LEAD FREE WAVE SOLDERING:
PROCESS OPTIMIZATION FOR SIMPLE TO HIGHLY COMPLEX BOARDS

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ABSTRACT

Today's wave soldering processes solder electronic assemblies within the large eutectic tin lead processing window. The issues surrounding the conversion to lead free assembly are multiple and varied. Logistics, cost, material selection, and equipment choices/options are some of these challenges that require planning and organization. However, at the core of lead free assembly is soldering. The iNEMI lead free wave soldering team embarked on a multi-tiered project that focuses specifically on two aspects: identifying the impact of critical parameters on the development of a reliable, robust lead free wave soldering process as well as determining the process that achieves the optimized soldered joint.

The critical aspects of the lead free wave soldering process can be broken down into several categories which include component reliability, board reliability, flux type and specifications, alloy and alloy composition, its melting behavior, wave equipment capacity and power requirements, profile attributes and flexibility.

This collaborative effort has investigated process parameter and material impact on the soldering process and joint formation. Addressed in this lead free implementation study were inspection criteria, failure definition and measurement, followed by root cause analysis and ultimately optimized process confirmation. The result of this investigation 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 wave soldering.

Overall, this investigation looks to bring an understanding of how critical wave soldering parameters correlate and provide the reader with the information necessary to make educated decisions in selecting materials. This study will also provide insight into the process issues that one will encounter so that a rational implementation strategy for a reliable and robust lead free wave soldering process can be achieved.

Key words: Lead Free, Pb Free, wave soldering, process, solder, alloy, flux.

INTRODUCTION

The 2004 iNEMI roadmap identified a gap in industry information and research relating to lead free wave soldering processes and reliability of these lead free assemblies. Since this time, only a limited number of comprehensive investigations have taken place.[1,2,3] As a result, the Lead Free Wave Soldering project was developed in order to characterize and quantify the impact caused by the transition to lead free solder on the wave process itself as well as the impact on the performance and reliability of lead free solder joints. The 2007 iNEMI roadmap was recently made available to member companies and will be released to the public in March 2007. Within the board assembly chapter, the technology forecast for wave soldering is described and is listed in Table 1.

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	^0C	95-130	100-160	100-160	100-160	100-160
Wave pot Temperature	^0C	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

Table 1. The 2007 iNEMI Technology Forecast for Wave Soldering.[4]

This updated table provides increased resolution on alloy composition, component pitch, contact time, and atmosphere compared to the 2004 iNEMI Technology Forecast.

The technology forecast continues to provide consistent data on the nature of the wave soldering landscape. The issues today continue to be led by the enduring changes in materials and their maturity combined with a significant effort to minimize cost. Alloys containing silver adversely affect cost thus pressuring assembly houses to find alternative cheaper materials. Another pressure is the complexity of board technology. Today's high end board designs are quickly migrating to increased layer count, thicknesses, and complexity, thus exacerbating the challenges already associated with developing and maintaining a robust and reliable wave soldering process. This results in an overall situation where materials are pushed to the limits of their respective specifications in terms of exposure to elevated temperature for extended times. As the lead free implementation progresses, various questions have arisen. This research takes an in-depth look at the challenges encountered in developing a lead free wave soldering process based on the specific products as well as on specific materials.

For these and other similar reasons, the iNEMI Lead Free Wave Soldering Project focused on three critical areas:

1. Materials Selection
2. Process Optimization
3. Solder Joint Performance

In order to achieve these goals the project participants developed a two-phase approach.

The companies supporting this project during the execution of Phase I are shown in Figure 1.

Figure 1. iNEMI Lead Free Wave Soldering Project Companies Supporting Phase I.

The first phase of the project focused on characterizing process-related challenges and optimization of a lead free wave soldering process for various factors including: fluxes, alloys, and board thicknesses. Characterizing the window of opportunity for various materials specifically designed for lead free assembly and its impact on wave soldering process is based on the quantification and analysis of specific defects. The research performed in Phase I accomplished the aforementioned goal by investigating various levels of two factors:

- First, selection of a broad variety of materials allows for the determination of specific interactions. Alloys, fluxes, board laminate and finishes, component types and metallurgy, board design including thickness, thermal tie design, finish, and component orientation exert individual restrictions on the wave soldering process that results in an overall window of opportunity.
- The second factor is the flexibility allowed in developing the robust soldering process. Development of the wave process requires selection and control of various parameters including flux amount, atmosphere, preheat temperature, contact time, alloy temperature, and wave configuration.

The findings provide insight into the optimization of the wave soldering process for given material combinations. Confirmation of the data analysis was achieved by soldering boards utilizing the optimized parameter settings for the respective material combinations. The focus of this latter effort was to provide a data driven solution for the optimized wave soldering process which is an essential part of a robust and reproducible lead free assembly process. The scope of the project included accomplishing this goal for three different lead free alloys as well as for tin lead on three different board thicknesses.

The goal of the iNEMI lead free wave project is to ultimately characterize solder joint performance. Phase I provides the optimized settings that result in IPC class 3 acceptable through-hole fill for specific material combinations. Phase II of the project focuses on standardizing the lead free wave assembly process based on the Phase I process development and optimization so that only solder joint performance will be evaluated. The intent of Phase II is to provide the electronics assembly industry with timely and statistically backed understanding of lead free wave soldered joints.

