Fill the Void VI: A Study of the Impact of Solder Alloy on Voiding in Solder Joints

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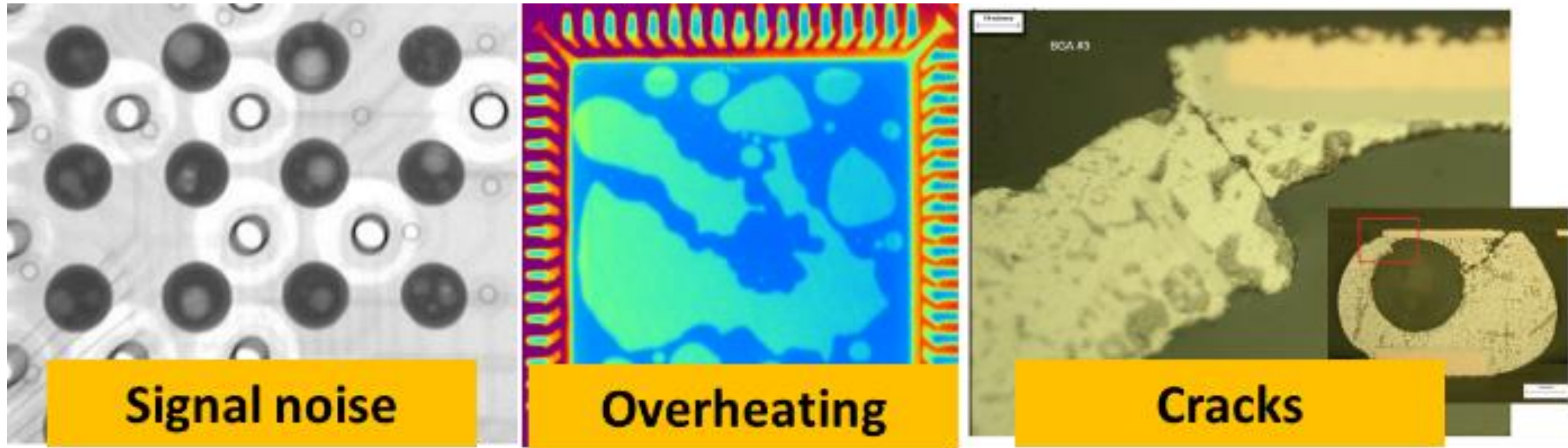
Outline/Agenda

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

INTRODUCTION

Introduction - Voiding & Reliability



Voiding in solder joints may pose reliability risks.

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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.

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Introduction - Voiding Root Causes

