IPC Midwest 2011

Thermal Pad Design at QFN Assembly for Voiding Control

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Executive Summary

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.

Thermal Pad Design at QFN Assembly for Voiding Control

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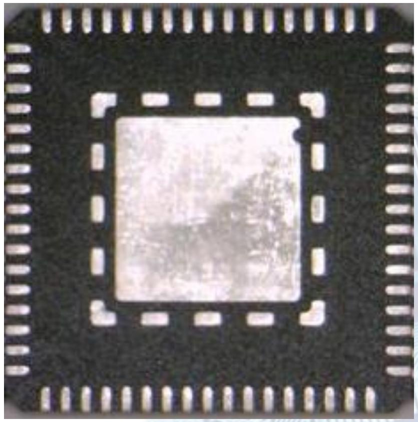
Background

- 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

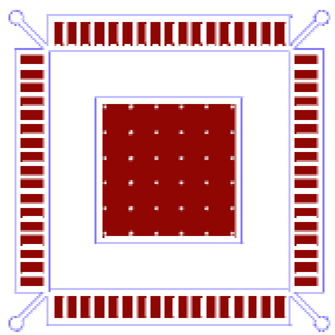
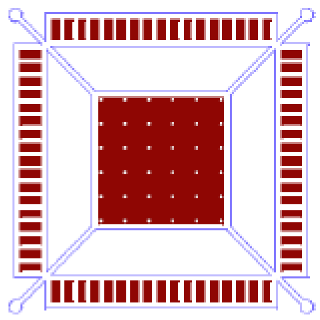
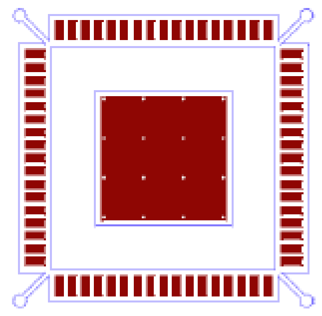
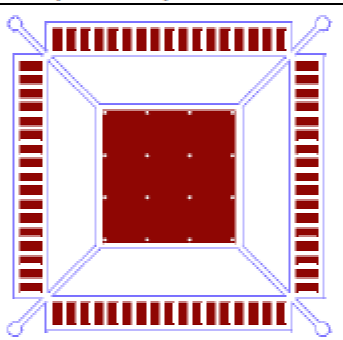
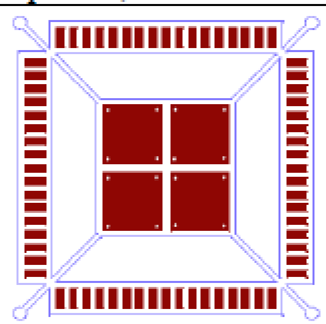
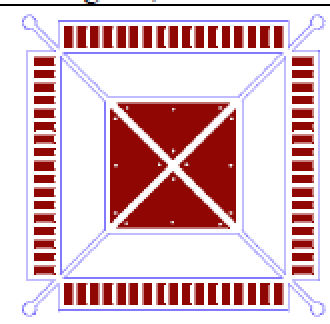
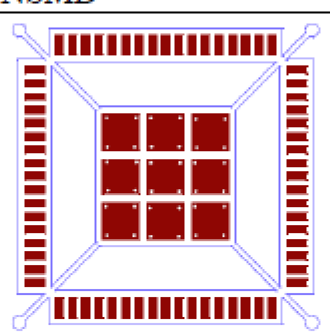
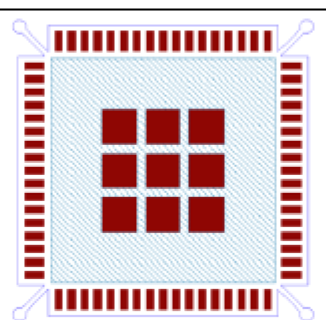
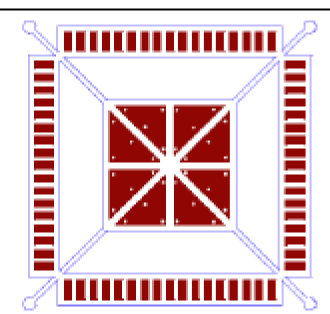
Parameters Studied

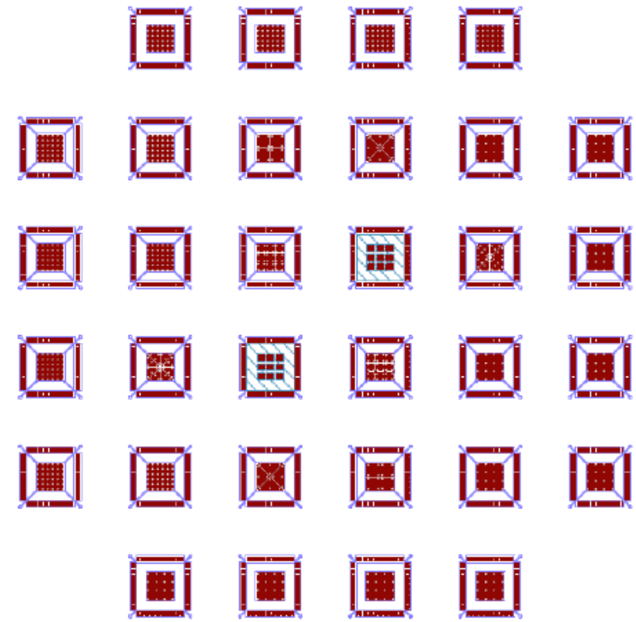
QFN with 68 pads, 10mm x 10mm, 0.5mm pitch, daisy-chained, Sn surface finish



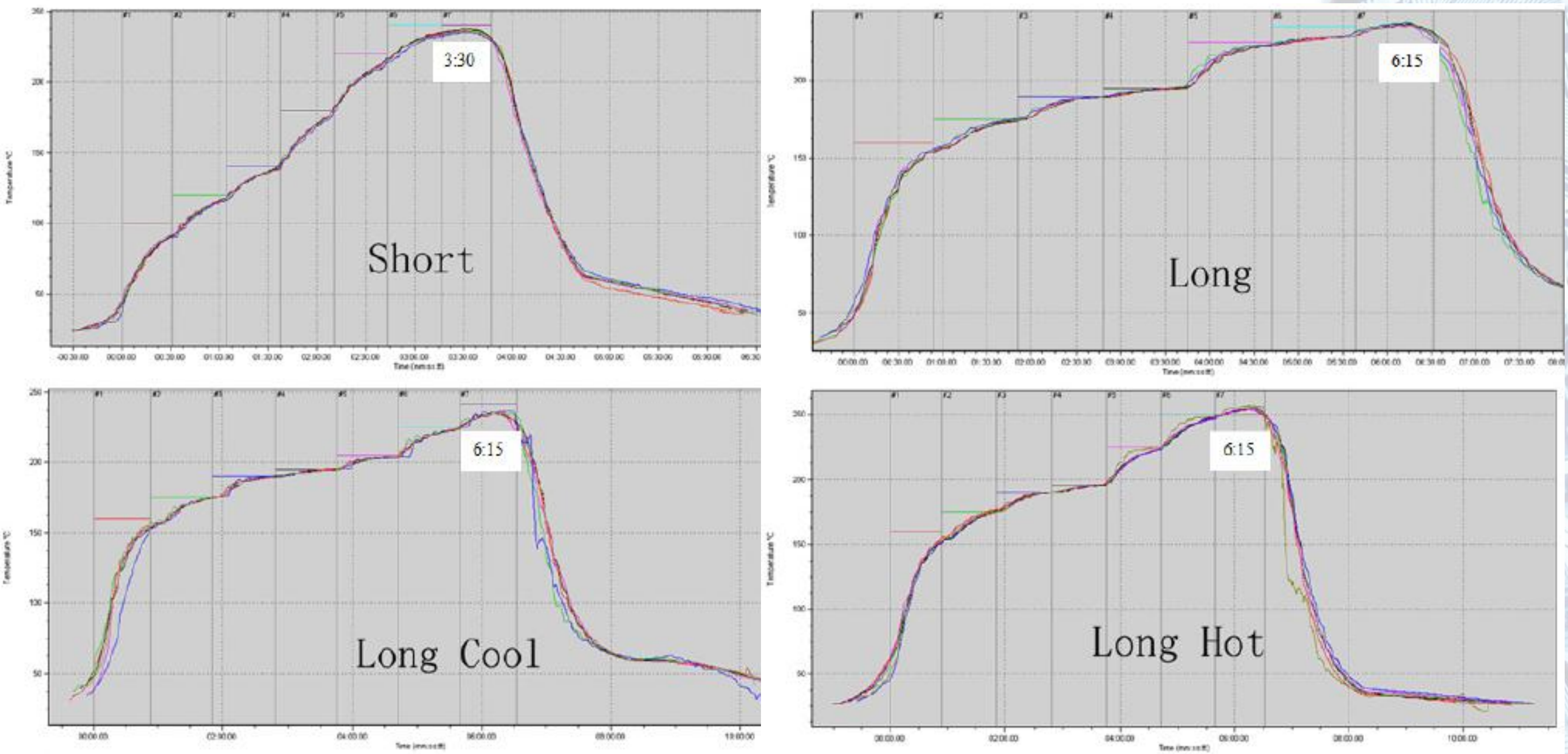
Parameter	Sub parameter	Layers
Thermal Pad on PCB	Thermal via number	0, 16, 32, 36
	Peripheral venting for full thermal pad	With and without
	Dividing method	Solder mask, venting channel (0.22 & 0.33 mm)
	Thermal sub-pad shape	Square, triangle
	Thermal sub-pad number	1, 4, 8, 9
Stencil	Aperture	85%, 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

