Pb-Free Wave Soldering Project

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APEX 2009

Advancing manufacturing technology

2009 iNEMI Wave Roadmap

Parameter	Definition	2007	2009	2011	2019
Bar Solder	Lead-free % US	30%	50%	75%	95%
	Lead-free % WW	75%	90%	95%	95%
	Alloy	SAC/Sn-Cu	SAC/Sn-Cu	SAC/Sn-Cu	SAC /Sn-Cu
	Alloy			Low Temp	Low Temp
Solder Pastes	Lead-free % US	30%	50%	75%	90%
	Lead-free % WW	60%	80%	85%	90%
	Alloy	SAC	Lower Silver SAC	Lower Silver SAC/Low Temp.	Lower Silver SAC/Low Temp. Lower Silver SAC/Low Temp.Temp
	Halogen-free	85%	90%	95%	95%
	Recycle ratio	5%	10%	25%	25%
Wave Solder Flux	VOC Free	40%	50%	60%	90%
	Halogen free	95%	95%	95%	95%

Parameter	Metric	2007	2009	2011	2013	2019
Wave/Selective Solder Flux	VOC free (%)	25	30	40	50	70
	Halogen free (%)	30	40	70	80	90
Wave/ Selective Lead-Free Alloy	Utilization % LF	30	40	60	70	80
	% SAC vs. other LF alloy	80/20	80/20	60/40	50/50	40/60
Minimum feasible PTH pitch in wave/selective soldering	Mil [mm]	80 [2.00]	60 [1.50]	50 [1.27]	40 [1.00]	40 [1.00]
Conventional/Selective Wave Soldering	Utilization % (conventional/selective)	80/20	80/20	75/25	70/30	65/45
SMT paste in hole/Wave Soldering	Utilization %	<5	<5	<5	<5	<5
Pre-heat Process Temperature	0C	100-130	100-140	100-160	100-160	130-160
Wave pot Temperature	0C	260-275	260-275	260-280	260-280	260-280
Wave/Selective solder contact time	Seconds	3-7	3-7	3-9	3-9	3-10
Environment process	N2/Air	60/40	60/40	65/35	65/35	70/30

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.

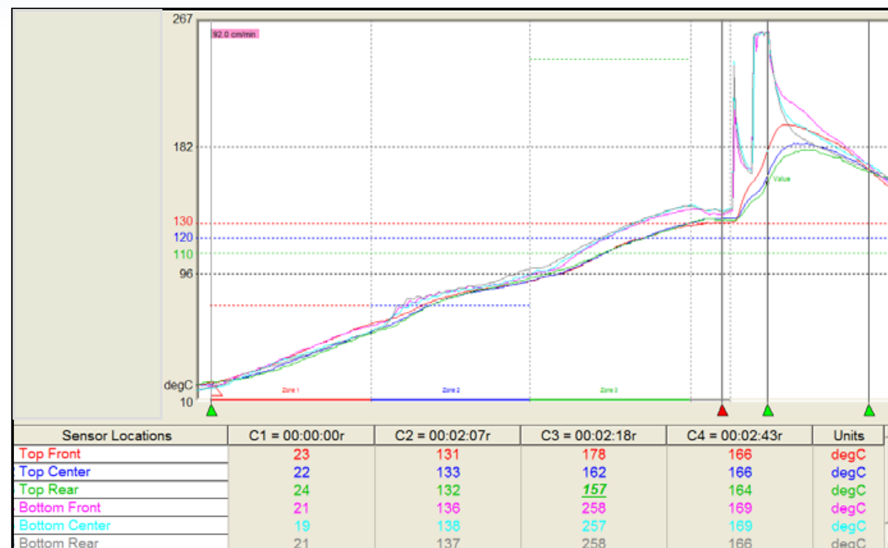
The result of Phase I is to lay the foundation for a broader effort to characterize the reliability of through-hole joints on a test vehicle specifically designed to test the norms and practices used in tin lead wave soldering and develop new standards for lead free wave soldering.

