other factors have a greater influence on voiding than reflow profile.

T. Lentz [6] studied reflow profile effects on voiding in Quad-Flat-No-Lead (QFN) thermal pad solder joints. 4 no-clean SAC305 solder pastes and 5 reflow profiles were tested and the voiding results varied by paste and profile. One solder paste clearly gave higher voiding than the others, and one clearly gave lower voiding than the others. Low peak temperatures tended to give higher voiding, and a standard ramp-soak-spike profile tended to give lower voiding. The PCBAs with existing voids were reflowed a 2nd time which increased 2D void area slightly. Many of the voiding results were similar with statistically insignificant differences. If the goal is to reduce mean voiding below an established limit, then adjustment of reflow profile may help to achieve that goal.

Experimental Methodology

The PCBA chosen for this experiment is the PR Test Board and the components used for voiding measurements are MLF68 QFNs and BGA360s which are pictured below (Figure 1).

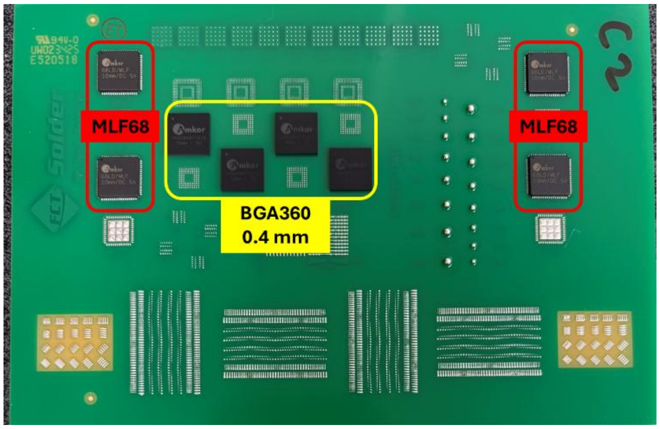


Figure 1. PR Test Board and Components Used for Voiding Studies.

This PCB is single sided, made from FR4 1.5 mm (0.059 inches) thick with 35 micrometers (1.38 mil) thick copper features and electroless nickel immersion gold (ENIG) surface finish. 4 x MLF68 and 4 x BGA360 (0.4 mm pitch) dummy components were placed per PCBA.

The stencil design for the MLF68 component is a standard 9 window-pane design with 65% area of coverage of solder paste and 508 µm (20 mil) wide webs (Figure 2). The stencil was made from laser cut 127 µm (5 mil) thick fine grain (FG) stainless steel, without nano-coatings.

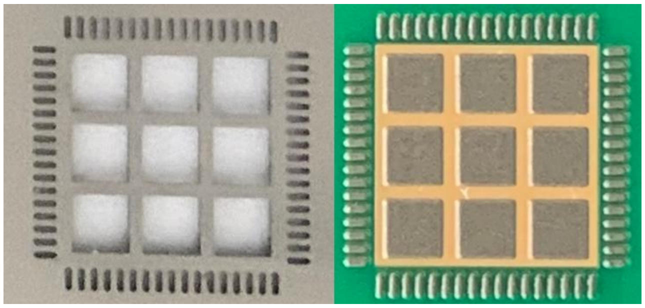


Figure 2. Stencil Design for the MLF68 Components.

The stencil design for the 0.4 mm pitch BGA360 components is a 0.254 mm (10 mil) square aperture with a 0.064 mm (2.5 mil) radius on the corners (Figure 3).

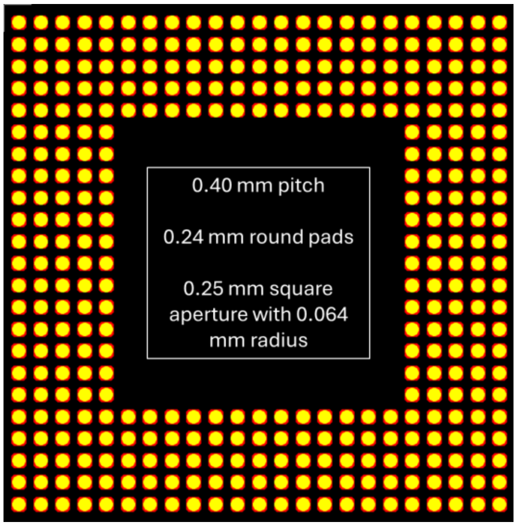


Figure 3. Pad and Stencil Design for the BGA360 Components.

The BGA360 pads are copper defined with a round shape and a diameter of 0.24 mm (9.4 mils). The solder mask opening around the pads is 0.32 mm (12.6 mils) diameter. The pitch of the BGA pads is 0.40 mm (15.7 mils) and the space between the edges of the BGA pads is 0.16 mm (6.3 mils). This small spacing between solder joints presents a bridging risk when vacuum is applied to solder joints with voids. Vacuum causes expansion of the solder joints which could bridge to nearby pads in the grid array.

The solder pastes used in this study are commercially available no-clean, Pb-free made with SAC305 IPC Type 4 (20-38 µm) solder powder. These solder pastes were selected from a previous study [6], and were chosen due to the low voiding potential of solder paste A and the relatively higher voiding potential of solder paste C. The solder pastes used are shown in Table 1 below.

Table 1. No-Clean SAC305 Type 4 Solder Pastes Used.

Solder Paste	Flux Class (IPC J-STD-004)	Metal Content (% wt)
A	ROL0	88.0
C	ROL0 (Halogen containing)	87.9

Printing was conducted on a commercially available printer with the settings shown below (Table 2).

Table 2. Printing Parameters.