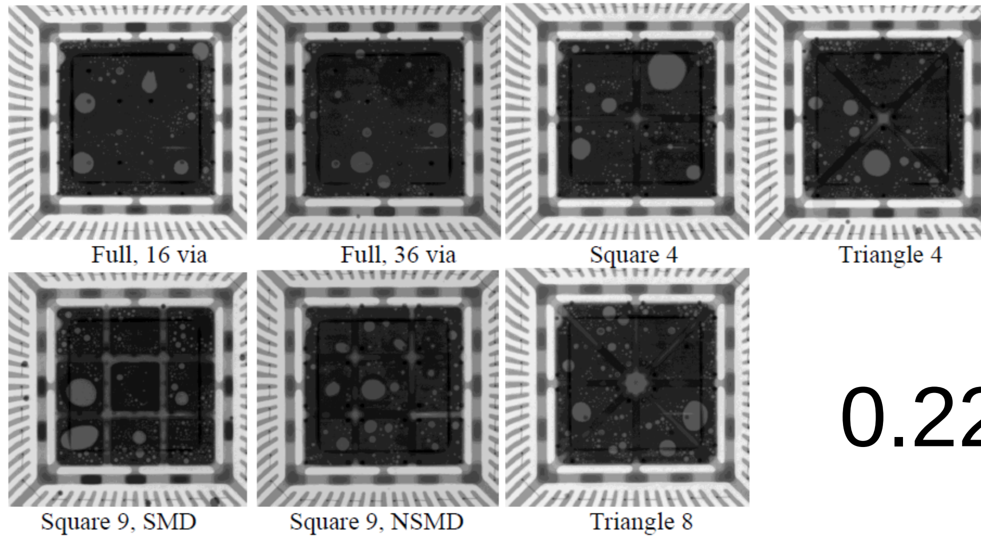


Figure 4. X-ray images of QFN solder joints for designs with 0.22mm wide channel reflowed with a long hot profile.

0.22 mm

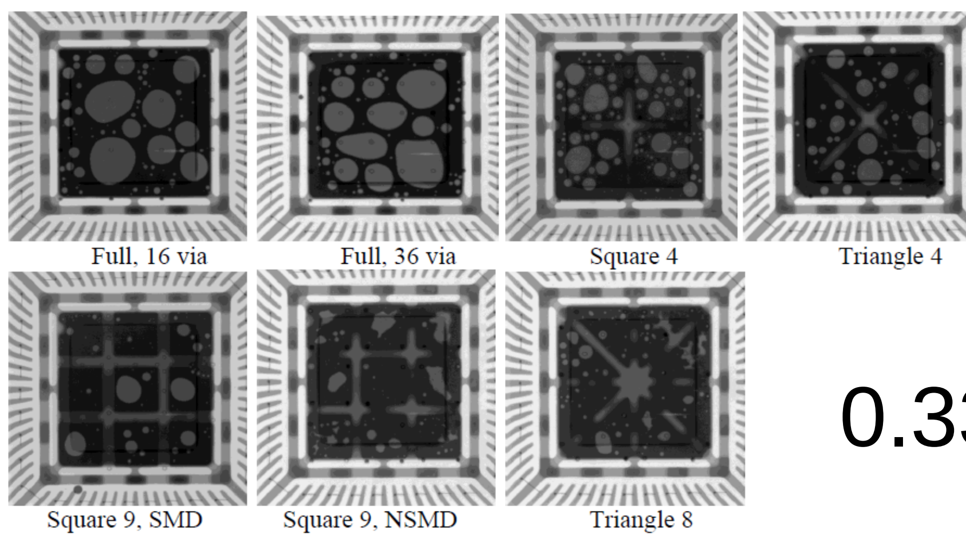


Figure 5. X-ray images of QFN solder joints for designs with a 0.33mm wide channel reflowed with a long cool profile.

0.33 mm

Definition of 3 Voiding Properties

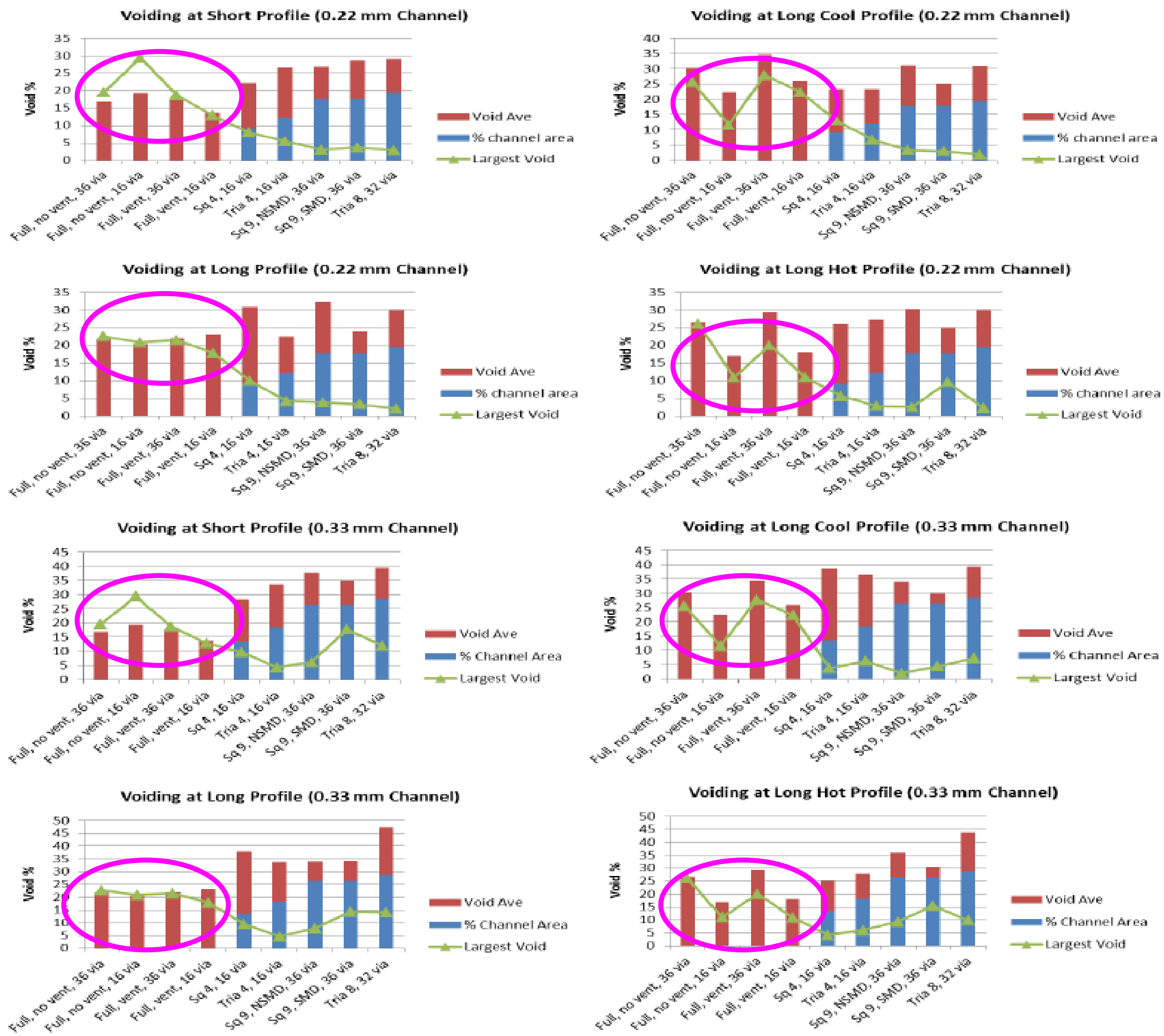
Property	Definition
Discontinuity	Percentage of area under the QFN thermal pad where the vertical metal continuity from QFN to PCB surface is interrupted
Void Average	Average of multiple QFNs for void area percentage within the metallic pad of QFN
Largest Void	The largest void measured for a category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

