International Electronics Manufacturing Initiative

Lead Free Wave Soldering

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Productronica

Advancing manufacturing technology

Phase I Project Participants

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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

Courtesy: iNEMI

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.

Getting Started

“brainstorming”

Experimental design and execution

Equipment setup and data reporting

Materials

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 x 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

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:

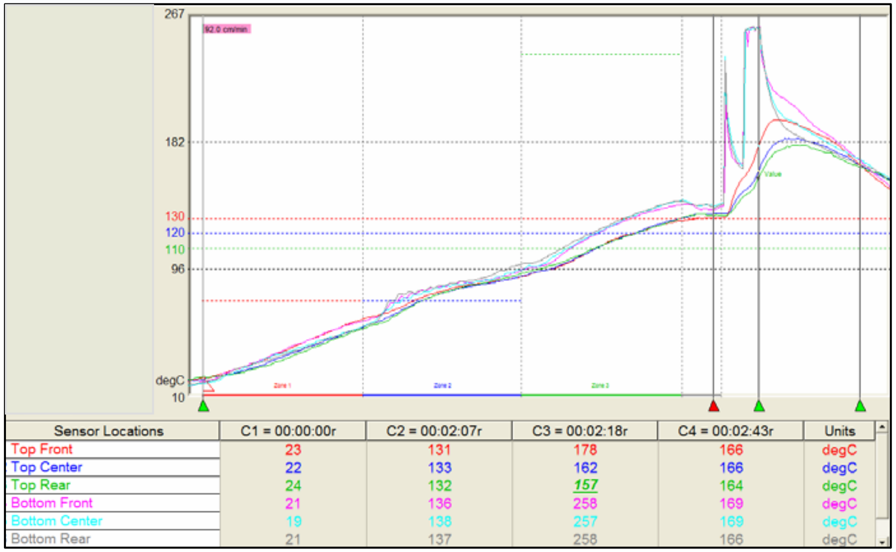
Forced convection
Forced convection
Calrod

Solder pot configuration:

Chip wave
Main wave

Nitrogen:

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



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

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

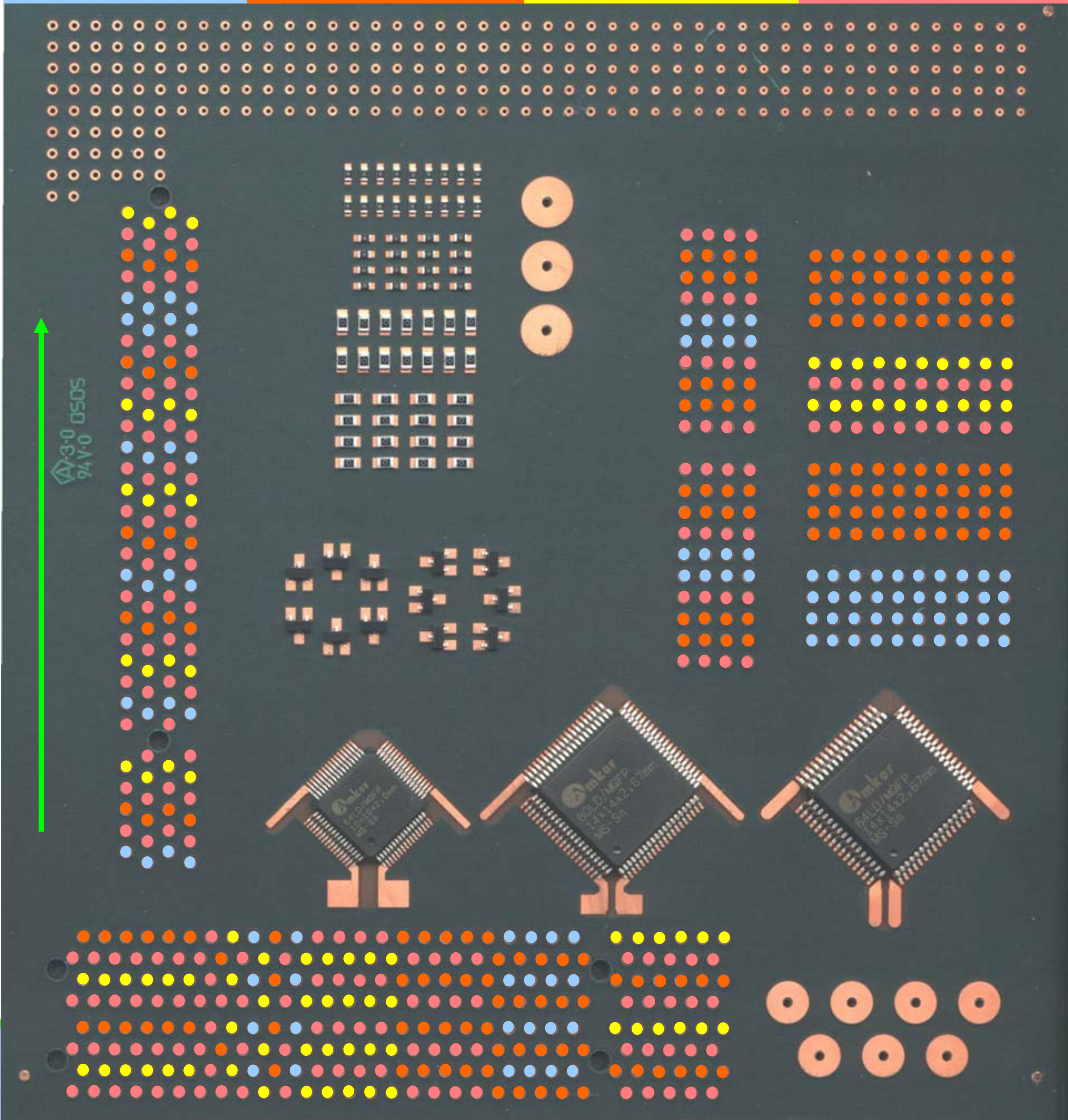
Alloys

- SAC 305
- SACX
- Sn100C
- SnPb

Components

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

No connection	Shorter spokes on WW	Longer spokes on WW	Direct to ground plane

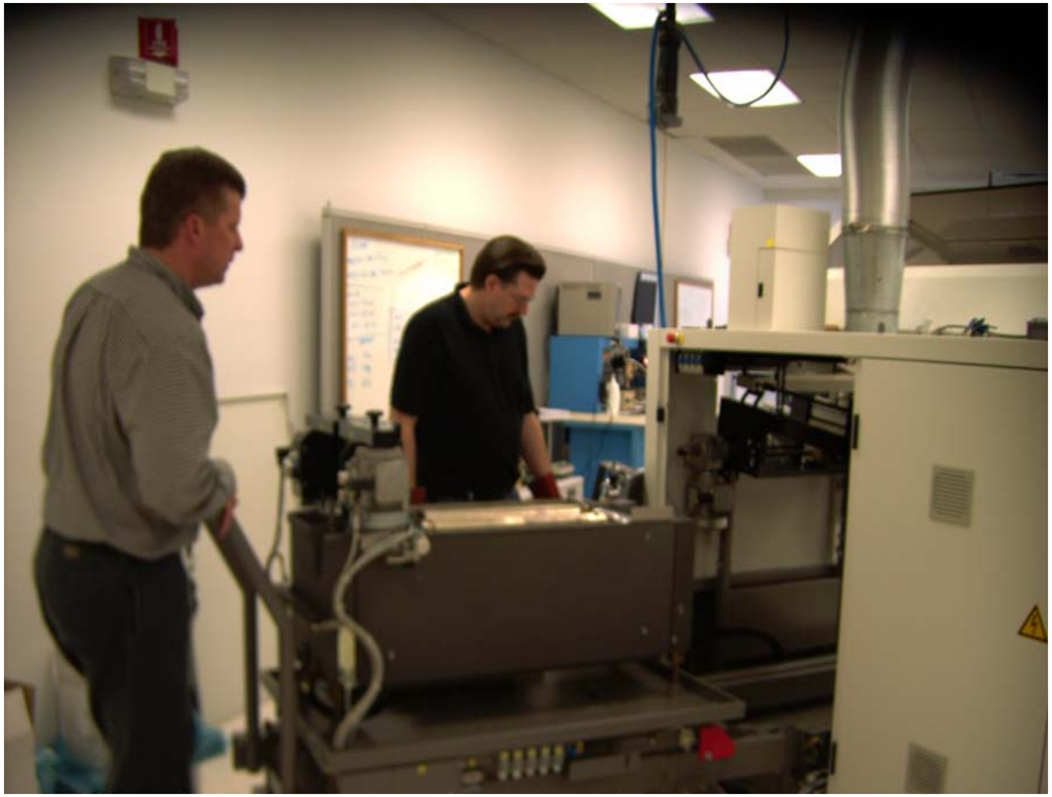


Experimental Execution

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

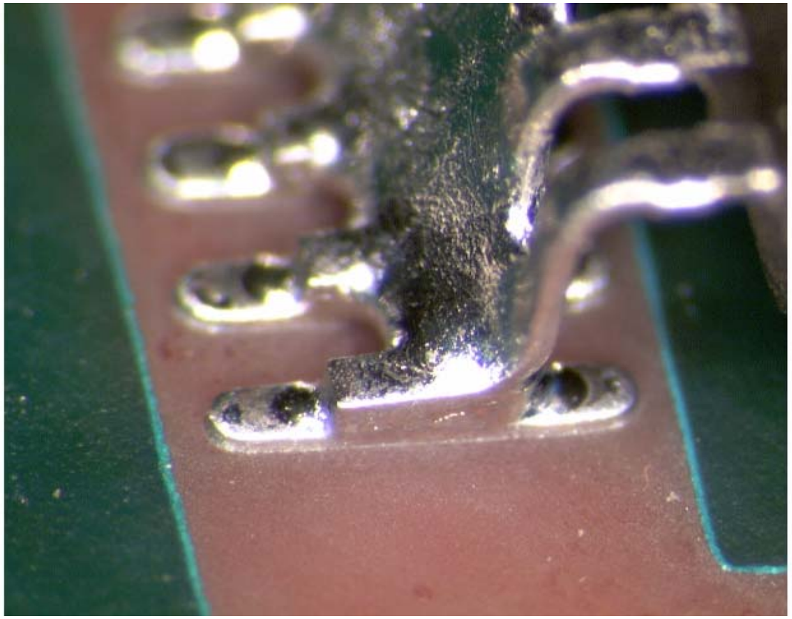
Data Collection

“working hard”

