# Lead Free - Process, Reliability, and Options

Presented by
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# Project Team

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# Objectives

- Investigate whether a safe, reliable, non-toxic and cost effective substitute exist for Tin/Lead Solder in the electronics industry.
- Understand material properties for the selection of substitutes, and determine their compatibility with manufacturing processes and equipment.
- Develop roadmap towards lead free electronics manufacturing.

# Lead Free Drivers

- European Parliament and Council Directive on Waste Electrical and Electronic Equipment Directive (WEEE)
  - Bans lead from certain electronic applications by 2008
- Japan
  - Japanese Electronics Recycling Law - 2001
  - Forbids companies toxic elements that leach into landfills - 2/3rd reduction by 2004

# Lead-Free Materials

## Lead Free Solders Available:

| ALLOYS USED | MELTING RANGE (°C) | INDUSTRY SERVED | COMPANY |
|---|---|---|---|
| SnAg | 221 - 226 | Automotive | Visteon (Ford) |
| SnAgBi | 206 - 213 | Military/Aerospace | Panasonic |
| | | Consumer | Hitachi |
| SnAgBiCu | | Military/Aerospace | Panasonic (FA Controller?) |
| SnAgBiCuGe | | Consumer | Sony |
| SnAgBiX | 206 - 213 | Consumer | Panasonic |
| SnAgCu | 217 | Automotive | Panasonic |
| | | Telecommunications | Nokia |
| | | | Nortel |
| | | | Panasonic |
| | | | Toshiba |
| SnBi | 138 | Consumer | Panasonic |
| SnCu | 227 | Consumer | Panasonic |
| | | Telecommunications | Nortel |
| SnZn | 198.5 | Consumer | NEC |
| | | | Panasonic |
| | | | Toshiba |

(Source: IPC Roadmap 3rd draft.)

# Lead-Free Materials

## Lead Free Solders Reviewed and/or Recommended by Other Organizations:

| Organization | Alloys |
|---|---|
| NEMI | Sn0.7Cu |
| | Sn3.5Ag |
| | SnAgCu |
| NCMS | Sn3.5Ag |
| | Sn58Bi |
| | Sn3.0Ag2.0Bi |
| | CASTIN |
| | Sn3.4Ag4.8Bi |
| | Sn20In2.8Ag (Indalloy) |
| | Sn3.5Ag0.5Cu1.0Zn |
| ITRI | SnAgCu<br>Sn2.5Ag0.8Cu0.5Sb<br>Sn0.7Cu<br>Sn3.5Ag<br>SnBiAg<br>SnBiZn |

(Source: IPC Roadmap 3rd draft.)

# Lead-Free Materials

## Lead Free Surface finishes for molded components:

| Finish | Manufacturing Experience | Concerns |
|---|---|---|
| NiPd | Yes | Material cost (Process is cheaper; must switch 100%) |
| NiPdAu | Yes | Material cost |
| SnBi | No | The assembly must be totally Pb free. |
| Sn | Yes | Tin whiskers |
| SnCu | Yes | Tin whiskers |

(Source: IPC Roadmap 3rd draft.)

# Lead-Free Materials

## Lead Free Surface finishes for PWBs:

| Potential Lead free finishes: |
| --- |
| Organic Solder Protectants (OSP) |
| Lead-free Hot Air Solder Level (HASL) |
| Immersion Finishes |
| Electroless Nickle Immersion Gold (NiAu) |

(Source: IPC Roadmap 3rd draft.)

# Toxicity Ranking Alloys

Toxicity ranking of common lead free solder alloying elements based on a report published by the Surface Mount Council

Bi < Zn < In < Sn < Cu < Sb < Ag < Pb

# Lead Free-Research: Phase # 1

- Determine which fluxes , lead free alloys and reflow profiles have the greatest influence on solder joint quality in terms of: good wetting ability on board land patterns
  - **good fillets per J-Standard-001B**
  - **no solder balls**
  - **no solder splashes**
  - **no voids**

# Test Vehicle:

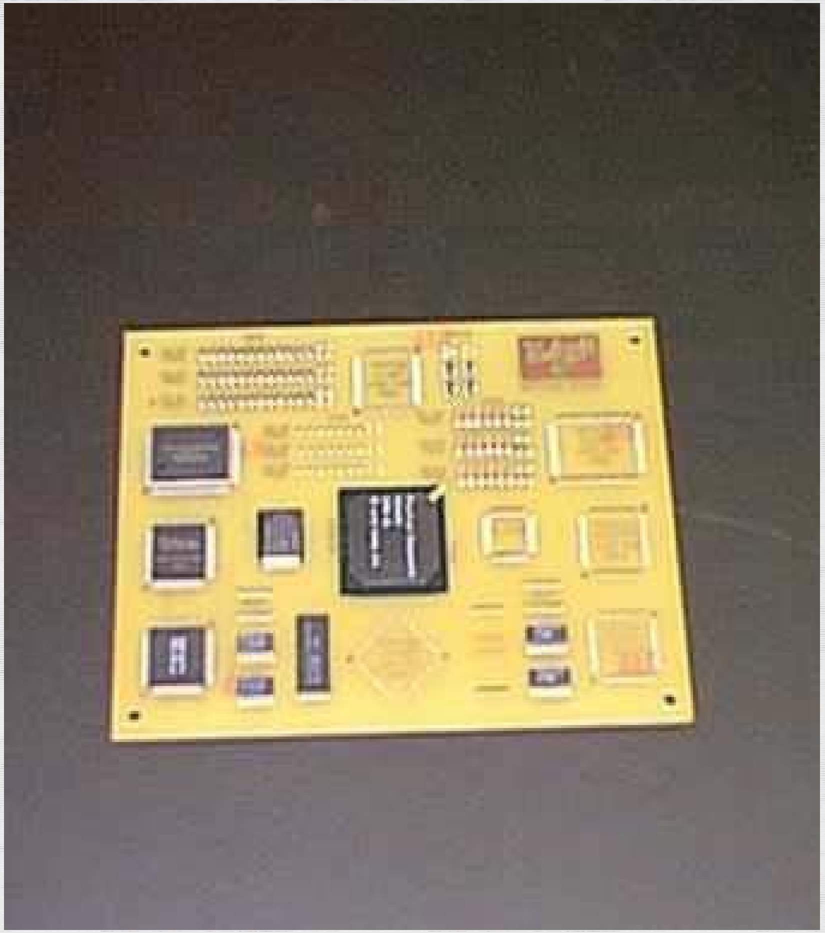
**Passives**

- 1206 - Qty 24
- 0804 - Qty 18
- 0402 - Qty 21

**IC/Semiconductor**

- LQFP120 - 0.0257 Pitch - Qty 1
- LQFP100 - 0.0157 Pitch - Qty 1
- TQFP100 - 0.01977 Pitch - Qty 1
- PLCC28 - Qty 1
- SO14 - Qty 2
- SO16 - Qty 2

