SMT Boston Chapter

Massachusetts Lead Free Consortium Update
9/17/2003

Dr. Sammy Shina
University of Massachusetts Lowell

Introduction

- Lead is a toxic material: major replacements paint and gasoline
- Tin-Lead eutectic solder (60/40 or 63/37))
  - used in electronics industry for more than 50 years
  - large installed manufacturing base
  - history of reliability data
- US electronics industry uses less than 2% of annual lead consumption
- Current Consensus:

There is no drop-in Lead Free replacement for lead soldering

Lead Free Drivers
Environmental

- 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

Project Plan - Material Selection and Manufacturing Processes

- Select the best recommended Material substitutes
  - PWB Surface Finishes
  - SMT Component Finishes
  - Lead Free Solders and Fluxing Materials
- Manufacturing Processes
  - Solder Reflow
    - Reflow Environment
    - Reflow Profiles
- Use existing Tin/Lead baseline for comparison

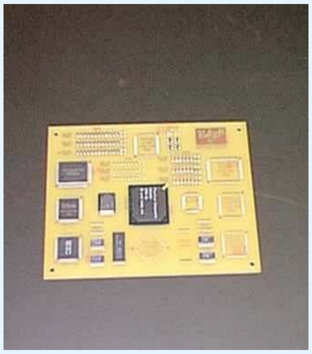
Lead Free Project Plan Quality and Reliability Issues

- Lead Free Solder Joints are Visually different
  - Training of employees, field service and customers
  - Use existing Industry standards: IPC JSTD-001
- Reliability
  - Fatigue, creep and Impact
  - Shock and Vibration
    - Drop Test and Vibration Frequency
  - Simulate with temperature Cycling
    - Cycling Profile
    - Power on/Off
    - Humidity Cycling with Temperature

Test Vehicle: BTU/Multicore

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



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 solders

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 Sn2.5Ag0.8Cu0.5Sb Sn0.7Cu Sn3.5Ag SnBiAg SnBiZn

(Source: IPC Roadmap 3rd draft.)

Lead-Free Surface Finishes

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.)

Lead Free Immersion Surface finishes include
Immersion Ag
Immersion Sn

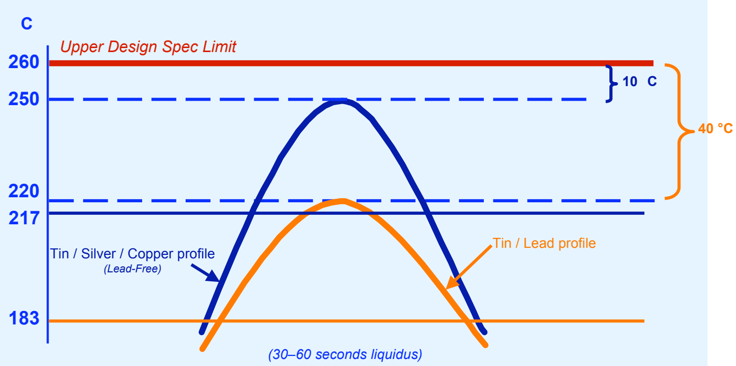
Lead-Free Component Finishes

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

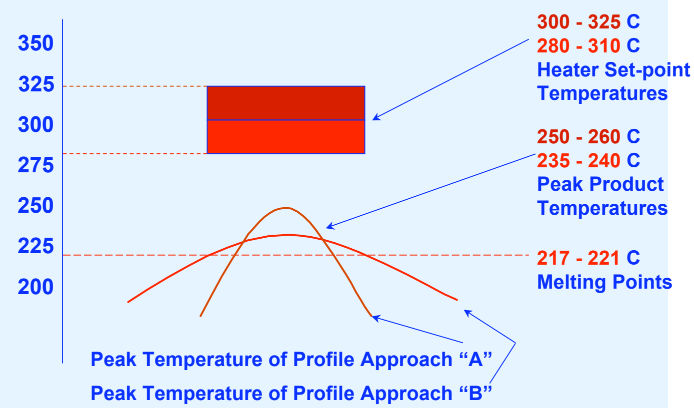
(Source: IPC Roadmap 3rd draft.)