Bridging

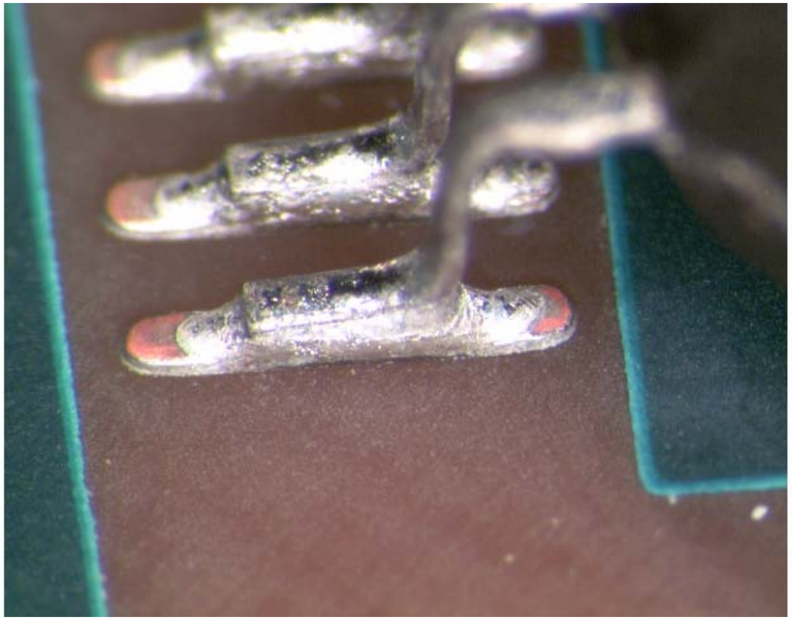
Through Hole Penetration

Analysis: Bridging with SAC 305



SAC 305 on SAC 305 HASL

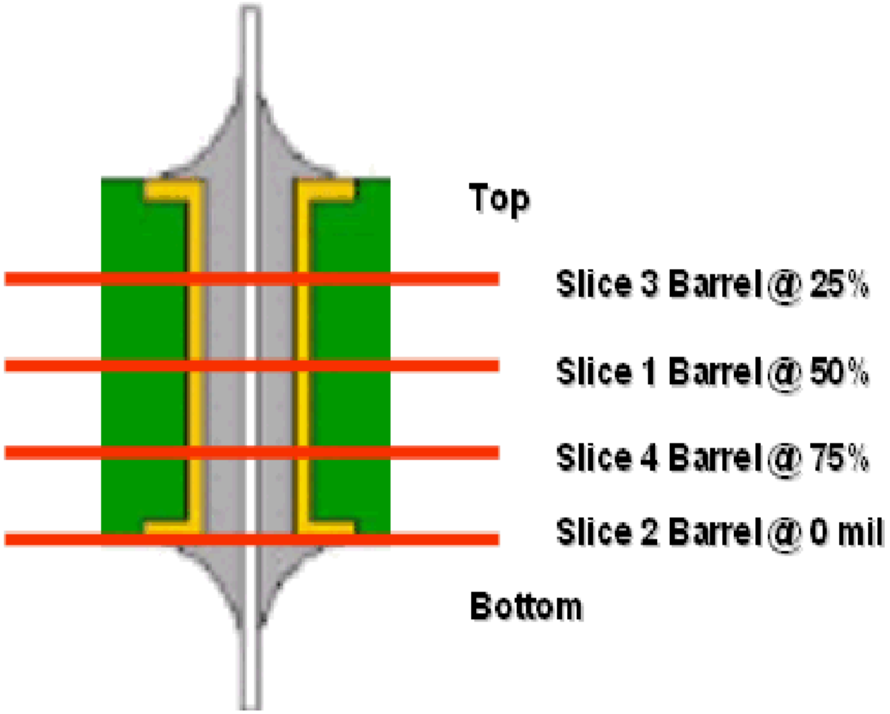
Total shorts on HASL: 299



SAC 305 on OSP

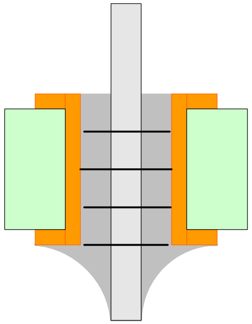
Total shorts on OSP: 451

5DX Measurement Calculation

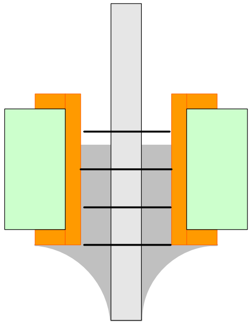


Confirmed by select cross sectioning and typical X-Ray techniques

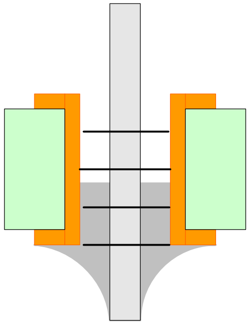
Through Hole Inspection Criteria



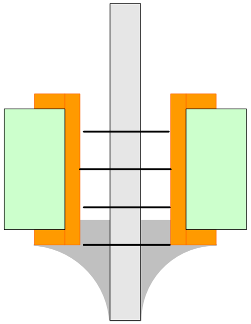
No defect



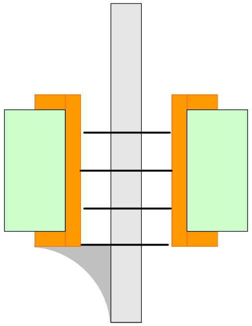
Defect
S3-25%



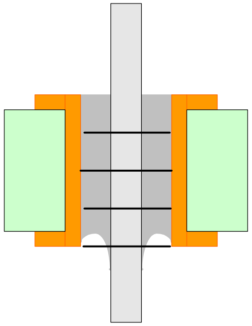
Defect
S3-25%
S1-50%



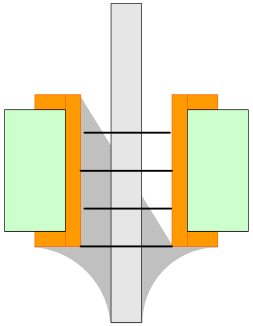
Defect
S3-25%
S1-50%
S4-75%



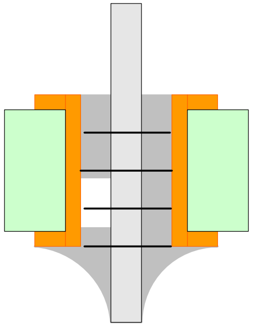
Defect
All Slices



Defect
S2-0%



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



Defect
S4-75%
Void

Analysis

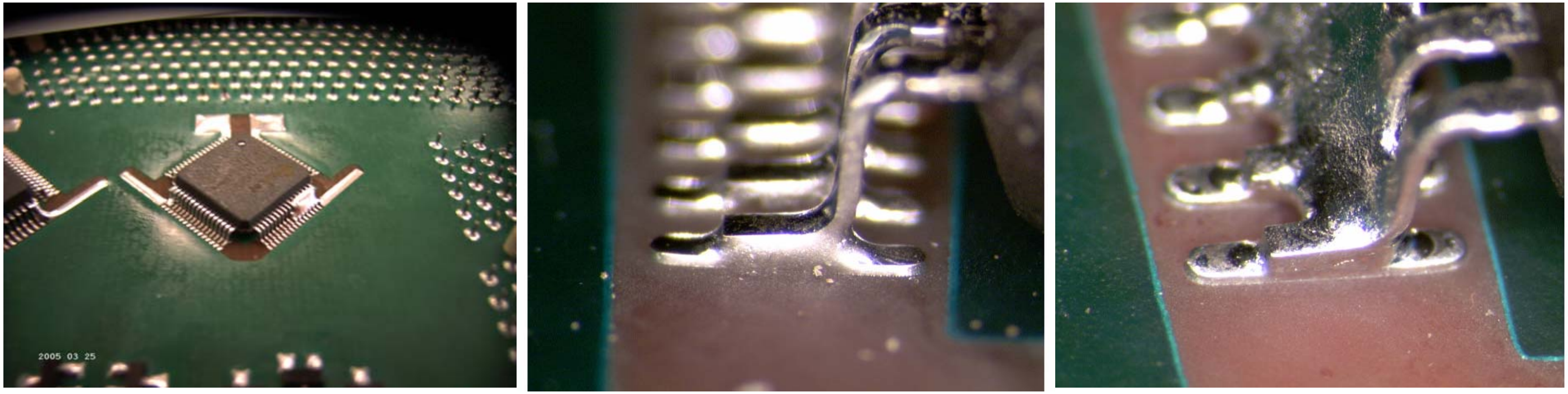
“interesting”

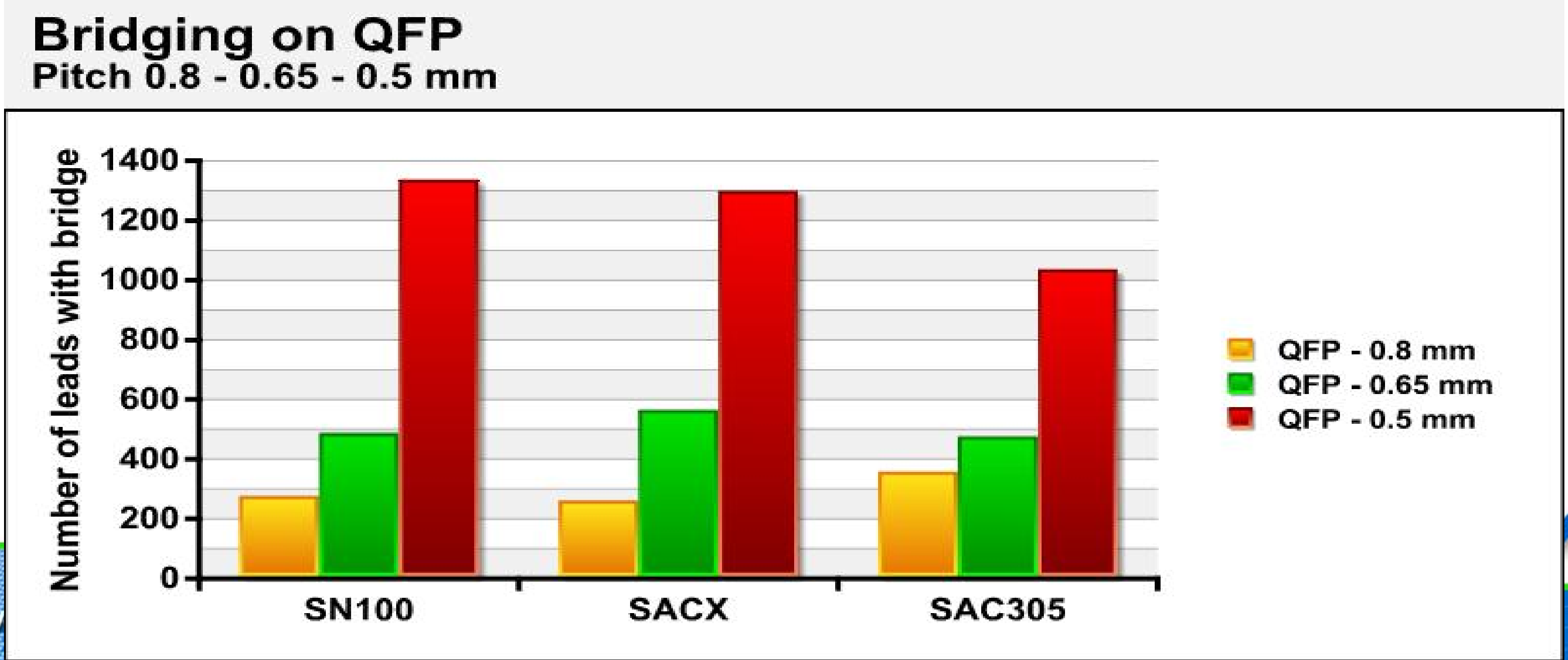
Influence of process parameters and materials