Individual Voiding Data Set

Void Ave
% channel area
Largest Void

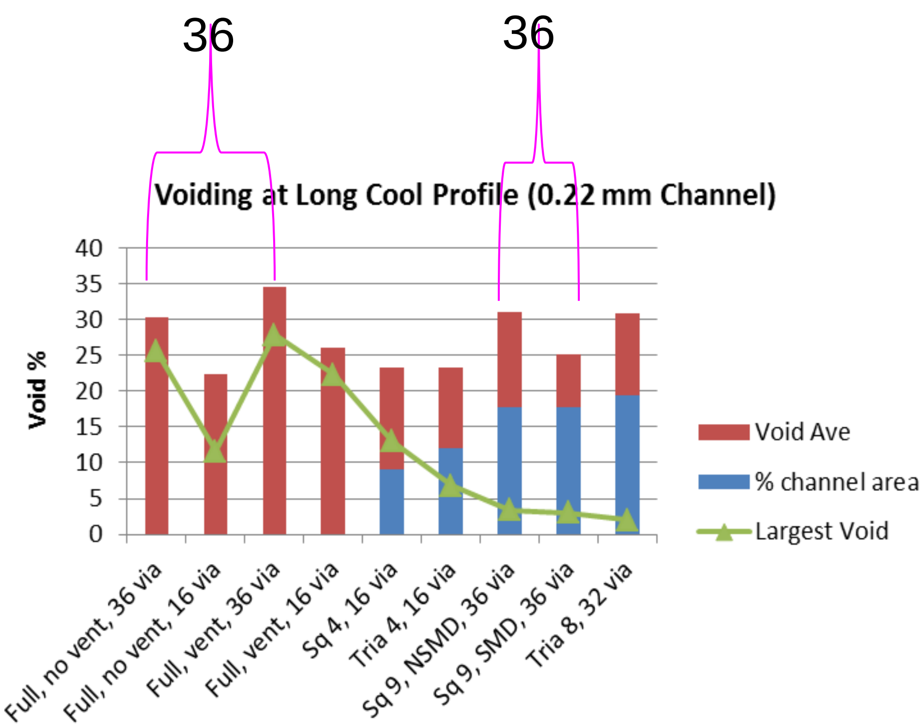
Dividing the thermal pads into sub-units results in an abrupt drop in the largest void but an increase in discontinuity

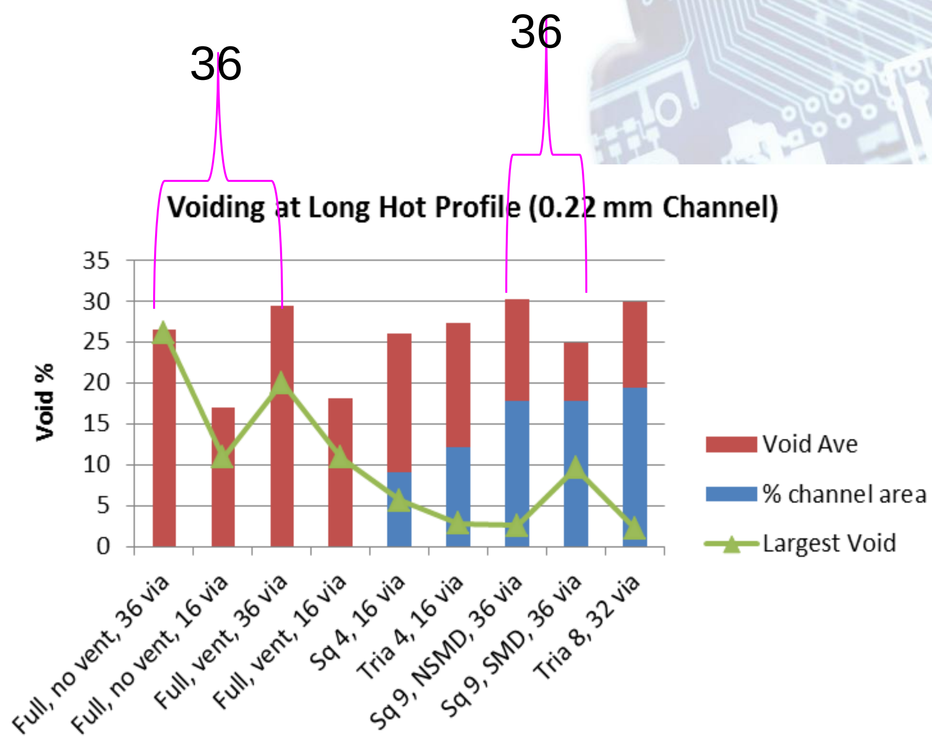
Net effect: a reduction in the uncontrollable, harmful large voids, replacing it with a controlled, even distribution of discontinuity



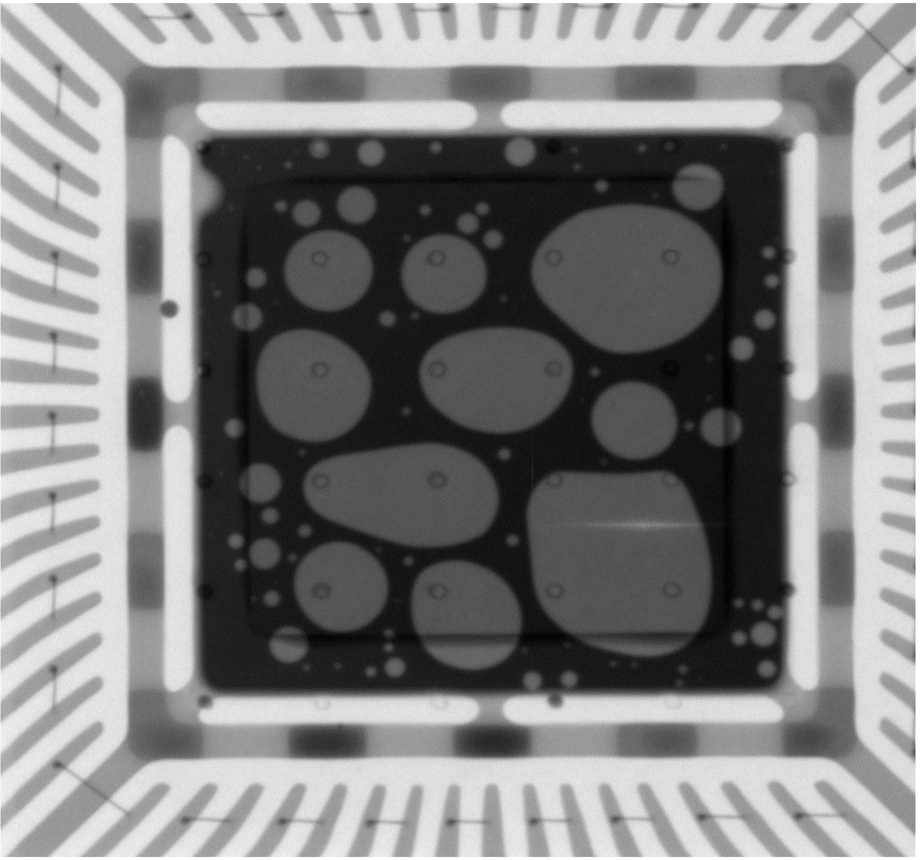
Dividing Desired for High Via No.

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



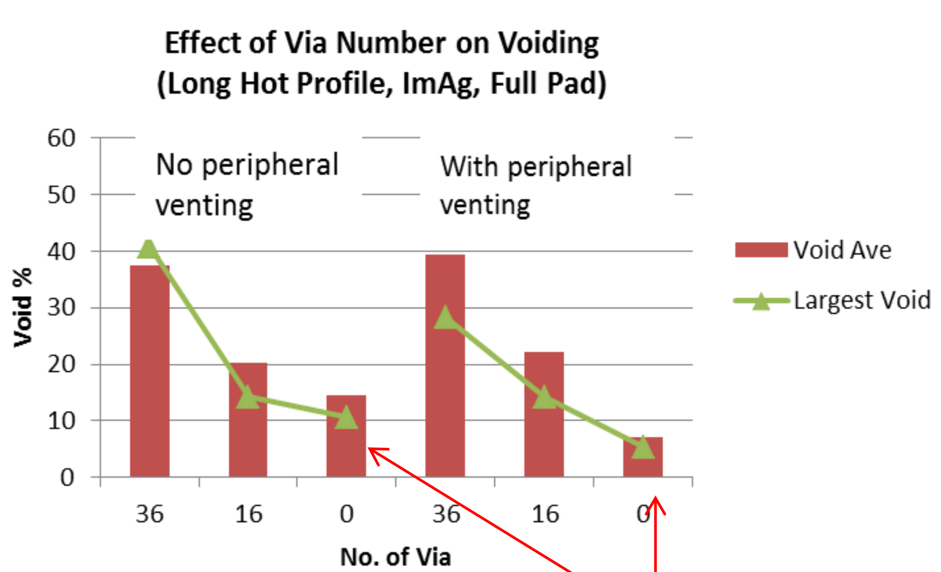


Thermal Via Aggravate Voiding



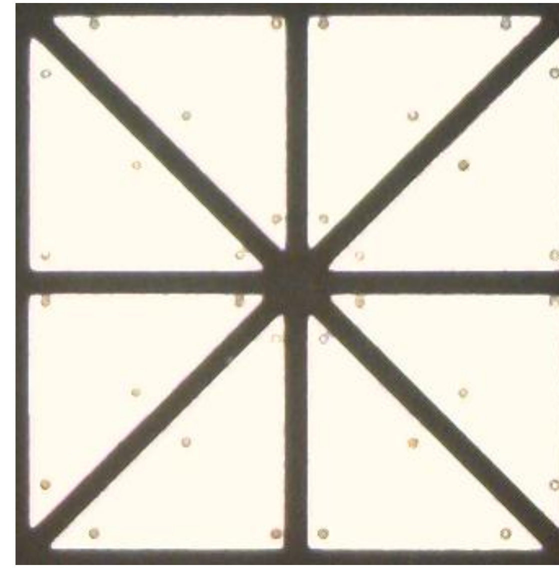
Propensity of voids at the via locations is particularly high for full pad solder joints