Machine Configuration

Delta Wave Solder machine

Fluxer:

Spray fluxer
FC7 for Alcohol and OA
FC16 for VOC free
Pump supply system



Sensor Locations	C1 = 00:00:00r	C2 = 00:02:07r	C3 = 00:02:18r	C4 = 00:02:43r	Units
Top Front	23	131	178	166	degC
Top Center	22	133	162	166	degC
Top Rear	24	132	157	164	degC
Bottom Front	21	136	258	169	degC
Bottom Center	19	138	257	169	degC
Bottom Rear	21	137	258	166	degC

Preheat configuration:

Forced convection
Forced convection
Calrod

Profiles Attributes

Flux amount and penetration
Mass measurement and pH paper
Preheating Temp:
ECD Super Mole
Contact Time:
ECD Wave Rider

Solder pot configuration:

Chip wave
Main wave

Nitrogen:

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

Test Vehicle "Skate"
(Cookson Design)

Board Specification

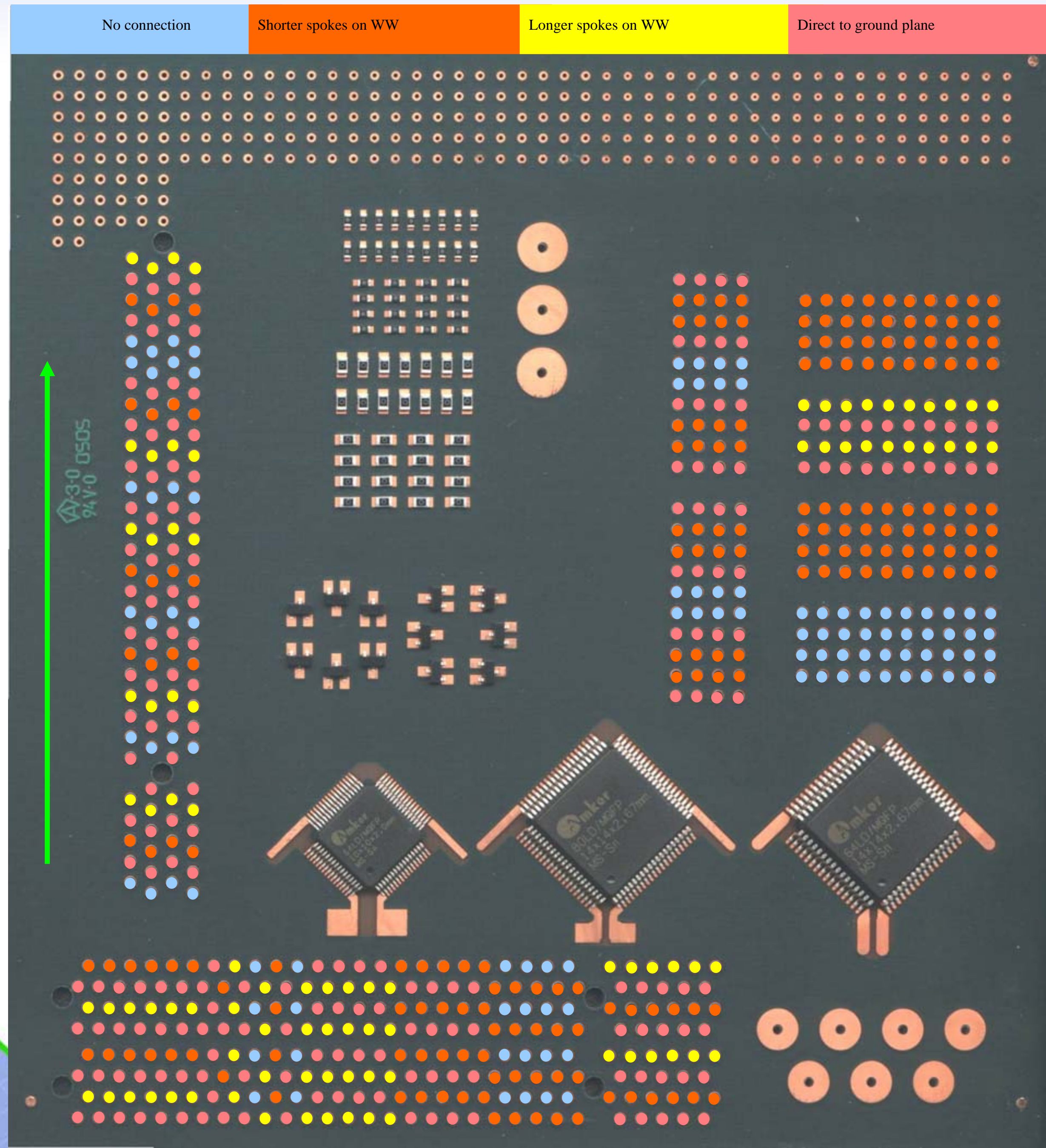
- –64 mil
- –93 mil
- –135 mil
- –CuOSP
- –HASL