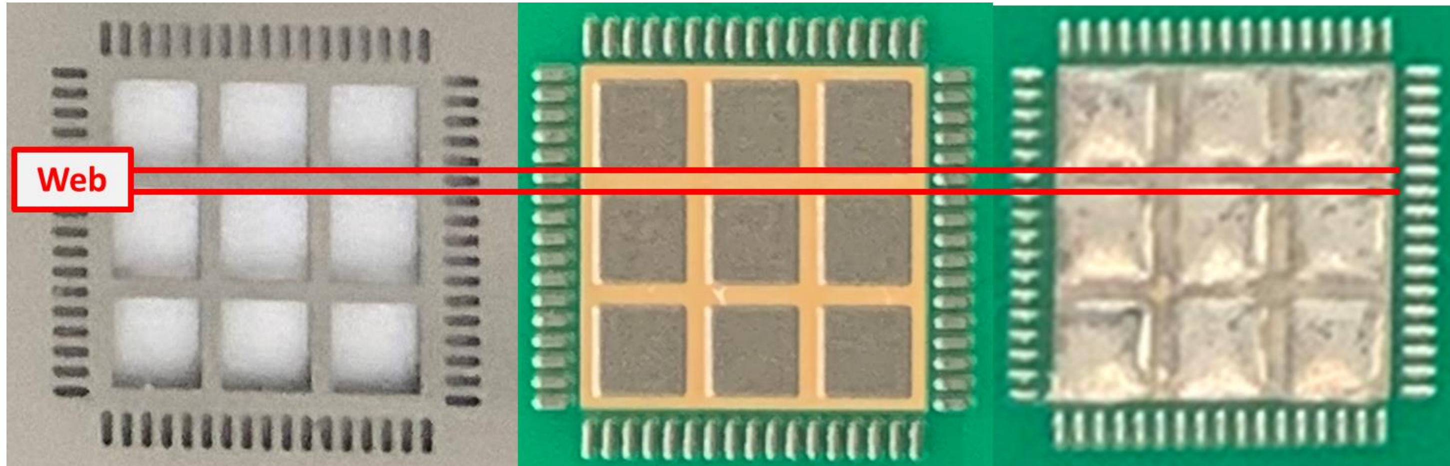
Gas Bubble Entrapment

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

Introduction - Voiding Root Causes

Wetting or Spread

- Stencil design, flux, alloy, surface finish, profile, etc.



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Introduction - Prior Work

- Window pane designs minimized voiding.
- 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.
- Reflow profiles altered voiding behavior.

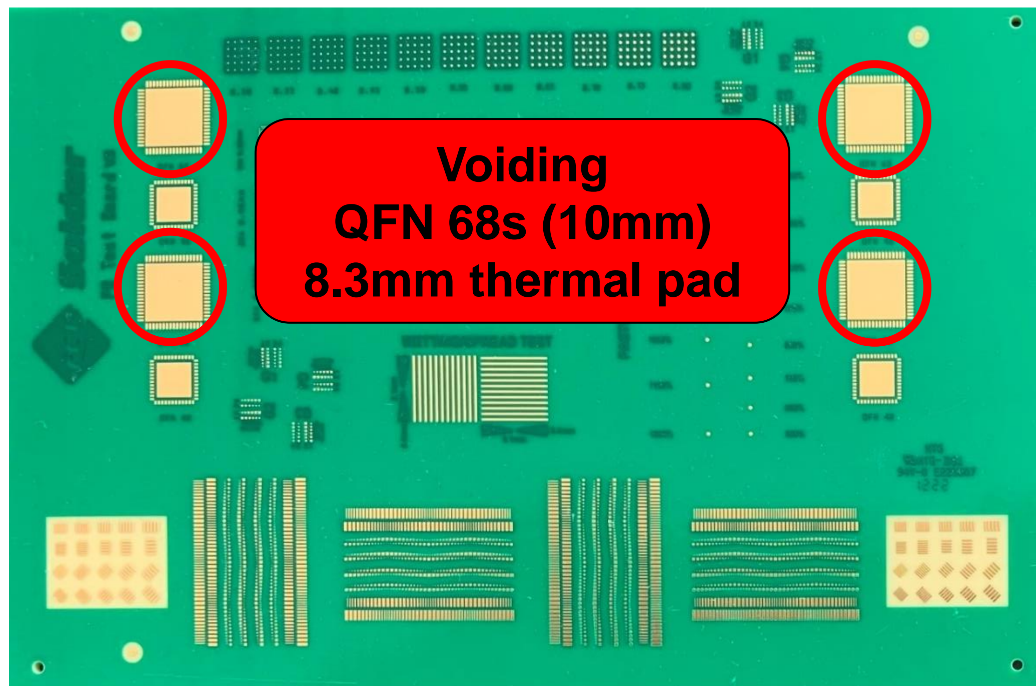
EXPERIMENTAL METHODOLOGY

Experimental Setup

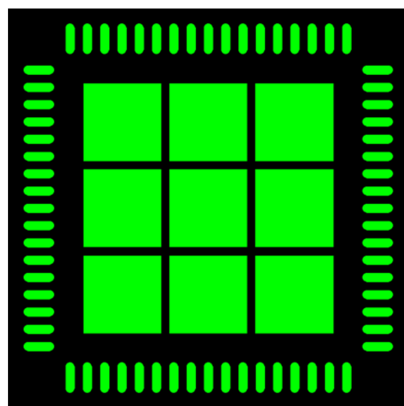
Property	Sn63/Pb37	SAC305	SN100CV	LF-C2	TS B37	Measuring method
Melting Range (°C)	183	218-219	221-225	208-213	139-174	DSC : 2°C/min 30-300°C JISZ3198-1
Composition	Sn63/Pb37	Sn3Ag0.5Cu	Sn1.5Bi0.7CuNi	Sn3.5Ag3Bi1Cu	Sn37BiX	
SG	8.4	7.4	7.4	7.5	8.1	@20°C
Tensile strength (MPa)	53	48	52	90	99	10mm/min @25°C
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 no-clean Pb-free solder paste flux