Thus, voiding increase w increasing

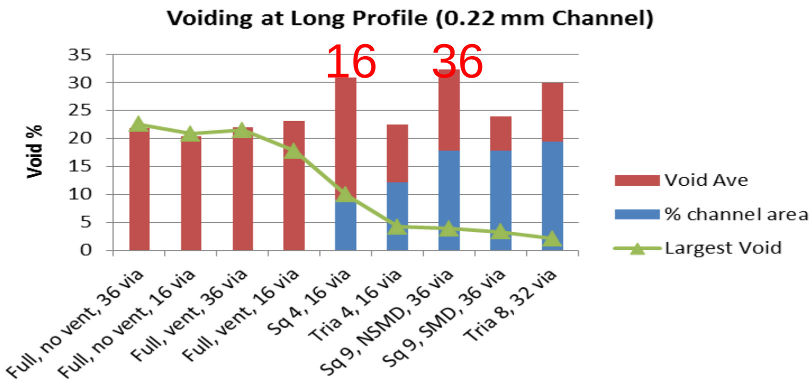


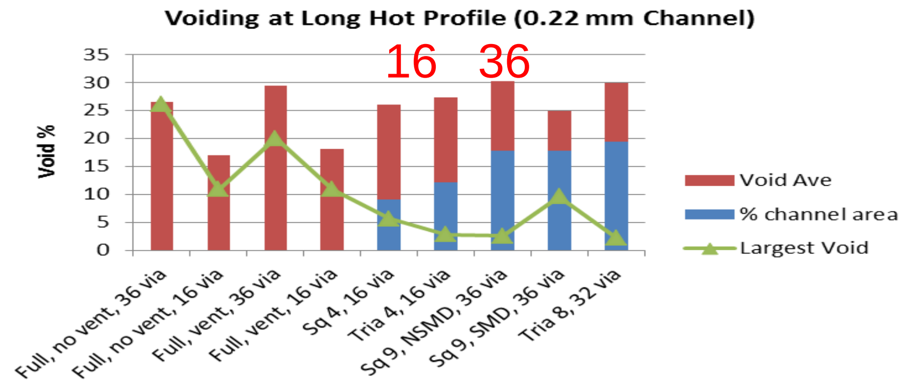
If high via no. is needed, plugging the via is the best option

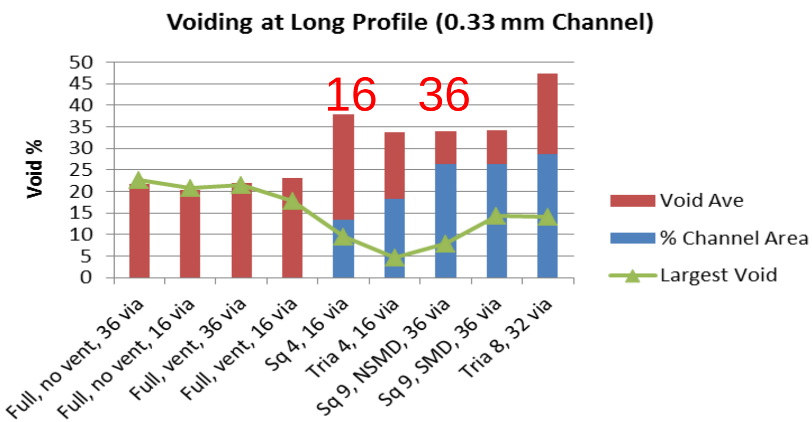
Divided Pads with Peripheral Via Not Sensitive to Via No. on Voiding

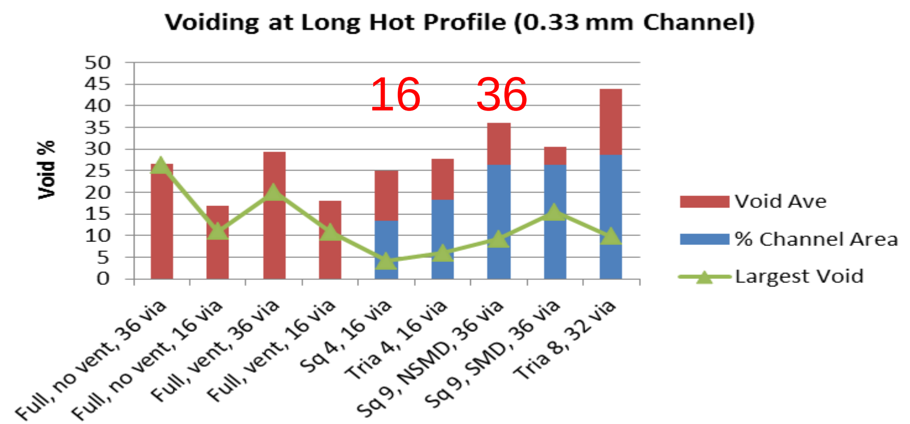


The number of thermal via bears no relation with voiding for divided pads. This is attributed to the peripheral location of thermal via for those divided pads. If plugging the thermal via is not an option, design the thermal via at peripheral locations whenever possible.

