Testing Results for Lead-Free PWB's by the Massachusetts Lead-Free Electronics Research Consortium

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Abstract

The world-wide movement to phase out lead from electronic products presents many challenges for companies throughout the electronics supply chain. University of Massachusetts Lowell has brought together eight Massachusetts firms to collaborate on the manufacture and testing of lead-free printed wiring boards. The results of the first set of experiments showed that zero-defect soldering is achievable with lead-free materials. Test factors included: solder alloys (Sn/Ag/Cu, Sn/Ag, Sn/Bi), PWB surface finishes (OSP and ENIG), thermal profiles (soak and linear with various times above liquidus) and reflow environments (air and nitrogen). Following thermal cycling, the boards were visually inspected and the leads were pull tested. The results of pull testing indicated that there is no significant degradation of solder strength after 2000 hours of thermal cycling using the profile in Figure 1. In addition, all conditions examined in the lead free experiments exhibited better reliability (in the form of higher value lead pull strengths) than the leaded solder baseline

A follow-on design of experiments stage was created and a second set of test PCBs with a wide variety of components and finishes were manufactured. The goal of this stage was to leverage new developments in the field and to further investigate conditions of various lead-free manufacturing processes. Three solder pastes based on the NEMI recommended Sn/Ag/Cu solder alloy were used with five commonly available surface finishes, and reflowed using either air or nitrogen. Visual inspection has been completed and reliability testing is underway. Reliability data will be available when completed.

Introduction

The world-wide movement to phase out lead from electronic products presents many challenges for companies throughout the electronics supply chain. Because lead is integral to the integrity and reliability of electronic products, it is necessary to make changes carefully, and with the full participation of all parts of the product supply chain. The University of Massachusetts Lowell and the Massachusetts Toxics Use Reduction

Institute have brought together several key companies in the Commonwealth to form a research consortium to investigate lead-free manufacturing.

This paper provides some background on the drivers for lead-free electronics and the approach being taken in Massachusetts. The Massachusetts Lead-Free Research Consortium's testing program and results are then presented. The first phase of testing was completed in 2001 and the results are summarized. For the second phase of testing which is currently underway, the testing program and variable matrix will be described and visual test results discussed.

Drivers for Change

In January, 2003, The European Union published Directives 2002/96/EC on Waste Electrical and Electronic Equipment (WEEE) and 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS). These emerging directives have been the primary driver for global movement toward lead-free electronics. The RoHS prohibits products that contain lead to be sold in the EU after January, 2006, unless the use is specifically exempted.

The second major influence has been the movement of electronics manufacturers, particularly Japanese companies, toward "green products." JEIDA, the Japanese Electronics Industries Association, developed a lead-free roadmap in 1998, and many firms have set targets for elimination of lead in their products, and have selected lead-free products already on the market.

In each case, suppliers must develop, test, and be able to ensure performance of lead-free components and assemblies for manufacturers of electronic products. The short timeframe for these changes requires a coordinated effort of all firms in the electronics supply chain, from manufacturers of basic materials and components, to assemblers and OEMs. In order to achieve the goal of an environmentally safer product life cycle, the supply chain also needs to include those that will "close the materials loop" – the recyclers.

The WEEE directive challenges electronics manufacturers to think in a fundamentally different way about their products and the materials they use, requiring both recycling at a product's end of life, and inclusion of recycled materials in new products. This, together with the required development of new materials that don't contain lead, cadmium, and other substances of concern, presents an opportunity for industry to design products that conserve resources and are safer for humans and the environment throughout their life cycle.

Massachusetts Lead-Free Research Consortium

The Massachusetts Toxics Use Reduction Act (TURA) program has a mission to assist companies in reducing or eliminating the use of toxic substances where possible, and in reducing the amount of toxic waste generated. TURA also has a goal "to sustain, safeguard and promote the competitive advantage of Massachusetts businesses, large and small, while advancing innovation in toxic use reduction and management." These goals come together as we assist firms in meeting international materials restrictions on lead in electronic products.

The Toxics Use Reduction Institute (TURI) at University of Massachusetts Lowell (UMass Lowell) provides training and information, and conducts research in innovative technologies in support of toxics use reduction. In 1999, as the movement toward lead-free emerged, TURI began supporting research at UMass Lowell to investigate the feasibility of alternative solders. As this work progressed under the leadership of Dr. Sammy Shina, it was clear that substituting such a basic material as tin-lead solder would require the collaboration of many parts of the supply chain.

The Massachusetts Lead-Free Research Consortium was formed in 2000, consisting of at least one representative of each part of the supply chain. Members contribute time, materials, facilities, funding and expertise as they jointly develop and implement testing plans. Current consortium members are: M/A-COM/Tyco Electronics, Texas Instruments, Raytheon Company, Schneider Electric, BTU International, Air Products and Chemicals, Analog Devices, UMass Lowell and TURI.

