The Effects of Non-filled Microvia in Pad on Pb-free Solder Joint Reliability of BGA and QFN Packages in Accelerated Thermal Cycling

Joe Smetana, Alcatel-Lucent, Plano, TX
Thilo Sack, Celestica, Toronto, Canada
David Love, Oracle, Santa Clara, CA
Chris Katzko, TTM (Meadville), China

Abstract
The High Density Packaging Users Group (HDPUG) Consortium has completed an experiment to investigate the effect of non-filled microvias in SMT solder joint pads and the associated solder voids on Pb-free solder joint reliability. Solder joint fatigue life for identical components soldered to pads with and without microvias was compared using air-to-air thermal cycling. Testing was carried out using three different BGAs having solder ball sizes ranging from 0.46mm diameter to 0.89mm diameter as well as a 72 I/O QFN. Weibull plots of the failure distributions are presented along with failure analysis and correlation of void size as measured by X-ray and observed cycles to failure.

Background
Voids from solder joints have shown to have an impact on solder joint life[1,2,3,4,5,6]. The impact of the void varies depending on the size and number of the void(s), and in particular the location of the voids relative to the crack or failure path. Microvia in pad constructions using non-filled (conformal) microvias result in a small void associated with the microvia in pad[7]. With SnPb soldering, microvia in pad constructions, when properly fabricated, the associated small voids located at the base of the solder joint have virtually no impact on BGA thermal cycle reliability as shown in the example of figure 1[8]. This is believed to be primarily due to the failure location almost always is on the package side of the component, away from the small void formed above the microvia as shown in Figure 2. With Pb-free SnAgCu (SAC) solders, the failure location is still most often on the component side of the solder joint, but is found on the board side of the solder ball much more frequently than with SnPb soldering. Additionally, SAC solder is stiffer than SnPb solders and has significantly different physical properties. This greater stiffness changes the distribution of stresses in the solder joints during thermal cycling. For these reasons, one might expect microvia associated voids to have a greater impact on Pb-free solder joints than on SnPb joints. The purpose of this study is to determine whether microvia-in-pad construction negatively affects thermal cycle reliability of SAC solder joints and, if so, whether increased voiding characteristic of this construction is a causative factor. A positive finding would support the need for using an alternative to conformal microvias [9,10,11,12,13] such as epoxy filled and capped or copper filled microvias that eliminate the void associated with the microvia. Implementing such alternatives would result in a cost penalty at fabrication (typically ~5-6% but board design dependent) compared to conformal microvias and would reduce the supplier base to only fabricators capable of providing the filled microvias.

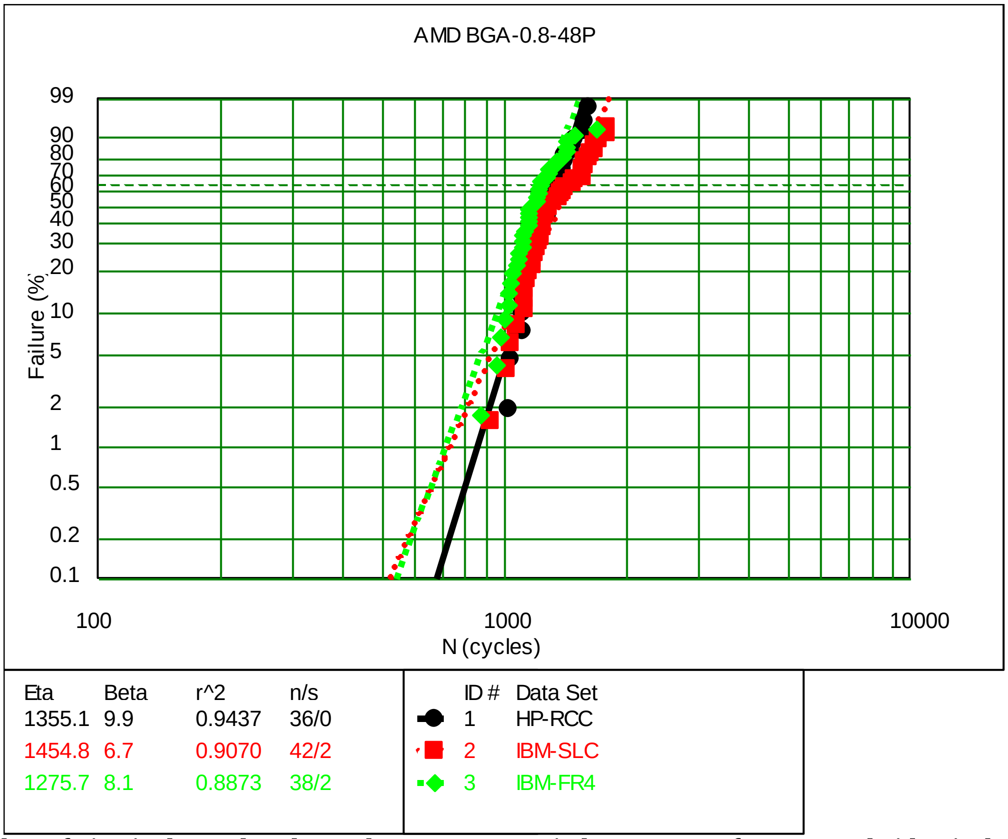


Figure 1: Weibull Plots of air-air thermal cycle results on a 0.8mm pitch 48IO BGA from 3 nearly identical artwork boards with minor differences in construction of outer layers assembled at the same time with SnPb solders. Two of these constructions (SLC and RCC) had microvia in pad (conformal). The all FR4 construction did not.

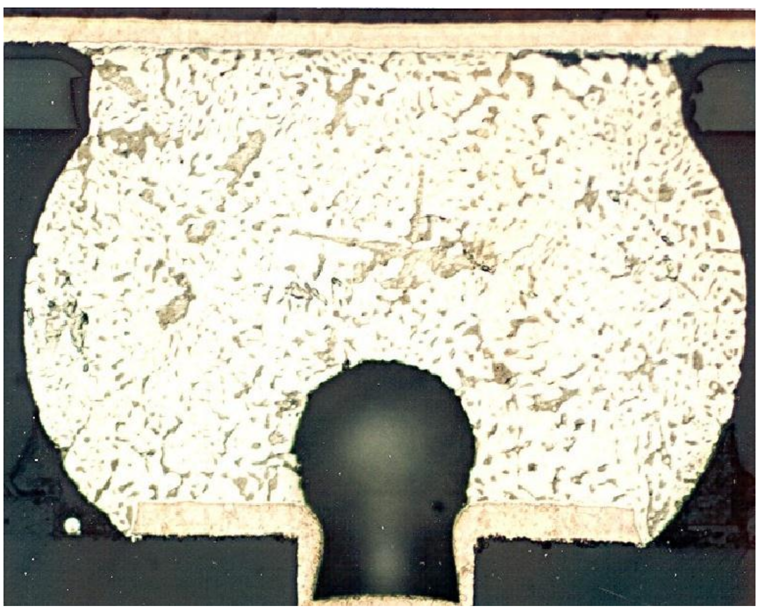


Figure 2: Example of a conformal microvia in pad and associated void in a SnPb assembly after thermal cycling. Fatigue crack is away from the void.

Overview of the Testing

The project goal was to determine what effect, if any, microvia-in-pad construction has on reliability of BGA and QFN SAC solder joints as characterized by air-to-air thermal cycling and whether the increased incidence of voiding characteristic of this construction has a causative relationship.

This was accomplished by building a test vehicle with both microvia-in-pad and no via-in-pad, thermal cycling to failure and comparing the results. BGAs with 3 different solder ball sizes and a QFN package were used for the evaluation.

Test Board Design

The test board was designed to have 4 each of 4 different component types. Table 1 lists the Bill of Materials (BOM) with details on the component types, die sizes, and ball sizes for each type. Components were chosen to represent different solder ball diameters. The solder ball diameter of the 0.8mm pitch BGA is within the typical range of solder ball diameters also found on 1mm pitch BGAs. Two of each component type were designed with a microvia in the SMT pad. The other 2 were designed with a fan-out to a microvia as shown in figure 3. Figure 4 shows a detailed example of the footprint and via fan-out for the BGA 192 component. The daisy chain connections were all on layer 2 of the design. The nominal board component pad sizes for each component are as follows:

CBGA483: .0285 inches diameter
BGA192: .014 inches diameter
BGA84: .010 inches diameter
QFN72: .011 x .049 inches

Table 1: Test Board Components, 4 each per board

Part Type	Body Size (mm)	Die Size (mm)	Pitch (mm)	Solder Ball Size (mm)	Solder Ball Alloy	Supplier	Comments
CBGA 483	29 x 29	NA	1.27	0.89	SAC405	NTK (Solder Balls added at Premier Semiconductor)	Ceramic. Supplied as LGA.
CABGA 192	14 x 14	12.065 x 12.065	0.8	0.46	SAC305	Practical Components	
CTBGA 84	7 x 7	5.08 x 5.08	0.5	0.3	SAC305	Practical Components	
QFN72 (MLF)	10 x 10	6 x 6	0.5	NA	NA	Practical Components	

The bare board is a 6 layer, 0.125 inch (3.175mm) thick, 7.0 x 6.5 inch (177.8 x 165.1 mm) design using a high Tg filled phenolic FR4 material and immersion silver surface finish. The prepregs between layers 1-2 and 5-6 were 2113 glass for a nominal thickness of approximately 3.3 mils and the laser drilled vias were drilled at a nominal dimension of 6 mils. This thickness and hole size combination was selected to represent the worst case hole size and thickness typically found in a conformal microvia-in-pad construction and thus represent the worst case voiding from a microvia-in-pad at assembly.

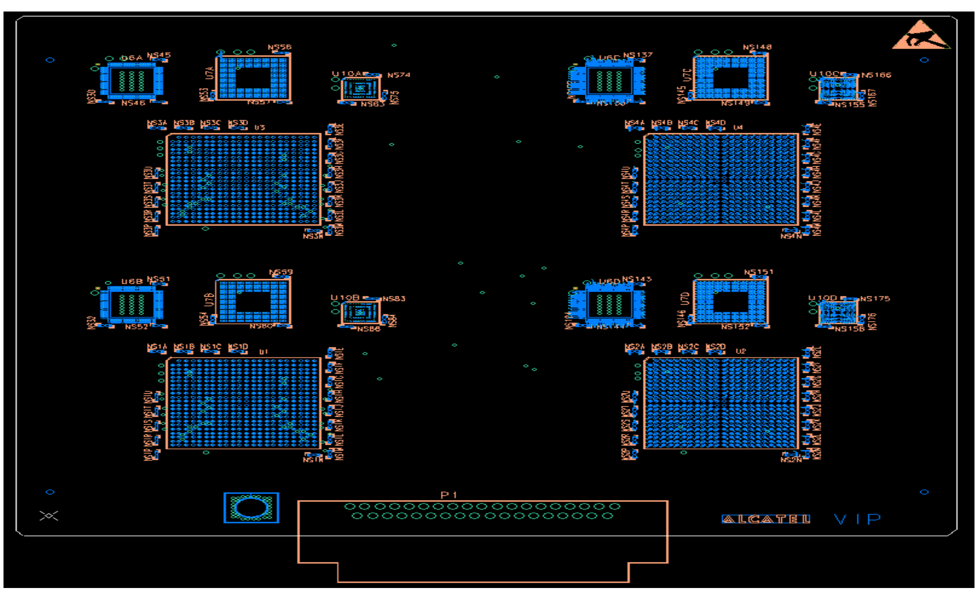


Figure 3: Test Vehicle design. 2 sets of components on the left side have microvia-in-pad. 2 sets of components on the right side do not have microvia-in-pad.

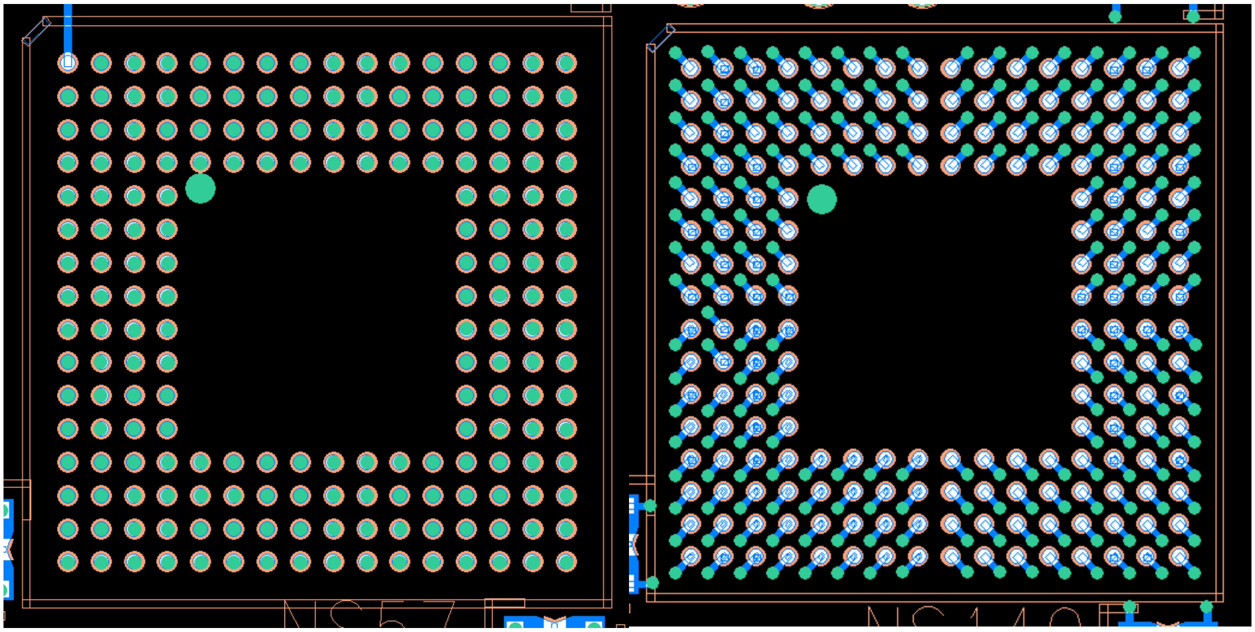


Figure 4: BGA192 – Left with Microvia in pad, Right, with fan out, no microvia in pad.

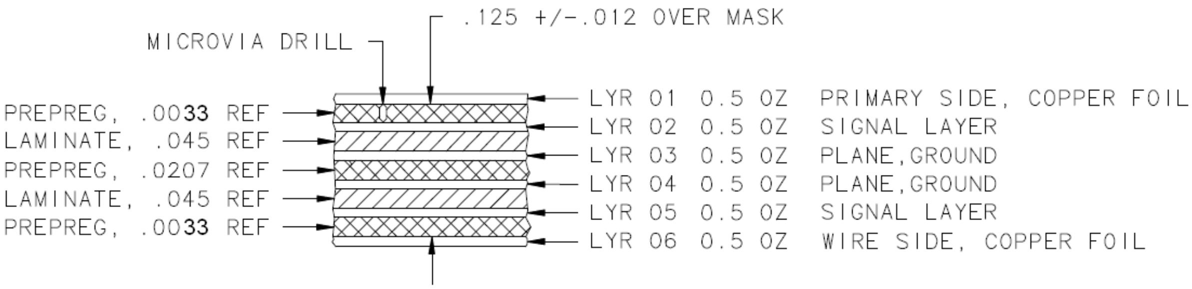


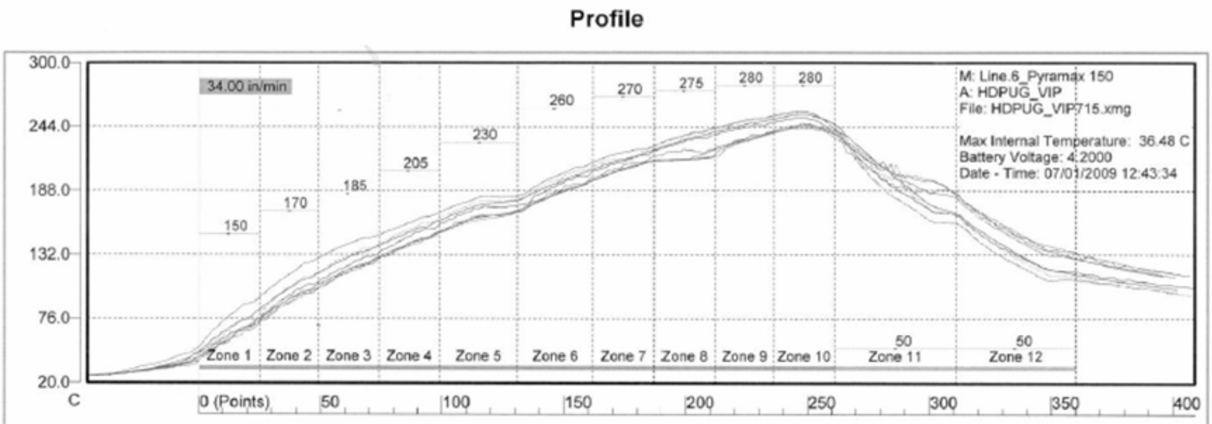
Figure 5: Board Stackup

Sample Size

16 boards, totaling 64 components of each type were tested, 32 with microvia-in-pad and 32 without microvia-in-pad.

Assembly

Assembly was performed at Celestica Thailand with a typical Pb-free SMT process using SAC 305 solder paste and the reflow profile shown in Figure 6. 40 boards were built in total (16 boards for ATC testing, 10 for the Micro-structure evolution project and the remaining for spares and additional testing and a setup board). After assembly, boards were tested electrically for continuity and X-rayed for voids using 5DX 3-D X-ray laminography. Two boards failed electrical testing. The root cause of both of these was broken internal wire bonds on the QFN72 packages. In X-ray, 21 boards out of 40 failed to meet the IPC-7095A Class 2 requirements for voiding in BGA solder balls (Reject class 2 if void size is greater than 45% of ball diameter or 20% of ball area). Six of these rejects were in locations with no microvia-in-pad, 15 of these were in locations with microvia-in-pad. The voiding found in the components without microvia-in-pad was attributable to voiding in the solder balls of the BGAs as received (see Figure 7). No doubt a portion of the rejects for voiding in the microvia-in-pad locations were also associated with voids in as-received BGAs. Nevertheless, there was a clear impact from the microvias on the existence of voids larger than the IPC criteria. Figure 8 shows the assembled test vehicle.