- SOT23 - Qty 4
- TSOP32 - 0.0197 Pitch - Qty 1
- TQFP100 - 0.01977 Pitch - Qty 1



# Design of Experiment Factors;

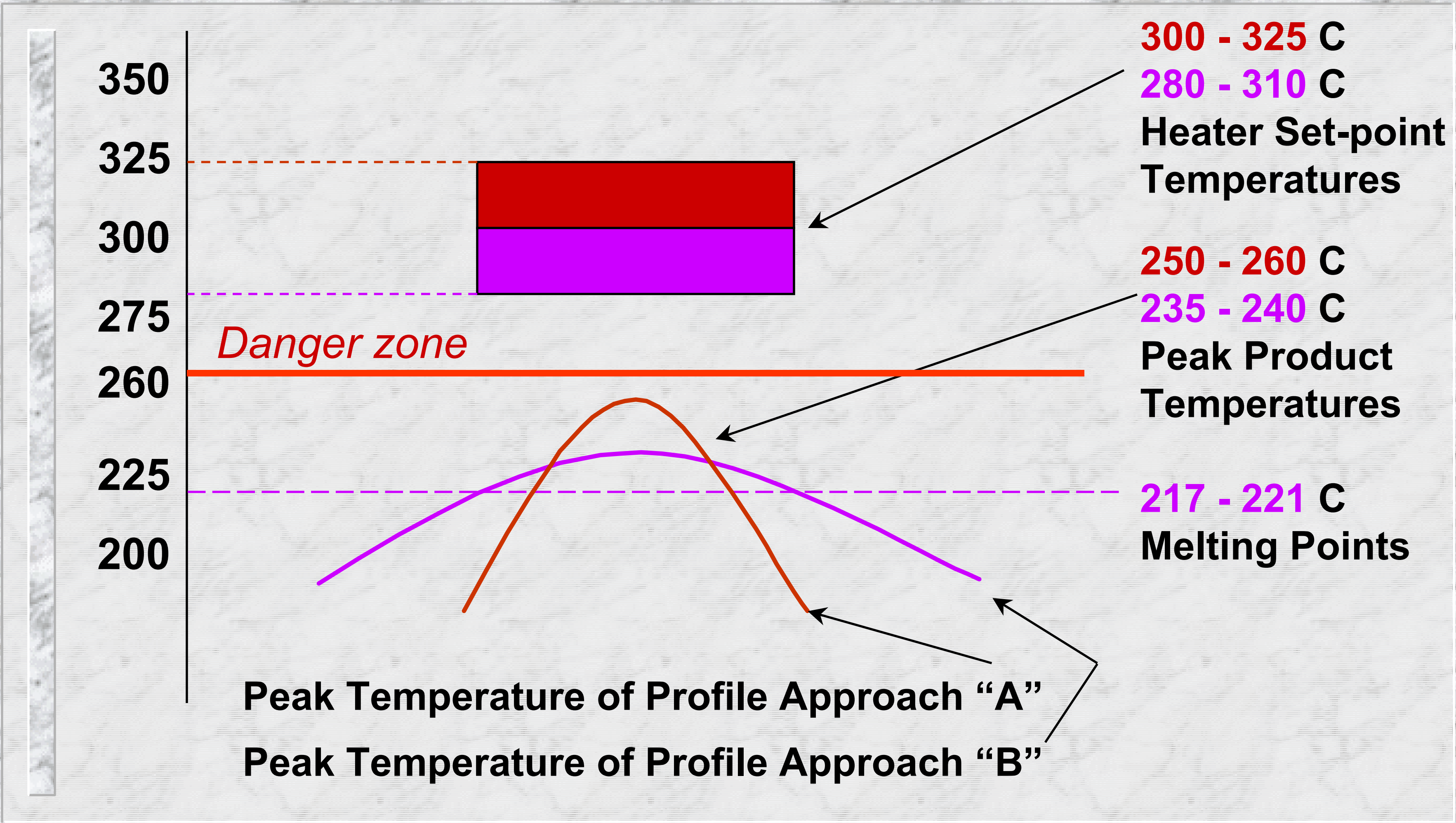
- Materials ( Alloys):
  - Sn/Ag (96/4)
  - Sn/Ag/Cu (95.5/3.8/0.7)
- Flux:
  - Flux 1: No clean, high residue, high activity
  - Flux 2: No clean, low residue, medium activity
  - Flux 3: No clean, high residue, medium activity
- Profiles:
  - Low temperature conventional profile
  - High temperature conventional profile
  - Low temperature linear profile
  - high temperature linear profile

