# Fill the Void VII: A Continuing Study of the Impact of Solder Alloy on Voiding in Solder Joints

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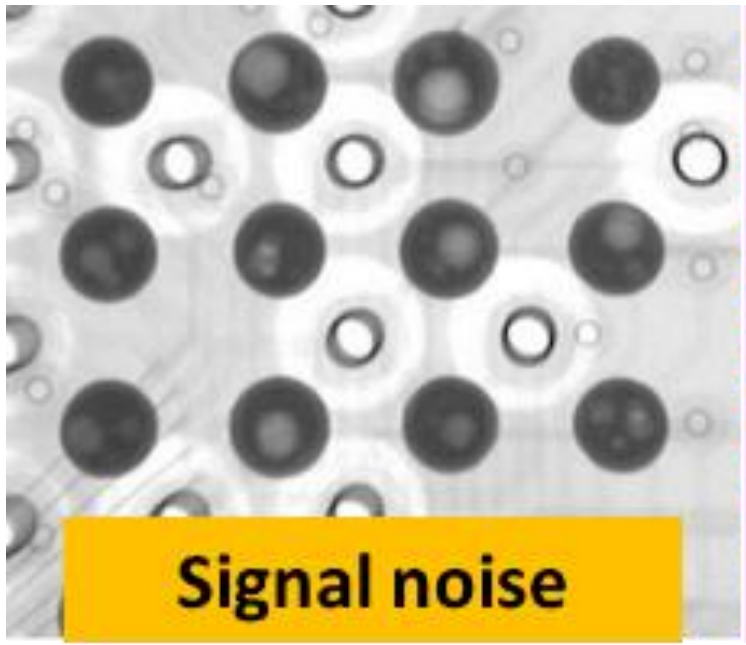
FCT Solder

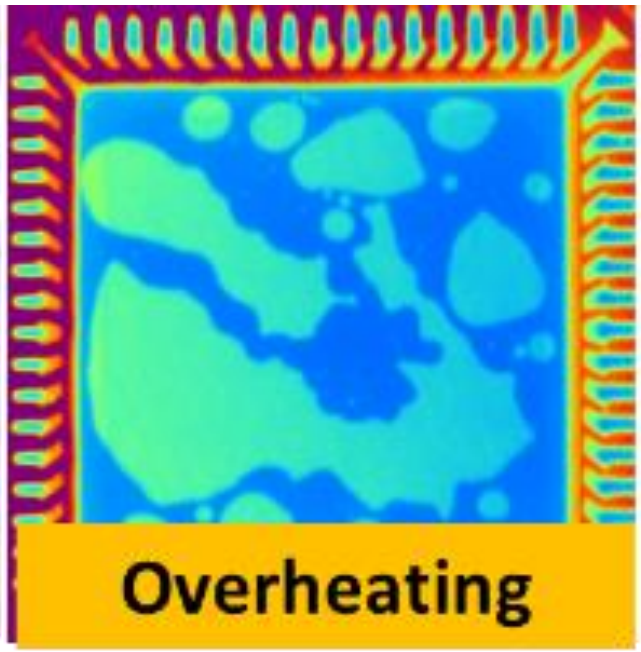
# Outline / Agenda

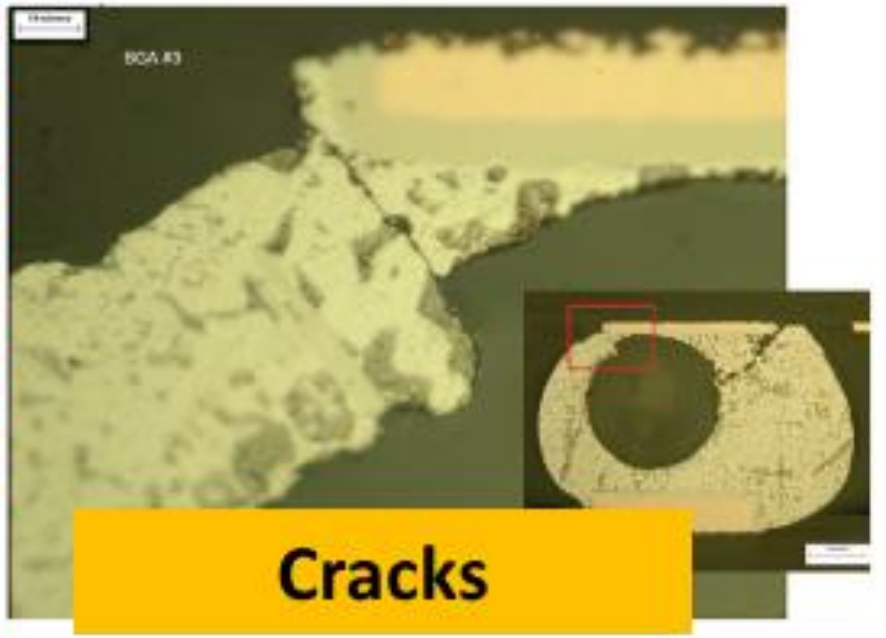
- Introduction
  - Voiding & Reliability Concerns
  - Voiding Limits
  - Voiding Root Causes
  - Prior Work
- Experimental Setup
- Results
  - Solder Paste Reflow Performance
  - Voiding Results
- Conclusions & Recommendations
- Q & A

# Introduction

# Introduction: Voiding & Reliability




- Voiding in solder joints may pose reliability risks.

# Introduction: Voiding & Reliability

- *Hillman, et. al., found no correlation between voiding and reliability for QFN's with 4 solder alloys.
- Field experience shows that voiding is related to reliability for some applications.

*Hillman, et. al., "Bottom Terminated Component (BTC) Void Concerns: Real and Imagined", Proceedings of SMTA International, 2019.

# Introduction: Voiding Limits

- IPC J-STD-001H & IPC-A-610G
  - 30% max area in BGAs
  - 50% max area in QFN thermal pads
- IPC-7093A BTCs
  - < 30% area typical on thermal pads (J-STD-001)
- IPC-7095C BGAs
  - < 25% area and < 50% diameter Classes 1&2
  - < 20% area and < 45% diameter Class 3

**Voiding limits are often set by end users and OEMs.**

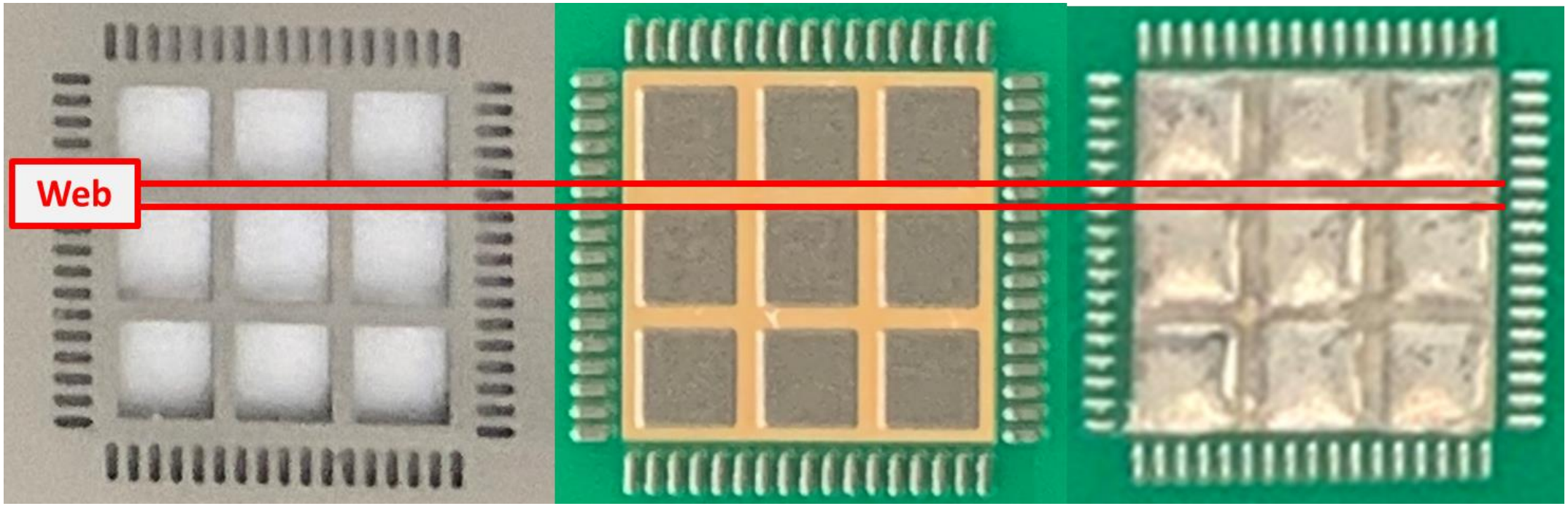
# Introduction: Voiding Root Causes

- Gas Bubble Entrapment
  - Flux, alloy, solder powder size, stencil design, reflow profile, etc.
  - Time for gas bubbles to leave the molten solder?

**Reflow – Time on Hot Plate**

# Introduction: Voiding Root Causes

- Wetting or Spread
  - Stencil design, flux, alloy, surface finish, profile, etc.



# Introduction: Prior Work*

- Window pane designs minimized voiding.
- Reflow profiles altered voiding behavior.
- LF-alloys showed different void behavior.
- Increasing area of printed solder paste coverage minimized voiding.
- Increasing stencil thickness and I/O pad volume decreased voiding.
- Solder alloys showed different voiding behavior with a no-clean solder paste.

*References appear in the paper.