In addition to supporting the consortium, TURI periodically brings together firms from the electronics supply chain to exchange information, to communicate the latest technical and regulatory developments, and to report out on the consortium's research program (for summaries of workshops, presentations, and technical papers, see TURI's web site: www.turi.org).

Summary of First Round of Testing

A preliminary round of testing compared 95.5Sn-3.8Ag-0.7Cu and 96.5Sn-3.5Ag with high, medium and low solids (residue) fluxes, ramp and soak versus linear ramp reflow profiles and a high versus low peak reflow oven temperature (250 vs. 230 °C with 60 seconds above liquidus for the ramp and soak and 235 vs. 225 °C with 90 – 120 seconds above liquidus for the linear ramp profile). The Design of Experiments results showed that flux was the most critical factor for reducing visual defects with high solids content providing the most protection. The linear profile with the 235 °C peak produced the fewest number of visual defects. Optimal results were obtained using these two conditions with the Sn-Ag-Cu solder alloy. It was also determined that the linear profile approach decreases the process window requiring tighter controls but used less energy and thus is more cost effective.

The first round of testing examined the effects of different lead-free solders (95.5Sn-3.8Ag-0.7Cu, 96.5Sn-3.5Ag, and 57Sn-43Bi) and their interactions with board surface finish (ENIG - Electroless Nickel-Immersion Gold and OSP – Organic Solder Preservative), atmosphere (air versus nitrogen), reflow profile (ramp and soak versus linear ramp), and time above liquidus (TAL) of (60, 90 120 seconds) on visual defects and on solder joint pull-test strength as reflowed and after thermal cycling. Thermal cycling used the profile shown in figure 1.[11]

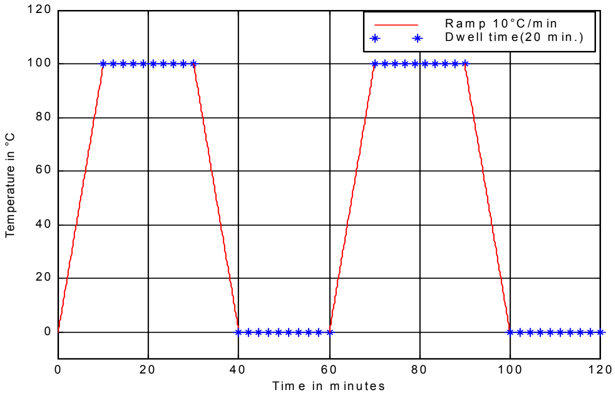

Figure 1. Thermal Profile for Reliability Testing of Lead free Soldering

A tin-lead eutectic control set of PCBs was run on OSP and ENIG finished boards in both air and nitrogen to provide baseline data for comparison with lead free reliability results obtained from pull tests.

Several of the combinations yielded visual defect free results. Table 1 shows these.

Table 1. Conditions for Defect free and lead fee soldering materials and processes.

.Paste	**S. Finish**	**TAL**	**Soak**	**Nitrogen**
Sn/Ag/Cu	***ENIG***	90sec	**No**	yes
Sn/Ag/Cu	***ENIG***	***120sec***	**Yes**	yes
Sn/Ag	***ENIG***	**60sec**	**Yes**	yes
Sn/Ag	***ENIG***	90sec	**No**	yes

There were no solder joint failures throughout the entire 2000 thermal cycles test. Pull tests resulted in the following observations:

- Solder paste composition was the most significant factor with Sn-Ag-Cu yielding the highest strengths and Sn-Bi the lowest.
- OSP PWB finish yielded slightly higher pull strengths, perhaps due to gold-tin intermetallic formation.
- Slightly higher strengths were achieved with the linear ramp profile.
- Strength increased after thermal cycling, as indicated by conventional wisdom, due to changes in the inter-metallic composition of the copper migrating through the alloy towards the components.

Figure 2 summarizes the pull test results with respect to the minimum pull strengths observed.