# Profiles:

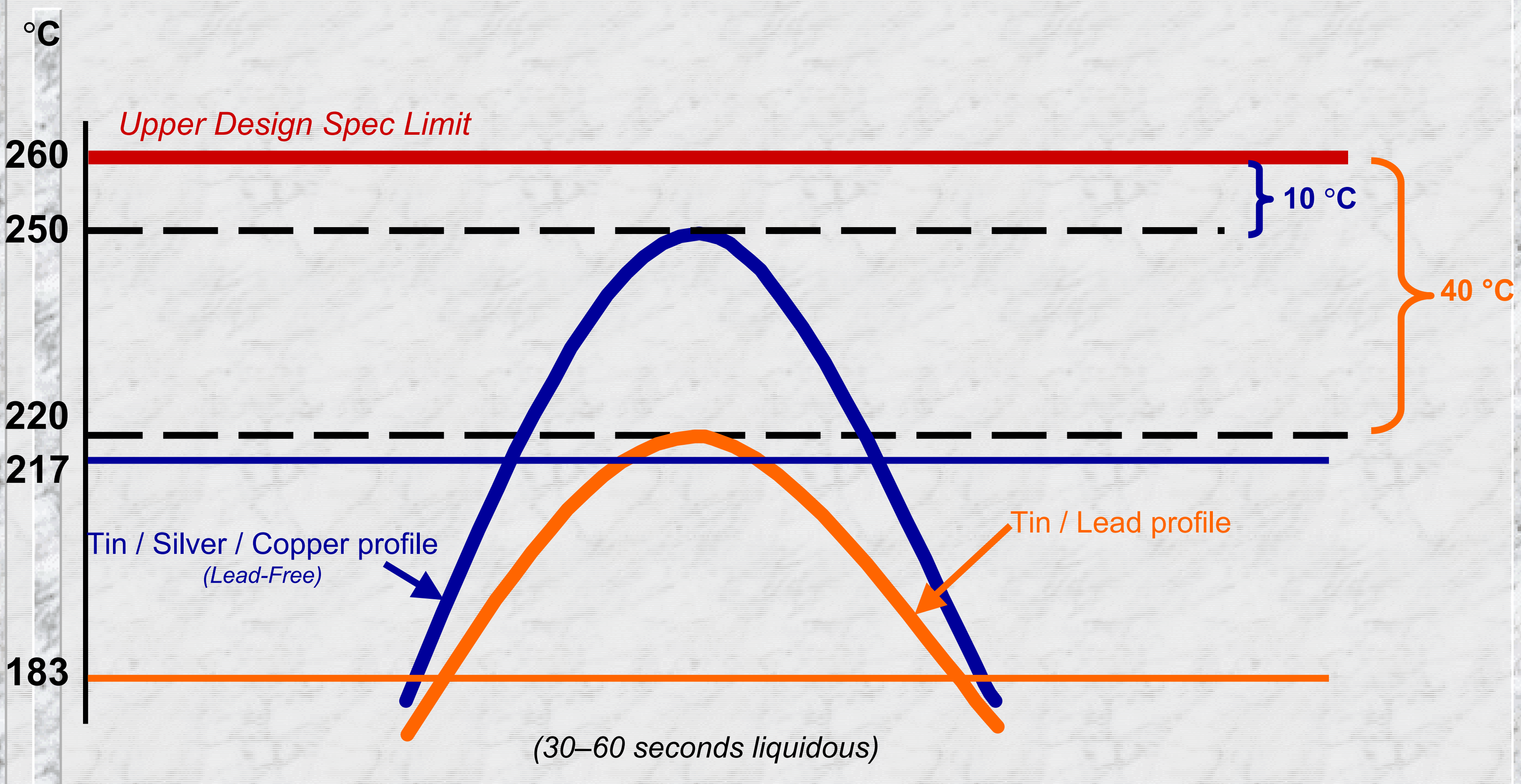
| Nominal Reflow Requirements | | | | | | |
|---|---|---|---|---|---|---|
| **Profile** | **Preheat Ramp Rate °C/sec** | **Soak Temperature (150 - 170 °C)** | **Reflow Ramp Rate°C/sec** | **Peak Temperature °C** | **Time above liquidus 217°C** | Profile Description |
| 1 | < 3 | 90 - 120 sec | < 3 | 230±5 | 60±15 | **Conventional Low Temp** |
| 2 | <3 | 90 - 120 sec | <3 | 250±5 | 60±15 | Conventional High Temp |
| 3 | < 2 | N/A | < 2 | 225±5 | 90-120 | Linear Low Temp |
| 4 | < 2 | N/A | < 2 | 235±5 | 90-120 | Linear High Temp |

Circuit Assembly, April 2000.

# The Lead-Free Reflow Strategies



# Lead-Free Process Windows




Look Again !

# Test Plan & Experiment Results (Visual Defect):

| Experiment | Alloy | Flux Chemistry | Profile | Replication (Lot Size of 5) | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 |
| 1 | SnAg | Flux 1 | 1 | 121 | 220 | 120 | 154 | 121 |
| 2 | SnAg | Flux 1 | 2 | 120 | 120 | 120 | 120 | 32 |
| 3 | SnAg | Flux 1 | 3 | 0 | 0 | 120 | 0 | 120 |
| 4 | SnAg | Flux 1 | 4 | 120 | 0 | 0 | 0 | 0 |
| 5 | SnAg | Flux 2 | 1 | 456 | 203 | 238 | 336 | 165 |
| 6 | SnAg | Flux 2 | 2 | 26 | 149 | 132 | 158 | 51 |
| 7 | SnAg | Flux 2 | 3 | 120 | 238 | 234 | 130 | 123 |
| 8 | SnAg | Flux 2 | 4 | 1 | 3 | 122 | 3 | 4 |
| 9 | SnAg | Flux 3 | 1 | 0 | 0 | 0 | 0 | 120 |
| 10 | SnAg | Flux 3 | 2 | 120 | 0 | 0 | 0 | 0 |
| 11 | SnAg | Flux 3 | 3 | 220 | 120 | 220 | 0 | 320 |
| 12 | SnAg | Flux 3 | 4 | 0 | 220 | 352 | 0 | 320 |
| 13 | SnAgCu | Flux 1 | 1 | 0 | 0 | 120 | 0 | 120 |
| 14 | SnAgCu | Flux 1 | 2 | 0 | 0 | 0 | 0 | 0 |
| 15 | SnAgCu | Flux 1 | 3 | 0 | 0 | 0 | 0 | 0 |
| 16 | SnAgCu | Flux 1 | 4 | 0 | 0 | 0 | 0 | 0 |
| 17 | SnAgCu | Flux 2 | 1 | 438 | 323 | 388 | 504 | 547 |
| 18 | SnAgCu | Flux 2 | 2 | 233 | 275 | 310 | 483 | 407 |
| 19 | SnAgCu | Flux 2 | 3 | 62 | 231 | 240 | 162 | 354 |
| 20 | SnAgCu | Flux 2 | 4 | 256 | 402 | 442 | 413 | 303 |
| 21 | SnAgCu | Flux 3 | 1 | 100 | 220 | 220 | 320 | 220 |
| 22 | SnAgCu | Flux 3 | 2 | 0 | 220 | 252 | 0 | 100 |
| 23 | SnAgCu | Flux 3 | 3 | 0 | 0 | 120 | 100 | 220 |
| 24 | SnAgCu | Flux 3 | 4 | 0 | 320 | 252 | 252 | 220 |

Circuit Assembly, April 2000.