Lead-Free Process Windows



Look Again !

Lead-Free Reflow Strategies



Project Team - Phase I

UMASS Lowell-Industry Lead Free Consortium

- **Dr. Sammy Shina; Dept. of Mechanical Engineering, University of Massachusetts, Lowell.**
- **L. Harriman, C. Pace, Toxic Use Reduction Institute of Massachusetts (TURI)**
- **K. Walters, BTU International**, North Billerica, MA.
- **T. Bresnan, Hadco Corporation**, Ward Hill, MA.
- **T. Skidmore, Multicore Solders**, Richardson, Texas.
- **D. Pinsky, Raytheon Corporation**, Lexington, MA.
- **P. Provencal, Solectron Corporation**, Westborough, MA.
- **D. Abbot, Texas Instruments**, Attleboro, MA.

Test Factors (source)

- **Solder Alloys (Multicore solders)**
  - **Sn/Ag/Cu(95.5/3.8/0.7)**
  - **Sn/Ag (96.5/3.5)**
  - **Sn/Bi (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.**

Visual Inspection

Lead Free Defect Results

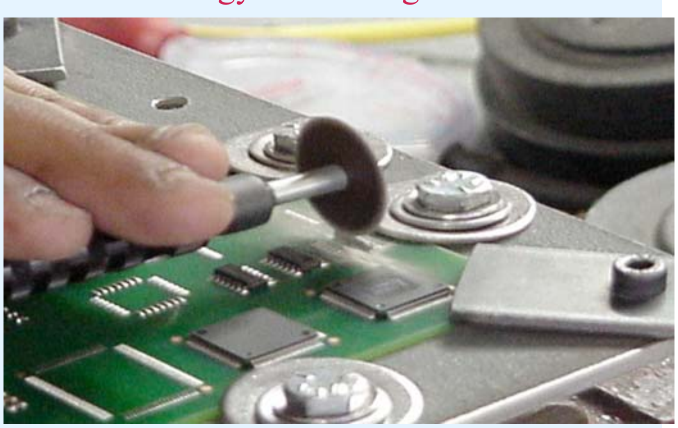
Sl.no.	Paste	S. Finish	TAL	Soak	Nitrogen	Board Label		Profile No.	Board Faults Visual		Total	Average
1	Sn/Ag/Cu	OSP	60sec	Yes	yes	1A	1B	1	797	944	1741	870.5
2	Sn/Ag/Cu	OSP	90sec	No	No	2A	2B	8	1213	1146	2359	1179.5
3	Sn/Ag/Cu	OSP	120sec	No	yes	3A	3B	6	874	890	1764	882
4	Sn/Ag/Cu	ENIG	60sec	No	No	4A	4B	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 Inspection conclusions

- **Metallurgy of Solder paste alloy and surface finish 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.**
- **Time above liquidus is significant.**
- **No major difference noted between soak and linear. Utilizing linear profile will minimize thermal shock and cost of ownership.**
- **None of the boards exhibited thermal damage to the FR4 laminate material.**
- **Optimal settings:**
  - **Sn/Ag or Sn/Ag/Cu**
  - **ENIG performs the best with these alloys.**
  - **Nitrogen Reflow Environment.**