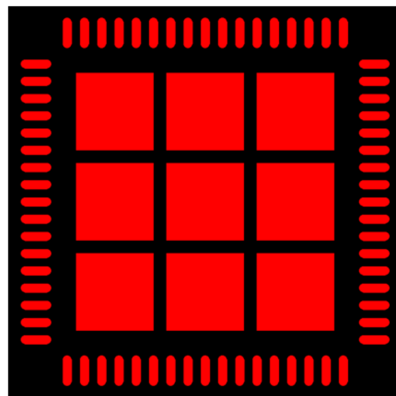
PR Board V3



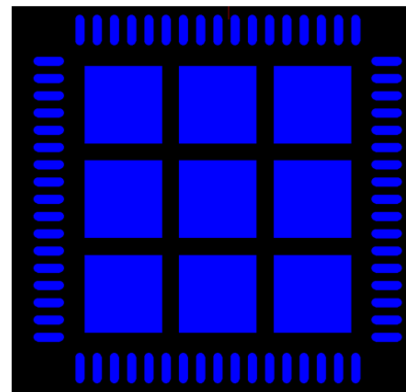
Stencil Web Width & Voiding



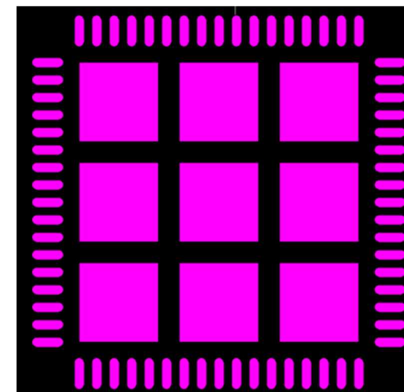
254 µm
10 mil



381 µm
15 mil



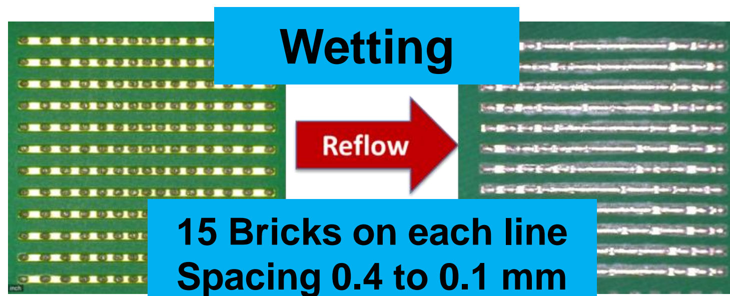
508 µm
20 mil

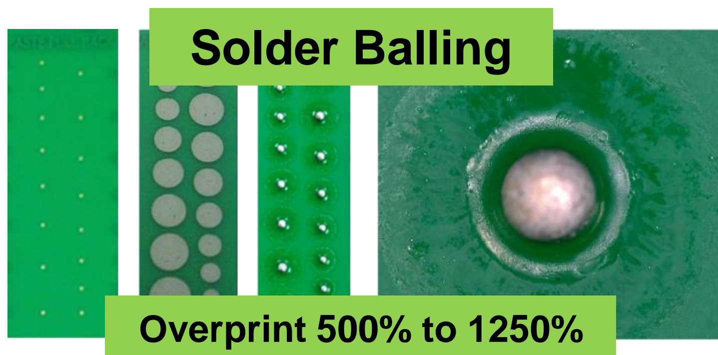


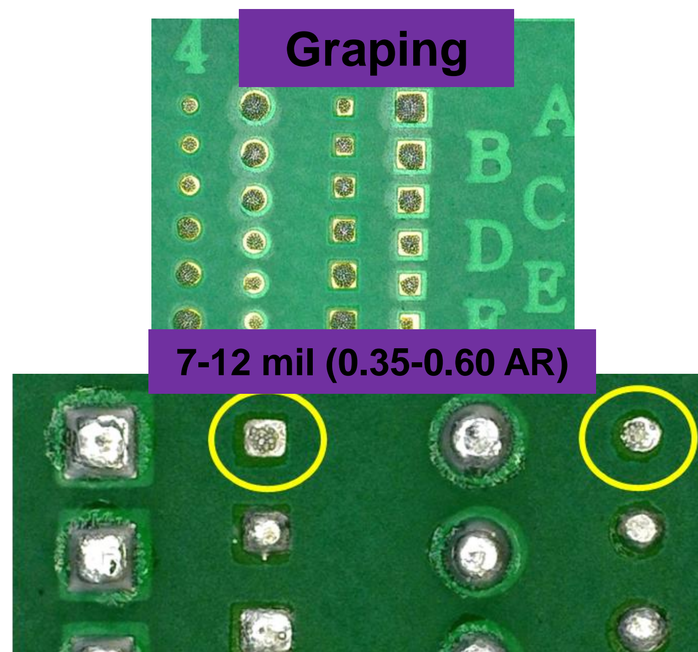
635 µm
25 mil

5 mil thick & 65% area of solder paste coverage

PR Board & General Paste Performance



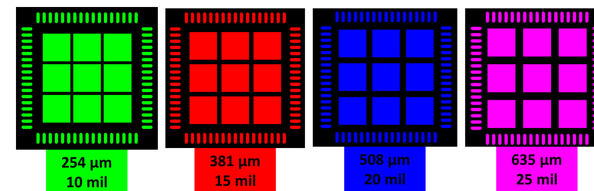




