The Last Will and Testaments of Tin/Lead and Lead-free BGA Voids

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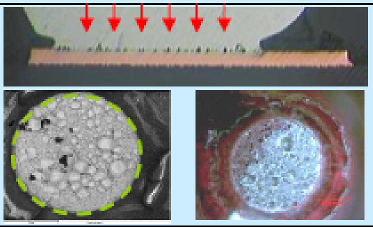
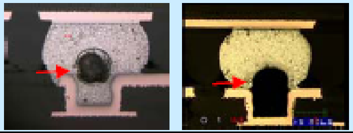
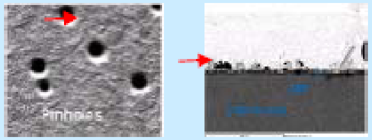
Agenda

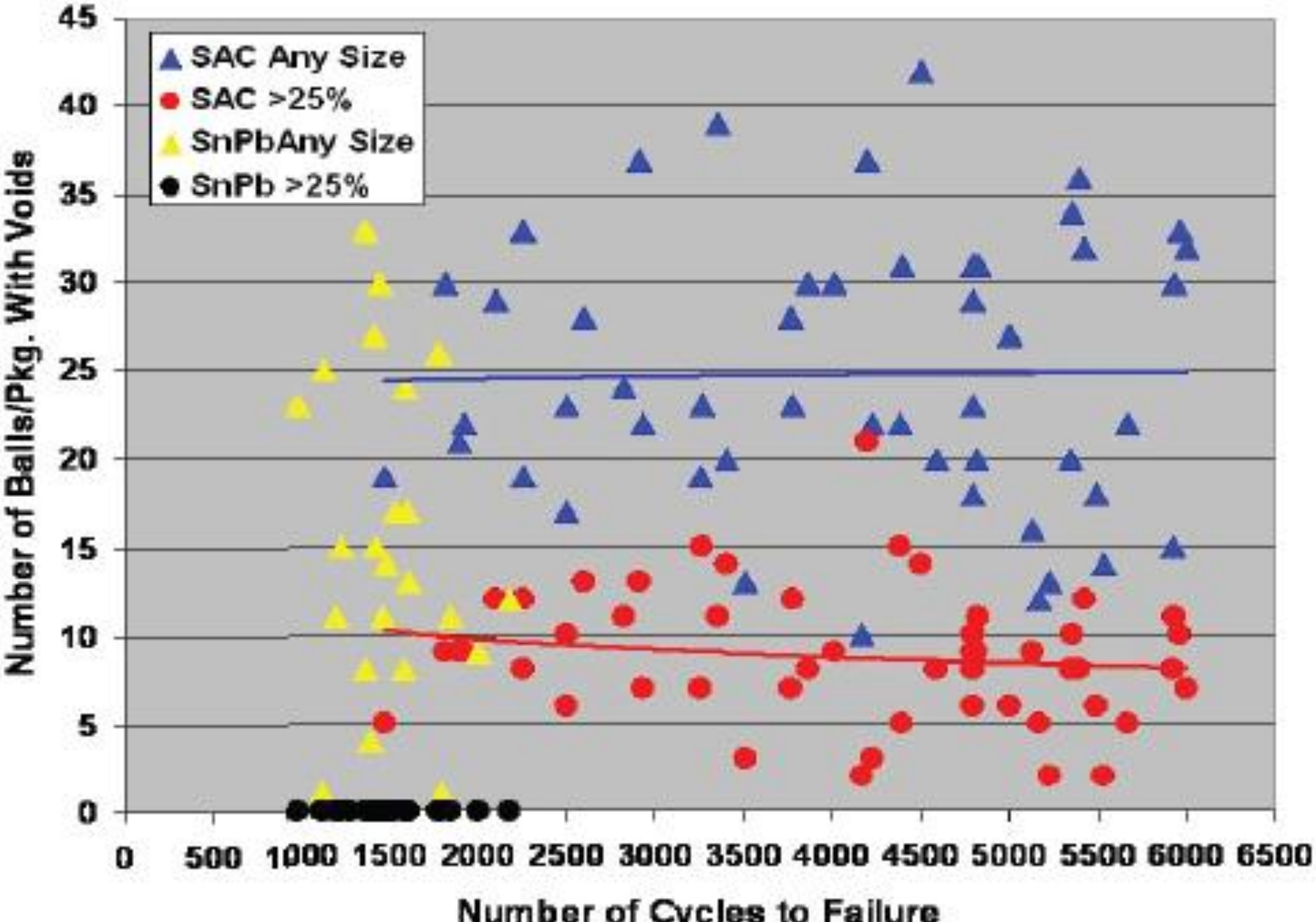
- Background
- Objectives
- Test Components & Vehicle
- X-ray Inspection
- Testing Protocol
- Test Results
- Conclusion
- Questions

Background - Terminology

Type of Voids	Description	Photos
Macro Voids	Voids generated by the evolution of volatile ingredients of the fluxes within the solder paste; typically 4 to 12 mils (100 to 300 µm) in diameter, these are usually found anywhere in the solder joint; IPC's 25% max area spec requirement is targeted toward process voids; NOT unique to LF solder joints. Sometimes referred to as "Process" voids	
Planar Micro Voids	Voids smaller than 1 mil (25 µm) in diameter, generally found at the solder to land interfaces in one plane; though recent occurrence on Immersion Silver surface finish has been highlighted these voids are also seen on ENIG and OSP surface finishes; cause is believed to be due to anomalies in the surface finish application process but root cause has not been unequivocally determined. Also called "champagne" voids	
Shrinkage Voids	Though not technically voids, these are linear cracks, with rough, `dendritic` edges emanating from the surface of the solder joints; caused by the solidification sequence of SAC solders and hence, unique to LF solder joints; also called sink holes and hot tears	
Micro-Via Voids	4 mil (100 µm) and more in diameter caused by microvias in lands; these voids are excluded from 25% by area IPC spec; NOT unique to LF solder joints	
Pinhole Voids	Micron sized voids located in the copper of PCB lands but also visible through the surface finish; Generated by excursions in the copper plating process at the board suppliers	
Kirkendall Voids	Sub-micron voids located between the IMC and the Copper Land; Growth occurs at High Temperatures; Caused by Difference in Inter-diffusion rate between Cu and Sn. Also Known as "Horsting" Voids.	

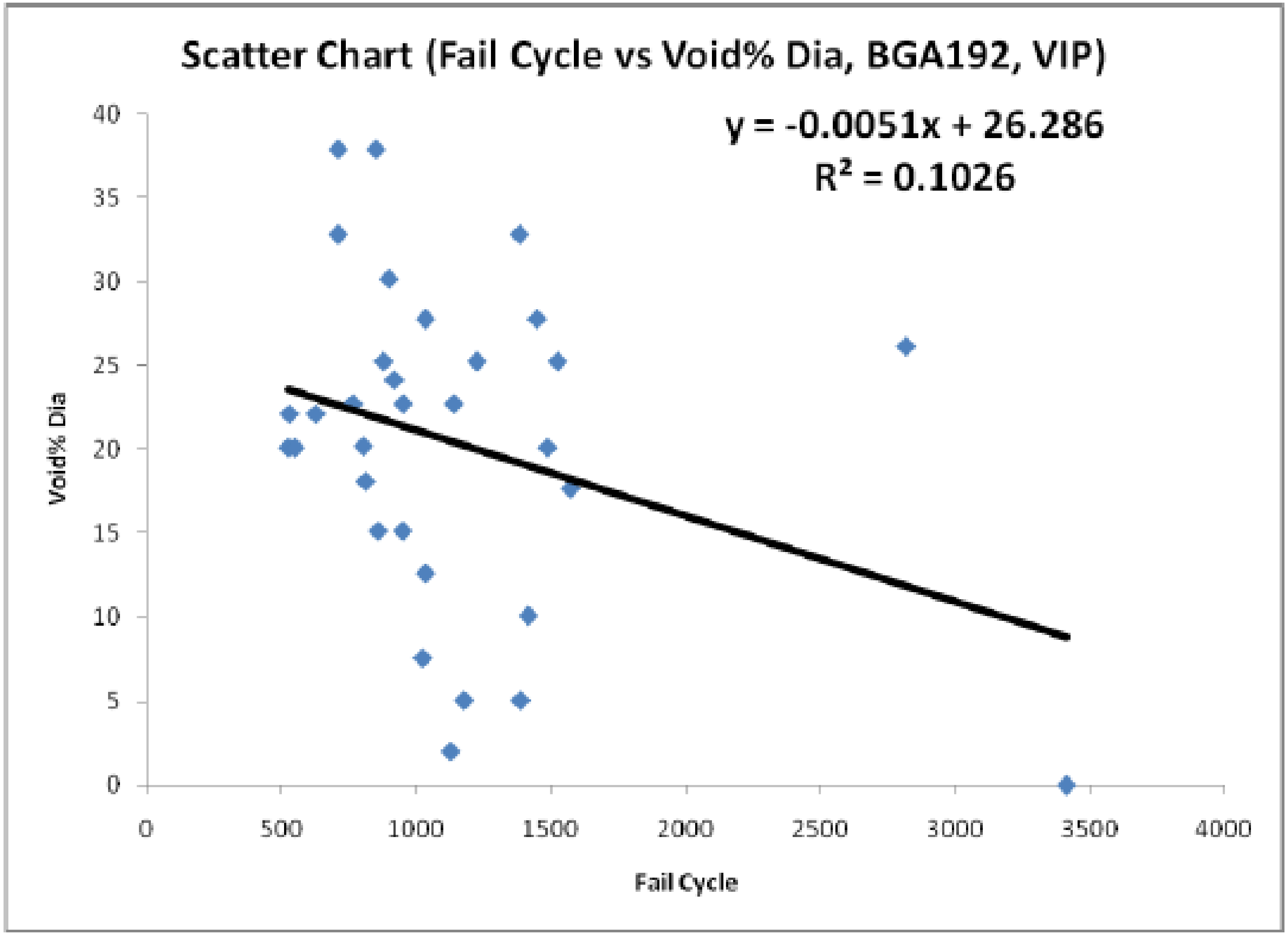
Graphic Source: R. Aspandiar, "Voids in Solder Joints", SMTAI Conference Proceedings, 2006