Print Parameter	Value
Print speed (mm/sec)	35 mm/sec
Blade angle (deg.)	60°
Blade length (mm)	200 mm

Print pressure (kg)	5.0 Kg
Separation speed (mm/sec)	20 mm/sec
Separation distance (mm)	1 mm
Print gap (mm)	0

Reflow was conducted in a Heller 1911-MK5-VR 10-zone reflow oven with vacuum capability. The vacuum chamber has a separate conveyor after the 10th zone and uses 3 infrared (IR) heaters to maintain temperature during vacuum. The reflow profiles without vacuum were run with the IR heaters turned on, and the conveyor paused under the heaters to simulate the same thermal conditions that occurred when reflow was run with vacuum turned on. Three reflow profiles were set up and numbered 1, 2, and 3 for ease of reference. The oven settings for these reflow profiles are shown below (Table 3).

Table 3. Reflow Oven Settings for the Reflow Profiles Used.

Reflow Profile #	Conveyor Speed (cm/min)	Z2 (°C)	Z3 (°C)	Z4 (°C)	Z4 (°C)	Z5 (°C)	Z6 (°C)	Z7 (°C)	Z8 (°C)	Z9 (°C)	Z10 (°C)	IRL (°C)	IRC (°C)	IRR (°C)
1	65	100	120	140	160	170	180	190	220	245	270	320	320	320
2	75	90	100	120	140	160	180	200	220	240	260	320	320	320
3	60	80	120	130	140	150	165	185	198	220	255	320	320	320

The measured reflow profiles are shown below (Figure 4).

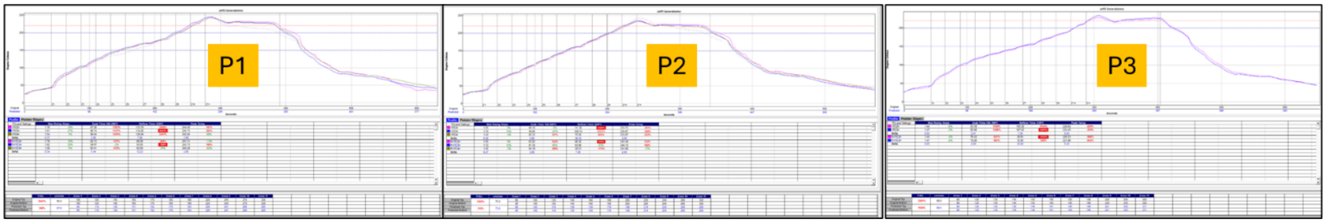


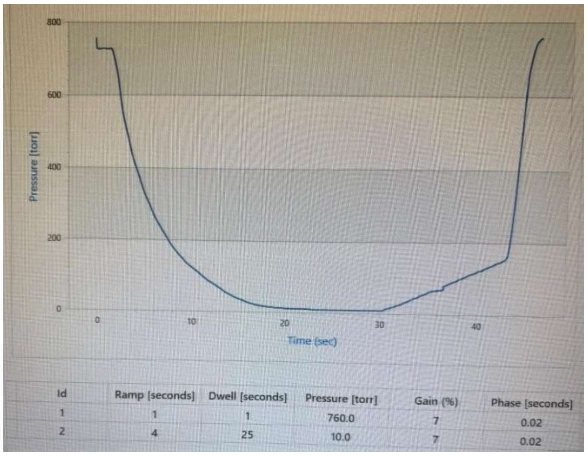
Figure 4. Measured Temperatures for the Reflow Profiles. Profile 1 (Left), Profile 2 (Middle), Profile 3 (Right).

The measured values from the reflow profiles are in Table 4 below.

Table 4. Measured Values for the Reflow Profiles Used.

Parameter	Profile #1	Profile #2	Profile #3
Soak time 150-200°C (sec)	87 - 89	59 - 62	83 - 86
Reflow Time >220°C (sec)	127 - 135	109 - 111	100 - 108
Peak temp (°C)	243 - 246	234 - 236	229 - 234

When vacuum was used, the pressure was 10 torr for 25 seconds, and the vacuum cycle is shown below (Figure 5).



Id	Ramp [seconds]	Dwell [seconds]	Pressure [torr]	Gain (%)	Phase [seconds]
1	1	1	760.0	7	0.02
2	4	25	10.0	7	0.02

Figure 5. Vacuum Cycle.

The general process used for this experiment is as follows and is shown in the diagram below (Figure 6). 2 solder pastes (A and C) were used with 3 reflow profiles (1, 2, and 3) and 2 vacuum options (On and Off). A total of 12 combinations of solder paste and reflow profile were run and 5 PCBAs were made per combination for a total of 60 PCBAs. A total of 20 x MLF68 and 20 x BGA360 components were placed per combination. Voiding was measured on each component, and the BGAs were inspected for bridging.

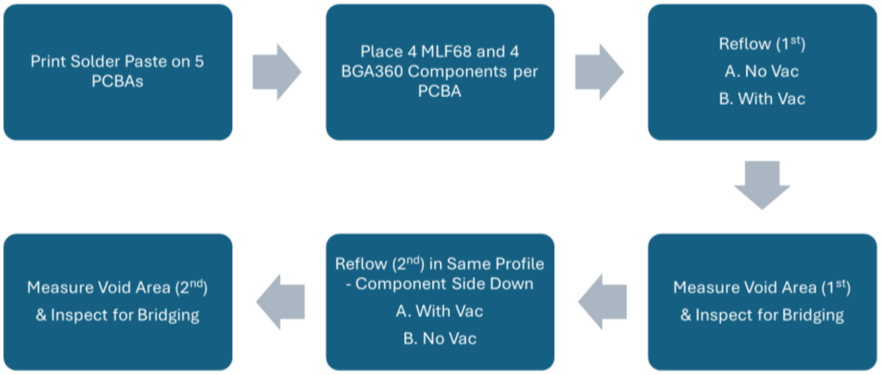


Figure 6. General Experimental Process.