		Maximum Temperature	Maximum Positive Slope	Maximum Negative Slope	Time Between Temperature	Time Between Temperature	Time Above Temperature: Total (+/-)
		||	||	||	|130-220C|	|170-220C|	220C
		C	C/sec	C/sec	sec	sec	sec
A1	U10C_BALL CENTE	257.8	1.7	-2.3	121.0	71	97
A2	U7B_BODY	252.0	1.5	-2.0	116.0	74	84
A3	U4_BODY	246.8	1.4	-1.7	115.0	60	77
A4	U4_BALL CENTER	242.9	1.3	-1.4	138.0	84	58
A5	U4_BALL CORNER	256.9	1.6	-2.0	119.0	76	91
B6	U1_BALL CORNER	244.2	1.3	-1.5	137.0	82	62
B7	U1_BALL CENTER	254.8	1.5	-1.9	121.0	74	92
B8	U7B_BALL CORNE	245.4	1.4	-1.5	133.0	75	64

Figure 6: SMT Reflow Profile

Figure 7: Voiding in the BGAs identified after assembly and as received.

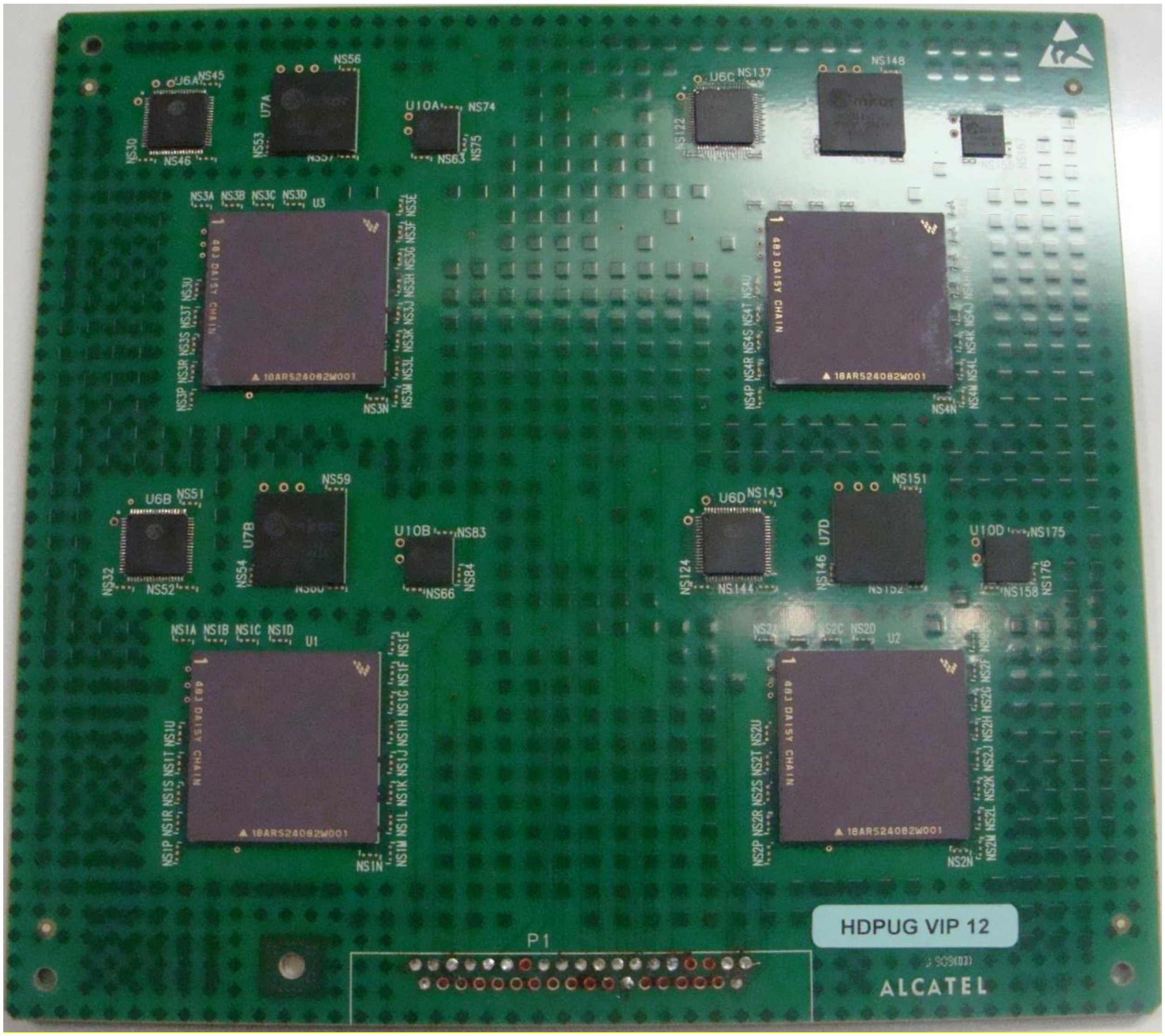


Figure 8: An assembled test vehicle

Thermal Cycling

The finished assemblies were thermal cycled from 0-100ºC with 10 minute ramps and 10 minute dwells at the temperature extremes. Cycling was stopped after 4279 cycles. See figure 9 for the actual thermal cycle.

During temperature cycling, event detectors are used to monitor the resistance through the piece part daisy chain nets. A failure is considered a resistance reading of 300 Ohms or higher in the practice of IPC-SM-785 and is logged with the associated cycle count to provide a record of exact cycles to failure.

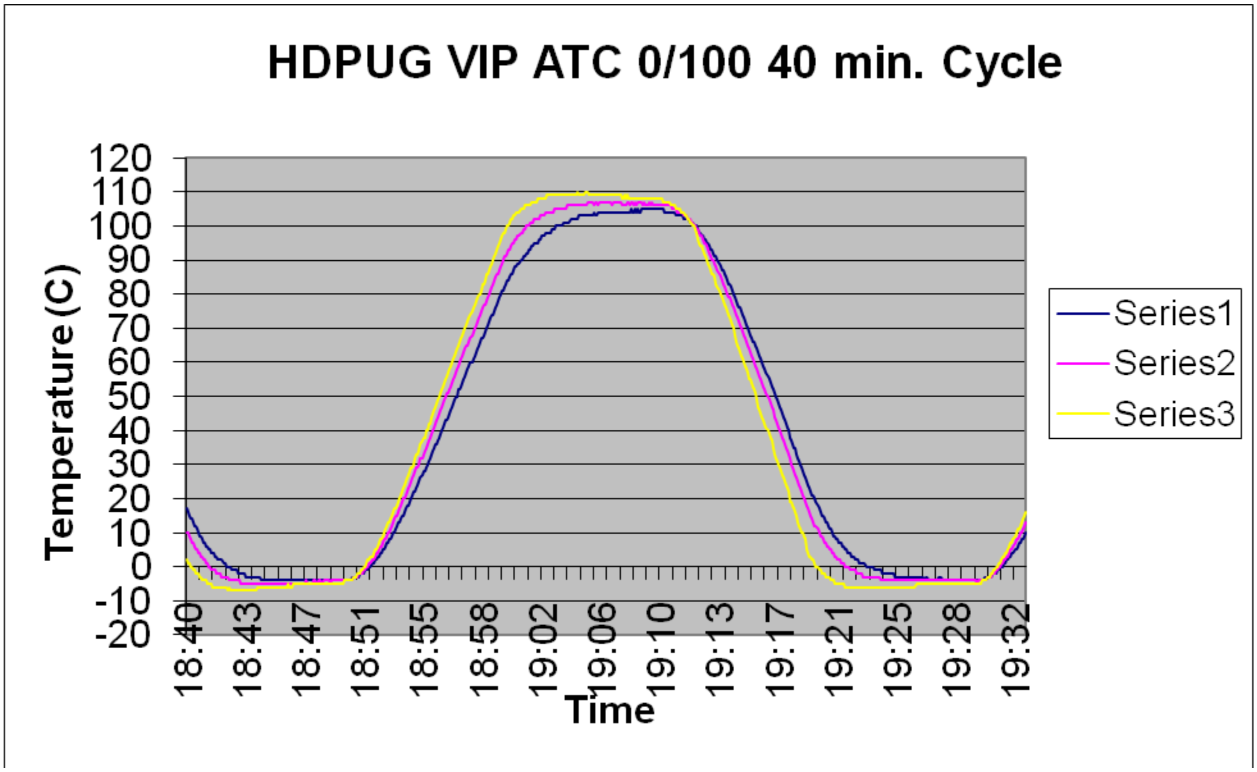


Figure 9: Air-Air Thermal Cycle Profile

Weibull and Regression Analysis

Extensive Weibull and regression analysis was completed on the failure data. The BGA84 had no failures through the entire 4279 thermal cycles. Figure 10 shows the Weibull plots for the CBGA 483. Statistically, these failure distributions are different at greater than 99% confidence. This data shows a 9% increase in the characteristic life without the microvia-in-pad, compared to the via-in-pad condition, and it also shows a statistically significant difference in the slope (Beta) of the distribution, such that the first failures for the microvia-in-pad components occur after the first failures for the no microvia-in-pad case. Weibull plots are shown, but the lognormal distribution is actually a better fit for these data sets. When combined into a single data set, the fit to a lognormal distribution is still excellent, though not as good statistically as either of the individual data sets. Given this, and the relatively small differences between the data sets, it can be stated the impact of the voids from a microvia-in-pad on this component is minor, and in practical application can generally be ignored. This may be due to the large solder ball size of this component.

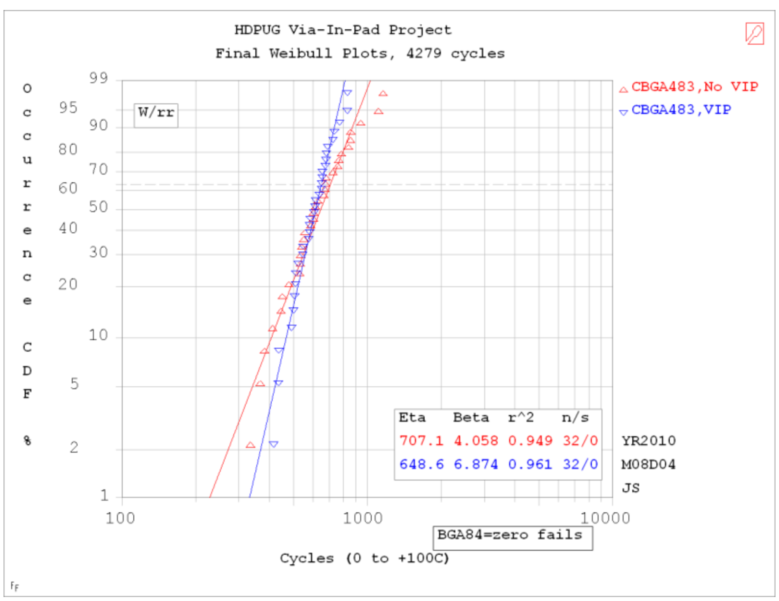


Figure 10: Weibull Plots of the CBGA483 failure data

Figure 11 shows the Weibull plots for the BGA192 components. The characteristic life of the no microvia-in-pad construction is 57% better than that of the same component with microvia in pad. The slopes (beta) of the 2 different distributions are not statistically different. The distributions are again best fit to the log normal distribution (not shown), but the conclusions are the same either way; the microvia-in-pad construction has a significant negative impact on the BGA solder joint reliability in accelerated thermal cycling for this component and solder ball size.

Figure 12 shows the Weibull plots for the QFN72 components. The characteristic life of the no microvia-in-pad construction is 12% better than the characteristic life of the microvia-in-pad construction. Additionally the slope (beta) of the distributions is larger for the no microvia-in-pad construction such that the time to first failure is significantly better also. These distributions both fit well to Weibull as plotted. In summary, the microvia-in-pad construction has a significant negative impact in the solder joint reliability of the QFN72 in this test.

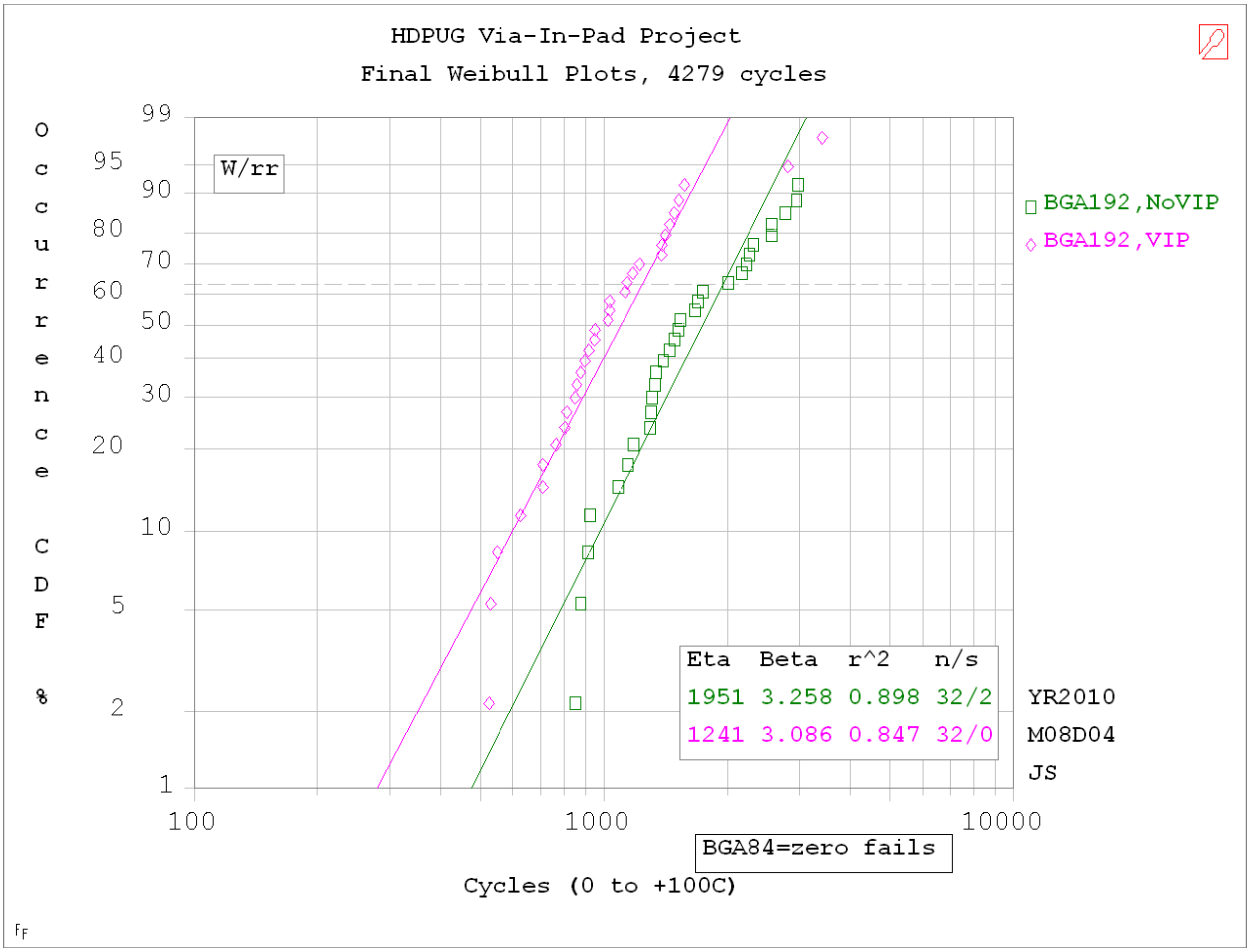


Figure 11: Weibull Plots of the BGA192 failure data

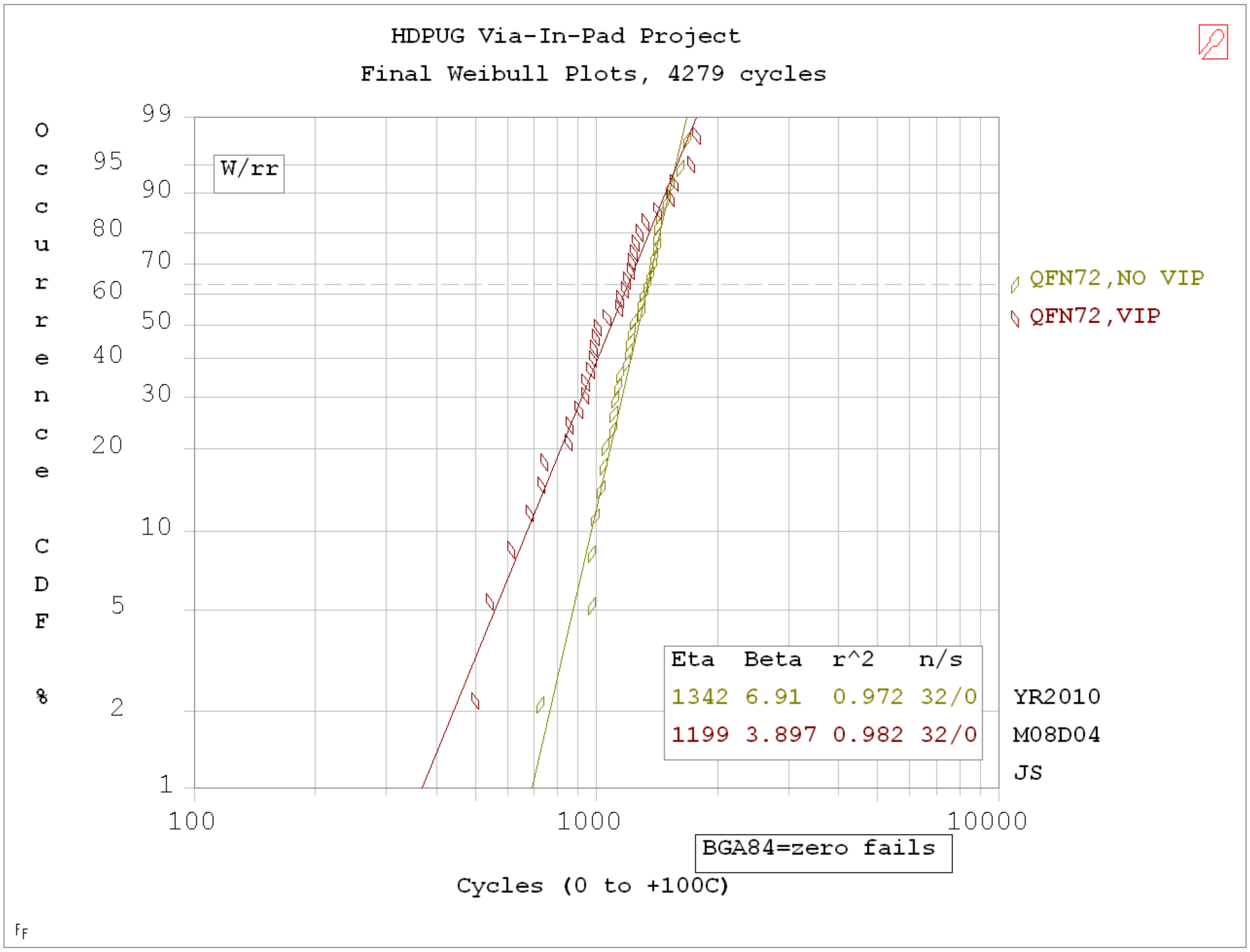


Figure 12: Weibull Plots of the QFN72 failure data

Voiding Analysis
Since it is hypothesized that the differences between the thermal cycle performance of the microvia-in-pad (VIP) versus the no microvia-in-pad (No VIP) constructions result from differences in voiding, an attempt was made to correlate the voiding in the solder balls to the failure cycles experienced. On the BGA192 (which has a large die compared to the package) and CBGA483 (which is ceramic and has a largely homogenous CTE across the component) components, the expected failure locations for these parts are the corner solder balls as they have the largest distance to neutral point and the greatest stresses during thermal cycling. As such, comparing the total voiding across the package would not be a viable comparison. Instead, the voids located specifically in the corner balls on the package or in the solder balls immediately adjacent to the corner balls were analyzed for their void percentage in volume and area and regression analysis completed comparing voiding to the failure cycle.