Optimized Process

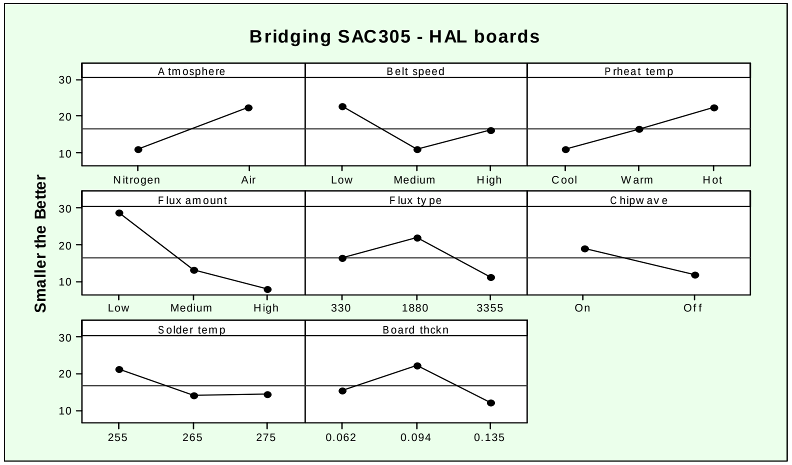
Confirmation

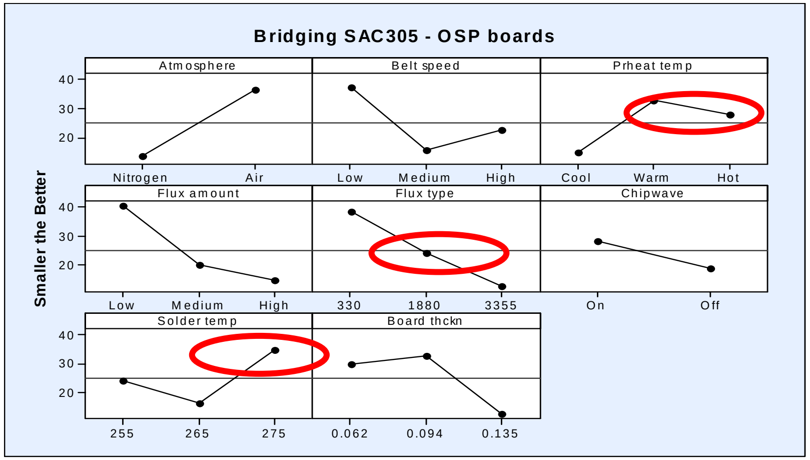
Occurrence of Bridging on QFP





Determination of Optimized Parameters for Minimal Bridging



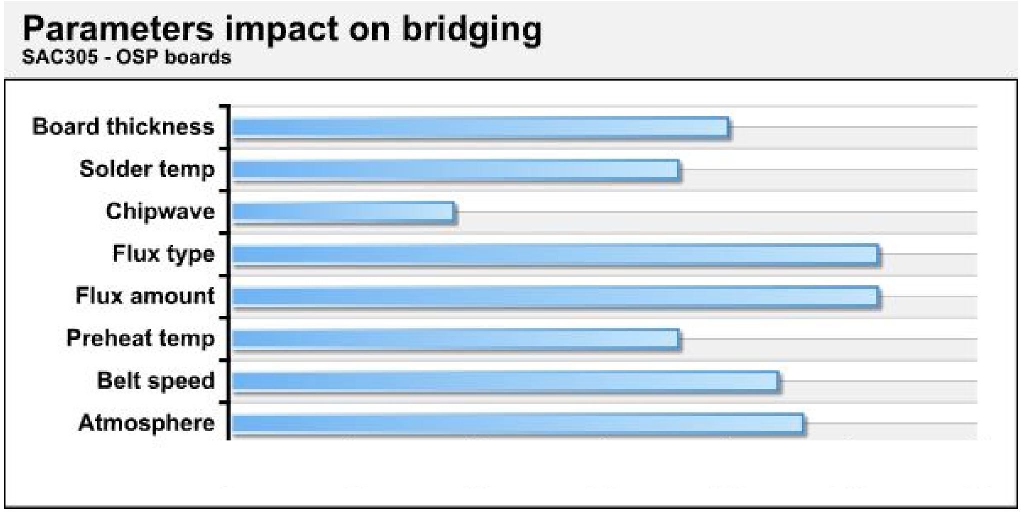


General Remark

For the PCI connector, as the board thickness increased, the lead protrusion decreased.
For the Berg Stick connector, the lead protrusion was kept constant over the three board thicknesses by mechanical means.

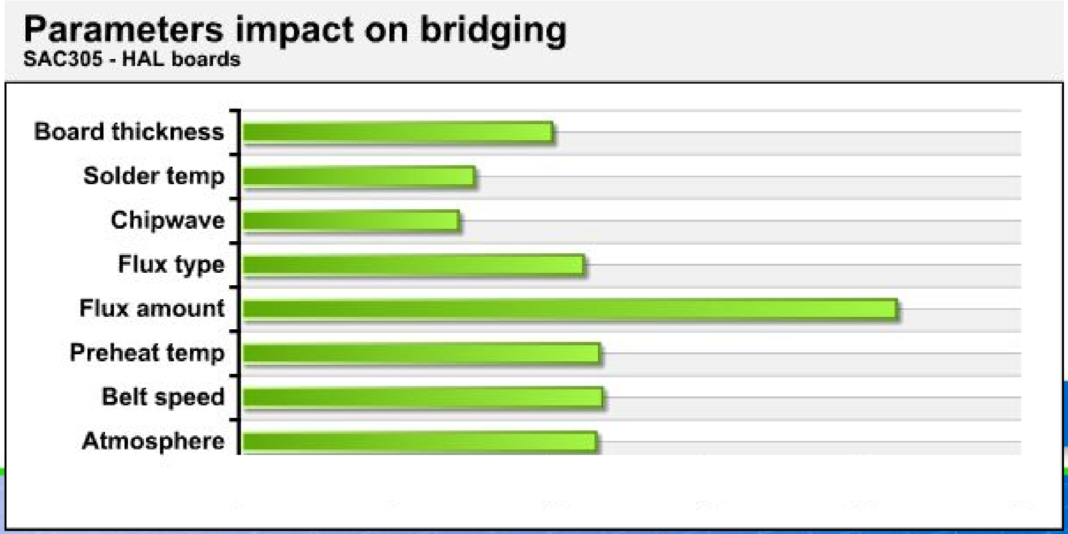
Bridging was found to be correlated to lead protrusion.

Interactions of Process Parameters on Bridging

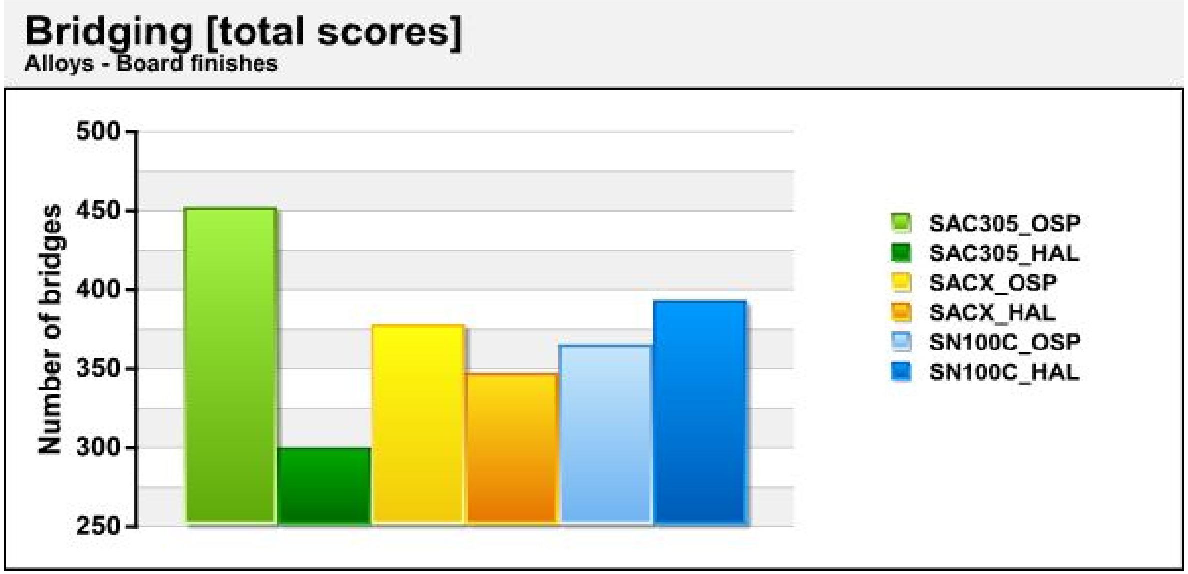


To avoid bridging

Select a proper flux, amount, and inert soldering environment



How to Minimize Bridging Based on Process and Materials



Recommended Settings

Atmosphere: Nitrogen
Belt speed: Med/High
Preheat temp: Cool
Flux amount: High
Chip wave: Off
Solder temperature: 265ºC