In order to achieve this goal, the team designed and fabricated a test vehicle that aims to understand future assembly requirements and consequently develop new standards and best practices for lead free wave soldering assembly. This board's call name is "GTLO", Get The Lead Out! As shown in Figure 2.

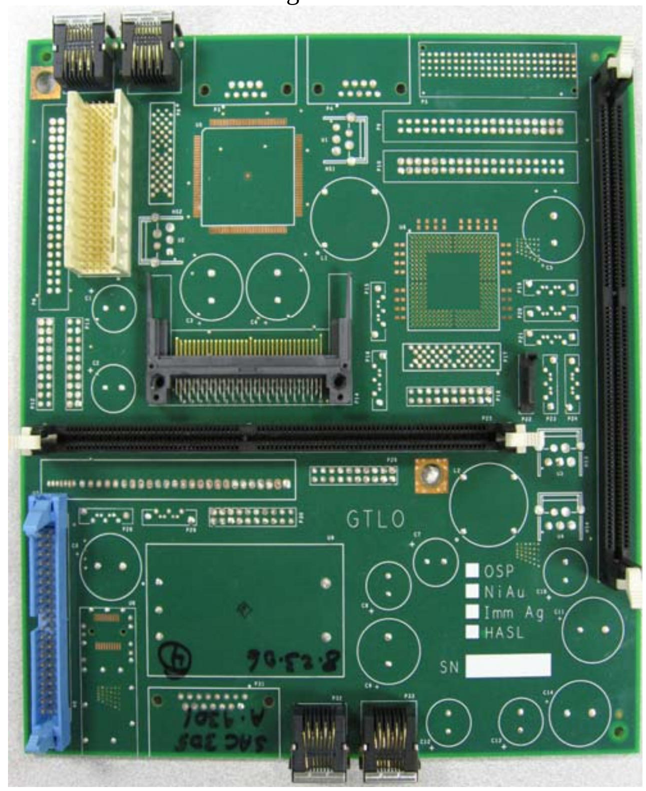

Figure 2. The GTLO Board

It is with this board and component mix that the team will derive solutions and specifications to the challenges posed in the technology forecast.

EXPERIMENTAL

In the design of this experiment a variety of materials were used. Criteria for the selection of these materials was based on industry assembly norms, gaps in information or industry need, and known reliability of specific materials not considered in the experiment. Wave soldering equipment use and setup was determined based on common industry practices, basic configuration and operation.

Materials

Fluxes

Soldering fluxes are known to exert a significant influence on the resulting solder joint. Without performing a comprehensive flux investigation, three fluxes from three flux composition categories were selected.

1. No Clean Alcohol Based Flux- 4.6% solids content
2. No Clean Water Based Flux
3. Organic Acid Water Soluble

Alloys

The various, available lead free alloys on the market today consist of tin in excess of 95%. As a result, the melting behavior of the alloys will be dominated by the melting point of tin, 232°C. In this experiment three lead free alloys were selected based on project interest at the time the experiment was executed. Tin lead was also included to provide a benchmark to the majority of today's production lines.

1. SAC 305
2. Sn100C
3. SACx
4. SnPb

Board

The test vehicle used in Phase I was a Cookson Electronics designed test board referred to as the "Skate" board. The fabrication included the use of Polyclad 370 HR laminate with a 175°C T_g and a high T_d.

The layout of the Skate test vehicle used in this experiment included two types of through-hole components, four banks of passives, two banks of SOT-23's oriented in two directions, and three QFP's with varying lead pitch. A bottom view is illustrated in Figure 3.

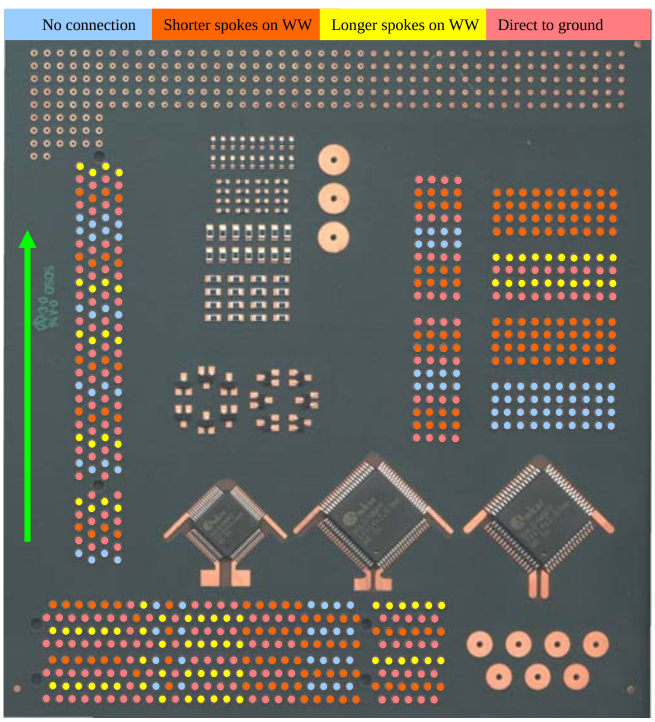

Figure 3. A Bottom Side View of the Skate Test Vehicle

Provided at the top of the board is a color code of the four copper connection types designed into the test vehicle. The four connection types are:

1. No connection
2. Short Spokes on Wagon Wheel
3. Long Spokes on Wagon Wheel
4. Direct to Ground

The color code is followed in the schematic per through-hole. There are three locations for 120 pin PCI and twelve 20 pin dual row berg stick connectors. This was done in order to assess the impact ground plane connection to the barrel has on through-hole penetration. The green arrow indicates the direction of the board as it travels in the wave soldering machine.