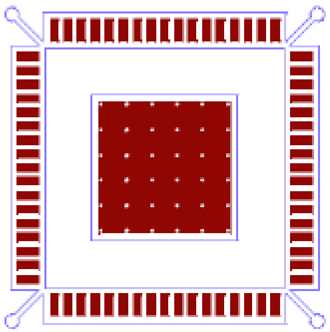


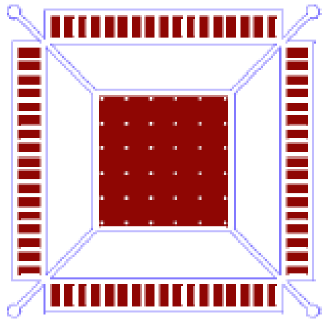


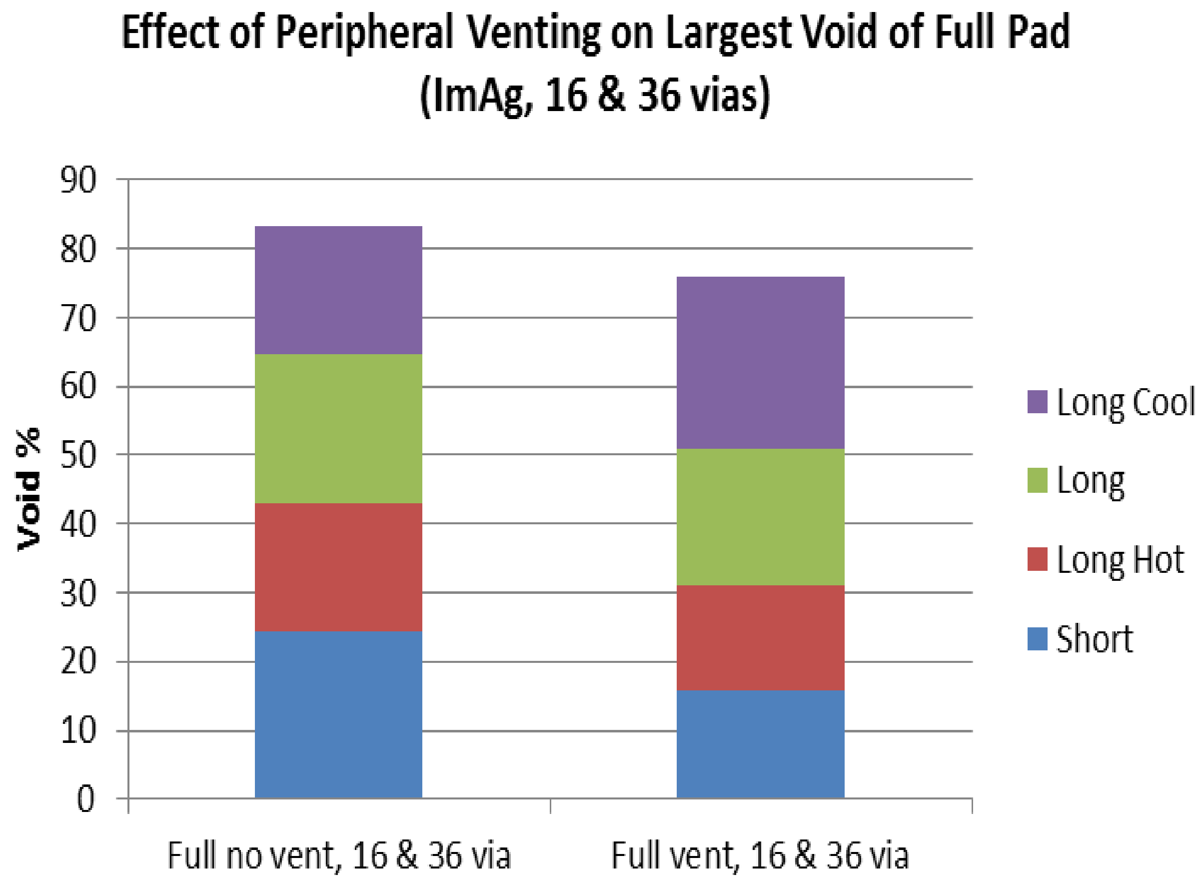




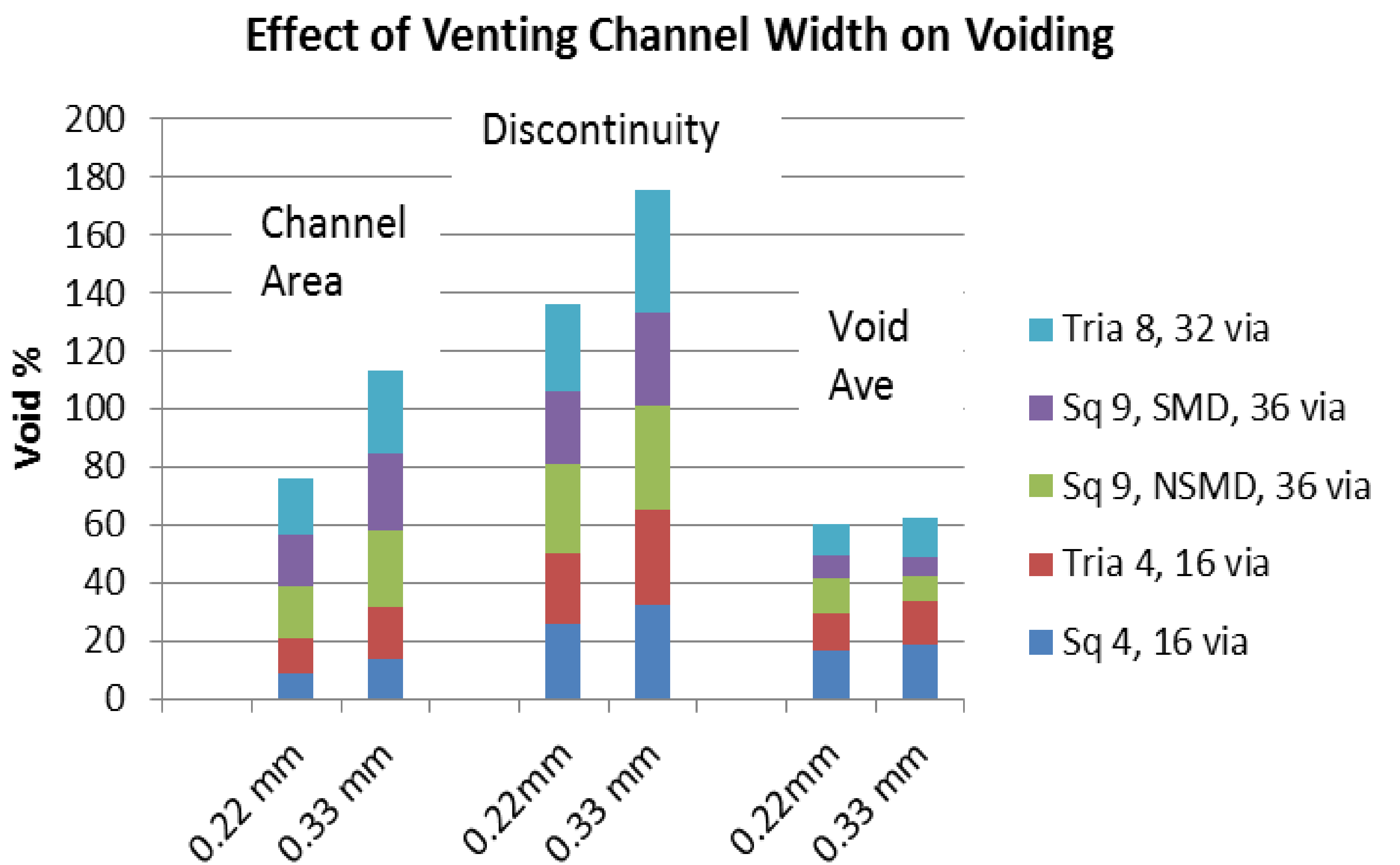
Peripheral Venting Reduce Size of The Largest Void on Full Pads Moderately







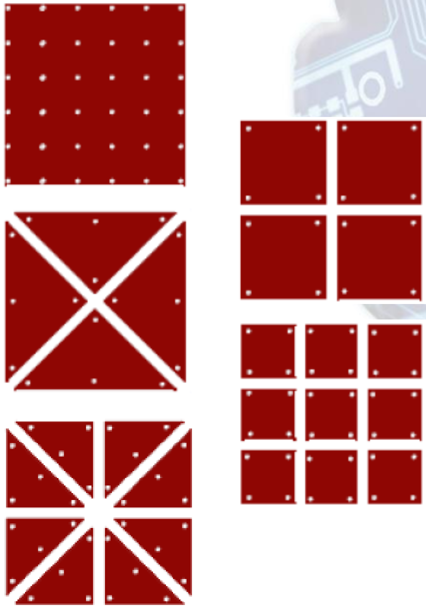
Increase Channel Width Has No Effect on Void Ave, but Increase Channel Area & Discontinuity



Calculated Venting Accessibility of Thermal Pad Designs

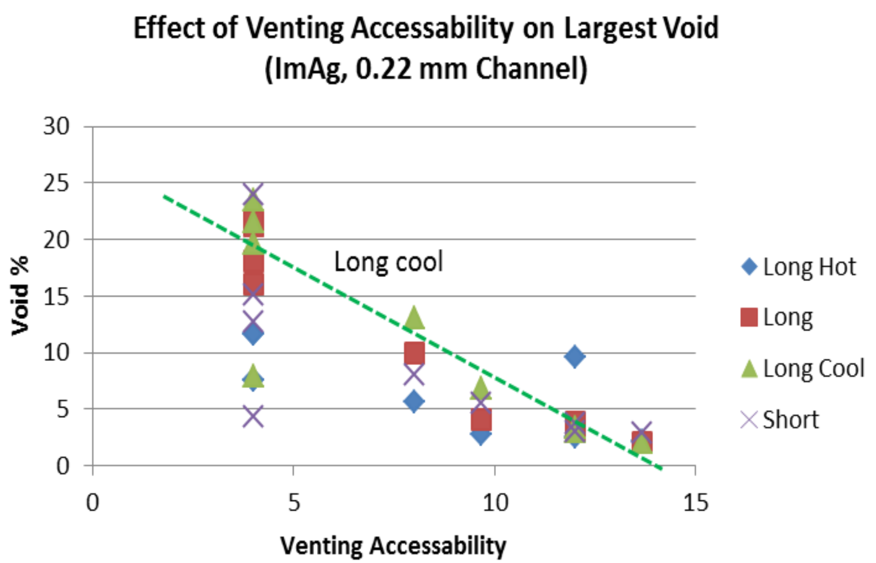
Venting Accessibility: Perimeter length per unit area of metal pad

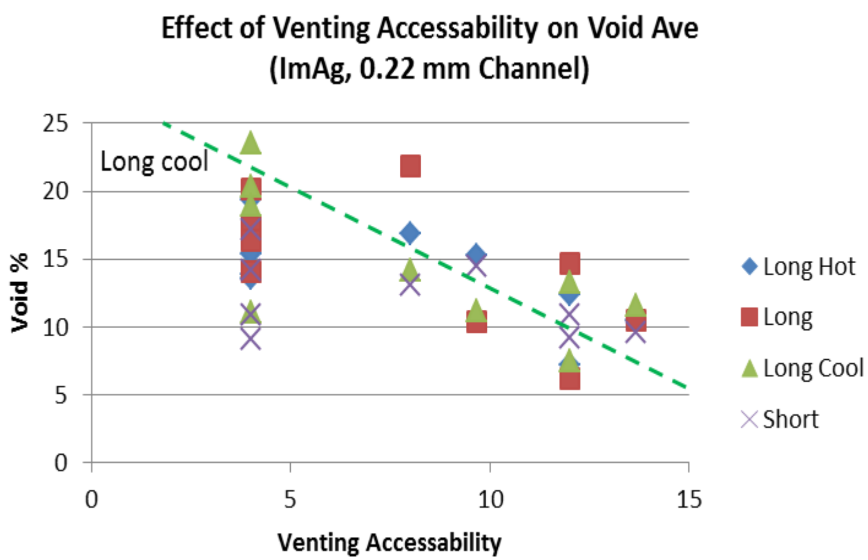
Thermal pad design	**Venting accessibility**
Full pad	4
Square 4	8
Triangle 4	9.66
Square 9	12
Triangle 8	13.66