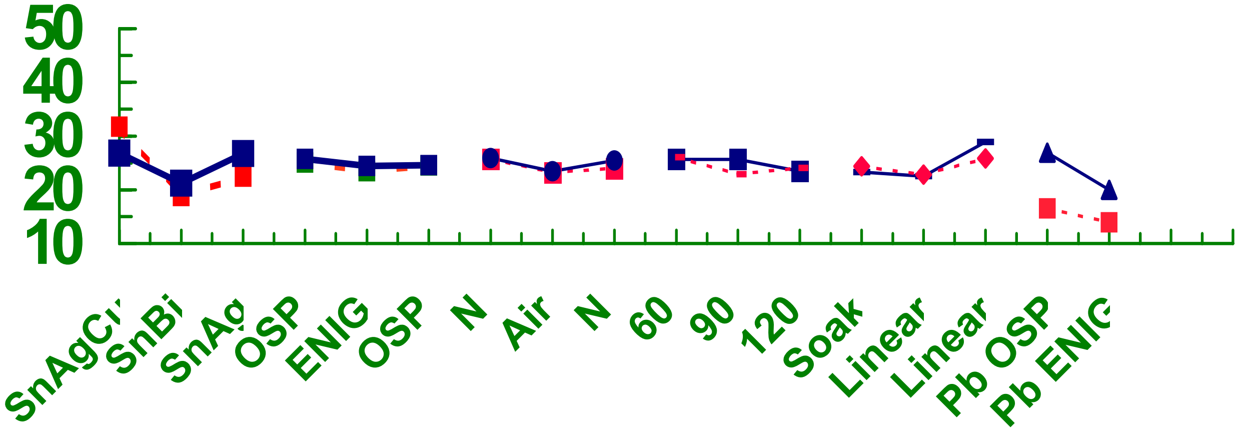

Figure 2. Minimum Pull strengths (Newtons) versus factors showing before (solid line) and after cycling (dashed line).

Experiment Matrix for Second Phase of Pb-free Testing.

Experimental Design Matrix

A designed experiment was developed with the following variables:

1. PWB Finishes – Five Treatments– Solder Mask Over Bare Copper with Hot Air Solder Leveling (SMOBC/HASL), Matte Finish Tin (Sn) Electroplate, Immersion Silver (Ag), Organic Solder Preservative (OSP), and Electroless Nickel Immersion Gold (ENIG).
2. Reflow Atmospheres – Two Treatments – Air and Nitrogen.
3. Solder Pastes – Three Treatments – all with the same alloy composition – 95.5Sn-3.8 Ag-0.7Cu (NEMI recommended) from three different vendors, all incorporating no-clean fluxes.
4. Component Lead Finishes – Four Treatments – matte Sn plating, Tin/Silver/Copper, Nickel/Palladium/Gold, and Nickel/Gold.
5. Sn-Pb eutectic solder PWB using the solder treatments as control PWBs.

The Design matrix is shown in Table 2.

Table 2. 2nd Phase Experimental Design Matrix

Experimentation Matrix				
				(Two (2) Circuit Boards per Trial)
PWB	**PWB Finish**	**Solder paste**	***Reflow Atmosphere**	**Component Finish**
1	SMOBC/HASL	"A"	Air	Pb- free
2	SMOBC/HASL	"A"	Nitrogen	Pb- free
3	SMOBC/HASL	"B"	Air	Pb- free
4	SMOBC/HASL	"B"	Nitrogen	Pb- free
5	SMOBC/HASL	"C"	Air	Pb- free
6	SMOBC/HASL	"C"	Nitrogen	Pb- free
7	SMOBC/HASL	Standard Sn-Pb	Air	Sn-Pb Leads
8	OSP	"A"	Air	Pb- free
9	OSP	"A"	Nitrogen	Pb- free
10	OSP	"B"	Air	Pb- free
11	OSP	"B"	Nitrogen	Pb- free
12	OSP	"C"	Air	Pb- free
13	OSP	"C"	Nitrogen	Pb- free
14	OSP	Standard Sn-Pb	Air	Sn-Pb Leads
15	ENIG	"A"	Air	Pb- free
16	ENIG	"A"	Nitrogen	Pb- free
17	ENIG	"B"	Air	Pb- free
18	ENIG	"B"	Nitrogen	Pb- free
19	ENIG	"C"	Air	Pb- free
20	ENIG	"C"	Nitrogen	Pb- free
21	ENIG	Standard Sn-Pb	Air	Sn-Pb Leads
22	Matte Sn	"A"	Air	Pb- free
23	Matte Sn	"A"	Nitrogen	Pb- free
24	Matte Sn	"B"	Air	Pb- free
25	Matte Sn	"B"	Nitrogen	Pb- free
26	Matte Sn	"C"	Air	Pb- free
27	Matte Sn	"C"	Nitrogen	Pb- free
28	Matte Sn	Standard Sn-Pb	Air	Sn-Pb Leads
29	Ag	"A"	Air	Pb- free
30	Ag	"A"	Nitrogen	Pb- free
31	Ag	"B"	Air	Pb- free
32	Ag	"B"	Nitrogen	Pb- free
33	Ag	"C"	Air	Pb- free
34	Ag	"C"	Nitrogen	Pb- free
35	Ag	Standard Sn-Pb	Air	Sn-Pb Leads

*Nitrogen was supplied by Air Products and Chemicals and contained 50 ppm Oxygen for these experiments.