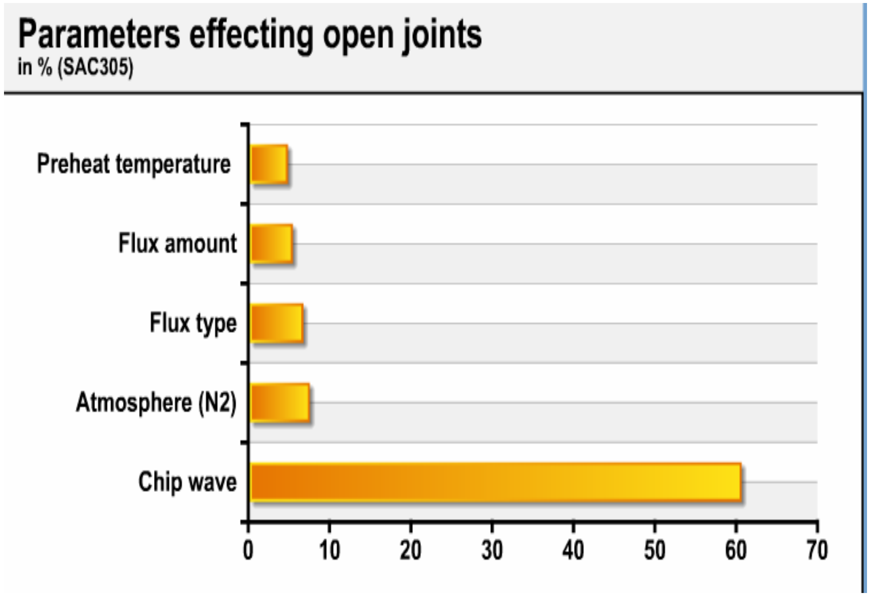
Open Joints/Skip on SOT's

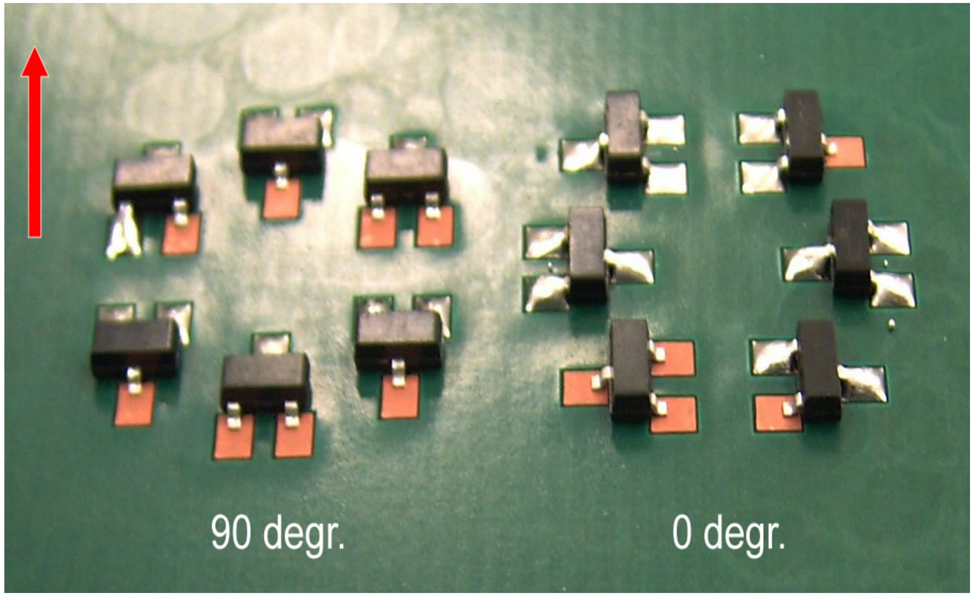
- **The orientation of the SOT is a critical design factor.**

(1.5x more defects)

- **Chip wave operation results in improved soldering results.**

(Double wave former prevents shadow effects)





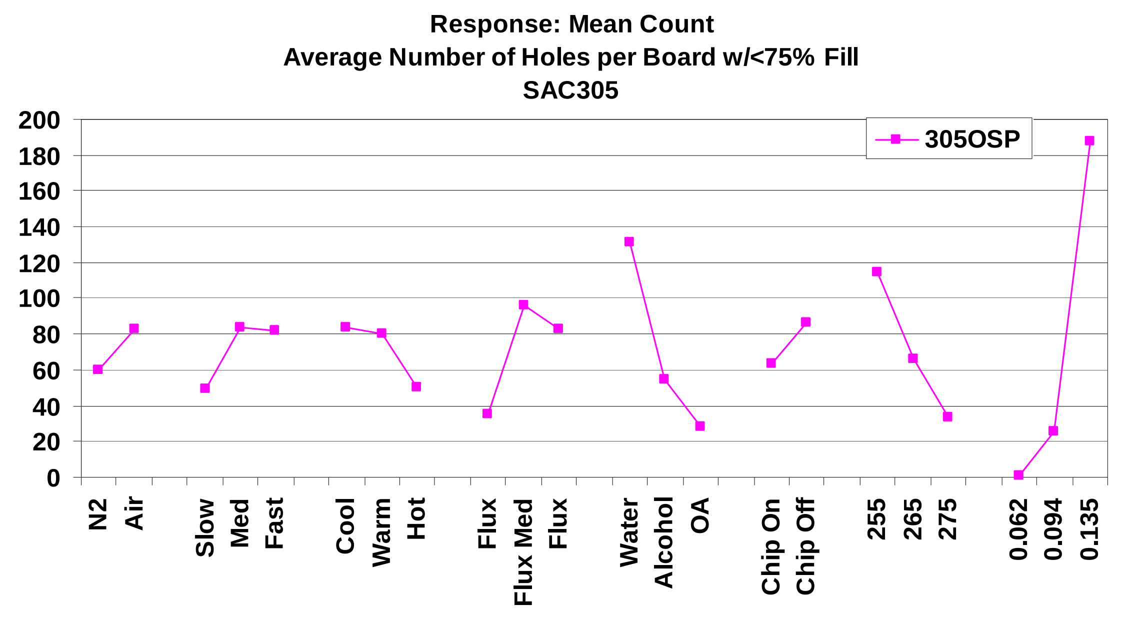
Hole Fill Defect Analysis

SAC 305

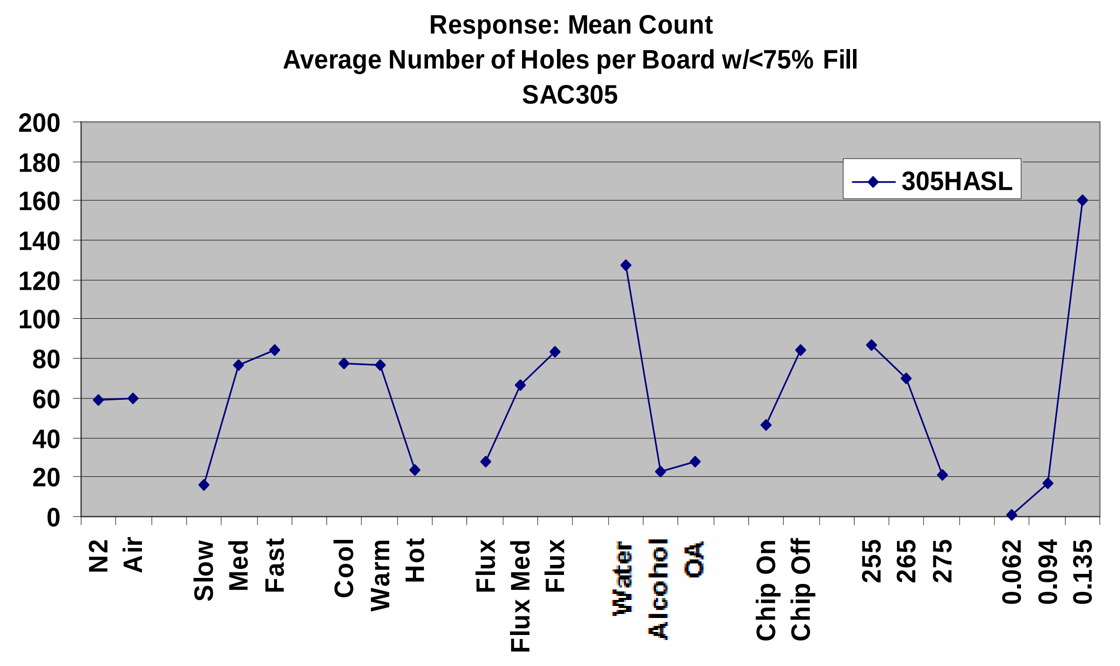
Actual Run Order	DOE Standard Order	Atmosphere	Speed Ft/min (cm/min)	Preheat Temp	Flux Quantity	Flux Type	Chip Wave	Solder Temp (°C)	Board Thickness	SAC 305	
										HASL	OSP
1	5	N_2	4.5 (138)	med	med	OA	on	255	0.062	0.0	0.0
2	1	N_2	3 (92)	low	low	Water	on	255	0.062	2.0	2.7
3	16	Air	6 (183)	low	high	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