Pull Test on Ni/Pd SO14

Methodology: Accessing the lead



Pull Test on Ni/Pd SO14

Lead-Free Results

Paste	S. Finish	TAL	Soak	N2	Board Label		Force (lbs)		Force (N)		Average
Sn/Ag/Cu	OSP	60sec	Yes	yes	1A	1B	7.968	8.2	35.458	36.49	35.9738
Sn/Ag/Cu	OSP	90sec	No	No	2A	2B	7.796	9	34.692	40.05	37.3711
Sn/Ag/Cu	OSP	120sec	No	yes	3A	3B	8.386	9.325	37.318	41.496	39.406975
Sn/Ag/Cu	ENIG	60sec	No	No	4A	4B	7.731	8.354	34.403	37.175	35.789125
Sn/Ag/Cu	ENIG	90sec	No	yes	5A	5B	7.957	7.152	35.409	31.826	33.617525
Sn/Ag/Cu	ENIG	120sec	Yes	yes	6A	6B	9.482	6.915	42.195	30.772	36.483325
Sn/Ag/Cu	OSP	60sec	No	yes	7A	7B	9.396	9.288	41.812	41.332	41.5719
Sn/Ag/Cu	OSP	90sec	Yes	yes	8A	8B	9.632	8.279	42.862	36.842	39.851975
Sn/Ag/Cu	OSP	120	No	No	9A	9B	8.086	7.78	35.983	34.621	35.30185
Sn/Bi	OSP	60sec	No	yes	10A	10B	6.701	8.107	29.819	36.076	32.9478
Sn/Bi	OSP	90sec	No	yes	11A	11B	6.905	7.474	30.727	33.259	31.993275
Sn/Bi	OSP	120sec	Yes	No	12A	12B	5.519	7.603	24.56	33.833	29.19645
Sn/Bi	ENIG	60sec	No	yes	13A	13B	5.487	6.056	24.417	26.949	25.683175
Sn/Bi	ENIG	90sec	Yes	No	14A	14B	5.122	4.95	22.793	22.028	22.4102
Sn/Bi	ENIG	120sec	No	yes	15A	15B	5.756	7.162	25.614	31.871	28.74255
Sn/Bi	OSP	60sec	Yes	No	16A	16B	6.615	6.099	29.437	27.141	28.28865
Sn/Bi	OSP	90sec	No	yes	17A	17B	7.527	6.582	33.495	29.29	31.392525
Sn/Bi	OSP	120sec	No	yes	18A	18B	7.774	7.796	34.594	34.692	34.64325
Sn/Ag	OSP	60sec	No	No	19A	19B	7.119	7.431	31.68	33.068	32.37375
Sn/Ag	OSP	90sec	Yes	yes	20A	20B	6.744	7.195	30.011	32.018	31.014275
Sn/Ag	OSP	120sec	No	yes	21A	21B	7.925	7.592	35.266	33.784	34.525325
Sn/Ag	ENIG	60sec	Yes	yes	22A	22B	6.282	7.076	27.955	31.488	29.72155
Sn/Ag	ENIG	90sec	No	yes	23A	23B	6.518	7.861	29.005	34.981	31.993275
Sn/Ag	ENIG	120sec	No	No	24A	24B	6.217	8.526	27.666	37.941	32.803175
Sn/Ag	OSP	60sec	No	yes	25A	25B	8.193	6.765	36.459	30.104	33.28155
Sn/Ag	OSP	90sec	No	No	26A	26B	6.829	7.646	30.389	34.025	32.206875
Sn/Ag	OSP	120sec	Yes	yes	27A	27B	6.271	6.948	27.906	30.919	29.412275

Pull Test on Ni/Pd SO14 Conclusion

- Solder Paste is the most significant factor (42.7%)
- Surface finish (7.3%) and Soak are significant (3.1%).
- OSP provided the highest pull strength.
- Time above liquidus insignificant therefore minimized time above liquidus will increase throughput.
- Reflow environment does not have any contribution in improving strength of the joint
- Optimal settings:
  - Sn/Ag/Cu
  - OSP
  - No Soak

Visual + Pull

Conclusions

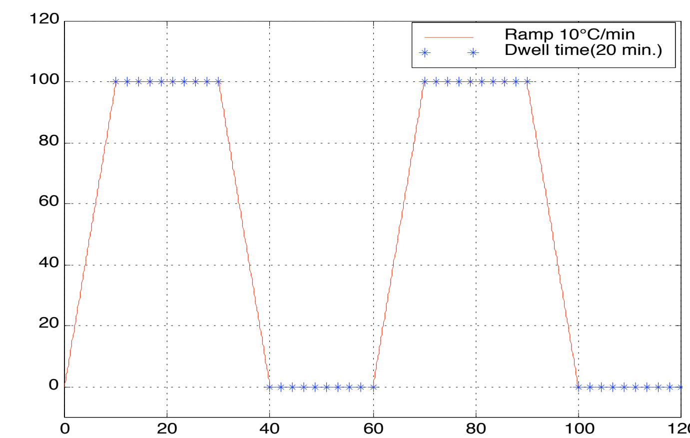
Factors	Percentcontributiontowards thevariation of				Percent