Board finish was divided into two categories:

1. Cu OSP
2. Alloy Specific HASL

For each of the three lead free alloys and tin lead, the respective board finish was applied. ie, In the experiments where SAC 305 alloy was used, the board finish was also SAC 305 HASL. The OSP applied was Entek Plus HT.

The board thicknesses utilized in this experiment were 62 mils, 94mils, and 135 mils.

Components

PCI Connector

One of the through-hole components selected was the 120 pin PCI connector with a lead free finish. This component was only available in one lead length. All three PCI connector locations were populated.

Berg Stick

The 20 pin dual row Berg Stick connector came in a lead free finish as well as a tin lead finish. The bottom side lead protrusion for this component was kept constant over the three board thicknesses by mechanical manipulation of the pins within the plastic housing. Seven out of the twelve locations were populated. Only one tin lead finished component was populated per board. The remaining six were lead free finish.

QFP

Three QFP sizes were used in this board design. Pad layout included solder thieves with varying design based on lead count and pitch.

- 64 lead – 0.5mm pitch
- 80 lead – 0.65mm pitch
- 64 lead – 0.8 mm pitch

SOT

A total of twelve SOT-23's were placed on each board. The twelve were divided into two groups of six. One group was parallel to the direction of board travel while the other group was perpendicular to the direction of board travel.

Passive Resistors

A total of four banks of passives were assembled onto each board. Two sizes were used including 0805 and 0603. As with the SOT configuration, the two banks of 0805's and 0603's were designed parallel and perpendicular to the direction of board travel.

Equipment

A Vitronics Soltec Delta 6622 wave soldering machine was used to assemble the boards for Phase I. The wave soldering machine was configured with a dual head spray fluxer which was operated with a pump system and delivered each flux with specifically designed nozzles. The preheat technology and configuration for the three zones of preheat consisted of forced convection modules in the first two preheating zones and a calrod module in the last preheating zone. The wave configuration consisted of a chip wave and main wave. The chip wave is designed to deliver a turbulent flow of solder and the main wave is designed to deliver a laminar flow of solder. The nitrogen inerting system works on the blanketing concept and was operating at the following N_2 flow settings of 30,50, and 80 l/min.

Parameter settings for each subsystem were controlled as required by individual runs in the design of experiments. Further, all systems, including transport, were calibrated to deliver directly comparable outputs. ie, The flux amount delivered was calibrated by flux type and conveyor speed so that a low amount of flux delivered to a board traveling at slow or fast speed was identical regardless whether the water based no-clean flux or the alcohol based flux was utilized. This was accomplished by measuring the mass, volume, and through-hole penetration of flux delivered to the board at all potential experimental conditions.

All alloys were contained in individual solder pots that were switched out as needed to complete the DOE. This was done in order to eliminate any possible cross contamination issues.

Design of Experiment

The goals of Phase I include ascertaining the relationship or influence of various parameters on the formation of defined defects; derivation and confirmation of an optimized process for each lead free alloy and board thickness. The team selected the Taguchi methodology to achieve these goals. During the development of the experiment, a number of process parameters and materials were of interest, based on the perspective of various industry segments. Ultimately a consensus was reached with eight parameters and materials placed into the inner array at three levels. This is listed in Table 2. The four alloys and two board finishes were placed in the outer array.

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	Water	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)

Table 2. Definition of Parameters and Materials Used for the Inner Array.

A Taguchi L18 orthogonal array, listed in Table 3, was required for this set of materials and process parameters. The L18 was executed for each individual alloy and board finish resulting in a total of eight separate but comparable sets of data. Three replicates were assembled for each run. The run order was determined by minimizing the time required between runs to complete the various parameter changeover.

The specific values of preheat temperature and flux quantity used in each run are based on the flux manufacturer's specification. Low and high settings are near the respective min and max of the recommended values and the medium setting is midway between to the two.

The criteria used to determine the optimized process is based on the characterization of the through-hole penetration as per IPC 610D Class 3 or 75% hole-fill. The target was also consistent for desired hole of 100%. Hole-fill was determined by 5DX laminographic analysis. Other defects such as shorts, solder balling, skips, and also solder shrinkage were visually characterized but not included in determining the optimized process.

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

Table 3. The Taguchi L18 Experiment Listed by Actual Run Number.

Profiles

Characterization of the temperature profile and contact time was accomplished by using the ECD Mole© profiler and the ECD WaveRider©. Similar to the flux calibration, contact time and preheat temperature were adjusted accordingly to ensure that the three levels of preheat and contact time were identical for each board thickness. Figure 4 illustrates a typical profile used to quantify topside preheat temperature and peak temperature on the Skate test vehicle.

Analysis

Various forms of analysis were employed in Phase I. The reporting in this research is based on visual characterization of shorts and skips as well as x-ray analysis of hole-fill.