As seen, all test PWBs were run versus the standard 63Sn-37Pb eutectic, no-clean solder as a control. Package types included several SOICs, a FPQFP, an MLP, a BGA, a ceramic SOIC, and chip capacitors and resistors.

The test PWB was laid out at M/A-COM taking into account daisy chain resistance test capabilities in some of the parts and fabricated by Sanmina-SCI with the five different finishes. Pastes were obtained from three vendors and a reflow profile was developed based on the manufacturers' product data sheets. A reflow profile board was populated with parts and three K-probe thermocouples (TC) were attached to the surface. One TC was attached at the leading edge of the PWB, one at the lead attach area of a large QFP and one near the trailing edge. The thermocouples were connected to an industry standard data logger. The thermal readings were downloaded to the data collector software for comparison to the manufacturer recommended profiles. All three manufacturers recommended a 'ramp to spike' curve. Several runs were performed to ensure consistent performance. The reflow profile used for all three Pb-free solders is shown in Figure 3.

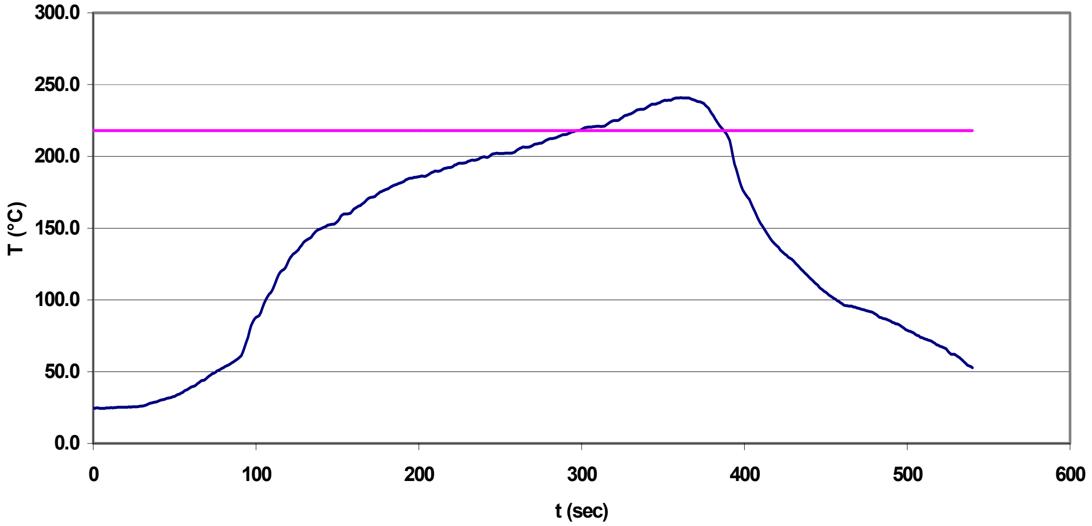

Figure 3. Reflow Profile for SMT Board Assembly

Solder paste prints were made using a 0.006” thick stainless steel laser cut, electropolished stencil. Ten percent aperture reductions were used on the fine pitch devices. PWBs were assembled at Schneider Electric on their assembly line consisting of an MPM AP-25 screen printer, Siemens S20 and F5 placement equipment and a BTU Pyramax 98N Reflow Oven with Air and Nitrogen capability supplied by BTU International for this experiment. The Schneider plant maintains a Relative Humidity (RH) level between 35-40%.

After reflow, boards were packaged in ESD bags and taken to M/A-COM where two University of Massachusetts – Lowell senior students visually inspected the solder joints based on training by a certified IPC inspector / trainer. Inspection criteria were established as follows: Total Defects, Cold Solder joints, Non-wetting, Solder Balls, Dewetting, Bridging, Pinholes, Shiny Appearance, Smooth Appearance, and Flux Residue. X-ray radiography of the BGA solder joints was also performed. Initial inspection data has been tabulated and statistically analyzed by University of Massachusetts – Lowell and Air Products. To date Board Finish, Atmosphere, and paste (A, B, C) have been analyzed. Work is in progress on lead finish and component type.

Results and Discussion to Date - Key Issues/Observations for Lead-Free Reliability

Results - Assembly Process

The major difficulties encountered in assembly were with stencil printing and placement system vision. In spite of using print parameters close to those in the application notes supplied for the three pastes, paste A had a tendency to adhere to the sides of the stencil openings. This resulted in scant prints on some of the fine pitch apertures. Paste B clogged the stencil necessitating cleaning after every four or five prints. Paste C performed as expected with little difficulty. All three pastes exhibited good tack or component holding qualities during and after placement. Vision problems were associated with the Sn-Pb version of the BGA. The difference in appearance (reflectivity) of the Sn-Pb spheres caused the vision system (programmed for the Pb-free spheres) to reject many of the Sn-Pb BGAs. These had to be placed by hand which may affect some results.