Overall Conclusion prior to Thermal Cycling

- Metallurgy of Solder Paste and PWBs surface finish are the most important factors
- A visually good looking joint may not be the best in terms of strength.
- Nitrogen as a reflow environment improves wetting
- Thermal Profile is significant and altering Time above liquidus improves quality of solder joints
- Higher oven temperature settings may reduce the overall throughput due to low belt speed
- Implementing Lead Free may induce overheads
- No immediate availability of all components as lead free
- Lead free soldering is possible

Reliability Test

Theoretical Thermal Cycling

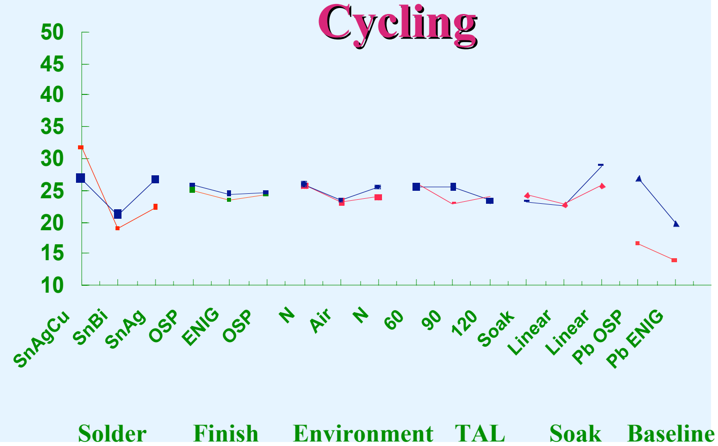


Pull Test on Ni/Pd SO14

Lead-Free Results after Thermal Cycling

	Paste	S. Finish	TAL	Soak	N2	Board Label		Force (lbs)		Force (N)		Average
1	Sn/Ag/Cu	OSP	60sec	Yes	yes	1A	1B	9.686	10.59	43.103	47.126	45.1141
2	Sn/Ag/Cu	OSP	90sec	No	No	2A	2B	10.65	10.18	47.393	45.301	46.34675
3	Sn/Ag/Cu	OSP	120sec	No	yes	3A	3B	10.46	10.18	46.547	45.301	45.924
4	Sn/Ag/Cu	ENIG	60sec	No	No	4A	4B	10.32	9.89	45.924	44.011	44.96725
5	Sn/Ag/Cu	ENIG	90sec	No	yes	5A	5B	10.54	7.388	46.903	32.877	39.8898
6	Sn/Ag/Cu	ENIG	120sec	Yes	yes	6A	6B	7.989	8.462	35.551	37.656	36.603475
7	Sn/Ag/Cu	OSP	60sec	No	yes	7A	7B	10.99	8.548	48.906	38.039	43.47205
8	Sn/Ag/Cu	OSP	90sec	Yes	yes	8A	8B	9.052	10.48	40.281	46.636	43.4587
9	Sn/Ag/Cu	OSP	120	No	No	9A	9B	8.913	9.342	39.663	41.572	40.617375
10	Sn/Bi	OSP	60sec	No	yes	10A	10B	7.925	6.174	35.266	27.474	31.370275
11	Sn/Bi	OSP	90sec	No	yes	11A	11B	8.837	6.722	39.325	29.913	34.618775
12	Sn/Bi	OSP	120sec	Yes	No	12A	12B	5.766	3.705	25.659	16.487	21.072975
13	Sn/Bi	ENIG	60sec	No	yes	13A	13B	5.412	9.632	24.083	42.862	33.4729
14	Sn/Bi	ENIG	90sec	Yes	No	14A	14B	3.297	8.623	14.672	38.372	26.522
15	Sn/Bi	ENIG	120sec	No	yes	15A	15B	8.827	3.436	39.28	15.29	27.285175
16	Sn/Bi	OSP	60sec	Yes	No	16A	16B	5.133	5.756	22.842	25.614	24.228025
17	Sn/Bi	OSP	90sec	No	yes	17A	17B	4.897	8.354	21.792	37.175	29.483475
18	Sn/Bi	OSP	120sec	No	yes	18A	18B	6.776	8.569	30.153	38.132	34.142625
19	Sn/Ag	OSP	60sec	No	No	19A	19B	9.632	8.719	42.862	38.8	40.830975
20	Sn/Ag	OSP	90sec	Yes	yes	20A	20B	10.12	10.19	45.034	45.346	45.18975
21	Sn/Ag	OSP	120sec	No	yes	21A	21B	9.492	9.31	42.239	41.43	41.83445
22	Sn/Ag	ENIG	60sec	Yes	yes	22A	22B	9.697	9.815	43.152	43.677	43.4142
23	Sn/Ag	ENIG	90sec	No	yes	23A	23B	9.224	8.709	41.047	38.755	39.900925
24	Sn/Ag	ENIG	120sec	No	No	24A	24B	9.707	6.142	43.196	27.332	35.264025
25	Sn/Ag	OSP	60sec	No	yes	25A	25B	9.031	10.08	40.188	44.856	42.521975
26	Sn/Ag	OSP	90sec	No	No	26A	26B	8.666	6.883	38.564	30.629	34.596525
27	Sn/Ag	OSP	120sec	Yes	yes	27A	27B	8.483	7.935	37.749	35.311	36.53005