Each PCBA was reflowed in profile 1, 2, or 3 with or without vacuum. Then the same PCBAs were reflowed a 2nd time in the same profile with the alternate vacuum setting from what was initially used. The PCBAs that were run without vacuum on the 1st side were run with vacuum on the 2nd side. The PCBAs that were run with vacuum on the 1st side were run without vacuum on the 2nd side. In all cases, the 2nd side reflow was run with the component side down, to mimic the normal process used in surface mount assembly. The solder joints were inspected again for voiding and bridging.

The codes used to designate the reflow profile combinations were as follows. A single number simply indicates that profile run without vacuum, e.g. 1, 2, or 3. A single number followed by the letter "V" was used to designate that profile run with vacuum, e.g. 1V, 2V, or 3V. A code followed by a dash "-" followed by a code was used to designate the 1st and 2nd reflow profile combinations. For example, "1-1V" indicates the 1st side reflow in profile #1 followed by 2nd side reflow in profile #1 with vacuum.

This data was summarized and statistical comparisons run on the data sets. The BGA arrays were inspected for bridging and a tally taken for comparisons.

Results

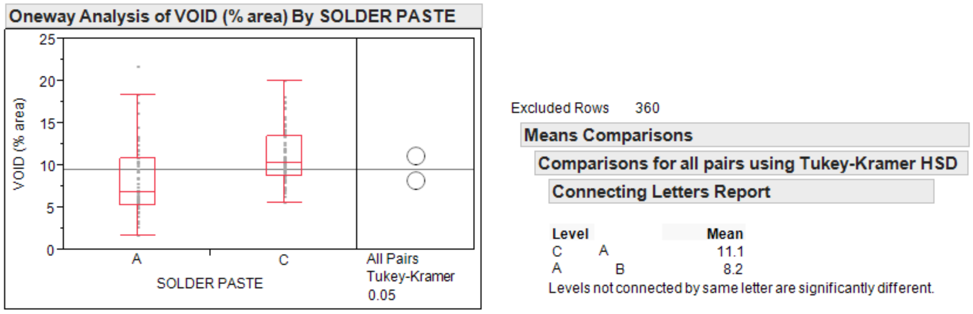
MLF68 Voiding Data

The voiding data for the MLF68 thermal pad solder joints is summarized in Table 5 below.

Table 5. MLF68 Void Data Summary.

Solder Paste	Reflow Profile	Min Void Area (%)	Mean Void Area (%)	Max Void Area (%)
A	1	2.7	7.58	18.4
A	1-1V	0.1	0.58	1.1
A	1V	0.0	0.98	1.9
A	1V-1	0.4	0.77	1.2
A	2	3.3	8.07	17.3
A	2-2V	0.5	0.97	1.5
A	2V	0.4	0.75	1.5
A	2V-2	0.5	1.31	2.0
A	3	1.7	8.96	21.7
A	3-3V	0.2	0.65	1.3
A	3V	0.2	0.56	1.9
A	3V-3	0.6	1.26	2.1
C	1	5.6	9.70	15.4
C	1-1V	0.4	1.29	2.7
C	1V	0.4	0.96	1.7
C	1V-1	0.7	1.45	5.1
C	2	7.9	12.62	20.0
C	2-2V	0.8	1.59	2.6
C	2V	0.5	1.11	2.0
C	2V-2	0.3	1.22	1.7
C	3	6.2	10.96	18.0
C	3-3V	0.3	1.19	1.9
C	3V	0.4	0.79	2.0
C	3V-3	0.3	1.04	1.6

Voiding overall on the 1st side was higher for solder paste C than solder paste A when reflowed without vacuum (Figure 7).



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Excluded Rows     360
Means Comparisons
Comparisons for all pairs using Tukey-Kramer HSD
Connecting Letters Report

Level          Mean
C    A         11.1
A       B       8.2
Levels not connected by same letter are significantly different.
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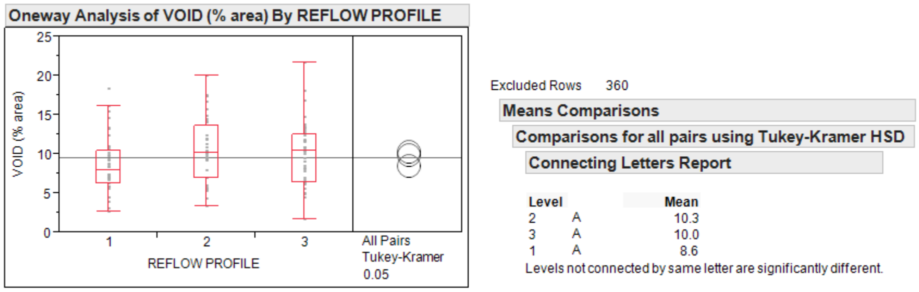
Figure 7. MLF68 Voiding Overall for the Solder Pastes on the 1st Side, Including All Reflow Profiles without Vacuum.

Voiding was statistically similar for the three reflow profiles (1, 2, and 3) run without vacuum (Figure 8). This data includes both solder pastes and is from 1st side reflow.



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Excluded Rows     360
Means Comparisons
Comparisons for all pairs using Tukey-Kramer HSD
Connecting Letters Report

Level          Mean
2    A         10.3
3    A         10.0
1    A          8.6
Levels not connected by same letter are significantly different.
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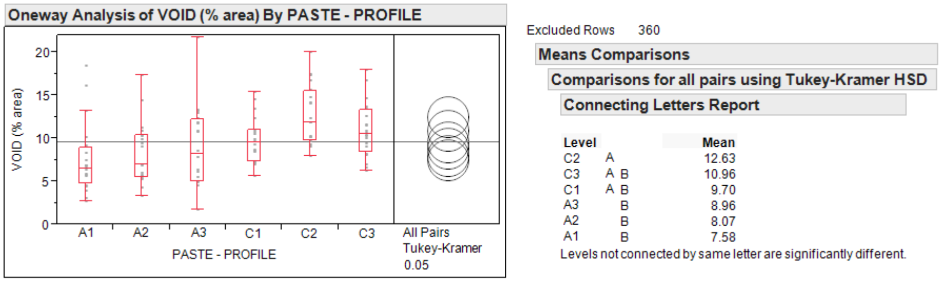
Figure 8. MLF68 Voiding Overall for the 1st Side Reflow Profiles without Vacuum, Including Both Solder Pastes.

