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International Electronics Manufacturing Initiative

Lead Free Wave Soldering Project Update

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Webinar
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Advancing manufacturing technology

2007 iNEMI Wave Roadmap

Parameter	Metric	2005	2007	2009	2011	2017
Wave/Selective Solder Flux	VOC free (%)	25	40	50	60	90
	Halogen free (%)	90	95	95	95	95
Wave/ Selective Lead-Free Alloy	Utilization % LF	30	60	80	85	90
	% SAC vs. other LF alloy	95/5	90/10	80/20	80/20	70/30
Minimum feasible PTH pitch in wave/selective soldering	Mil [mm]	80 [2.00]	60 [1.50]	50 [1.27]	50 [1.27]	40 [1.00]
Conventional/Selective Wave Soldering	utilization % (conventional/selective)	80/20	75/25	70/30	70/30	65/35
SMT paste in hole/Wave Soldering	Utilization %	< 5 %	< 5 %	< 5 %	< 5 %	< 5-10 %
Pre-heat Process Temperature	⁰ C	95-130	100-160	100-160	100-160	100-160
Wave pot Temperature	⁰ C	255-265	260-275	260-275	260-275	260-275
Wave/Selective solder contact time	second	3-5	3-7	3-7	3-7	3-7
Environment process	N ₂ /Air	50/50	60/40	60/40	50/50	50/50



Lead Free Wave Soldering Project Goals

This investigation looks to determine the impact of process parameters and materials on the wave soldering process and solder joint formation.

This study aims to provide insight into the process issues that one will encounter so that a rational implementation strategy for a robust lead free wave soldering process can be achieved.

The Phase I iNEMI Lead Free Wave Soldering Project focused on three critical areas:

- *Materials Selection*
Fluxes, alloys, components, and board complexity.
- *Process Optimization*
Defined “Window of Opportunity” based on flux amount, preheat temperature, contact time, solder temperature, wave configuration, and atmosphere.
- *Solder Joint Yield*
Defined failure levels and defect types using inspection criteria – IPC class 3 combined with best practices, yield determined by hole fill characterized by 5DX data analysis.

The result of Phase I is to lay the foundation for a broader effort to characterize the reliability of through-hole joints on a test vehicle specifically designed to test the norms and practices used in tin lead wave soldering and develop new standards for lead free wave soldering.



Design of Experiment for Phase I

- Taguchi Methodology Chosen
 - Time and cost efficient for studying multiple variables.
 - DoE based on standard Taguchi L18 ($2^1 \times 3^7$) orthogonal array.
- Variable Selection
 - Brainstorming to collect list of possible variables for wave solder process. This represented perspectives of many areas of assembly.
 - Review by team members to prioritize list.
 - Discussion and consensus vote to pick final selection.

Inner Array Variables

**Atmosphere,
conveyor speed,
preheat temperature,
flux quantity,
flux type,
chip wave,
solder temperature,
board thickness**

Outer Array Noise Factors

**SAC 305,
Sn100C,
SACx,
SnPb,

CuOSP finish,
Pb-free HASL finish**

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Experimental Layout

Variable	Level 1	Level 2	Level 3	Comments
Atmosphere	Nitrogen	Air	N/A	
Belt speed ft/min (cm/min)	3 (91) 2 (61)	4.5 (137) 3.5 (107)	6 (183) 5 (152)	.062"/.094" .135"
Preheat Temp	90°C 100°C	110°C 115°C	130°C 130°C	(alcohol flux) (VOC free flux)
Flux Quantity	low	med	high	
Flux type	VOC free	Alcohol	OA	
chip wave	on	off	on	
solder temperature	255°C	265°C	275°C	
board thickness	0.062 (1.6)	0.094 (2.4)	0.135 (3.5)	Inches (mm)

Machine Configuration

Delta Wave Solder machine Fluxer:

Spray fluxer

FC7 for Alcohol and OA

FC16 for VOC free

Pump supply system

Preheat configuration:

Forced convection

Forced convection

Calrod

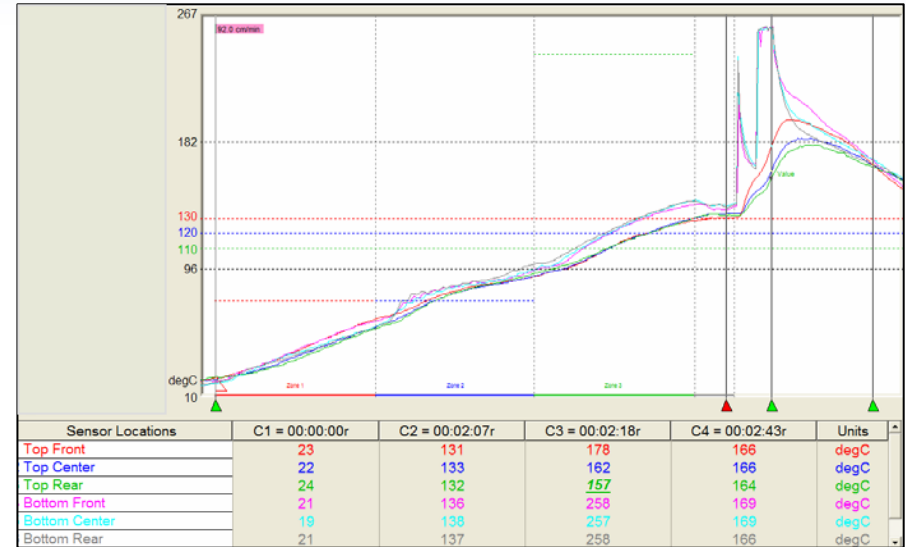
Solder pot configuration:

Chip wave

Main wave

Nitrogen:

Inerting Blanket system between waves: 30-50-80 l/min



Profiles Attributes

Flux amount and penetration

Mass measurement and pH

paper

Preheating Temp:

ECD Super Mole

Contact Time:

ECD Wave Rider



Test Vehicle "Skate"

(Cookson Design)