Visual Defects - Statistics

Eight main categories of common defects were selected and all boards were inspected. Those defects observed were photographed and recorded into a spreadsheet. After statistical analysis the following significant effects were determined (all shown by the letter Y and a number indicating the rank starting with 1 being the most significant) are shown in Table 3 including interactions of various factors. Individual factor average defect analysis is shown in Tables 4 – 6 as well as an analysis of visual defect types.

Table 3: Statistically Significant Effects Summary

	Main Effects			2 Factor Interactions			3 Factor Interaction
Property	Finish	Paste	Atmosphere	Finish*Paste	Finish*Atmosphere	Paste*Atmosphere	Finish*Paste*Atmosphere
Total Defects	Y - 3	Y - 2	Y - 1	N	N	Y	N
Cold Solder Joining	Y - 3	Y - 2	Y - 1	N	N	Y	N
Nonwetting	N	Y - 2	Y - 1	N	N	N	N
Solder Balls	Y	N	N	N	N	N	N
Dewetting	N	N	N	N	N	N	N
Bridging	Y	N	N	N	N	N	N
Pin/Blow Holes*	N	N	N	N	N	N	N
Shiny**	Y - 1	Y - 2	N	N	N	N	N
Residue**	N	Y - 1	Y - 2	N	N	N	N
Smooth**	N	N	N	N	N	N	N

Table 4: Atmosphere Results Summary

	Atmosphere	
Property	Air	Nitrogen
Total Defects	**150.30**	**6.00**
Cold Solder Joining	**102.70**	**1.10**
Nonwetting	**33.30**	**1.60**
Solder Balls	9.07	2.83
Dewetting	5.10	0.43
Bridging	0.13	0.03
Pin/Blow Holes*	0.00	0.00
Shiny**	0.63	0.43
Residue**	**0.83**	**0.47**
Smooth**	0.80	0.97

Nitrogen reflow atmosphere was shown to be significant in total defects, cold solder joints, non-wetting and residue generated.

Table 5: Pb-Free Paste Results Summary

	Pb-Free Paste		
Property	B	A	C
Total Defects	**11.35**	**171.25**	**51.90**
Cold Solder Joining	**0.20**	**137.45**	**18.10**
Nonwetting	**2.60**	**20.25**	**29.50**
Solder Balls	8.00	6.35	3.50
Dewetting	0.50	7.15	0.65
Bridging	0.05	0.05	0.15
Pin/Blow Holes*	0.00	0.00	0.00
Shiny**	**0.80**	**0.30**	**0.50**
Residue**	**0.85**	**0.70**	**0.40**
Smooth**	0.95	0.90	0.80

A statistically significant Paste effect means that one or more of the pastes studied differ significantly from each other in terms of the type and / or number of defects generated. Significance is noted with bold numbers

Table 6: Board Surface Finish Results Summary

Property	Finish ENIG	Imm. AG	Matte Sn	OSP	SMOBC/HASL
Total Defects	**20.42**	**29.67**	**62.92**	**107.58**	**170.25**
Cold Solder Joining	**5.83**	**13.83**	**43.75**	**101.75**	**94.42**
Nonwetting	7.75	13.42	6.50	3.50	56.08
Solder Balls	**6.08**	**2.00**	**1.33**	**1.67**	**18.67**
Dewetting	0.75	0.42	11.33	0.67	0.67
Bridging	**0.00**	**0.00**	**0.00**	**0.00**	**0.42**
Pin/Blow Holes*	0.00	0.00	0.00	0.00	0.00
Shiny**	**0.17**	**0.75**	**0.50**	**0.67**	**0.58**
Residue**	0.83	0.58	0.42	0.67	0.75
Smooth**	0.83	0.92	0.75	0.92	1.00

A statistically significant Board Finish effect means that one or more of the surface finishes studied differ significantly from each other. Significance is noted with bold numbers

Legend for all Tables

* Pin/Blow Holes: No defects of this type were observed
** Qualitatively measured properties
Statistically significant effects are bolded and in blue.

As seen in Table 3, the two major defects observed were cold solder joints and non-wetting. All major variables impacted these two defects and a significant interaction effect between paste and atmosphere on cold solder joints was also observed. Solder ball defects were also impacted by board finish. Some variables also had a significant effect on the solder joint appearance with respect to shininess and flux residue. Since Pb-free solder is different in appearance, these were considered important for visual inspection criteria as well.

Figure 3 shows the main visual defect phenomenon observed. This appears to be a function of flux, reflow atmosphere, and paste volume. The small volume of paste and flux resulted in the flux being "spent" prior to reaching the reflow temperature. These images are of a very fine pitch print with paste A that exhibited some problems with adherence of the paste to the side-walls of the stencil, especially in small apertures such as these. Figure 4 shows the same sample on a larger pitch part where the paste / flux volume did not dry out or become "spent" prior to reflow.