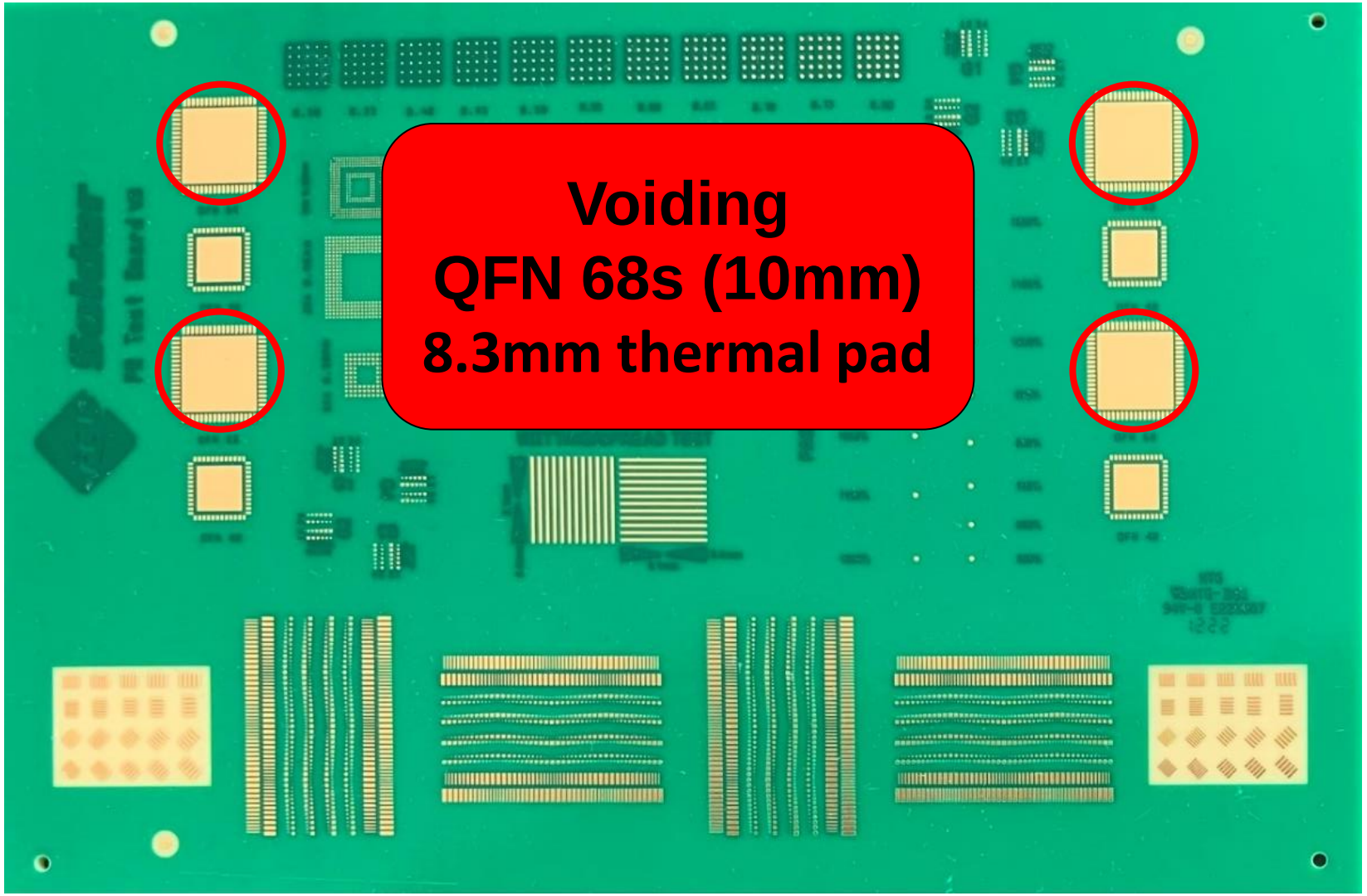
# Experimental Setup

# Experimental Setup

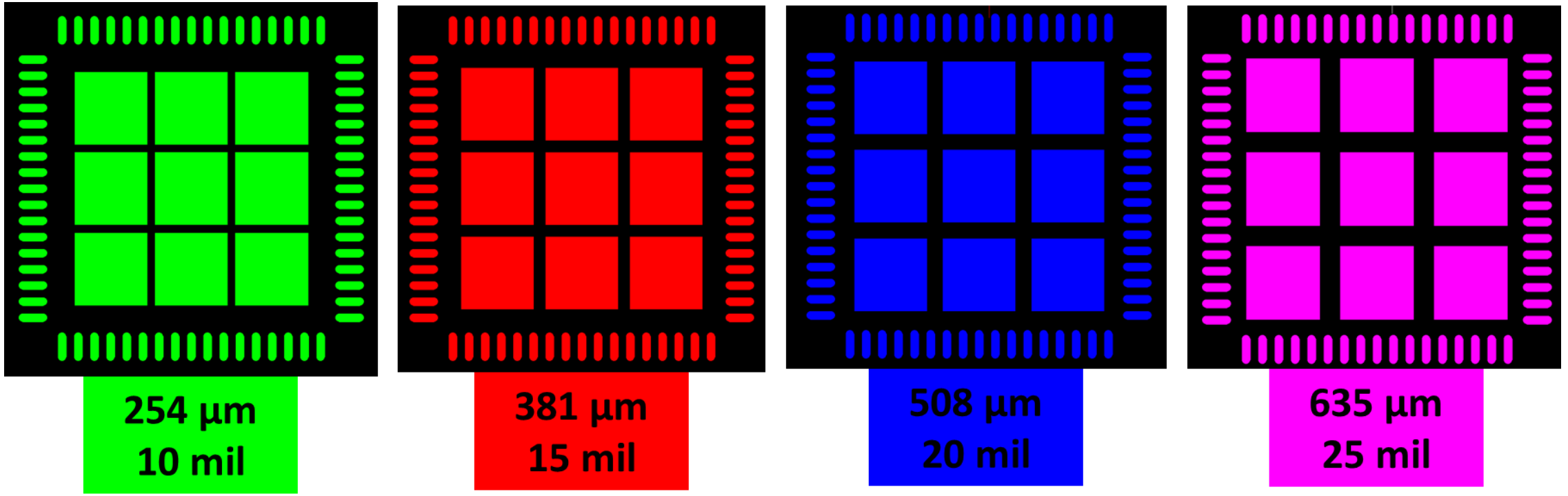
| Property | Sn63/Pb37 | SAC305 | SnBiCuNi | SnAgBiCu | Sn37BiX | Measuring method |
|---|---|---|---|---|---|---|
| Melting Range (°C) | 183 | 218-219 | 221-225 | 205-213 | 139-174 | DSC : 2°C/min 30-300°C JISZ3198-1 |
| Composition | Sn63/Pb37 | Sn3Ag0.5Cu | Sn1.5Bi0.7CuNi | Sn3.5Ag3Bi1Cu | Sn37BiX | |
| Specific Gravity (g/cc) | 8.4 | 7.4 | 7.4 | 7.5 | 8.1 | @20°C |
| Tensile strength (MPa) | 53 | 48 | 52 | 90 | 99 | 10mm/min @25°C |
| Elongation (%) | 32 | 33 | 33 | 16 | 20 | 10mm/min @25°C |
| ε 0.2% (MPa) | 16 | 41 | 39 | 61 | 81 | 10mm/min @25°C |
| Young's modulus (GPa) | 32 | 51 | 56 | 55 | 47 | JIS Z2280 |
| Thermal expansion (ppm/K) | 25 | 23 | 24 | 24 | 22 | -40 - +150°C |
| Thermal conductivity (W/m·K) | 50 | 58 | 54 | 53 | | Laser flush |
| Thermal mass (J/(kg·K)) | 150 | 219 | 224 | 232 | | Laser flush |
| Electric conductivity (μΩm) | 0.14 | 0.14 | 0.14 | 0.16 | | 4 terminal bridge |

**5 solder alloys with the same Water-soluble Pb-free solder paste flux**

# Experimental Setup: PR Test Board V3

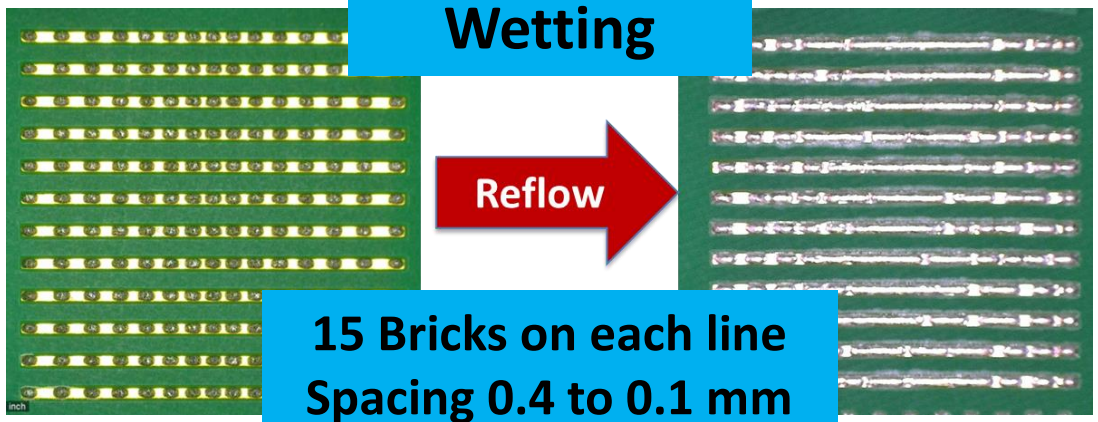


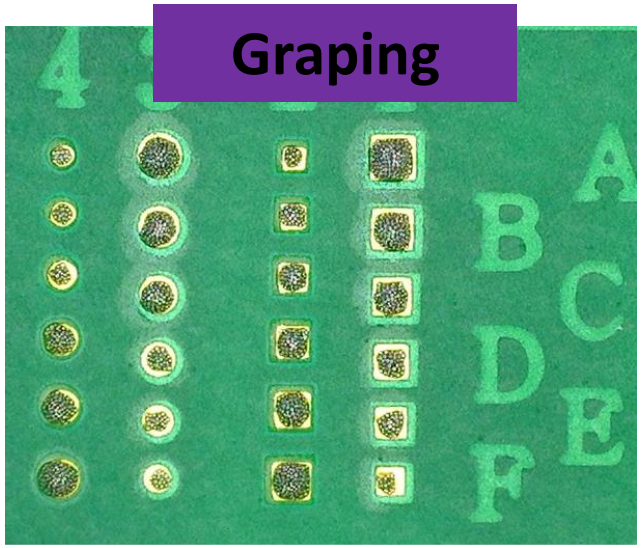
# Experimental Setup: Stencil Web Width & Voiding