Background



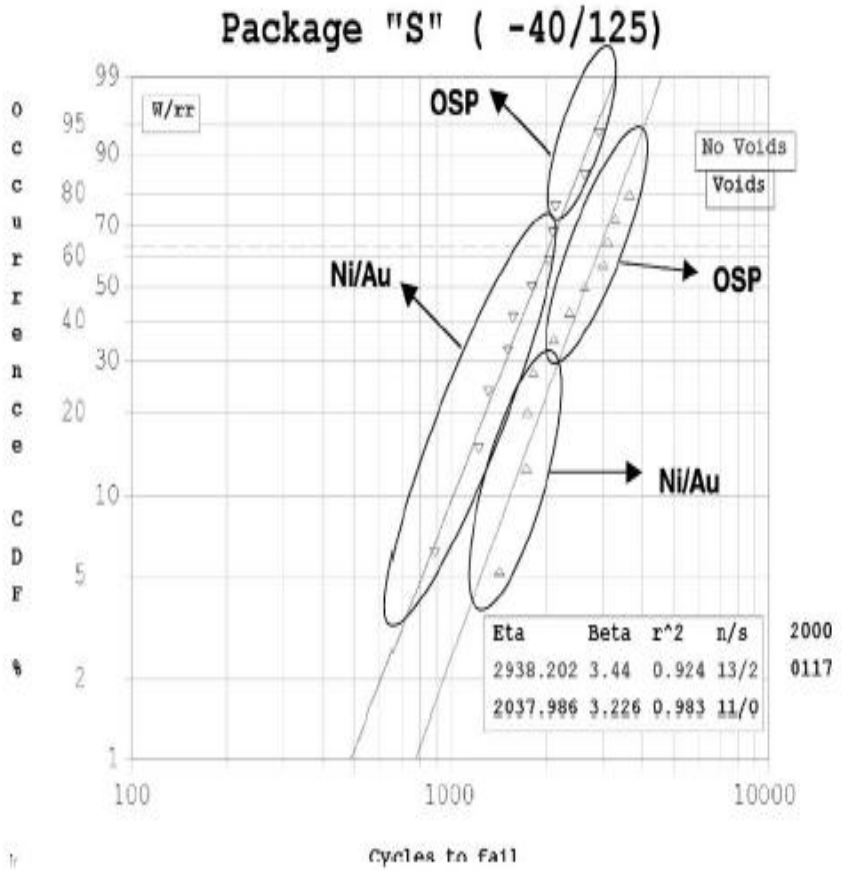
Graphic Source: IPC Solder Products Value Council, “The Effect of Voiding in Solder Interconnections Formed from Lead-free Solder Pastes with Alloys of Tin, Silver and Copper”, White Paper

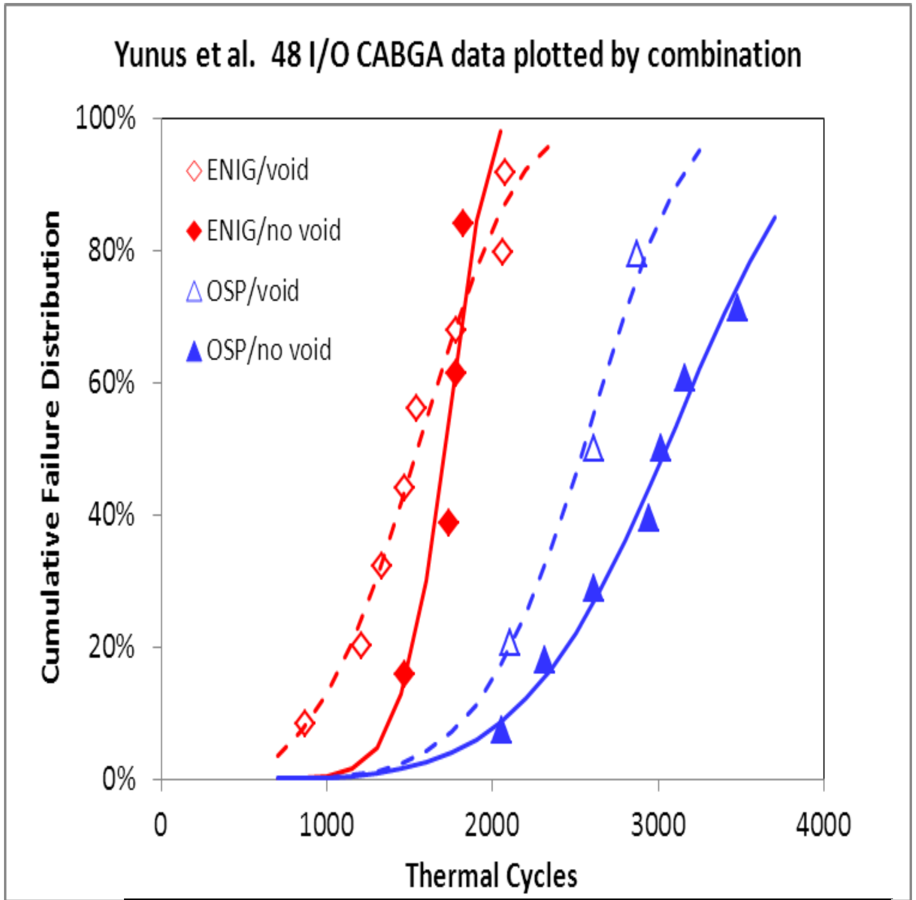
Background



Graphic Source: J. Smetana, et al, "The Effects of Non-filled Microvia in Pad on Pbfree Solder Joint Reliability of BGA and QFN Packages in Accelerated Thermal Cycling", IPC APEX Conference Proceedings, S28-02, 2011.

Background – Industry Controversy





	ENIG/void	ENIG/no void	OSP/void	OSP/no void
beta	3.70	9.61	5.99	5.15
N63	1710	1781	2707	3271
R^2	97.5%	80.8%	96.3%	97.7%

Left Graphic Source: M. Yunus et al, "Effect of Voids on the Reliability of BGA/CSP Solder Joints", Microelectronics Reliability 43 (2003)

Background – Baseline

- **Current IPC JSTD 001 Specification Requirement:**

"25% or Less of ball X-ray Image Area"

- **The Requirement was Not "Made Up"!**
  - **Data Submitted to IPC-JSTD-001 Committee for Field Data for Class 3 Airborne Flight Critical Product – All Inspected per 25% Requirement**

- **But – Technology Has Changed! Time for a New Investigation**

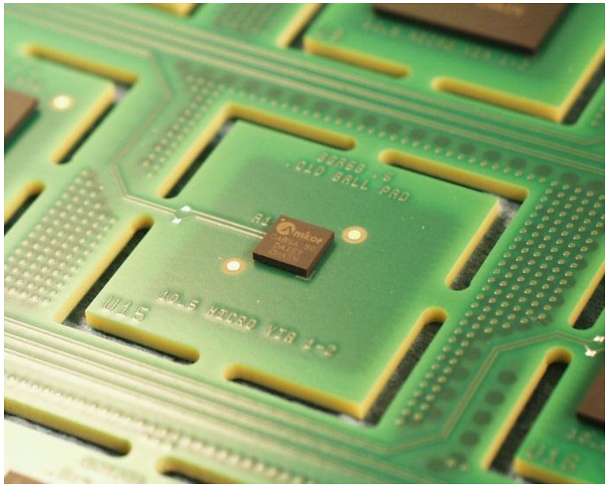
Objectives

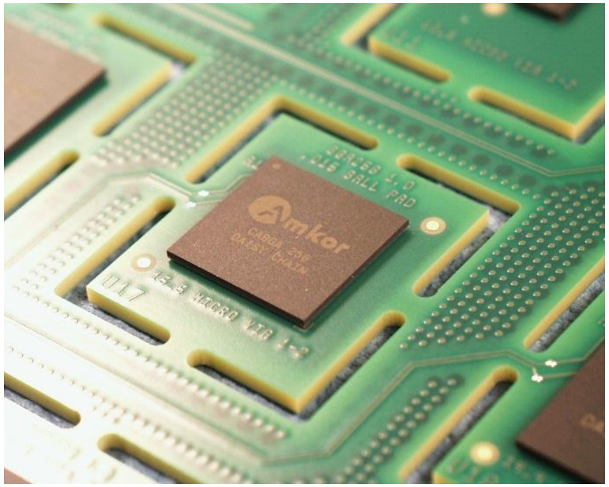
(1) Determine if a correlation between solder joint void size/location and solder joint thermal cycle integrity existed for the thermal cycle range of -55C to +125C for tin/lead and lead-free soldered BGAs

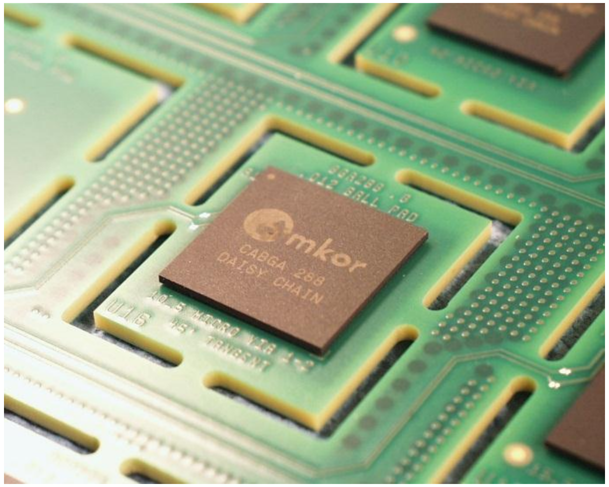
(2) Derive a BGA/CSP solder joint void criteria for submission to the IPC-JSTD-001 committee for review

Test Components & Vehicle

Part	Size	Pitch	Part Number
BGA56	6x6 mm	0.5 mm	A-CABGA56-.5mm-6mm-DC
BGA256	17x17 mm	0.8 mm	A-CABGA256-1.0mm-17mm-DC
BGA288	19x19 mm	1.0 mm	A-CABGA288-.8mm-19mm-DC

