Pad Design and Process for Voiding Control at QFN Assembly

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ABSTRACT

Quad Flat No Leads (QFN) package designs receive more and more attention in electronic industry recently. This package offers a number of benefits including (1) small size, such as a near die size footprint, thin profile, and light weight; (2) easy PCB trace routing due to the use of perimeter I/O pads; (3) reduced lead inductance; and (4) good thermal and electrical performance due to the adoption of exposed copper die-pad technology. These features make the QFN an ideal choice for many new applications where size, weight, electrical, and thermal properties are important. However, adoption of QFN often runs into voiding issue at SMT assembly. Upon reflow, outgassing of solder paste flux at the large thermal pad has difficulty escaping and inevitably results in voiding. It is well known that the presence of voids will affect the mechanical properties of joints and deteriorate the strength, ductility, creep, and fatigue life. In addition, voids could also produce spot overheating, lessening the reliability of the joints. This is particularly a concern for QFN where the primary function of thermal pads is for heat dissipation. Thermal pad voiding control at QFN assembly is a major challenge due to the large coverage area, large number of thermal via, and low standoff. Both design and process were studied for minimizing and controlling the voiding. Eliminating the thermal via by plugging is most effective in reducing the voiding. For unplugged via situations, a full thermal pad is desired for a low number of via. For a large number of via, a divided thermal pad is preferred due to better venting capability. Placement of a thermal via at the perimeter prevents voiding caused by the via. A wider venting channel has a negligible effect on voiding and reduces joint continuity. For a divided thermal pad, the SMD system is more favorable than the NSMD system, with the latter suffering more voiding due to a thinner solder joint and possibly board outgassing. Performance of a divided thermal pad is dictated by venting accessability, not by the shape. Voiding reduction increases with increasing venting accessability, although the introduction of a channel area compromises the continuity of the solder joint. Reduced solder paste volume causes more voiding. Short profiles and long hot profiles are most promising in reducing the voiding. Voiding behavior of a QFN is similar to typical SMT voiding and increases with pad oxidation and further reflow.

Key Words: QFN, thermal pad, thermal via, design, void, solder, solder paste, flux, SMT, reflow, assembly

INTRODUCTION

Quad Flat No Leads (QFN) package designs are receiving more and more attention in electronics industry. This package offers a number of benefits including (1) small size, such as a near die-sized footprint, thin profile, and light weight; (2) easy PCB trace routing due to the use of perimeter I/O pads; (3) reduced lead inductance; and (4) good thermal and electrical performance due to the adoption of exposed copper die-pad technology. These features make the QFN an ideal choice for many new applications where size, weight, electrical, and thermal properties are important. However, adoption of QFN often runs into voiding issues during SMT assembly. Upon reflow, outgassing of solder paste flux at the large thermal pad has difficulty escaping and inevitably results in voiding [1]. It is well known that the presence of voids will affect the mechanical properties of joints and deteriorate the strength, ductility, creep, and fatigue life [2,3,4]. In addition, voids could also produce spot overheating, lessening the reliability of joints. This is a particular concern for QFN where the primary function of thermal pads is for heat dissipation. In this study, various designs of thermal pads, stencil patterns, and reflow profiles are evaluated in order to identify the optimal condition for minimizing the voiding. The effect of each variable on voiding is analyzed and presented in the paper.

EXPERIMENTAL DESIGN

In this work, a dummy QFN component A-MLF68-10mm-0.5mm-DC-Sn was used with 68 peripheral pads, 10mm long on each side, 0.5mm pitch, daisy-chained, with a Sn surface finish, as shown in Figure 1.

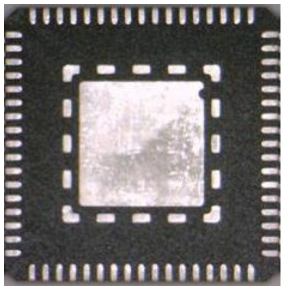


Figure 1. QFN component used for voiding study

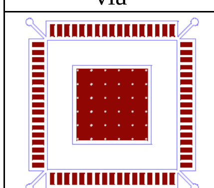
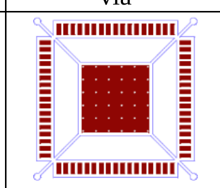
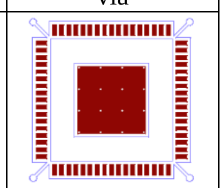
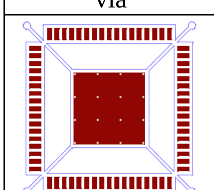
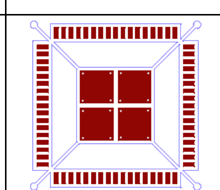
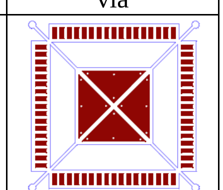
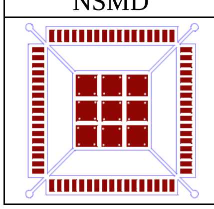
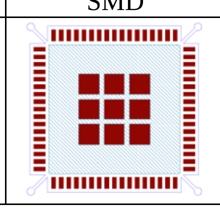
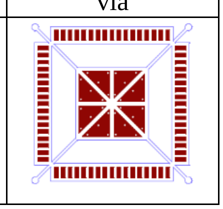
The primary focus for voiding control is the thermal pad design on a FR-4 test board, including (1) a venting channel through the solder mask at the peripheral of the thermal pad; (2) the number of thermal via on the thermal pad; (3) a solder mask versus a venting channel when dividing the thermal pad; and (4) the number and shape of divided thermal pads. Impact of the solder paste volume is controlled by regulating the stencil aperture size. The effect of a soldering profile and heat history is also examined. All parameters involved are shown in Table 1.

Table 1. Parameters used in voiding study

Parameter	Sub parameter	Layers
Thermal Pad on PCB	Microvia number	0, 16, 32, 36
	Peripheral venting for full thermal pad	With and without
	Dividing method	Solder mask, venting channel
	Thermal subpad shape	Square, triangle
	Thermal subpad number	1, 4, 8, 9
Stencil	Aperture	85%, 100%
Heat History	Reflow profile	Short, long cool, long, long hot
	Other heat treatment	Prebake, 1 reflow, 2 reflow

Table 2 shows the design of various thermal pads on a test board. The dimension of a full thermal pad is identical to that of the QFN. The surface finish for all pads, depicted in red, on the test board is immersion silver. Figure 2 shows the layout of the test board.

Table 2. Design of thermal pads on test board.

Full, no vent, 36 via	Full, vented, 36 via	Full, no vent, 16 via
		
Full, vented, 16 via	Square 4, 16 via	Triangle 4, 16 via
		
Square 9, 36 via, NSMD	Square 9, 36 via, SMD	Triangle 8, 32 via
		

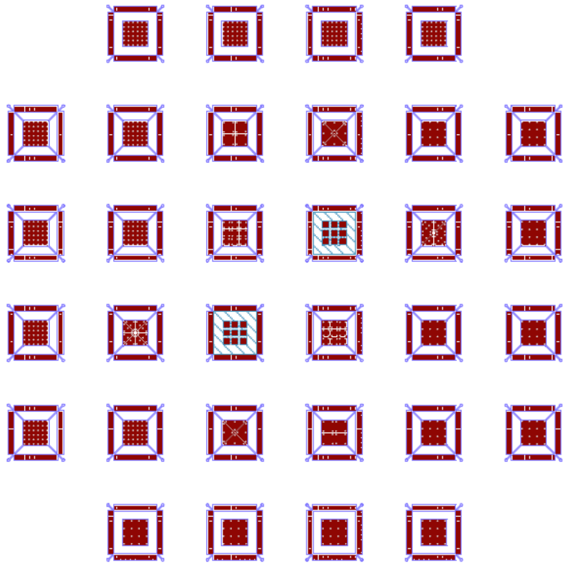


Figure 2. Layout of test board

EXPERIMENTAL PROCEDURE

A no-clean solder paste with 88.5% SAC305 with type 4 metal load was used for assembly of the QFN. For the test, the solder paste was printed through a stencil with 125 micron thickness onto the test board. The aperture design is 1:1, unless otherwise specified. The QFN components were then placed and sent through a BTU oven with air atmosphere. Four reflow profiles were used: short, long cool, long, and long hot, as shown in Figure 3.

To simulate the soldering conditions of a double-sided board, the voiding performance of the following two conditions were also checked. In one instance, the board was prebaked by sending the board through an oven prior to printing the solder paste. In another, the printed board was reflowed twice.

VOIDING ASSESSMENT

The voiding performance was determined with X-ray, as shown in Figure 4 for designs with a 0.22mm wide channel and reflowed with a long hot profile, and in Figure 5 for designs with a 0.33mm wide channel and reflowed using a long cool profile. The drastic difference in voiding behavior between the two sets demonstrates the tremendous impact of design and process conditions. Three properties are determined, as defined in Table 3. For some solder joints, cross-sectioning was also conducted in order to elucidate the characteristics of voiding.

RESULTS

1. Individual Data Set

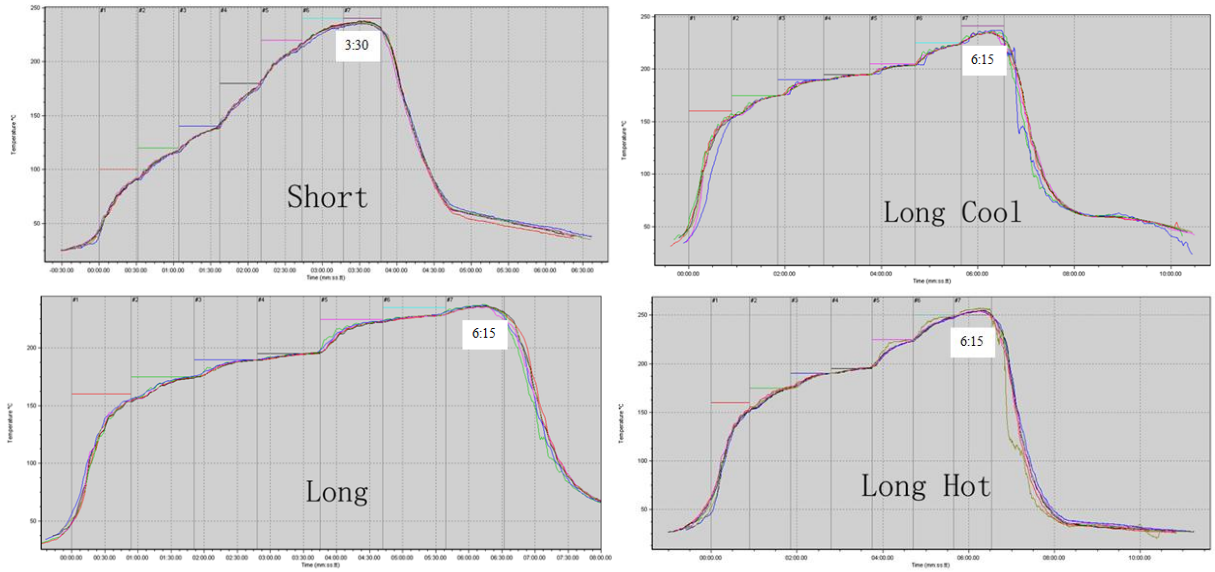


Figure 3. Reflow profiles used in the voiding study: short, long cool, long, and long hot.

The individual data set for each of the test conditions are shown in Figure 6. A couple trends can be noticed quickly. Dividing the thermal pads into sub-units results in an abrupt drop in the largest void. In the meantime, the presence of a channel area also results in an increase in discontinuity, as reflected by the raised height of the average void plus the channel area. Apparently, the immediate effect of dividing the thermal pad is a reduction in the uncontrollable, harmful large voids, replacing it with a controlled, even distribution of discontinuity. The discontinuity of the latter may be equal or higher than the former.

2. Effect of the Number of Thermal Via

Via is a direct contributor to voiding, mainly due to the presence of a dead corner where the entrapped flux cannot escape at the solder coalescence stage [5, 6]. This can be easily noticed in Figures 4 and 5 where the propensity of voids at the via locations is particularly high for full pad solder joints. Accordingly, the voiding extent will be expected to increase with an increasing number of thermal via. This is exactly what was observed in this study when reflowed using a long hot profile, as shown in Figure 7. When the thermal via number is high, the discontinuity of a full pad becomes comparable with that of a divided pad, and the sporadic occurrence of large voids becomes a distinct disadvantage of the full pad design, as evidenced in Figure 6.

Since a high number of thermal via is desired for efficient heat dissipation, the best option will be to plug the via with a solderable material, such as plated copper.

The number of thermal via bears no relation with voiding for divided pads, as evidenced in Figures 4 and 5. This is attributed to the peripheral location of thermal via for those divided pads. Although flux may still get entrapped in those vias, outgassing does not form voids easily due to the easy escape of volatiles [7].

If plugging the thermal via is not an option, based on the benign impact of peripheral via for divided pads, it is advisable to design the thermal via on a full pad at peripheral locations whenever possible.

Table 3. Definition of three voiding properties.

Property	Definition
Discontinuity	Percentage of area under the QFN thermal pad where the vertical metal continuity from QFN to PCB surface is interrupted
Void Average	Average of multiple QFNs for void area percentage within the metallic pad of QFN
Largest Void	The largest void measured for a category of QFN joints

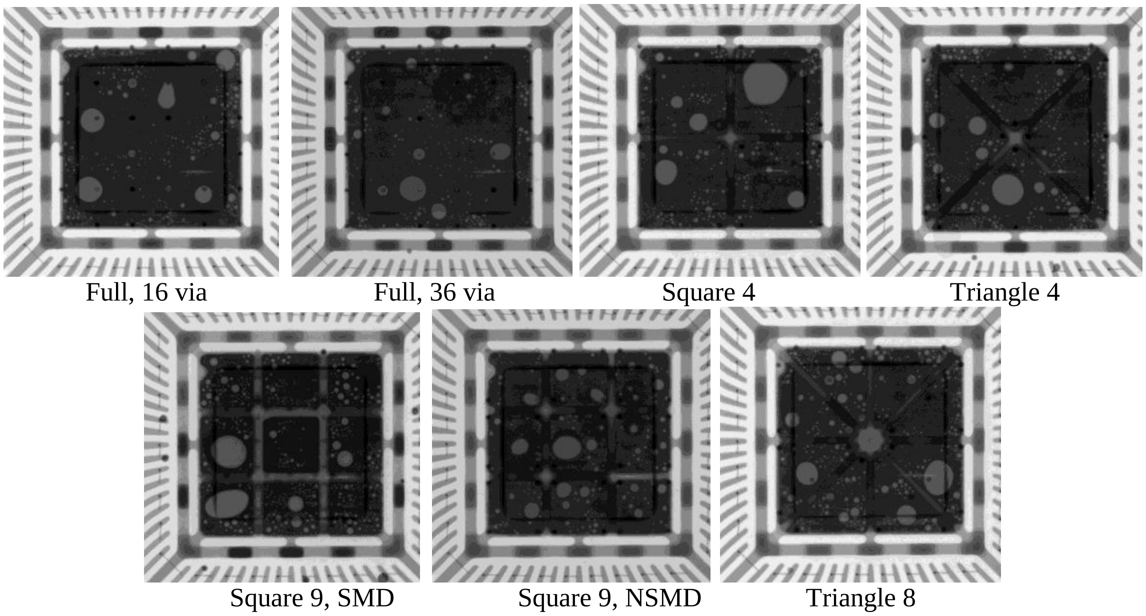


Figure 4. X-ray images of QFN solder joints for designs with 0.22mm wide channel reflowed with a long hot profile.