Voiding for the solder paste & reflow profile combinations without vacuum on the 1st side is shown below (Figure 9).



Excluded Rows 360

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

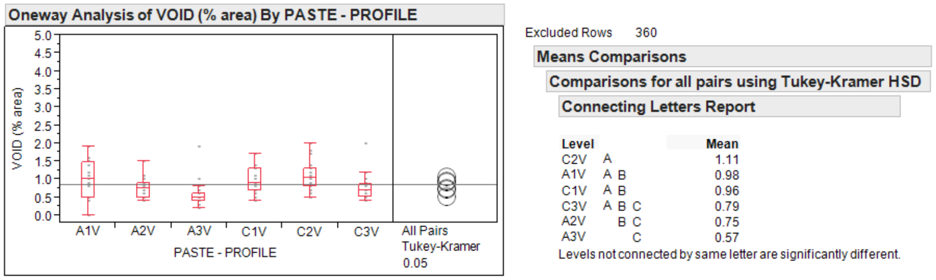
Connecting Letters Report

Level		Mean
C2	A	12.63
C3	A B	10.96
C1	A B	9.70
A3	B	8.96
A2	B	8.07
A1	B	7.58

Levels not connected by same letter are significantly different.

Figure 9. MLF68 Voiding for Each Solder Paste & Reflow Profile Combination without Vacuum.

Solder paste C and reflow profiles 2 and 3 tended to give higher voiding, while solder paste A and reflow profile 1 tended to give lower voiding. Voiding for each solder paste & reflow profile combination with vacuum on the 1st side is shown below (Figure 10).



Excluded Rows 360

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Connecting Letters Report

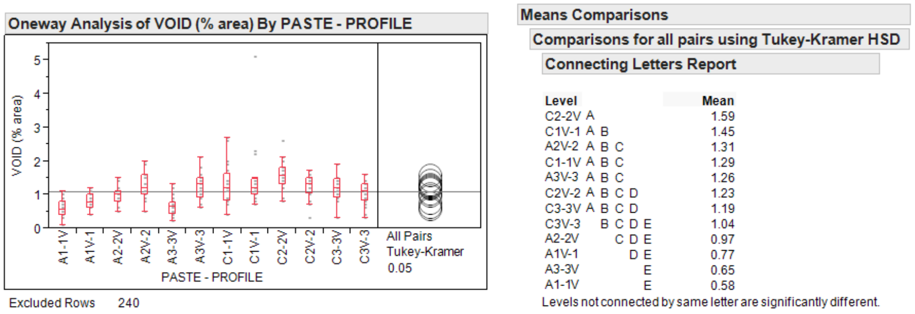
Level		Mean
C2V	A	1.11
A1V	A B	0.98
C1V	A B	0.96
C3V	A B C	0.79
A2V	B C	0.75
A3V	C	0.57

Levels not connected by same letter are significantly different.

Figure 10. MLF68 Voiding for Each Solder Paste & Reflow Profile Combination with Vacuum.

The voiding for each solder paste & reflow profile combination run with vacuum is ~90% lower than the corresponding combinations without vacuum.

Voiding for the 1st side reflow followed by 2nd side reflow is shown below (Figure 11). 1st side reflow was done with or without vacuum followed by the opposite vacuum setting on side 2 with the same reflow profile.



Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Connecting Letters Report

Level		Mean
C2-2V	A	1.59
C1V-1	A B	1.45
A2V-2	A B C	1.31
C1-1V	A B C	1.29
A3V-3	A B C	1.26
C2V-2	A B C D	1.23
C3-3V	A B C D	1.19
C3V-3	B C D E	1.04
A2-2V	C D E	0.97
A1V-1	D E	0.77
A3-3V	E	0.65
A1-1V	E	0.58

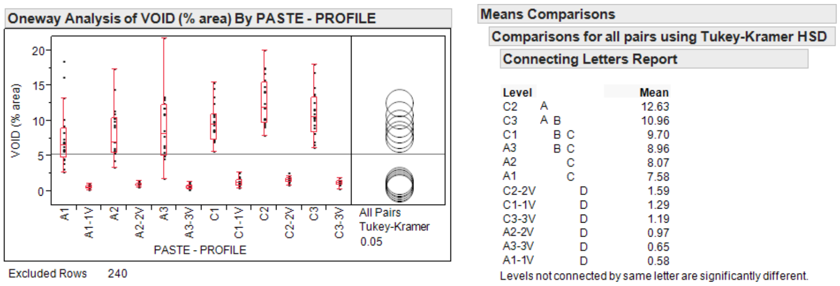
Levels not connected by same letter are significantly different.

Excluded Rows 240

Figure 11. MLF68 Voiding after 2nd Side Solder Paste & Reflow Profile Combination with Vacuum.

The voiding for the 1st side & 2nd side solder paste & reflow profile combinations includes vacuum as a part of each combination, which lowers the voiding significantly from reflow without vacuum.

Reflow on the 1st side without vacuum followed by 2nd side reflow with vacuum significantly lowered the voiding. A direct comparison of this voiding data is shown below (Figure 12).



Level					Mean
C2	A				12.63
C3	A	B			10.96
C1		B	C		9.70
A3		B	C		8.96
A2			C		8.07
A1			C		7.58
C2-2V				D	1.59
C1-1V				D	1.29
C3-3V				D	1.19
A2-2V				D	0.97
A3-3V				D	0.65
A1-1V				D	0.58

Levels not connected by same letter are significantly different.