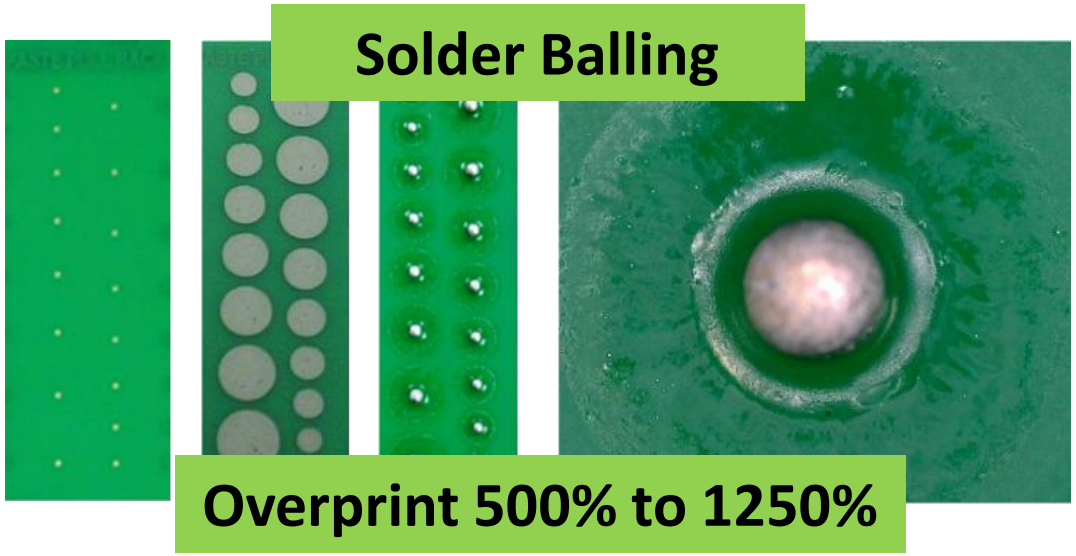


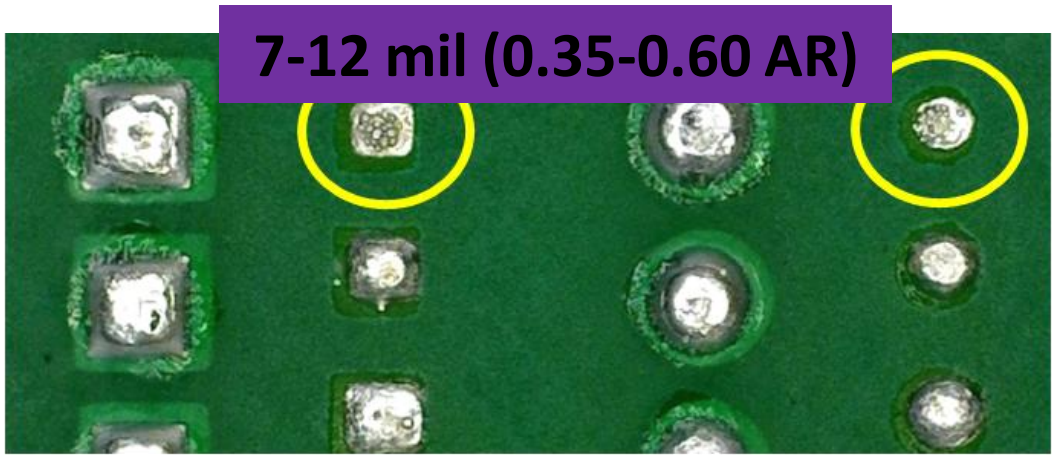

5 mil thick & 65% area of solder paste coverage

# Experimental Setup: PR Board & General Paste Performance



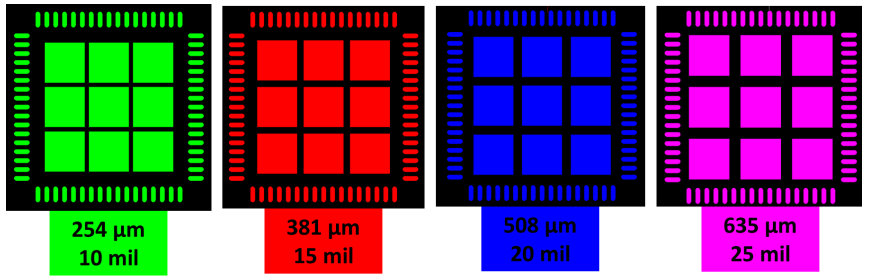



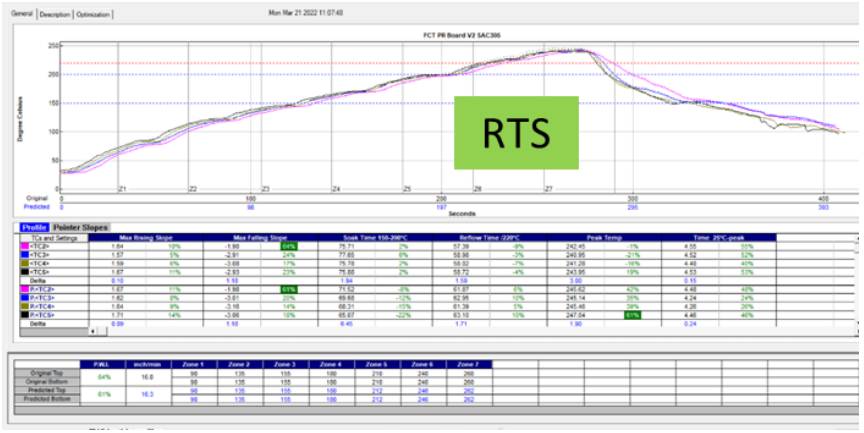



# Experimental Setup: Test Variables

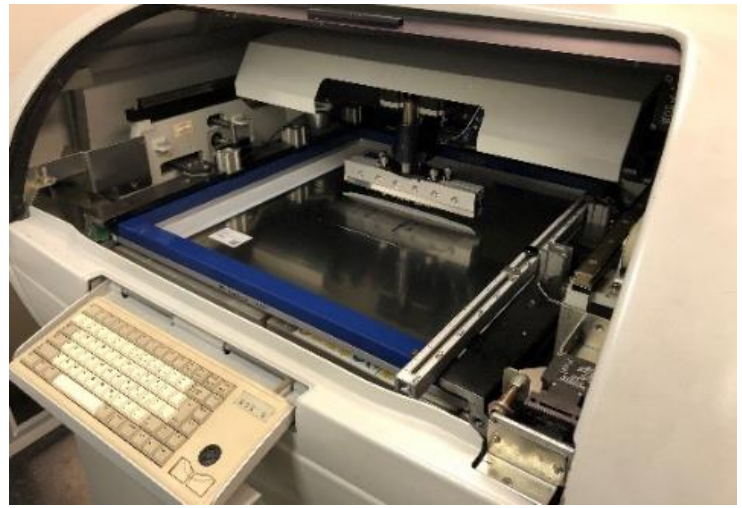
- Five alloys in WS-LF (ORH1) solder paste
  - Sn63/Pb37, SAC305, SnBiCuNi, SnAgBiCu, Sn37BiX
  - Compared to previous study with NC-LF (ROL0) paste
- Four stencil web widths
  - 10, 15, 20, 25 mils
- SAC305 RTS reflow profile
- 20 combinations
  - 5 PCBs per combo
  - 4 QFNs per PCB
  - 20 void measurements per combo
  - +2 extra combos for profile comparison
- Gas bubble escape test
  - 20.0g solder paste, Hotplate (250 or 280°C)



# Experimental Setup: Test Parameters

| Print Parameter | Value |
|---|---|
| Print speed (mm/sec) | 30 mm/sec |
| Blade length (mm) | 300 mm |
| Print pressure (kg) | 5.0 kg |
| Separation speed (mm/sec) | 3 mm/sec |
| Separation distance (mm) | 1 mm |
| Stencil thickness (µm) | 127 microns |
| Stencil material | FG stainless steel |

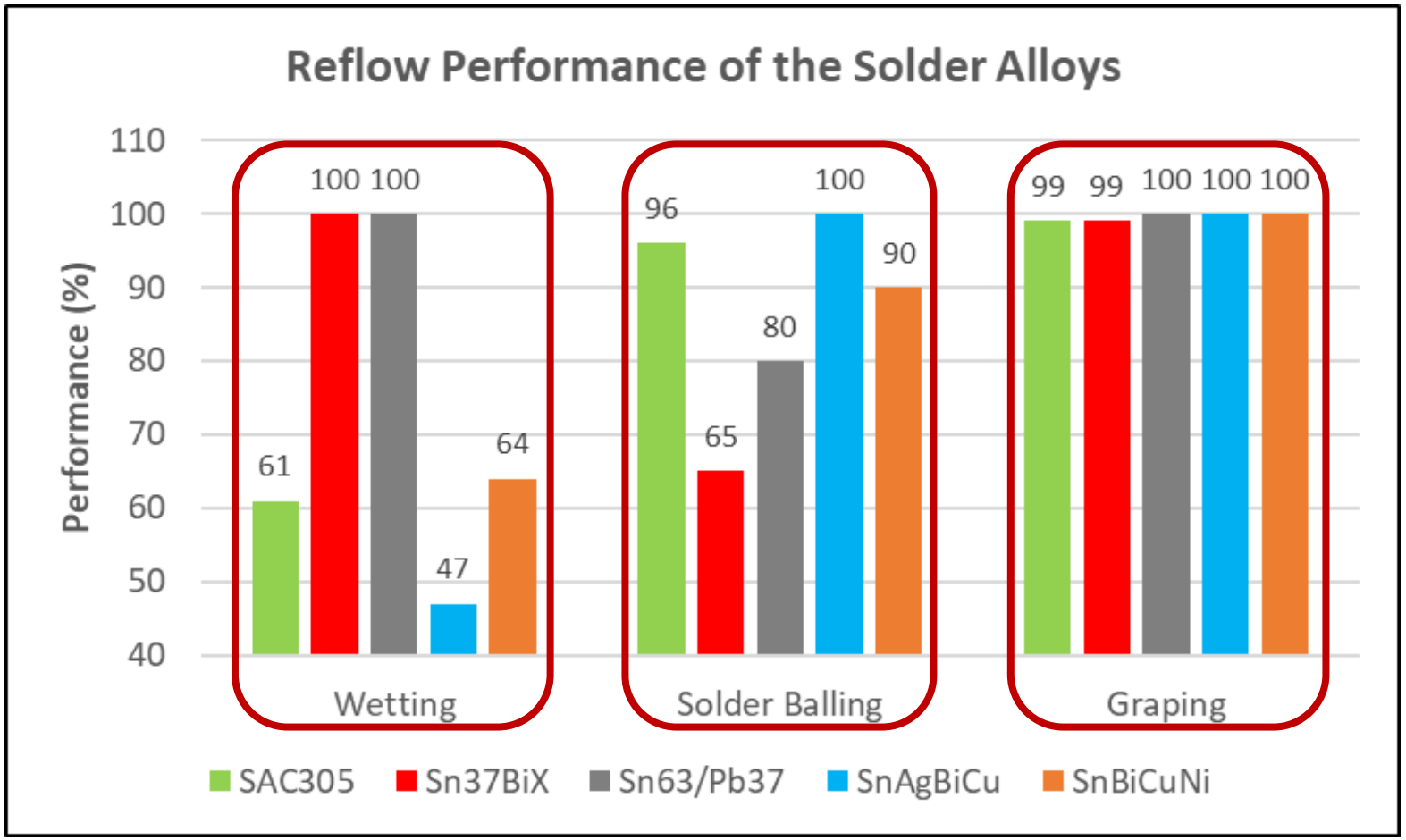


| Reflow Parameter | RTS SAC305* | RTS Sn63/Pb37* | RTS Sn37BiX* |
|---|---|---|---|
| Time above Liquidus | 57-59 sec >220 °C | 67-70 sec >183 °C | 75-77 sec >174 °C |
| Peak temp | 241-244 °C | 208-210 °C | 200-203 °C |
| Time 25 °C to peak temp | 4.4-4.6 min | 3.6-3.7 min | 4.8-5.0 min |