3. Effect of Peripheral Venting

The peripheral venting channel on a solder mask around the full pad was designed to facilitate outgassing, since

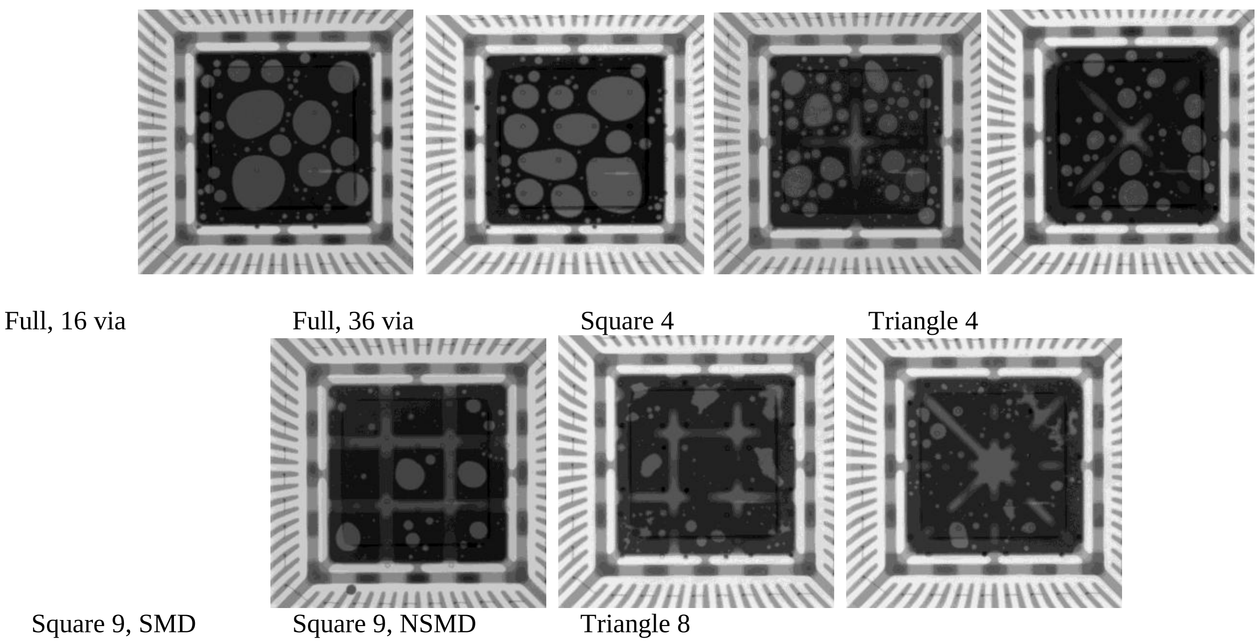


Figure 5. X-ray images of QFN solder joints for designs with a 0.33mm wide channel reflowed with a long cool profile.

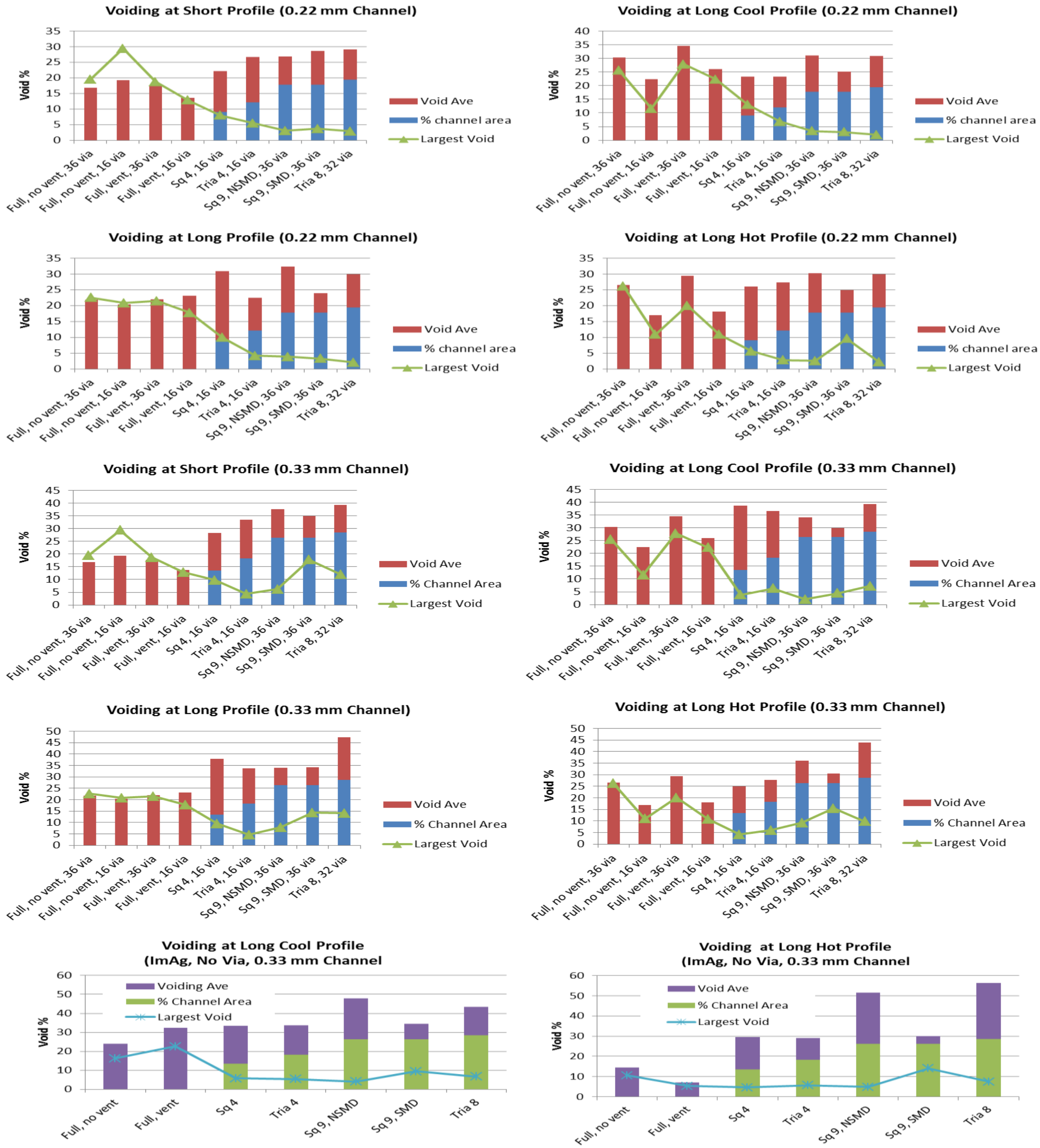


Figure 6. Individual voiding data set for designs.

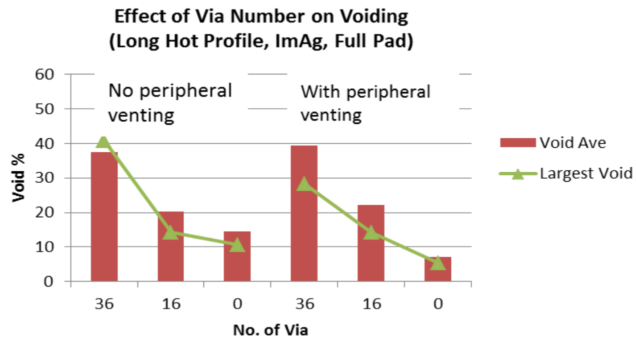


Figure 7. Effect of the number of vias on voiding when using long hot reflow profile.

The bottom of the QFN is nearly sitting on the top of board surface. Figure 8 shows that peripheral venting does reduce the size of the largest void on full pads. The effect appears to be moderate. When examing the void average, the effect of peripheral venting appears to be insignificant. Presumably, the additional venting capability due to a peripheral venting channel is negligible when compared with the clearance between the QFN and the board surface.

4. Effect of Venting Channel Width

When examining Figure 4, solder bridges across the venting channel was observed for a 0.22mm wide channel. It is unclear whether these solder bridges will obstruct the outgassing significantly, thus affecting the voiding extent. Figure 9 compares the average voiding behavior of all profiles for venting channels with 0.22mm and 0.33mm widths. An increase in channel width has no effect on the voiding average, but does cause a net increase in the channel area, and consequently an increase in discontinuity.

5. Effect of Venting Accessability

Theoretically, the closer the outgassing is to an open space or a venting channel, the less chance for a void to be developed. This venting accessability can be defined as perimeter length per unit area of metal pad. Table 4 shows the calculated venting accessability of various thermal pad designs.

With increasing venting accessability, the void average and largest void decrease readily, especially for the long cool profile, as shown in Figures 10 and 11, respectively. However, the advantage of voiding reduction is offset by the increase in discontinuity, particularly for the short profile, as shown in Figure 12. For a long cool profile, the discontinuity increases only moderately with increasing venting accessability. In other words, when the voiding is a major threat, such as designs with a high number of thermal vias, or when a short profile is not a viable option, then a venting channel design becomes a favorable choice. Although some data scattering still exists, the venting accessability concept allows engineers to design thermal pads with a minimal need of empirical run.

6. Solder Mask Defined versus Non-Solder Mask Defined

Solder does not wet onto either the solder mask or FR-4 between thermal pads. Wherever there is no solder, there is opportunity for venting. Based on the venting accessability discussed in the previous session, a thermal pad divided by either a solder mask or a venting channel on FR-4 are expected to have similar effects on voiding. However, when comparing Square 9 (SMD) with Square 9 (NSMD) designs, the void average of the NSMD (venting channel design) is quite a bit higher than the SMD design, as shown in Figures 6 and 13.

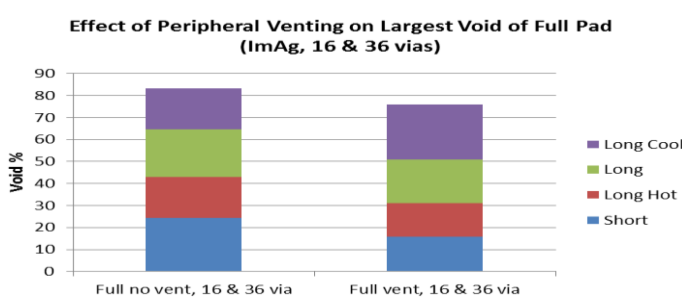


Figure 8. Relation between peripheral venting and the largest void for full pads.

Table 4. Calculated venting accessibility of thermal pad designs

Thermal pad design	Venting accessibility
Full pad	4
Square 4	8
Triangle 4	9.66
Square 9	12
Triangle 8	13.66

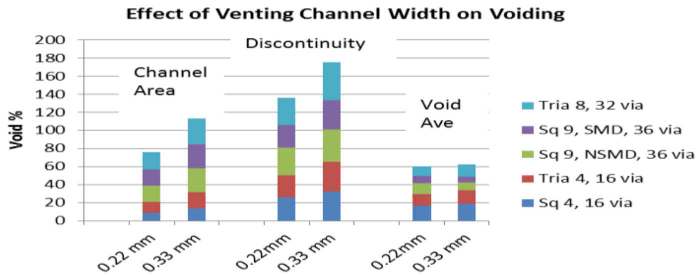


Figure 9. Effect of the venting channel width on average voiding behavior of all profiles

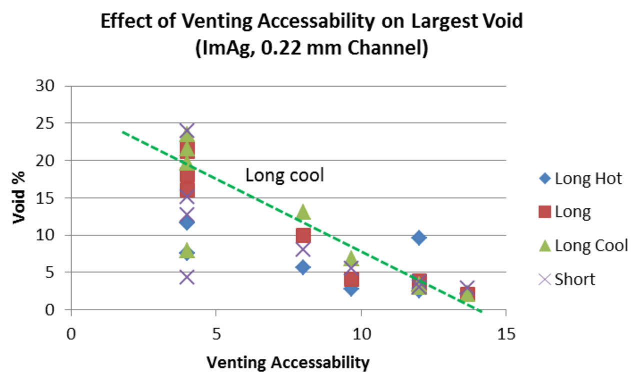


Figure 10. Effect of venting accessibility on void average

The unexpectedly high void average performance of the NSMD system can be attributed partly to its thinner solder joint, as shown in Figure 14. The solder joint thickness is 63µ and 79µ for the NSMD and SMD systems, respectively. A thinner solder joint would have a greater difficulty for the void to escape [1,8]. The thicker solder joint for an SMD system is attributable to the higher solder paste volume deposited due to the presence of a solder mask at printing. The thickness of the solder mask measured is about 21µ. However, this thickness factor is considered, at best, a secondary factor.

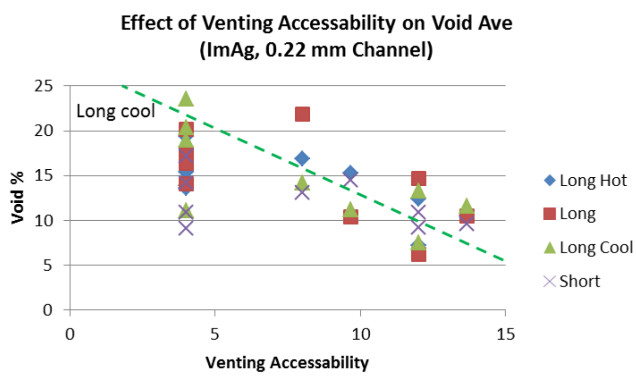


Figure 11. Effect of venting accessibility on largest void

thicker solder joint for an SMD system is attributable to the higher solder paste volume deposited due to the presence of a solder mask at printing. The thickness of the solder mask measured is about 21μ. However, this thickness factor is considered, at best, a secondary factor.

Another factor, which could be the primary factor contributing to the high voiding of a NSMD system, is the outgassing of FR-4 during reflow. With the venting channel frequently blocked by the solder bridges, volatiles from FR-4 can not be vented readily and, consequently, result in more voiding under the QFN. In the event of an SMD system, the solder joint is totally separated from the FR-4 and, thus, is not affected by any FR-4 outgassing.

Use of an SMD system may have a higher value in the largest void than a NSMD system, when comparing Square 9 (SMD) and Square 9 (NSMD) in Figure 6. This may be caused by the blocked venting path due to the presence of solder mask in both well sealed channel and partially open channel, as shown in left top and left bottom pictures in Figure 15, respectively. For a NSMD system, the venting channel often is more open in most cases, as shown in right bottom picture, although a nearly complete seal may also occur, as shown in right top picture in Figure 15.

Overall, the SMD system appears to be a better design than the NSMD system, in terms of reducing voiding.

7. Solder Paste Volume Effect

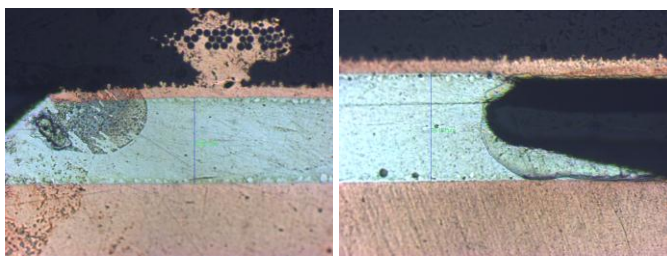


Figure 14. Comparison of the solder layer thickness for NSMD (venting channel) and SMD systems.