# Design of Experiment Anova Analysis:

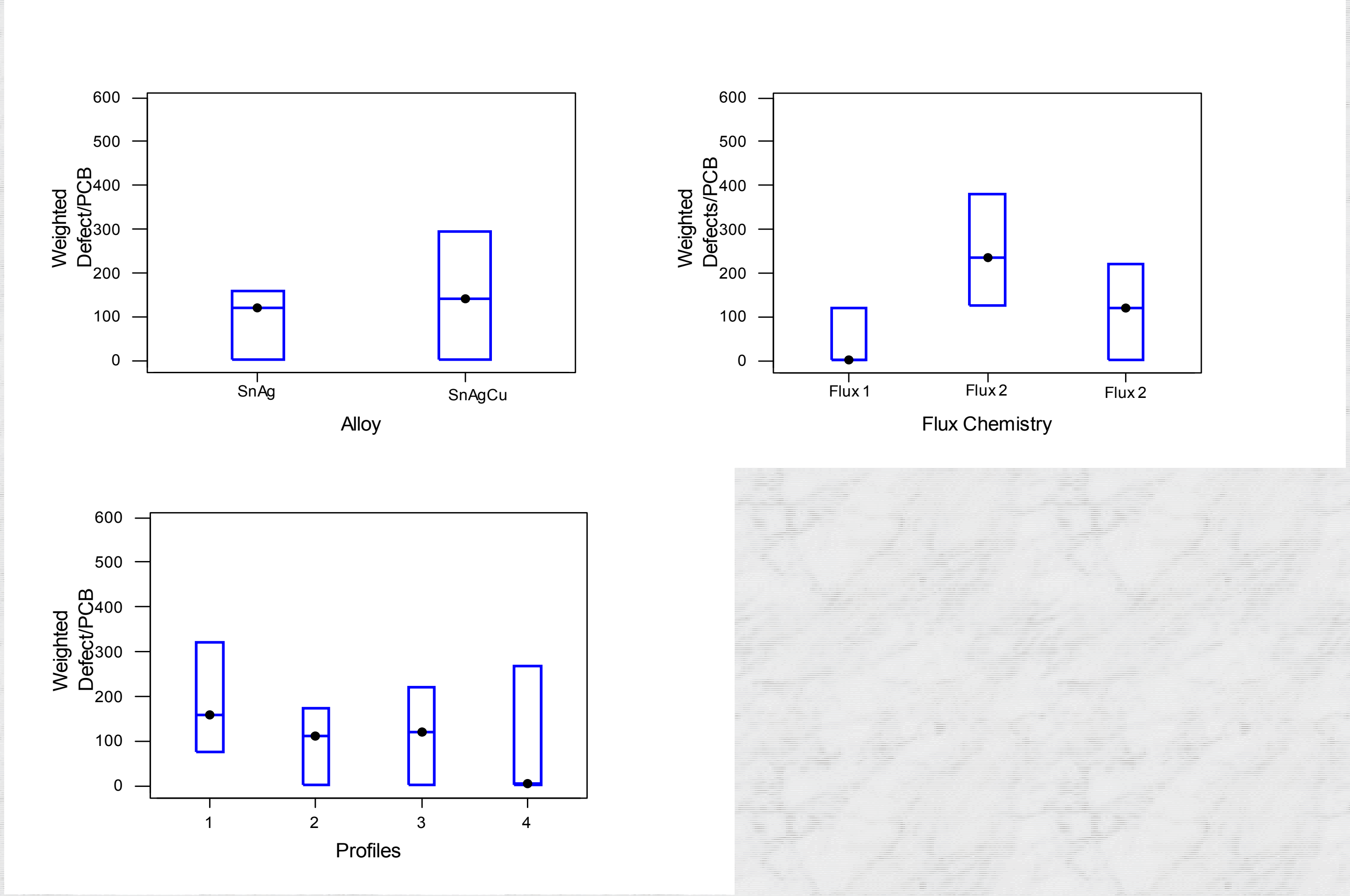
**ANOVA Table For Randomized Complete Block Design**

| Source of Variation | Sum of Squares | Degrees of Freedom | Mean Square | F Test Statistic | f.05v1,v2 | Percent Contribution |
|---|---|---|---|---|---|---|
| Flux | 769989.8167 | 2 | 384994.9083 | 54.93067467 | 3.07(3.102) | 31.5% |
| Profile | 122105.6917 | 3 | 40701.89722 | 5.807304529 | 2.68(2.712) | 5.0% |
| Alloy | 110231.4083 | 1 | 110231.4083 | 15.72770314 | 3.92(3.952) | 4.5% |
| Flux/Profile | 192033.1833 | 6 | 32005.53056 | 4.566515942 | 2.17(2.202) | 7.9% |
| Flux/Alloy | 344692.6167 | 2 | 172346.3083 | 24.59019272 | 3.07(3.102) | 14.1% |
| Profile/Alloy | 91501.29167 | 3 | 30500.43056 | 4.351769833 | 2.68(2.712) | 3.7% |
| Flux/Profile/Alloy | 139668.7833 | 6 | 23278.13056 | 3.321299552 | 2.17(2.202) | 5.7% |
| Error | 672839.2 | 96 | 7008.741667 | | | |
| Total | 2443061.992 | 119 | | | | |

**Null hypothesis rejected at significance level .05 if FA=MSA/MSE >= fa,(r-1),abc(n-1)**

Circuit Assembly, April 2000.