Board Specification

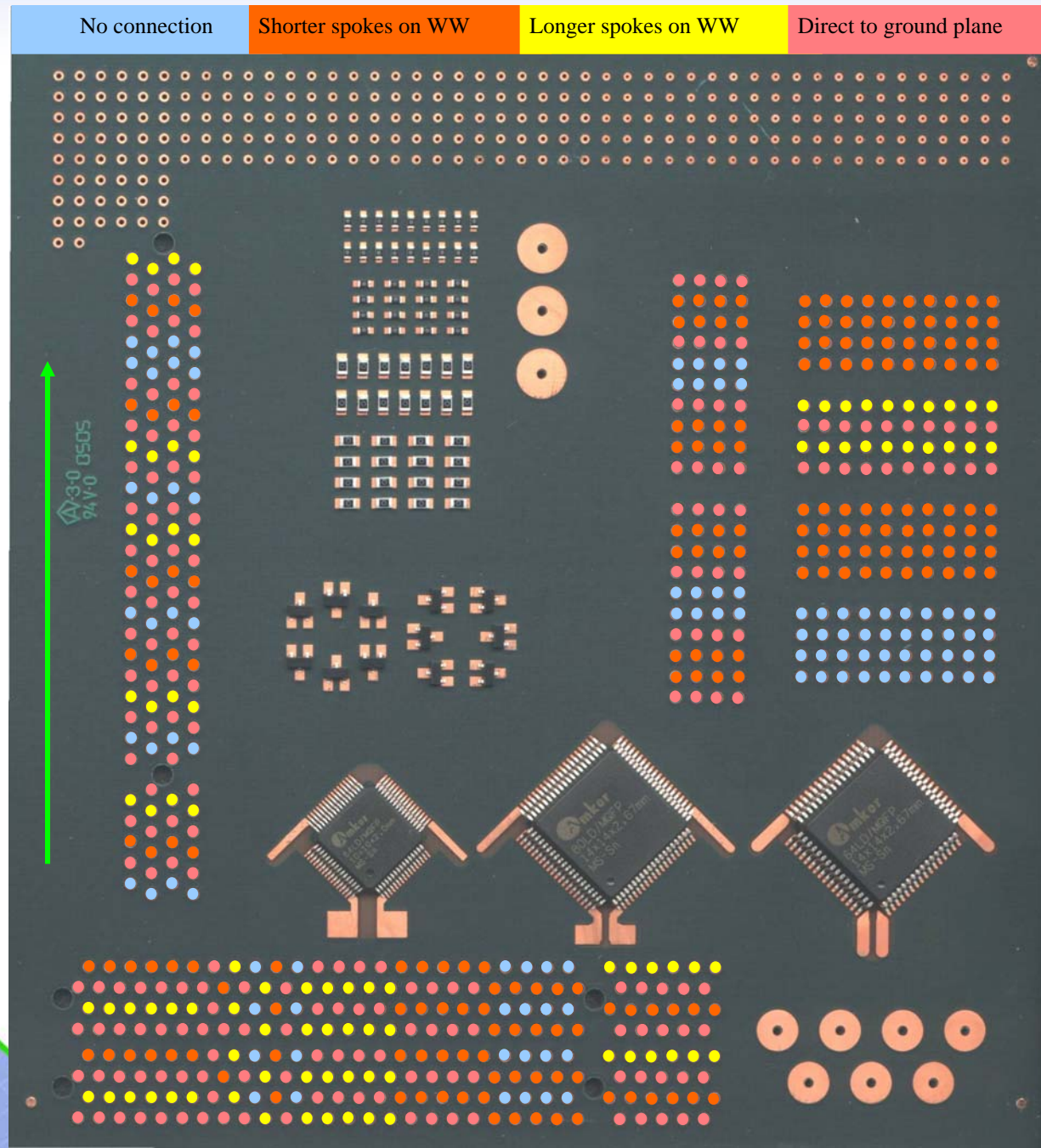
- 64 mil
- 93 mil
- 135 mil
- CuOSP
- HASL

Alloys

- SAC 305
- SACX
- Sn100C
- SnPb

Components

- QFP's, SOT, Passives
- PCI, Berg Stick



Experimental Execution

Actual Run Order	DOE Standard Order	Atmosphere	Speed Ft/min (cm/min)	Preheat Temp	Flux Quantity	Flux Type	Chip Wave	Solder Temp (°C)	Board Thickness
1	5	N ₂	4.5 (138)	med	med	OA	on	255	0.062
2	1	N ₂	3 (92)	low	low	Water	on	255	0.062
3	16	Air	6 (183)	low	high	Alcohol	on	255	0.094
4	12	Air	2 (61)	high	med	Alcohol	on	255	0.135
5	14	Air	3.5 (107)	med	high	Water	off	255	0.135
6	9	N ₂	6 (183)	high	low	OA	off	255	0.094
7	10	Air	3 (92)	low	high	OA	off	265	0.062
8	2	N ₂	3 (92)	med	med	Alcohol	off	265	0.094
9	15	Air	4.5 (138)	high	low	Alcohol	on	265	0.062
10	7	N ₂	5 (152)	low	med	Water	on	265	0.135
11	6	N ₂	4.5 (138)	high	high	Water	on	265	0.094
12	17	Air	5 (152)	med	low	OA	on	265	0.135
13	13	Air	4.5 (138)	low	med	OA	on	275	0.094
14	4	N ₂	3.5 (107)	low	low	Alcohol	off	275	0.135
15	8	N ₂	6 (183)	med	high	Alcohol	on	275	0.062
16	11	Air	3 (92)	med	low	Water	on	275	0.094
17	3	N ₂	2 (61)	high	high	OA	on	275	0.135
18	18	Air	6 (183)	high	med	Water	off	275	0.062

Required for logistics reason



Four Days/Nights of Soldering



1 Alloy/day

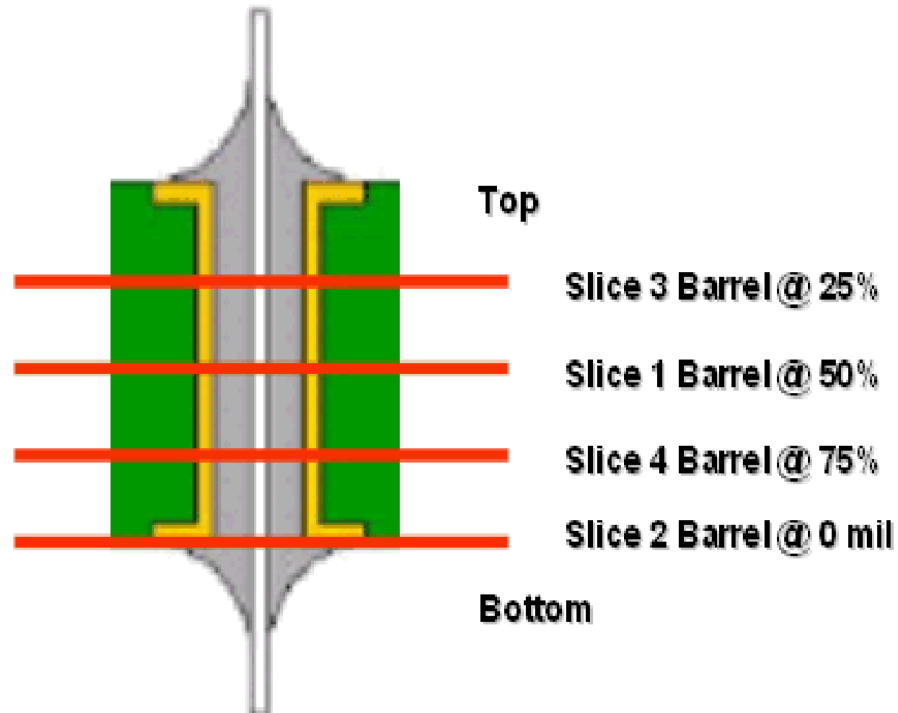
18 Runs/day

- 18 flux recipes
- 18 heating profiles
- 18 contact times

Every day two full L18 Taguchi experiments including
3 repetitions = 108 boards/day