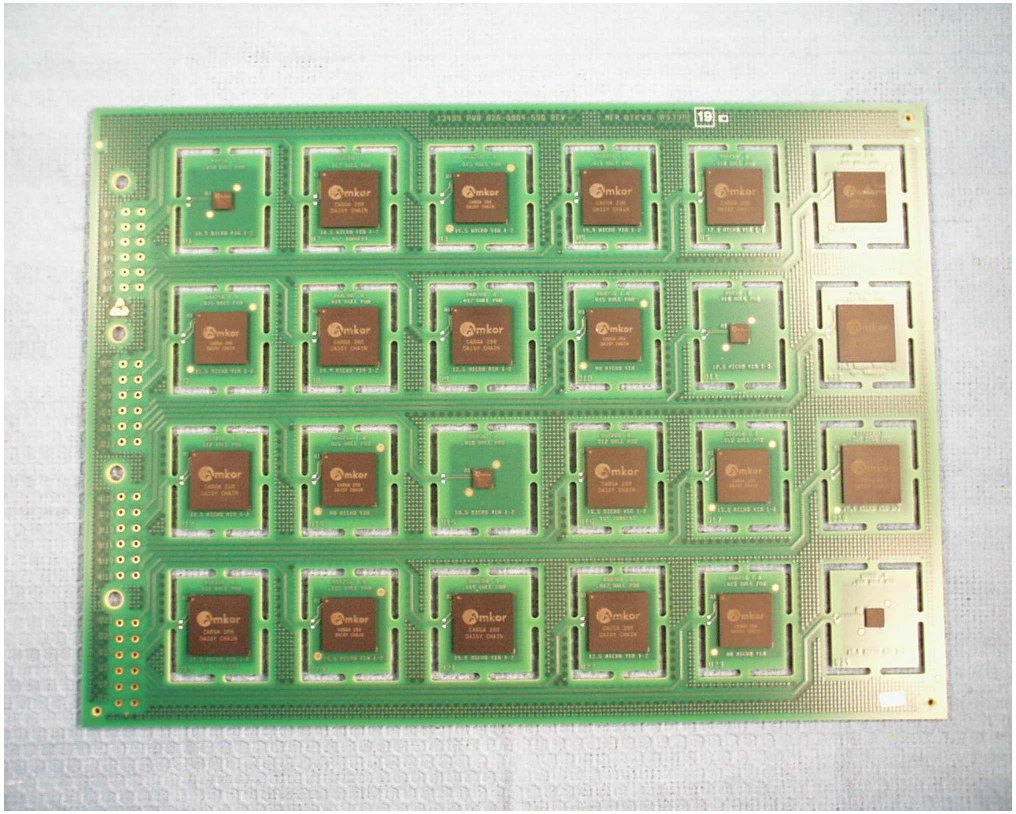






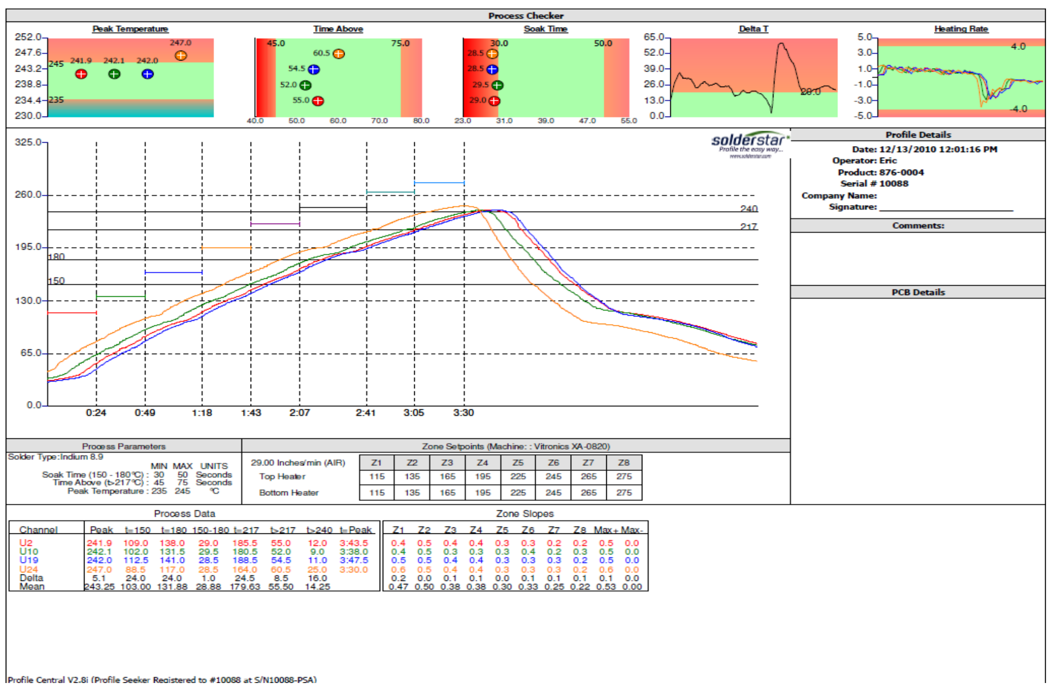
Test Components & Vehicle

- **Test Vehicle Specifics**
  - 2.18mm (0.086 inches) thick
  - 14 layers of 0.5 ounce copper
  - Board per IPC-6012, Class 3, Type 4 requirements
  - Via in Pad per IPC-2315, Type II
  - FR4 per IPC-4101/126
  - ENIG Surface Finish

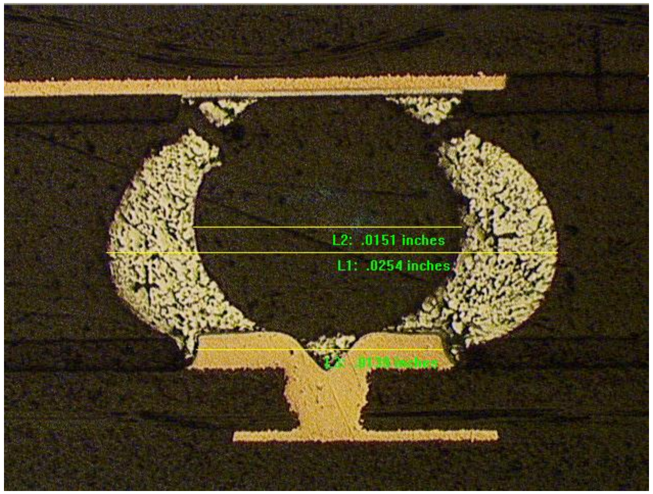


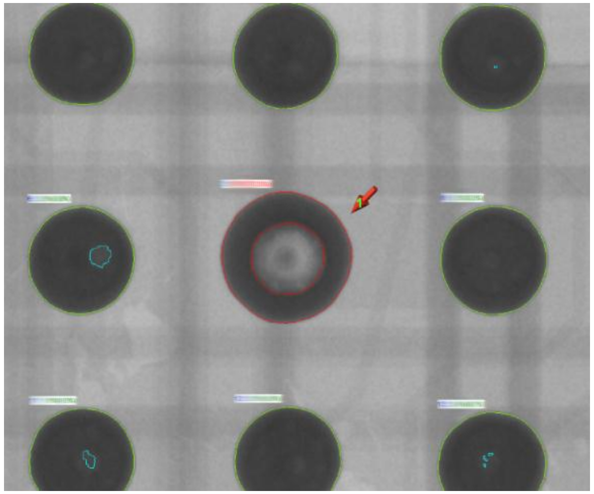
Test Vehicle Assembly

- Test vehicle assembly by RIM & Rockwell Collins
- Sn63Pb37 solder paste (supplied by Rockwell Collins)
- SAC387 lead-free solder paste (supplied by Indium)



X-ray Inspection - Terminology





$$Diameter\% = \frac{Diameter\ void}{Diameter\ ball}$$

$$Area\% = \frac{Area\ void}{Area\ ball} = \frac{0.25 * \pi * {d_v}^2}{0.25 * \pi * {d_b}^2} = \frac{{d_v}^2}{{d_b}^2}$$

(Assuming circular shapes)

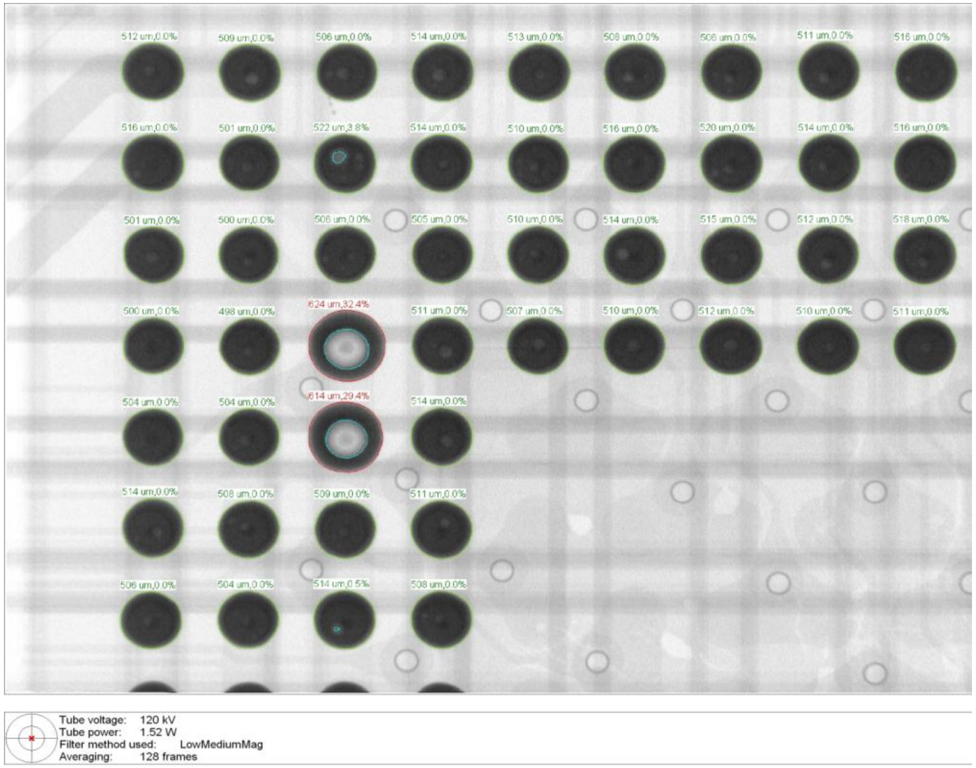
$$Diameter\% = \frac{0.0151}{0.0254} * 100$$