# Design of Experiment Box Plot Analysis




Circuit Assembly, April 2000.

# Design of Experiment Result summary:

» Flux is the most critical factor (31.5%).

» Flux 1 had the highest solid content which protected the molten solder from oxidation during reflow and, hence, produced the best solder joint results

» Profiles are significant but at a low percentage (5%).

» The linear profile (4) with a peak of 235 °C produced the best results.

» None of the boards exhibited thermal damage to the FR4 laminate material.

» Some boards experienced slight discoloration with conventional high temperature profile

Circuit Assembly, April 2000.

# Design of Experiment Result summary:

- The linear profile saw a maximum slope of 2 °C/sec which will reduce shock to the board and its components.
- The maximum ramp rate, 3 °C/sec, observed on the conventional profile with a peak temperature of 250 °C. The ramp rates observed during testing did not cause solder balls or solder splashes. Hence, it can be concluded that these ramp rates are not critical to solder splashing.
- Alloys are significant but at a low percentage (4%).

# Design of Experiment Conclusion:

» Flux 1 with Tin/Silver/Copper Alloy will be tested with Linear Profile (4) during test validations at beta sites.

» Temperatures seen under this lead free solder will not cause thermal damage to the FR4 board laminate.

» Higher Temperature Furnace Set points will be required

» A Superior flux and cooling system will be required in the reflow process.

» Utilizing the linear profile will minimize cost of ownership for utilities for customers

Circuit Assembly, April 2000.

# Lead Free-Research: Phase # 2

- **66 Printed Wiring Boards (PWB's)**
  - **Two lead free surface finishes.**
  - **Lead free components.**
  - **lead free solders.**
  - **Leaded base line using leaded components and lead based solder.**
- **Design of experiment:**
  - **Orthogonal array L27.**
  - **one replication.**
- **Solder joints are to be analyzed for:**
  - **Defects by visual inspection .**
  - **Pull test prior and after thermal cycling.**
  - **Reliability testing through thermal cycling.**
  - **Cross sectioning for Intermetallic growth.**
- **Lead Free results compared to lead baseline (12 PWBs).**

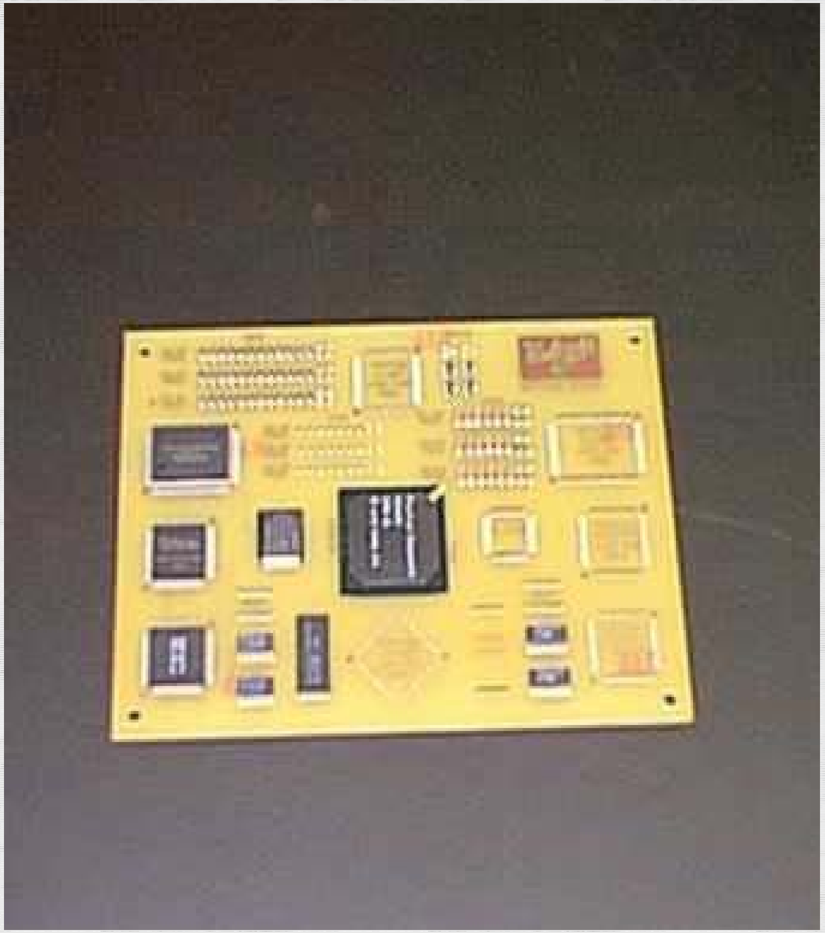
# Test Vehicle: ( Lead free components)

**Passives (Sn finish)**

- 1206 - Qty 24
- 0805 - Qty 42
- 0402 - Qty 27

**IC/Semiconductor (NiPd finish)**

- LQFP120 - 0.0257 Pitch - Qty 2
- LQFP100 - 0.0157 Pitch - Qty 2
- SO14 - Qty 3
- SO16 - Qty 3



# Test Factors (source)

- Solder Alloys (Multicore solders)
  - Sn/Ag/Cu(95.5/3.8/0.7)
  - Sn/Ag (96.5/3.5)
  - Sn/Bi eutectic (57/43)
- PWB Surface Finishes (HADCO)
  - OSP(Organic Solder Protectants)
  - Electroless Nickel Immersion Gold (ENIG)
- Thermal Profiles (BTU)
  - Soak with 60sec, 90sec, 120sec above liquidus temp.
  - Linear with 60sec, 90sec, 120sec above liquidus temp.
- Reflow Environment (Solectron)
  - Nitrogen vs. Air reflow.