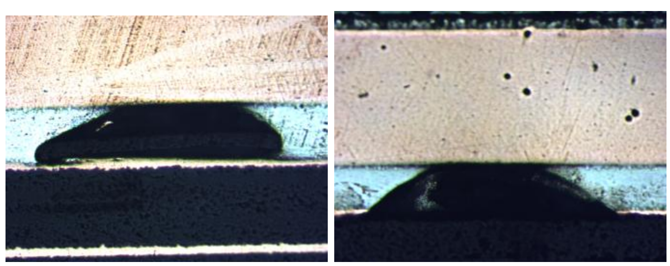


Figure 15. Cross-section of a venting channel of an SMD system (left) and a NSMD system (right).

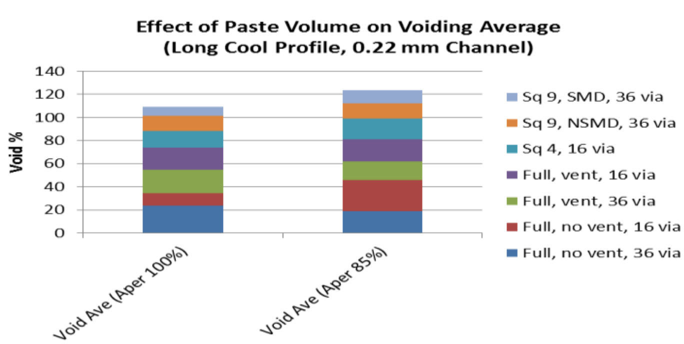


Figure 16. Effect of solder paste volume on void average.

The effect of solder paste volume is controlled by the stencil aperture size. An aperture dimension of 1:1 is compared with an 85% opening, as shown in Figire 16. A moderately adverse effect of a smaller aperture opening is observed. Presumably, this can also be attributed to the thinner solder joints caused by a reduced solder paste volume, as discussed in the previous session.

8. Effect of Reflow Profile

The effect of a reflow profile on voiding is shown in Figures 17, 18, and 19. Overall, both short and long hot profiles rendered lower voiding than the other profiles in between. The short profile is preferred for a low void average, while the long hot profile is better for reducing the largest void.

The favorable voiding behavior of short and long hot profiles can be explained by the outgassing diagram shown in Figure 20. In general, all fluxes outgas upon heating. The outgassing increases with increasing heat input, whether it is due to an increase in temperature or time. Eventually, the volatiles get depleted, and the outgassing decreases with a further increase in heat input. For fluxes, the solvents usually vaporize during an early heating stage, followed by the volatile solids getting vaporized at a higher temperature.

Voiding in solder joints occur when volatiles are generated from the interior of a solder joint when the solder is at molten state. In order to minimize the outgassing at soldering temperatures, the outgassing rate should be minimized at temperatures above liquidus. This can be accomplished through two approaches. First, heat the flux quickly to a temperature slightly above the melting tempearture, then cool down rapidly before the volatile solids get a chance to vaporize. This corresponds to zone 1 on the diagram and can be exemplified by the upper profile on the right. Second, bring the flux to a temperature right below the melting temperature of solder, hold at that temperature until most of the volatiles are gone, then bring the flux to slightly above the melting temperature, followed by rapid cooling. This corresponds to zone 2, and can be exemplified by the lower profile on the right.

In this work, the short profile reflects the zone 1 approach, while the long hot profile reflects the zone 2 approach. Long cool and long profiles may reflect the rapid outgassing region between zones 1 and 2, thus render more voiding than both short and long hot profiles.

9. Effect of Prebake

Prebaking is conducted by sending the bare test boards through the reflow oven set at a short profile. The boards are then printed with solder paste, followed by QFN placement and reflow, again using the short profile. Figure 21 shows that the prebaked boards exhibit a higher void average than the fresh boards. This increase in voiding caused by the pad oxidation at prebaking indicates that, similar to voiding phenomena associated with other SMT component assemblies, a surface finish robust against oxidation will be beneficial when attempting to control voiding of QFN for a doublesided board.

10. Effect of Double Reflow

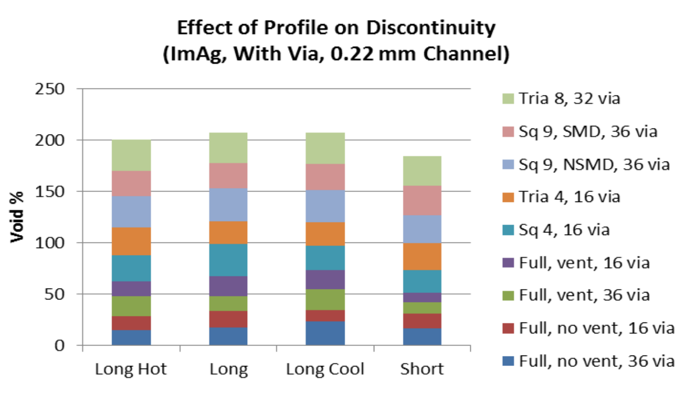


Figure 17. Effect of profile on discontinuity.

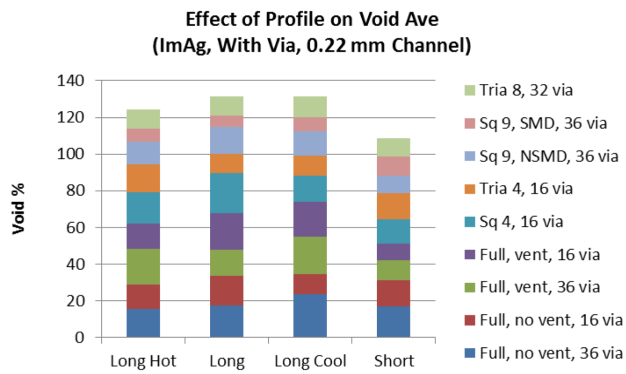


Figure 18. Effect of profile on void average.

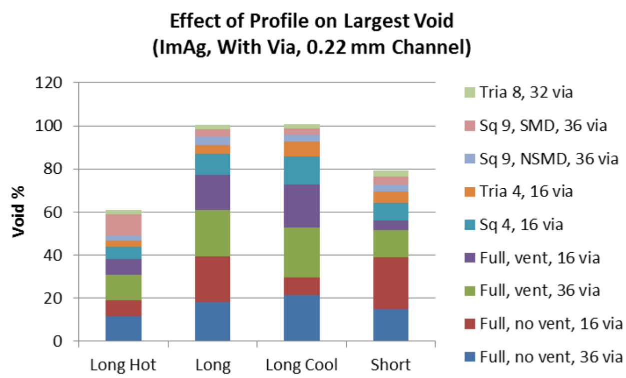


Figure 19. Effect of profile on largest void.

A double reflow results in a higher void average, as shown in Figure 22. Apparently, this is attributable to the the additional outgassing at the second reflow and is fairly similar to voiding behavior experienced with typical SMT assembly processes.

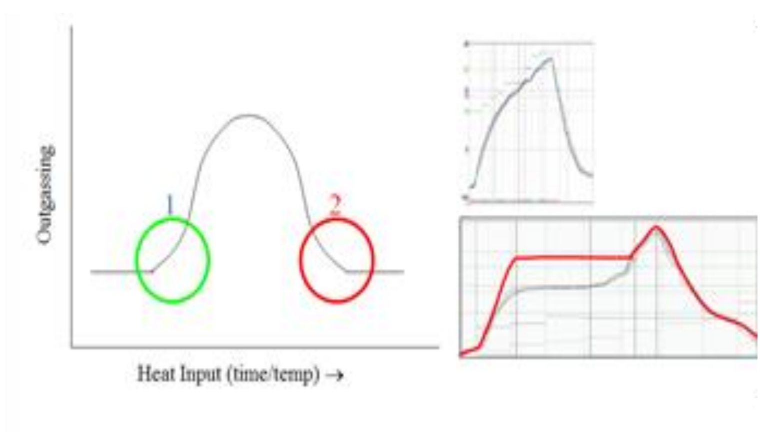


Figure 20. Relation between heat input and outgassing.

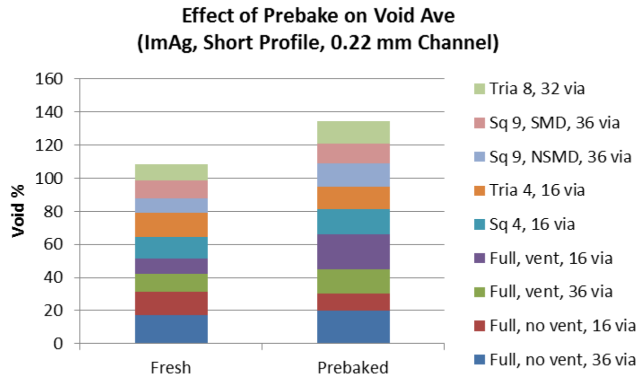


Figure 21. Effect of prebake on void average.

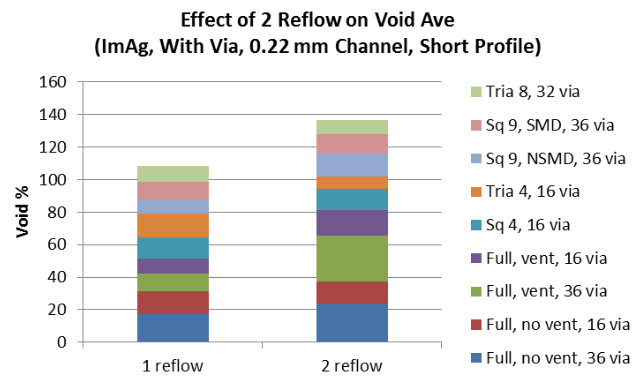


Figure 22. Effect of double reflow on void average.

DISCUSSION

1. Prospect of Thermal Via

The heat removal efficiency from the QFN increases with an increasing number of thermal via on the thermal pad. For drilled thermal via, the via diameter is typically 0.3 – 0.33mm [9-17], with pitch 1-1.2mm [9-15,17], as the return on heat-dissipation efficiency diminishes at pitches smaller than 1mm [11,12]. However, for advanced QFNs to be assembled on thin PCBs, the mechanical thermal via is replaced with microvia, and the via pitch reduces below 1mm. This suggests that the thermal via density may become higher with further miniaturization. The bad news is that unplugged thermal via contributes to voiding and the industry is reluctant to plug the via due to additional costs.

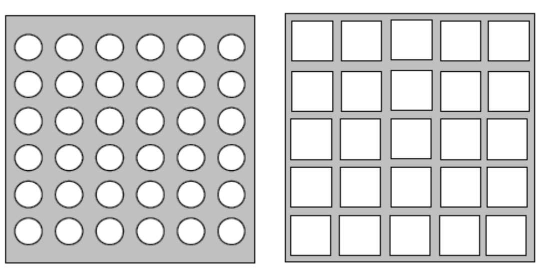


Figure 23. Solder paste print pattern on thermal pad for voiding control

2. How Much Voiding Is Too Much?

Although voids are not desired at the thermal pad, void content up to 50% [9,15] or even 60% [13] of the pad area can still be acceptable on thermal behavior - but, there is a catch. The void size should not be bigger than the via pitch. Otherwise, some thermal via covered by the void will be rendered invalid, thus compromising the thermal performance [9].

3. What Is Less Evil?

Obviously neither high void content nor large voids are desired. In between is the grey area and it is not always easy to judge which situation is worse. A "hot" spot may cause early failure, while a system with more voids, but finely dispersed, may be thermally acceptable.

4. Patterned Solder Paste

The most common approach to controlling voiding is to break down the solder paste deposit into multiple deposits, as exemplified by patterns shown in Figure 23.

Typical recommended stencil design for a thermal pad area is multiple openings with 50-80% coverage [9-14,17], and a spacing of 0.2mm [10,12] or 0.15-0.3mm [17].

5. Permanent Venting Channel Desired

Although the stencil design described above is better than a full print for a thermal pad area, voiding is still ailing the industry in practice, due to the closing up of the temporary paste spacing during reflow. Apparently, a permanent venting channel would be the desired solution. In this work, a divided thermal pad with SMD and NSMD designs were investigated.

6. Permanent Discontinuity?

Obviously, the down side of a permanent venting channel is a permanent discontinuity for a vertical heat conduction, regardless of whether it is caused by a solder mask or the lack of metal land. As mentioned earlier, the immediate effect of dividing the thermal pad is a reduction in the uncontrollable, harmful large voids, replacing it with a controlled, even distribution of discontinuity. This trade-off approach may be a good design, considering a voiding area up to 50% can still be thermally acceptable [9,15].

7. Venting or Being Vented?

In terms of allowing outgassing of fluxes, the divided metal pads should be a better design, since the venting channel is free from obstruction of the solder mask itself. However, the venting channel formed by removing part of the metal pad also allows possible venting of moisture from the FR-4. This may cause considerably more voids in the thermal pad area, thus defeat the original purpose of venting channel.

8. What's Next?

Since moisture outgassing of the board is probably inevitable, a venting channel formed with a thin, narrow solder mask may be the ultimate and better solution for a controlled, even distribution of minimal discontinuity. This design may be desired for a large thermal pad, even if the thermal via is plugged up.

9. Short vs Long Hot

Both short and long hot profiles are favorable for low voiding. Short profiles showed a lower void average, apparently due to the lack of volatile solids coming out. However, the window between drying out the solvent and volatile solids coming out may be fairly narrow and hard to catch; therefore, suffering a higher data scattering than that of long hot profile. This is evidenced in Figure 6, where "full, 16 via" designs may show a higher void average than "full, 36 via", and the largest void may occur at "full, 16 via" for a short profile. In the case of a long hot profile, "full, 36 via" designs consistently show a higher void average, as well as an increase in the largest void, than the "full, 16 via" design, as predicted from physics. This consistency is attributed to subsided outgassing near the zone 2 plateau in Figure 20. However, the price for this may be the exhaustion of solder paste flux activity, if the flux chemistry is not properly engineered. The narrow data scattering of a long hot profile also resulted in a decrease in the largest void, although it also showed a slightly higher void average than the short profile, as shown in Figures 19 and 18, respectively.

CONCLUSION

Thermal pad voiding control at the QFN assembly is a major challenge due to the large coverage area, large number of thermal via, and low standoff. Both design and process were studied for minimizing and controlling the voiding. Eliminating the thermal via by plugging is most effective in reducing the voiding. For unplugged via situations, a full thermal pad is desired for a low number of via. For a high number of thermal via, a divided thermal pad is preferred, due to better venting capability. Placement of thermal via at the perimeter prevents voiding caused by via. A wider venting channel has a negligible effect on voiding, and reduces joint continuity. For a divided thermal pad, a, SMD system is more favorable than a NSMD system, with the latter suffering more voiding due to a thinner solder joint and possibly board outgassing. Performance of a divided thermal pad is dictated by venting accessability, not by the shape. Voiding reduction increases with increasing venting accessability, although the introduction of a channel area compromises the continuity of the solder joint. Reduced solder paste volume causes more voiding. A short profile and a long hot profile are most promising in reducing the voiding. Voiding behavior of the QFN is similar to typical SMT voiding and increases with pad oxidation and further reflow [18].