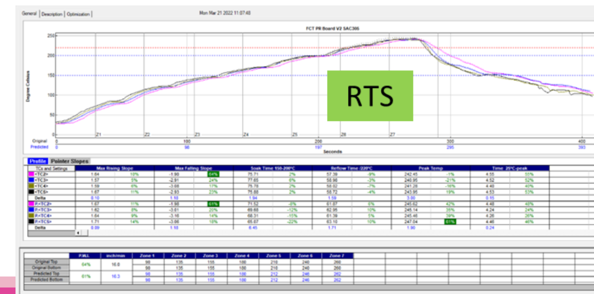
Test Variables

Five alloys in NC-LF solder paste
- Sn63/Pb37, SAC305, SN100CV, LF-C2, TempSave B37

Four stencil web widths
- 10, 15, 20, 25 mils



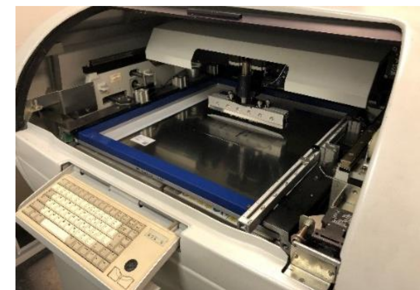
SAC305 RTS reflow profile



20 combinations
- 5 PCBs per combo
- 4 QFNs per PCB
- 20 void measurements per combo
- +2 extra combos for profile comparison

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 TS B37*
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 & TS B37 profile comparison