Venting Accessibility Effect on Largest Void & Void Average

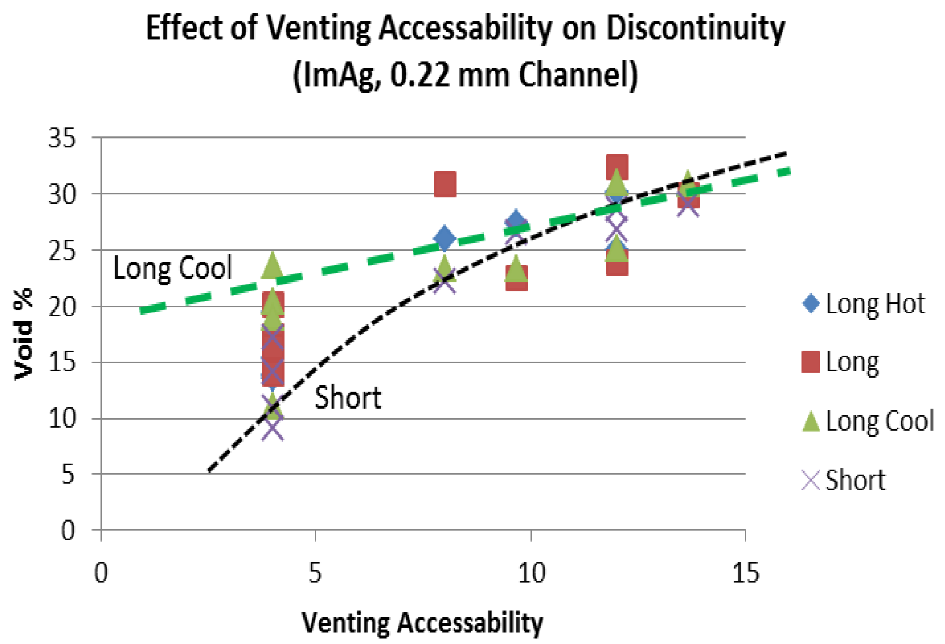
With increasing venting accessibility, the void average and largest void decrease readily





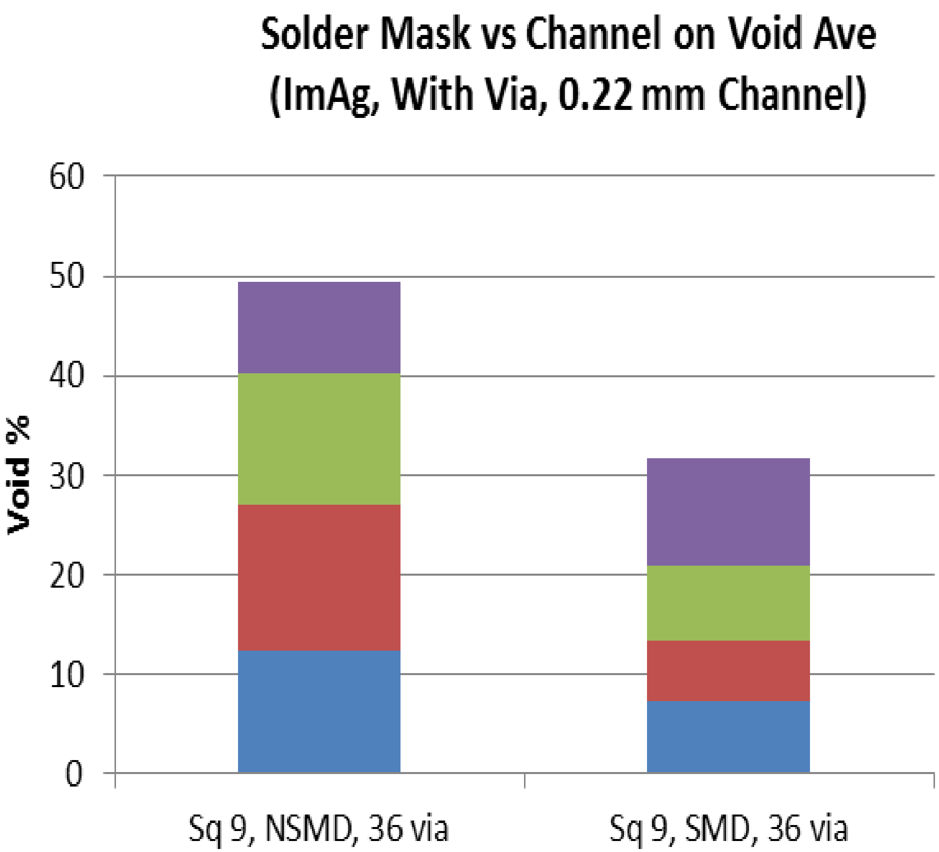
Divided Pad A Preferred Design When Voiding A Major Threat

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



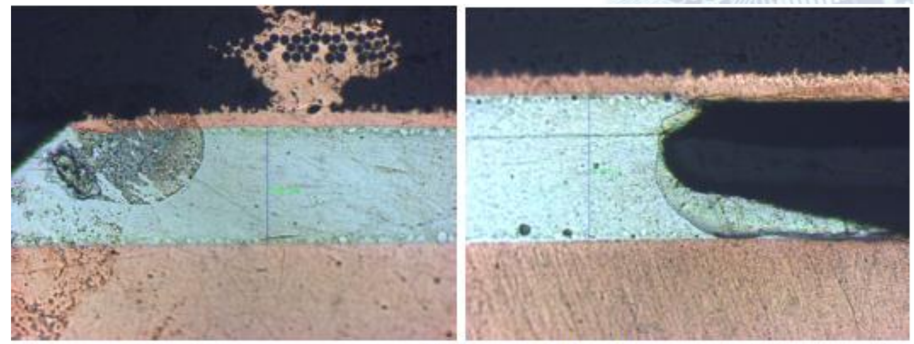
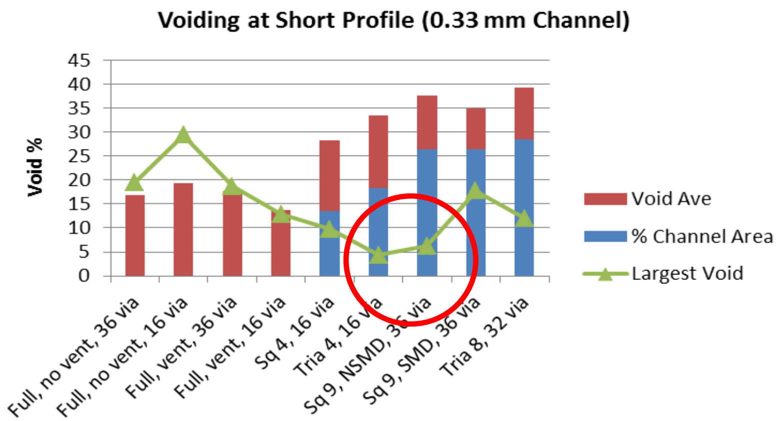
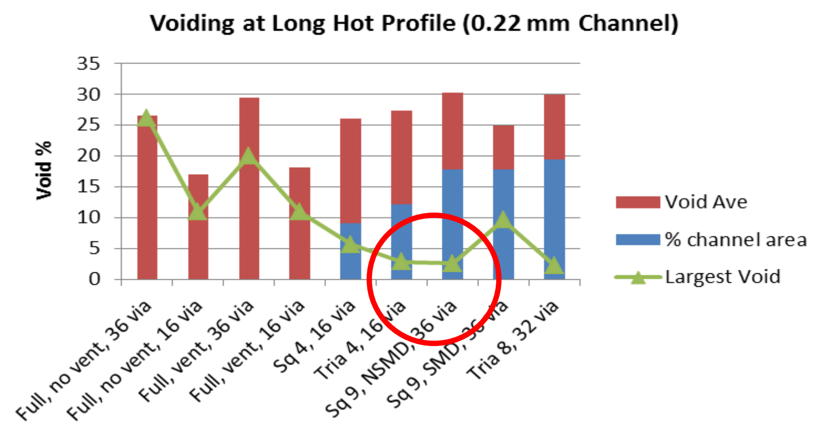


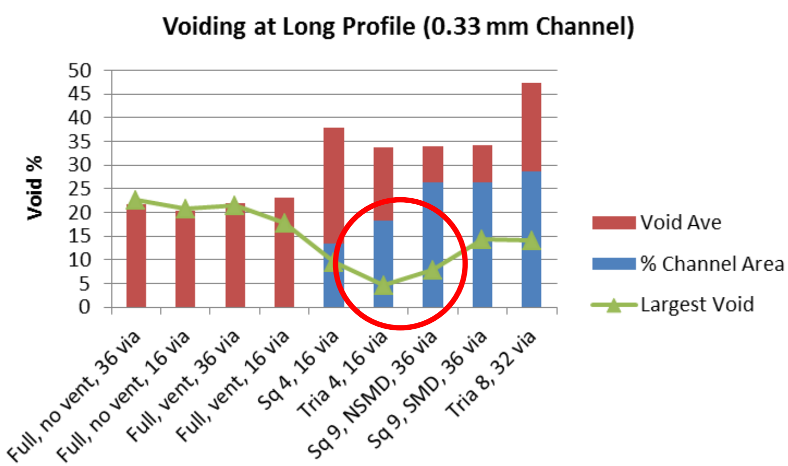
Figure 14. Comparison of the solder layer thickness for NSMD (venting channel, left) and SMD (right) systems.