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Pad Design and Process for Voiding Control at QFN Assembly

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Dr. Ning-Cheng Lee

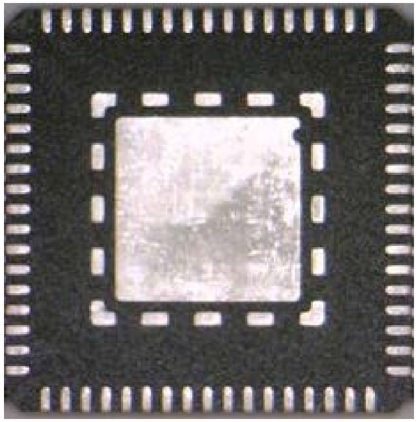
Indium Corporation

Background

- QFN prevailing due to (1) small size & light weight; (2) easy PCB trace routing due to the use of perimeter I/O pads; (3) reduced lead inductance; and (4) good thermal and electrical performance due to the adoption of exposed copper die-pad technology
- Voiding is issue at SMT assembly due to the large coverage area, large number of thermal via, and low standoff
- Both design and process were studied for minimizing and controlling the voiding

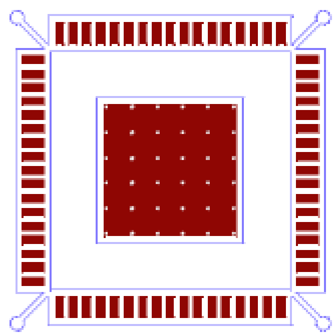
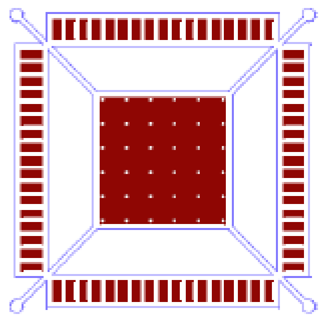
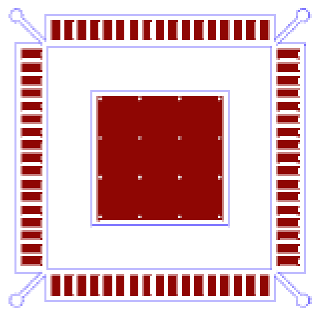
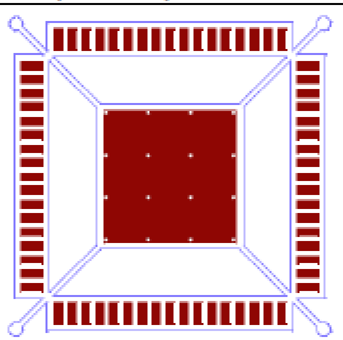
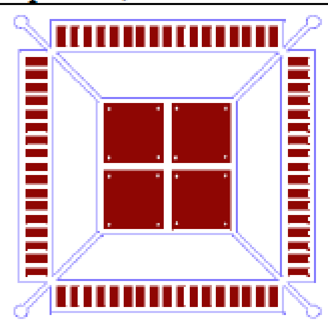
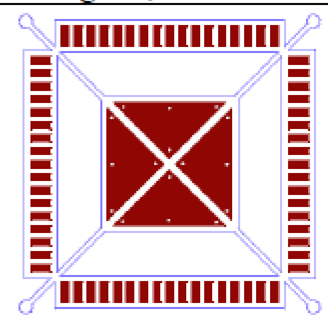
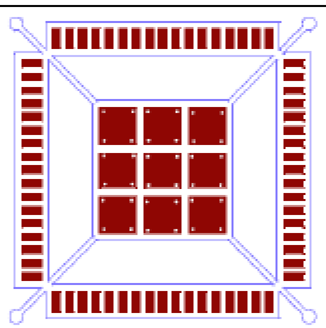
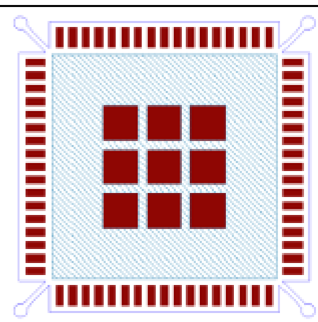
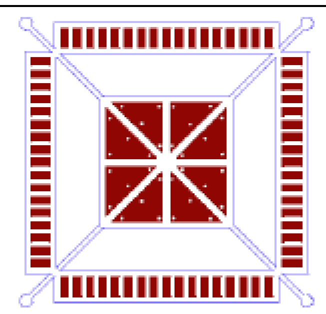
Parameters Studied

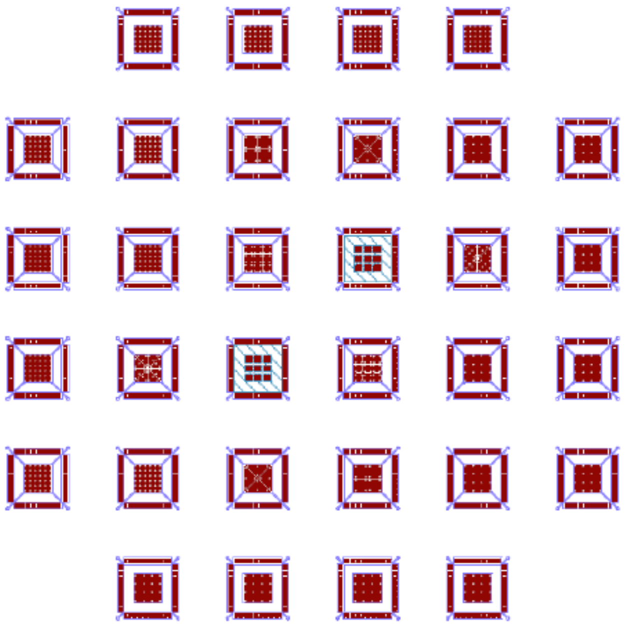
QFN with 68 pads, 10mm x 10mm, 0.5mm pitch, daisy-chained, Sn surface finish



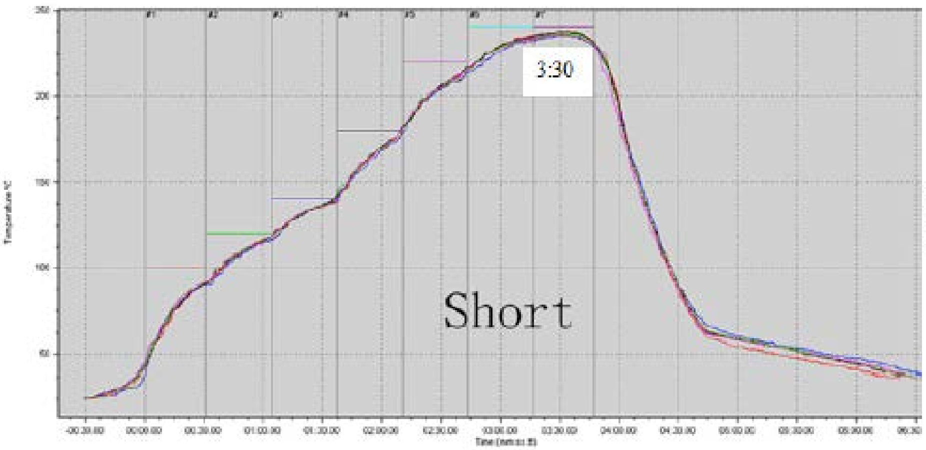
Parameter	Sub parameter	Layers
Thermal Pad on PCB	Thermal via number	0, 16, 32, 36
	Peripheral venting for full thermal pad	With and without
	Dividing method	Solder mask, venting channel (0.22 & 0.33 mm)
	Thermal sub-pad shape	Square, triangle
	Thermal sub-pad number	1, 4, 8, 9
Stencil	Aperture	85%, 100%
Heat History	Reflow profile	Short, long cool, long, long hot
	Other heat treatment	Prebake, 1 reflow, 2 reflow

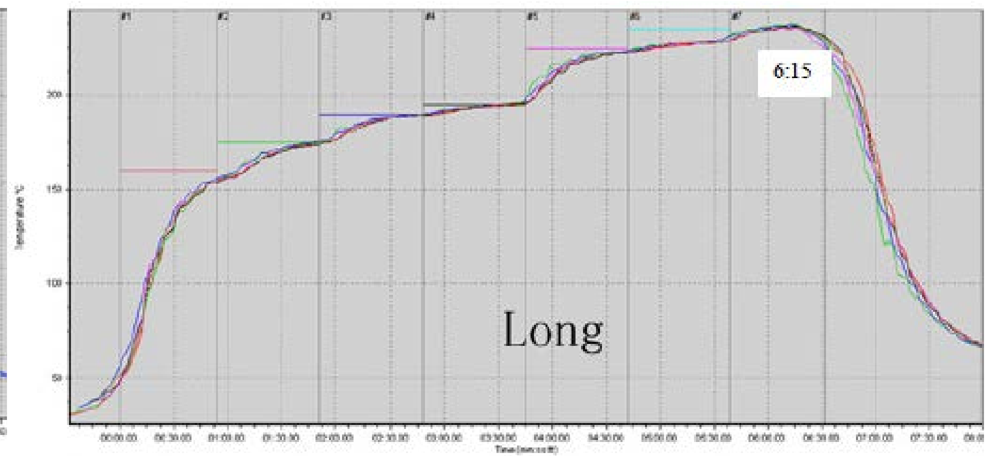
Design of Thermal Pads on Test Board

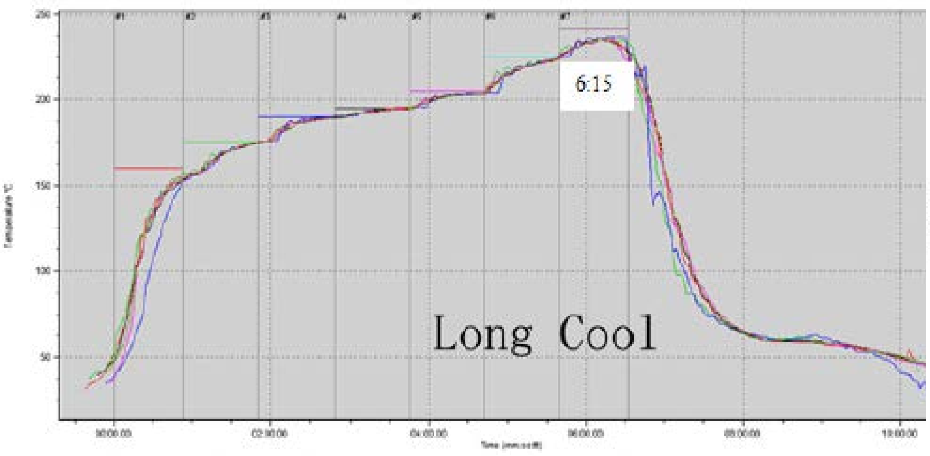
Full, no vent, 36 via	Full, vented, 36 via	Full, no vent, 16 via
		
Full, vented, 16 via	Square 4, 16 via	Triangle 4, 16 via
		
Square 9, 36 via, NSMD	Square 9, 36 via, SMD	Triangle 8, 32 via
		

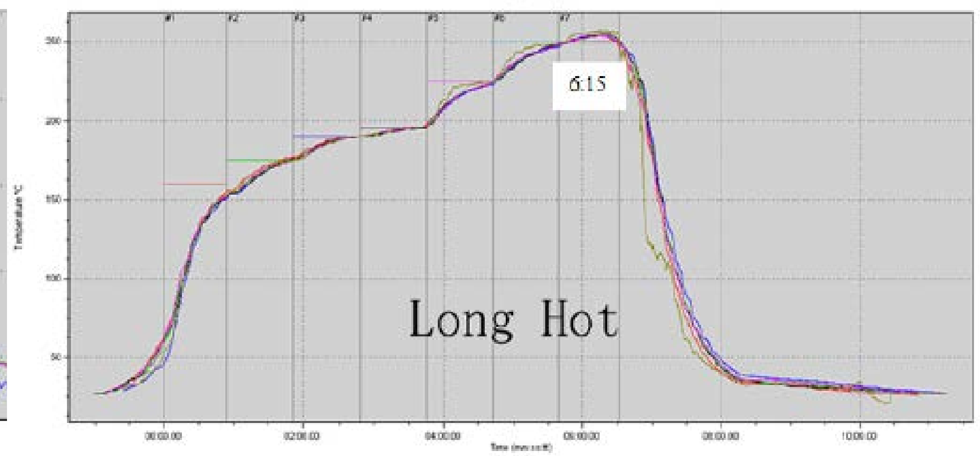


Reflow Profiles Used in Voiding Study









Voiding Examples

The drastic difference in voiding behavior between the two sets demonstrates the tremendous impact of design and process conditions

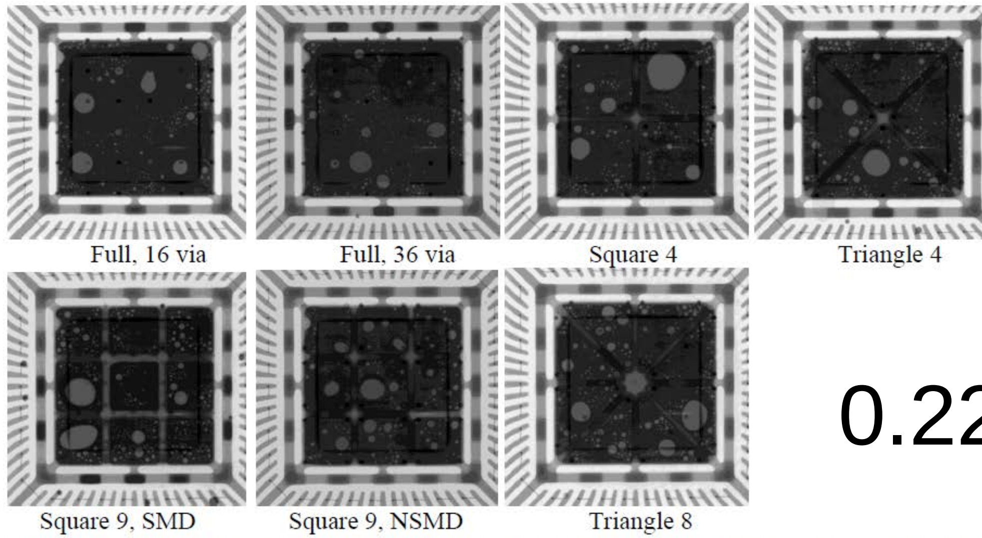


Figure 4. X-ray images of QFN solder joints for designs with 0.22mm wide channel reflowed with a long hot profile.

0.22 mm

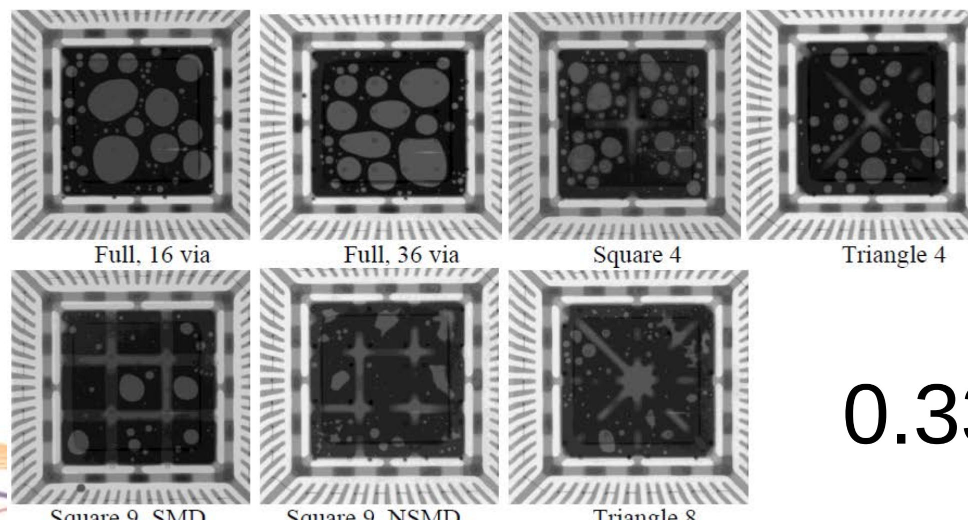


Figure 5. X-ray images of QFN solder joints for designs with a 0.33mm wide channel reflowed with a long cool profile.