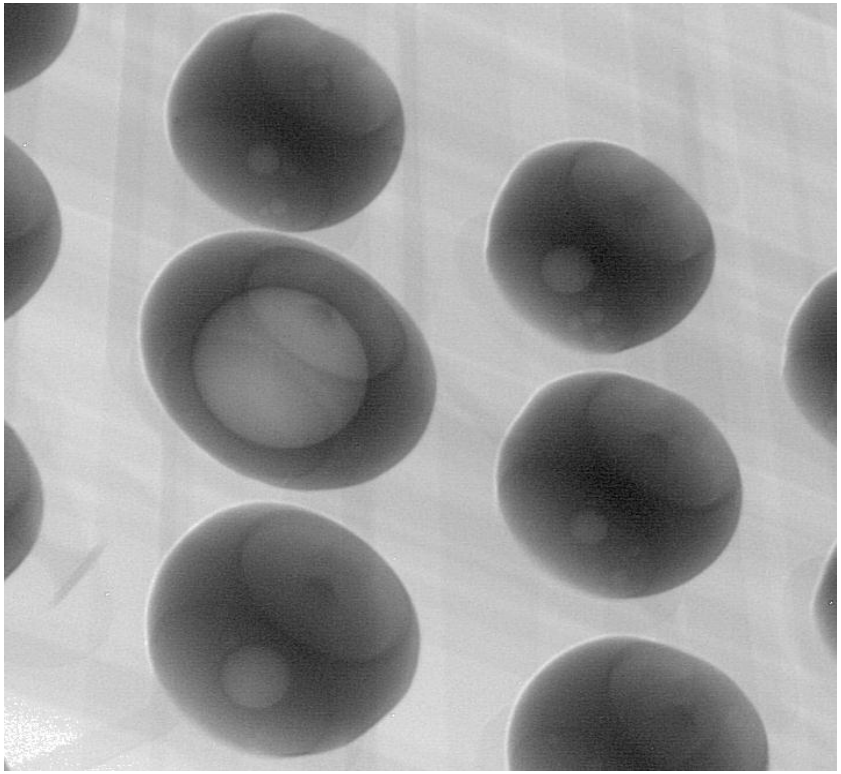
$$Area\% = \frac{0.0151^2}{0.0254^2} * 100 = \frac{2.28 * 10^{-4}}{6.45 * 10^{-4}} * 100$$

$$Diameter\% = 59.4\%$$

$$Area\% = 35.3\%$$

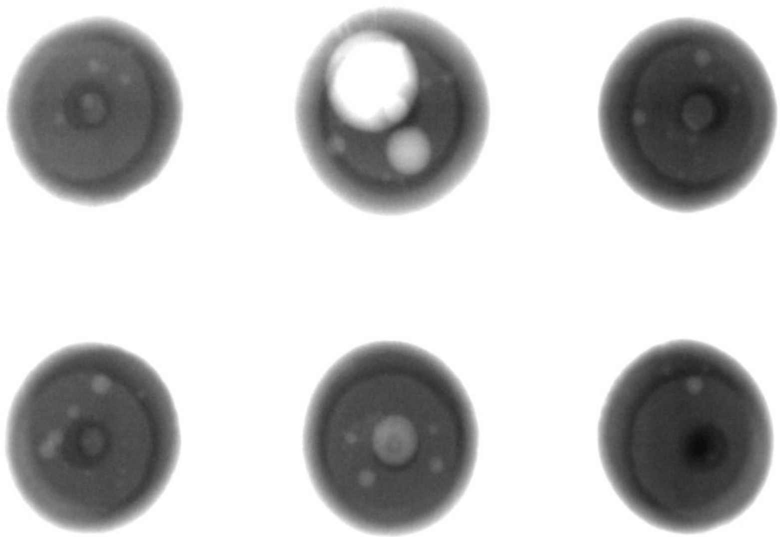
X-ray Inspection





X-ray Examination of Test Vehicle Revealing: Left - Voids of 32% and 29% Area, Right - Oblique Angle X-ray View of 30% Void in BGA

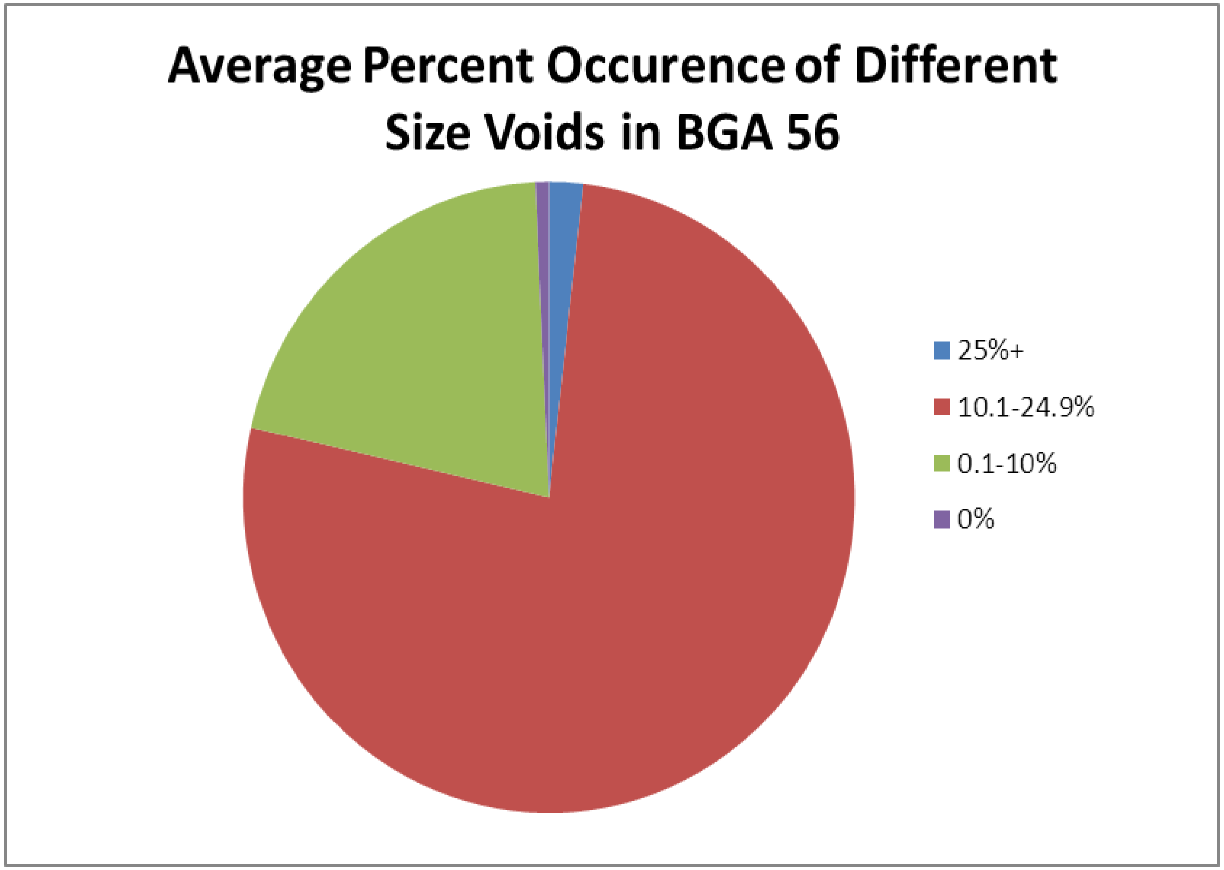
X-ray Inspection



Test Vehicle #7, Component U21, Major Void – 32% of X-ray Image Area

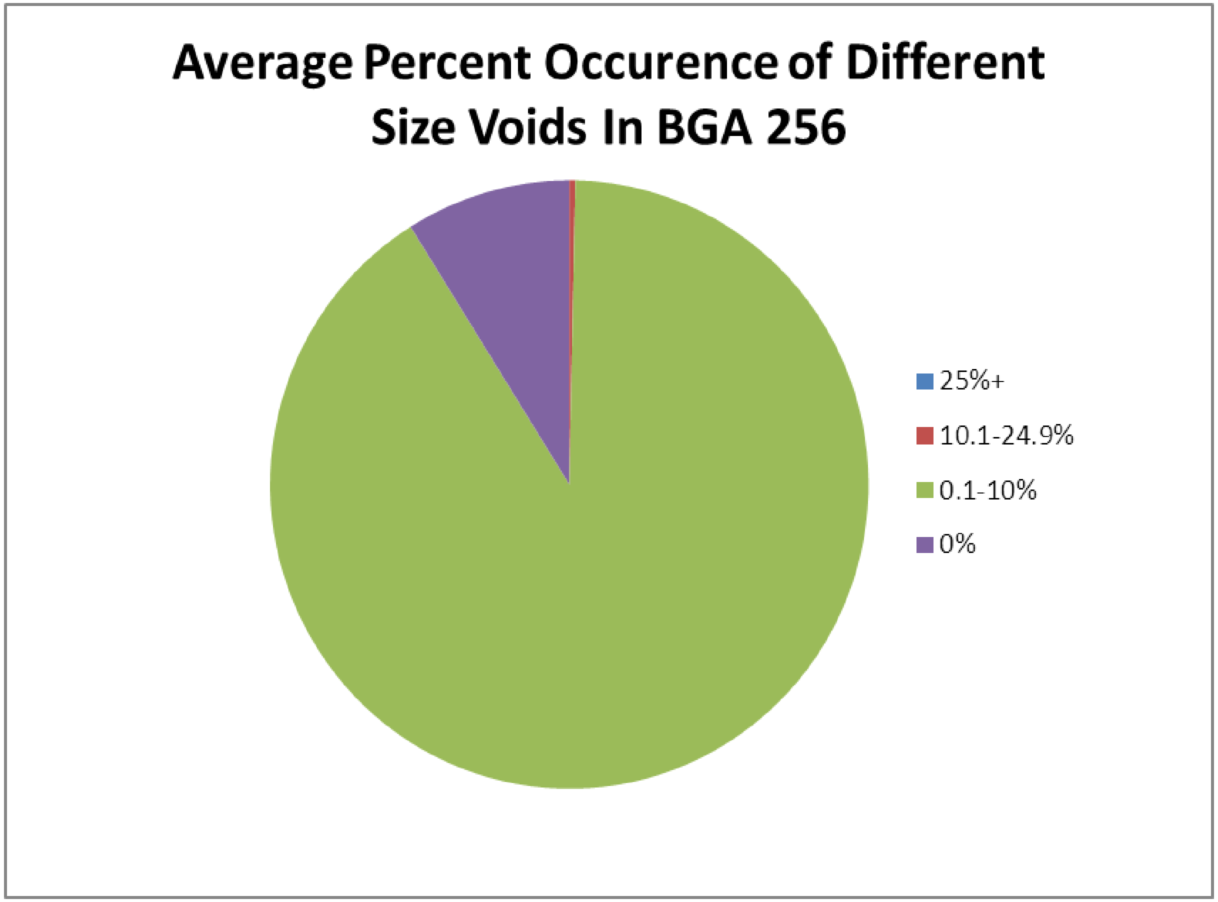
Test Vehicle #9, Component U13, Major Void – 42% of X-ray Image Area