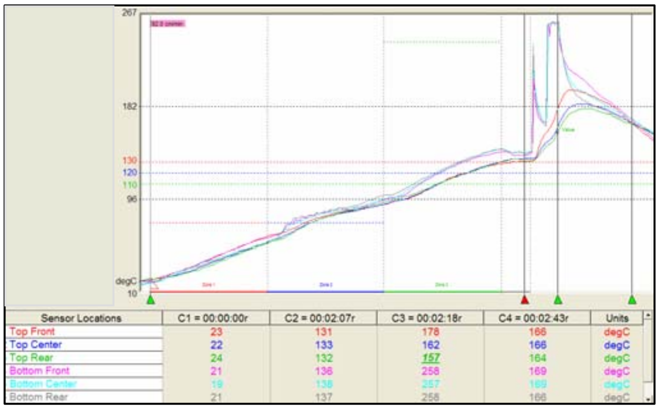

Figure 4. Typical Lead Free Wave Profile.

5 DX X-Ray Analysis

Hole-fill was determined by using a programmed Agilent 5DX x-ray instrument. The data collection of barrel hole-fill was based on quarter percentiles as illustrated in Figure 5. The types of defects observed are illustrated in Figure 6. For the purposes of optimizing the process, only defects at the 75% hole-fill or the top quartile were processed. However, increased sensitivity to process variations was provided by defects occurring at the various levels. Theis measurement was made on both the Berg Stick and PCI connectors.

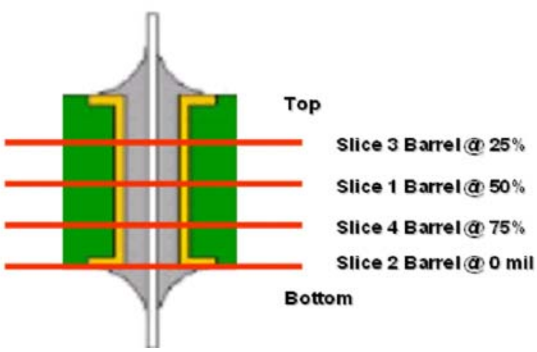

Figure 5. 5DX Analysis of Through-Hole Penetration Based on 25% Increments from Bottomside.

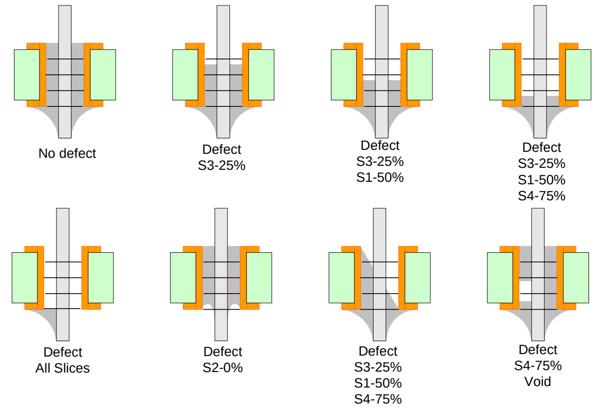

Figure 6. Data Reporting Scenarios for Through-Hole Penetration Based on 5DX Analysis.

Cross Sectioning

Select samples were cross sectioned to perform various analyses including hole-fill, barrel integrity, board integrity, and intermetallic formation. The procedure used to make these cross sections has been documented previously.[5]

RESULTS AND DISCUSSION

The execution of Phase I included the fabrication of the test vehicle, applying the correct finish onto the defined board thicknesses, procurement of the components, surface mount assembly and glue cure, flux procurement, and equipment setup. Once this was in place, a total of 324 boards were assembled per the Taguchi L_{18} orthogonal array experiment. The boards were visually inspected on site, followed by further inspection by professionally trained inspectors at an EMS, and then sent for the characterization of through-hole solder penetration by 5DX. As explained in the Experimental section, the criteria employed to determine the output response was hole-fill greater than 75%. In Table 4, the results of x-ray analysis are provided for SAC 305 on CuOSP and HASL finished boards. The same procedure was performed on the SACx and Sn100C runs.

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

Table 4. Through-Hole Penetration Defect Reporting for SAC 305 on CuOSP and SAC305 HASL.

The defect data provided is the average number of defects per board as measured by 5DX. It is interesting to note that there are three runs which resulted in no defects while two runs resulted in hundreds of defects. The remaining runs are distributed between 1 defect and 80.3 defects. This provided the team with the distribution of data points that allows for a statistically significant determination of both process interaction and optimization. Figures 7 and 8 chart the influence of the eight inner array parameters on through-hole solder penetration for CuOSP and SAC305 HASL finished boards, respectively. A lower y-axis value represents fewer through-hole defects.

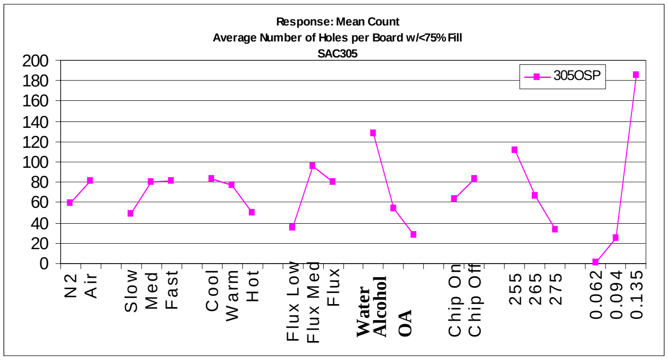

Figure 7. Response Chart for the Eight Inner Array Parameters Influence on Through-Hole Solder Penetration for SAC305 on CuOSP .