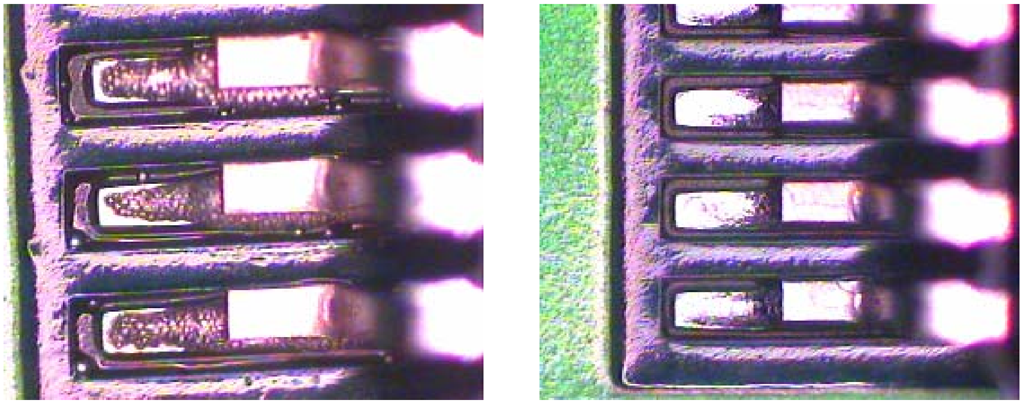

Figure 3. Left: Paste A reflowed in Air – Right: Paste A in Nitrogen - fine pitch print, Ni-Pd-Au lead – SMOBC-HASL.

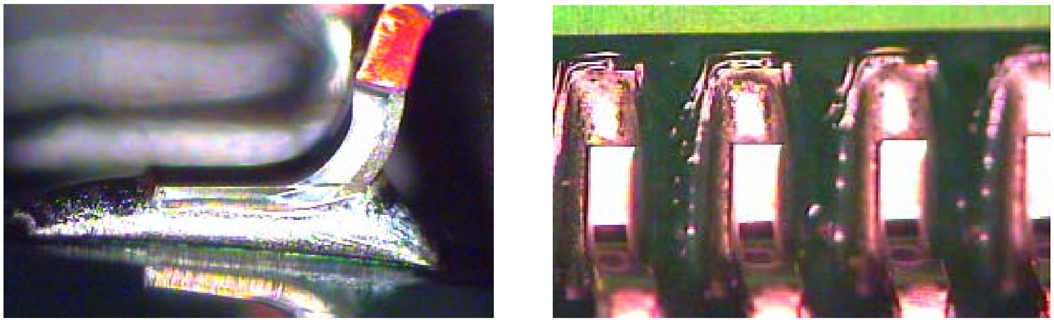

Figure 4. Paste A in Air, SOIC leads on the same board. Left: lead finish plated tin - Right: Ni-Pd-Au plated leads –SMOBC-HASL

Visual inspection, of course, does not tell the entire story. It is a good method of finding many defects but does not reveal weak solder joints, large internal voids, or many BGA solder joint defects. Moreover, the correlation between appearance and reliability has not been established for Pb-free solders, in the way that it has for Sn63 – type solders. This correlation will be explored during the continuation of this study.