RESULTS: REFLOW PERFORMANCE

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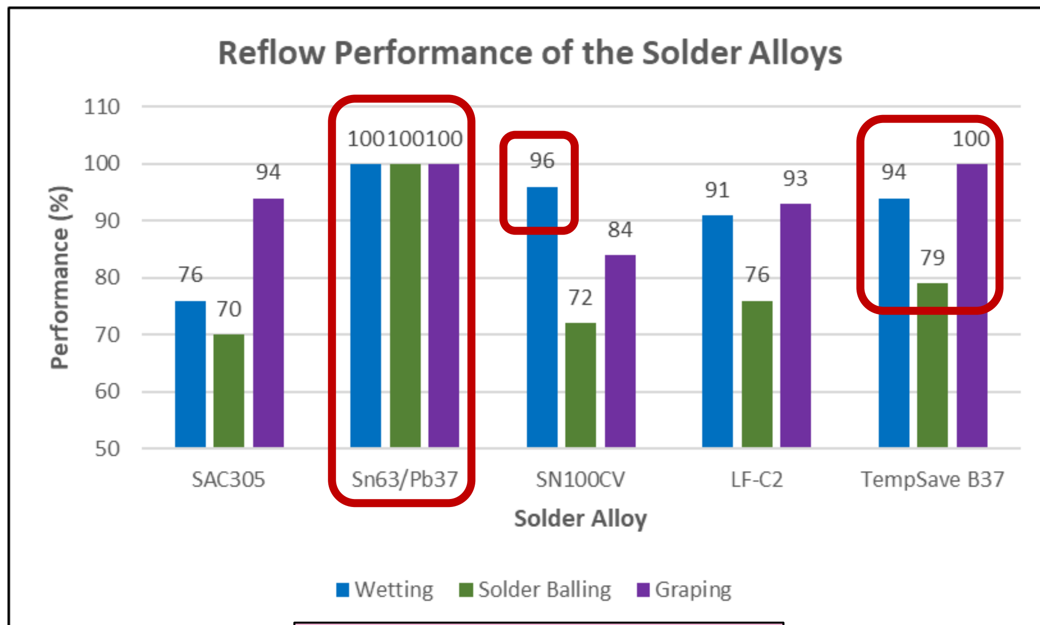
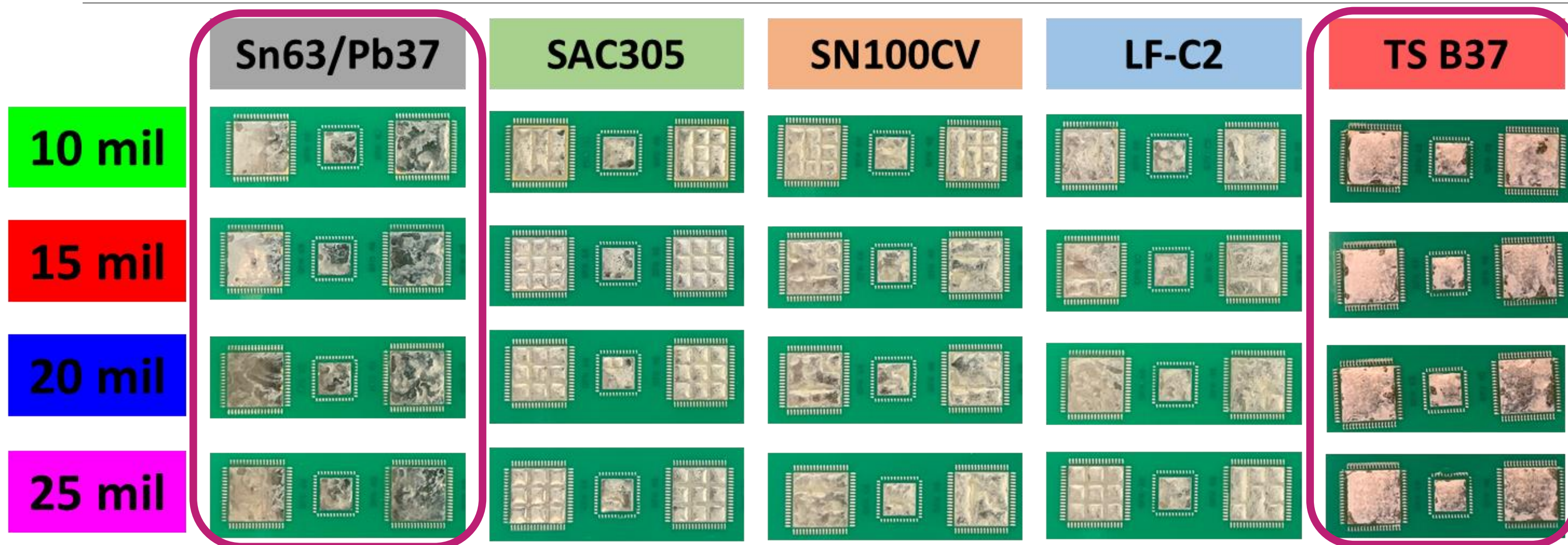
Solder Paste Reflow Performance (SAC305 Profile)