Table 2 gives a summary of the voiding on these components in the corner and adjacent solder balls. For the CBGA483, where the impact of VIP is minimal on the thermal cycle performance, every component had some voiding on either the corner or adjacent solder balls, regardless of whether there was VIP or not. The average void percentage in both area and diameter was significantly greater for the VIP construction, and the maximum void percentage exceeded 50% (both diameter and area) for the VIP and 30% and 10%, diameter and area respectively, for the no VIP construction. The VIP construction clearly has an impact on the amount of voiding. However, a study was done to determine if the voiding could be correlated to the failure cycle. In all cases, the correlation coefficient is less than .01. Figure 13 provides just one example of the lack of correlation between void percentage and failure. The component with the highest voiding percentage (area and diameter) in the corner or adjacent solder balls, with over 50% was not the first part to fail, but rather the sixth, and a component with 20% (diameter) and 3% (area) voiding failed before it. The voiding percentage in the corner and adjacent solder balls, where the failure is expected, does not correlate to the performance of the CBGA 483 component in accelerated thermal cycling.

For the BGA192, where the presence of VIP has a significant impact on the thermal cycle performance, the average void % in diameter and area on the corner and adjacent solder balls is roughly four times greater for the VIP construction than the non-VIP construction. Additionally a much greater percentage of the components had voiding in the corner or adjacent solder balls with VIP than without (97% vs. 25%). The maximum void percentages on this component were not dramatically different, however (37% vs. 30% in diameter, 14% vs. 9% in area). As with the CBGA analysis, there was no correlation between the failure cycle in thermal cycling vs. the void percentage in area or diameter. Figure 14 provides an example.

The BGA 84, which had no failures in this thermal cycle testing, had similar results to the BGA 192 with a significantly greater amount of voiding on the VIP construction compared to the non-VIP construction. As with the BGA 192, the maximum void percentages were not notably different. Since there were no failures during the thermal cycling, no correlation can be performed to compare the voiding percentages to the failure cycles.

In summary, microvia-in-pad increases the amount of voiding in BGA solder joints, but the voiding percentage in area or diameter on the corner and adjacent solder balls does not correlate to the failure cycle in thermal cycling. For the boards tested, none of the BGA 192 or BGA 84 components had voiding in the corner or adjacent solders balls exceeding the IPC 7095A Class 2 requirements. The CBGA 483 components did have one component that exceeded the IPC requirements in the corner or adjacent solder balls. Twelve CBGA 483 components, out of 64 total, failed before this specific component during the testing.

Table 2: Summary of the Voiding Statistics for the Corner and adjacent solder balls on the BGAs

Component and whether or not VIP	Average Void% in Diameter	Average Void% in Area	Maximum Void% in Diameter	Maximum Void% in Area	# of components with no voiding in the corner or adjacent solder balls
CBGA 483 VIP	30.10	9.03	57.41	50.20	0 of 32
CBGA 483 No VIP	18.66	3.39	32.12	10.32	0 of 32
BGA 192 VIP	20.44	5.08	37.84	14.32	1 of 32
BGA 192 No VIP	5.02	1.24	30.27	9.16	24 of 32
BGA 84 VIP	14.96	3.34	27.76	7.71	9 of 32
BGA 84 No VIP	3.29	0.49	27.76	5.90	27 of 32

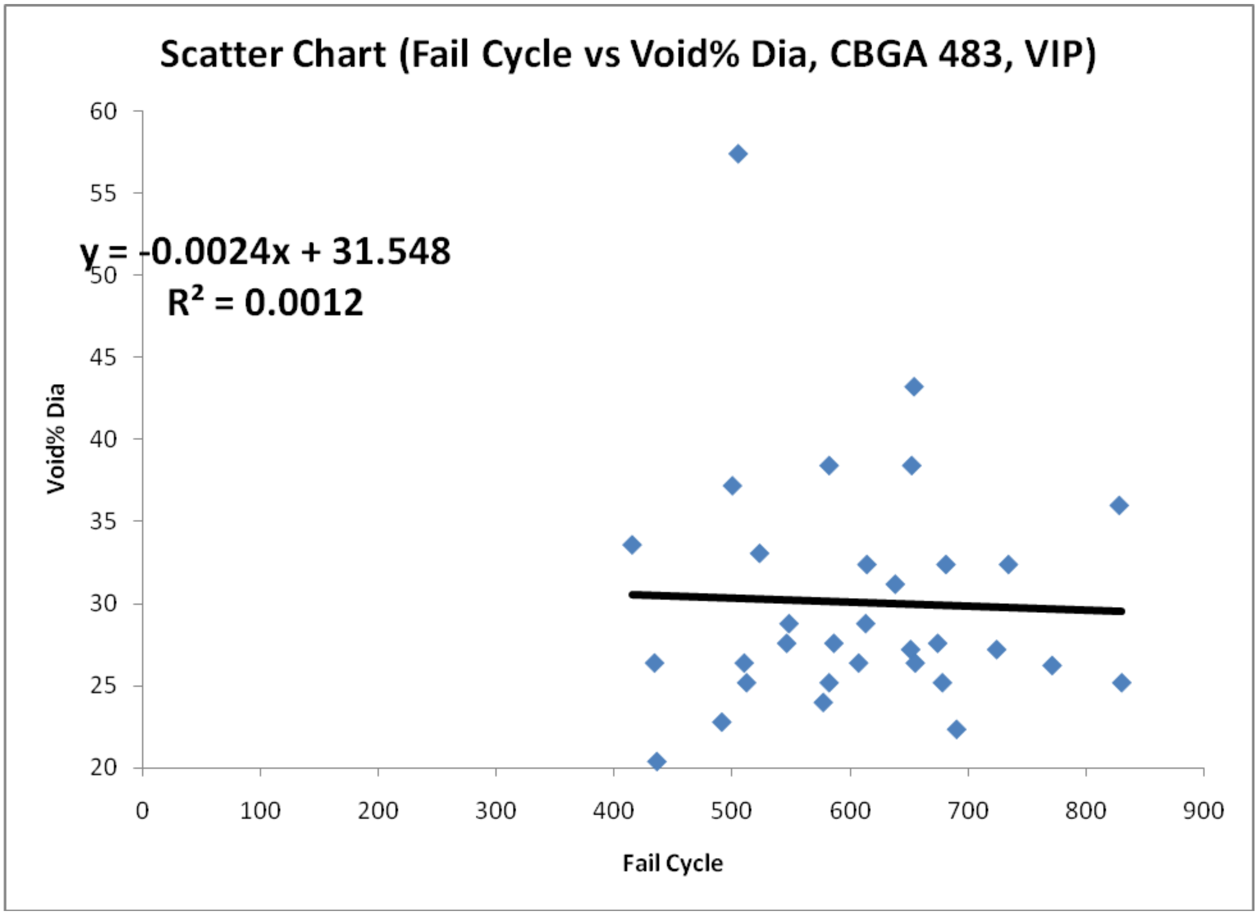


Figure 13: Scatter Chart showing the void percentage in %diameter in the corner or adjacent solder balls versus the failure cycle for the CBGA 483 component with microvia-in-pad.

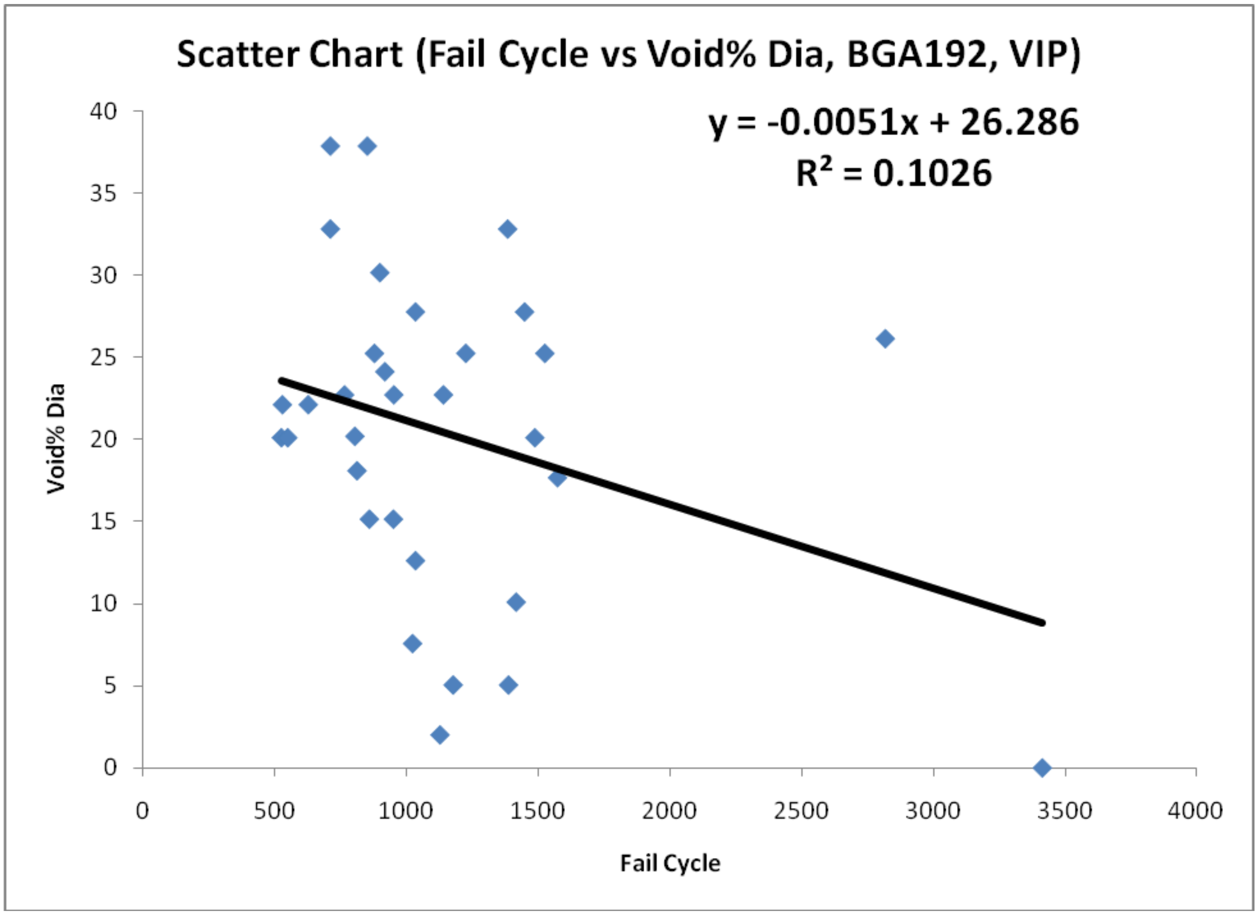


Figure 14: Scatter Chart showing the void percentage in %diameter in the corner or adjacent solder balls versus the failure cycle for the BGA 192 component with microvia-in-pad.

Failure Analysis

Limited failure analysis cross-sections were done after completion of thermal cycling, one each of every part type with and without microvia in pad. The goal was to compare the failure for microvia-in-pad construction compared to no microvia-in-pad. The expectation was that we would see a difference in the crack paths with and without microvia-in-pad. The parts selected were from the first failures in the distributions, which mean that they also experienced a large number of thermal cycles after failure, which makes it nearly impossible to identify the first failure location.

Figures 15 and 16 are representative cross-sections of the CBGA 483 with and without microvia-in-pad respectively. Both of these show that the failure locations could be either on the board or on the component side with this component. Though the void associated with the microvia in pad could be in the crack path, the influence of this void does not appear to have a major impact on the crack path. This is in agreement with the relatively small differences between the data sets as seen in the Weibull plots of the failure data for these components earlier.

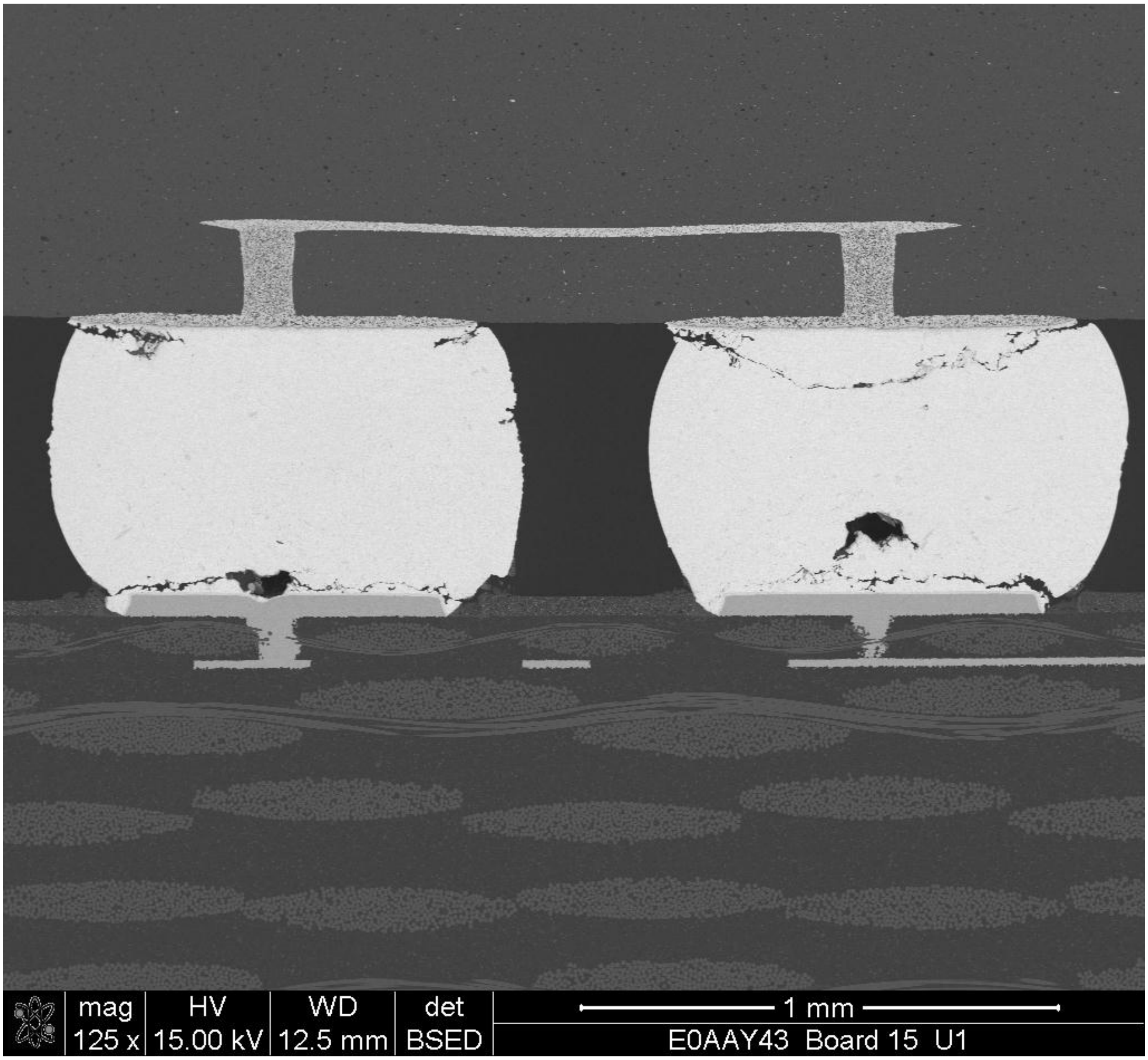


Figure 15: CBGA 483 VIP, after 4279 cycles. Failure cycle 434.