0.33 mm

Definition of 3 Voiding Properties

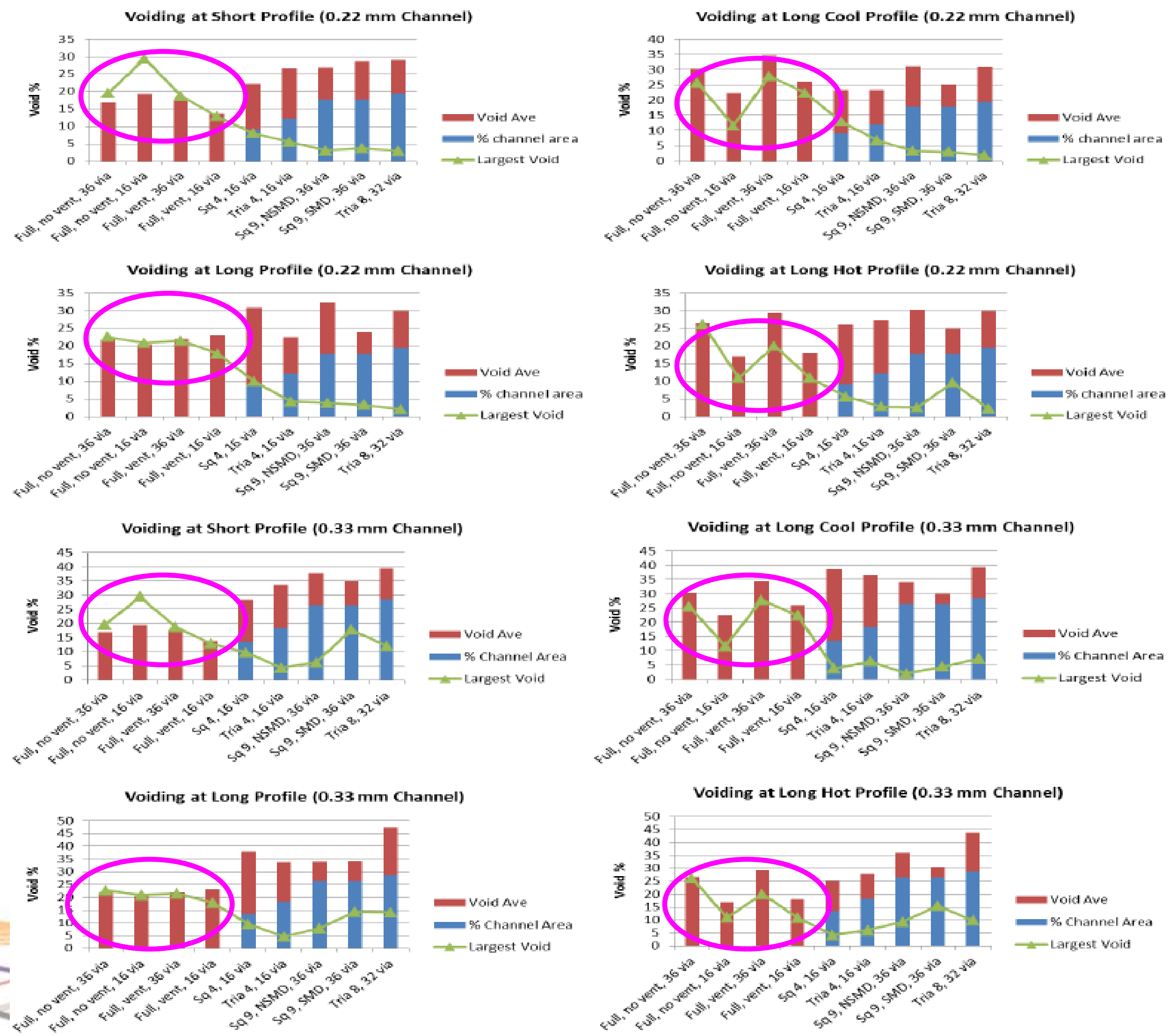
Property	Definition
Discontinuity	Percentage of area under the QFN thermal pad where the vertical metal continuity from QFN to PCB surface is interrupted
Void Average	Average of multiple QFNs for void area percentage within the metallic pad of QFN
Largest Void	The largest void measured for a category of QFN joints

Individual Voiding Data Set

Void Ave
% channel area
Largest Void

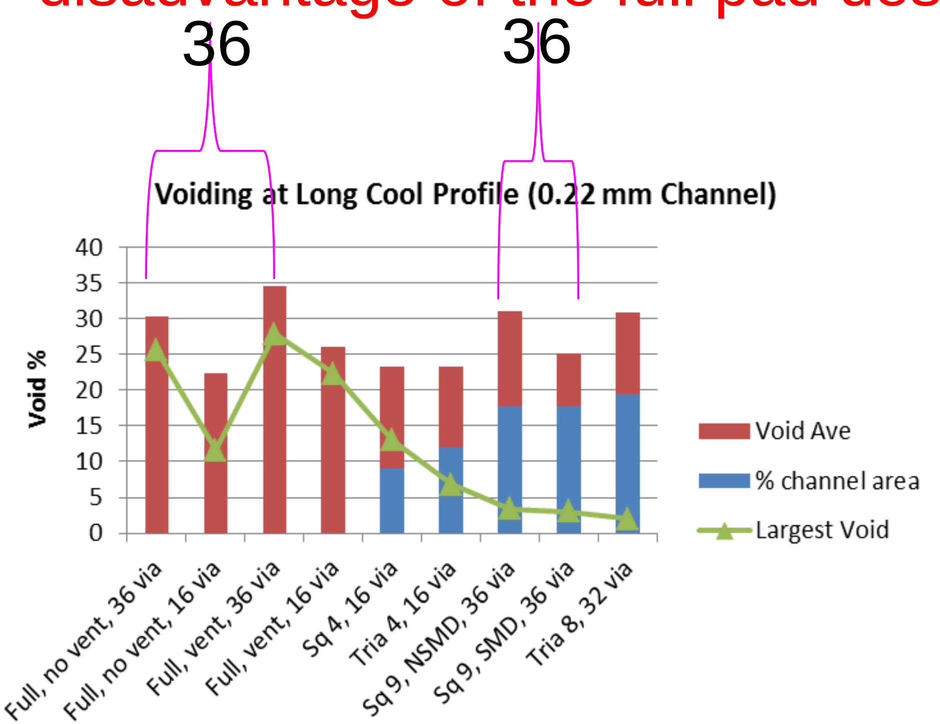
Dividing the thermal pads into sub-units results in an abrupt drop in the largest void but an increase in discontinuity

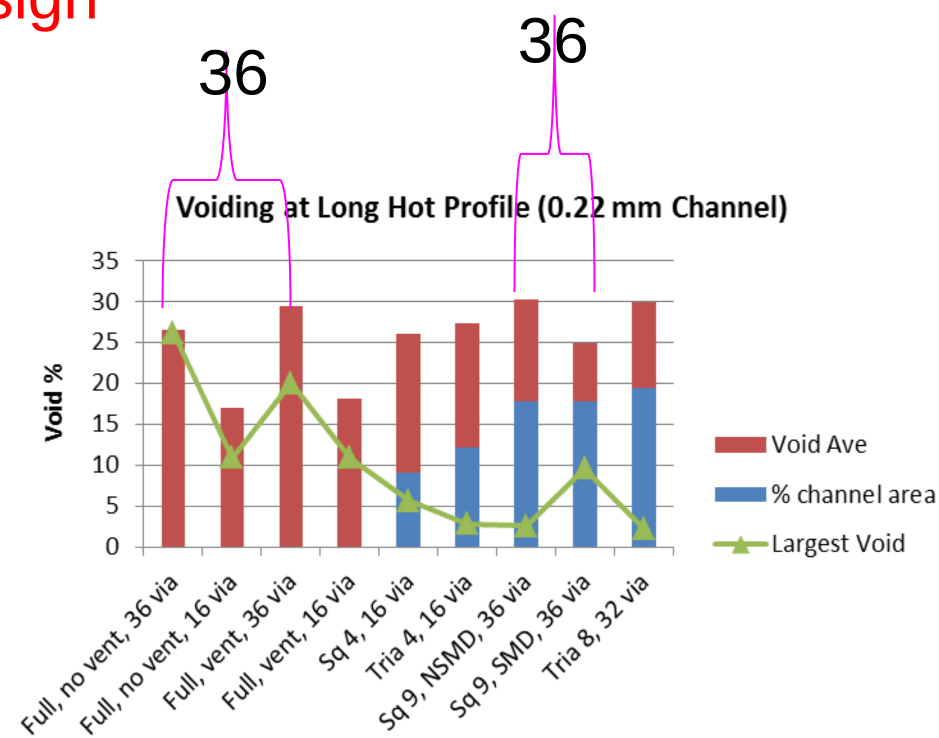
Net effect: a reduction in the uncontrollable, harmful large voids, replacing it with a controlled, even distribution of discontinuity



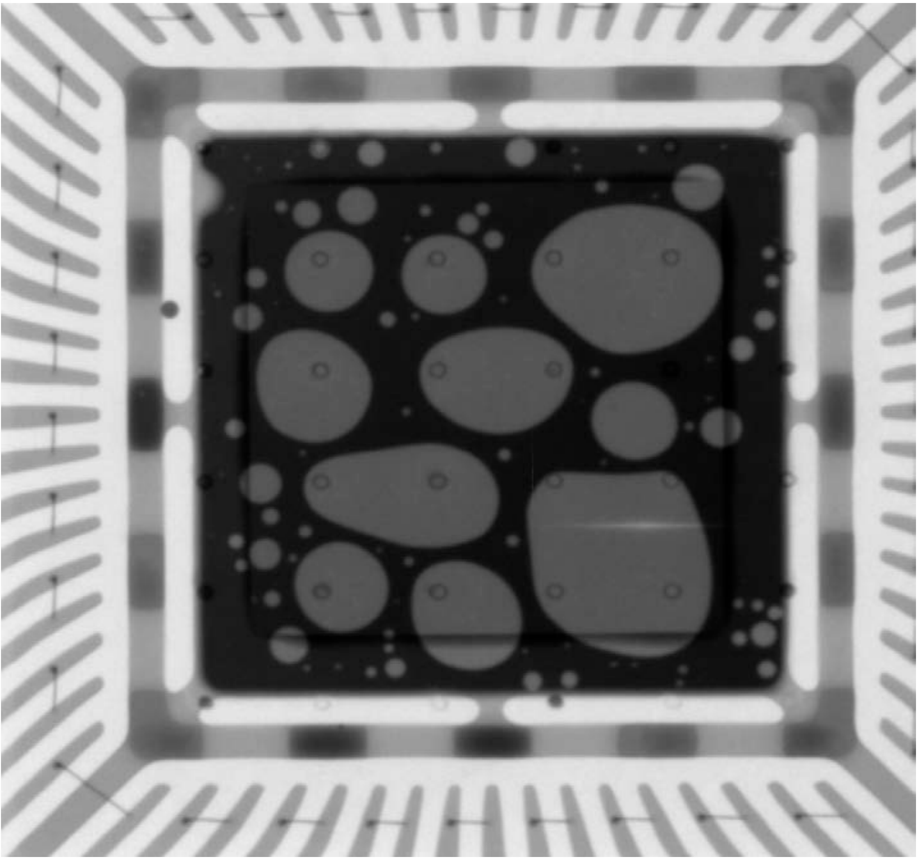
Dividing Desired for High Via No.

When the thermal via number is high, the discontinuity of a full pad becomes comparable with that of a divided pad, and the sporadic occurrence of large voids becomes a distinct disadvantage of the full pad design

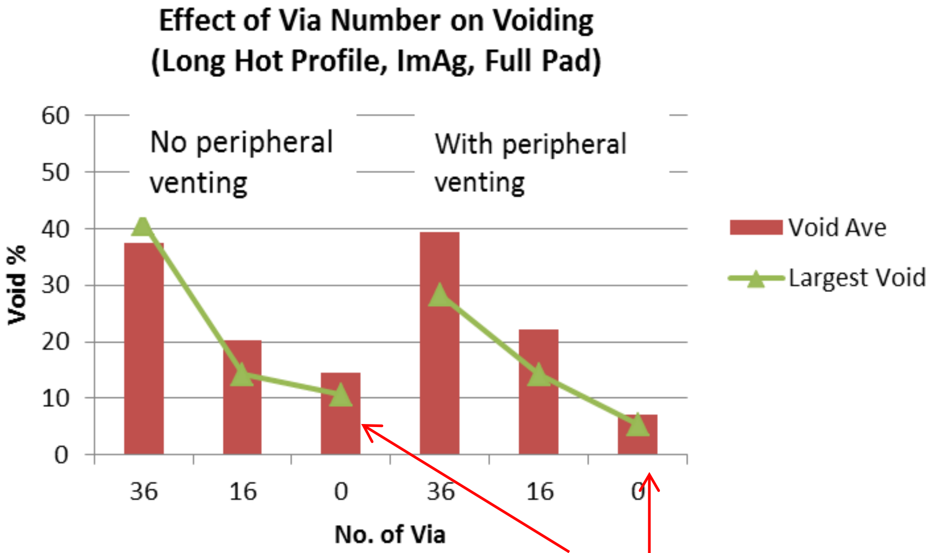




Thermal Via Aggravate Voiding

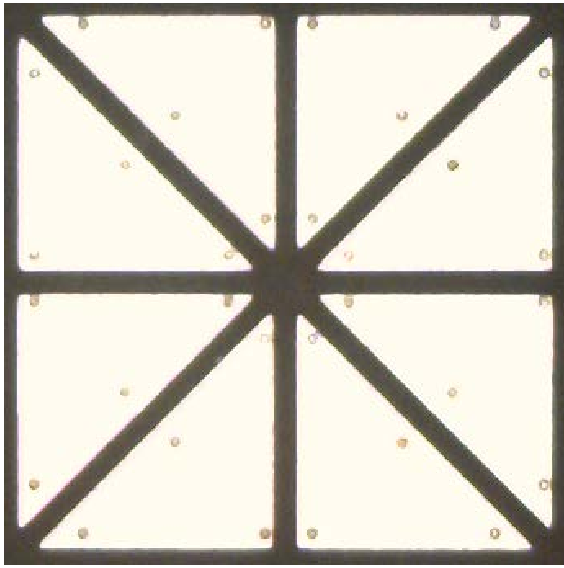


Propensity of voids at the via locations is particularly high for full pad solder joints

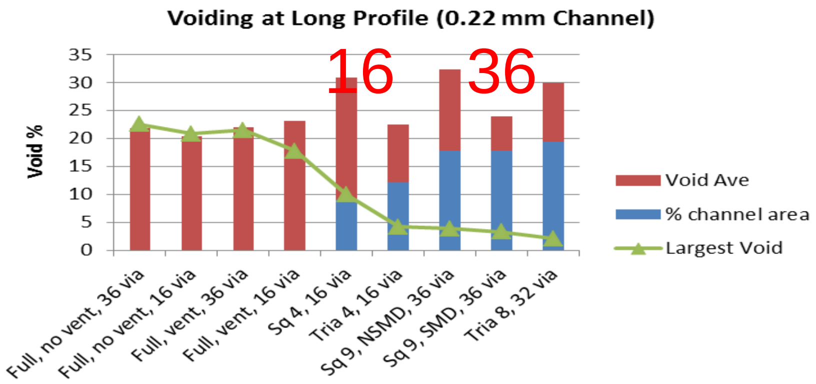


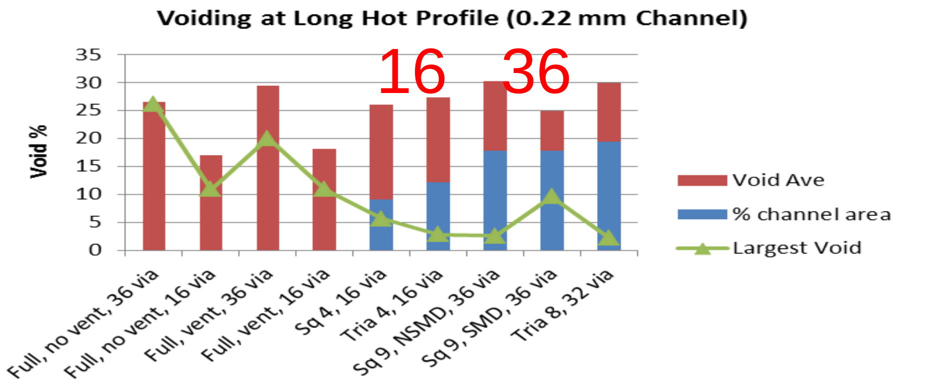
If high via no. is needed, plugging the via is the best option