Figure 12. MLF68 Voiding for 1st Side Reflow without Vacuum Followed by 2nd Side Reflow with Vacuum.

Representative X-ray images of these results are shown below (Figure 13).

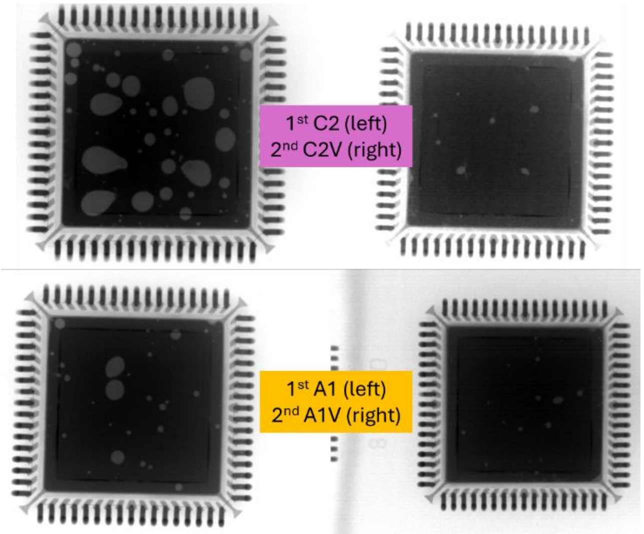


Figure 13. MLF68 Voiding for 1st Side Reflow without Vacuum Followed by 2nd Side Reflow with Vacuum.

BGA360 Voiding Data

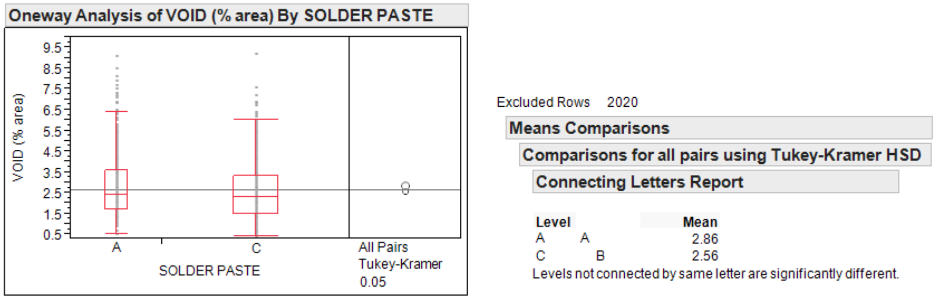
The BGA360 components were inspected for voiding and bridging in the corners of each array. Many of the solder joints had 0% void area which influenced the distribution of data, so the zero void data points were removed. All of the subsequent Tukey Kramer HSD analysis were generated from the non-zero void data. The min, mean and max void area data in Table 6 below were generated from the non-zero data points.

Table 6. BGA360 Void Data Summary from the Non-Zero Data Points.

Solder Paste	Reflow Profile	Min Void Area (%)	Mean Void Area (%)	Max Void Area (%)	Bridges Total	Total # Non-Zero Void Data Points	Total # Zero Void Data Points
A	1	1.2	3.33	9.1	5	183	1106
A	1-1V	1.6	3.01	6.6	0	85	1290
A	1V	0.5	1.94	5.7	0	194	1041
A	1V-1	1.4	2.81	6.6	6	41	1310
A	2	0.5	2.28	7.7	0	178	958
A	2-2V	1.4	2.70	6.3	0	83	1252
A	2V	1.3	2.70	6.5	0	115	1146
A	2V-2	1.2	2.74	5.9	2	101	1255
A	3	1.6	3.16	6.5	0	52	869
A	3-3V	0.7	2.42	5.1	0	94	1222
A	3V	0.7	2.47	6.5	0	130	1168
A	3V-3	1.0	2.41	6.2	1	125	1195
C	1	0.4	2.17	9.2	0	384	914
C	1-1V	1.2	3.48	8.6	0	155	1209

C	1V	0.5	2.35	5.6	0	192	1103
C	1V-1	0.8	3.41	7.3	10	95	1280
C	2	1.1	2.86	7.6	0	241	978
C	2-2V	1.3	3.11	7.3	0	132	1274
C	2V	0.5	2.52	5.8	0	154	1173
C	2V-2	1.3	3.11	7.3	5	132	1274
C	3	0.7	2.93	7.2	0	219	1145
C	3-3V	1.7	3.31	5.2	0	22	1681
C	3V	1.3	2.83	8.0	0	111	877
C	3V-3	1.3	2.53	6.3	4	59	1412

The overall BGA360 voiding levels for the solder pastes including all three 1st side reflow profiles without vacuum is shown below (Figure 14).



Excluded Rows 2020

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

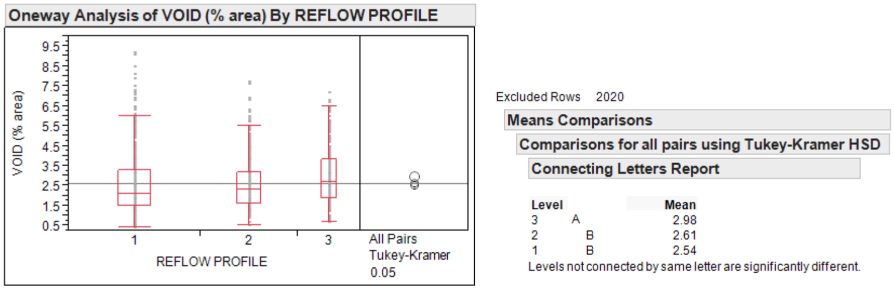
Connecting Letters Report

Level			Mean
A	A		2.86
C		B	2.56

Levels not connected by same letter are significantly different.

Figure 14. BGA360 Voiding for the Solder Pastes on the 1st Side, Including All Reflow Profiles without Vacuum.