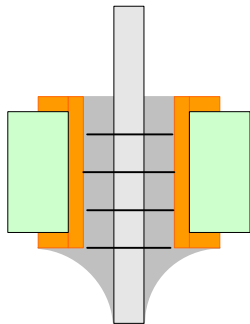
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5DX Measurement Calculation

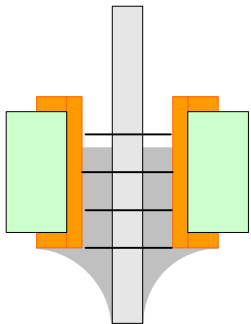


Confirmed by select cross sectioning and typical X-Ray techniques

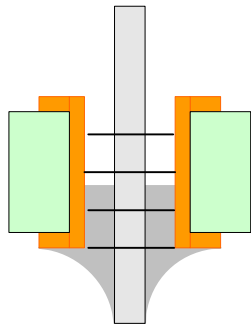
Through Hole Inspection Criteria



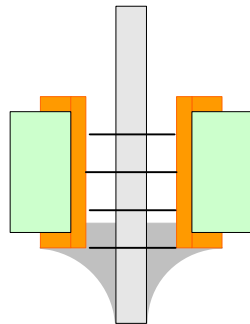
No defect



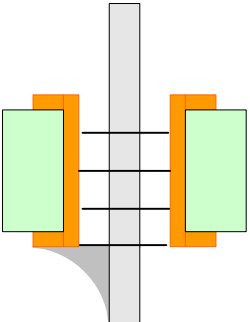
Defect
S3-25%



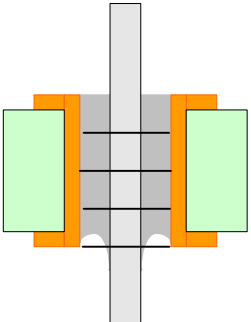
Defect
S3-25%
S1-50%



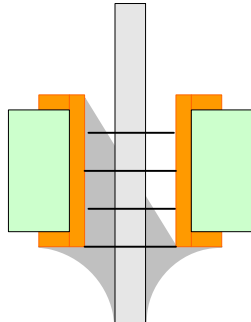
Defect
S3-25%
S1-50%
S4-75%



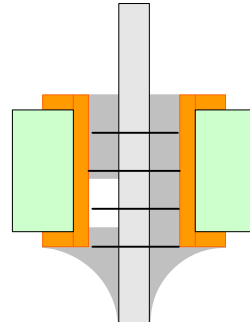
Defect
All Slices



Defect
S2-0%



Defect
S3-25%
S1-50%
S4-75%



Defect
S4-75%
Void

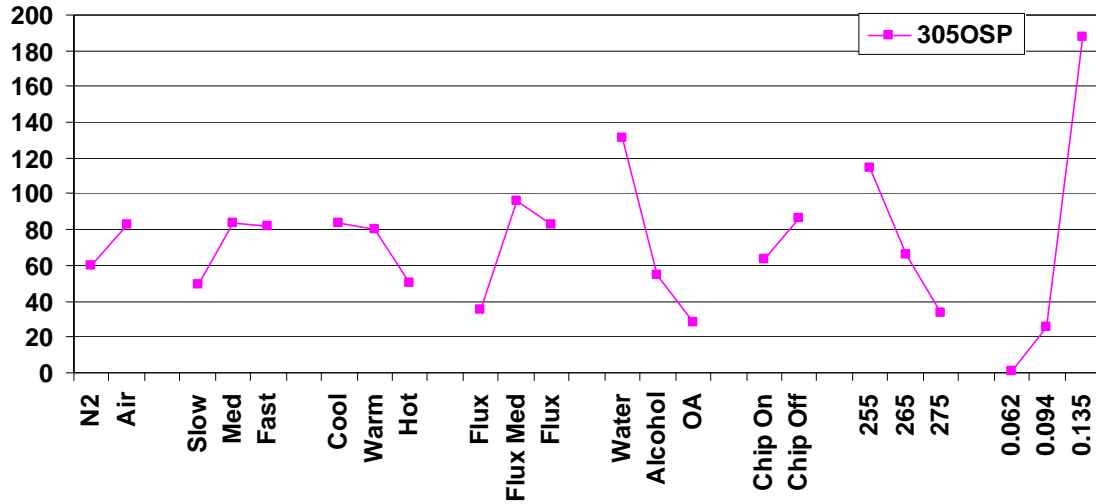


Hole Fill Defect Analysis

SAC 305

Actual Run Order	DOE Standard Order	Atmosphere	Speed Ft/min (cm/min)	Preheat Temp	Flux Quantity	Flux Type	Chip Wave	Solder Temp (°C)	Board Thickness	SAC 305	
										HASL	OSP
1	5	N ₂	4.5 (138)	med	med	OA	on	255	0.062	0.0	0.0
2	1	N ₂	3 (92)	low	low	Water	on	255	0.062	2.0	2.7
3	16	Air	6 (183)	low	high	Alcohol	on	255	0.094	41.0	44.0
4	12	Air	2 (61)	high	med	Alcohol	on	255	0.135	32.7	200.0
5	14	Air	3.5 (107)	med	high	Water	off	255	0.135	399.0	394.3
6	9	N ₂	6 (183)	high	low	OA	off	255	0.094	48.0	44.3
7	10	Air	3 (92)	low	high	OA	off	265	0.062	0.0	0.0
8	2	N ₂	3 (92)	med	med	Alcohol	off	265	0.094	3.0	0.0
9	15	Air	4.5 (138)	high	low	Alcohol	on	265	0.062	0.0	0.0
10	7	N ₂	5 (152)	low	med	Water	on	265	0.135	358.3	350.3
11	6	N ₂	4.5 (138)	high	high	Water	on	265	0.094	0.3	0.3
12	17	Air	5 (152)	med	low	OA	on	265	0.135	56.3	47.3
13	13	Air	4.5 (138)	low	med	OA	on	275	0.094	6.0	25.0
14	4	N ₂	3.5 (107)	low	low	Alcohol	off	275	0.135	56.7	80.3
15	8	N ₂	6 (183)	med	high	Alcohol	on	275	0.062	2.3	3.0
16	11	Air	3 (92)	med	low	Water	on	275	0.094	1.7	37.0
17	3	N ₂	2 (61)	high	high	OA	on	275	0.135	58.7	55.0
18	18	Air	6 (183)	high	med	Water	off	275	0.062	1.0	1.0