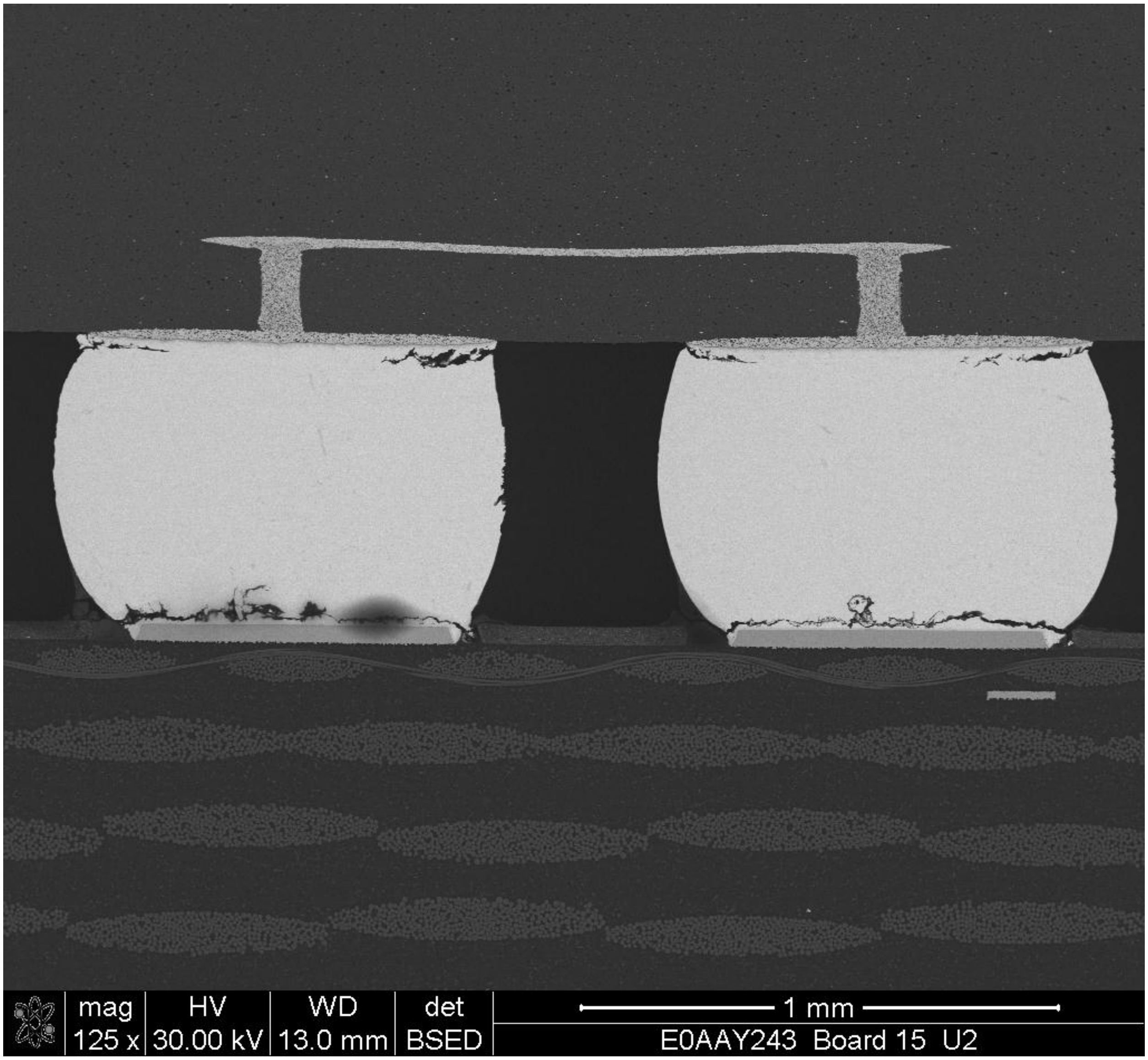


Figure 16: CBGA 483, No VIP, after 4279 thermal cycles. Failure cycle 334.

Figures 17 and 18 are representative cross-sections of the BGA 192 with and without microvia-in-pad respectively. In these samples, the crack path for the microvia-in-pad construction is on the component side away from the void from the microvia-in-pad. The crack path for the no microvia-in-pad construction, on the other hand, is on the board side (through the bulk solder adjacent to the intermetallic). If there had been a void here (potentially associated with the microvia-in pad), it would have influenced the crack path and likely reduced the life of the component (as the via size is 6 mils diameter vs. a board pad size of 14 mils diameter). This failure analysis is not conclusive, but suggests that the microvia in pad could negatively impact the life of the component in thermal cycling as was seen in the Weibull plots for these components previously.

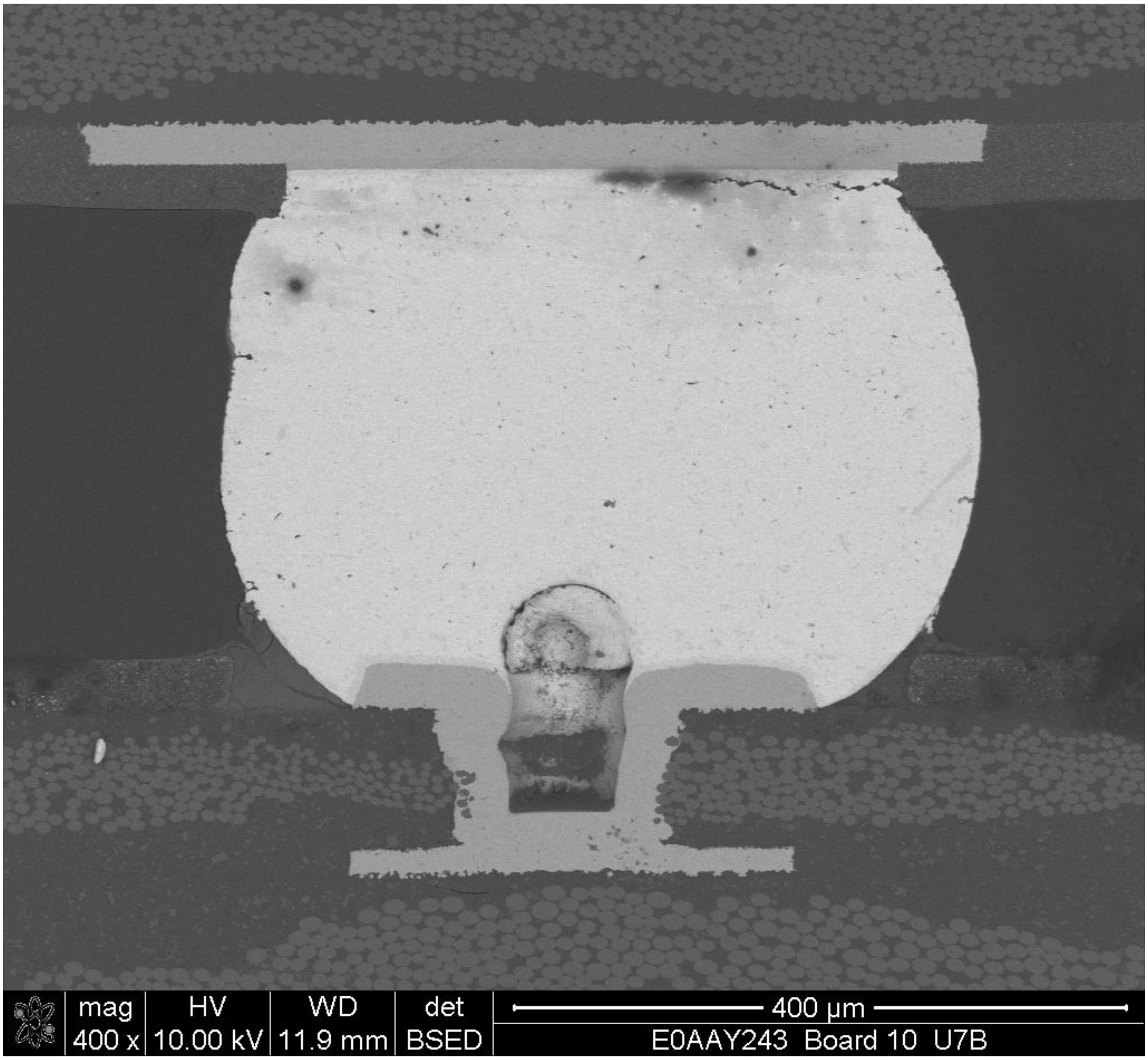


Figure 17: BGA192, VIP, after 4279 cycles. Failure Cycle 529

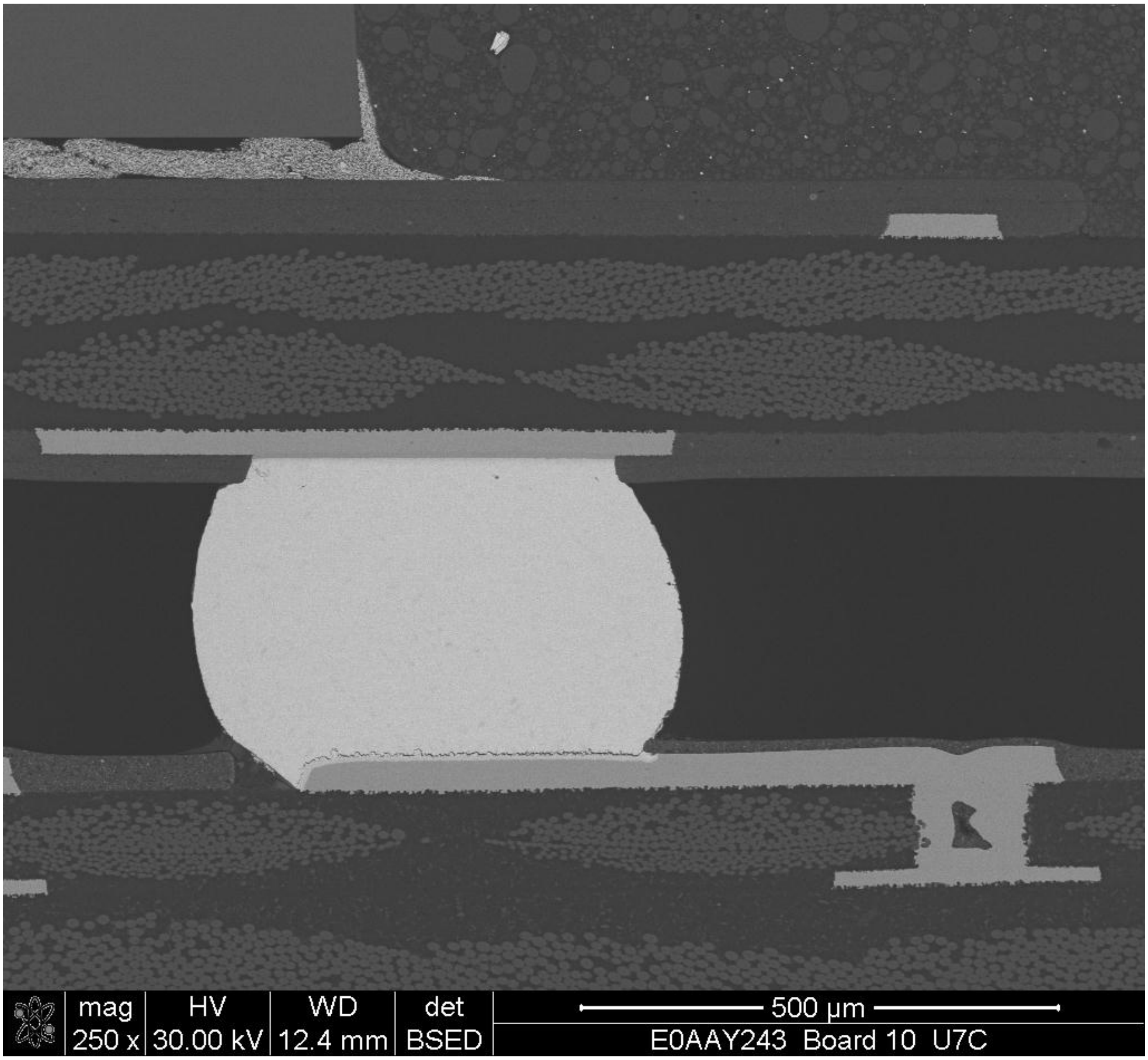


Figure 18: BGA 192, No VIP, after 4279 cycles. Failure Cycle 854

Figures 19 and 20 are representative cross-sections of the BGA 84 with and without microvia-in-pad respectively. Neither of these had failed after 4279 thermal cycles. Both of them have voids in the solder ball. In both cases, the crack paths are influenced by the void. In both cases the crack paths are near the board side, which is also near where the void is. Other cross-sections, not shown, without obvious voids in the cross-sections, show the beginnings of cracks on both the board side in one cross-section and on the component side in another cross-section. Another cross-section (not shown) that is in a solder ball without a microvia-in-pad, but has a similar size void, shows a fatigue crack from the center of the solder ball to the nearby void. This clearly shows that the solder void affects the crack path in this BGA solder ball. It does not however, conclusively show that the voiding would necessarily make the failure earlier.

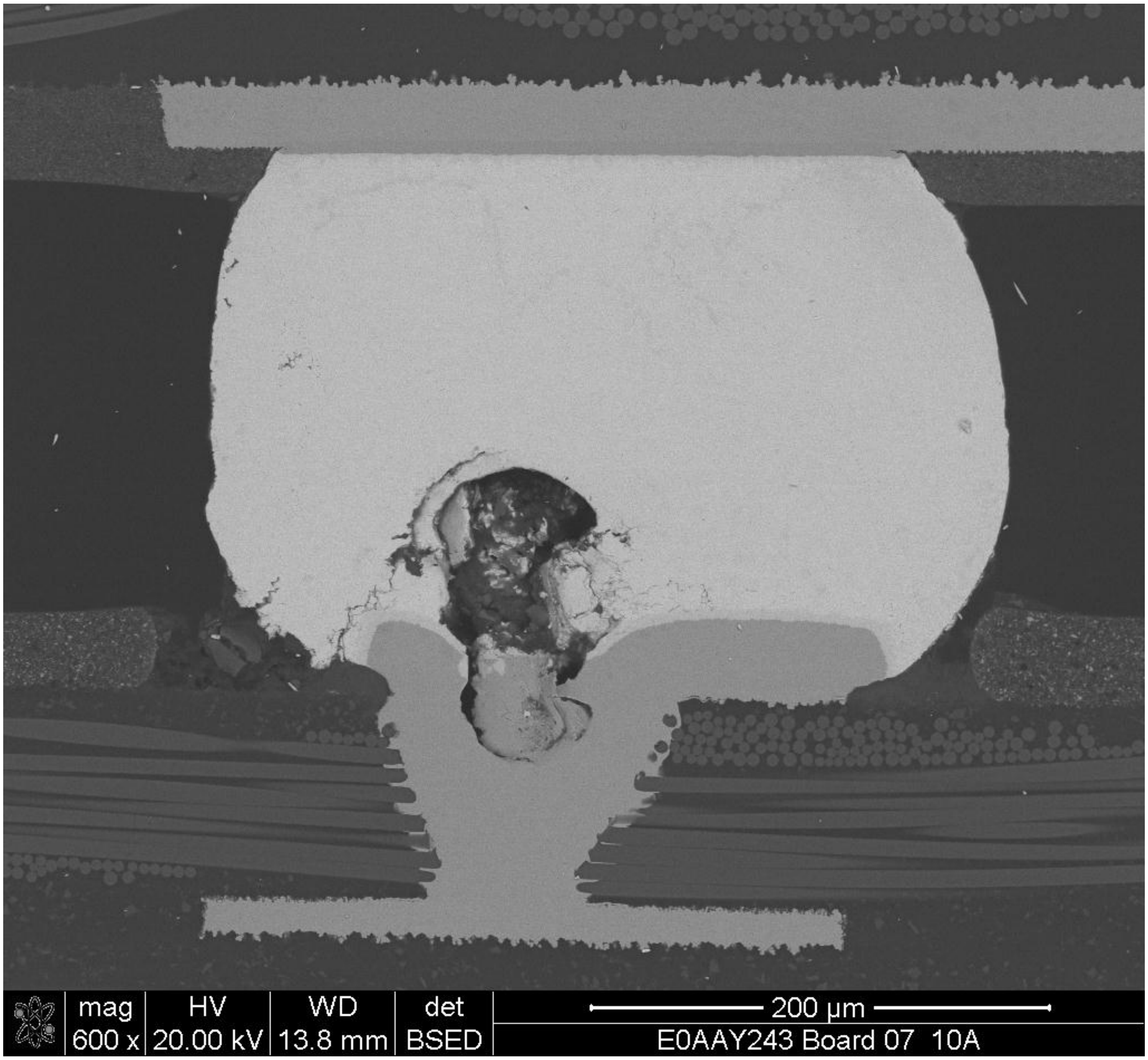


Figure 19: BGA 84, VIP, after 4279 thermal cycles. Did not fail

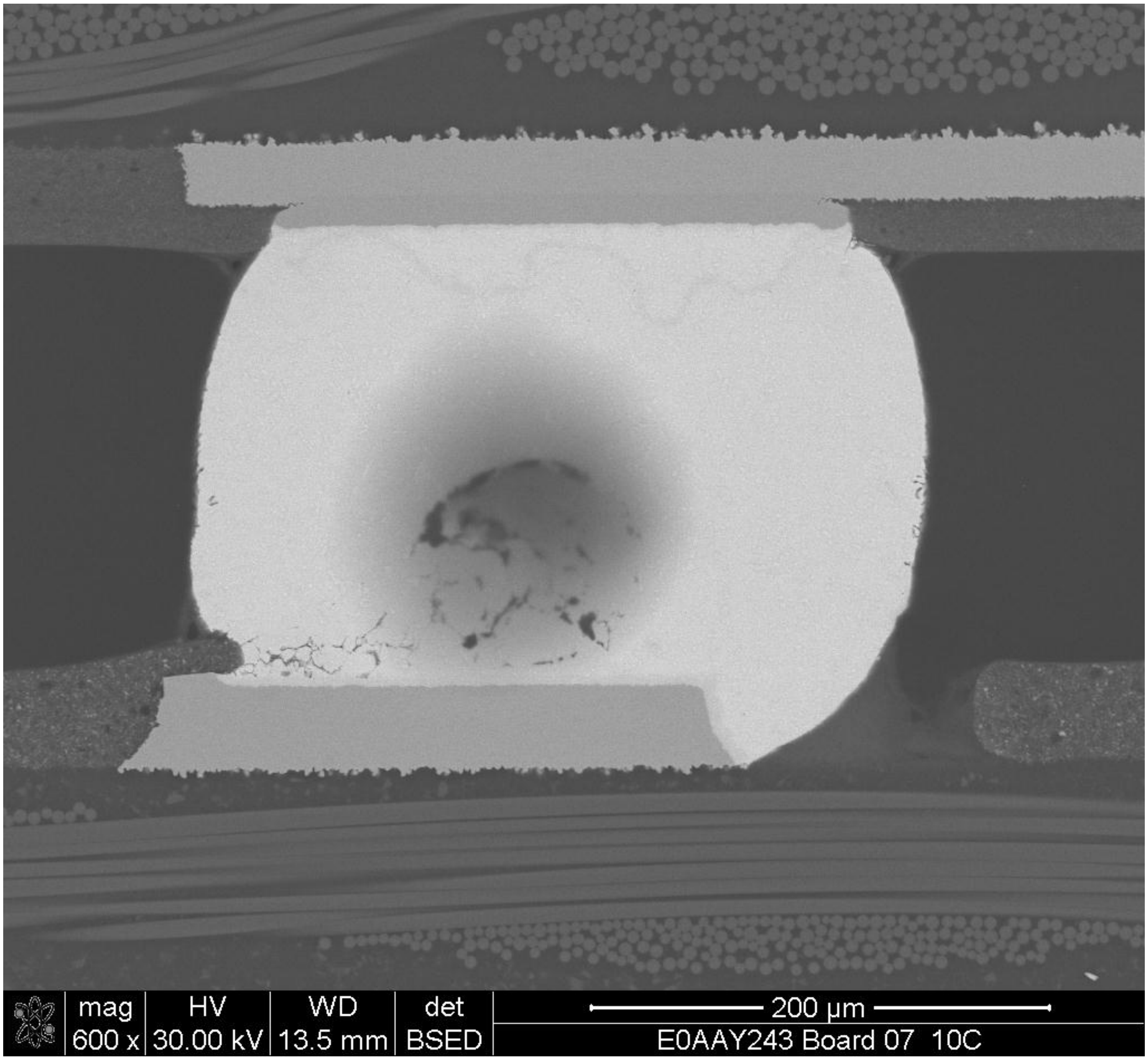


Figure 20: BGA 84, No VIP. After 4279 cycles. Did not fail.