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



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

Confirmed Optimized Process

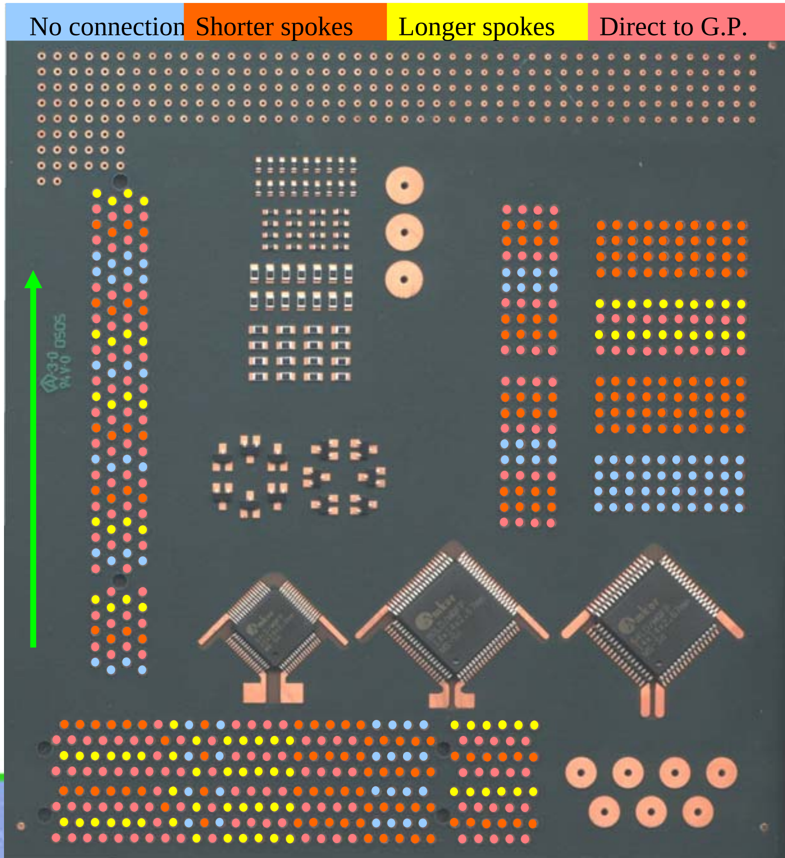
Alloy	Atmosphere	Speed	Preheat Temperature	Flux Amount	Flux Type	Solder Temperature	Board Thickness
		(ft/min)	(°C)			(°C)	(mil)
SAC 305	N_2	3	130	Med	Alcohol	265	62, 93, 135
SACx	N_2	3	110	Med	Alcohol	265	62, 93, 135
SN100C	N_2	3	110	Med	Alcohol	265	62, 93, 135

- **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.**

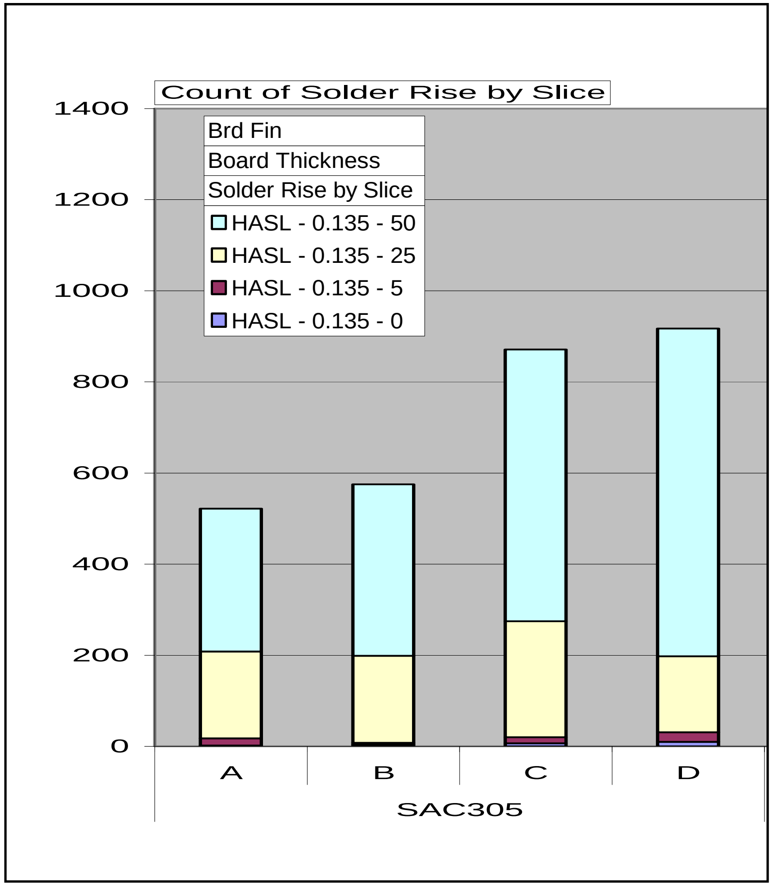
Board Thickness	SAC305	SACx	Sn100C
62 mil	0	0	0
93 mil	0	0	0
135 mil	2	7	3