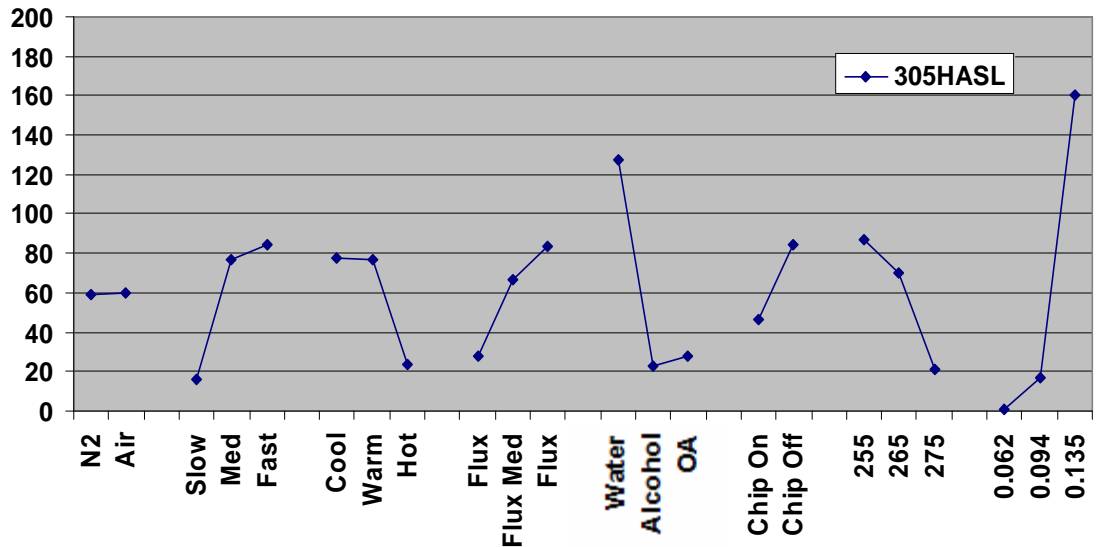
Response: Mean Count
Average Number of Holes per Board w/<75% Fill
SAC305



Impact of Process Parameters on Hole Fill

SAC 305

Response: Mean Count
Average Number of Holes per Board w/<75% Fill
SAC305



Confirmed Optimized Process

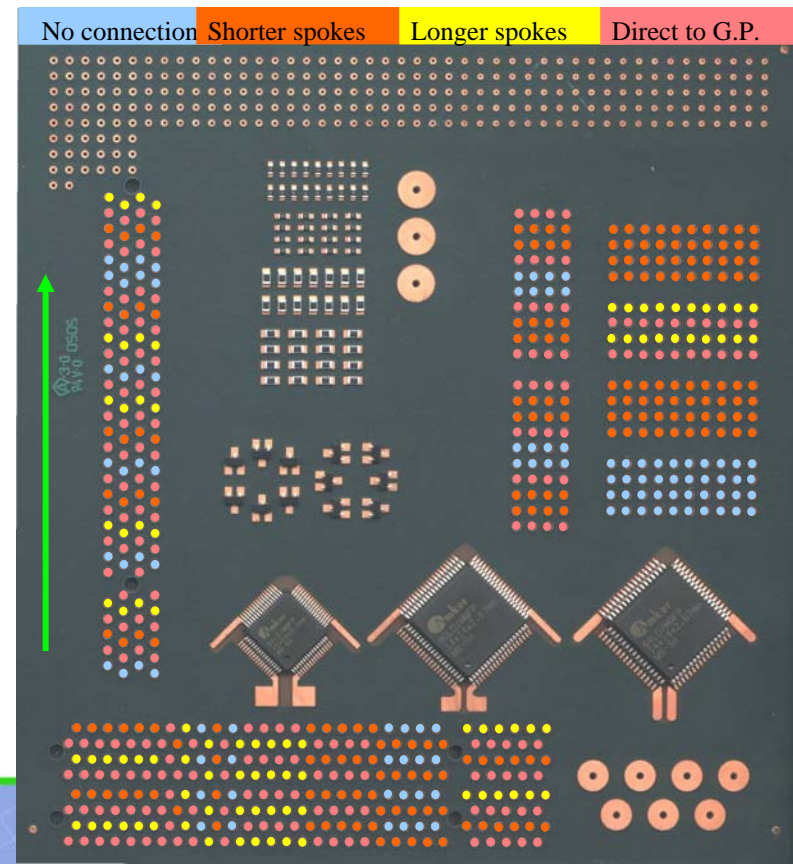
Alloy	Atmosphere	Speed	Preheat Temperature	Flux Amount	Flux Type	Solder Temperature	Board Thickness
		(ft/min)	(°C)			(°C)	(mil)
SAC 305	N ₂	3	130	Med	Alcohol	265	62, 93, 135
SACx	N ₂	3	110	Med	Alcohol	265	62, 93, 135
SN100C	N ₂	3	110	Med	Alcohol	265	62, 93, 135

- **Process was confirmed by soldering at the defined process settings and materials.**

Confirmation Results

- **Process confirmation was not positive for the 135 mil board indicating the influence of board complexity and lead protrusion.**