Figures 21 and 22 are representative cross-sections of the QFN 72 with and without microvia-in-pad respectively. There is nothing obvious in these cross-sections that the small void associated with the microvia-in-pad has anything to do with the crack path or failure cycle. In fact, as can be seen from the cross-section, the microvia location is actually external to the crack path, and beyond the edge of the component. This does not correspond to the Weibull data and is unexplainable at this time.

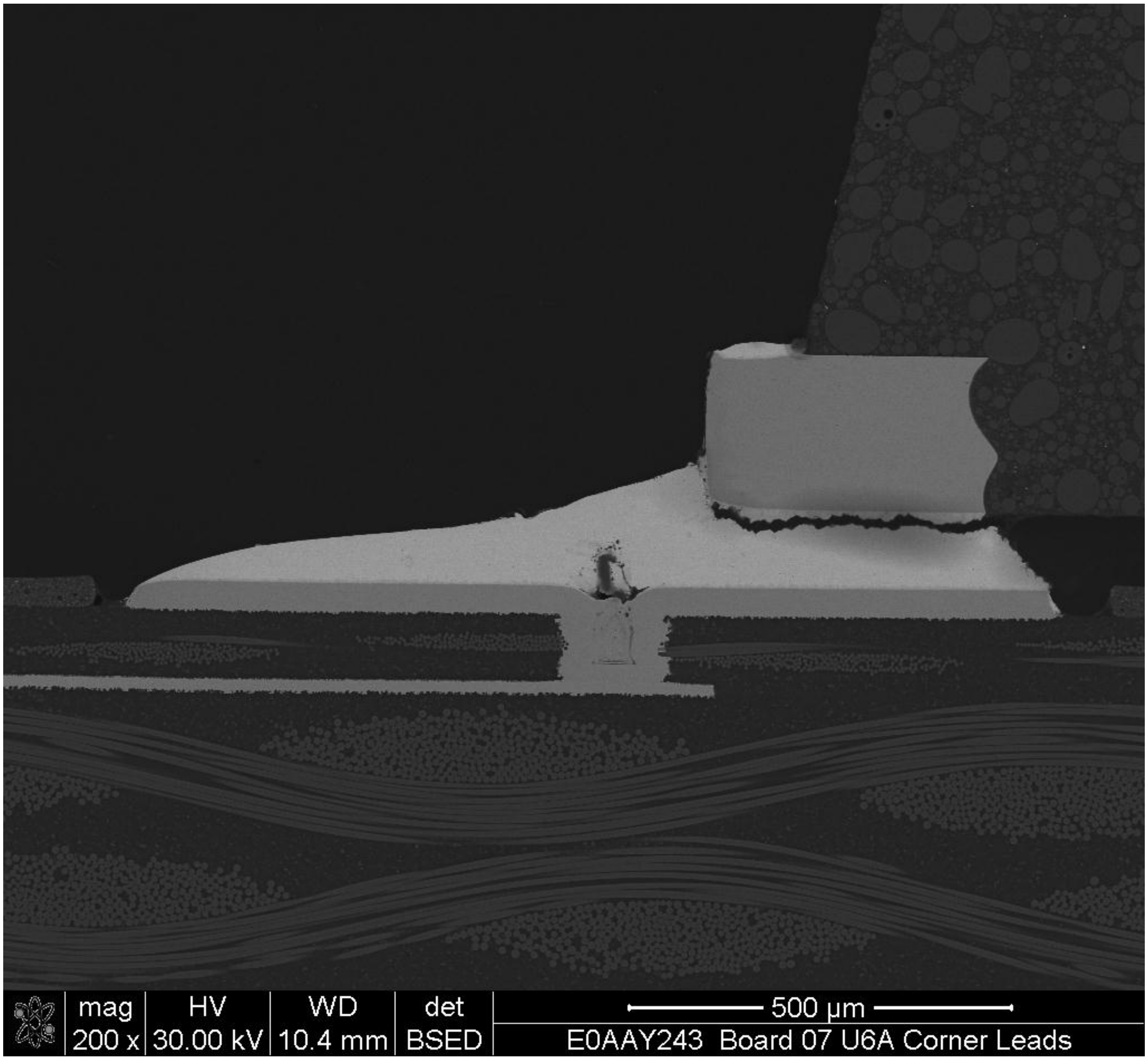


Figure 21: QFN72, VIP, after 4279 cycles, Failure Cycle 504

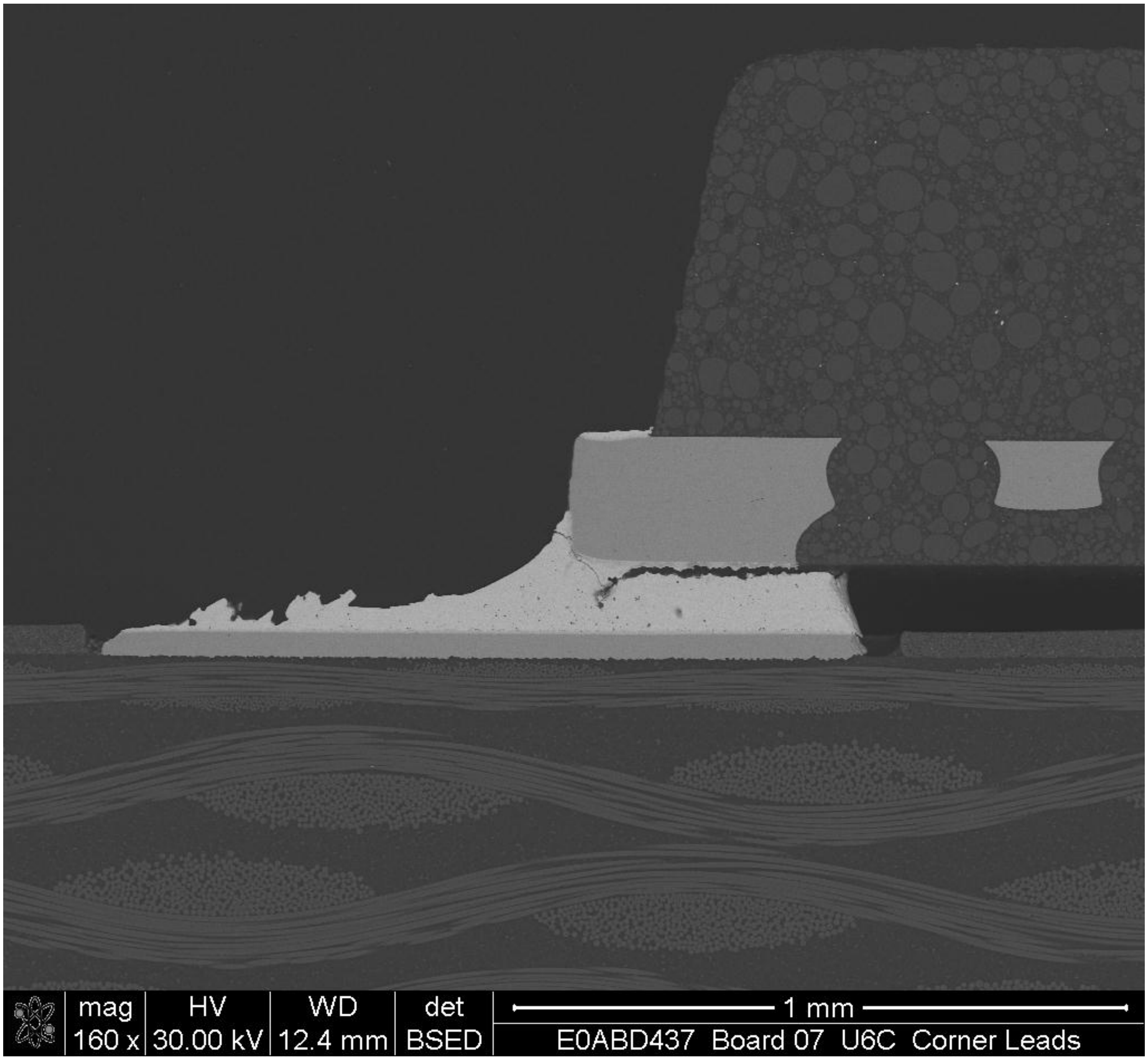


Figure 22: QFN72, No VIP, after 4279 cycles, Failure Cycle 982

Summary and Conclusions

This work has demonstrated that depending on the particular device package type, conformal microvia-in-pad constructions can have an impact on the thermal cycle reliability of Pb-free SAC alloys BGA's when soldered with SAC solders potentially requiring the use of an alternative such as a filled and planar microvias.

The voiding associated with the conformal microvia is believed to be the cause of the reduced solder joint life, however, the failure analysis results, though suggestive of this behavior, are not conclusive. The impact and size of the void associated with a microvia in pad is a function of the component type, solder ball size, microvia drill size and laminate thickness. However, the void location is arguably more important than its size having a greater potential impact on solder joint failure when located in the fatigue crack path. Based upon this, it has been hypothesized that microvia-in pad construction should result in poorer fatigue life performance for Pb-free solder joints than SnPb joints since the former exhibit a somewhat higher incidence of failure due to cracking in the board side of the solder ball where microvia related voids can influence fatigue crack propagation.

For the package types investigated in this study the reliability impact of conformal microvia-in-pad construction was found to be device dependent. Degradation in fatigue life for conformal microvia-in-pad construction compared to no microvia-in-pad construction was negligible for a large CBGA 483 with 0.89mm solder balls. Degradation in fatigue life for conformal microvia-in-pad construction compared to no microvia-in-pad construction was significant for the CABGA192 with 0.46mm solder balls, and the QFN 72. Test boards populated with CTBGA 84 packages having 0.3mm balls had no failures in thermal cycle testing (4279 cycles) for either the microvia-in-pad or non microvia-in-pad construction.

The voiding percentage in area or diameter on the corner and adjacent solder balls (the expected failure locations for these parts) does not correlate to the failure cycle in thermal cycling. For example, in the case of the CBGA 483 components, only one had voids in the corner balls exceeding the IPC 7095A Class 2 requirements and this failed after 12 others that met the voiding spec. None of the BGA 192 components had unacceptable levels of voiding in the corner or adjacent balls but showed degraded fatigue life for the microvia-in-pad construction, which, on average increases the amount of voiding in the solder joints.

Limited cross sectional analysis of both microvia-in-pad and no microvia-in-pad samples that failed during thermal cycling was done to seek direct evidence of microvia related voids supporting enhanced fatigue cracking. A few of the cross-sections showed evidence of a void in the solder ball affecting the crack path, but none of the cross-sections directly identified microvia voids enhancing the fatigue cracking. In the cross sections examined, there were several examples where the fatigue crack was on the component side rather than the board side where interaction between the void and crack could take place. The results in those cases where the fatigue crack was on the board side of the package, though suggestive that a microvia void could have had an influence on the fatigue crack propagation, were again inconclusive.

Though unfilled (conformal) microvia-in-pad can have a negative impact on the thermal cycle reliability, particularly for the BGAs with small solder balls, it may still be an acceptable construction depending on the field life requirements of the application.

Due to the density of traces in the immediate vicinity and directly underneath large pin count BGAs, these components are prime candidates for via-in-pad construction. The results of these tests indicate that the large BGA ball on CBGA, as it tends to fail at ball/package interface, may successfully be used with via-in-pad construction. This, of course, needs to be validated with the specific package and board materials/geometry set that is being planned. Unfortunately, this comes at a potential penalty in either poor assembly yields or very tight assembly process windows, due to the higher likelihood of rejectable voiding in a via-in-pad BGA component after assembly.

An alternative to conformal (unfilled) microvia in pad constructions is to use a filled and planar microvia in pad construction which eliminates voiding associated with the microvias. This can be done by either plating the microvias full or by filling (with a non-conductive material) and plating over the microvias. These options have sourcing, cost, and design considerations, separate from the technical considerations associated directly with the microvia in pad and any possible voiding.

Follow-up Work

This work examined the influence of a microvia-in-pad in a worst case construction using conformal microvias. Two potential follow-up studies could also be considered.

1) Repeat the test using filled and planar microvias in pad.
2) Repeat the test using a less challenging construction with a slightly thinner dielectric on the outer layers (such as a 1078 laser drillable prepreg) and a smaller microvia hole (such as a 5 mil drill size rather than a 6 mil drill size).

Acknowledgements

This work was completed under the auspices of the High Density Packaging User's Group Consortium (HDPUG). A number of other people were critical in making this project happen. Special thanks to the Celestica assembly team in Thailand: Teng Hoon Ng, Dussanee Chanwiboon, and Theeraphong Kanjanupathum.

---

[1] Mohammad Yunus, K. Srihari, J.M. Pitarresi, Anthony Primavera, "Effect of voids on the reliability of BGA/CSP solder joints", Microelectronics Reliability 43 (2003) 2077–2086.

[2] D.Banks, T.Burnette, Y.Cho, W.deMarco, A.Mawer, "The Effects of Solder Joint Voiding on Plastic Ball Grid Array Reliability," Surface Mount International 1996, Sept. 1996.

[3] Lau, J.H., and A.H. Jeans. "Effects of Voids on SMT Solder Joint Reliability," in Proceedings of the 2nd ASM International Electronic Materials and Processing Congress, 1989, pp. 177-87.

[4] Mawer, A.J., S.C. Bolton, and E. Mammo, "Plastic BGA Solder Joint Reliability Considerations," in Proceedings of Surface Mount International, 1994, pp. 239-51.

[5] Lee NCh, O'Hara. "Voiding in BGA" in Proceeding of Surface Mount International, San Jose, California, 1995.

[6] D. R. Banks, T. E. Burnette, Y.-C. Cho,W. T. deMarco, and A. J. Mawer, "The effects of solder joint voiding on plastic ball grid array reliability," in Proc. Surface Mount Int.'96, San Jose, Ca, Sept. 10–12, 1996, pp.121–126.

[7] Grano, F., Bruno, F., Korf, D. and O'Keeffe, E. "Impact of microvia-in-pad design on void formation", Proceedings of Surface Mount International, 2003, Chicago.

[8] Unpublished HDPUG study.

[9] Eric Stafstrom, Adam Singer, James McLenaghan and Keisuke Nishu, "Reducing Solder Voids with Copper-Filled Microvias", Circuits Assembly April 2003.

[10] George Allardyce, Mark Lefebvre, Hideki Tsuchida, Masaru Kusaka, and Shinjiro Hayashi, "Copper Electroplating Technology for Microvia Filling", Circuitree, March 2004

[11] Mark Lefebvre, Elie Najjar, Luis Gomez, Leon Barstad, "Next Generation Electroplating Process for HDI Microvia Filling and Through Hole Plating", IEEE.

[12] Maria Nikolova, Jim Watkowski, Donald Desalvo, Ron Blake, "New Generation Solution for Micro Via Metallization and Through Hole Plating". MacDermid. http://www.macdermid.com/electronics/pdf/ManuSpec_VF_100.pdf

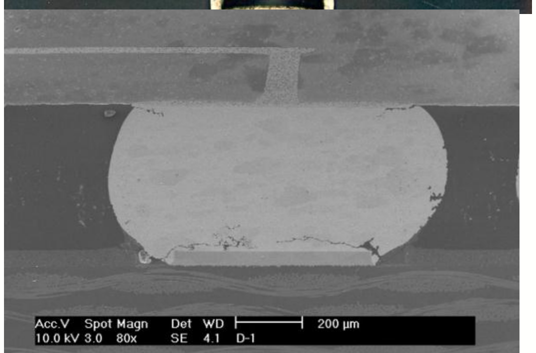
[13] Chrys Shea and David Ormerod," Copper Via Fill: A Solution for HDI Via-in-Pad", Printed Circuit Design and Fabrication, October 2007.

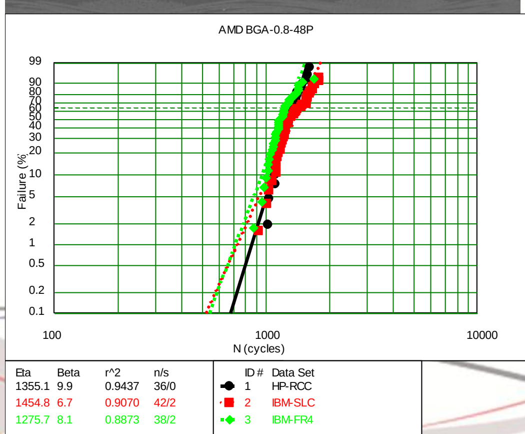
The Effects of Non-filled Microvia in Pad on Pb-free Solder Joint Reliability of BGA and QFN Packages in Accelerated Thermal Cycling

Joe Smetana, Alcatel-Lucent, Plano, TX
Thilo Sack, Celestica, Toronto, Canada
David Love, Oracle, Santa Clara, CA
Chris Katzko, TTM (Meadville), China

IPC/APEX, April 2011, Las Vegas, NV

Background





- With SnPb soldering – microvia in pad constructions (and associated small voids) have no impact on BGA thermal cycle reliability (lower left)
  - The failure location is virtually always on the package side of the component, away from the small void formed above the microvia (Top Left)
  - (This is not to say the voiding doesn’t or can’t affect SnPb solder joint reliability)
- With Pb-free SAC soldering, the failure location can be on either the component side or the board side of the solder ball (Bottom Left)
  - More likely with ceramic parts and waferscale parts.
  - The solder is stiffer than SnPb, and stresses are distributed differently in the solder joints.
  - Does the void associated with a microvia in pad negatively affect thermal cycle reliability?