The mean void levels for each solder paste are quite low (<3% area). Solder paste C gave overall lower voiding than solder paste A when averaging all reflow profiles without vacuum. The voiding split by reflow profile (without vacuum) on the 1st side including both solder pastes is shown below (Figure 15).



Excluded Rows 2020

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

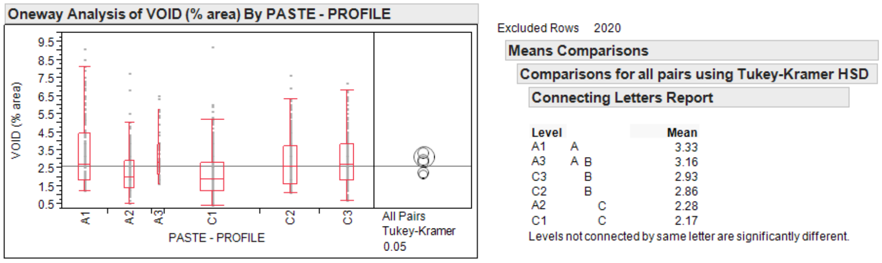
Connecting Letters Report

Level			Mean
3	A		2.98
2		B	2.61
1		B	2.54

Levels not connected by same letter are significantly different.

Figure 15. BGA360 Voiding Overall for the 1st Side Reflow Profiles without Vacuum, Including Both Solder Pastes.

Reflow profile 3 gave overall higher voiding for the BGA solder joints than the other profiles. The voiding for each solder paste – reflow profile combination without vacuum on the 1st side is shown below (Figure 16).



Excluded Rows 2020

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

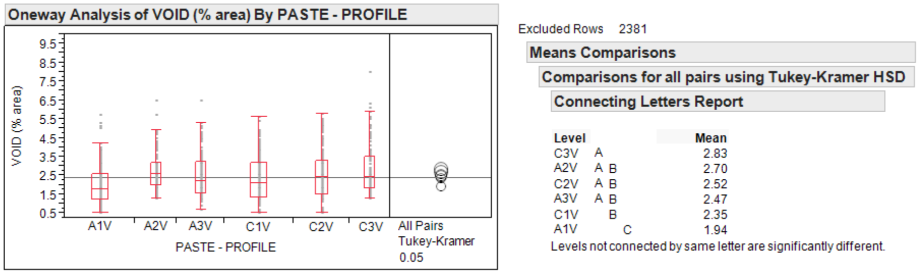
Connecting Letters Report

Level				Mean
A1	A			3.33
A3	A	B		3.16
C3		B		2.93
C2		B		2.86
A2			C	2.28
C1			C	2.17

Levels not connected by same letter are significantly different.

Figure 16. BGA360 Voiding for the 1st Side Reflow of Each Solder Paste & Profile Combination without Vacuum.

Solder paste C with reflow profile 1 and solder paste A with reflow profile 2 gave the overall lowest voiding, without vacuum. Voiding for each solder paste – reflow profile combination with vacuum on the 1st side is shown below (Figure 17).



Excluded Rows 2381

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

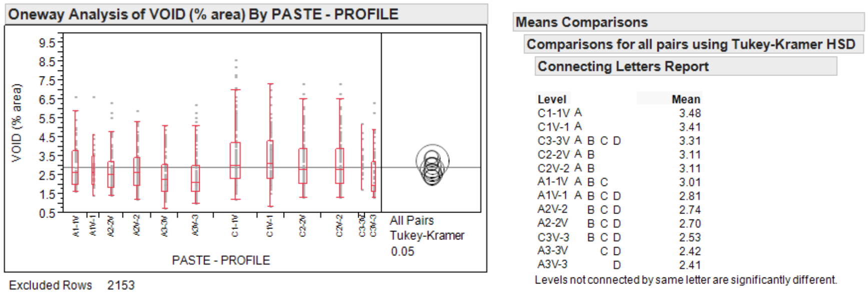
Connecting Letters Report

Level				Mean
C3V	A			2.83
A2V	A	B		2.70
C2V	A	B		2.52
A3V	A	B		2.47
C1V		B		2.35
A1V			C	1.94

Levels not connected by same letter are significantly different.

Figure 17. BGA360 Voiding for Each Solder Paste & Reflow Profile Combination with Vacuum on the 1st Side.

With vacuum, the voiding for each solder paste – reflow profile combination is similarly low. The combinations with solder paste A gave slightly lower voiding than the combinations with solder paste C. The combinations with reflow profile 1 gave slightly lower voiding than the combinations with the other profiles. Voiding after the 2nd side reflow of each solder paste – reflow profile combination is shown below (Figure 18).



Excluded Rows 2153

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

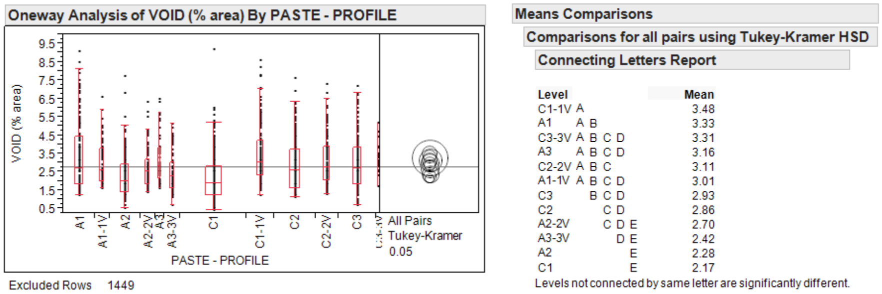
Connecting Letters Report

Level					Mean
C1-1V	A				3.48
C1V-1	A				3.41
C3-3V	A	B	C	D	3.31
C2-2V	A	B			3.11
C2V-2	A	B			3.11
A1-1V	A	B	C		3.01
A1V-1	A	B	C	D	2.81
A2V-2		B	C	D	2.74
A2-2V		B	C	D	2.70
C3V-3		B	C	D	2.53
A3-3V			C	D	2.42
A3V-3				D	2.41

Levels not connected by same letter are significantly different.