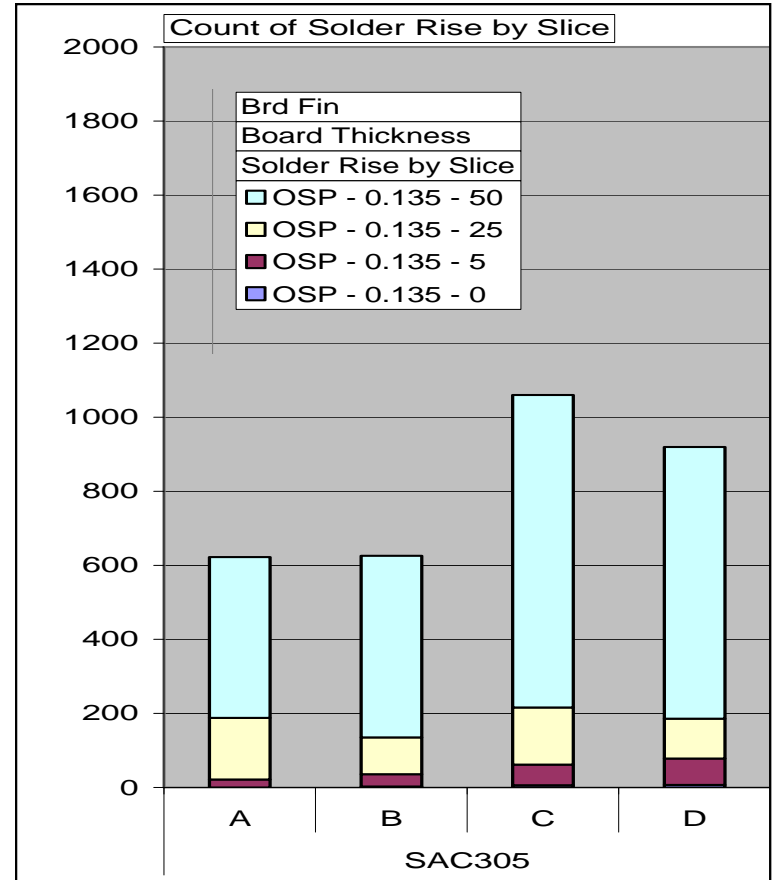
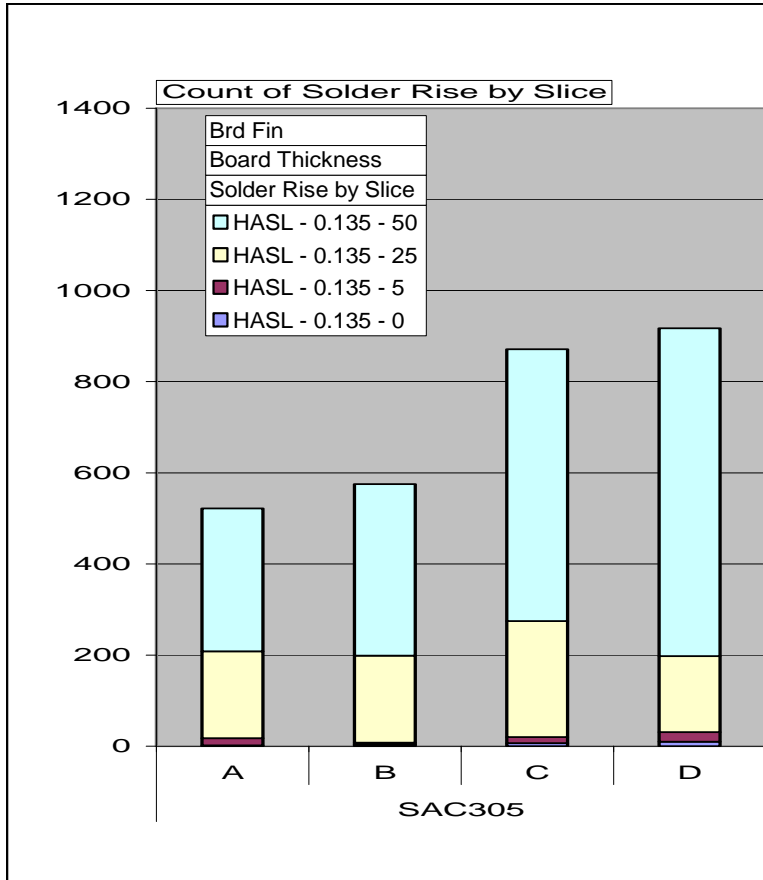
Board Thickness	SAC305	SACx	Sn100C
62 mil	0	0	0
93 mil	0	0	0
135 mil	2	7	3