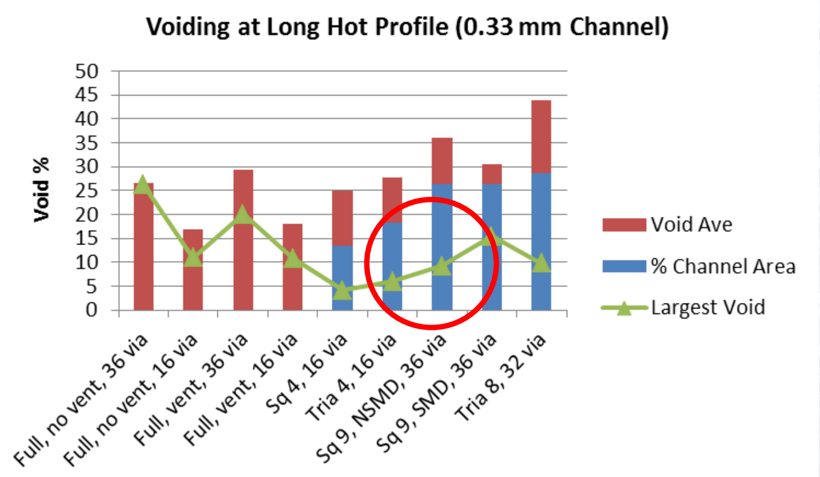
Largest Void Bigger for SMD

- Due to Blocked Venting by SM

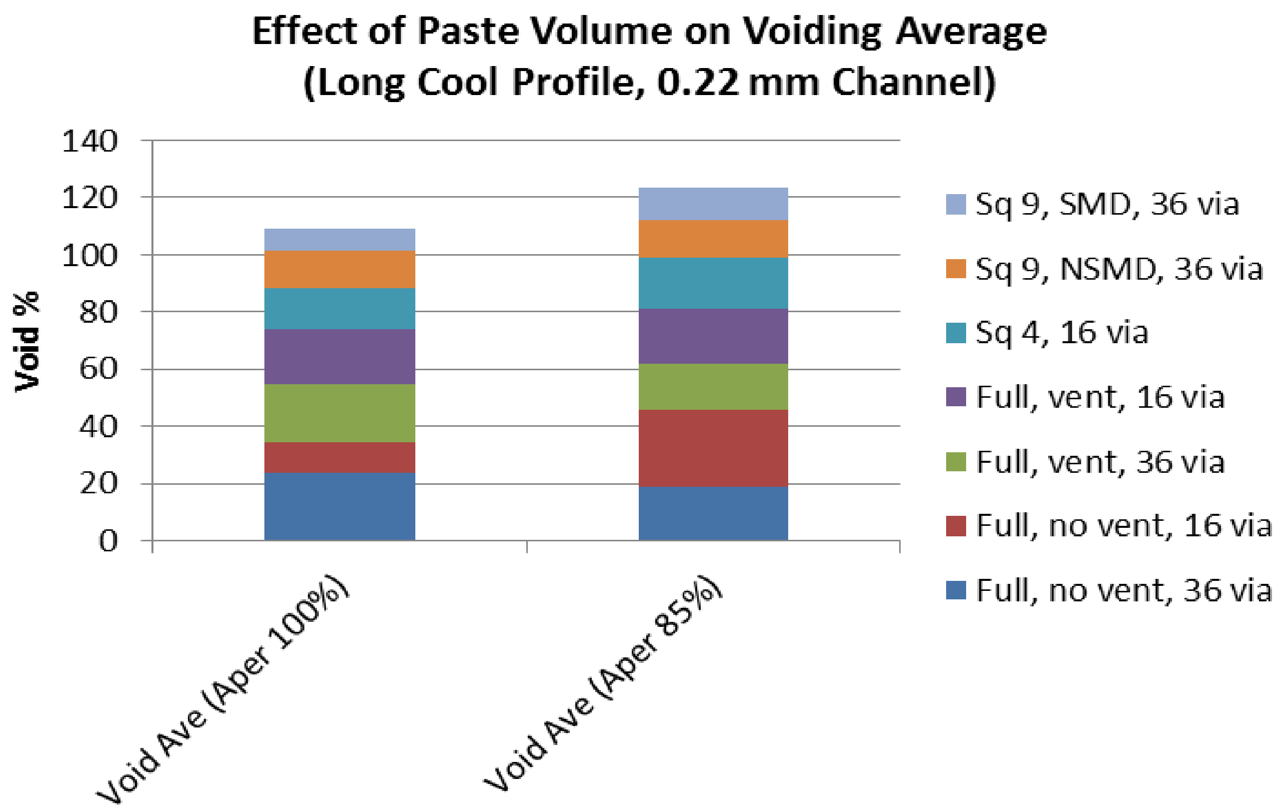






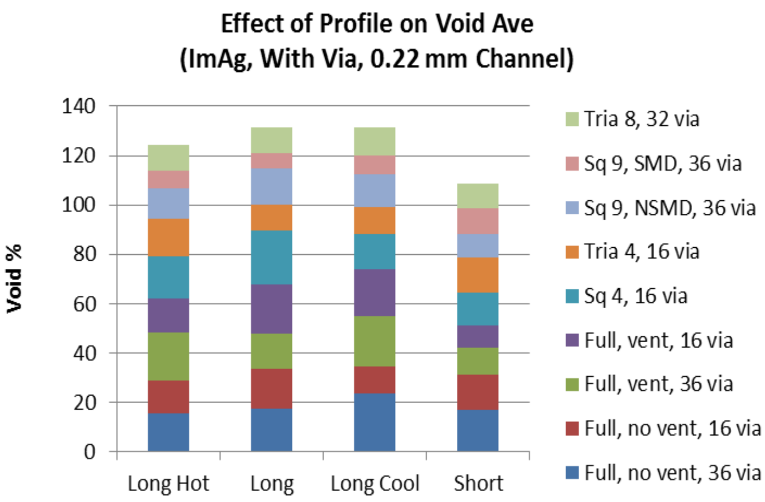


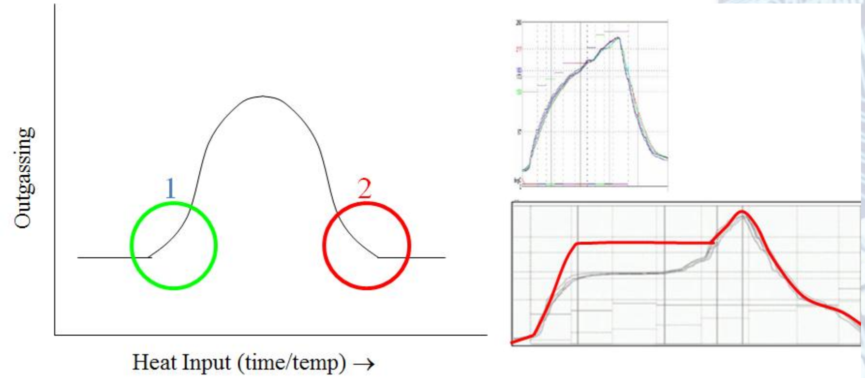
Smaller Paste Volume Cause Slightly More Voiding - Due to Thinner Joint