Alloys

- –SAC 305
- –SACX
- –Sn100C
- –SnPb

Components

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

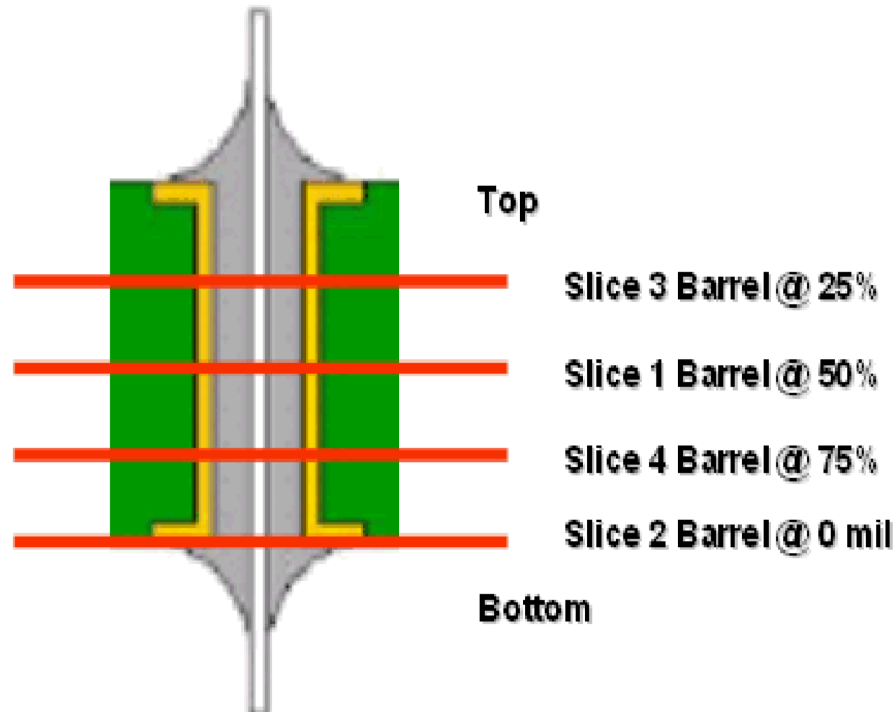


Experimental Execution

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

5DX Measurement Calculation

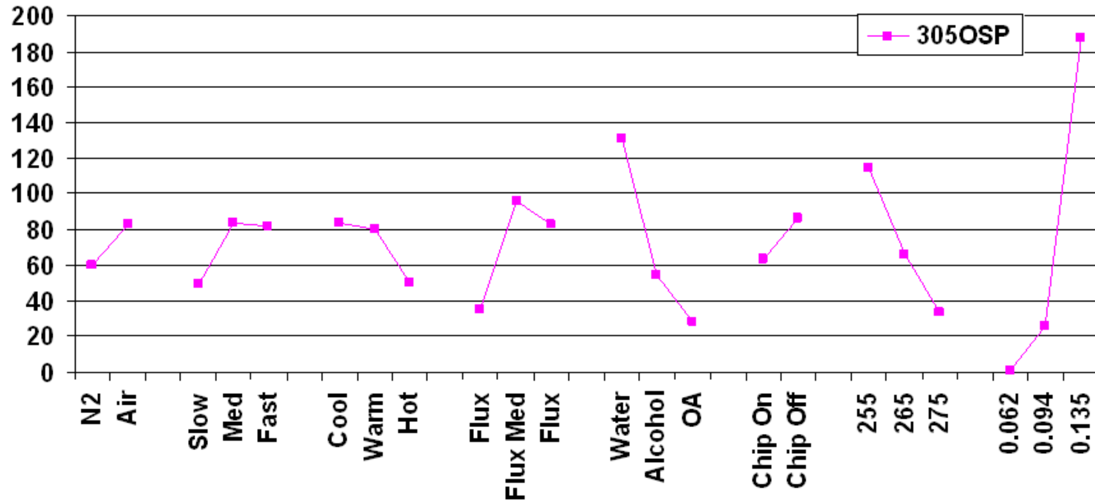


Confirmed by select cross sectioning and typical X-Ray techniques