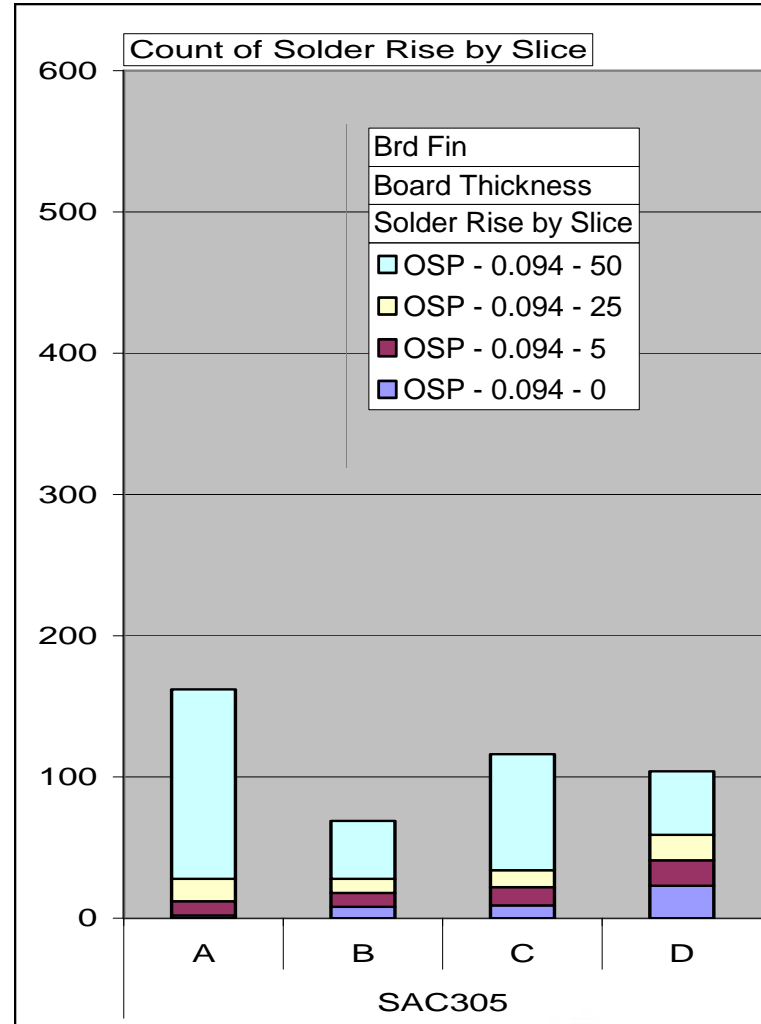
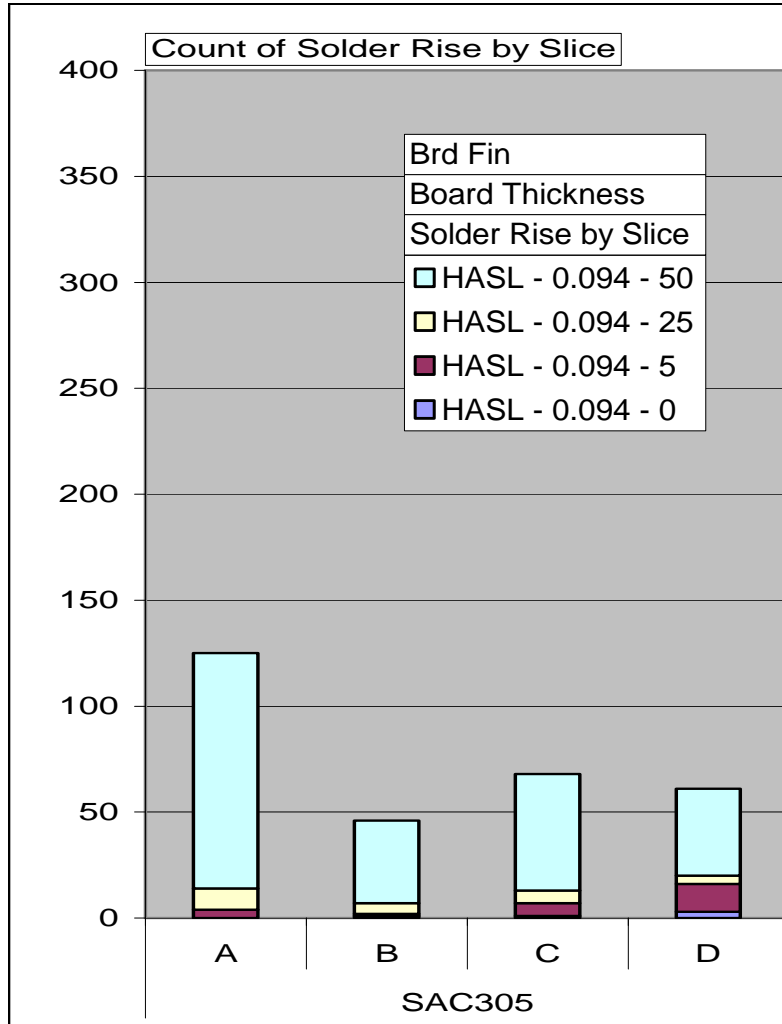
Through-Hole Defect Analysis

- **A secondary effort was made to characterize how far up the via solder traveled, or solder rise.**
- **This was performed on all thicknesses and each board finish.**
- **Over 30,000 defects were recorded and analyzed.**
- **Data mining permits us to identify how materials impact the process window and how challenging it is to derive the optimized process.**

Solder Rise for the 135 mil Test Vehicle



Solder Rise for the 94 mil Test Vehicle



Influence of the Process Parameters

Response charts for each thickness were created to provide sensitive data influenced by board complexity.

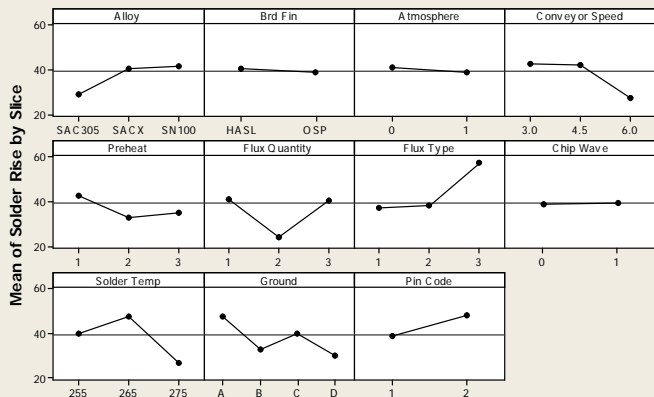
Influence of Process Parameters on Solder Rise

Characterization of the solder rise for the three board thicknesses allows for the identification of the influence of the various process parameters and materials.

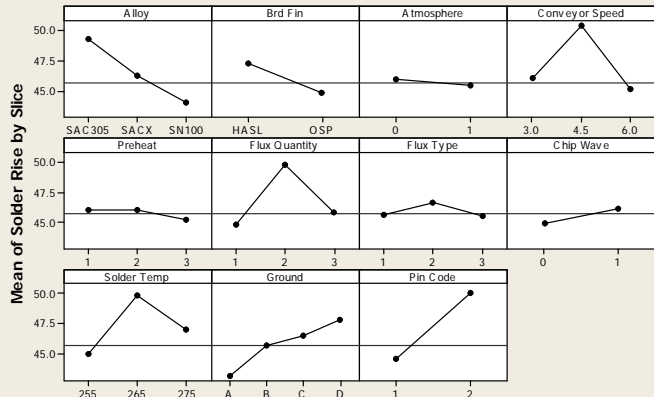
The extent of the process window is estimated by this relationship.

	0.062	0.094	0.135
Alloy	O	+	+
Board Finish	-	+	O
Atmosphere	-	-	+
Conveyor Speed	O	+	+
Preheat	+	-	+
Flux Quantity	+	+	+
Flux Type	+	O	+
Chip Wave	-	O	+
Solder Temperature	+	+	+
Pin Complexity	O	+	+

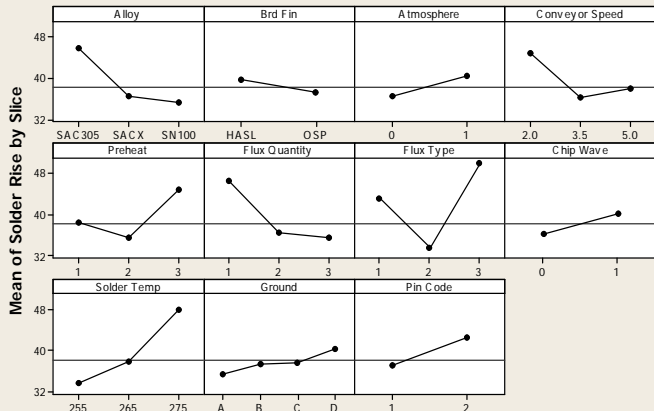
Main Effects Plot - Solder Rise by Slice 0.062" Boards



Main Effects Plot - Solder Rise by Slice 0.094" Boards



Main Effects Plot - Solder Rise by Slice 0.135" Boards



Trends

“learning as we go”