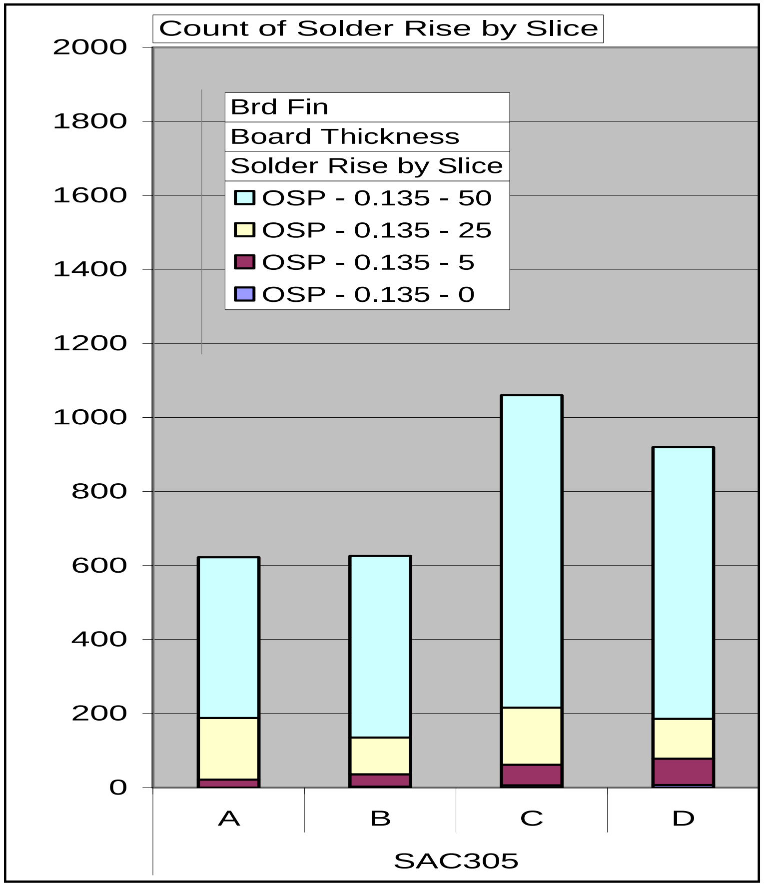


Through-Hole Defect Analysis

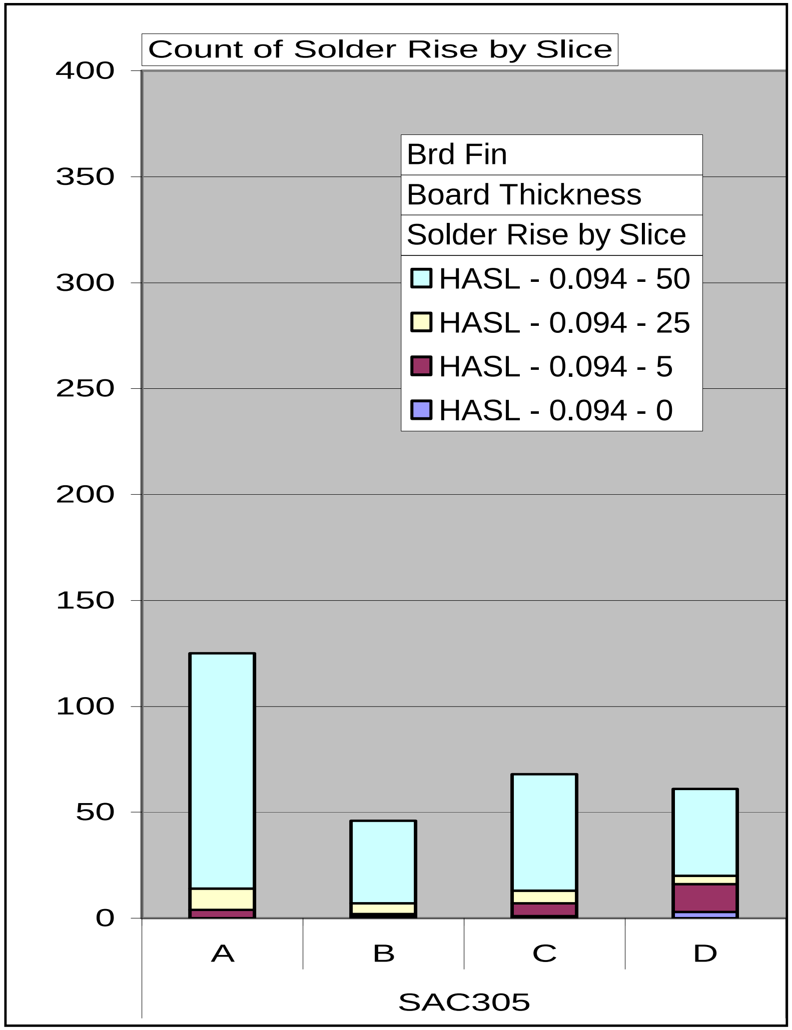
- **A secondary effort was made to characterize how far up the via solder traveled, or solder rise.**
- **This was performed on all thicknesses and each board finish.**
- **Over 30,000 defects were recorded and analyzed.**
- **Data mining permits us to identify how materials impact the process window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

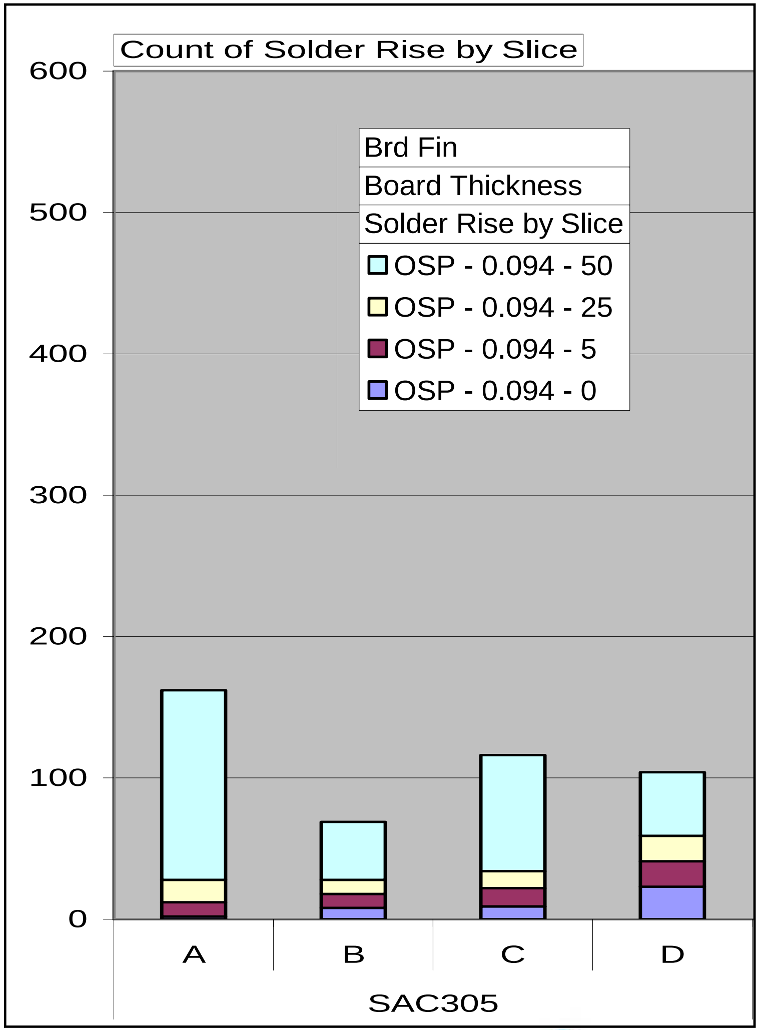
Solder Rise for the 135 mil Test Vehicle