Hole Fill Defect Analysis

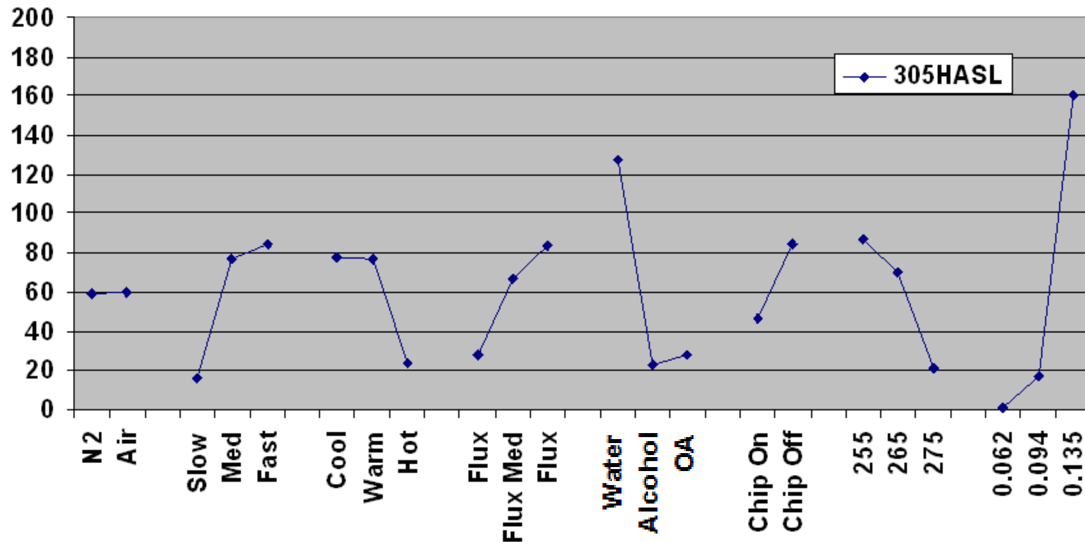
SAC 305

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



Impact of Process Parameters on Hole Fill

SAC 305



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Confirmed Optimized Process

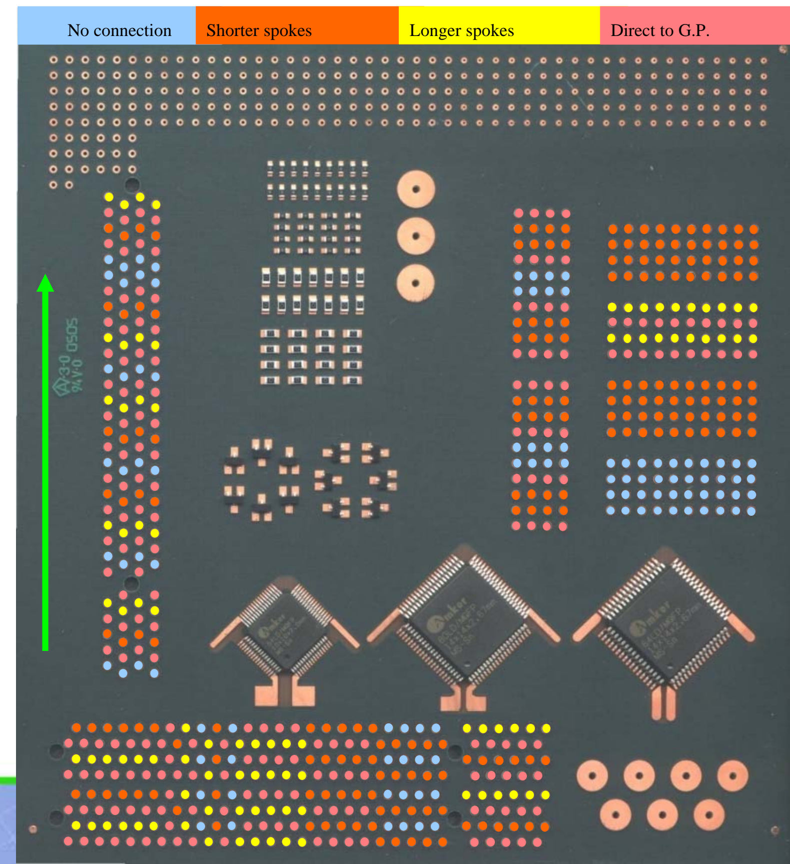
Alloy	Atmosphere	Speed	Preheat Temperature	Flux Amount	Flux Type	Solder Temperature	Board Thickness