Pull Test - MIN Before and After Thermal Cycling



Recommendations/Further Work Phase I

- Reliability testing has to be continued till any failure is noticed
- Inter-metallic growth have to be investigated
- More investigation and beta testing may be required
- Visual Standards need to be compatible with lead-free
- Need of a standardized test vehicle
- Pull test methodology has to be standardized

Project Team - Phase II

UMASS Lowell-Industry Lead Free Consortium

Additions of More companies

- TURI, Todd McFadden
- Tyco Electronics, MA/COM, Lowell MA
  George Wilkish, Quality; Richard Anderson, Engineering and Helena Pasquito, Inpsection
- Schneider Electric; Andover, MA, Mark Quealy
- Analog Devices, Wilmington, MA, Richard McCann and Alan Grust
- Air Products and Chemicals, Inc, Marie Kistler
- 3 Solder Suppliers

Lead-Free Solder Recommendations

- NEMI Task Force - 2/2001
  - Sn3.9Ag0.6Cu for surface mount
  - Sn0.7Cu(first priority) and Sn3.5Ag (second priority) for wave soldering
  - (The compositions are in weight %; for example, Sn3.9Ag0.6Cu is 3.9%Ag, 0.6%Cu, balance Sn.)
- NEMI Roadmaps
  - Low Cost - Computer
  - Hand Held - Cell Phone
  - Harsh Environment - Autos
  - Hi-Performance - Communications

Phase II: Lead Free Material Solder Supplier Selection

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. Nitrogen was supplied by Air Products and Chemicals and contained 50 ppm Oxygen for these experiments
3. **Solder Pastes** – Three Treatments – all with the same alloy composition – 95.5Sn-3.8 Ag-0.7Cu (NEMI recommended) from three different suppliers (A, B and C), all incorporating no-clean fluxes.
4. **Component Lead Finishes** – Four Treatments – matte Tin plating, Tin/Silver/Copper, Nickel/Palladium/Gold, and Nickel/Gold.

Sn-Pb eutectic solder PWB using the solder treatments as control PWBs.

Test Vehicle: (Lead free components)

Visual Inspection

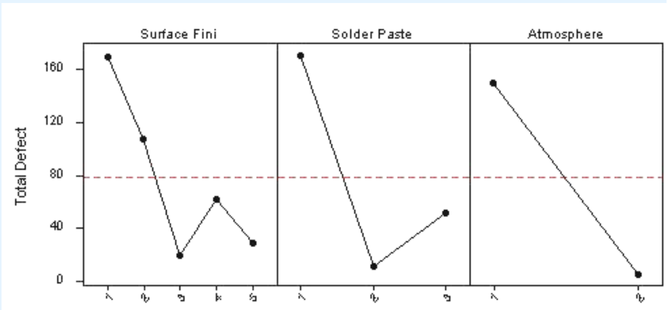
Lead Free Defect Results

Experiment#	SurfaceFinish	Solderpaste	Atmo-sphere1

"A"Air2

"A"Nitroge

Visual Inspection
Average Analysis Lead Free Defect



Visual Inspection Conclusions Phase II

- SMOBC/HASL significantly differs from all others. No other finishes were found to be statistically different from one another
- All Pastes were found to differ significantly from all other pastes.
- Nitrogen preformed significantly better than Air
- The A Pb-Free, Air combination and 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