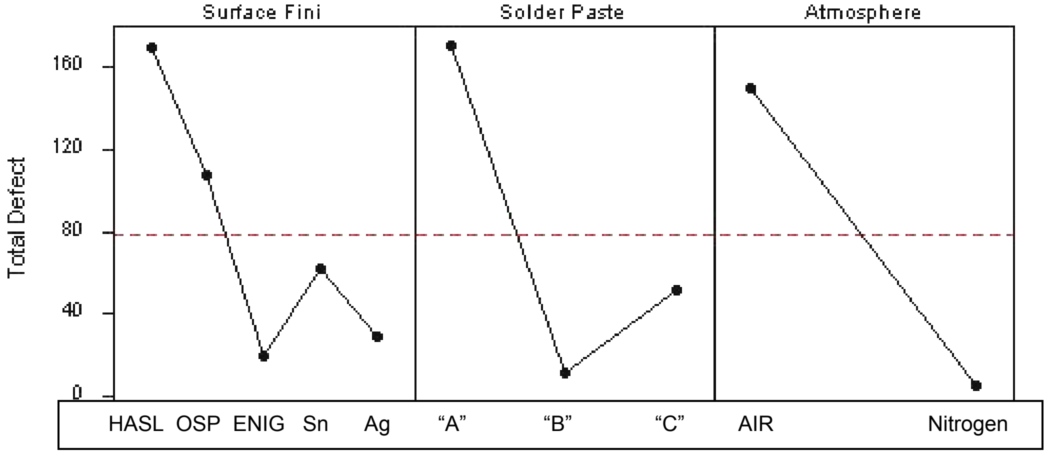

Figure 5. Defect Density versus Independent Variables

Based on Figure 5, ENIG, Paste “B”, and Nitrogen would be considered “winners” with Ag a close second for PCB finish. Within the confines of effect of these variables on visual defects / appearance issues this is correct. However, manufacturing cost issues were not addressed as part of the overall analysis. Nitrogen does cost more than using ambient Air so defect costs may have to be offset by Nitrogen costs. Electroless nickel used in ENIG has often been associated with “black pad” solderability defects (not an issue in this study) that may occur in some PWB assemblies. As noted above, paste B clogged the stencil requiring cleaning after every four or five prints and thus could have a large effect on throughput and other line costs.

As shown in Figure 3 above, paste A clung to the aperture walls during printing resulting in scant prints on fine pitch pads. The flux tended to flow during reflow ramp and soak. Therefore, it was not able to prevent the paste spheres from re-oxidizing before reflow with an inappropriate volume of paste. The paste under the lead did wet and flow, as did areas with more paste volume. Perhaps an experiment to develop a better stencil print would improve this result. The other alternative, Nitrogen, is more forgiving so this paste may be fine for larger pitch or when using Nitrogen for a reflow atmosphere.

For Figure 5, paste "C" had more defects, mainly in Air, but also gave a good print nearly every board. Further experiments may improve performance for all pastes, "C", "B", and "A". One must also consider that these pastes are not necessarily fully developed with good histories as Pb-free processing itself is still in its infancy.

Total Defect Analysis Results

Analysis provided by Tom Bzik of the Statistical Science Group and Air Products and Chemicals, Inc.

Table 7 - Statistical Analysis – Total Defects

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                    ANOVA for 0.35 Power Transformed Total Defect Data

                                   The GLM Procedure

Dependent Variable: Total Defect
                                              Sum of
       Source                      DF        Squares      Mean Square    F Value    Pr > F

       Model                       29     363.4838458     12.5339257       8.23     <.0001
       Error                       30      45.7076735      1.5235891
       Corrected Total             59     409.1915194

                       R-Square     Coeff Var      Root MSE       TD Mean
                       0.888298      43.38638      1.234338      2.844989

       Source                    DF      Type III SS     Mean Square    F Value    Pr > F

       Board Finish               4      44.6816022      11.1704005       7.33    0.0003
       Paste                      2      78.9621665      39.4810833      25.91    <.0001
       Atmosphere                 1     132.3624551     132.3624551      86.88    <.0001
       Finish*Paste               8      16.0395976       2.0049497       1.32    0.2735
       Finish*Atmosphere          4      15.2827444       3.8206861       2.51    0.0629
       Paste*Atmosphere           2      54.3289039      27.1644519      17.83    <.0001
       Finish*Paste*Atmosphere    8      21.8263762       2.7282970       1.79    0.1184
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As seen above, the ANOVA (Analysis of Variance) is significant for the overall experiment and for the variables highlighted with probabilities Pr less then .05.

Ryan-Einot-Gabriel-Welsch Multiple Range Test for Total Defects
(Board Finish)

Means with the same REGWQ Grouping letter (A, B) are not significantly different.

REGWQ Groupings	Mean	N	Finish
A	170.25	12	SMOBC/HASL
B	107.58	12	OSP
B			
B	62.92	12	Matte Sn
B			
B	29.67	12	Imm. AG
B			
B	20.42	12	ENIG

Interpretation: The PCB Finish level SMOBC/HASL significantly differs from all other finishes. No other finishes were found to be statistically different from one another at the 0.05 level.

Ryan-Einot-Gabriel-Welsch Multiple Range Test for Total Defects
(Paste)

Means with the same REGWQ Grouping letter (A, B, …) are not significantly different.

REGWQ Grouping	Mean	N	Paste
A	171.25	20	A Pb-Free
B	51.90	20	C Pb-Free
C	11.35	20	B Pb-Free

Interpretation: All Pastes were found to differ significantly from all other pastes. B Pb-Free performed best.

Ryan-Einot-Gabriel-Welsch Multiple Range Test for Total Defects
(Atmosphere)

Means with the same REGWQ Grouping letter (A, B, …) are not significantly different.

REGWQ Grouping	Mean	N	Atmosphere
A	150.33	30	Air
B	6.00	30	Nitrogen

Interpretation: Nitrogen preformed significantly better than Air.

Ryan-Einot-Gabriel-Welsch Multiple Range Test for Total Defects
(Paste x Atmosphere Interaction)

Means with the same REGWQ Grouping letter (A, B) are not significantly different.