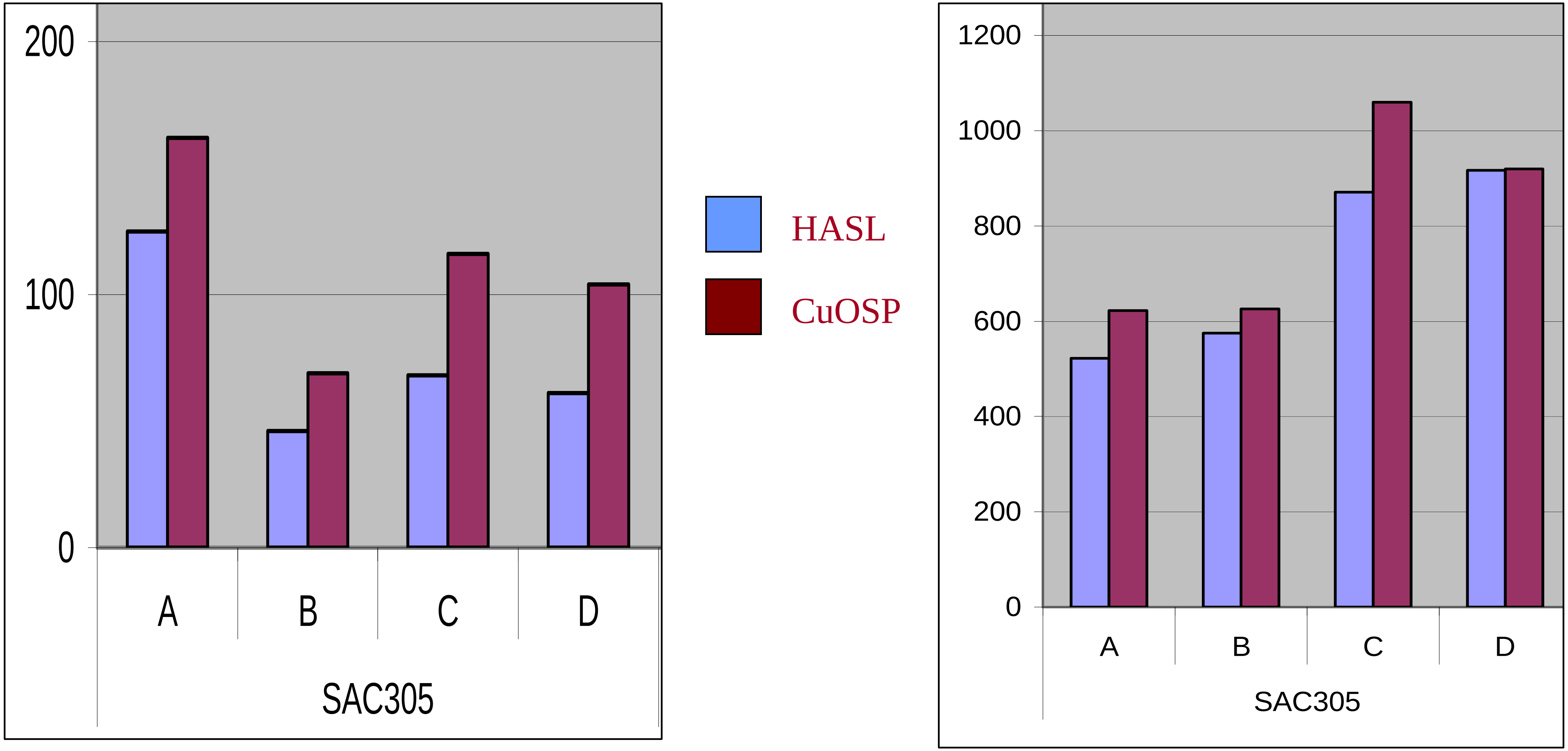


Solder Rise for the 94 mil Test Vehicle





Impact of Board Finish on Solder Rise



93 mil thick

125 mil thick

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

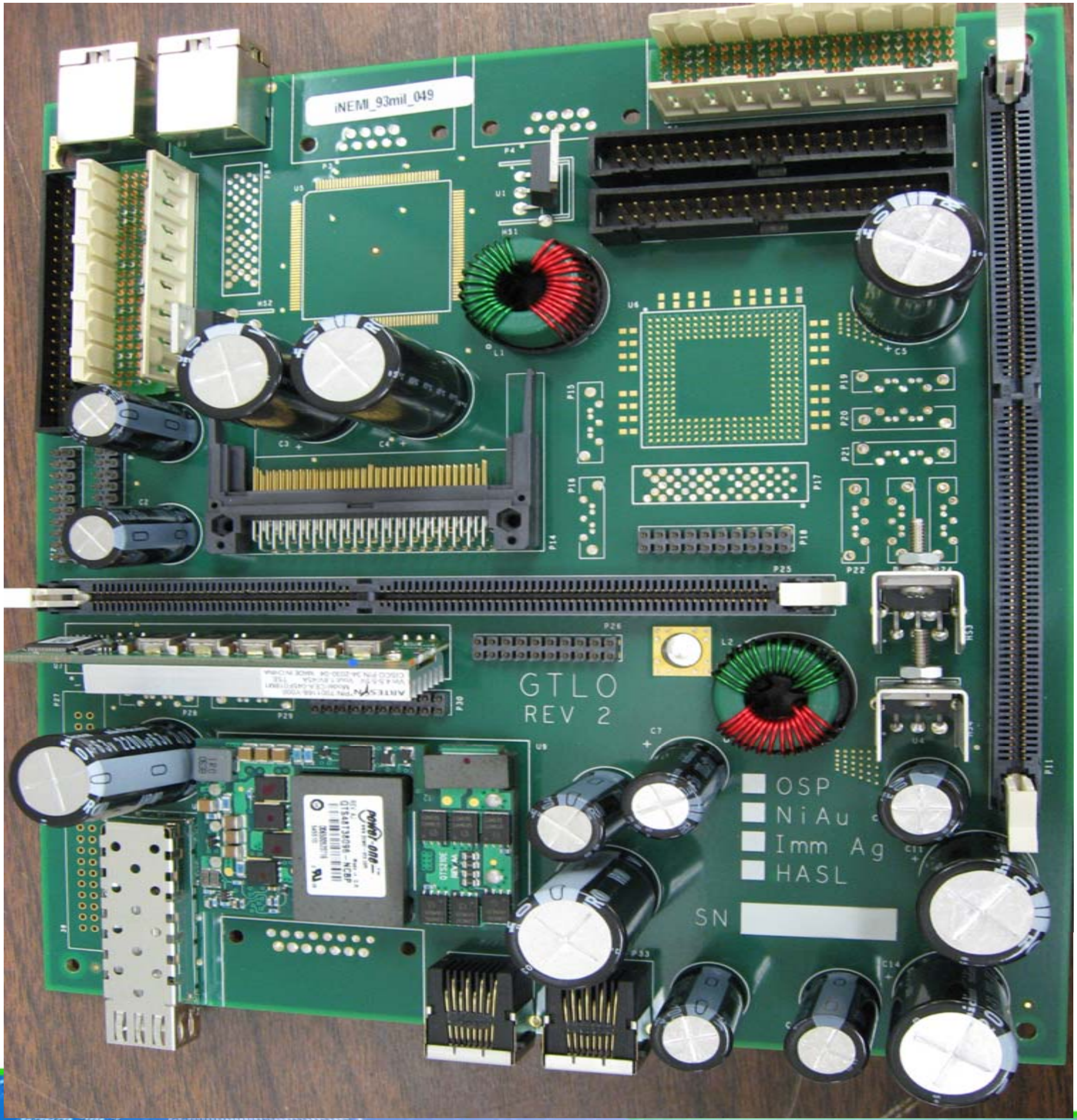
"the end goal"

Unique Board Design

Fixed Process

Lead Free Solder Joint Performance

GTLO Test Vehicle



- **Designed specifically for wave soldering.**
- **Includes components and design features from automotive, consumer, industrial communications, computer.**
- **Five daisy chains**

Scope

Test Condition	Alloy	Thickness	Surface Finish
Initial Analysis (X-section, X-ray, Pull, Shear, etc…)	SnPb	0.062	OSP
			NiAu
			Imm Ag
			HASL
		0.093	OSP
			NiAu
			Imm Ag
			HASL
	SAC	0.062	OSP
			NiAu
			Imm Ag
			HASL
		0.093	OSP
			NiAu
			Imm Ag
			HASL
	SnCuNi	0.062	OSP
			NiAu
		0.093	OSP
			NiAu
	SACx	0.062	OSP
			NiAu
		0.093	OSP
			NiAu
ATC -40 to 125C	SnPb	0.062	OSP
			NiAu
			Imm Ag
			HASL
		0.093	OSP
			NiAu
			Imm Ag
	SAC	0.062	OSP
			NiAu
			Imm Ag
			HASL
		0.093	OSP
			NiAu
			Imm Ag
	SnCuNi	0.062	OSP
			NiAu
		0.093	OSP
			NiAu
	SACx	0.062	OSP
			NiAu
		0.093	OSP
			NiAu
ATC 0 to 100C	SnPb	0.062	OSP
			NiAu
		0.093	OSP
			NiAu
	SAC	0.062	OSP
			NiAu
		0.093	OSP
			NiAu
Drop	SnPb	0.062	OSP
			NiAu
		0.093	OSP
			NiAu
	SAC	0.062	OSP
			NiAu
		0.093	OSP
			NiAu
Vibration	SnPb	0.062	OSP
			NiAu
		0.093	OSP
			NiAu
	SAC	0.062	OSP
			NiAu
		0.093	OSP
			NiAu
	SnCuNi	0.062	OSP
			NiAu
		0.093	OSP

Interest	Test	Alloy	Thickness	Surface Finish
Core - Baseline	-	-	-	-
Temp Age	-40 to 125C	SAC	0.093	OSP
Selective Solder	-40 to 125C	SAC	0.093	OSP
other	-40 to 125C	SAC	0.093	OSP

- **600 boards**
- **300,000 components**
- **3 alloys, 4 finishes, 1 flux, 2 thicknesses**

Next Steps

- Agilent 5DX analysis on all 500+ boards.
  - Quantitative data at 10 slices on the via. 20,30,40,50,60,70,75,80,90,100%
- Thermal cycling
  - -40°C to 125°C for 6000 cycles
- Vibration and Drop
- Time zero analysis
  - Cross sectioning
  - Microscopy
  - IMC characterization
- Goal is to investigate and characterize joint performance.

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