X-ray Inspection Lead-free Population Measurement



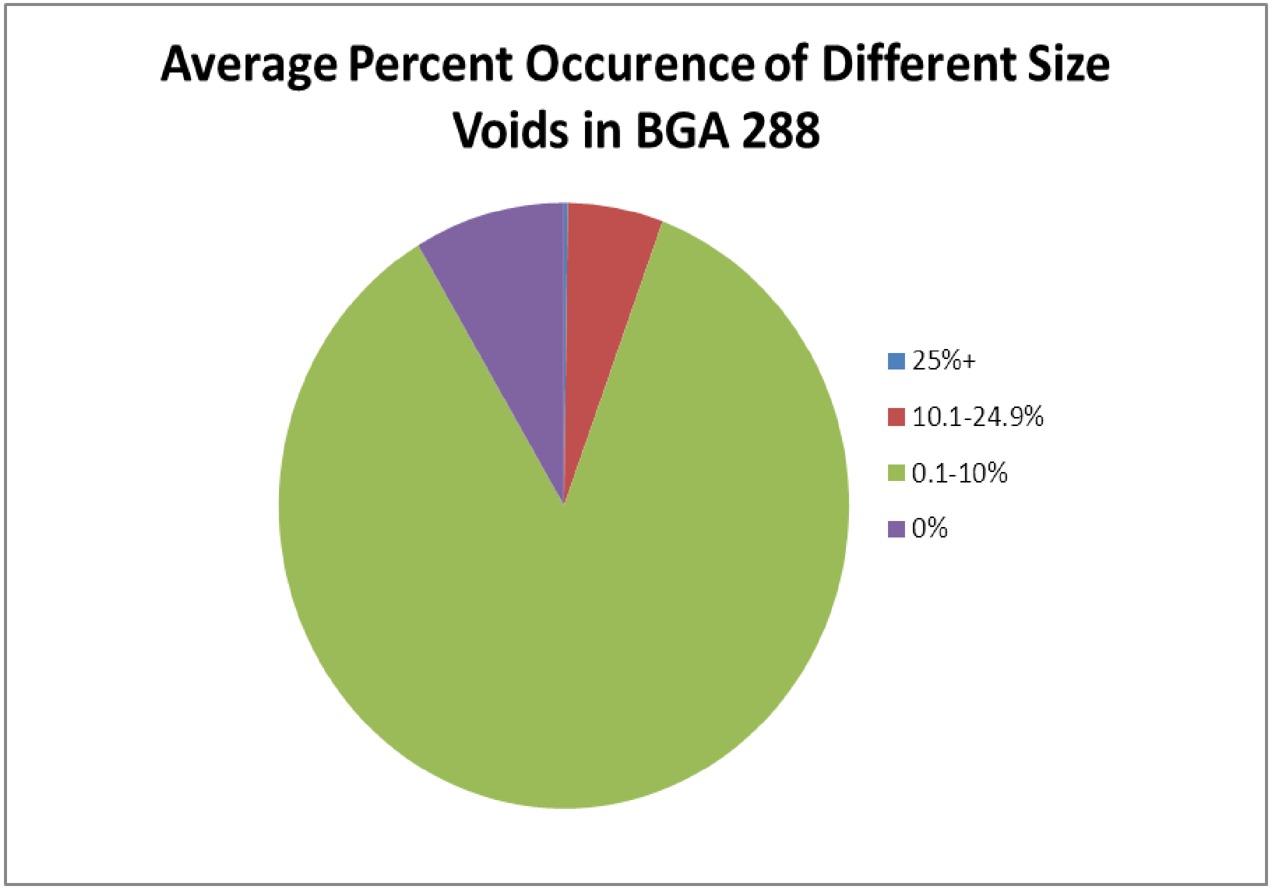
BGA56 Test Component Solder Joint Void Characterization

X-ray Inspection Lead-free Population Measurement



BGA256 Test Component Solder Joint Void Characterization

X-ray Inspection Lead-free Population Measurement

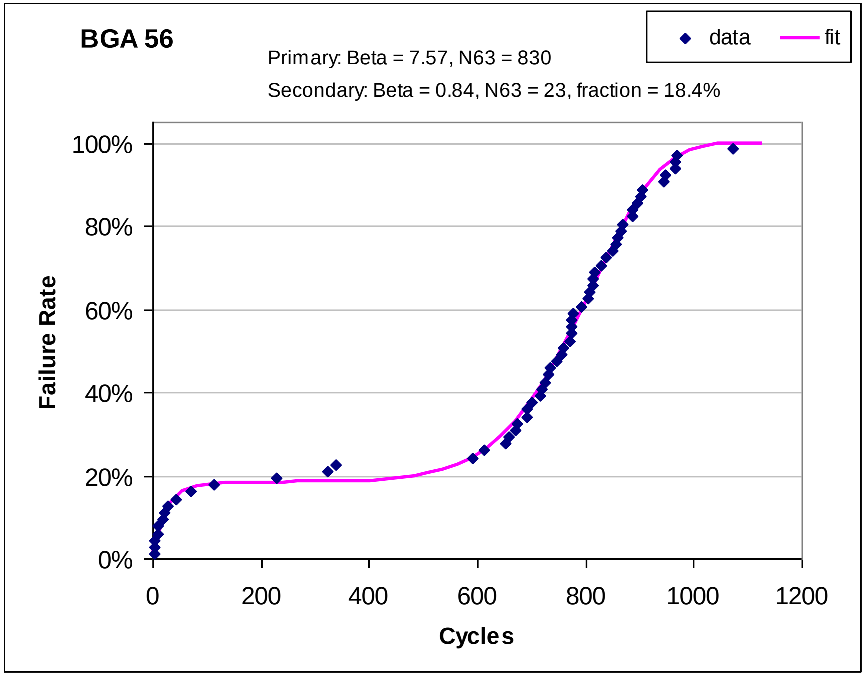


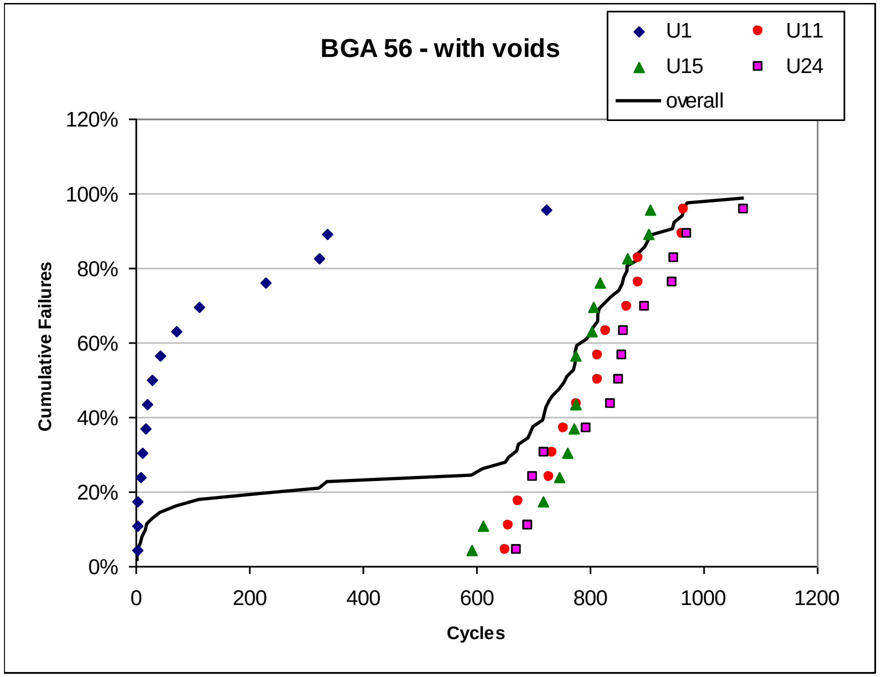
BGA288 Test Component Solder Joint Void Characterization

Testing Protocol

- **<u>Test Specifics</u>**
  - **1150 to 2000 cycles**
  - **-55° C - +125° C**
  - **15 minute dwells at either extreme**
  - **8-10° C / min ramp rates**
  - **Per IPC-9701**
  - **Resistance Monitored**
    - **Recorded an event for 15 consecutive cycles,**
    - **Had five consecutive detection events within 10% of current life of test, or**
    - **Became electrically open.**