REGWQ Grouping	Mean	N	Paste x Atmosphere Interaction
A	337.10	10	A Pb-Free with Air
B	98.70	10	C Pb-Free with Air
C	15.20	10	B Pb-Free with Air
C			
C	7.50	10	B Pb-Free with Nitrogen
C			
C	5.40	10	A Pb-Free with Nitrogen
C			
C	5.10	10	C Pb-Free with Nitrogen

Interpretation: The A Pb-Free, Air combination was significantly worse than all other combinations. The C Pb-Free, Air combination was significantly worse than all other remaining combinations. The bottom four combinations could not be told statistically apart from each other within the limitations of the current study.

Only in the case of solder paste B; it was shown that there is no significant difference between the use of Air or Nitrogen. However, as noted earlier this paste exhibited certain process issues relating to the cost of more frequently cleaning the stencil in the production process.

Part of this effort is to develop inspection criteria for Pb-free solder joints. Two items inspected for were shiny appearance and flux residue. Like other effects these may bear on each other. Flux residue is often glossy and may cause a joint to “look better” than a dry joint. This may be further confused with Air versus Nitrogen, as a joint with residue may have less of a tendency to oxidize while cooling than an unprotected surface.

There is considerable work to be done in terms of mechanical properties (lead pull, ball and chip shear), joint x-rays for voids and BGA flaws, and stress testing via thermal cycling (0 to 100 °C) followed by more mechanical testing. Further analysis on lead finishes also is in progress and requires this data.

Conclusions to Date

We have shown the effects of atmosphere, paste selection, and surface finish on visual appearance defects. While Nitrogen and paste “B” yielded the fewest defects and SMOBC – HASL was significantly worse as a surface finish, the assembly process was not optimized for any of the variable options. Further, throughput and cost can be significant issues that may override some of these results. Other data to be taken needs to be correlated with these findings to further clarify the effects of these variables on solder joint reliability and yield.. These data show it is possible to obtain visually acceptable solder joints using a variety of board finishes, lead finishes, paste formulations and Air/Nitrogen combinations. Visual inspection is often the only means of defect detection other than circuit testing, and the two often verify one another thus indicating a good Pb-free reflow process with high yield can be achieved. The TURI Lead-Free Consortium has demonstrated that Pb-Free SMT processing is feasible and can result in robust solder joints with a reasonable degree of experimentation on the process parameters, thus enabling Pb-free, environmentally responsible circuit assembly.

There is considerable work to be done in terms of mechanical properties (lead pull, ball and chip shear), joint x-rays for voids and BGA flaws, and stress testing via thermal cycling (0 to 100 °C) followed by more mechanical testing. Further analysis on lead finishes also is in progress and requires this data. The final report will present processing Considerations to ensure good reflow and assembly.

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References and Consortium Publications

1. Lead Free Electronics Workshop, hosted by Lucent technologies, Merrimack Valley Works, North Andover. MA, Tuesday April 13, 2000.
2. TURI continuing education conference, “TUR in Massachusetts: the Next Generation” on Tuesday April 25th 2000, Session, C2, the Lead Free electronics, at the Best Western Royal Plaza and Trade Center, Marlborough, MA.
3. State of Massachusetts Legislative committee on education policy, UMASS President Bulger’s Office, May 4th, 2000.
4. IMAPS New England, 27th annual symposium and exhibition, May 2000, Holiday Inn Conference Center, Boxborough, MA, session F, Surface Mount Technology.
5. CEAM /TURI Colloquy on University Research in Sustainable Technologies Program (URST) at UMass Lowell, June 2000
6. 2nd Workshop on Lead-Free Electronics, Technical Issues and Challenges in the Transition To Lead-Free Technologies, Thursday, June 29, 2000, at BTU International North Billerica, Massachusetts
7. Consortium authors, “Design Of Experiments For Lead Free Materials, Surface Finishes And Manufacturing Processes Of Printed Wiring Boards”, published by the SMTA International Conference at Rosemount trade center, Chicago, IL, September 2000
8. Consortium authors, “Design Of Experiments For Lead Free Materials, Surface Finishes And Manufacturing Processes Of Printed Wiring Boards”, published by the Chinese Electronics Association Journal
9. Consortium authors, “Selecting Material and Process Parameters for Lead Free SMT Soldering Using Design of Experiments Techniques”, Apex Conference, January 2001, San Diego, CA,
10. Consortium authors, “Reliability Testing Techniques For Lead Free Soldering Of SMT Technology”, ETRONIX Conference, Anaheim, CA, March 2001.
11. “Process and Material Selection for zero defects and superior adhesion Lead Free SMT soldering”, SMTA International Conference, Chicago, IL September 2001.
12. Shina, S., Six Sigma for Electronics Design and Manufacturing, McGraw-Hill, NY, 2002.