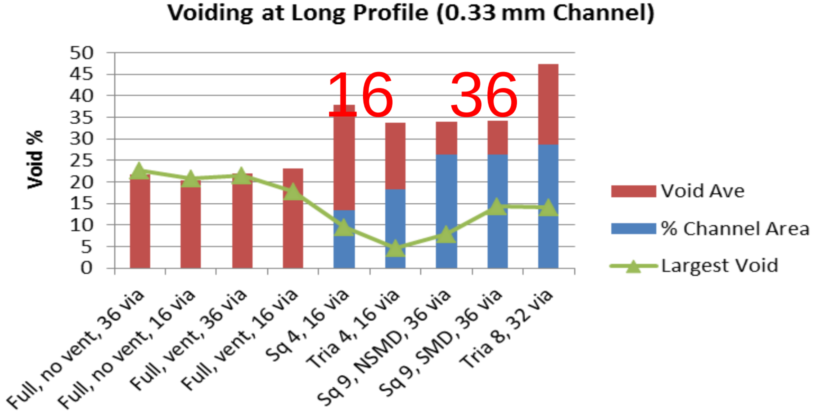
Divided Pads with Peripheral Via Not Sensitive to Via No. on Voiding

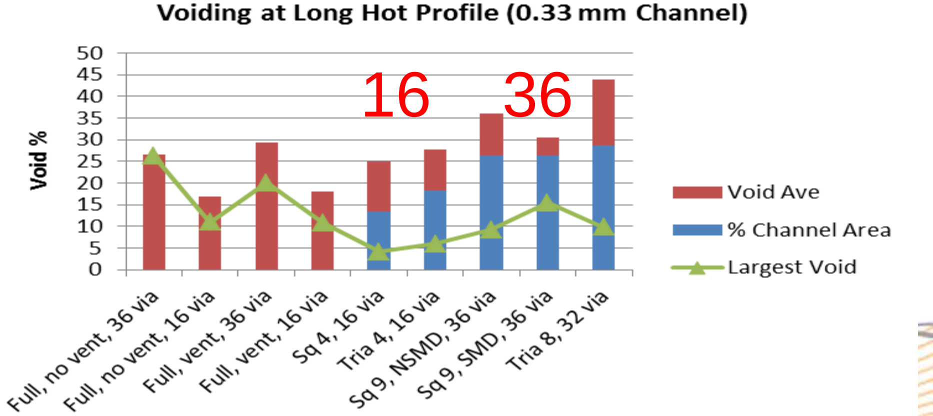


The number of thermal via bears no relation with voiding for divided pads. This is attributed to the peripheral location of thermal via for those divided pads. If plugging the thermal via is not an option, design the thermal via at peripheral locations whenever possible.

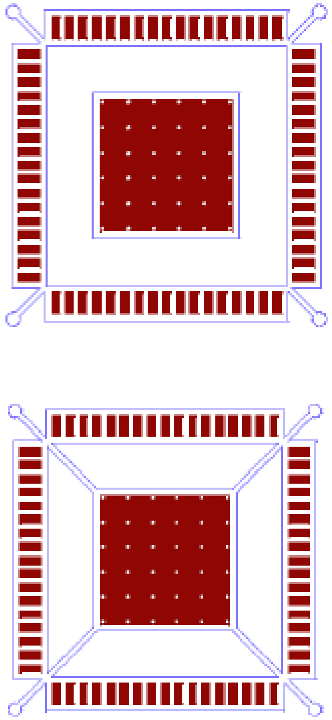


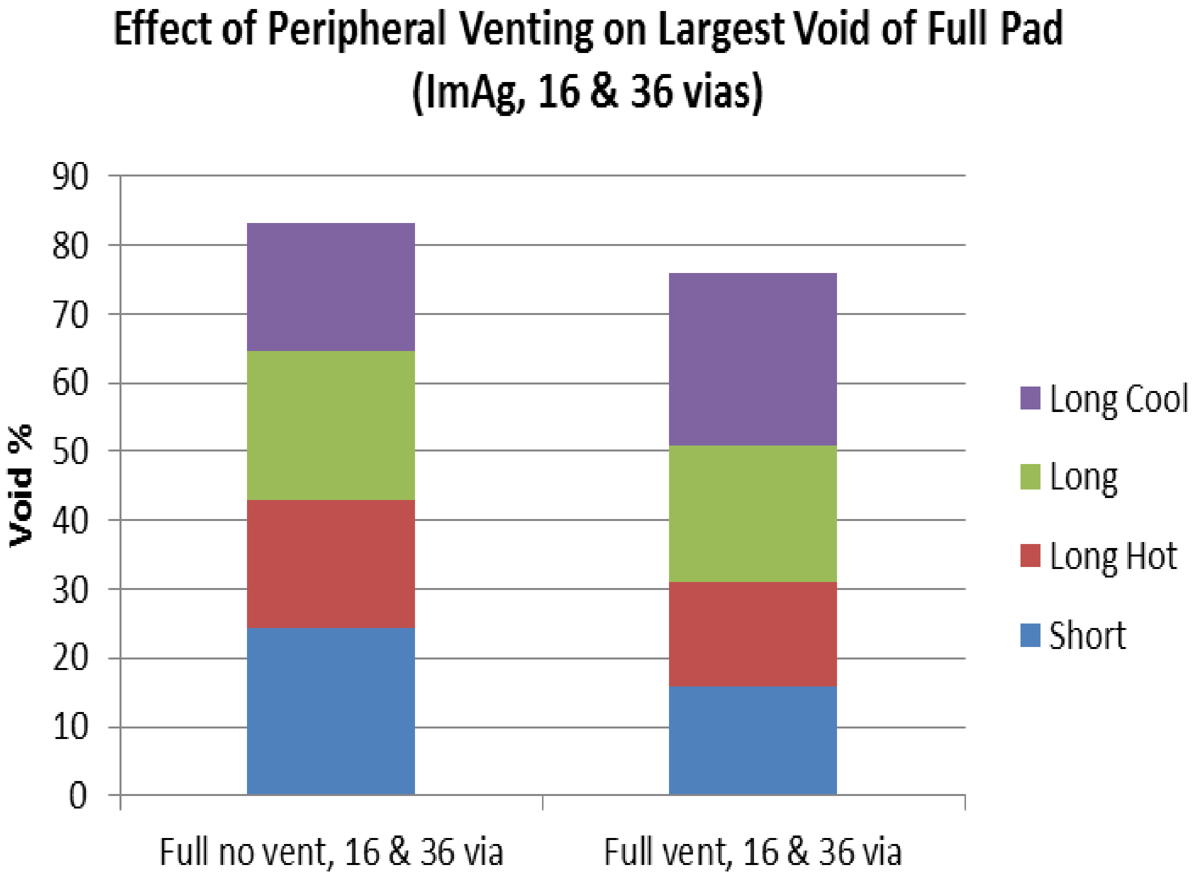




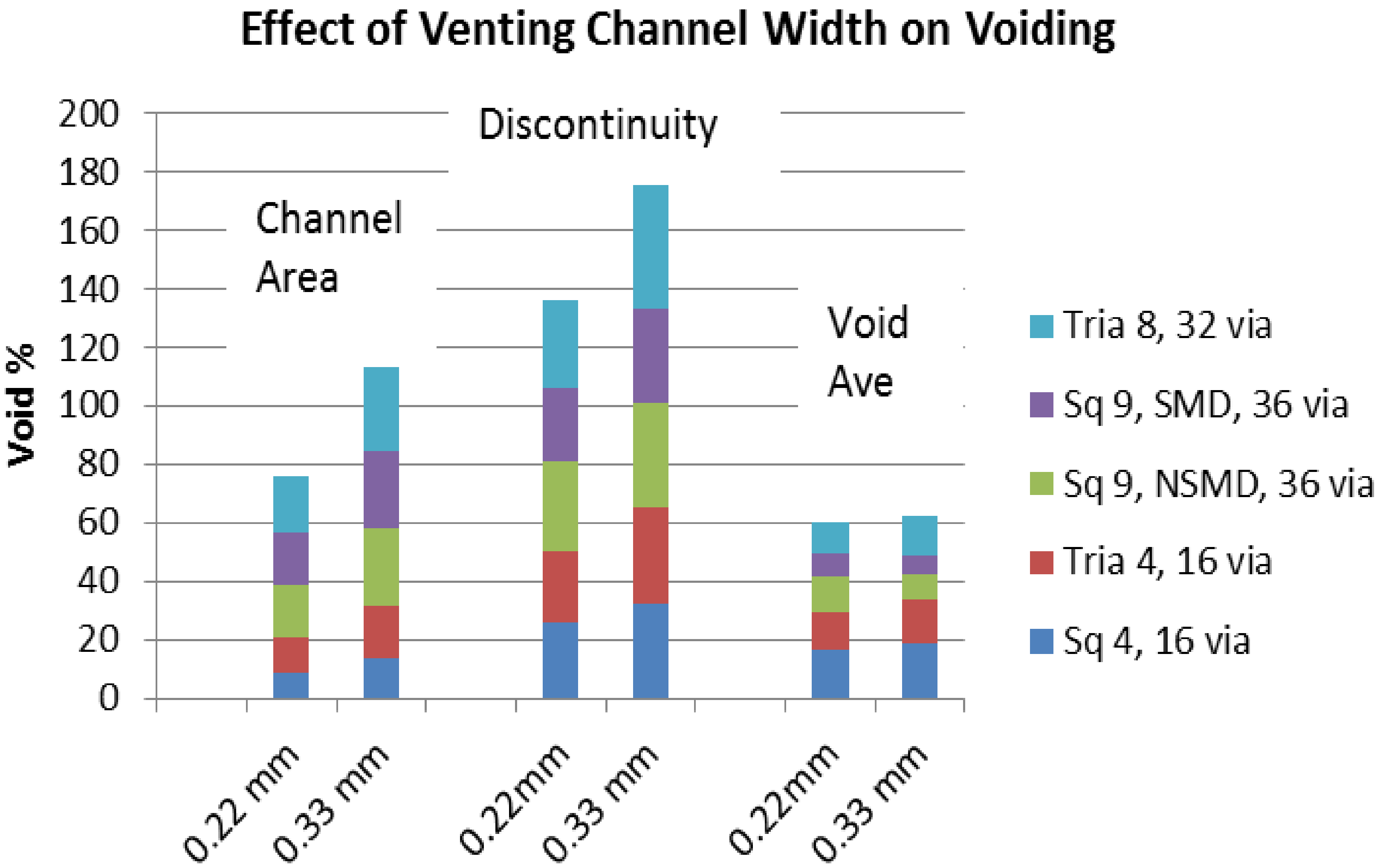


Peripheral Venting Reduce Size of The Largest Void on Full Pads Moderately





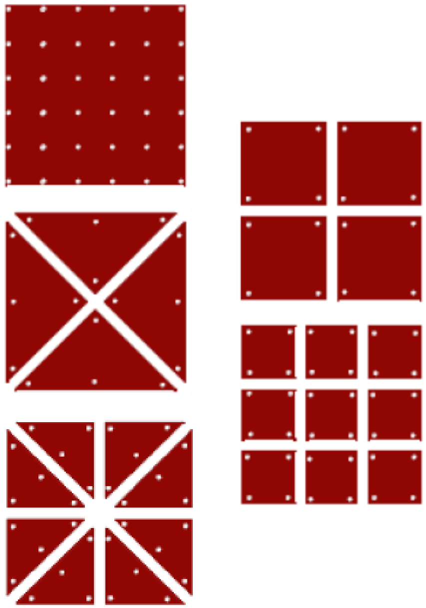
Increase Channel Width Has No Effect on Void Ave, but Increase Channel Area & Discontinuity



Calculated Venting Accessibility of Thermal Pad Designs

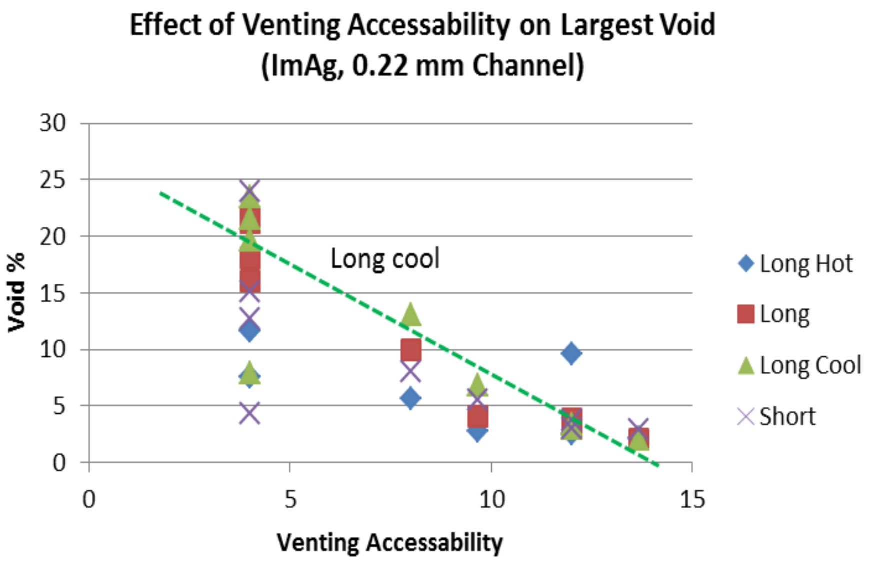
Venting Accessibility: Perimeter length per unit area of metal pad

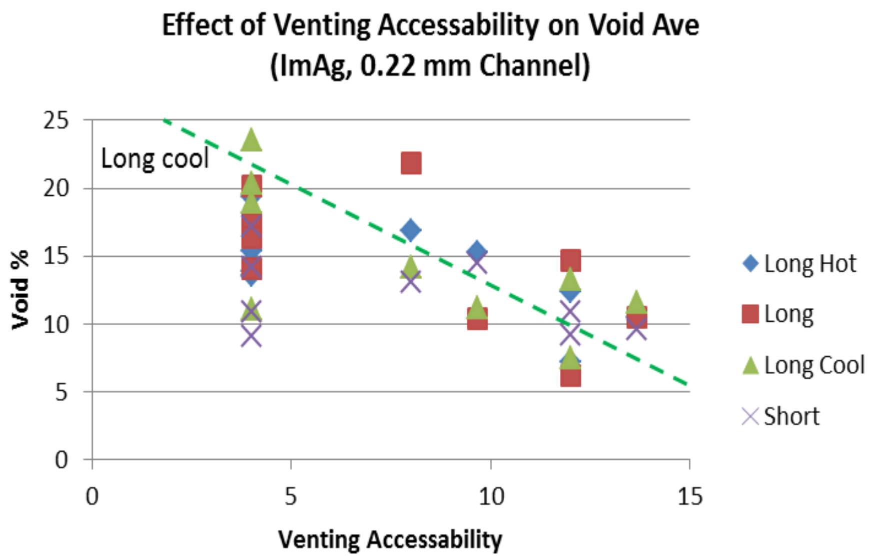
Thermal pad design	Venting accessibility
Full pad	4
Square 4	8
Triangle 4	9.66
Square 9	12
Triangle 8	13.66