Test Results

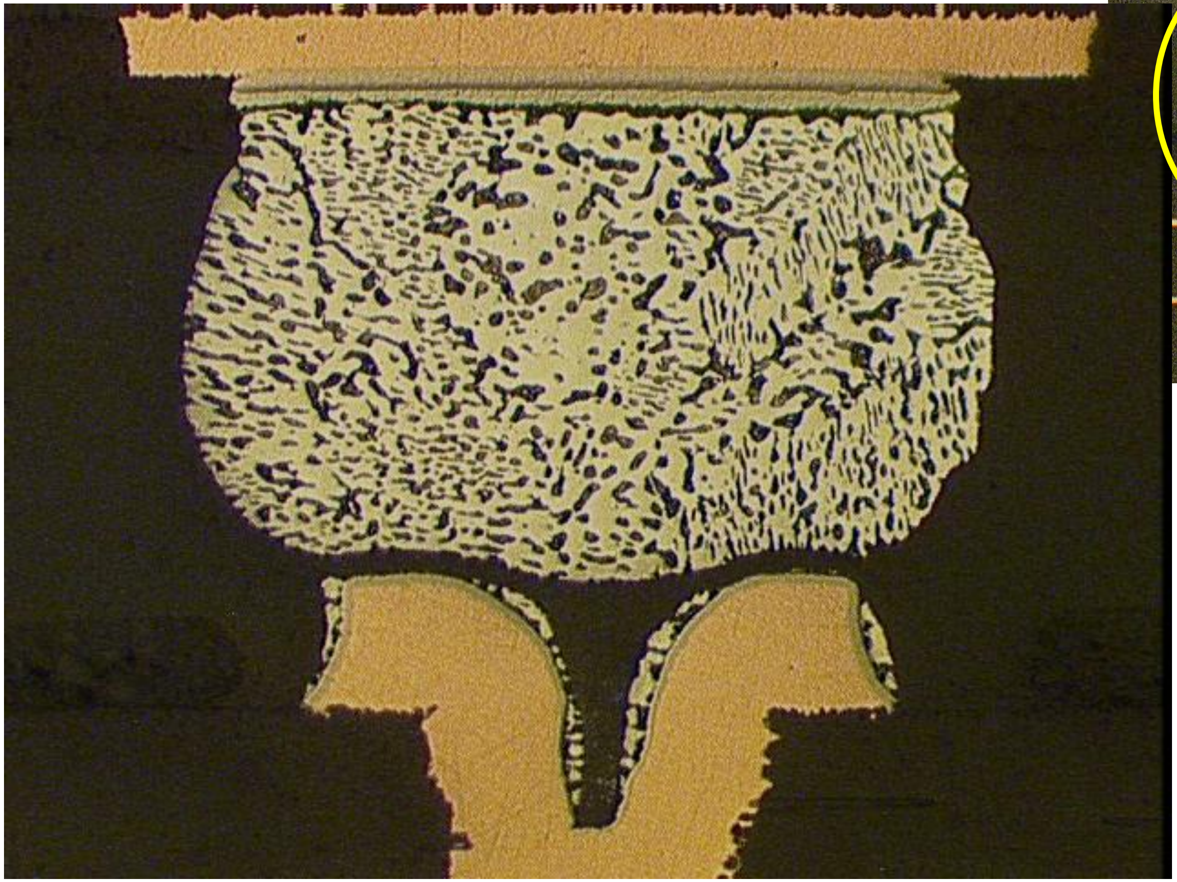


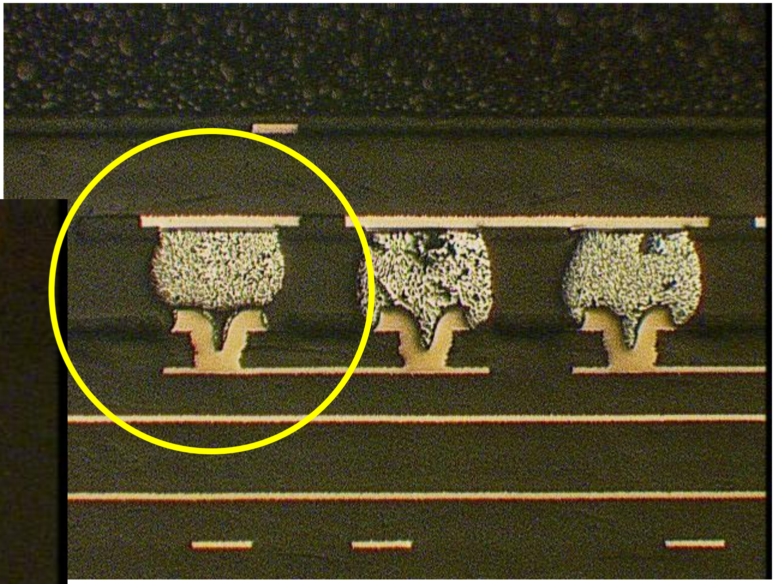


Mixed Mode Weibull Fit for BGA56 Data with Voids

Failure Distributions for BGA56, by Reference Designator, With Voids

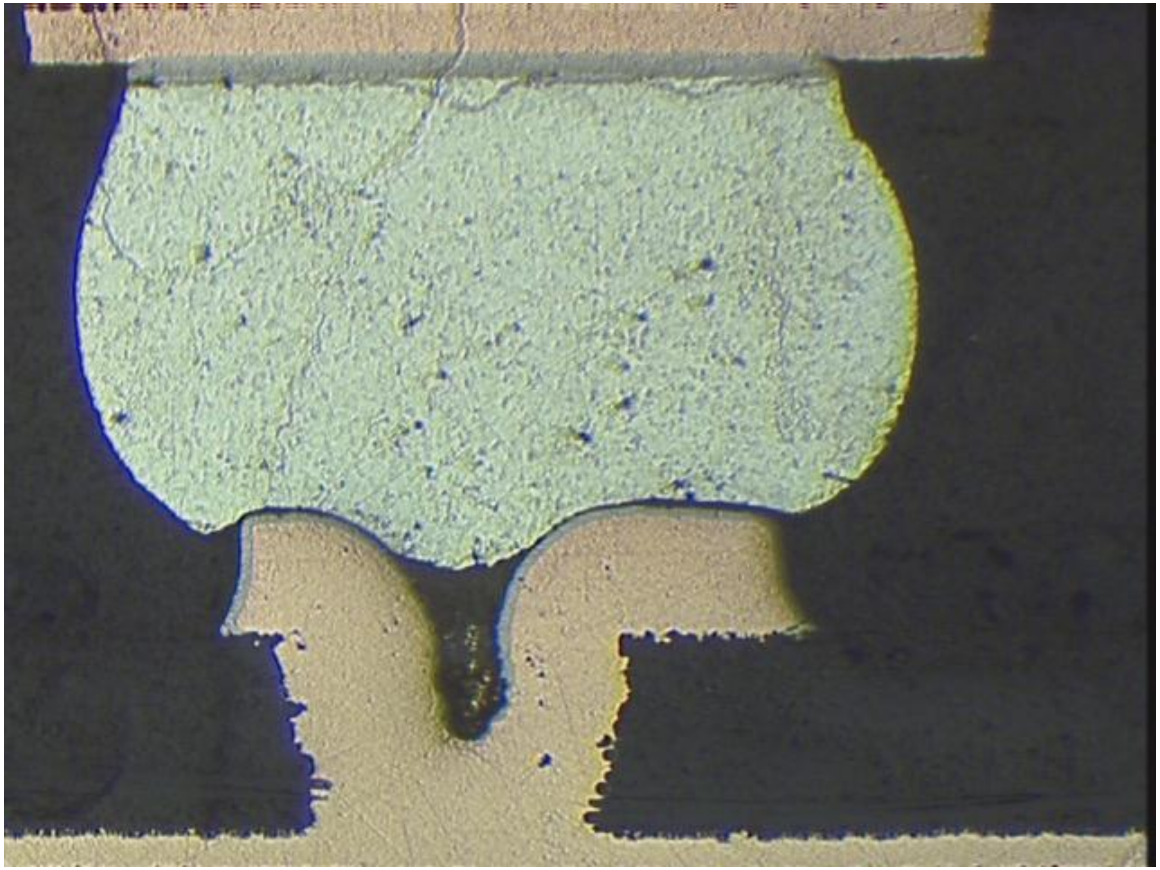
Tin/Lead Test Results

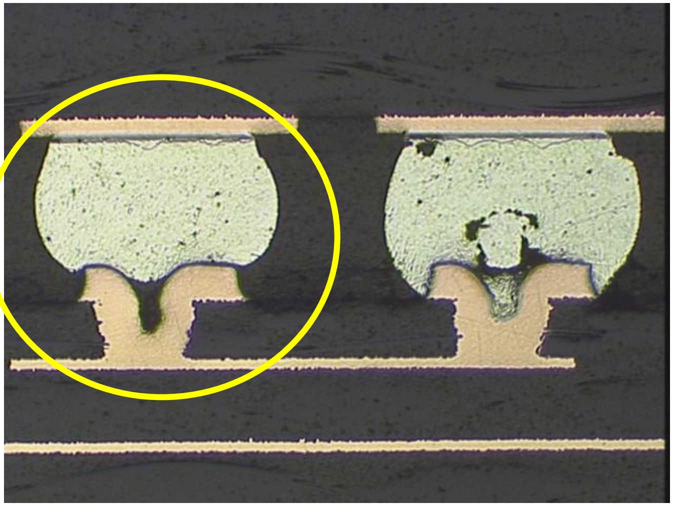




BGA56, U1 Component, Cross-section Showing Assembly Induced Solder Joint Defect, Failed @ 18 Cycles