# Thermal Profiles:

| Profile # | Preheat Ramp Rate °C/sec | Soak Time (sec) between 150-170 °C | Peak Temperature °C | Time above liquidus 217°C sec | Cool Down Rate °C/sec | N2 | Profile Description |
|---|---|---|---|---|---|---|---|
| 1 | < 3° | 90-120 | 235±5 | 60 | <4° | yes | Soak |
| 2 | < 3° | 90-120 | 235±5 | 90 | <4° | yes | Soak |
| 3 | < 3° | 90-120 | 235±5 | 120 | <4° | yes | Soak |
| 4 | < 2° | NA | 235±5 | 60 | <4° | yes | Linear |
| 5 | < 2° | NA | 235±5 | 90 | <4° | yes | Linear |
| 6 | < 2° | NA | 235±5 | 120 | <4° | yes | Linear |
| 7 | < 2° | NA | 235±5 | 60 | <4° | No | Linear |
| 8 | < 2° | NA | 235±5 | 90 | <4° | No | Linear |
| 9 | < 2° | NA | 235±5 | 120 | <4° | No | Linear |

Sn/Bi eutectic

| Profile # | Preheat Ramp Rate °C/sec | Soak Time (sec) between 120-130 °C | Peak Temperature °C | Time above liquidus 138°C | Cool Down Rate °C/sec | N2 | Profile Description |
|---|---|---|---|---|---|---|---|
| 10 | <2° | 60-120 | 168±5 | 60 | <4° | No | Soak |
| 11 | <2° | 60-120 | 168±5 | 90 | <4° | No | Soak |
| 12 | <2° | 60-120 | 168±5 | 120 | <4° | No | Soak |
| 13 | <2° | NA | 168±5 | 60 | <4° | yes | Linear |
| 14 | <2° | NA | 168±5 | 90 | <4° | yes | Linear |
| 15 | <2° | NA | 168±5 | 120 | <4° | yes | Linear |

# Test Matrix &

# Visual Defect Test Results

**Lead Free:**

| Sl.no. | Paste | S. Finish | TAL | Soak | Nitrogen | Board Label | | Profile No. | Board Faults Visual | | Total | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Sn/Ag/Cu | OSP | 60sec | Yes | yes | 1A | 1B | 1 | 797 | 944 | 1741 | 870.5 |
| 2 | Sn/Ag/Cu | OSP | 90sec | No | No | 2A | 2B | 8 | 1213 | 1146 | 2359 | 1179.5 |
| 3 | Sn/Ag/Cu | OSP | 120sec | No | yes | 3A | 3B | 6 | 874 | 890 | 1764 | 882 |
| 4 | Sn/Ag/Cu | ENIG | 60sec | No | No | 4A | 4B | 7 | 544 | 594 | 1138 | 569 |
| 5 | Sn/Ag/Cu | ENIG | 90sec | No | yes | 5A | 5B | 5 | 0 | 0 | 0 | 0 |
| 6 | Sn/Ag/Cu | ENIG | 120sec | Yes | yes | 6A | 6B | 3 | 0 | 0 | 0 | 0 |
| 7 | Sn/Ag/Cu | OSP | 60sec | No | yes | 7A | 7B | 4 | 828 | 819 | 1647 | 823.5 |
| 8 | Sn/Ag/Cu | OSP | 90sec | Yes | yes | 8A | 8B | 2 | 902 | 960 | 1862 | 931 |
| 9 | Sn/Ag/Cu | OSP | 120 | No | No | 9A | 9B | 9 | 1182 | 1164 | 2346 | 1173 |
| 10 | Sn/Bi | OSP | 60sec | No | yes | 10A | 10B | 13 | 1134 | 963 | 2097 | 1048.5 |
| 11 | Sn/Bi | OSP | 90sec | No | yes | 11A | 11B | 14 | 875 | 1136 | 2011 | 1005.5 |
| 12 | Sn/Bi | OSP | 120sec | Yes | No | 12A | 12B | 12 | 967 | 1146 | 2113 | 1056.5 |
| 13 | Sn/Bi | ENIG | 60sec | No | yes | 13A | 13B | 13 | 1024 | 960 | 1984 | 992 |
| 14 | Sn/Bi | ENIG | 90sec | Yes | No | 14A | 14B | 11 | 1016 | 1002 | 2018 | 1009 |
| 15 | Sn/Bi | ENIG | 120sec | No | yes | 15A | 15B | 15 | 843 | 560 | 1403 | 701.5 |
| 16 | Sn/Bi | OSP | 60sec | Yes | No | 16A | 16B | 10 | 1148 | 1067 | 2215 | 1107.5 |
| 17 | Sn/Bi | OSP | 90sec | No | yes | 17A | 17B | 14 | 781 | 606 | 1387 | 693.5 |
| 18 | Sn/Bi | OSP | 120sec | No | yes | 18A | 18B | 15 | 765 | 882 | 1647 | 823.5 |
| 19 | Sn/Ag | OSP | 60sec | No | No | 19A | 19B | 7 | 1212 | 1279 | 2491 | 1245.5 |
| 20 | Sn/Ag | OSP | 90sec | Yes | yes | 20A | 20B | 2 | 1131 | 988 | 2119 | 1059.5 |
| 21 | Sn/Ag | OSP | 120sec | No | yes | 21A | 21B | 6 | 1027 | 933 | 1960 | 980 |
| 22 | Sn/Ag | ENIG | 60sec | Yes | yes | 22A | 22B | 1 | 0 | 0 | 0 | 0 |
| 23 | Sn/Ag | ENIG | 90sec | No | yes | 23A | 23B | 5 | 0 | 0 | 0 | 0 |
| 24 | Sn/Ag | ENIG | 120sec | No | No | 24A | 24B | 9 | 180 | 240 | 420 | 210 |
| 25 | Sn/Ag | OSP | 60sec | No | yes | 25A | 25B | 4 | 796 | 829 | 1625 | 812.5 |
| 26 | Sn/Ag | OSP | 90sec | No | No | 26A | 26B | 8 | 1205 | 1146 | 2351 | 1175.5 |
| 27 | Sn/Ag | OSP | 120sec | Yes | yes | 27A | 27B | 3 | 868 | 935 | 1803 | 901.5 |