Venting Accessibility Effect on Largest Void & Void Average

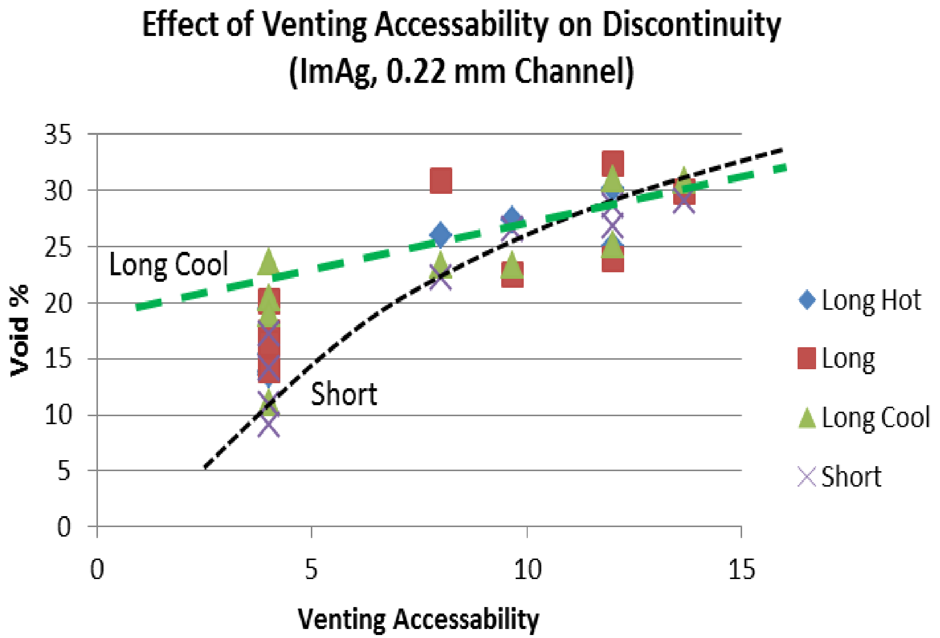
With increasing venting accessibility, the void average and largest void decrease readily





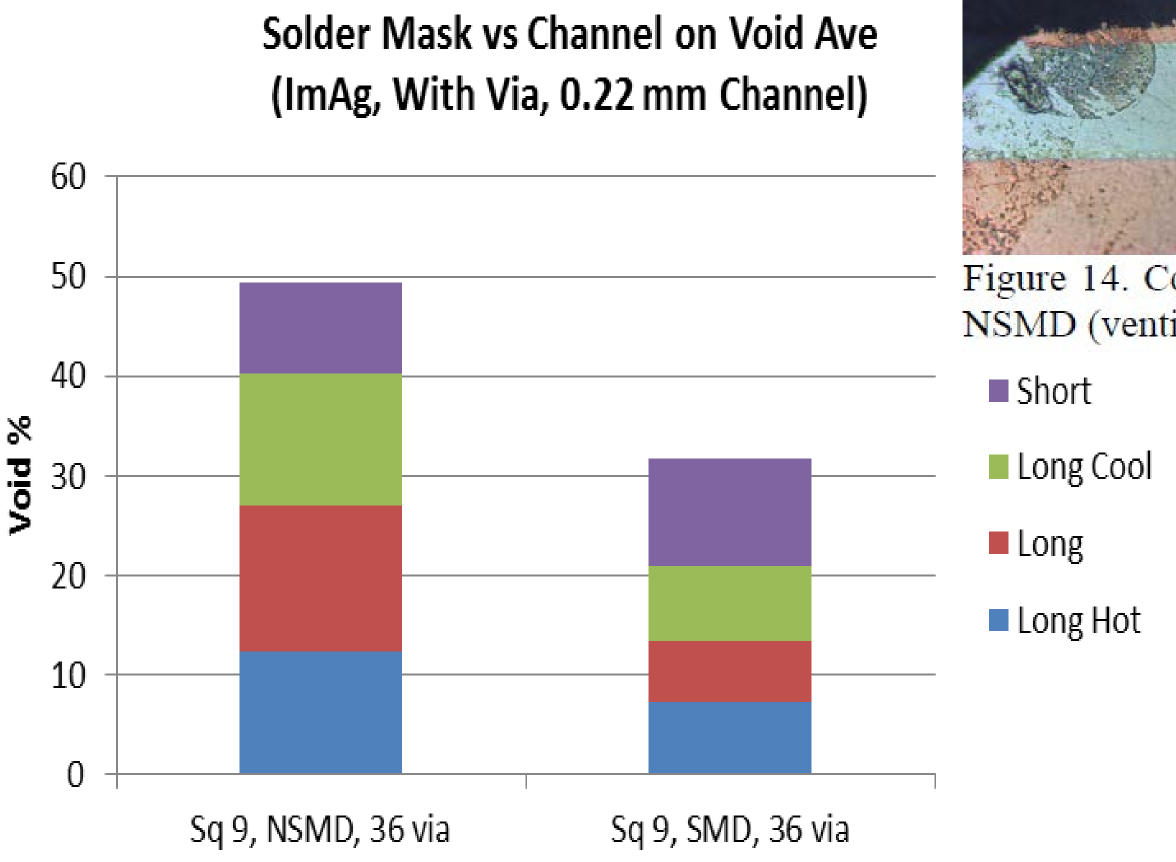
Divided Pad A Preferred Design When Voiding A Major Threat

However, the advantage of voiding reduction is offset by the increase in discontinuity, particularly for the short profile.
For a long cool profile, the discontinuity increases only moderately with increasing venting accessibility. In other words, when the voiding is a major threat, such as designs with a high number of thermal vias, or when a short profile is not a viable option, then a venting channel design becomes a favorable choice.



Divided Thermal Pads - SMD vs Channel (NSMD)

The higher voiding of channel system (NSMD) is attributed to (1) thinner solder joint, (2) FR4 outgassing



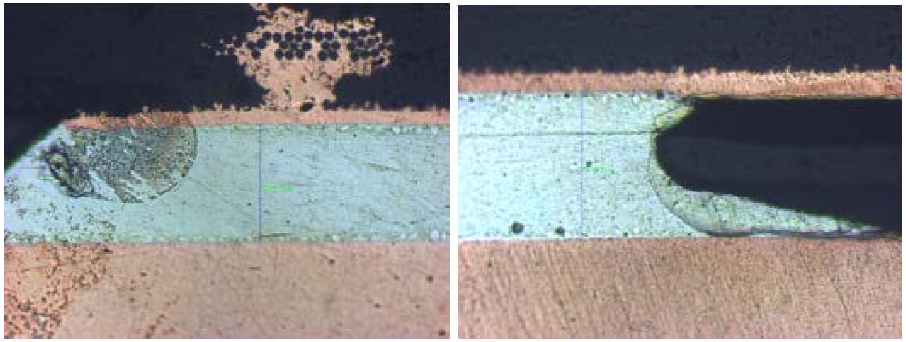
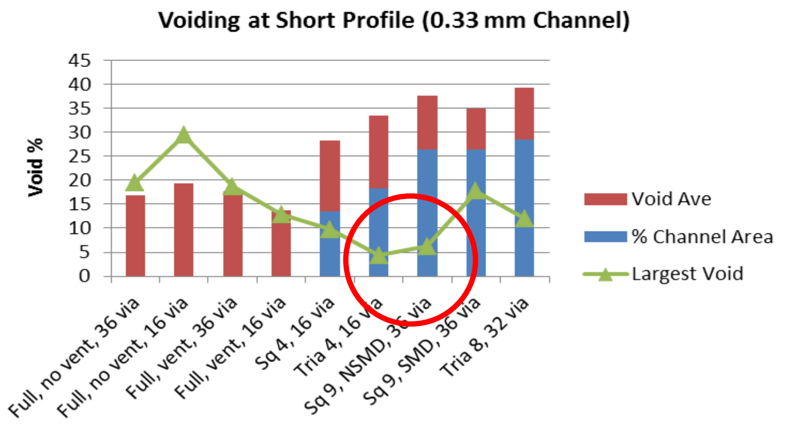
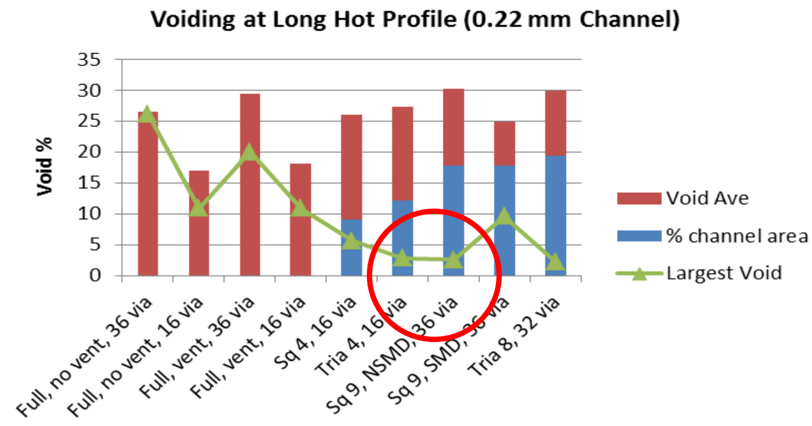
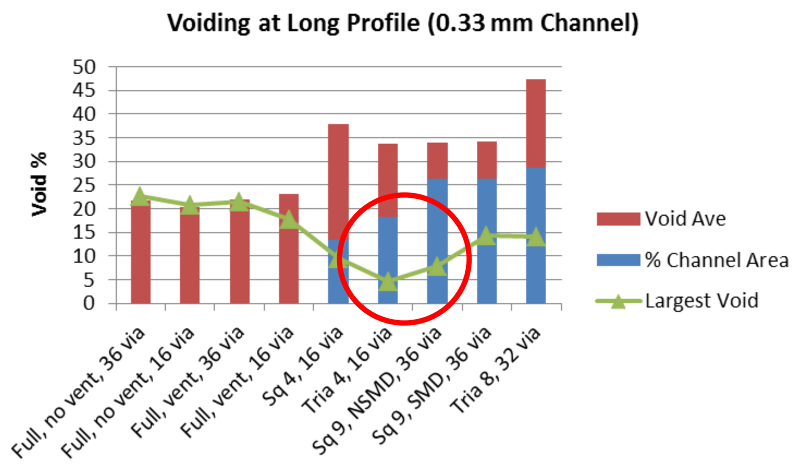


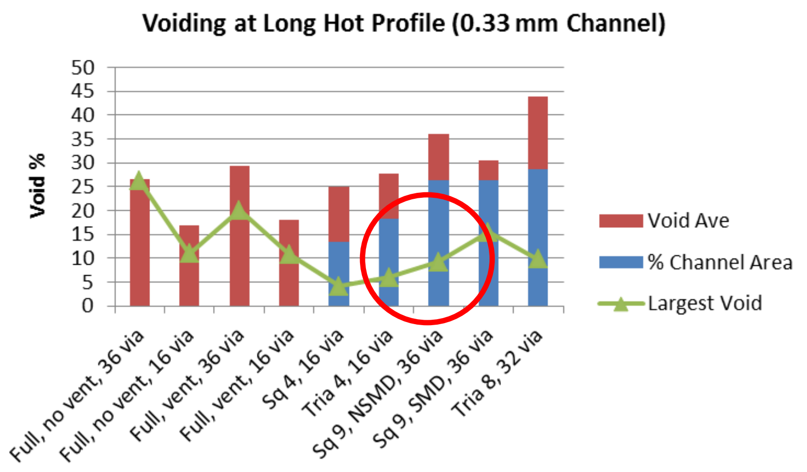
Figure 14. Comparison of the solder layer thickness for NSMD (venting channel, left) and SMD (right) systems.

Largest Void Bigger for SMD
- Due to Blocked Venting by SM

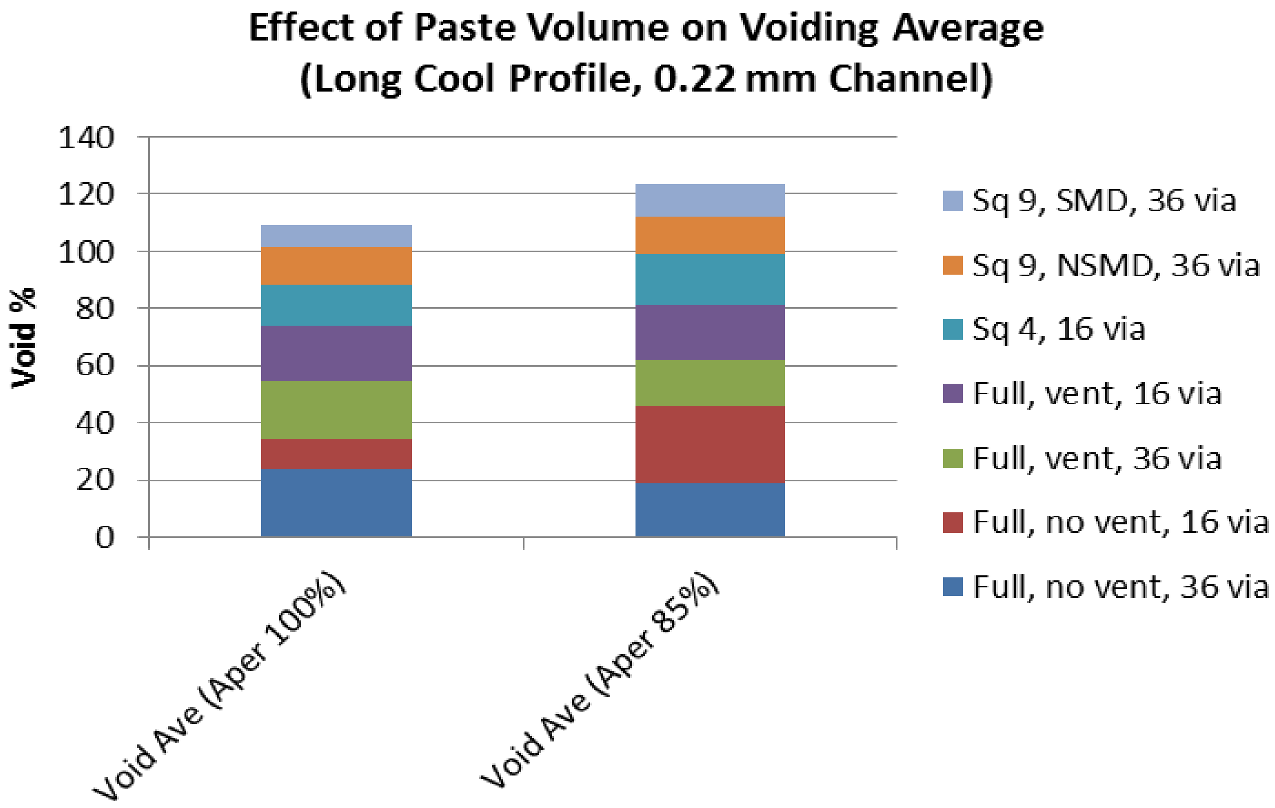






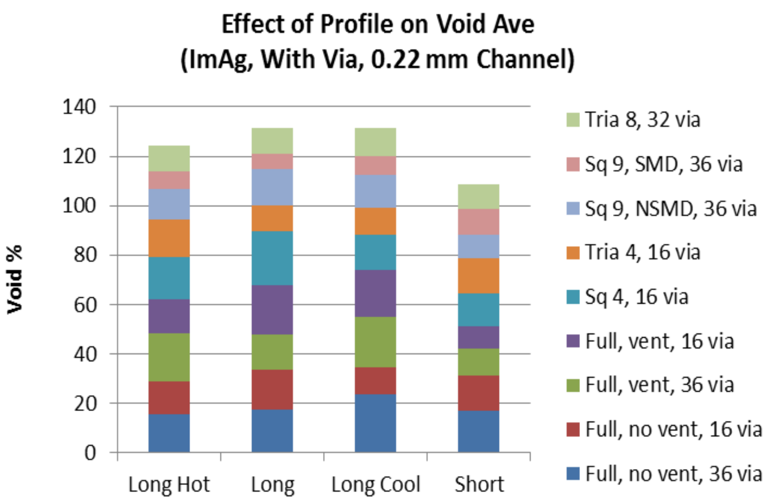


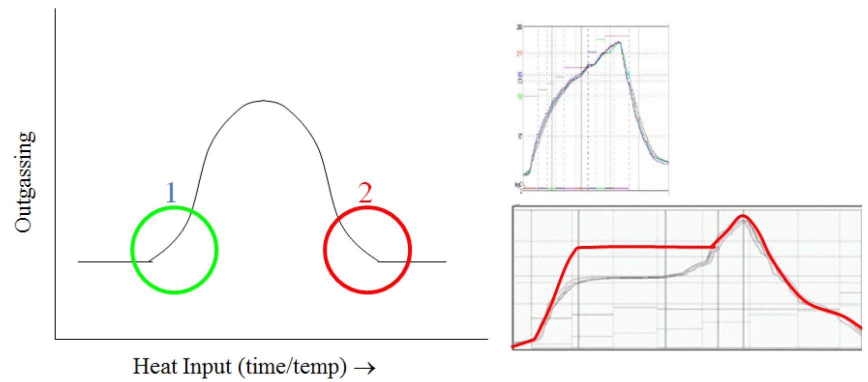
Smaller Paste Volume Cause Slightly More Voiding - Due to Thinner Joint