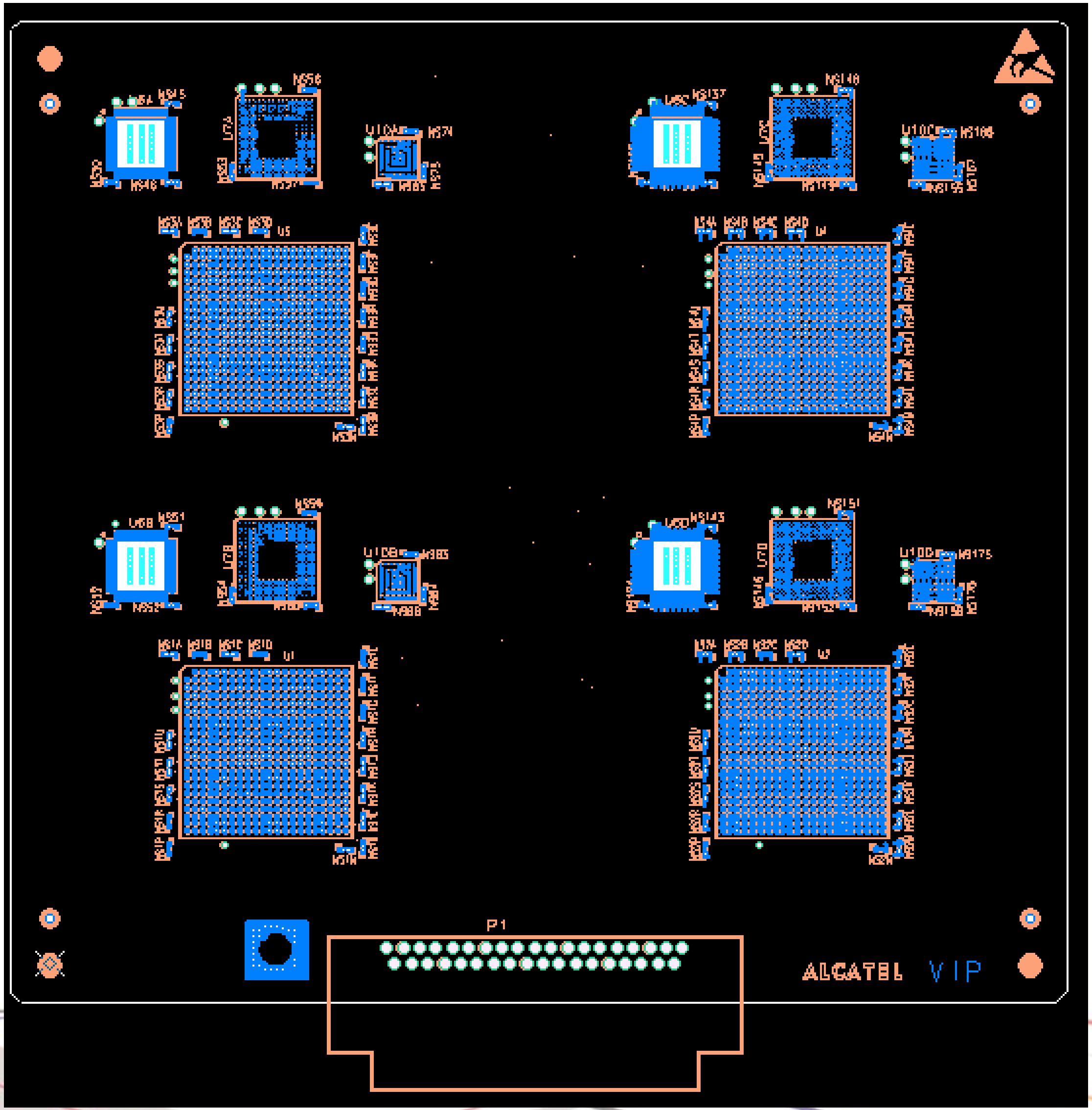
Project Goal

- Determine what effect, if any, microvia-in-pad construction has on reliability of BGA and QFN SAC solder joints as characterized by air-to-air thermal cycling and whether the increased incidence of voiding characteristic of this construction has a causative relationship

Test Plan

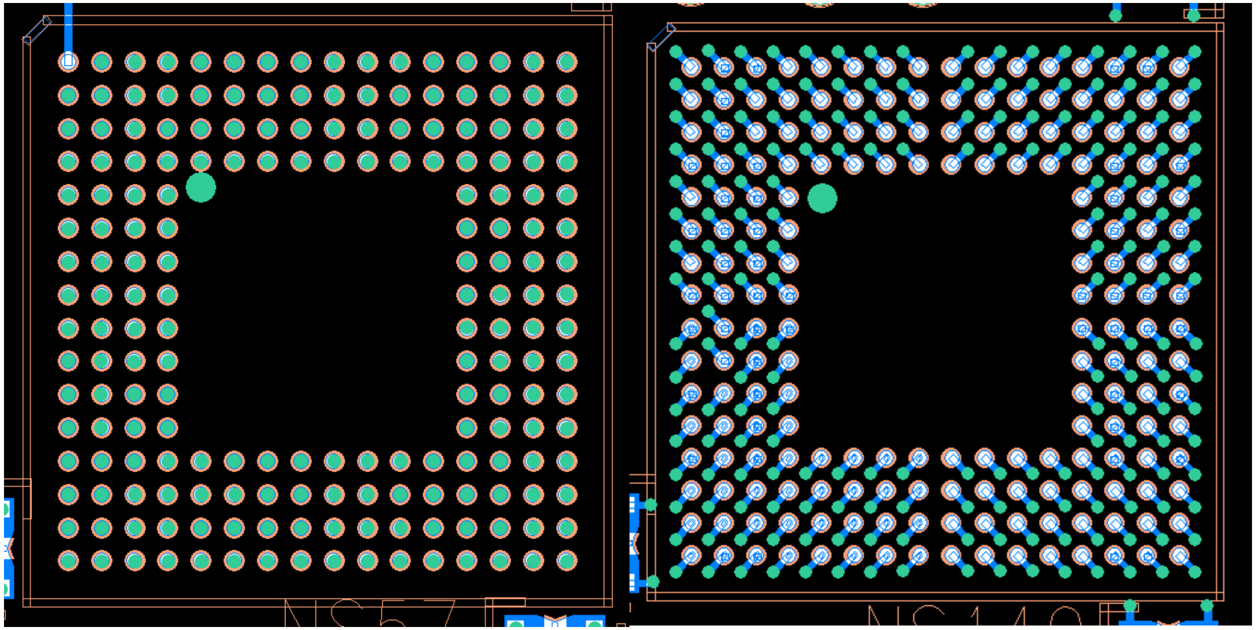
- Design and build a circuit board with components with VIP (not filled) and without.
- ATC to failure
- Compare results

VIP Test Board



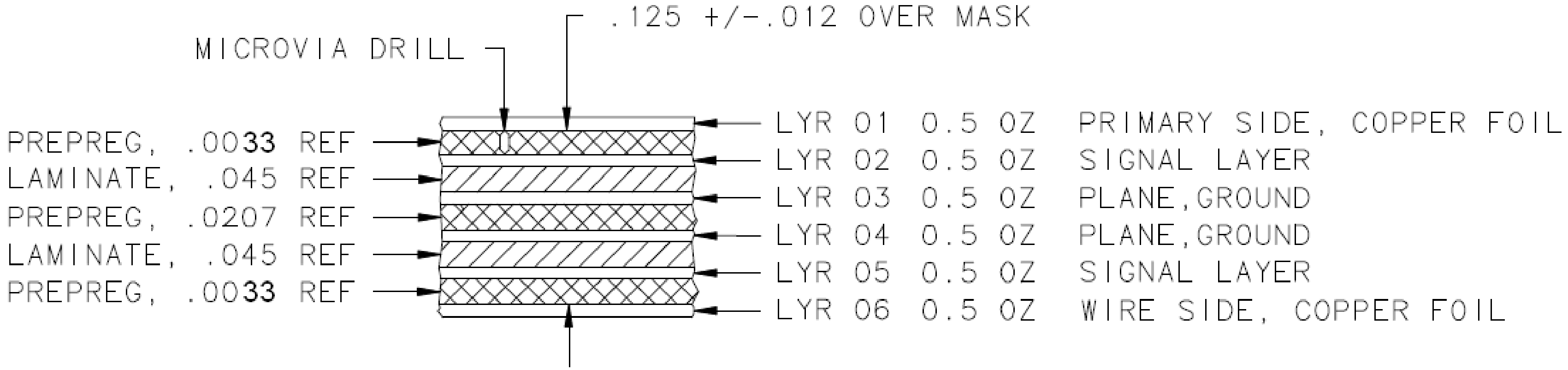
- 4 each of 4 component types per board
  - 2 sets on left – Via in Pad
  - 2 sets on right – No vias in pad
- Test Board Size: 6.5” x 7”x .125” thick
- Connector not populated – for wiring only
- Extra ground lug point added

VIP vs. No VIP Design



BGA192 – Left with Microvia in pad,
Right, with fan out, no microvia in pad

Test Board Stackup



- Most routing on Layer 2
- Layers 3 and 4 are planes
- Open areas on L2 and 5 are thieved
- L1-L2 (and L5-6) were built with 2113 glass style
  - To better represent the worst case thickness.
  - Nominal microvia laser drill size prior to plating was 6 mils

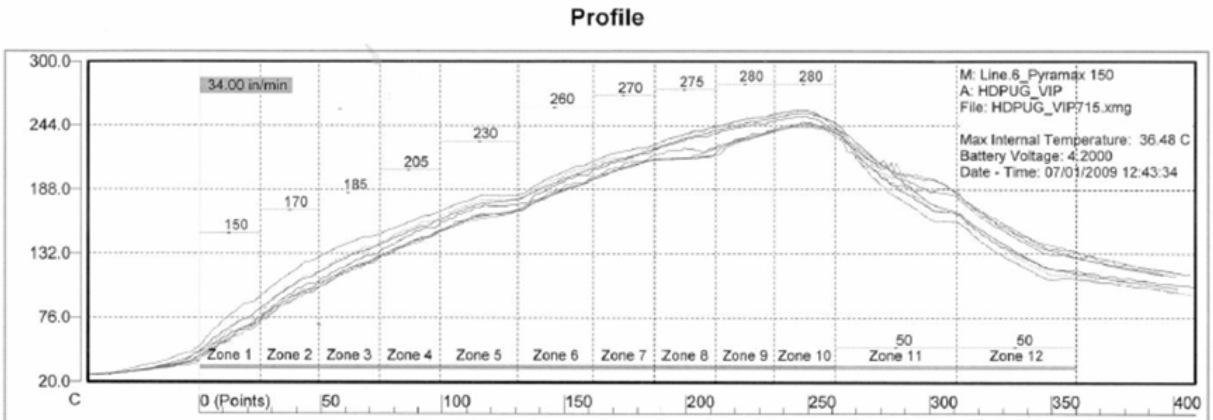
Component Types

Part Type	Body Size (mm)	Die Size (mm)	Pitch (mm)	Solder Ball Size (mm)	Solder Ball Alloy	Supplier	Comments
CBGA 483	29 x 29	NA	1.27	0.89	SAC405	NTK (Solder Balls added at Premier Semiconductor)	Ceramic. Supplied as LGA.
CABGA 192	14 x 14	12.065 X 12.065	0.8	0.46	SAC305	Practical Components	
CTBGA 84	7 x 7	5.08 x 5.08	0.5	0.3	SAC305	Practical Components	
QFN72 (MLF)	10 x 10	6 x 6	0.5	NA	NA	Practical Components	

Components – other info

- Components selected such that ball size (or no ball in the case of QFN) is evaluated
- Larger die packages will reduce ATC cycles and shorten test time
  - Large, but not largest, die size in the QFN-72 package to reduce potential issues with very early, separate failure mode seen in other testing.

Assembly

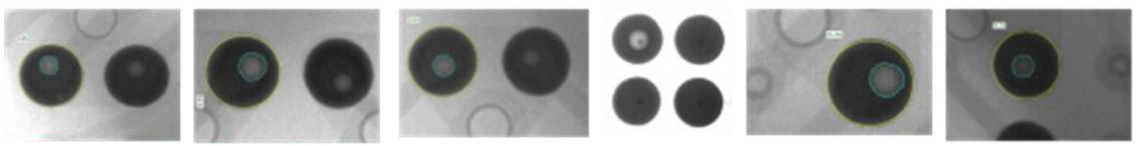


		Maximum Temperature	Maximum Positive Slope	Maximum Negative Slope	Time Between Temperature	Time Between Temperature	Time Above Temperature: Total (+/-)
		||	||	||	|130-220C|	|170-220C|	220C
		C	C/sec	C/sec	sec	sec	sec
A1	U10C_BALL CENTE	257.8	1.7	-2.3	121.0	71	97
A2	U7B_BODY	252.0	1.5	-2.0	116.0	74	84
A3	U4_BODY	246.8	1.4	-1.7	115.0	60	77
A4	U4_BALL CENTER	242.9	1.3	-1.4	138.0	84	58
A5	U4_BALL CORNER	256.9	1.6	-2.0	119.0	76	91
B6	U1_BALL CORNER	244.2	1.3	-1.5	137.0	82	62
B7	U1_BALL CENTER	254.8	1.5	-1.9	121.0	74	92
B8	U7B_BALL CORNE	245.4	1.4	-1.5	133.0	75	64

Standard SMT Reflow Profile

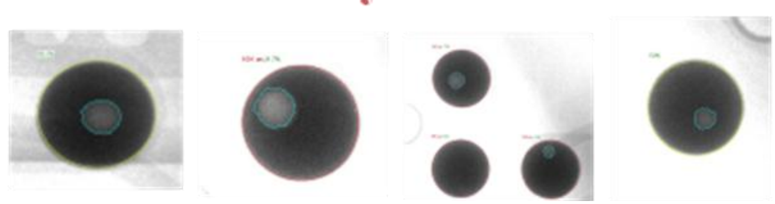
In X-ray, 21 of 40 failed to meet the IPC-7095A Class 2 requirements for voiding in BGA solder balls (Reject class 2 if void size > 45% of ball diameter or 20% of ball area). Six of these rejects were with No VIP, 15 of these were with VIP