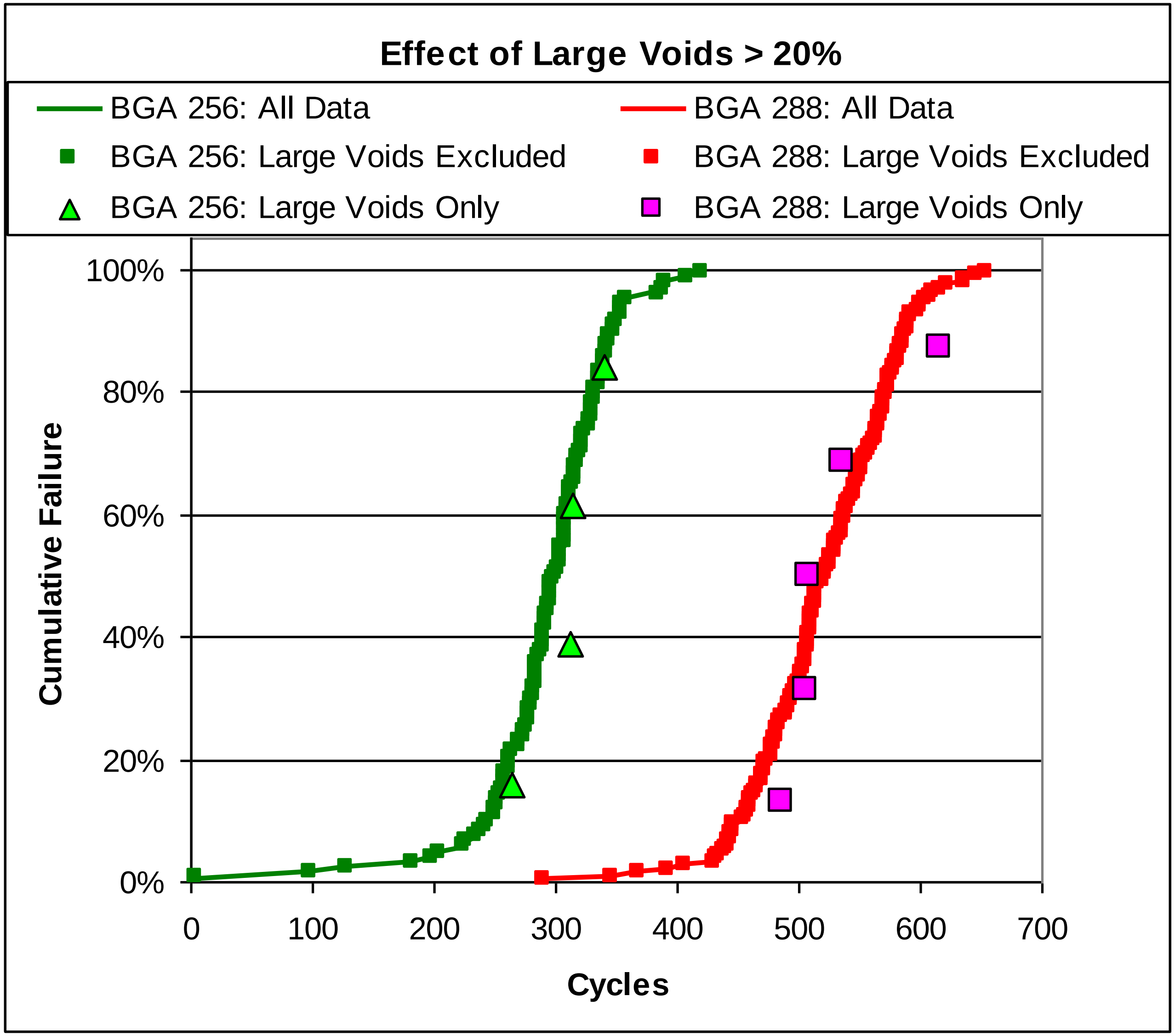
Lead-free Test Results



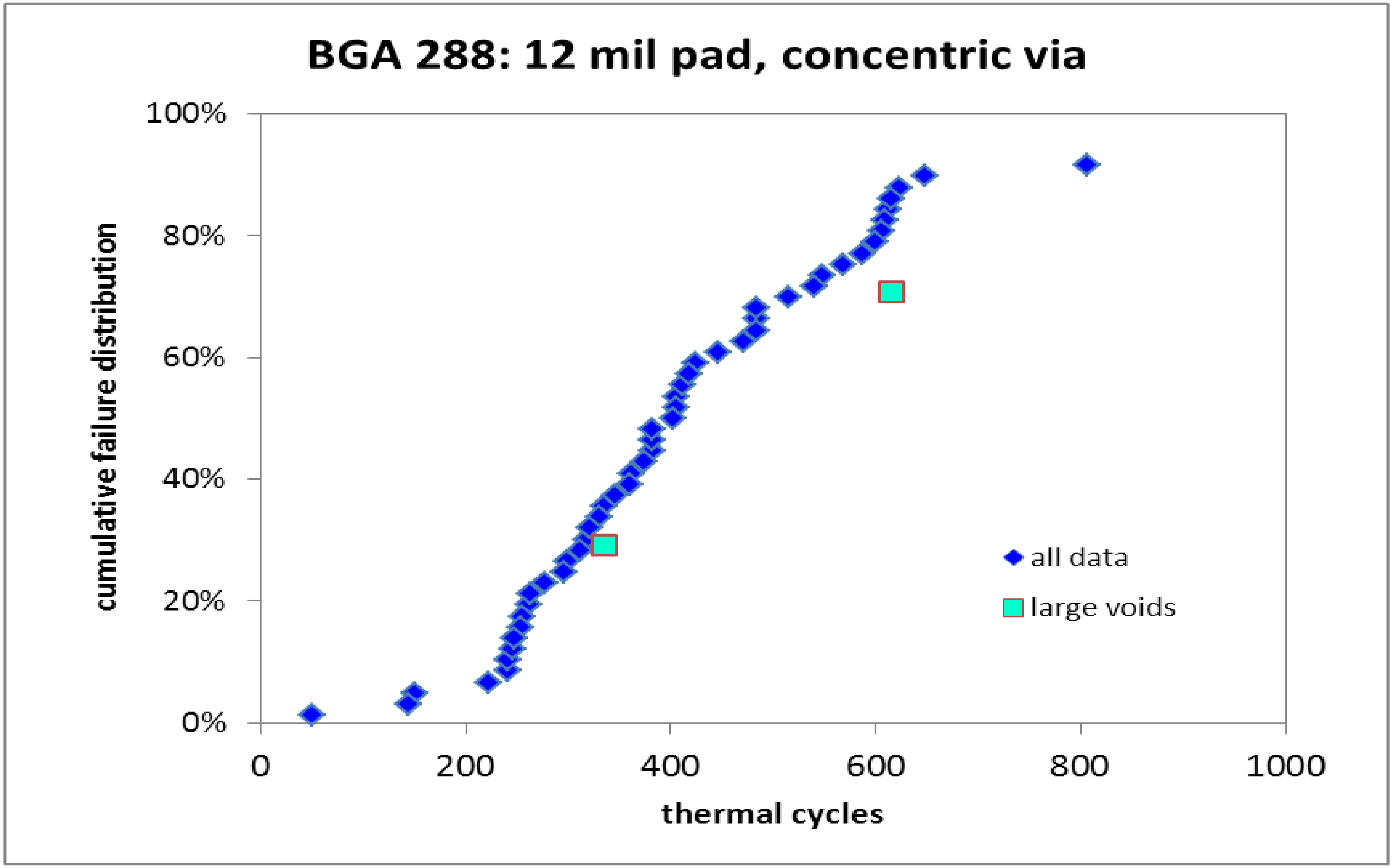


BGA56, U1 Component, Cross-section Showing Assembly Induced Defect, Insufficient Solder, Failed @ 1 Cycles