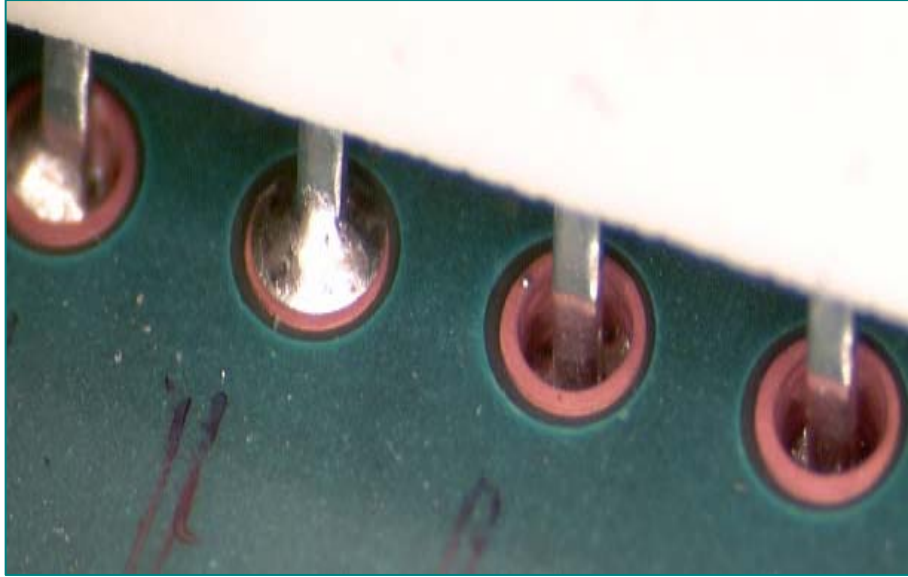
Points of Interest



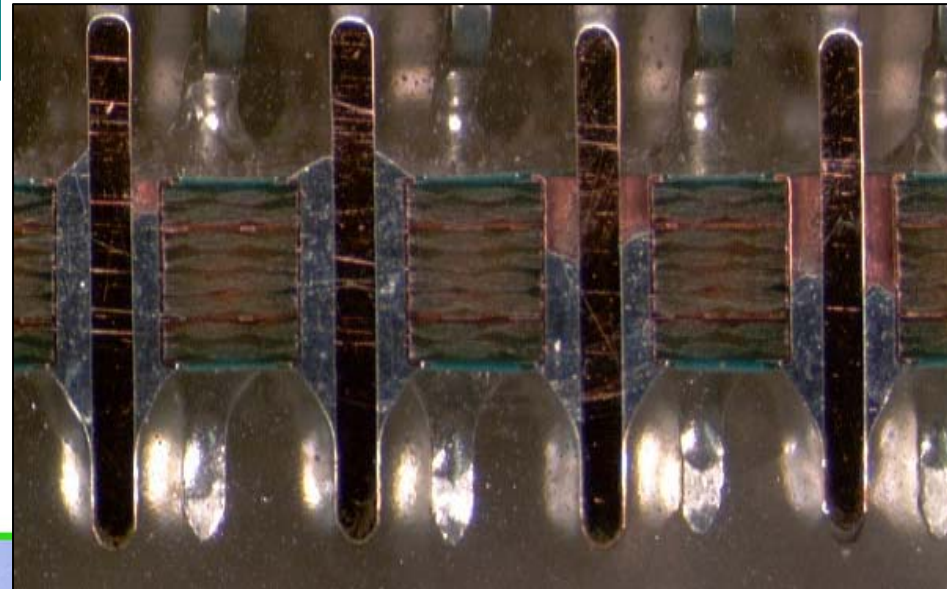
Influence of Copper Tie-In

Root Cause Analysis

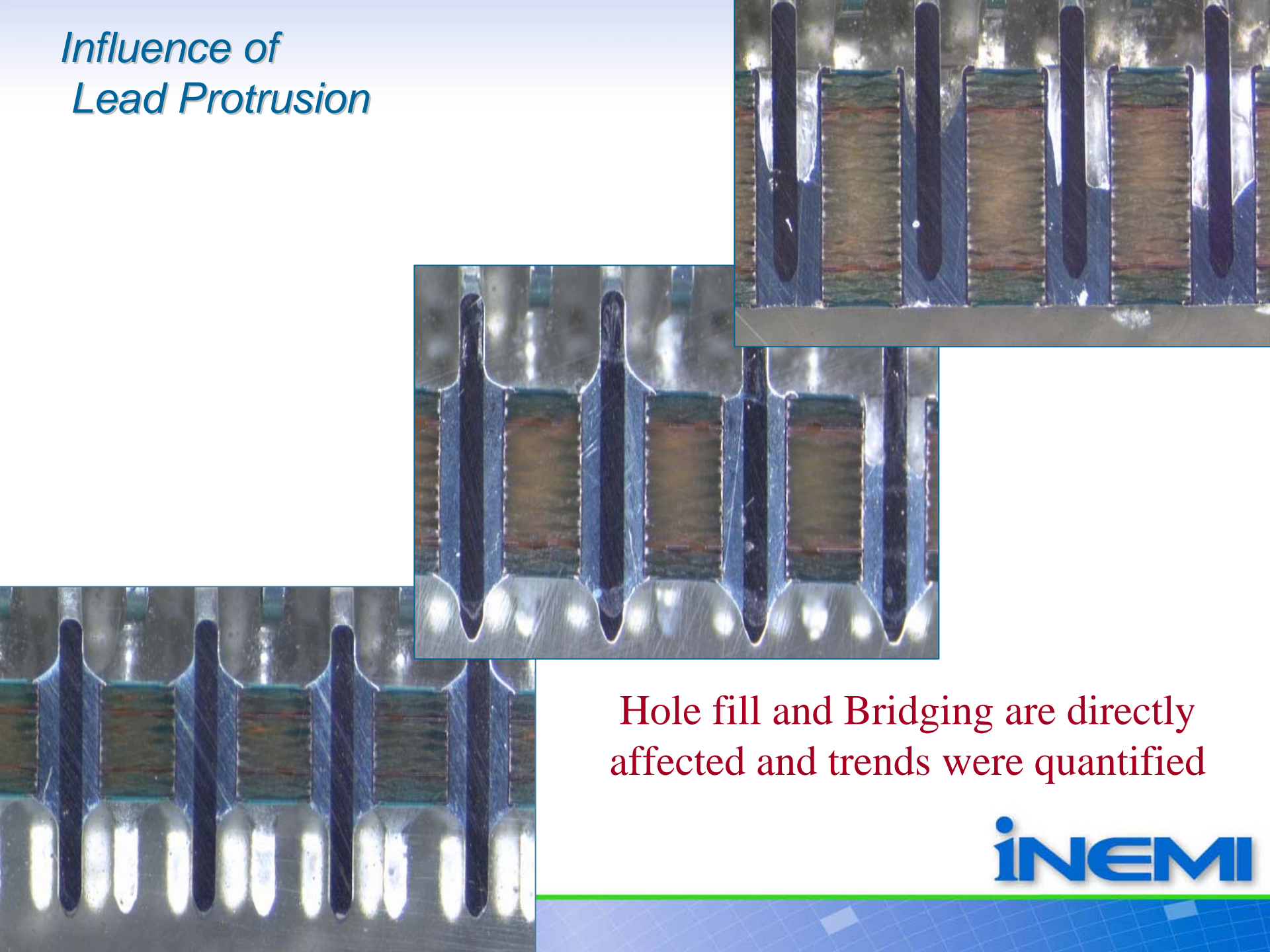
- **An un-optimized process will produce such results.**
- **Board complexity – thickness and layers – will significantly influence the process' window of opportunity.**