The behavioral analysis for the eight parameters on through-hole solder penetration for CuOSP finished boards is characterized by both linear or first order interactions except for flux amount which peaks at the medium amount. Based on this response chart, the optimized process is readily identifiable. The derived optimized process for best through-hole penetration for SAC 305 on CuOSP is:
Atmosphere: nitrogen
Transport Speed: 3ft/min
Flux type: OA
Flux amount: low
Preheat temperature: 130°C
Chip Wave: On
Pot Temperature: 275°C
Board Thickness: 62 mil

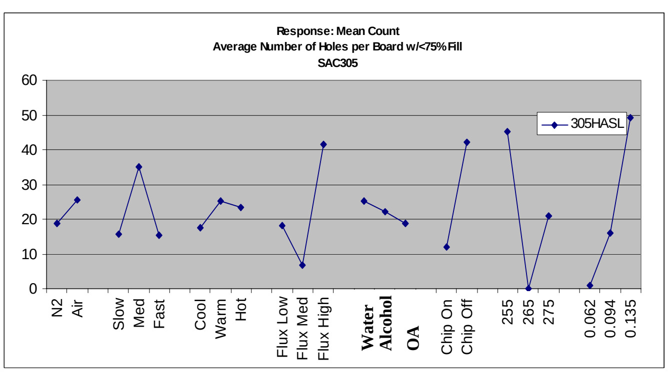

Figure 8. Response Chart for the Eight Inner Array Parameters Influence on Through-Hole Solder Penetration for SAC305 on SAC305 HASL.

The same analysis was performed for SAC305 on SAC305 HASL finished boards. As shown in Figure 8, the optimized process for best through-hole penetration varies to an extent compared to results on the CuOSP finished boards. The derived optimized process for best through-hole penetration for SAC 305 on SAC 305 HASL is:
Atmosphere: nitrogen
Transport Speed: 3ft/min or 6ft/min
Flux type: OA
Flux amount: medium
Preheat temperature: 90°C
Chip Wave: on
Pot Temperature: 265°C
Board Thickness: 62 mil

The intent of Phase I was to develop and confirm an optimized process for three lead free alloys and on varying board thickness and board finish. Furthermore, the team regarded as a priority, developing a process that most resembled the majority of typical assembly methods utilized by project members. Based on this, it was not possible to select one board thickness or OA flux. The team elected to confirm the statistical model by soldering all board thicknesses with the no clean alcohol based flux.

Table 5 lists the derived optimized processes for the three lead free alloys. The only difference listed is the required topside preheat temperature of SAC305 versus both Sn100C and SACx. The former requires a temperature of 130°C versus 110°C for the two latter alloys.

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

Table 5. Derived Optimized Process for the Three Lead Free Alloys.

Confirmation of the derived optimized process is required to ensure that the design and results of the L_{18} Taguchi experiment are valid. Upon finalization of the optimized process, confirmation runs were performed on the original lot of boards. Due to the amount of time that passed between the executions of the original experiment to the confirmation runs, the stored boards had absorbed a significant amount of moisture that resulted in board outgassing during the wave process and thus created numerous defects. A second batch of confirmation runs were then performed on boards that were baked at 125°C for a minimum of 24 hours in a high purity pure nitrogen atmosphere. Only HASL boards were utilized in the confirmation run since the OSP finish was compromised.

Completion of the confirmation runs for each lead free alloy was successful after taking the proper precautions and PWB conditioning. Through-hole solder penetration was then measured using the same technique and criteria as in the analysis described for the L_{18} experiment.

Table 6 provides the defect results for through-hole solder penetration as a function of alloy and board thickness as measured on all Berg Stick locations.

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

Table 6. Through-Hole Solder Penetration Defect Count for HASL Boards Assembled at the Optimized Settings.

The derived optimized wave soldering process for the three alloys were confirmed based on defect free soldering for the 62 mil and 93 mil thick boards. The 135 mil thick boards had minimal instances of less than 75% hole-fill for each of the alloys. Overall, it is possible to conclude that the L_{18} Taguchi experiment was successful in providing the data needed to develop an optimized process for a variety of materials including flux type, alloy type, and board thickness. The information gathered in Phase I will be used in the development of a fixed soldering process for Phase II in which the focus is not process optimization but solder joint performance.

GENERAL OBSERVATIONS AND TRENDS

Over the course of Phase I, a number of challenges had to be addressed and solved in order to meet the stated goals. This section provides some insight into various industry questions, challenges, and wave soldering assembly defect trends.

Impact of Component Design on Through-Hole Solder Penetration

Although the Skate test vehicle only had two types of through-hole connectors, sourcing the PCI connector with varying lead lengths was not possible. As a result, the PCI connector lead protrusion changed as a function of board thickness to the extent that no lead protrusion was observed on the 135 mil thick card. Figures 9A-C illustrate the challenges encountered with lead protrusion on the PCI connector. A direct correlation was observed between through-hole solder penetration and lead protrusion. An inverse relationship exists wherein as the lead protrusion decreases, defects increase.