- Sn63/Pb37 optimal reflow
- SN100CV best LF wetting
- TempSave B37 best solder balling and graping

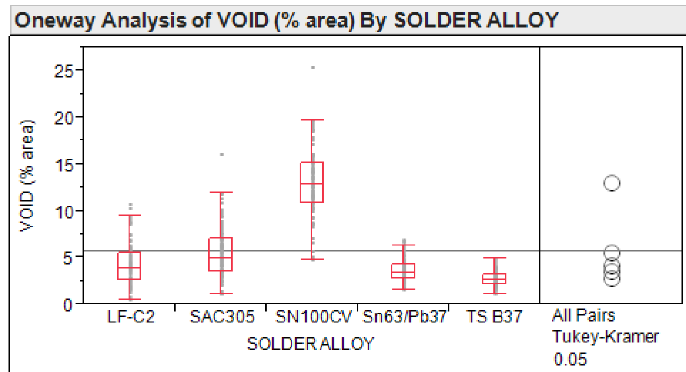
Solder Alloy Spread
(SAC305 Profile)



- Sn63/Pb37 & TS B37 fully spread & leveled on all web widths
- Best to worst: 63/37 & TS B37, SN100CV, LF-C2, SAC305

RESULTS: VOIDING

Voiding by Solder Alloy
(All Webs - SAC305 Profile)



Excluded Rows 40

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Connecting Letters Report

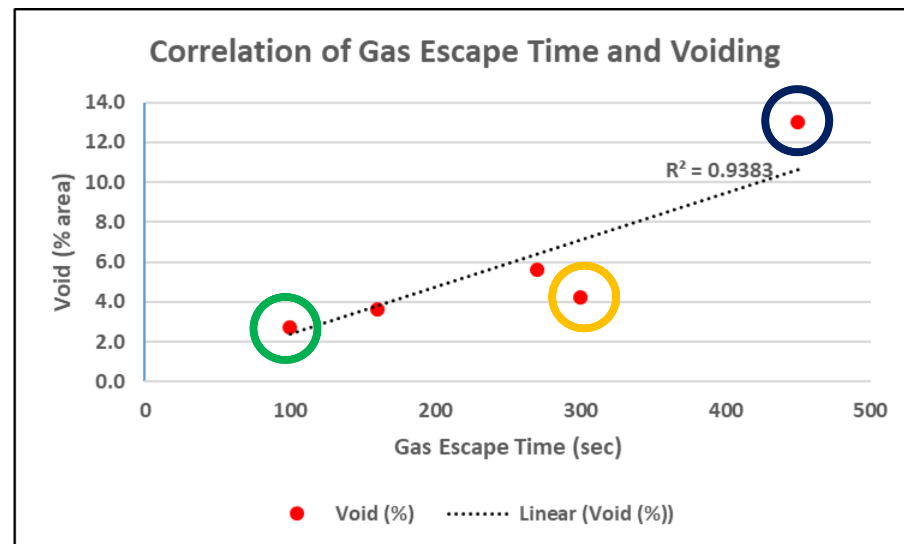
Level					Mean
SN100CV	A				13.0
SAC305		B			5.6
LF-C2			C		4.2
Sn63/Pb37			C	D	3.6
TS B37				D	2.7

Levels not connected by same letter are significantly different.