		(ft/min)	(°C)			(°C)	(mil)
SAC 305	N_2	3	130	Med	Alcohol	265	62, 93, 135
SACx	N_2	3	110	Med	Alcohol	265	62, 93, 135
SN100C	N_2	3	110	Med	Alcohol	265	62, 93, 135

- **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.**

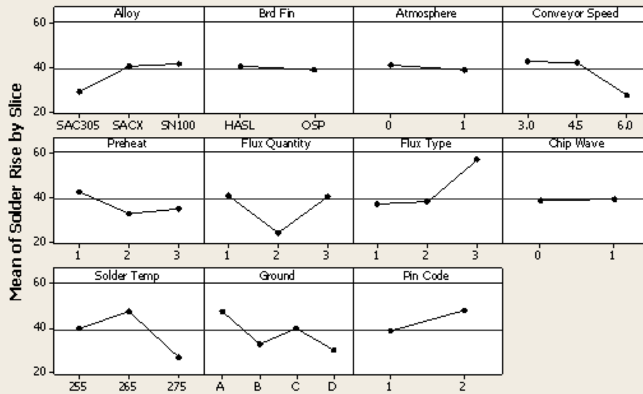
Board Thickness	SAC305	SACx	Sn100C
62 mil	0	0	0
93 mil	0	0	0
135 mil	2	7	3