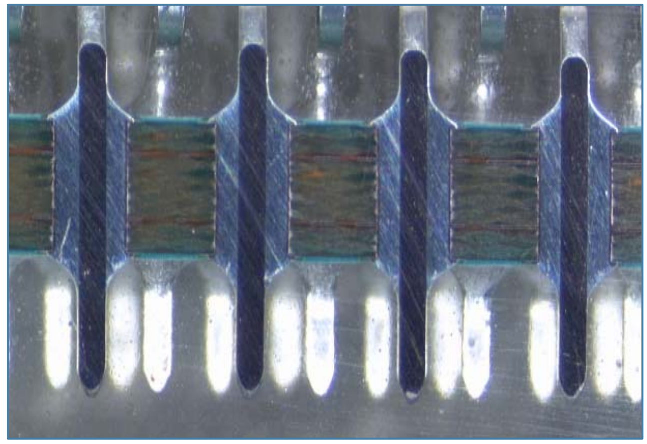

Figure 9A. PCI Lead Protrusion on the 62 mil Thick Card.

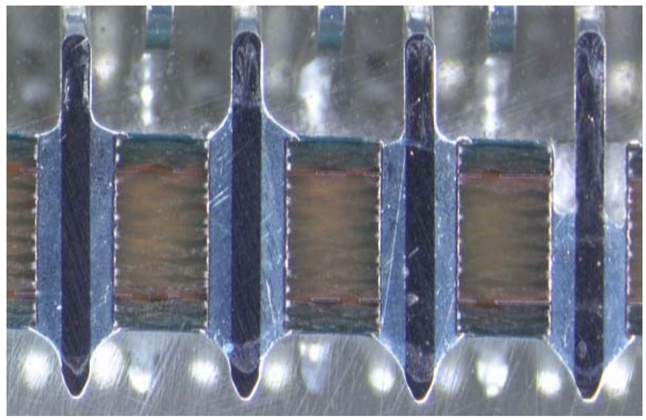

Figure 9B. PCI Lead Protrusion on the 93 mil Thick Card.

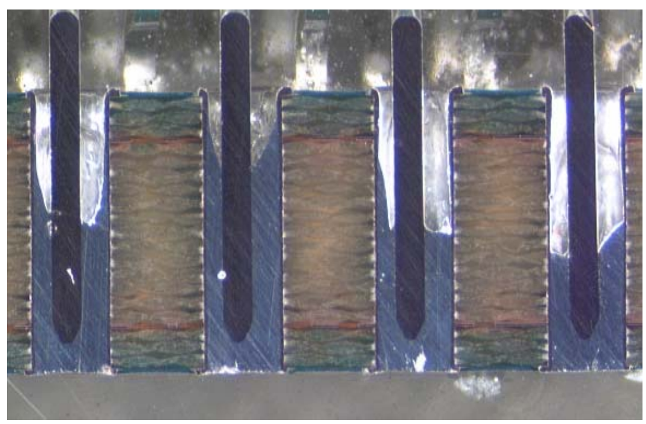

Figure 9C. PCI Lead Protrusion on the 135mil Thick Card.

Impact of Board Construction on Through-Hole Penetration

The Skate test vehicle was designed with specific barrel tie-ins consisting of varying amounts of copper as defined in Figure 3. This investigation collected and analyzed the impact of copper connection to through-hole solder penetration. Figures 10A and 10B illustrate the impact of a marginal wave soldering process on through-hole solder penetration. Figure 10A provides a topside view of the PCI connector through-holes which is visible to the inspector while Figure 10B provides the cross sectional view which allows one to measure actual hole fill. Moreover, the influence of copper tie-ins to the barrel is observed in one of the L_{18} runs. In these images the barrel construction is described from left to right as short spoke on wagon wheel, no connection, long spoke on wagon wheel, and direct connection.

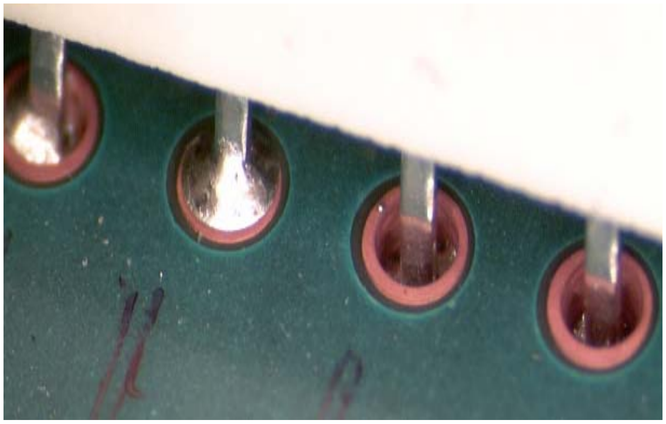

Figure 10A. Visual Inspection of Specific Through-Hole Vias.