- SN100CV highest voiding
- 63/37 & TS B37 lowest

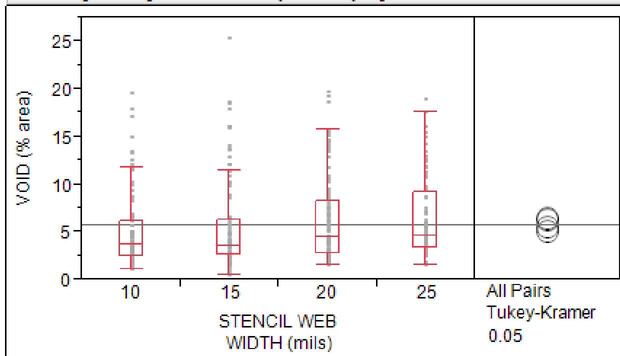
Gas Bubble Escape by Solder Alloy

Solder Alloy	Time for Gas Bubble Escape (sec)	Void Mean (% Area)
TempSave B37	100	2.7
Sn37/Pb37	160	3.6
SAC305	270	5.6
LF-C2	300	4.2
SN100CV	450	13.0



Voiding by Web Width
(All Alloys - SAC305 Profile)

Oneway Analysis of VOID (% area) By STENCIL WEB WIDTH (mils)



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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.

- Web width did not change voiding with all alloys included

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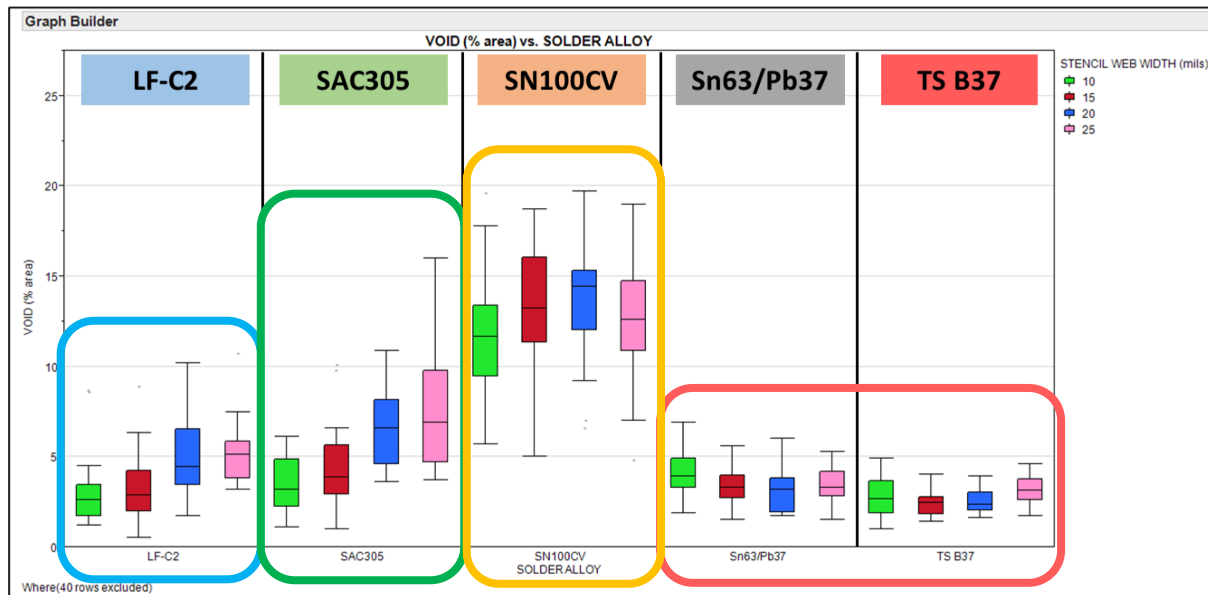
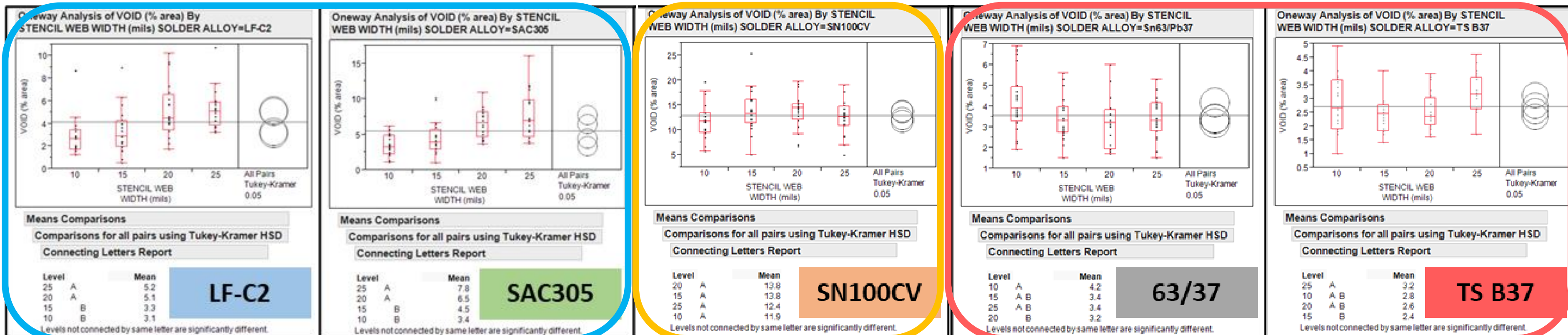
Voiding by Alloy & Web Width (SAC305 Profile)