*SAC305 profile for all tests. 63/37 & Sn37BiX profile comparison

# Results: Reflow Performance

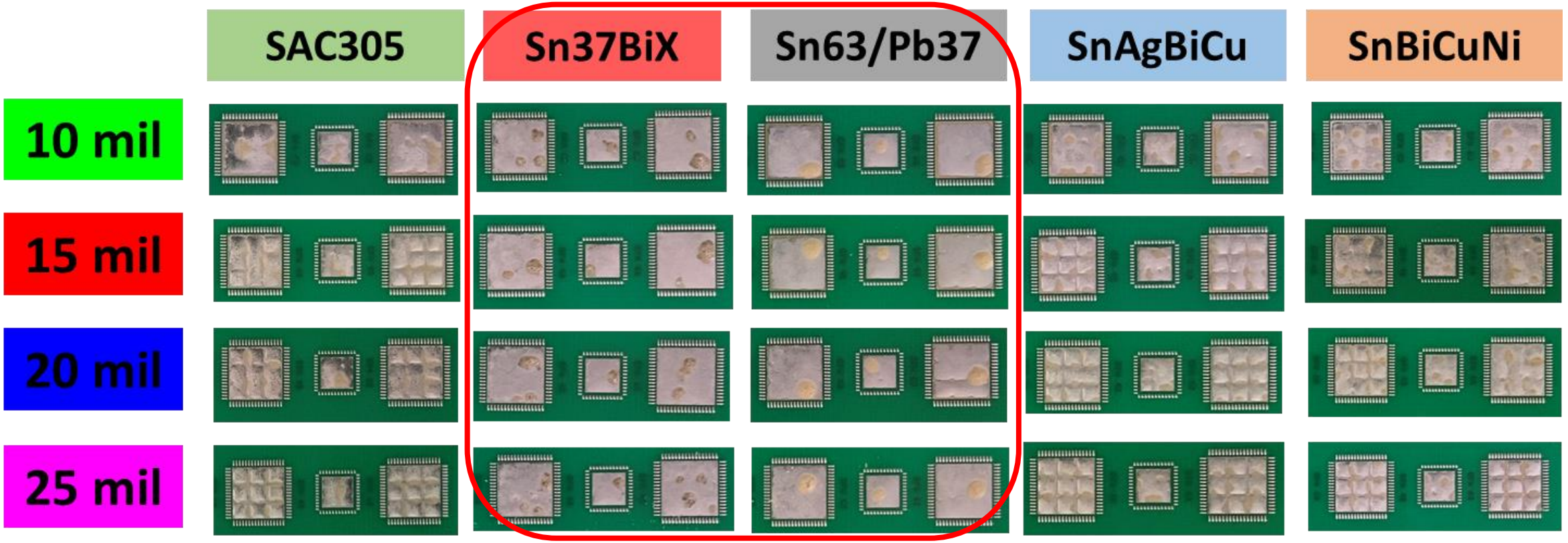
# Solder Paste Reflow Performance (SAC305 Profile)




- Sn37BiX & Sn/Pb best wetting. All others much lower.
- SnAgBiCu, SAC305 & SnBiCuNi best solder balling. Others much lower.
- Graping is ideal for all alloys.

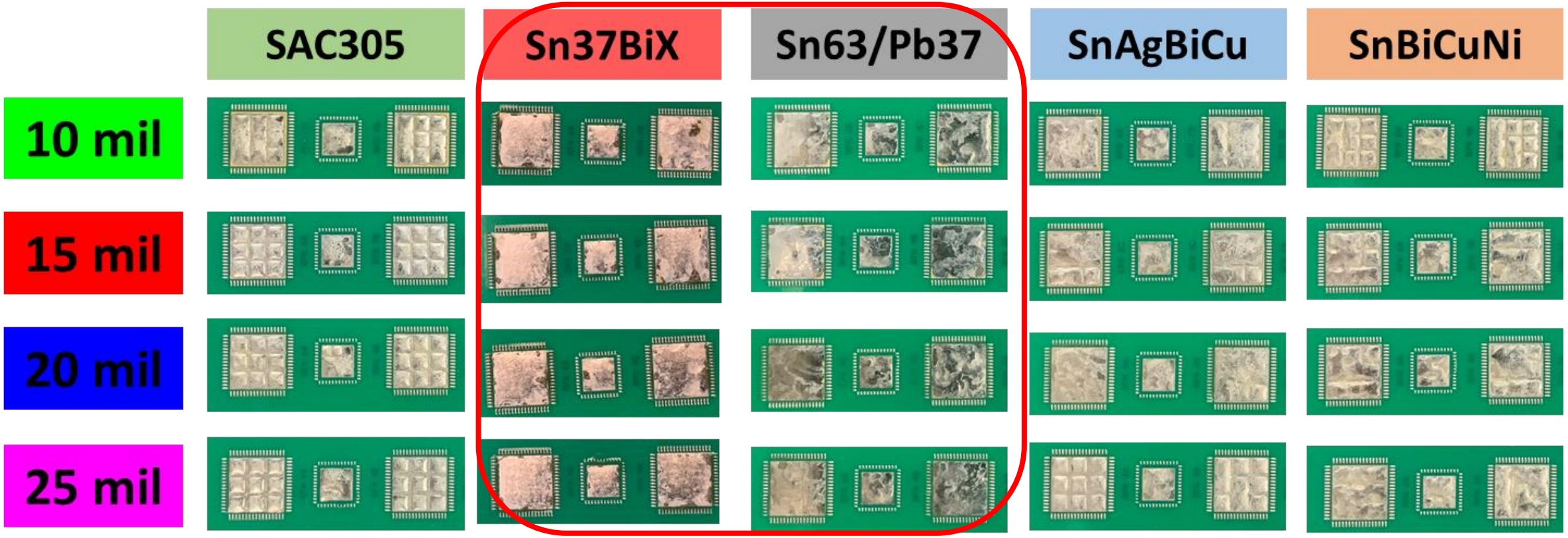
100% Performance is Ideal

# Solder Alloy Spread (WS, SAC305 Profile)




- Sn37BiX & Sn/Pb fully spread and leveled on all web widths
- Best to worst spread: Sn37BiX = Sn/Pb > SnBiCuNi > SAC305 = SnAgBiCu

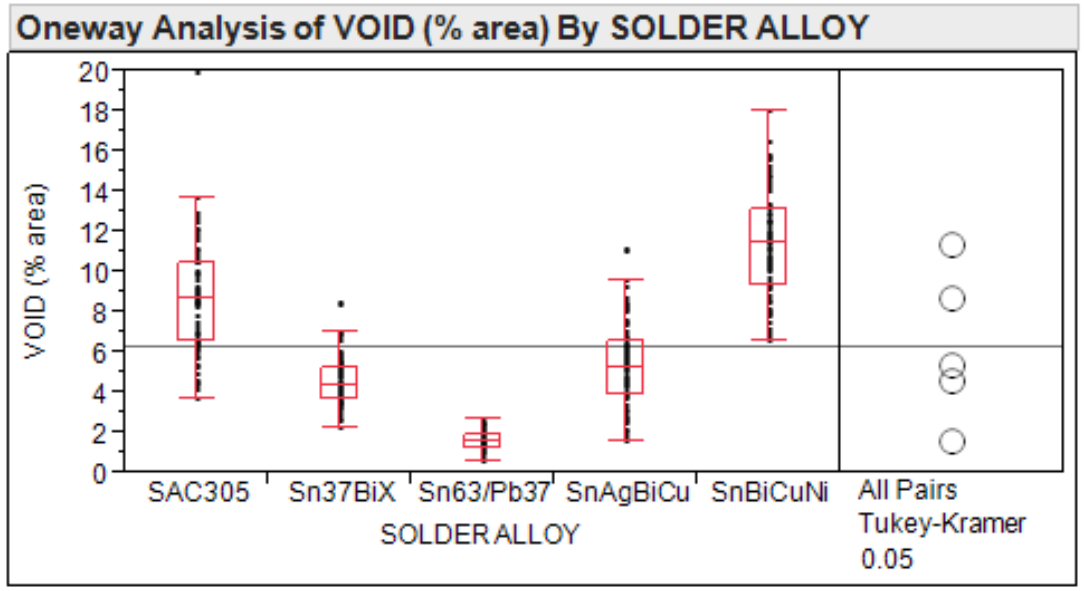
# Solder Alloy Spread (No Clean, SAC305 Profile)




- Sn37BiX & Sn/Pb fully spread and leveled on all web widths
- Best to worst spread: Sn37BiX = Sn/Pb > SnBiCuNi > SnAgBiCu = SAC305

# Results: Voiding

# Voiding by Solder Alloy: All Webs & SAC305 Profile Water Soluble Solder Paste




Excluded Rows 40

**Means Comparisons**

**Comparisons for all pairs using Tukey-Kramer HSD**

**Connecting Letters Report**

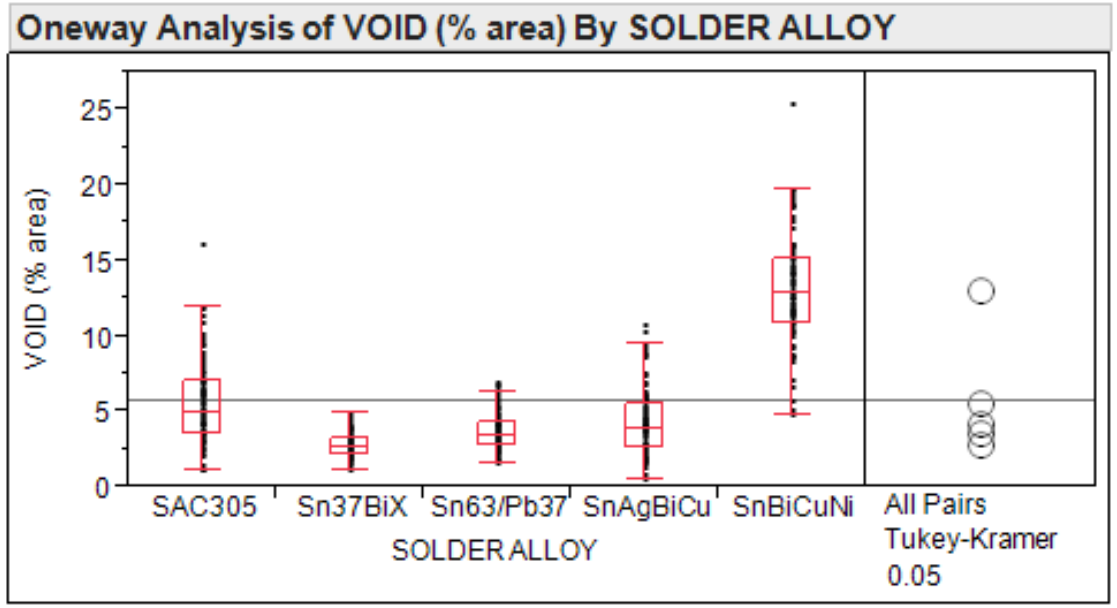
| Level | | Mean |
|---|---|---|
| SnBiCuNi | A | 11.4 |
| SAC305 | B | 8.7 |
| SnAgBiCu | C | 5.3 |
| Sn37BiX | C | 4.5 |
| Sn63/Pb37 | D | 1.6 |

Levels not connected by same letter are significantly different.