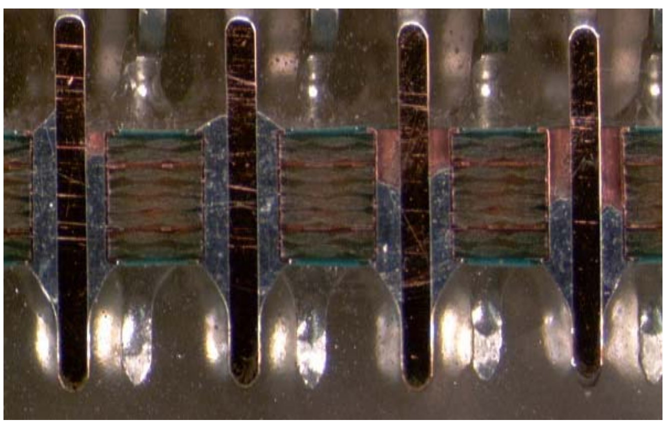

Figure 10A. Cross sectional view of Specific Through-Hole Vias.

In the cross sectional view it is possible to determine that the long spoke wagon wheel (third from the left) and direct connection (fourth from the left) have less then 75% through-hole penetration. This behavior was observed regardless of alloy or board finish and is mainly dependent on two factors: the wave soldering process and board complexity/construction.

Impact of QFP Pitch on Bridging

Based on the visual inspection data collected after the assembly of the 324 boards, it was possible to determine some empirical trends on QFP bridging. Figures 11A and 11B illustrate two instances of shorts occurring on a QFP.

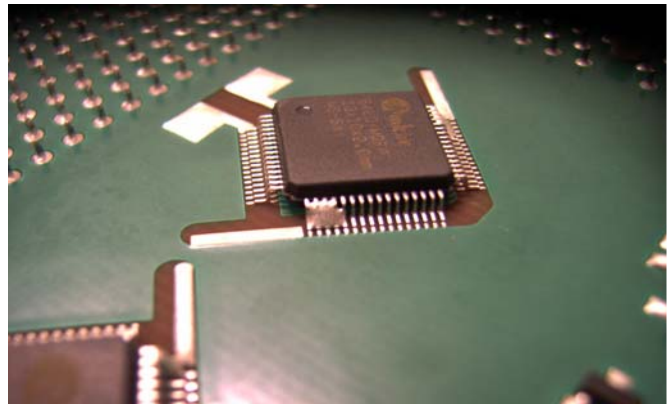

Figure 11A. A Five Pin Short on the 0.5mm QFP

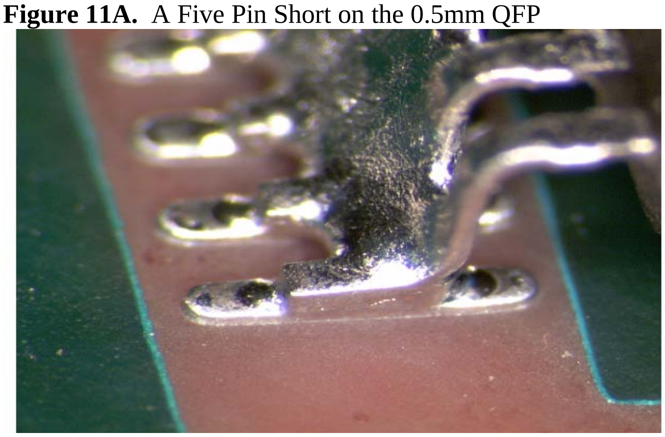

Figure 11B. Closeup of Multi-lead Bridging on a QFP.

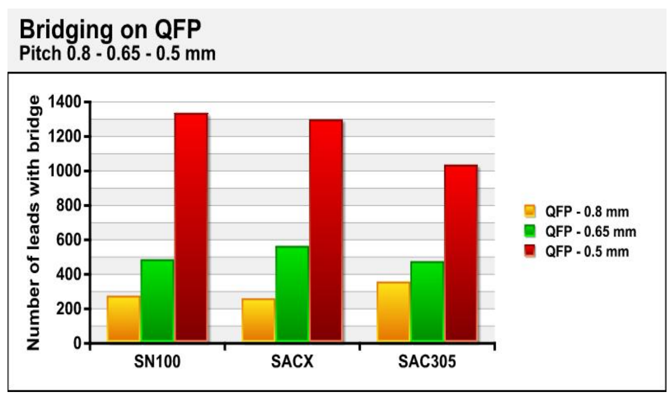

Table 7. Relationship of Bridging to QFP Lead Pitch and Alloy.

The analysis of the bridging occurrence clearly provides the challenge one has in assembling QFP's with pitches less than 0.65mm. All alloys were characterized by greater than 1000 leads with bridges on the 0.5mm pitch QFP. Comparison between alloys is less definitive since it is observed that each alloy performed equal to or better than the other two for different QFP's.

Impact of Board Layout on Skips

The Skate test vehicle component layout included surface mount components aligned parallel and perpendicular to the direction of the board over the wave. In addition, the DOE inner array design focused on the utilization of the turbulent flow chip wave. Analysis of the visual data collected on skips in the area of SOT-23's, as shown in Figure 12, provides insight into which parameter(s) are most critical in minimizing skips. As listed in Table 8, the single most important parameter is the use of the chip wave. The turbulent solder flow penetrates the areas of the component lead/pad that are biased against proper wetting. Thus allowing for a proper joint to form.