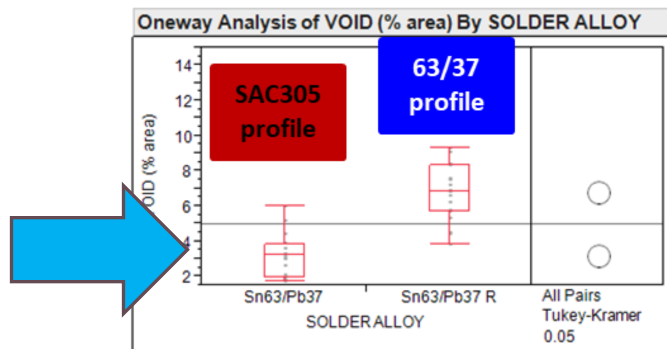
- LF-C2 low voiding - increases with web
- SAC305 low to mod voiding - increases with web
- SN100CV high voiding - all webs
- 63/37 & TS B37 lowest voiding - all webs

Voiding by Alloy & Web Width (SAC305 Profile)



- LF-C2 & SAC305 voiding higher with 20 & 25 mil webs
- SN100CV high voiding for all webs
- Sn63/Pb37 & TempSave B37 low voiding for all webs

Voiding by Profile for LT Alloys
(20 mil web, profile comparison)



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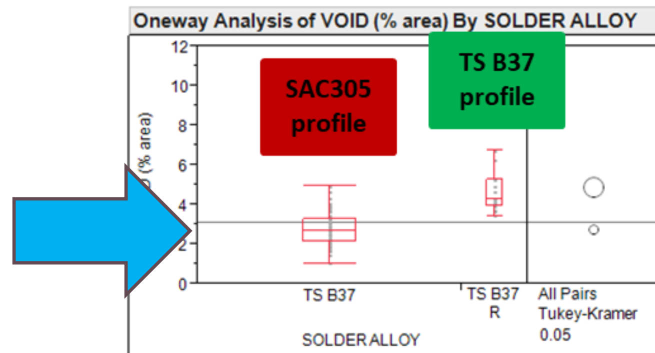
Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Connecting Letters Report

Level			Mean
Sn63/Pb37 R	A		6.8
Sn63/Pb37		B	3.2

Levels not connected by same letter are significantly different.



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Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Connecting Letters Report

Level			Mean
TS B37 R	A		4.8
TS B37		B	2.7

Levels not connected by same letter are significantly different.

- Sn63/Pb37 & TS B37 have lower voiding in SAC305 profile

CONCLUSIONS & RECOMMENDATIONS

Conclusions

- Gas entrapment & poor wetting/spread increase voiding potential.
- Solder alloy & web width affect voiding.
  - 63/37 & TS B37 = low voiding - regardless of web.
  - LF-C2 = low voiding - increased with web.
  - SAC305 = low to mod voiding - increased with web.
  - SN100CV = high voiding - regardless of web.
- Reflow profile influenced voiding for 63/37 & TS B37.

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Recommendations to Fill the Void

- Choose solder alloys with low voiding potential.
  - Changing alloys may not be possible.
- Minimize web width in stencil designs.
- Tune reflow profile for solder paste and alloy.

Thank You!

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