# Visual Defect Test Results

**Tin/Lead Baseline:**

| Sl.no. | Board | S.Finish | N2 | Defects |
|---|---|---|---|---|
| 1 | Pb1 | OSP | N2 | 120 |
| 2 | Pb2 | OSP | N2 | 120 |
| 3 | Pb3 | OSP | N2 | 240 |
| 4 | Pb4 | OSP | air | 725 |
| 5 | Pb5 | OSP | air | 654 |
| 6 | Pb6 | OSP | air | 664 |
| 7 | Pb7 | ENIG | N2 | 0 |
| 8 | Pb8 | ENIG | N2 | 0 |
| 9 | Pb9 | ENIG | N2 | 0 |
| 10 | Pb10 | ENIG | air | 60 |
| 11 | Pb11 | ENIG | air | 0 |
| 12 | Pb12 | ENIG | air | 30 |

# Anova Defect Analysis:

| Column | Factors | DOF | SS | Variance | F-ratio | SS' | % |
|---|---|---|---|---|---|---|---|
| 1 | Solder Paste | 2 | 611,320.79 | 305,660.39 | 43.96798 | 597,417.01 | 7.160587 |
| 2 | Surface Finish | 2 | 4,412,024.55 | 2,206,012.27 | 317.3257 | 4,398,120.77 | 52.71548 |
| 3&4 | Paste X S.Finish | 4 | 1,887,269.19 | 471,817.30 | 67.86897 | 1,859,461.65 | 22.28734 |
| 5 | Time above Liquidus | 2 | 61,309.46 | 30,654.73 | 4.409556 | 47,405.69 | 0.5682 |
| 6&7 | Paste X TAL | 4 | 83,840.91 | 20,960.23 | 3.015042 | 56,033.37 | 0.671611 |
| 9 | Soak | | | | | Pooled | Pooled |
| 10 | Nitrogen (Env.) | 2 | 909,057.76 | 454,528.88 | 65.3821 | 895,153.99 | 10.72924 |
| 8&11 | S.Finish X TAL | 4 | 148,894.32 | 37,223.58 | 5.354458 | 121,086.78 | 1.451335 |
| 12 | Not used | | | | | Pooled | Pooled |
| 13 | Not used | | | | | Pooled | Pooled |
| | Replication | 33 | 229,412.23 | 6,951.89 | | 368,449.94 | 4.416208 |
| | | | | | | | |
| | Total | 53 | 8,343,129.20 | | | 8,343,129.20 | 100 |

# Defect Analysis Conclusion:

- Surface finish, nitrogen, and solder paste alloy is  the most critical factor in producing good solder joints.
- Surface finish is the biggest contributor (52%).
- Reflow environment improves the quality of solder joints with nitrogen having 10% statistical contribution.
- Nitrogen facilitates better heat transfer.
- Nitrogen allows lower peak temperature and a shorter time above liquidus.
- Nitrogen improves uniformity and hence, the reflow process window.
- Nitrogen improves marginal defect conditions.
- Nitrogen reduced the clear flux residue and thus will reduce defaults in in circuit test.

# Defect Analysis Conclusion:

- Solder Paste contributed by 7% to the quality of the solder joint.
- Time above liquidus is significant.
- No major difference could be noted in results produced using Soak or linear profile. This shows the necessity of employing a multi-layer board as a test vehicle populated with small and large component types.
- None of the boards exhibited thermal damage to the FR4 laminate material.
- Optimal settings:
  - Sn/Ag/Cu
  - ENIG performs the best with these alloys.
  - Nitrogen
  - Linear profile with 120 sec above liquidus.
  - This can be observed by the matrix and the result, however further statistical analysis is in progress to conclude the best settings.

# Test Matrix &

## Pull Test Results

Experiment matrix in a L27

| Sl.no. | Paste | S. Finish | TAL | Soak | Nitrogen | Board Label | | Force (N) | | Total Force (N) | Ave Force (N) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Sn/Ag/Cu | OSP | 60sec | Yes | yes | 1A | 1B | 35.4576 | 36.49 | 71.9476 | 35.9738 |
| 2 | Sn/Ag/Cu | OSP | 90sec | No | No | 2A | 2B | 34.6922 | 40.05 | 74.7422 | 37.3711 |
| 3 | Sn/Ag/Cu | OSP | 120sec | No | yes | 3A | 3B | 37.3177 | 41.49625 | 78.81395 | 39.406975 |
| 4 | Sn/Ag/Cu | ENIG | 60sec | No | No | 4A | 4B | 34.40295 | 37.1753 | 71.57825 | 35.789125 |
| 5 | Sn/Ag/Cu | ENIG | 90sec | No | yes | 5A | 5B | 35.40865 | 31.8264 | 67.23505 | 33.617525 |
| 6 | Sn/Ag/Cu | ENIG | 120sec | Yes | yes | 6A | 6B | 42.1949 | 30.77175 | 72.96665 | 36.483325 |
| 7 | Sn/Ag/Cu | OSP | 60sec | No | yes | 7A | 7B | 41.8122 | 41.3316 | 83.1438 | 41.5719 |
| 8 | Sn/Ag/Cu | OSP | 90sec | Yes | yes | 8A | 8B | 42.8624 | 36.84155 | 79.70395 | 39.851975 |
| 9 | Sn/Ag/Cu | OSP | 120 | No | No | 9A | 9B | 35.9827 | 34.621 | 70.6037 | 35.30185 |
| 10 | Sn/Bi | OSP | 60sec | No | yes | 10A | 10B | 29.81945 | 36.07615 | 65.8956 | 32.9478 |
| 11 | Sn/Bi | OSP | 90sec | No | yes | 11A | 11B | 30.72725 | 33.2593 | 63.98655 | 31.993275 |
| 12 | Sn/Bi | OSP | 120sec | Yes | No | 12A | 12B | 24.55955 | 33.83335 | 58.3929 | 29.19645 |
| 13 | Sn/Bi | ENIG | 60sec | No | yes | 13A | 13B | 24.41715 | 26.9492 | 51.36635 | 25.683175 |
| 14 | Sn/Bi | ENIG | 90sec | Yes | No | 14A | 14B | 22.7929 | 22.0275 | 44.8204 | 22.4102 |
| 15 | Sn/Bi | ENIG | 120sec | No | yes | 15A | 15B | 25.6142 | 31.8709 | 57.4851 | 28.74255 |
| 16 | Sn/Bi | OSP | 60sec | Yes | No | 16A | 16B | 29.43675 | 27.14055 | 56.5773 | 28.28865 |
| 17 | Sn/Bi | OSP | 90sec | No | yes | 17A | 17B | 33.49515 | 29.2899 | 62.78505 | 31.392525 |
| 18 | Sn/Bi | OSP | 120sec | No | yes | 18A | 18B | 34.5943 | 34.6922 | 69.2865 | 34.64325 |
| 19 | Sn/Ag | OSP | 60sec | No | No | 19A | 19B | 31.67955 | 33.06795 | 64.7475 | 32.37375 |
| 20 | Sn/Ag | OSP | 90sec | Yes | yes | 20A | 20B | 30.0108 | 32.01775 | 62.02855 | 31.014275 |
| 21 | Sn/Ag | OSP | 120sec | No | yes | 21A | 21B | 35.26625 | 33.7844 | 69.05065 | 34.525325 |
| 22 | Sn/Ag | ENIG | 60sec | Yes | yes | 22A | 22B | 27.9549 | 31.4882 | 59.4431 | 29.72155 |
| 23 | Sn/Ag | ENIG | 90sec | No | yes | 23A | 23B | 29.0051 | 34.98145 | 63.98655 | 31.993275 |
| 24 | Sn/Ag | ENIG | 120sec | No | No | 24A | 24B | 27.66565 | 37.9407 | 65.60635 | 32.803175 |
| 25 | Sn/Ag | OSP | 60sec | No | yes | 25A | 25B | 36.45885 | 30.10425 | 66.5631 | 33.28155 |
| 26 | Sn/Ag | OSP | 90sec | No | No | 26A | 26B | 30.38905 | 34.0247 | 64.41375 | 32.206875 |
| 27 | Sn/Ag | OSP | 120sec | Yes | yes | 27A | 27B | 27.90595 | 30.9186 | 58.82455 | 29.412275 |