- SnBiCuNi highest voiding
- Sn37BiX & Sn/Pb lowest voiding

# Voiding by Solder Alloy: All Webs & SAC305 Profile

## No Clean Solder Paste




**Means Comparisons**

**Comparisons for all pairs using Tukey-Kramer HSD**

**Connecting Letters Report**

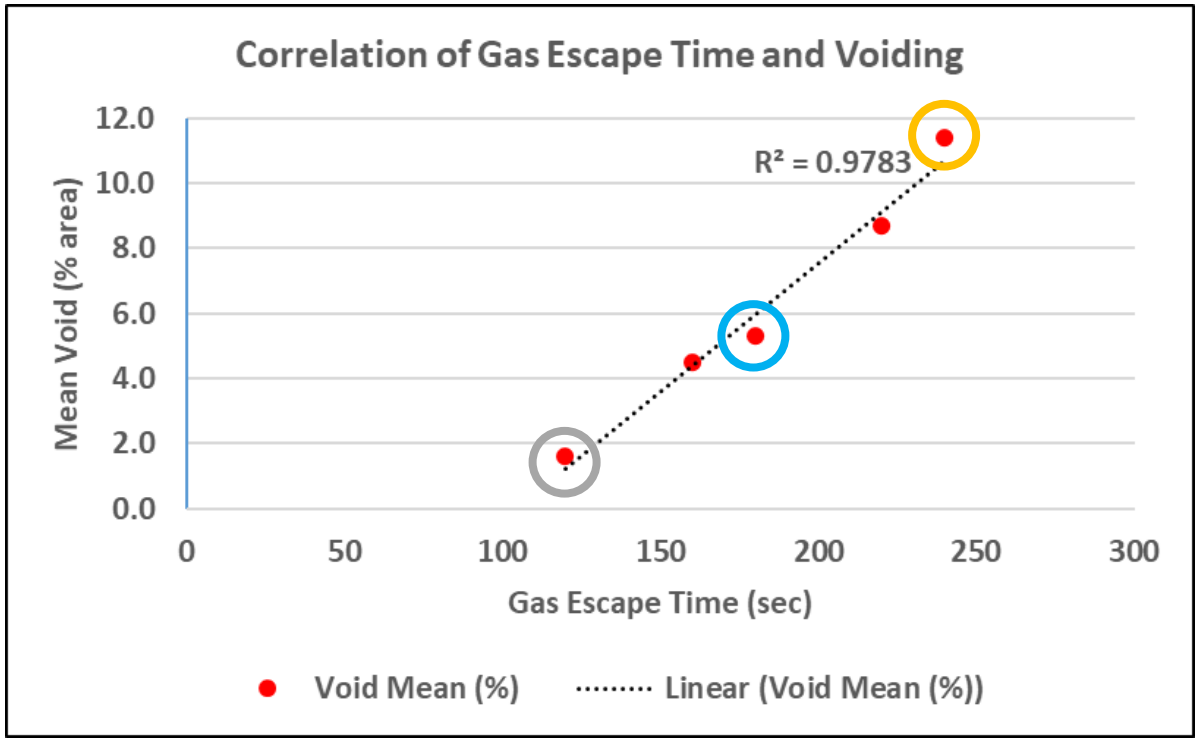
| Level | | | | Mean |
|---|---|---|---|---|
| SnBiCuNi | A | | | 13.0 |
| SAC305 | | B | | 5.6 |
| SnAgBiCu | | | C | 4.2 |
| Sn63/Pb37 | | | C | D 3.6 |
| Sn37BiX | | | | D 2.7 |

Levels not connected by same letter are significantly different.

- SnBiCuNi highest voiding
- Sn37BiX & Sn/Pb lowest voiding

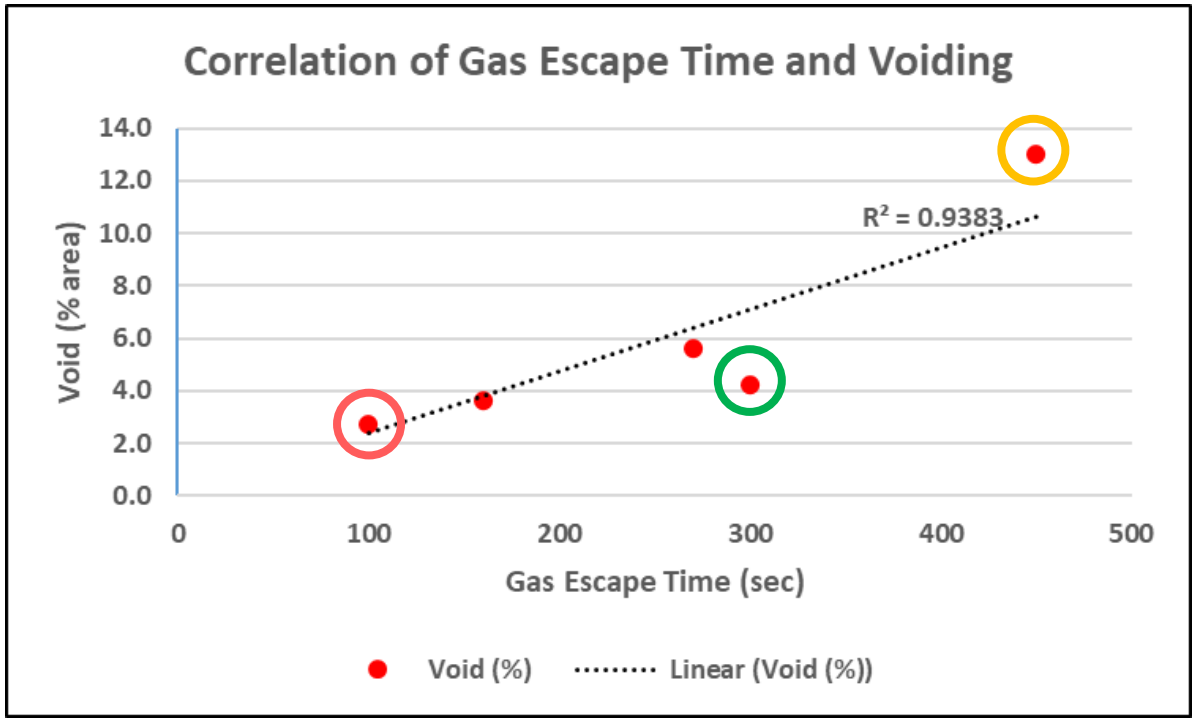
# Gas Bubble Escape by Solder Alloy
# Water Soluble Solder Paste


| Solder Alloy | Time for Gas Bubble Escape (sec) | Void Mean (%) |
|---|---|---|
| Sn63/Pb37 | 120 | 1.6 |
| Sn37BiX | 160 | 4.5 |
| SnAgBiCu | 180 | 5.3 |
| SAC305 | 220 | 8.7 |
| SnBiCuNi | 240 | 11.4 |

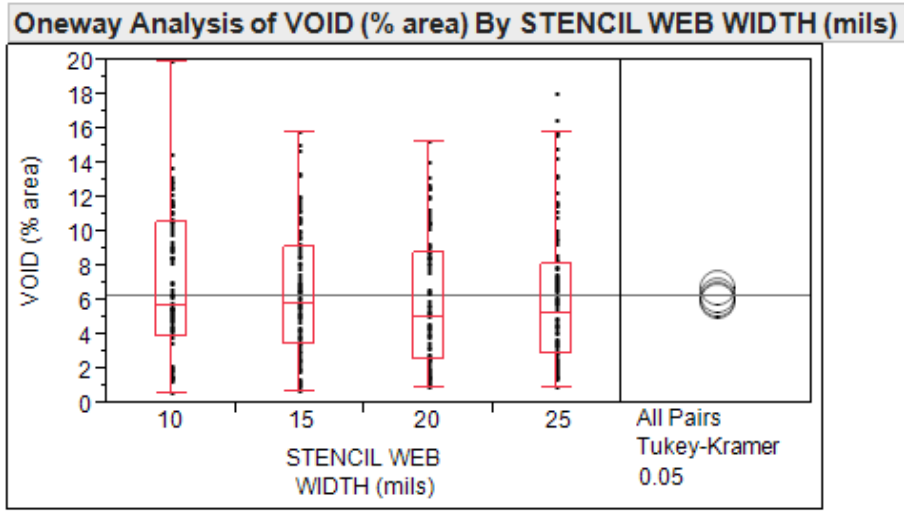


# Gas Bubble Escape by Solder Alloy
## No Clean Solder Paste


| Solder Alloy | Time for Gas Bubble Escape (sec) | Void Mean (%) |
|---|---|---|
| Sn37BiX | 100 | 2.7 |
| Sn63/Pb37 | 160 | 3.6 |
| SAC305 | 270 | 5.6 |
| SnAgBiCu | 300 | 4.2 |
| SnBiCuNi | 450 | 13.0 |



# Voiding by Web Width: All Alloys & SAC305 Profile




Excluded Rows 40

**Means Comparisons**

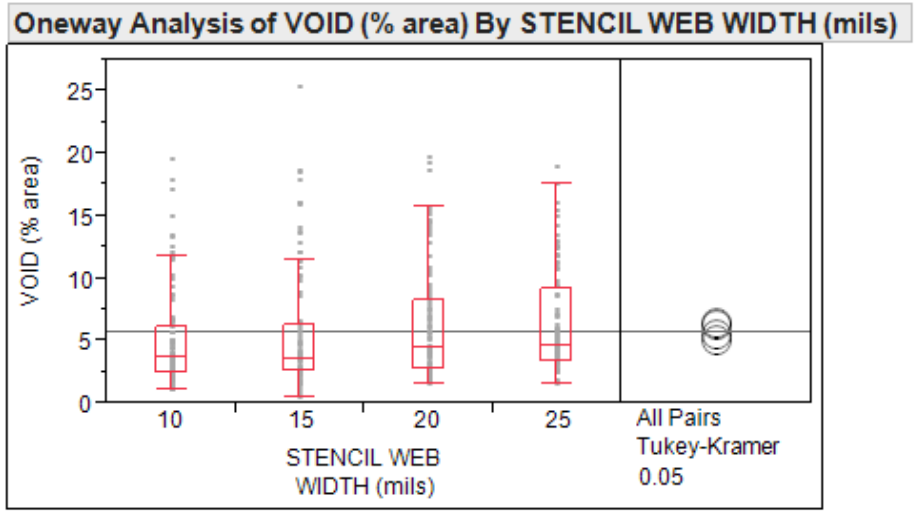
**Comparisons for all pairs using Tukey-Kramer HSD**

**Connecting Letters Report**

| Level | | Mean |
|---|---|---|
| 10 | A | 6.7 |
| 15 | A | 6.3 |
| 25 | A | 6.1 |
| 20 | A | 6.0 |

Levels not connected by same letter are significantly different.