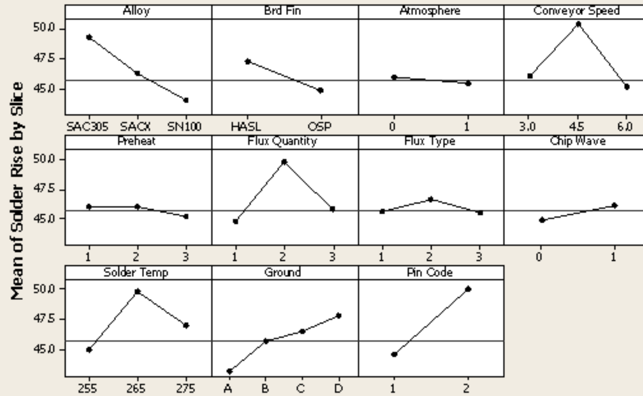


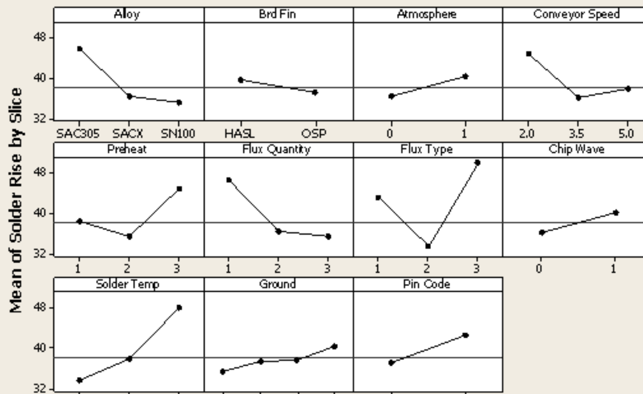
Through-Hole Defect Analysis

- 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.

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	+	+

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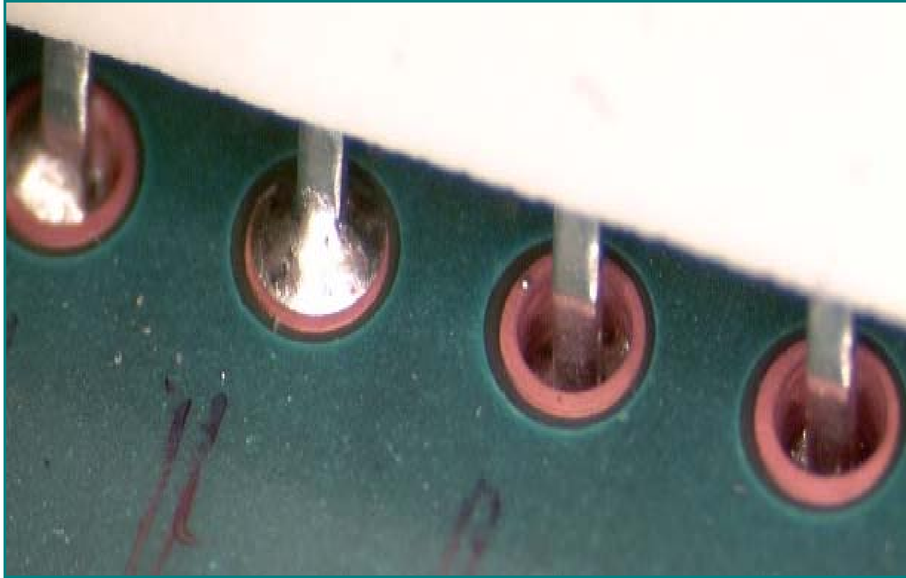
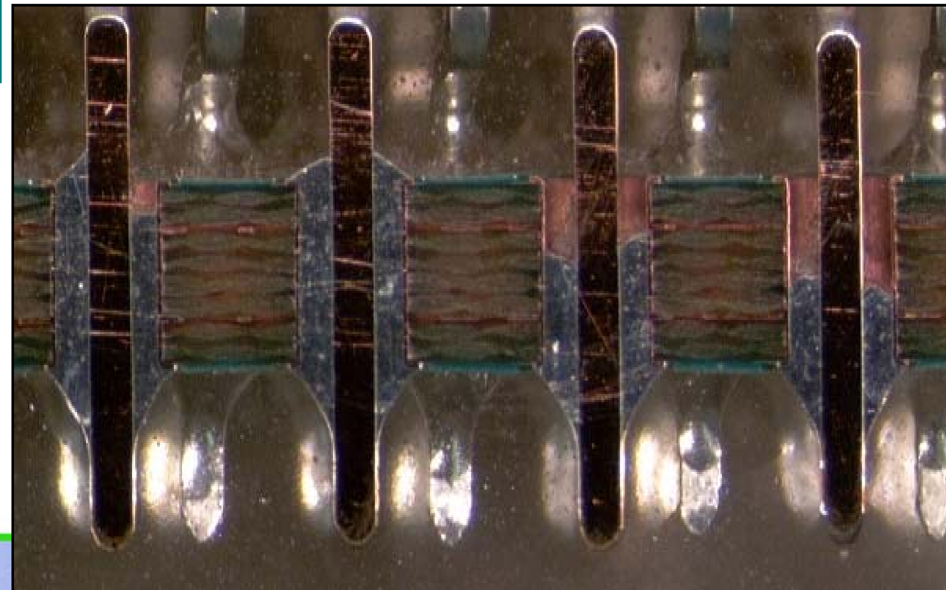
Influence of Copper Tie-In