# Pull Test Results

| Tin/Lead Base line | | | |
|---|---|---|---|
| **Board** | **S.Finish** | **N2** | **Force (N)** |
| Pb1 | OSP | N2 | 25.94795 |
| Pb2 | OSP | N2 | 26.85575 |
| Pb3 | OSP | N2 | 22.60155 |
| Pb4 | OSP | air | 27.9549 |
| Pb5 | OSP | air | 28.81375 |
| Pb6 | OSP | air | 29.96185 |
| Pb7 | ENIG | N2 | 21.2176 |
| Pb8 | ENIG | N2 | 22.2678 |
| Pb9 | ENIG | N2 | 19.3041 |
| Pb10 | ENIG | air | 22.36125 |
| Pb11 | ENIG | air | 24.94225 |
| Pb12 | ENIG | air | 31.8709 |

# Anova Pull Test Analysis:

| Column | Factors | DOF | SS | Variance | F-ratio | SS' | % |
|---|---|---|---|---|---|---|---|
| 1 | Solder Paste | 2 | 570,578.00 | 285,289.00 | 24.023 | 546.83 | 42.789 |
| 2 | Surface Finish | 2 | 117.40 | 58.70 | 4.942 | 93.65 | 7.328 |
| 3&4 | Paste X S.Finish | 4 | | | | Pooled | 0 |
| 5 | Time above Liquidus | 2 | | | | Pooled | 0 |
| 6&7 | Paste X TAL | 4 | | | | Pooled | 0 |
| 9 | Soak | 2 | 63.07 | 31.53 | 2.655 | 39.32 | 3.076 |
| 10 | Nitrogen (Env.) | 2 | | | | Pooled | 0 |
| 8&11 | S.Finish X TAL | 4 | | | | Pooled | 0 |
| 12 | Not used | | | | | Pooled | Pooled |
| 13 | Not used | | | | | Pooled | Pooled |
| | Other/Error | 47 | 526.89 | 11.21 | | 598.15 | 46.81 |
| | | | | | | | |
| | Total | 69 | 1,277.94 | | | 1,277.94 | 100.00 |

# Pull Test Analysis Conclusion:

- Paste was the most significant factor (42.7%)
- In terms of ductility it was found that SnBi<SnAg<SnAgCu
  - SnBi broke at leg
  - SnAg broke at leg and pad
  - SnAgCu broke at pad
- Surface finish (7.3%) and no-soak were significant (3.1%).
- OSP provided the highest pull strength.
- No Soak for the 4” x 5.5”  test board is required hence there will be less thermal shock (~1°C/sec)
- No-soak will increase production throughput.
- Time above liquidus insignificant, and therefore, minimized time above liquidus will increase throughput.

# Pull Test Analysis Conclusion:

- Optimal settings:
  - Sn/Ag/Cu
  - OSP
  - No Soak
  - This can be observed by the matrix and the result, however further statistical analysis is in progress to conclude the best settings.

# Test Options

## Pull test

- Lack of Standards or Fixtures for Pull Tests.
- Used Instron machine.
- Important that the Z axis is floating.
- Pull rate is important

## Reliability

- Test for both fatigue and creep
- Preferred Range -40'C - 125 ' C
- Prefer a slow rise and fall times (1'C/min)
- Team selected 0 - 100'C for 200 cycles due to time constraint.
- Did not use daisy chained components
  - may have to visually check for failures every 100 cycles.

# Project Status and *Future Work*

- Visual Inspection completed.
- Pull test completed.
- Reliability testing will be performed with Raytheon.
- Results to be published (TURI, June 2, 2000) in academic (JQE, ICED) and industrial journals (PCFab, Circuits Assembly) and national conferences (SMTA, NEPCON, APEX)
- *Establish connections to other Lead free Projects*
- *More emphasis on Lead free alloy selection*

# Questions ?

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