**Water Soluble**




Excluded Rows 40

**Means Comparisons**

**Comparisons for all pairs using Tukey-Kramer HSD**

**Connecting Letters Report**

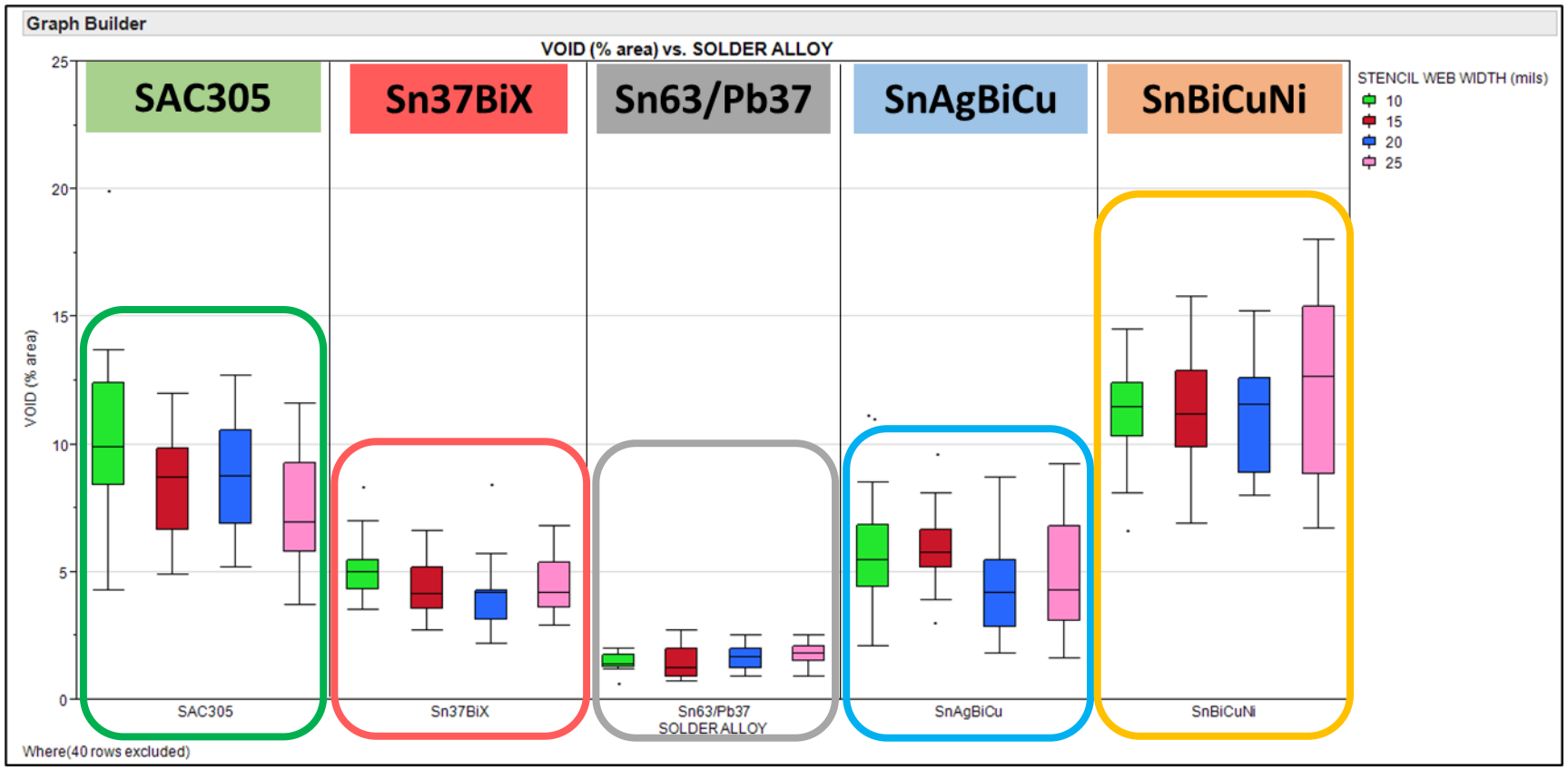
| Level | | Mean |
|---|---|---|
| 25 | A | 6.4 |
| 20 | A | 6.2 |
| 15 | A | 5.5 |
| 10 | A | 5.1 |

Levels not connected by same letter are significantly different.

**No Clean**

- Web width did not change voiding (all alloys averaged)
- Same result with No clean

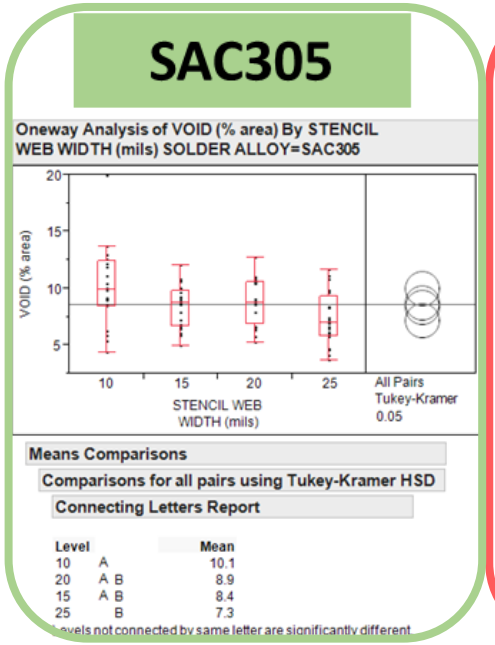
# Voiding by Alloy & Web Width: SAC305 Profile Water Soluble Solder Paste



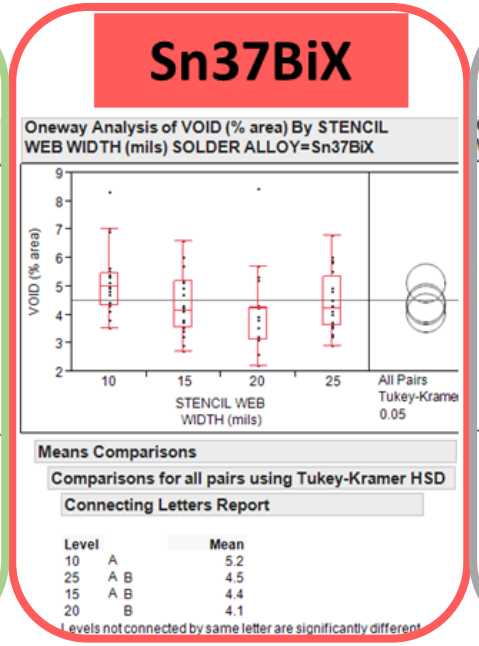

- SAC305 moderate voiding – changes with web
- Sn37BiX & Sn/Pb lowest voiding
- SnAgBiCu low-mod voiding
- SnBiCuNi highest voiding