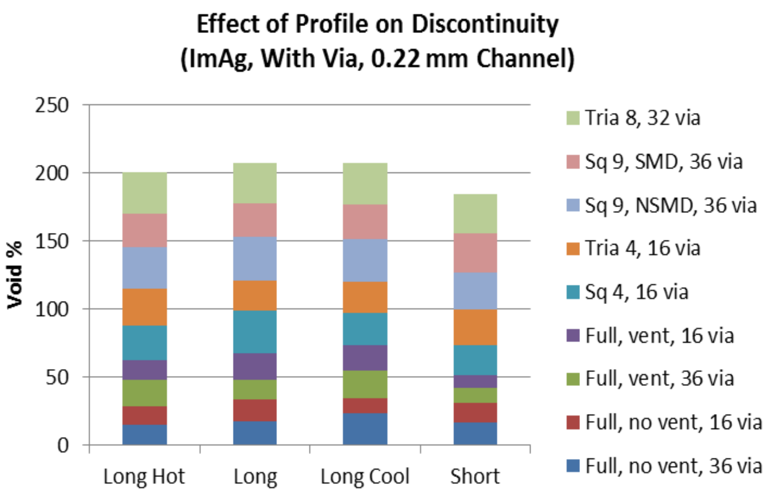


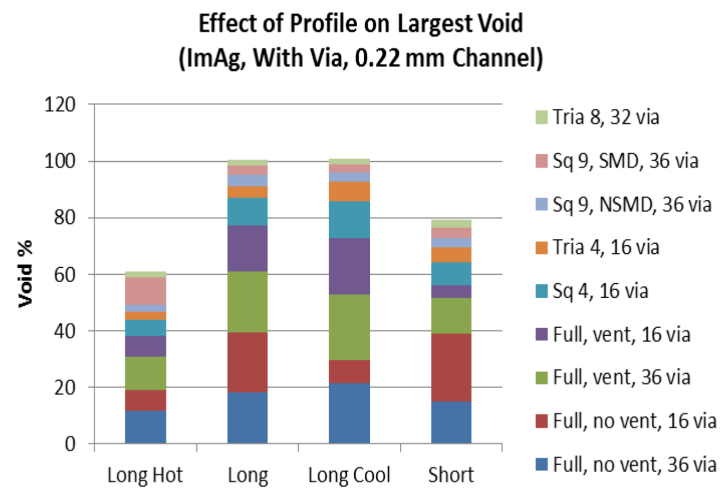
Effect of Profile on Voiding

The short profile is preferred for a low void average, while the long hot profile is better for reducing the largest void

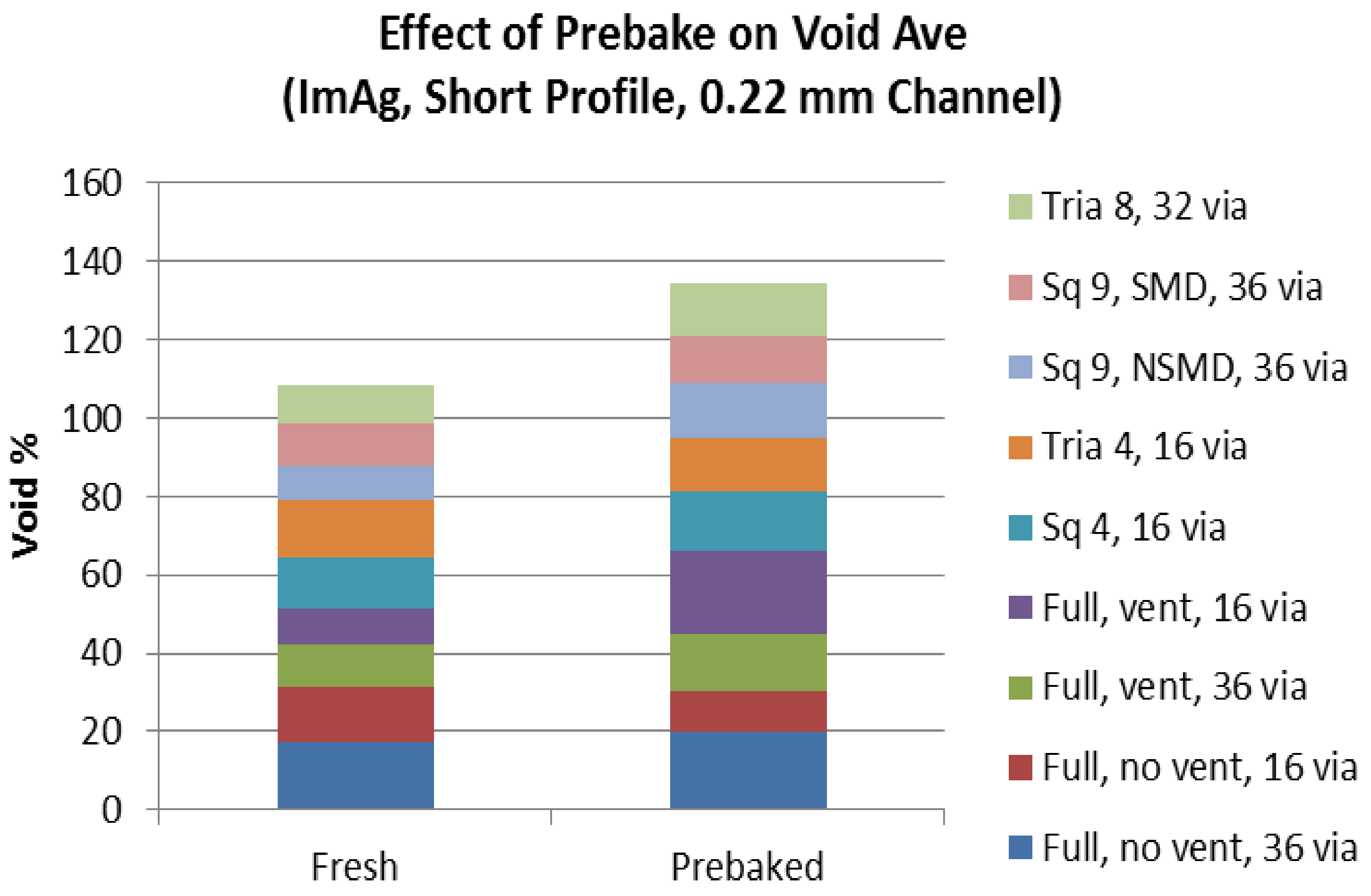




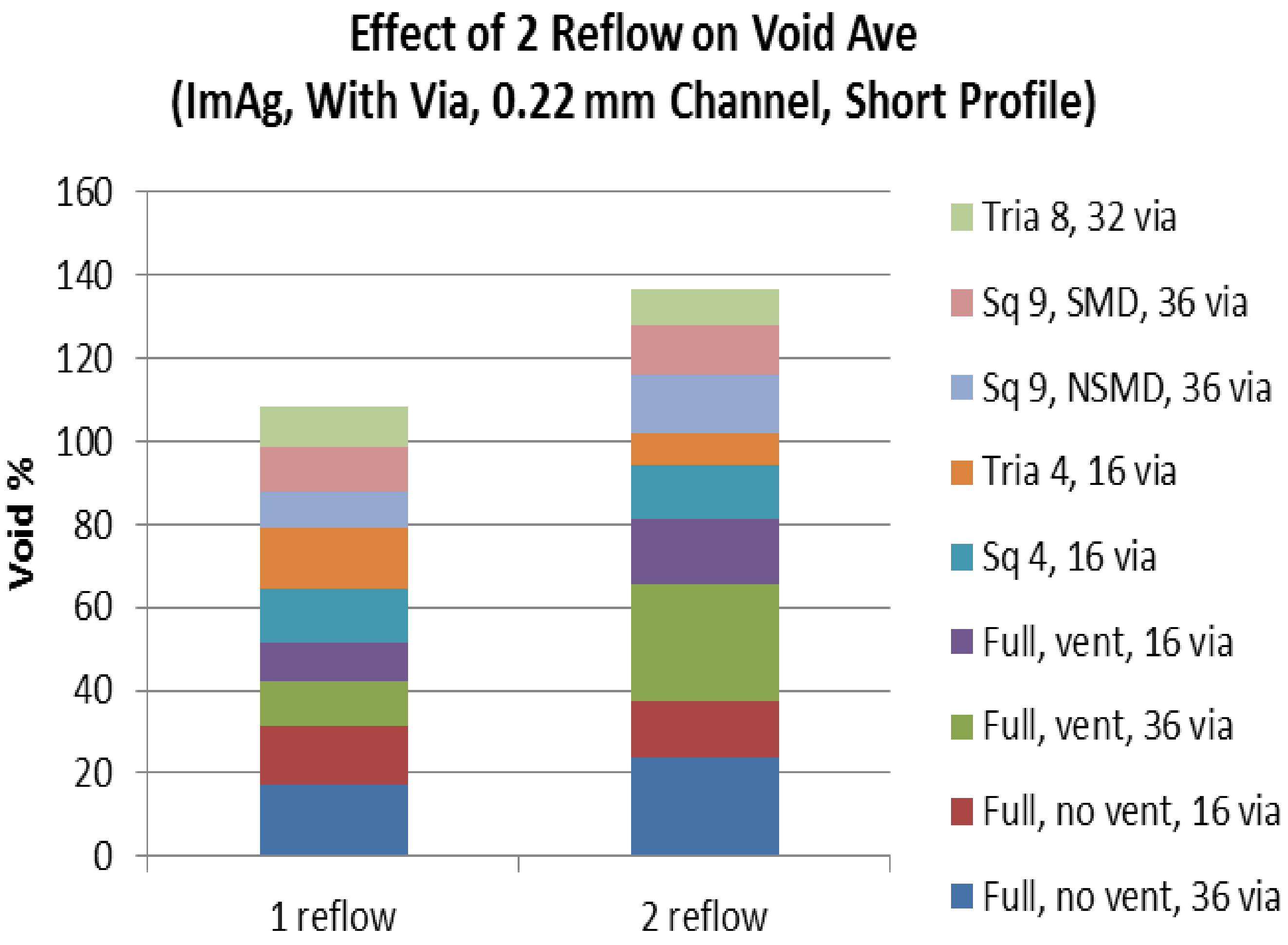




Prebake Aggravate Voiding Due to More Oxidation



Double Reflow Cause Higher Voiding Due to More Outgassing at 2nd

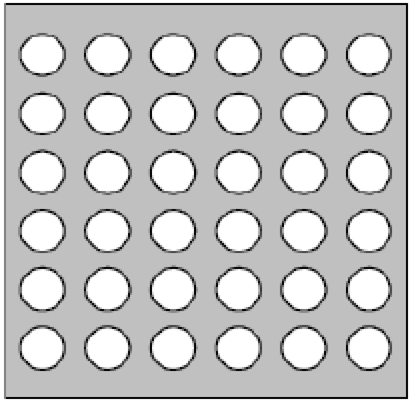


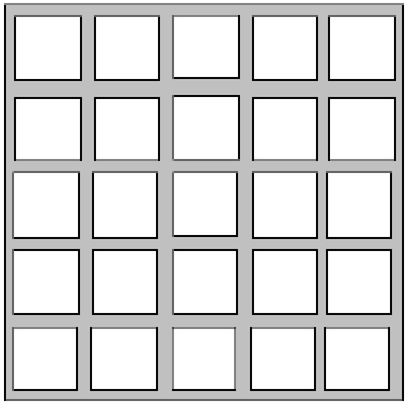
Discussion (1)

- Prospect of thermal via
  - When mechanical drilled thermal via evolve to microvia, the via pitch decreases, thermal via density may becomes higher, & voiding may worsen
- How much voiding is too much?
  - Voiding up to 50% or even 60% OK
  - But, the largest void should be < pitch
- What is less evil?
  - High void or uneven size distribution?

Discussion (2)

- Patterned solder paste common approach
  - Multiple opens
  - 50-80% coverage
  - 0.15-0.3 mm spacing
  - But, still has voiding issue





- Permanent venting channel desired
  - Higher discontinuity may be acceptable, since 50% voiding acceptable
  - Controlled even distribution of discontinuity better

Discussion (3)

- Venting or being vented?
  - – Remove metal to form channel less obstruction on vending
  - – But, allow FR4 to outgass moisture from channel
- What is next?
  - – Thin solder mask for SMD thermal pad
- Short vs long hot
  - – Long hot more consistent, due to a wider reflow process window
  - – Price – slightly higher void average

Conclusion (1)

- Plugging is most effective in reducing voiding
- For unplugged via situations, a full thermal pad is desired for a low no. of via
- For a high no. of thermal via, a divided thermal pad is preferred, due to better venting capability
- Placement of thermal via at the perimeter lessens voiding caused by via
- A wider venting channel has a negligible effect on voiding, but reduces joint continuity
- For a divided thermal pad, a SMD system is more favorable than a channel (NSMD) system, with the latter suffering more voiding due to a thinner solder joint and possibly board outgassing

Conclusion (2)

- Performance of a divided thermal pad is dictated by venting accessibility, not by the shape
- Voiding decreases with increasing venting accessibility, although the introduction of a channel area compromises the continuity of the solder joint
- Reduced solder paste volume causes more voiding
- A short profile and a long hot profile are most promising in reducing the voiding
- Voiding behavior of the QFN is similar to typical SMT voiding and increases with pad oxidation and further reflow