Figure 18. BGA360 Voiding after 2nd Side Solder Paste & Reflow Profile Combination.

The combinations which included solder paste A tended to give lower voiding, but the reflow profiles do not show a clear trend likely due to the influence of vacuum. Voiding for reflow of the 1st side without vacuum followed by the 2nd side with vacuum is shown below (Figure 19).



Excluded Rows 1449

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Connecting Letters Report

Level						Mean
C1-1V	A					3.48
A1	A	B				3.33
C3-3V	A	B	C	D		3.31
A3	A	B	C	D		3.16
C2-2V	A	B	C			3.11
A1-1V	A	B	C	D		3.01
C3		B	C	D		2.93
C2			C	D		2.86
A2-2V			C	D	E	2.70
A3-3V				D	E	2.42
A2					E	2.28
C1					E	2.17

Levels not connected by same letter are significantly different.

Figure 19. BGA360 Voiding for 1st Side Reflow without Vacuum Followed by 2nd Side Reflow with Vacuum.

The voiding was reduced significantly by 2nd side reflow with vacuum for most combinations. Solder paste C with reflow profile 1 and solder paste A with reflow profile 2 gave lower voiding without vacuum than some combinations with vacuum. Representative X-ray images of these results are shown below (Figure 20).

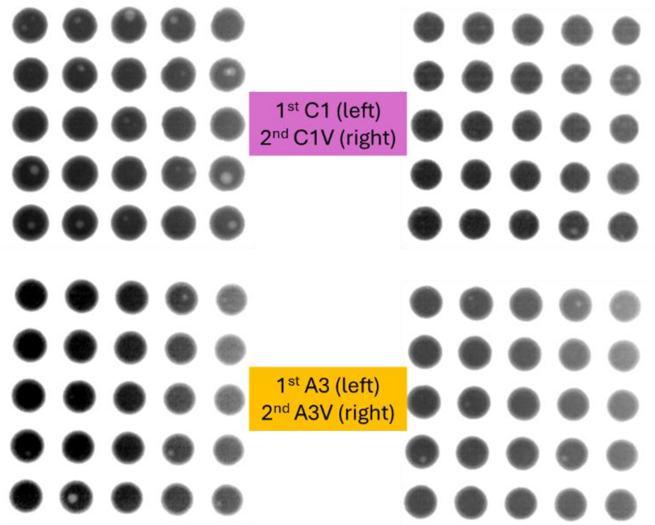


Figure 20. BGA360 Voiding for 1st Side Reflow without Vacuum Followed by 2nd Side Reflow with Vacuum.

The number of BGA solder joints that showed 0% voiding was influenced by solder paste – reflow profile combination and vacuum. The ratio of number of solder joints with voids to the total number measured is shown below. (Figure 21).

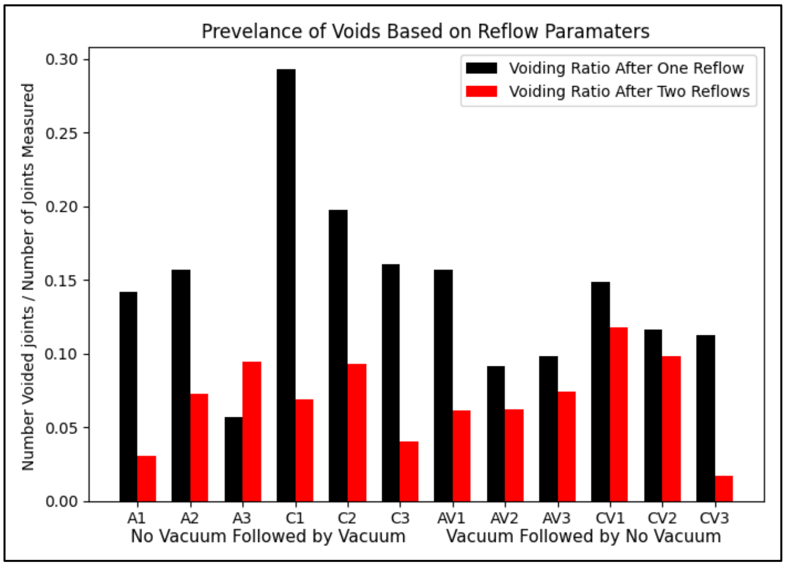


Figure 21. Ratio of Voided BGA Solder Joints over the Total Solder Joints Measured, After 1 Reflow and 2 Reflows

Bridging in the BGA arrays was measured and an increase in the number of bridges was found when vacuum was used. No bridging was found after 1 reflow without vacuum. These same PCBAs were reflowed for a 2nd time with vacuum which produced bridging. (Table 6)

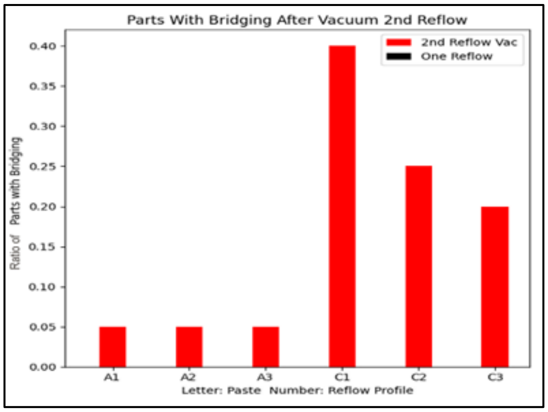


Figure 22. Ratio of BGA360 Parts of Measured Set which Contain Bridged Solder Joints.

Discussion

Vacuum reflow proved to be extremely effective in reducing voiding across all use cases. Results summarized in table 5 show this reduction effectively. Reflow performed without vacuum appear in the un-lettered reflow profile showing a modest mean voiding area in the MLF68 parts. The parts showed mean voiding around 10% ubiquitously, however when vacuum is added as a parameter the mean drops by an order of magnitude. Importantly this is a broad distribution reduction as well, such that minimum values and maximum values experience roughly the same order of magnitude reduction.