# Voiding by Alloy & Web Width: SAC305 Profile Water Soluble Solder Paste

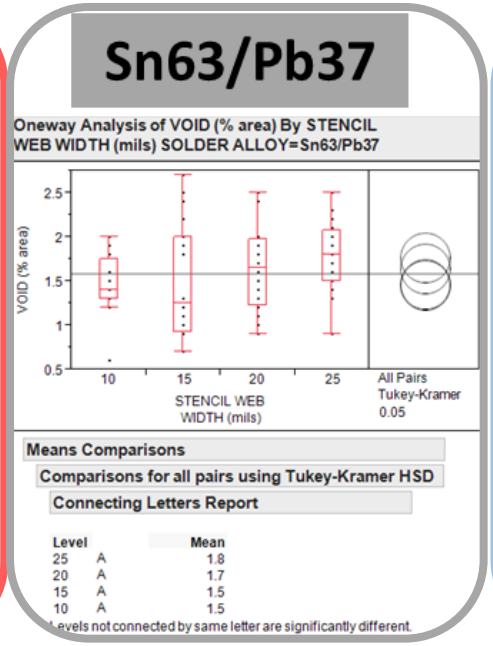
## SAC305



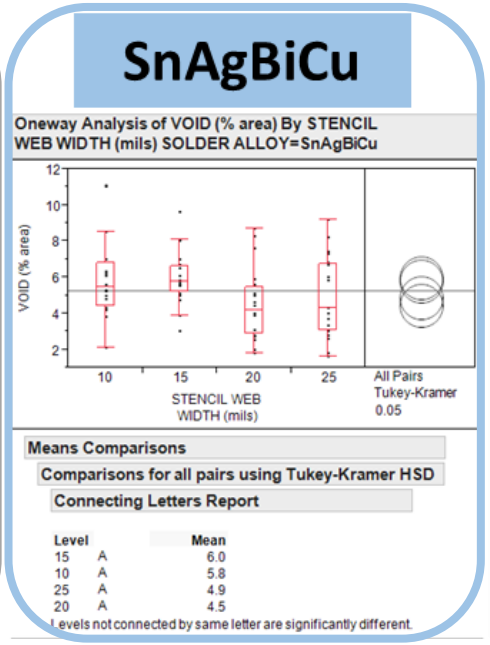

## Sn37BiX



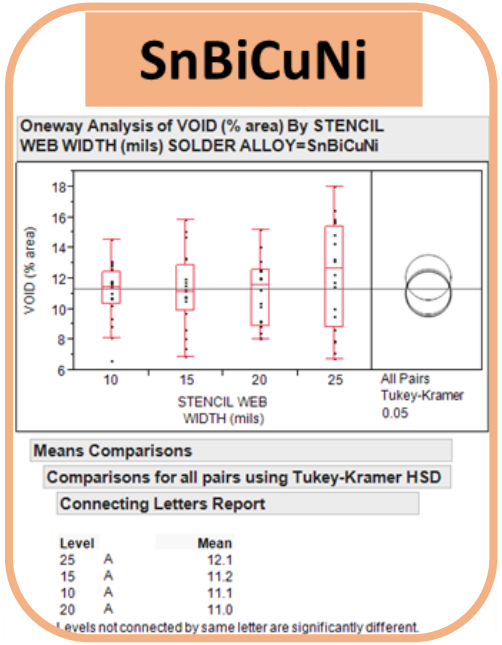

## Sn63/Pb37




## SnAgBiCu



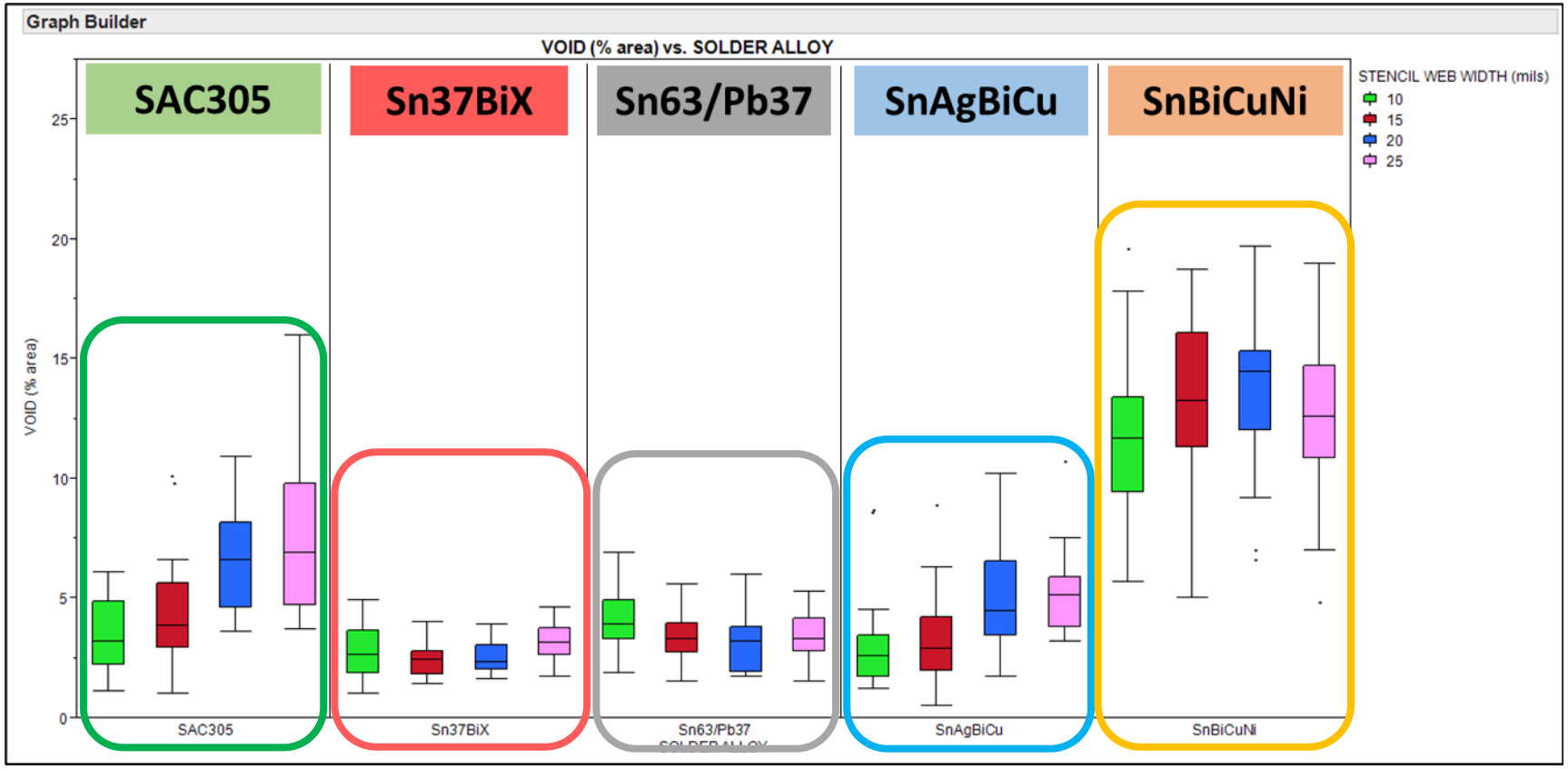

## SnBiCuNi




- SAC305 & Sn37BiX voiding higher for 10 mil webs
- Sn/Pb, SnAgBiCu, & SnBiCuNi voiding same for all webs

# Voiding by Alloy & Web Width: SAC305 Profile

## No Clean Solder Paste

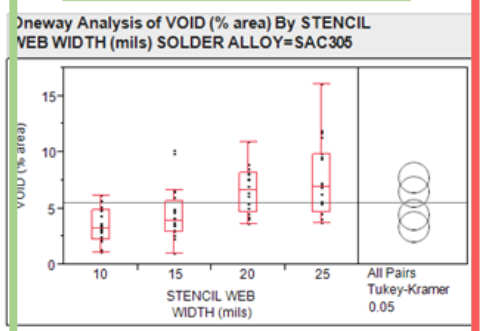



- SAC305 low to mod voiding – changes with web
- Sn37BiX & Sn/Pb lowest voiding
- SnAgBiCu low voiding – changes with web
- SnBiCuNi highest voiding

# Voiding by Alloy & Web Width: SAC305 Profile

## No Clean Solder Paste

### SAC305




Means Comparisons

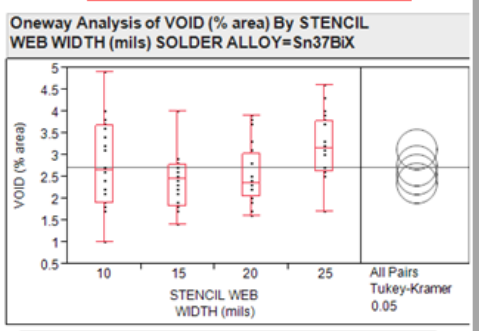
Comparisons for all pairs using Tukey-Kramer HSD

Connecting Letters Report

| Level | | Mean |
|---|---|---|
| 25 | A | 7.8 |
| 20 | A | 6.5 |
| 15 | B | 4.5 |
| 10 | B | 3.4 |

Levels not connected by same letter are significantly different.

### Sn37BiX




Means Comparisons

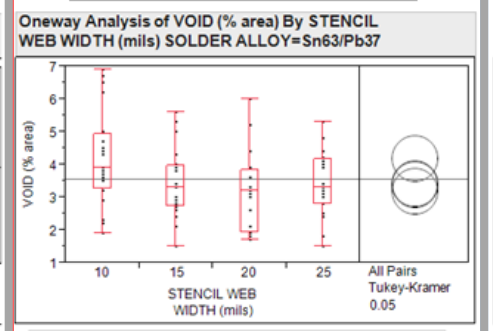
Comparisons for all pairs using Tukey-Kramer HSD

Connecting Letters Report

| Level | | Mean |
|---|---|---|
| 25 | A | 3.2 |
| 10 | A B | 2.8 |
| 20 | A B | 2.6 |
| 15 | B | 2.4 |

Levels not connected by same letter are significantly different.

### Sn63/Pb37




Means Comparisons

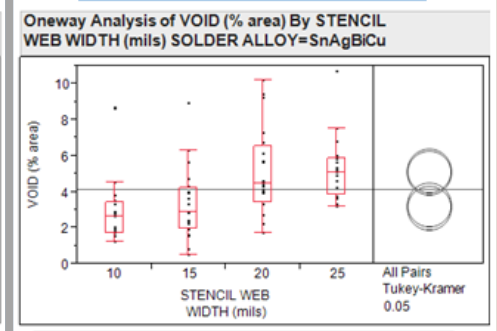
Comparisons for all pairs using Tukey-Kramer HSD

Connecting Letters Report

| Level | | Mean |
|---|---|---|
| 10 | A | 4.2 |
| 15 | A B | 3.4 |
| 25 | A B | 3.4 |
| 20 | B | 3.2 |

Levels not connected by same letter are significantly different.

### SnAgBiCu




Means Comparisons

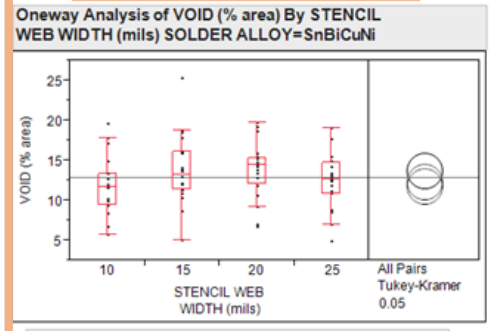
Comparisons for all pairs using Tukey-Kramer HSD

Connecting Letters Report

| Level | | Mean |
|---|---|---|
| 25 | A | 5.2 |
| 20 | A | 5.1 |
| 15 | B | 3.3 |
| 10 | B | 3.1 |

Levels not connected by same letter are significantly different.