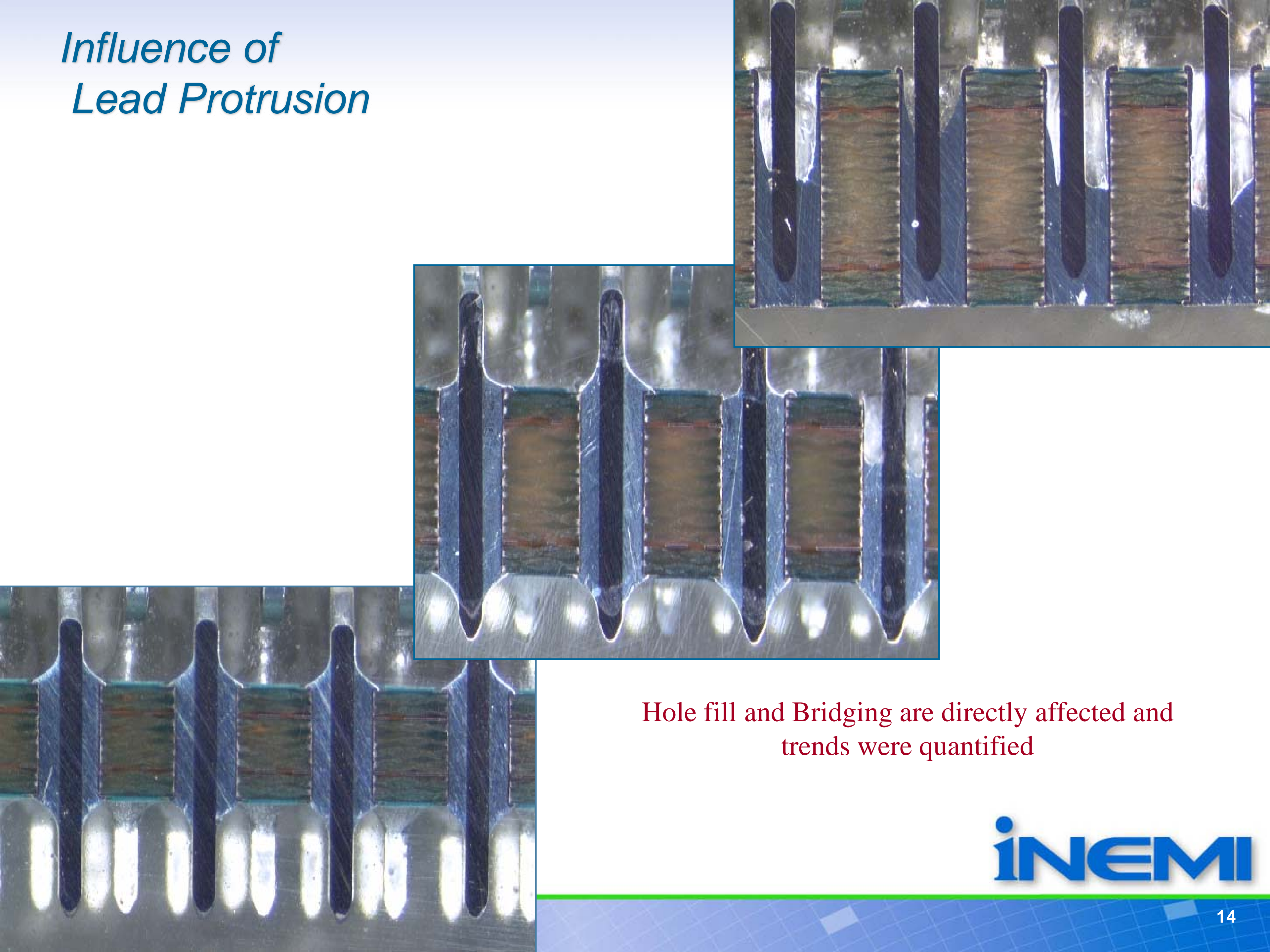
Root Cause Analysis

- **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
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14

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

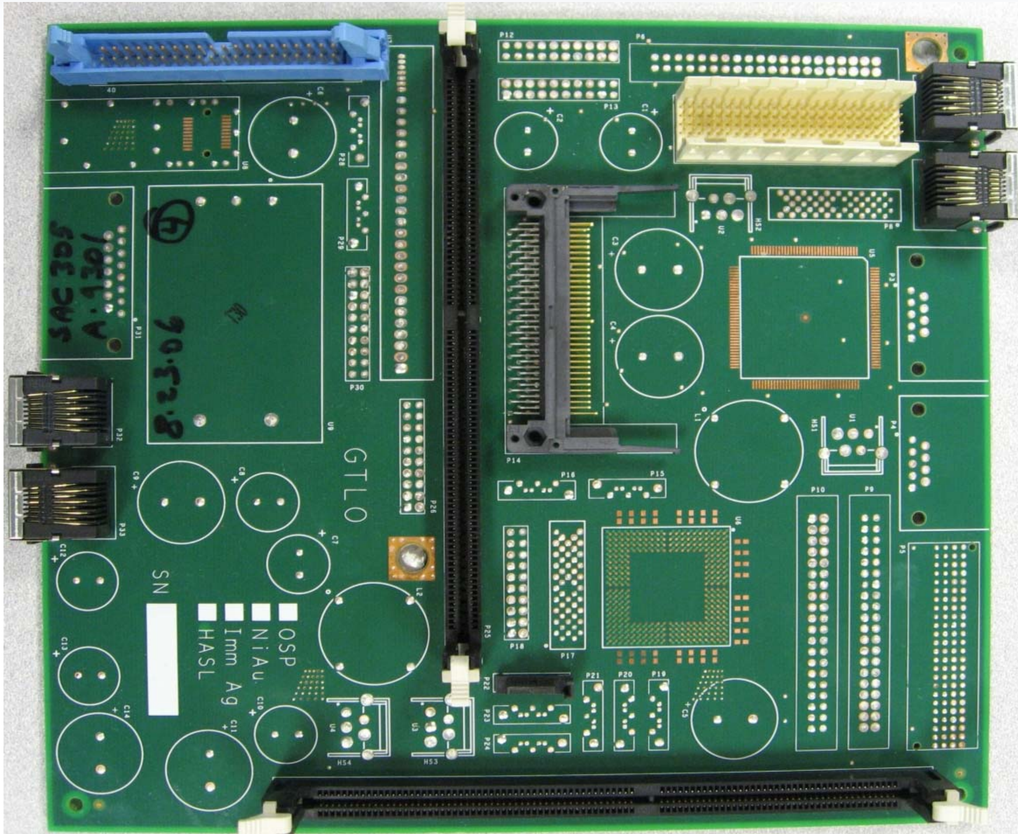
"the end goal"

Unique Board Design

Fixed Process

Lead Free Solder Joint Performance

GTLO Test Vehicle



- **Thermal cycling of -40 to 125°C in progress with 3000+ hours already complete with limited failures.**

Acknowledgements

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