The reduction is ubiquitous across paste identity and reflow profile. Comparison of figures 9 and 10 shows the voiding of the MLF68 part for profiles with and without vacuum after a single reflow pass. The voiding in figure 9, no vacuum, is a full order of magnitude higher in every comparable pair. Importantly, this is an effect of the vacuum as no reflow profile particularly shows substantially lower voiding than another as is seen in figure 8.

The potential value of vacuum reflow becomes more evident in the multiple reflowed PCBAs. Figure 11 shows the voiding for the MLF68 part in multiple reflowed boards. In cases where a vacuum reflowed part is reflowed without vacuum for the second pass, for example the A1V-1 board, the low void resultant from the first pass is maintained. Similarly, where a part has high voiding from its initial non-vacuum pass, the voiding is greatly reduced by the second pass. This can be seen in figure 12 where the void results drop substantially by second pass vacuum.

Much the same results can be seen in the BGA360 void data. Herein the void data is reported on a per joint basis rather than a per part basis. As would be expected, the mode of such data is a void value of zero percent; meaning most of the individual joints had no voids whatsoever while the overall part had meaningful voiding. This can be seen in the summary table 6. Solder paste identity and reflow profile show voiding trends in figures 14 and 15 although the difference in mean voiding is very low, and well below typical industry limits.

Further consequence of reporting on a per joint basis rather than a per part basis is the apparent modest reduction in voiding between vacuum and non-vacuum profiles. Between figures 16 and 17, the voiding across all profiles and paste is only reduced by a small fraction as compared to the order of magnitude of the MLF68 parts. The change in void area between vacuum and non-vacuum profiles is minimal and in some cases is insignificant. However, the number of joints with no void is vastly increased in the case of vacuum for most of the solder paste – reflow profile combinations.

For the multiple reflow steps the BGA360 data is summarized in figures 18 and 19. Again the magnitude of reduction seen in a second vacuum reflow on a per joint basis is not nearly as large as in the QFN thermal pads. Figure 19 shows that the largest apparent reduction in voiding in the BGA parts occurs in paste A across two of the three reflow profiles. Interestingly, paste C seems unaffected in void area reduction with a second vacuum reflow step. Again, though this data hides the decrease in overall voiding across the part via the reduction in total number of voids and not in the void size. As with the MLF68 part in the case of a second non-vacuum reflow, the low voiding condition seen through the first reflow is maintained through the second.

As has been discussed the main mechanism for the reduction of voiding in the BGA parts is not the shrinking of voids but rather the reduction in the total number of voids. Figure 21 shows this reduction through the ratio of voided joints vs the total number of measured joints. For all conditions approximately 1300 joints were measured and the proportion of joints that are voided is highest in paste C no vacuum reflow across all profiles. Except in the case of the anomalous A3 profile all the first reflow void ratios are high for the non-vacuum case on the left-hand side of the figure. After the additional vacuum reflow all the ratios drop precipitously. For the right-hand side, where the initial reflow is vacuum reflow the ratio of voided joints starts out lower after the vacuum reflow but then remains low after the non-vacuum reflow. Both the reduction in total number of voids as well as the reduction in size of voids through vacuum reflow are required to understand the value of introducing the vacuum step into the process for the reduction of total voiding in BGA parts.

However, the picture for vacuum reflow is not entirely positive. An interesting emergent property of vacuum reflow was discovered especially for paste C. Vacuum reflow generally carries the risk of splattering or bridging due to the rapid physical movement of flux vapor or solvent during the application of the vacuum. The sudden drop in atmospheric pressure can lead to rapid boiling of these vapors, creating randomizing motion. In this case, for the first reflow with vacuum no evidence of these negative reactions were observed. No joint in the 43200 studied joints was found to have bridged due to this rapid expansion of gases. However, when vacuum is applied on the second reflow, substantial bridging was observed. It is unlikely this was a product of the specific solder pastes used, as this was unobserved for first reflow vacuum. However, a side product of the release of the trapped gases specifically in voids of the first reflow process was a tendency to cause bridges. This is of particular import as bridging is not an individual joint lifetime shortening defect but can cause the failure of an entire part. As such, the tendency to bridge is summarized in figure 22 where the ratio of parts with bridges of total parts studied is used to present this issue. The frequency and severity of this failure demands further study not presented in this work. Alteration of the vacuum profile used could also alter the frequency of this failure with slower pressure ramp rates seeing fewer common failures.

Conclusions

Vacuum reflow processing was found to substantially reduce void formation in both QFN and BGA solder joints for either as a first reflow pass or a second reflow pass. The low ambient pressure evacuates entrapped flux volatiles and process gases leading to improved wetting and lower voiding. This is true when vacuum is added in both the first reflow process but also importantly the case for a use of vacuum as a second reflow process. Additionally important, the reduction in voiding is maintained from a first vacuum reflow step past a second reflow wherein vacuum is not used. As would be hoped, a single vacuum step can massively reduce voiding despite its timing in assembly, reflow profile, or paste used.

However, simultaneously vacuum was not without its risks. With the rapid depressurization of the chamber comes rapid boiling of residual solvents or fluxes including the trapped gasses within voids. This rapid evaporation event can lead to splattering and in this case substantial bridging. Thus, when using vacuum reflow on a specific paste step, it is vital to consider all the previously formed solder joints and what reaction they may have to the rapid depressurization of the system.

Reflow without vacuum shows that voiding varies for component, solder paste, and reflow profile. This is consistent with previous studies and confirms that voiding is a complex issue with many factors to consider. Vacuum reflow tends to reduce voiding regardless of these factors and can be used to help “Fill the Void.”

Acknowledgements

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