### SnBiCuNi




Means Comparisons

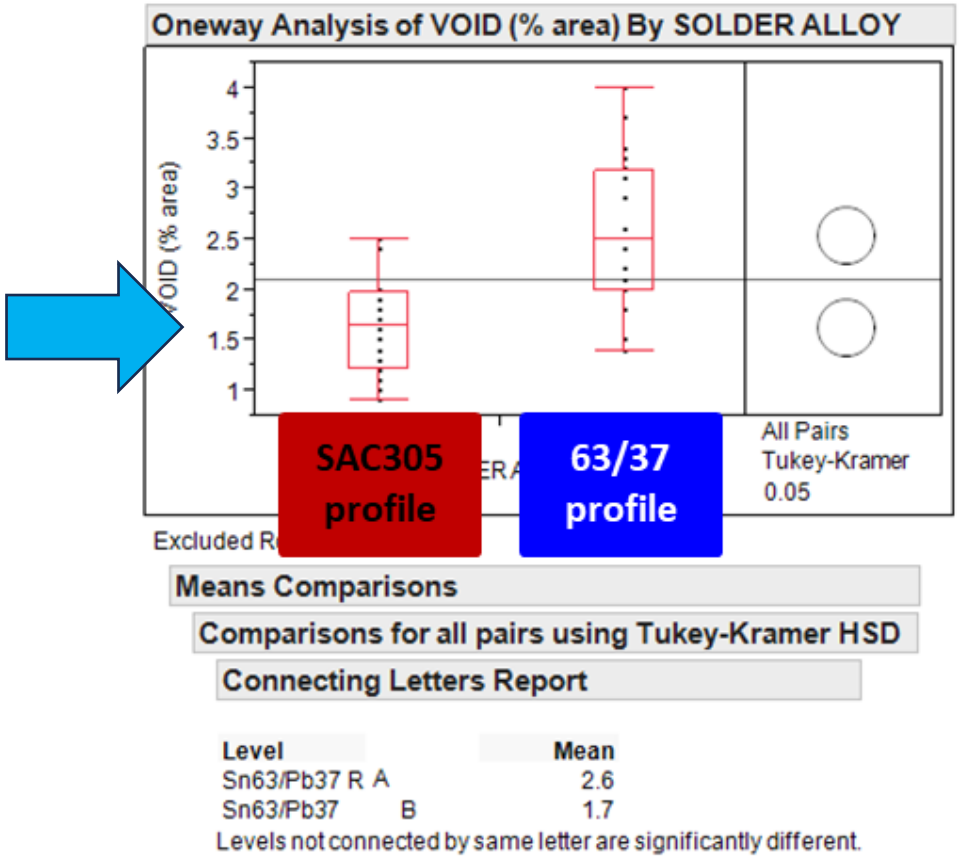
Comparisons for all pairs using Tukey-Kramer HSD

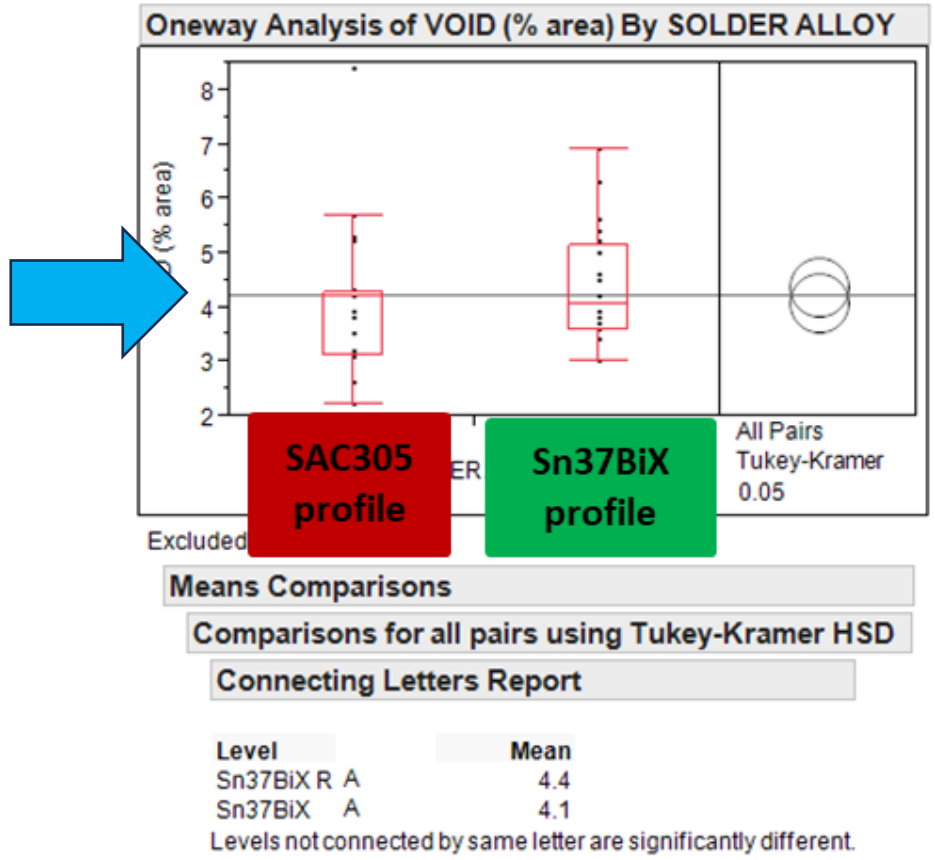
Connecting Letters Report

| Level | | Mean |
|---|---|---|
| 20 | A | 13.8 |
| 15 | A | 13.8 |
| 25 | A | 12.4 |
| 10 | A | 11.9 |

- SAC305 & SnAgBiCu voiding higher for 20 & 25 mil webs
- Sn37BiX & Sn/Pb low voiding for all webs
- SnBiCuNi high voiding for all webs

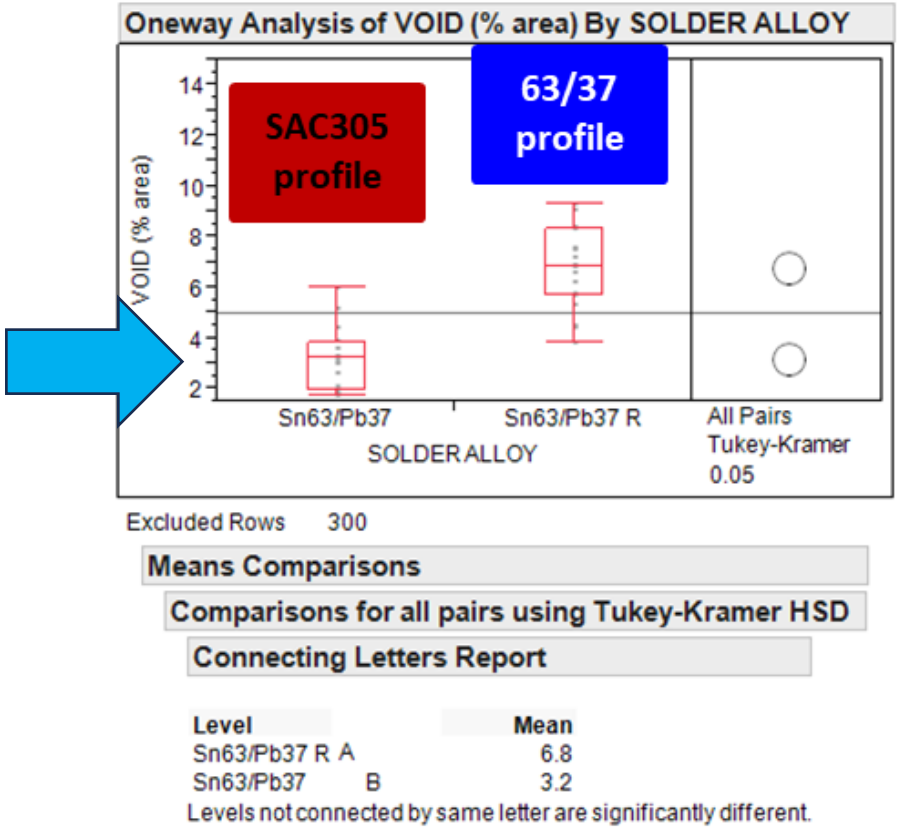
# Voiding by Profile for LT Alloys: 20 mil Web Water Soluble Solder Paste

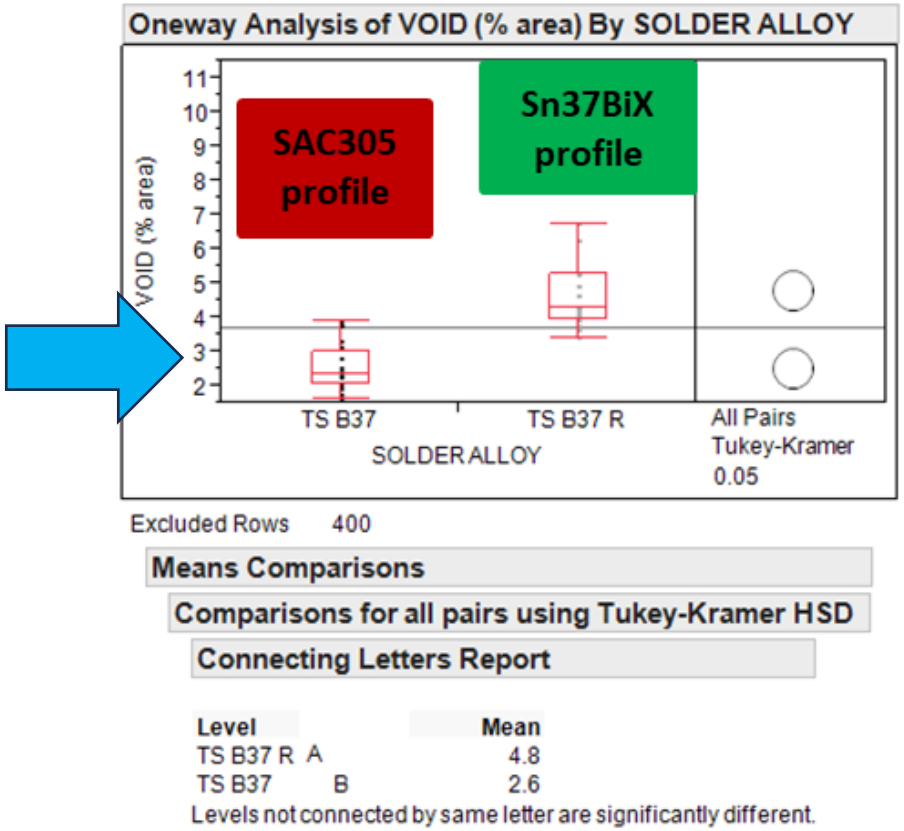



- Sn/Pb has lower voiding in SAC305 profile
- Sn37BiX mean voiding does not change with profile

# Voiding by Profile for LT Alloys: 20 mil Web
## No Clean Solder Paste




- Sn/Pb & Sn37BiX have lower voiding in SAC305 profile

# Conclusions & Recommendations

# Conclusions (Water Soluble Solder Paste)

- Gas entrapment & poor wetting/spread increase voiding potential.
- Reflow profile influenced voiding for 63/37.
- Solder alloy & web width affect voiding.

| Alloy | Voiding | Web Effect on Voiding |
|---|---|---|
| SAC305 | Moderate | Decreased – Larger Web |
| Sn37BiX | Low | Decreased – Larger Web |
| Sn/Pb | Low | No Change |
| SnAgBiCu | Low to Mod | No Change |
| SnBiCuNi | High | No Change |

# Conclusions (No Clean Solder Paste)

- Gas entrapment & poor wetting/spread increase voiding potential.
- Reflow profile influenced voiding for 63/37 & Sn37BiX.
- Solder alloy & web width affect voiding.

| Alloy | Voiding | Web Effect on Voiding |
|---|---|---|
| SAC305 | Low to Mod | Increased – Larger Web |
| Sn37BiX | Low | No Change |
| Sn/Pb | Low | No Change |
| SnAgBiCu | Low to Mod | Increased – Larger Web |
| SnBiCuNi | High | No Change |

# Thank you!

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FCT Solder