After assembly



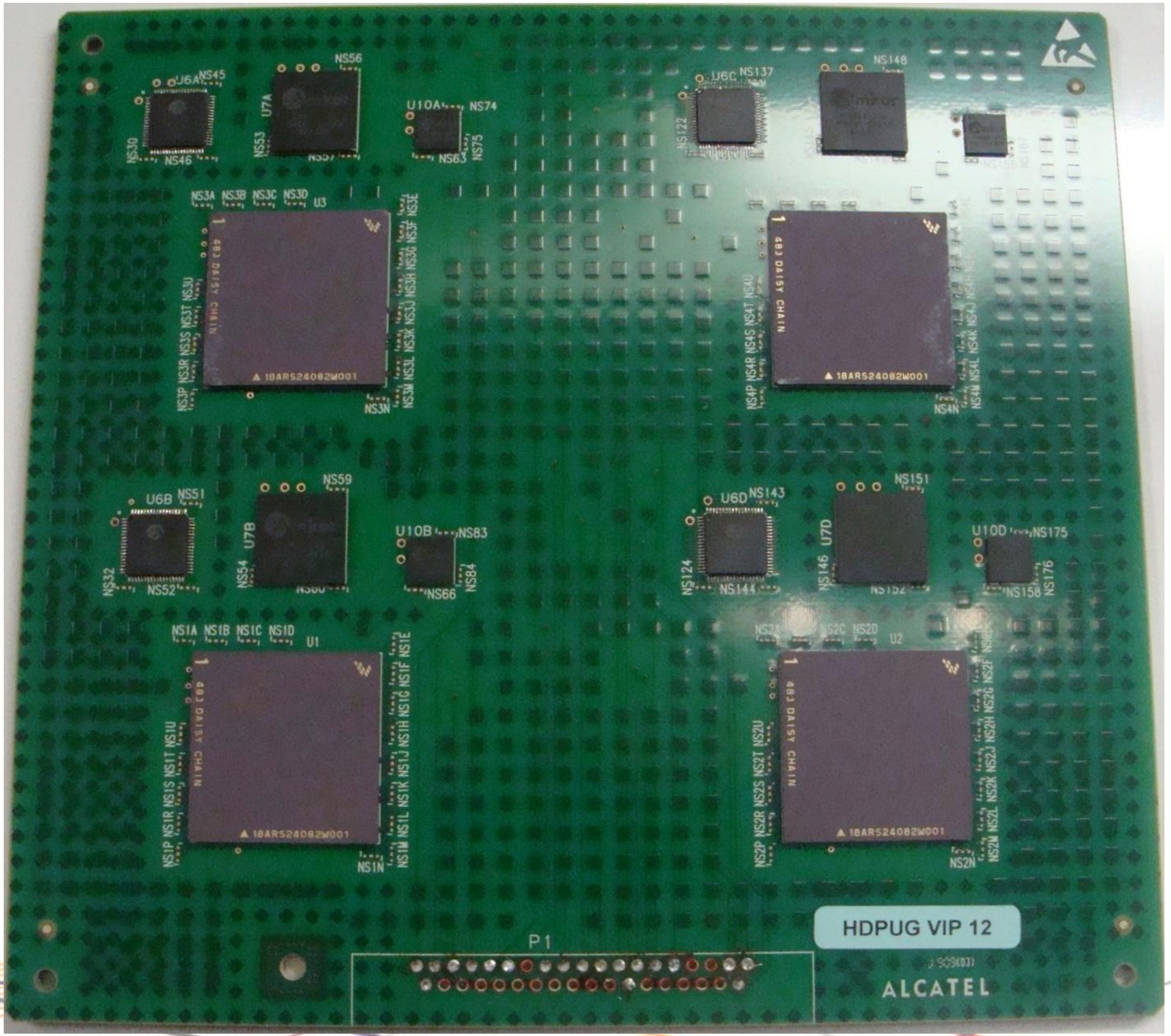
HDPUGVIP_07 HDPUGVIP_08 HDPUGVIP_14 HDPUGVIP_17 HDPUGVIP_29 HDPUGVIP_39

Before assembly



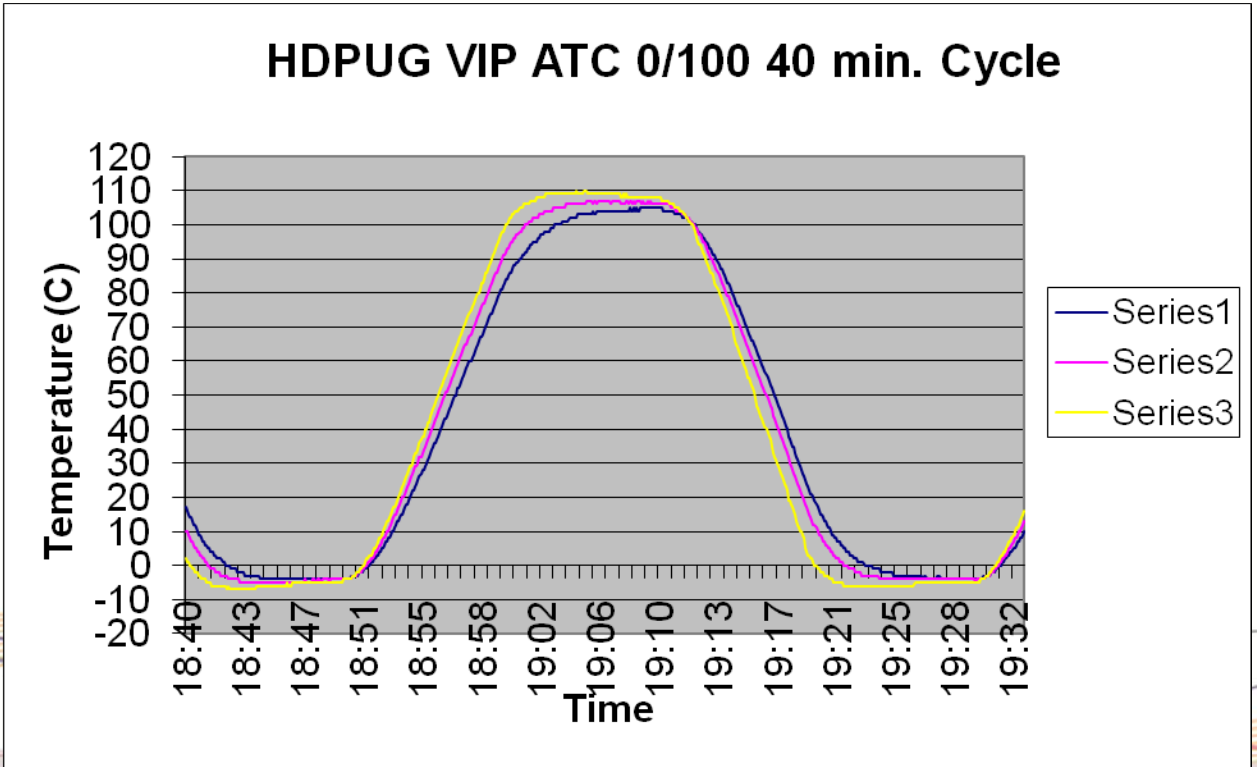
Some of the voiding attributable to voids in components as received.

Finished Assembly



Thermal Cycling

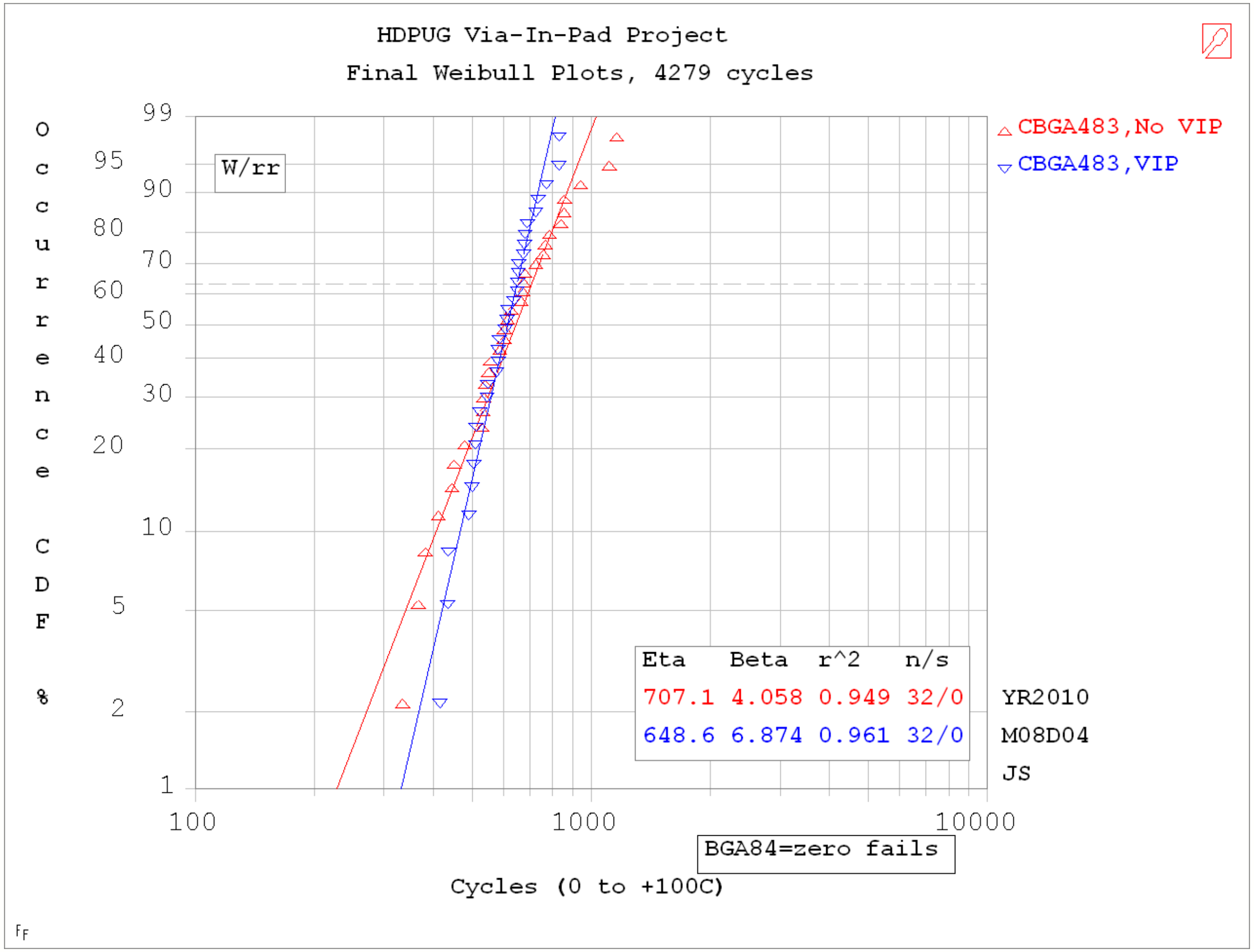
- 0 to +100ºC at Freescale Semiconductor
  - Completed 4279 cycles



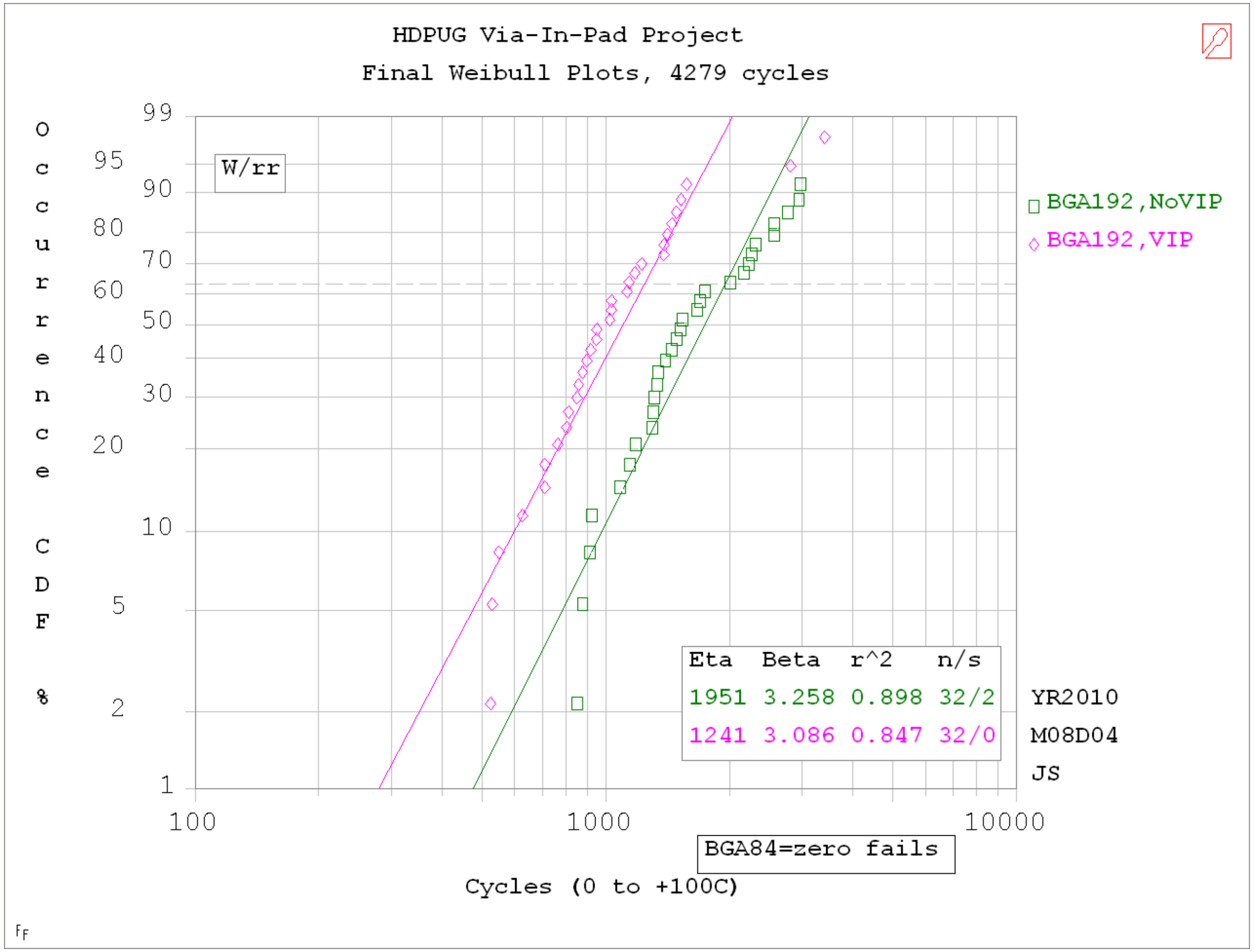
Sample Sizes

- 32 each for VIP/no VIP
- 16 PCB's
- 256 total nets (1 event detector)

Weibull Analysis CBGA483

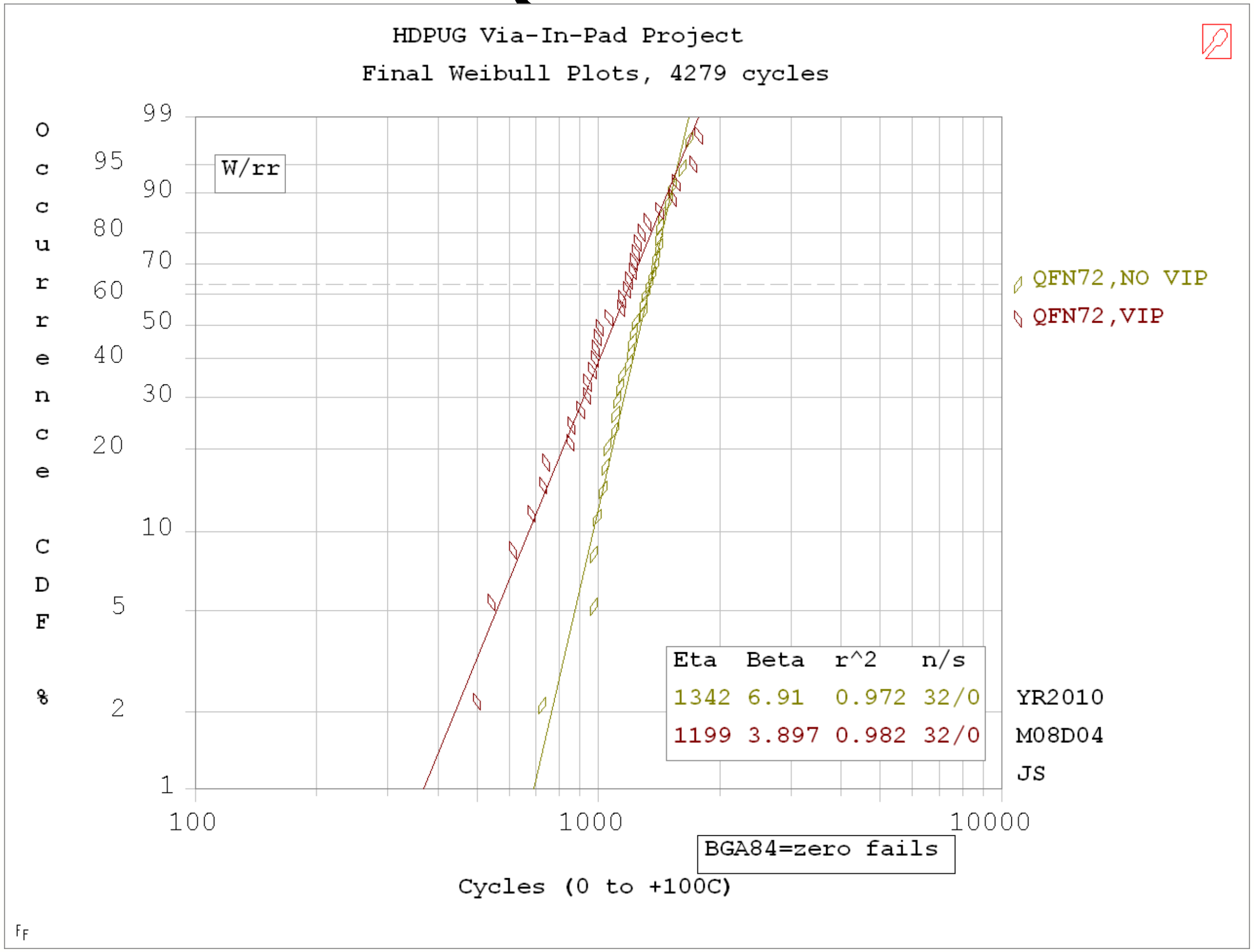


BGA192



The characteristic life of the no microvia-in-pad construction is 57% better than that of the same component with microvia in pad

QFN72



Characteristic life of the no VIP construction is 12% > than VIP construction. Slope (beta) of the distributions is larger for the No VIP construction → time to first failure is significantly better also

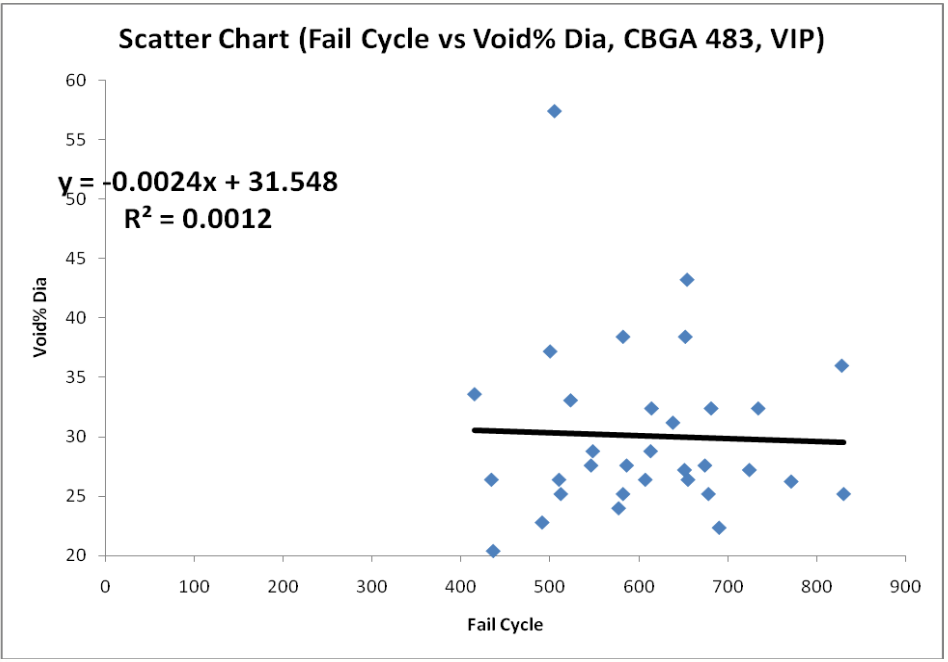
Voiding Analysis

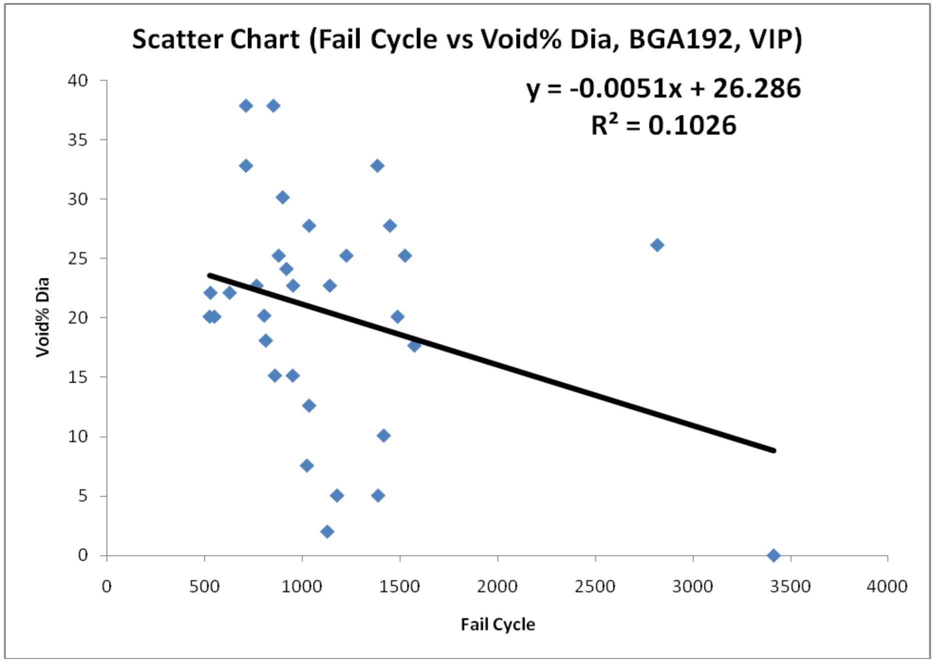
- Differences between the ATC performances of VIP versus No VIP constructions are expected to be because of the voiding.
  - Attempted to correlate the voiding in the solder balls to the failure cycles
- For both the CBGA and the BGA192 with a large die – expected failure locations are corner balls
  - Comparing the total voiding across the package would not be a viable comparison
  - Voids located specifically in the corner balls on the package or in the solder balls immediately adjacent to the corner balls were analyzed for their void percentage in volume and area and regression analysis completed comparing voiding to the failure cycle