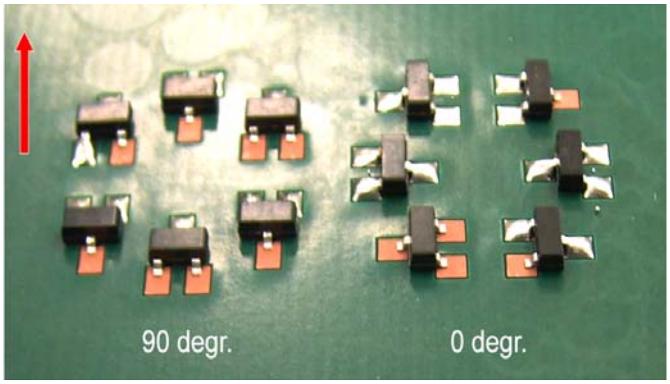

Figure 12. Board Layout as Per IPC and Contrary to IPC Design Guidelines.

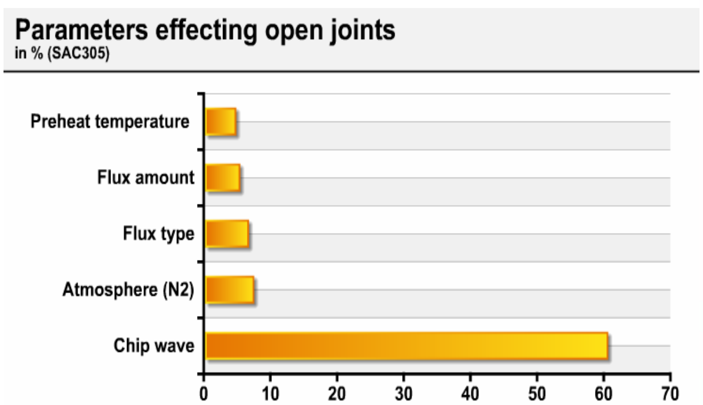

Table 8. The Influence of Process Parameters on Minimizing Skips.

CONCLUSION

This research provides insight into several of the key questions and challenges observed in today's lead free wave soldering process. The iNEMI lead free wave soldering team embarked on a multi-tiered project that focuses specifically on two aspects: Identifying the impact of critical parameters on the development of a reliable, robust lead free wave soldering process and determining the process that achieves the optimized soldered joint.

It is clear that in order to achieve the optimized lead free wave soldering process one must identify component features, board finish and thickness, flux type and specifications, alloy and alloy composition, its melting behavior, wave equipment capacity and power requirements, profile attributes and flexibility.

This collaborative effort investigated process parameter and material impact on the soldering process and joint formation. All types of solder joints were produced ranging from highly oxidized, not solder-able surfaces as illustrated in Figure 13 to the optimum solder joint in Figure 14.

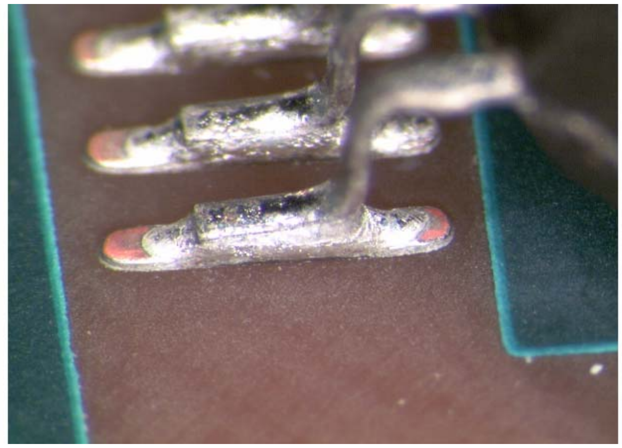

Figure 13. Poor Wettability Resulting in Unacceptable Joints.

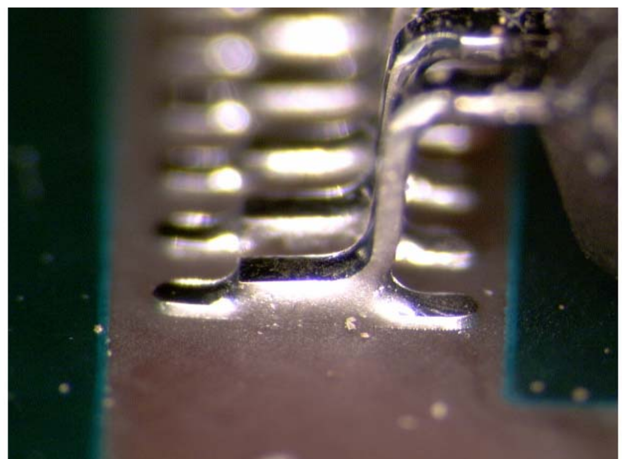

Figure 14. Perfectly Formed Joints.

Addressed in this study are inspection criteria, failure definition and measurement, followed by root cause analysis and ultimately optimized process confirmation. The result of this investigation was to lay the foundation of a broader effort to characterize the performance of through-hole solder joints on a test vehicle specifically designed for testing the norms of tin lead wave soldering.

Overall, this investigation looks to bring an understanding of how critical wave soldering parameters influence the various outputs. It also attempts to provide the reader with the information necessary to make educated decisions in selecting materials and controlling various process parameters in order to execute a rational implementation strategy for a reliable and robust lead free wave soldering process.

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