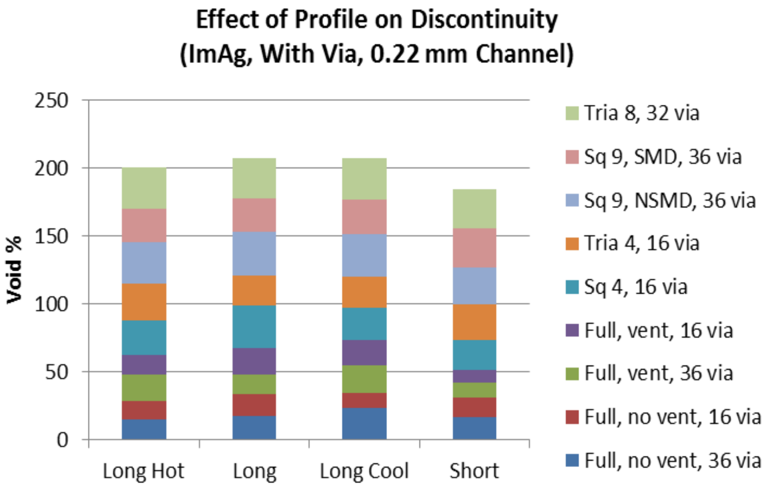


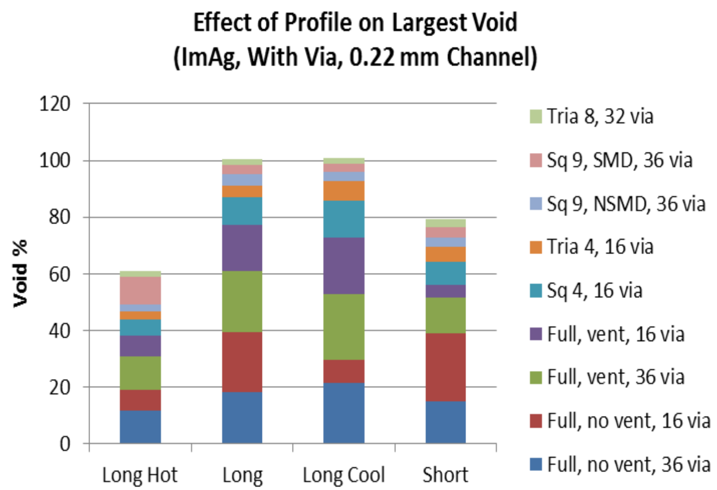
Effect of Profile on Voiding

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

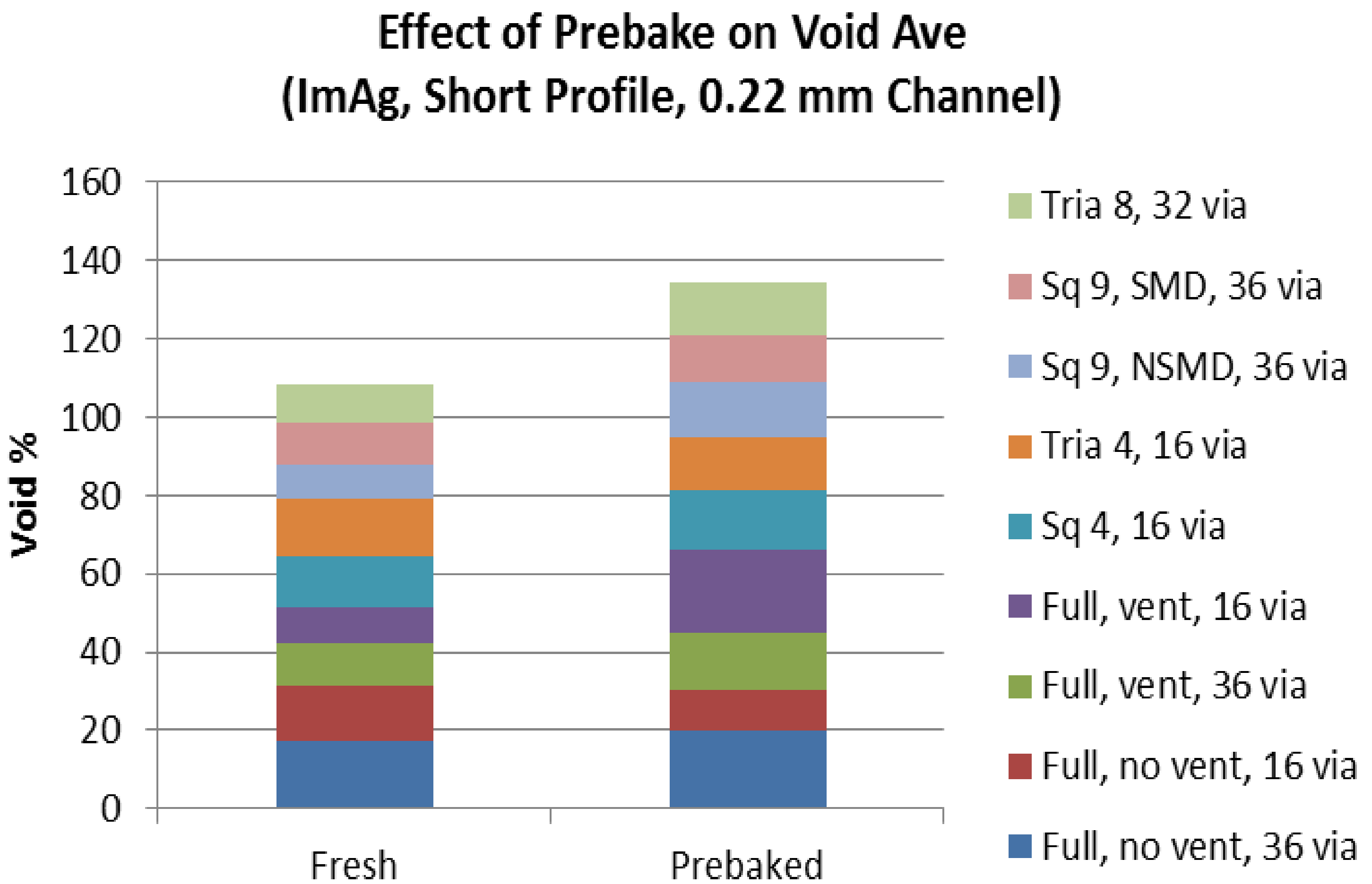




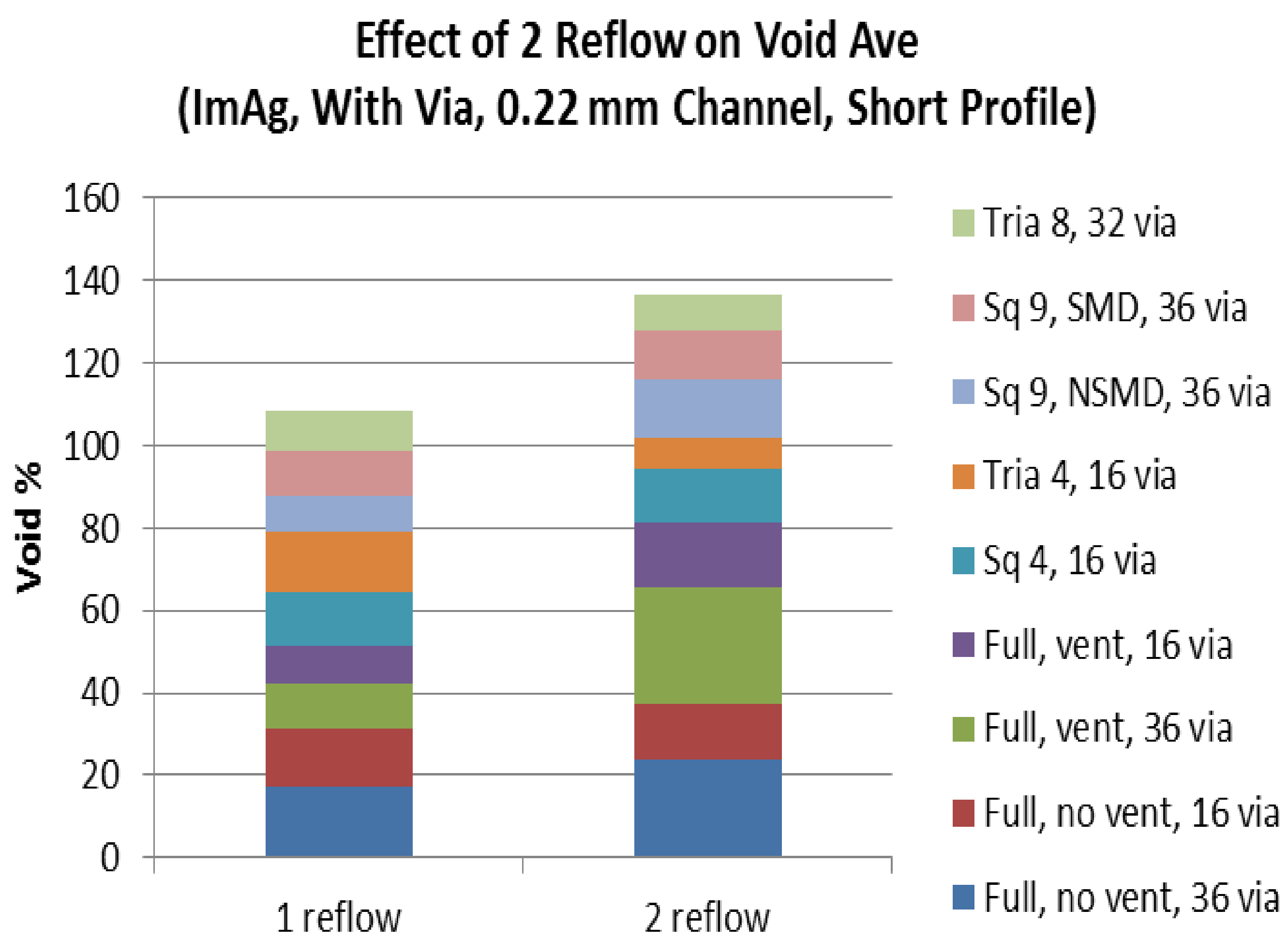




Prebake Aggravate Voiding Due to More Oxidation



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

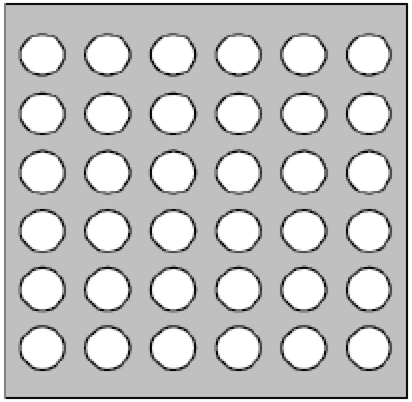


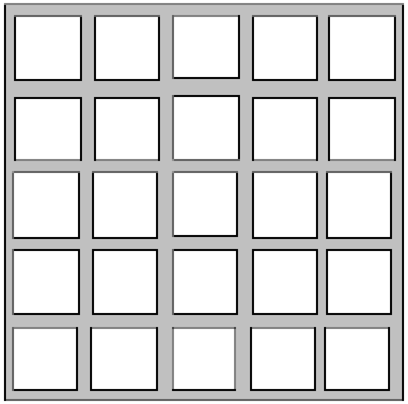
Discussion (1)

- 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