Voiding Summary

Component and whether or not VIP	Average Void% in Diameter	Average Void% in Area	Maximum Void% in Diameter	Maximum Void% in Area	# of components with no voiding in the corner or adjacent solder balls
CBGA 483 VIP	30.10	9.03	57.41	50.20	0 of 32
CBGA 483 No VIP	18.66	3.39	32.12	10.32	0 of 32
BGA 192 VIP	20.44	5.08	37.84	14.32	1 of 32
BGA 192 No VIP	5.02	1.24	30.27	9.16	24 of 32
BGA 84 VIP	14.96	3.34	27.76	7.71	9 of 32
BGA 84 No VIP	3.29	0.49	27.76	5.90	27 of 32

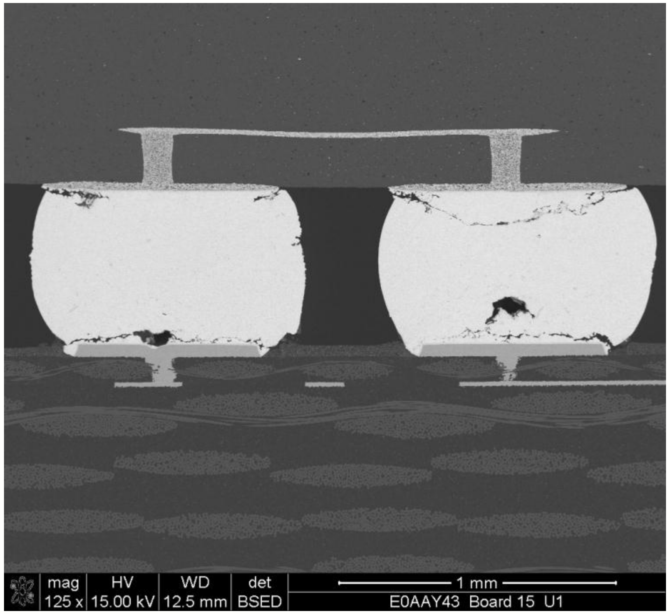
Voiding Correlation to corner and adjacent solder balls



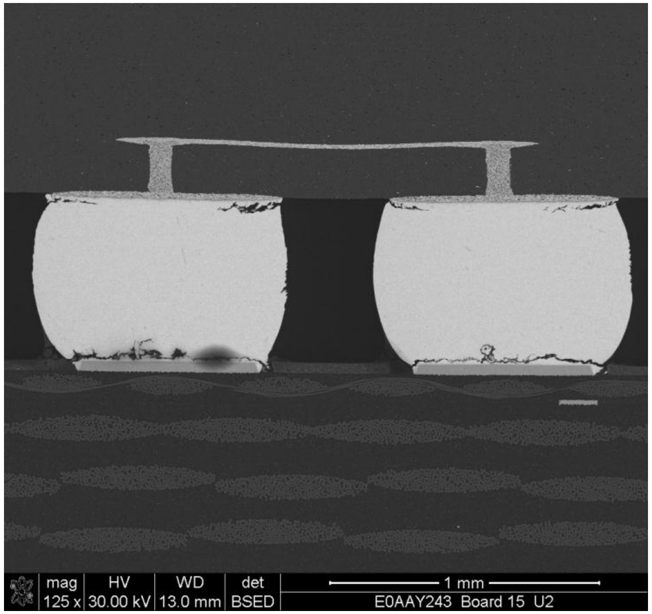


No Correlation

Failure Analysis – CBGA 483



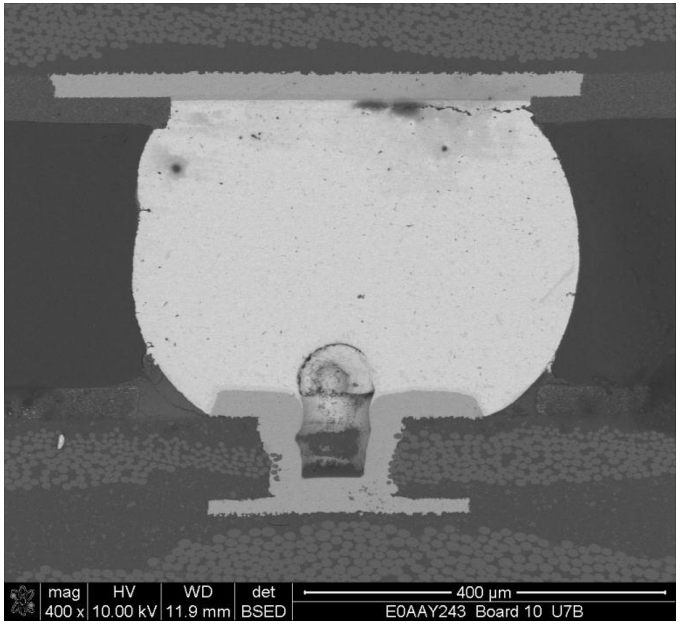
CBGA 483 VIP, after 4279 cycles. Failure cycle 434.



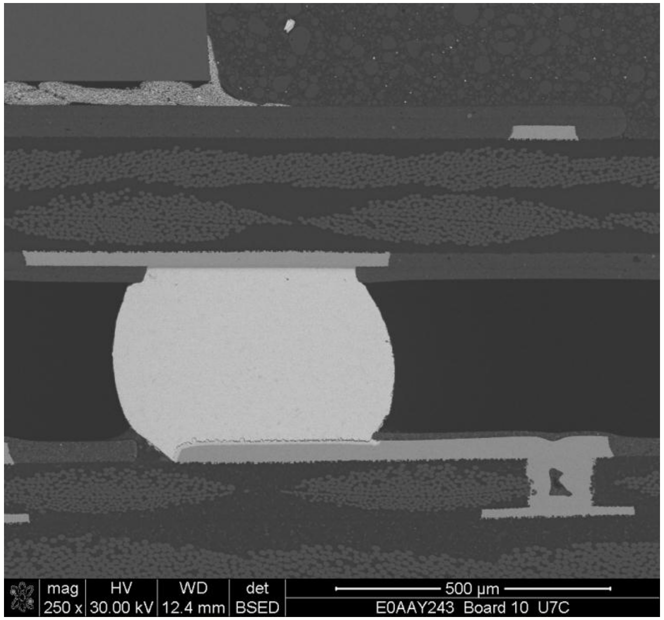
CBGA 483, No VIP, after 4279 thermal cycles. Failure cycle 334.

- Failure locations could be board or component side.
- The influence of this void does not appear to have a major impact on the crack path.
- In agreement with the relatively small differences between the data sets as seen in the Weibull plots components earlier.

Failure Analysis – BGA 192



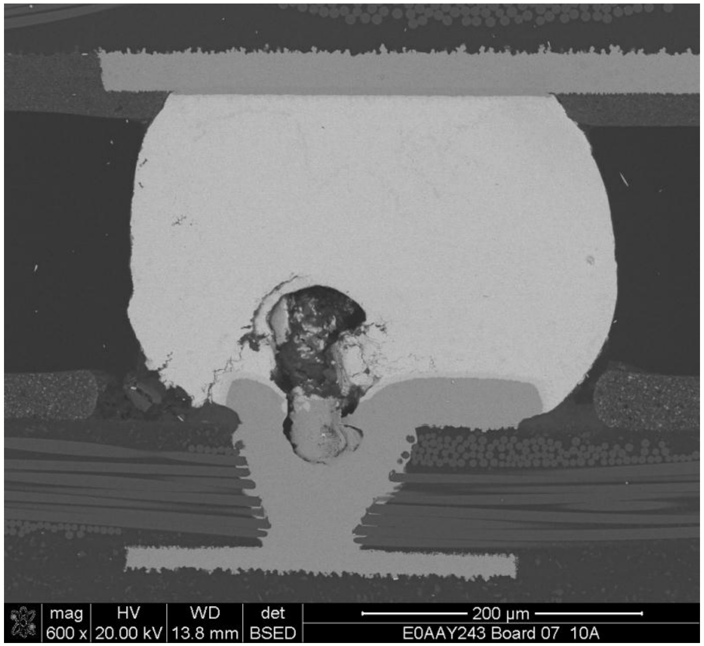
BGA192, VIP, after 4279 cycles. Failure Cycle 529



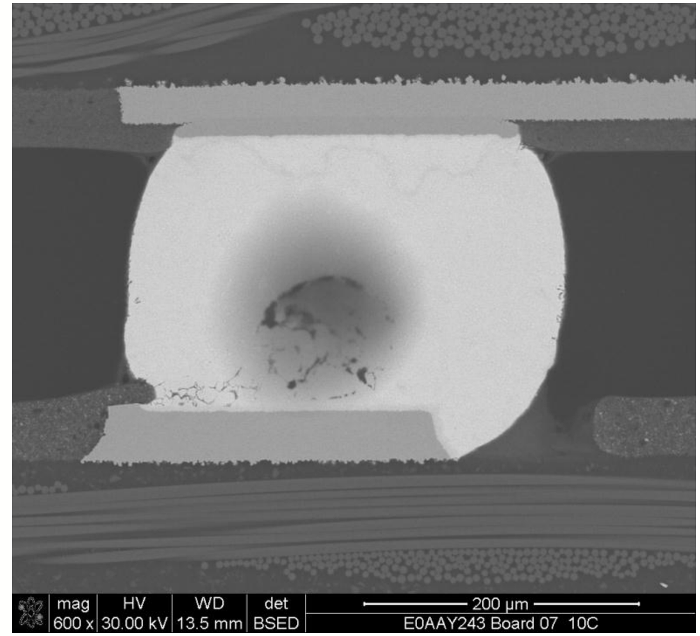
BGA 192, No VIP, after 4279 cycles. Failure Cycle 854

Crack path VIP → component side away from the void
Crack path No VIP →on the board side (through the bulk solder)
If there had been a void here it would have influenced the crack path and likely reduced the life.
FA not conclusive, suggests VIP could negatively impact the life as seen in the Weibull plots

Failure Analysis – BGA84



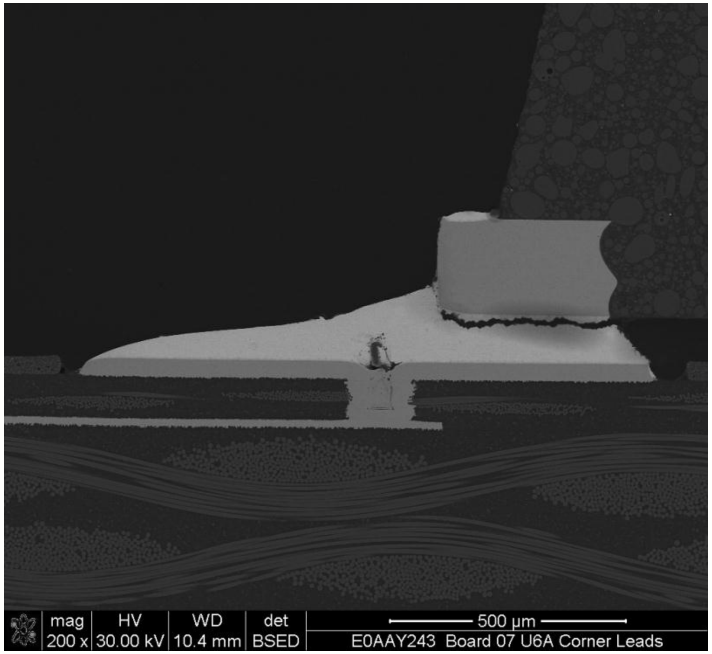
BGA 84, VIP, after 4279 thermal cycles. Did not fail



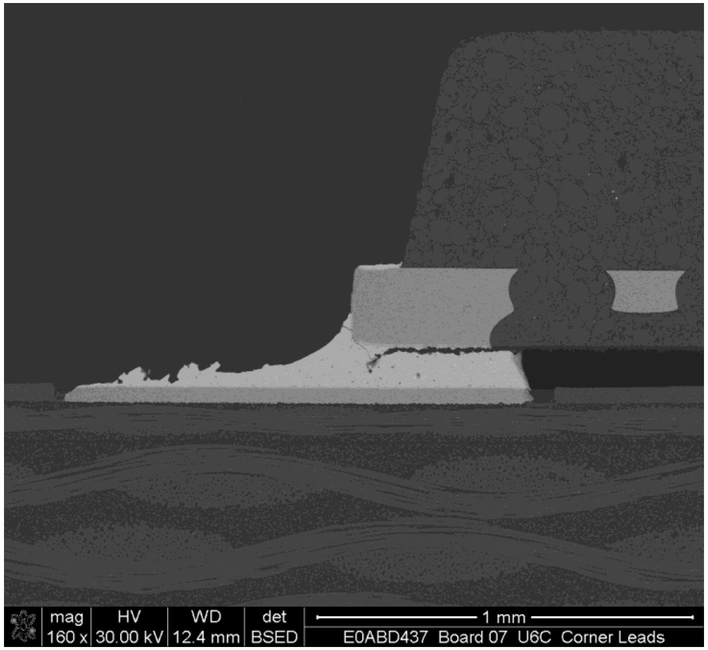
BGA 84, No VIP. After 4279 cycles. Did not fail

Both have voids→ crack paths are influenced by the void.
Crack paths are near the board side, which is also near where the void is.
Another cross-section (not shown) that is in a solder ball without a microvia-in-pad, but has a similar size void, shows a fatigue crack from the center of the solder ball to the nearby void.
Clearly shows that the solder void affects the crack path in this BGA solder ball.
Does not <u>conclusively</u> show that the voiding would necessarily make the failure earlier.

Failure Analysis – QFN 72



QFN72, VIP, after 4279 cycles, Failure Cycle 504



QFN72, No VIP, after 4279 cycles, Failure Cycle 982

Nothing obvious that the small void associated with the VIP has anything to do with the crack path or failure cycle.

Microvia location is external to the crack path, and beyond the edge of the component.

Does not correspond to the Weibull data →unexplainable at this time.

Summary – Part 1

- Depending on the particular device package type, conformal microvia-in-pad constructions can have an impact on the thermal cycle reliability of Pb-free SAC alloys BGA's when soldered with SAC solders potentially requiring the use of an alternative such as a filled and planar microvias
- For the package types investigated in this study the reliability impact of conformal microvia-in-pad construction was found to be device dependent.
  - CBGA 483 with 0.89mm solder balls: Degradation in fatigue life with VIP vs. no VIP was negligible.
  - CABGA192 with 0.46mm solder balls: Degradation in fatigue life with VIP vs. no VIP was significant.
  - QFN 72: Degradation with VIP vs. No VOP was significant, but FA did not identify an clear reason.
  - CTBGA 84 packages with 0.3mm balls had no failures in thermal cycle testing (4279 cycles) for either the VIP or no VIP construction.

Summary – Part 2

- Voiding associated with the conformal microvia is believed to be the cause of the reduced solder joint life
  - FA though suggestive of this behavior, is not conclusive.
  - The impact and size of the void associated with a microvia in pad is a function of the component type, solder ball size, microvia drill size and laminate thickness.
  - Void location is arguably more important than its size having a greater potential impact on solder joint failure when located in the fatigue crack path.
    - Based upon this, → hypothesized VIP construction should result in poorer fatigue life performance for Pb-free solder joints than SnPb joints since the former exhibit a somewhat higher incidence of failure due to cracking in the board side of the solder ball where microvia related voids can influence fatigue crack propagation.

Summary – Part 3

- Voiding % (area or diameter) on the corner and adjacent solder balls does not correlate to the failure cycle in thermal cycling.
  - For the CBGA 483 components, only one had voids in the corner balls exceeding the IPC 7095A Class 2 requirements and this failed after 12 others that met the voiding spec.
  - None of the BGA 192 components had unacceptable levels of voiding in the corner or adjacent balls but showed degraded fatigue life for the microvia-in-pad construction, which, on average increases the amount of voiding in the solder joints.

Summary Part 4

- Though unfilled (conformal) VIP can have a negative impact on the thermal cycle reliability, particularly for the BGAs with small solder balls, it may still be an acceptable construction depending on the field life requirements of the application.
- Due to the density of traces in the immediate vicinity and directly underneath large pin count BGAs, these components are prime candidates for via-in-pad construction.
  - Results indicate that the large BGA ball on CBGA, as it tends to fail at ball/package interface, may successfully be used with via-in-pad construction.
    - Needs to be validated with the specific package and board materials/geometry set
    - Potential penalty in either poor assembly yields or very tight assembly process windows, → likelihood of rejectable voiding in a VIP BGA t after assembly.
- An alternative to conformal (unfilled) microvia in pad constructions is to use a filled and planar microvia in pad construction which eliminates voiding associated with the microvias.
  - Can be done by either plating the microvias full or by filling (with a non-conductive material) and plating over the microvias.
  - This option has sourcing, cost, and design considerations, separate from the technical considerations associated directly with the microvia in pad and any possible voiding.

Follow-up Work

- This work examined the influence of a microvia-in-pad in a worst case construction using conformal microvias. Two potential follow-up studies could also be considered.
  - Repeat the test using filled and planar microvias in pad.
  - Repeat the test using a less challenging construction with a slightly thinner dielectric on the outer layers (such as a 1078 laser drillable prepreg) and a smaller microvia hole (such as a 5 mil drill size rather than a 6 mil drill size).

Acknowledgements

- Special thanks to the Celestica assembly team in Thailand: Teng Hoon Ng, Dussanee Chanwiboon, and Theeraphong Kanjanupathum.