Short spoke; no tie-in; long spoke; direct tie-in



Influence of Lead Protrusion



Hole fill and Bridging are directly affected and trends were quantified

Conclusions

This investigation determined the impact of process parameters and materials on the wave soldering process and solder joint formation.

This study provided insight into the process issues that one will encounter during so that a rational implementation strategy for a robust lead free wave soldering process can be achieved.

Phase I of this project provided information of each of the critical areas that was the focus.

Materials Selection

The interaction of the various materials on the formation of defects was quantified.

Process Optimization

Determined and tested the optimized process based on materials and parameter control.

Solder Joint Yield

Defined failure levels and defect types using inspection criteria – IPC class 3 combined with best practices, yield determined by hole fill characterized by 5DX data analysis.

The result of Phase I was to lay the foundation for a broader effort to characterize the reliability of through-hole joints on a test vehicle specifically designed to test the norms and practices used in tin lead wave soldering and develop new standards for lead free wavesoldering.



Phase II
“the end goal”

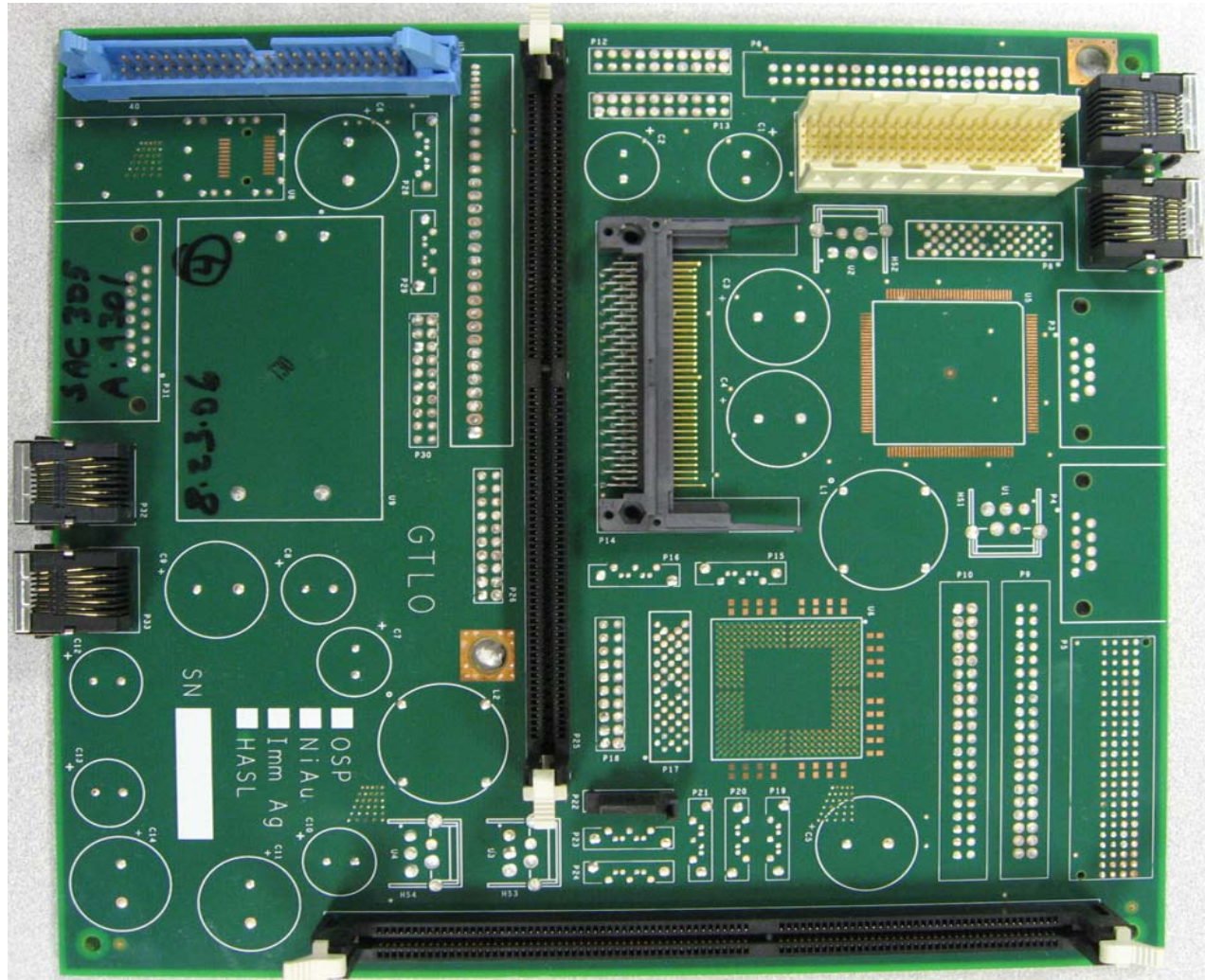
Unique Board Design

Fixed Process

Lead Free Solder Joint Performance

iNEMI

GTLO Test Vehicle



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Acknowledgements

- The authors and project members would like to gratefully thank the following people for support during the execution of Phase I and its analysis: *John Norton, Norm Faucher, Gerjan Diepstraten, and Bruce Quigley* for build support, *Ursula Marquez de Tino* for the many cross sections, *Sam Greenfield* for performing all of the 5DX analysis.
- The authors would also like to thank the management of each participating company for their support in this endeavor. Without their continued support, this project would not have achieved its Phase I goals.



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