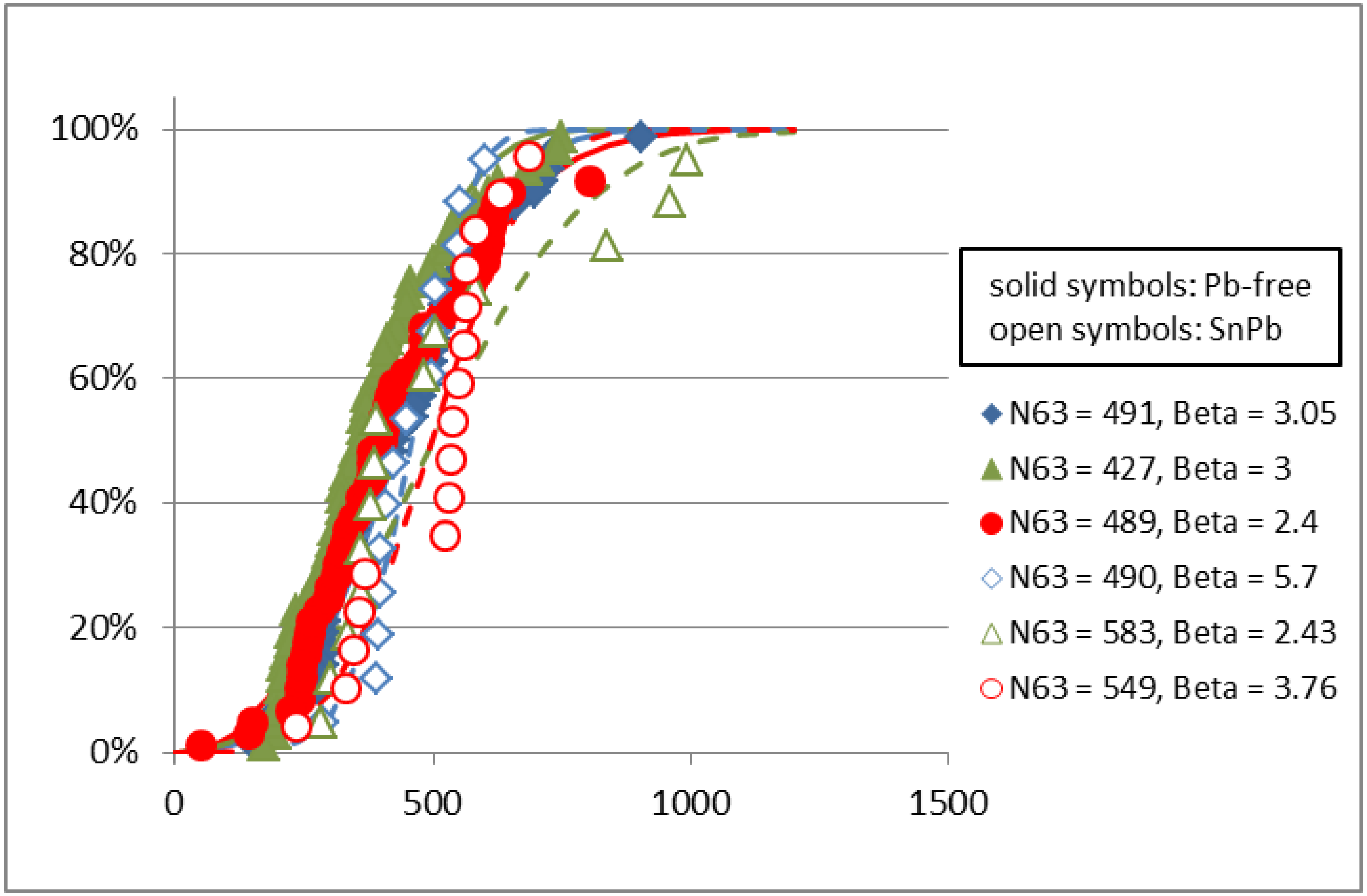
Tin/Lead Test Results



Lead-free Test Results

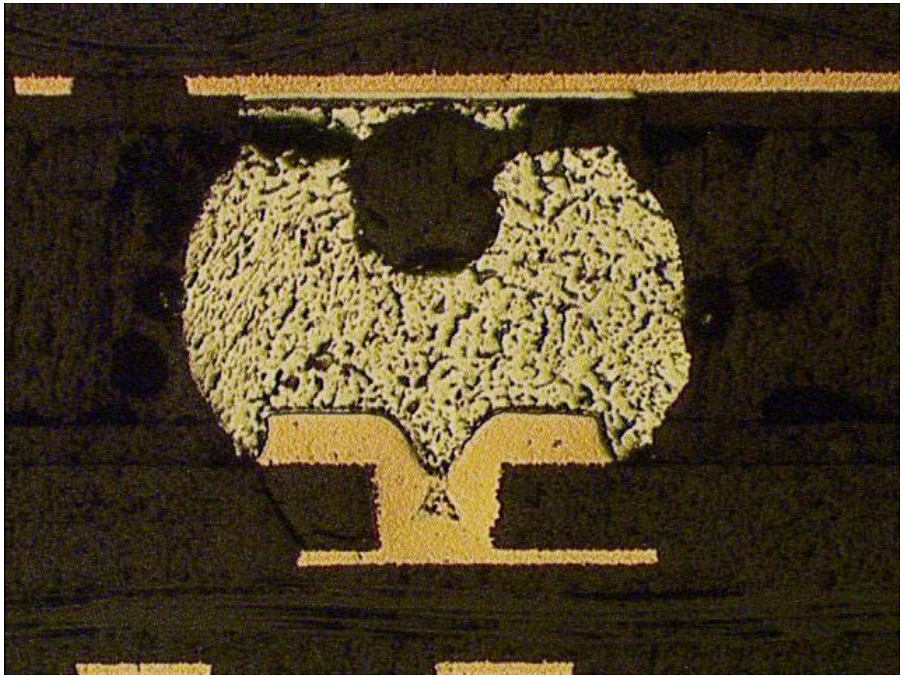


Combine Test Results

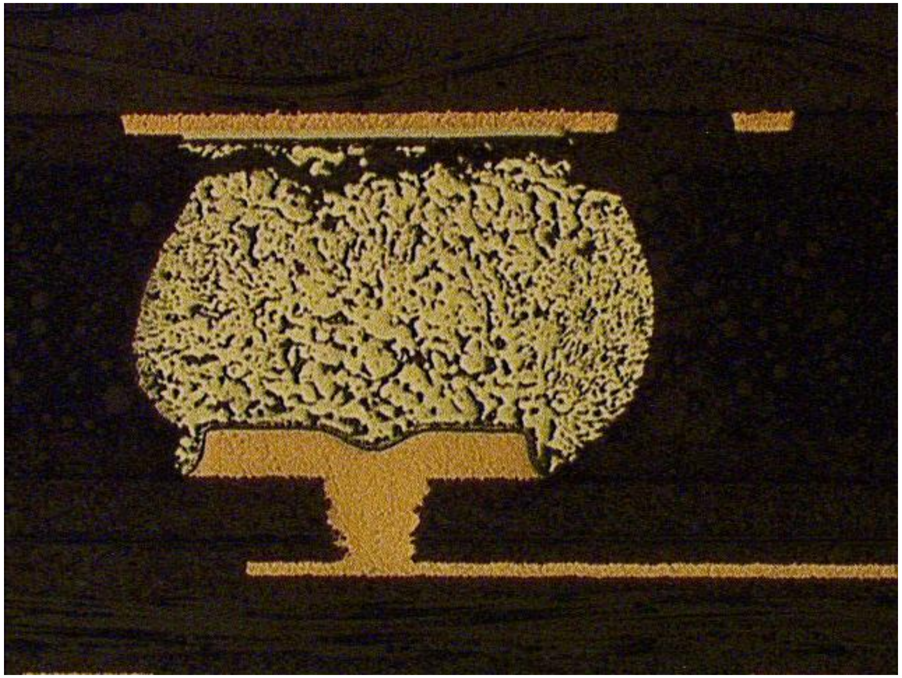


SnPb Vs. Lead-free Solder Alloy Comparison of Solder Joint Integrity Failure (256 I/O and 288 I/O)

Test Results

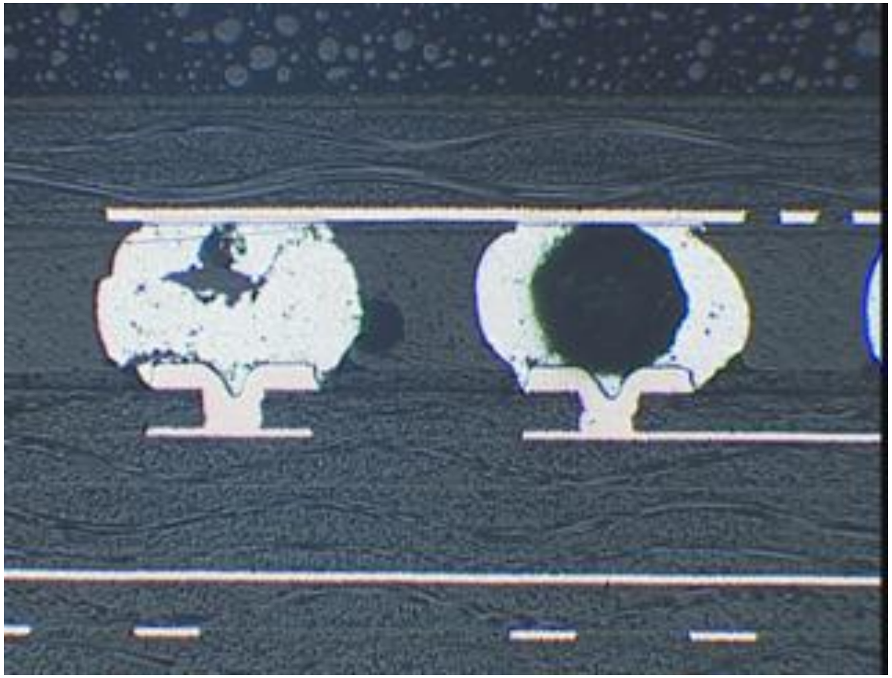


Magnified View, BGA Void Assessment: 18% Void, Outer Row, 264 Cycles, BGA256

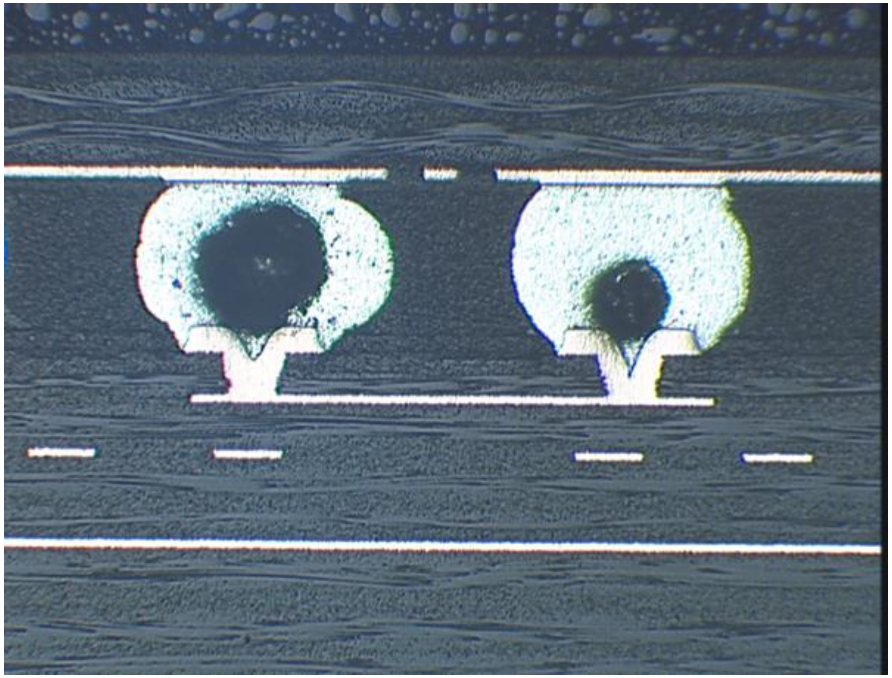


Magnified View, BGA Void Assessment: No Void, Outer Row, 311 Cycles, BGA256

Test Results

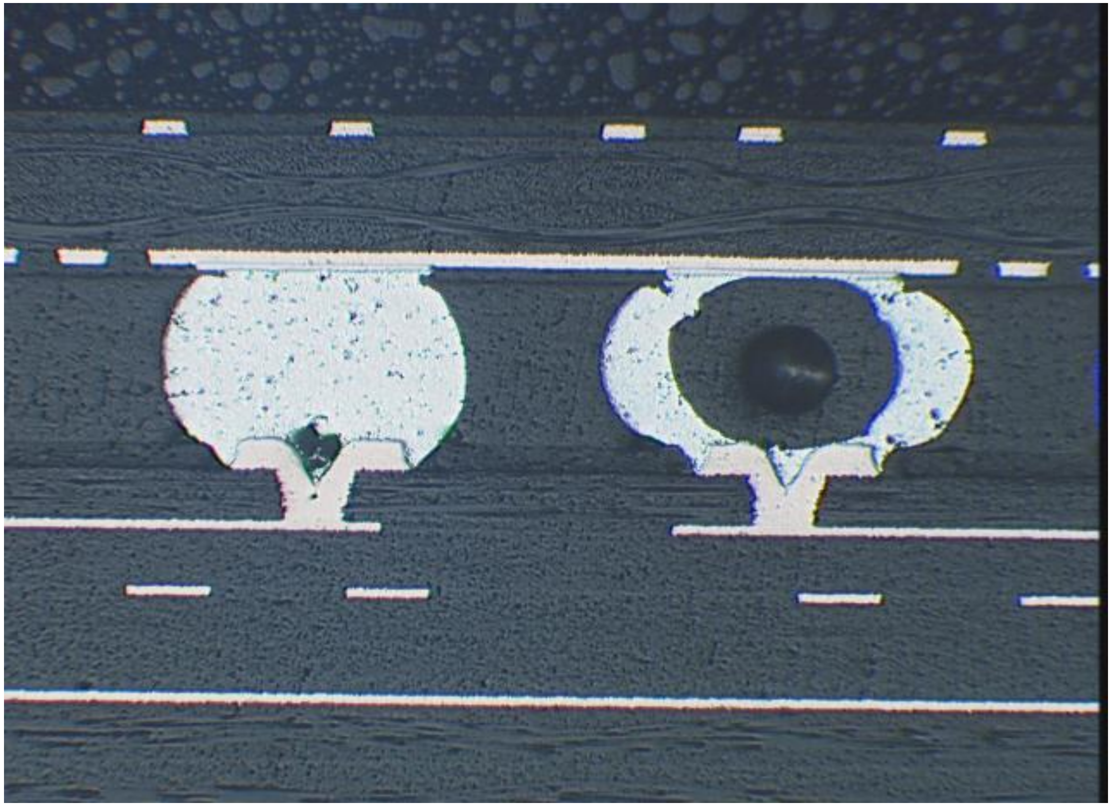


BGA256 Component with Failed Solder Joint and Non-failed Solder Joint Containing 39% Void



BGA288 Component with Non-failed Solder Joint Containing 34% Void

Test Results



BGA288 Test Component with Non-failed Solder Joint Containing 42% Void

Conclusions

- **Tin/Lead BGAs: The location of the void within the solder joint was the primary root cause for the loss of solder joint integrity.**

- **Lead-free BGAs: The statistical analysis and the metallographic cross-sectional analysis results revealed that the presence or size of the solder joint voids did not correlate to the loss of lead-free solder joint integrity.**

- **A single set of BGA solder joint void process control limits is applicable for both tin/lead and lead-free BGA solder joints.**

Proposed BGA Solder Joint Void Criteria to the JSTD-001 Committee

- **Remove current 25% maximum of x-ray image area requirement from the JSTD-001 specification**

- **Replace with: 15% maximum of x-ray image area process indicator with 30% maximum x-ray image area requirement**

Questions ???