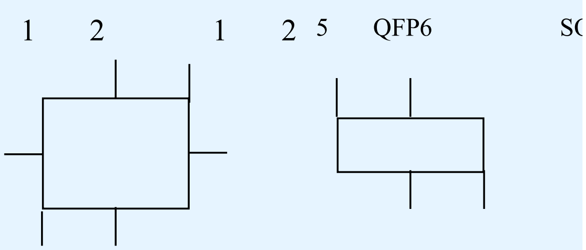
  B Pb-Free with Air

  B Pb-Free with Nitrogen

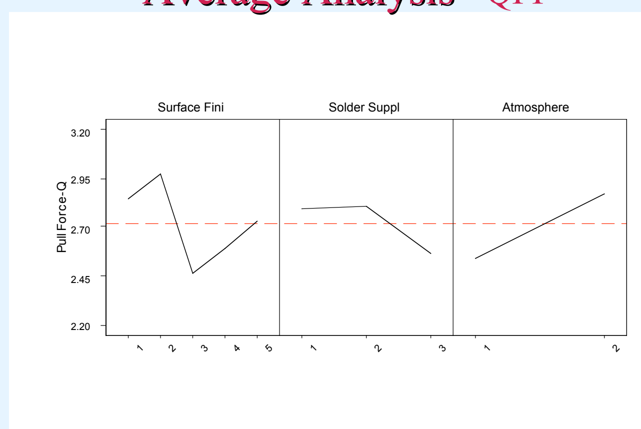
  A Pb-Free with Nitrogen

  C Pb-Free with Nitrogen
- Other factors should be considered such as stencil clogging

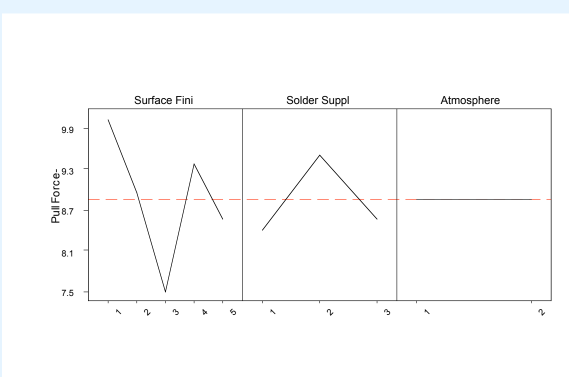
Pull Test Methodology

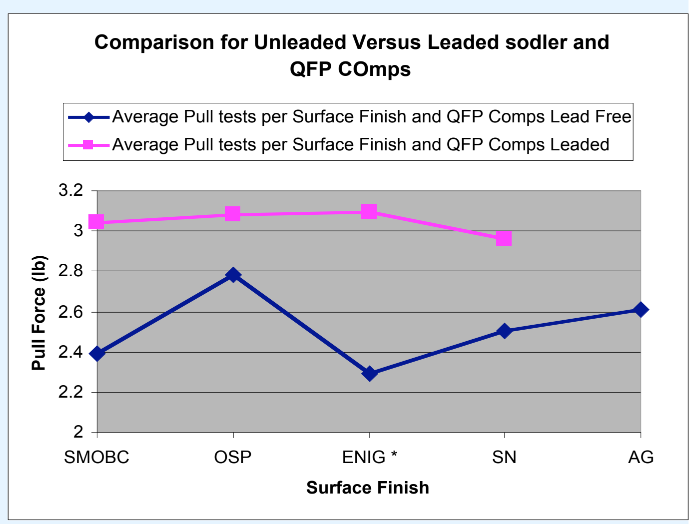


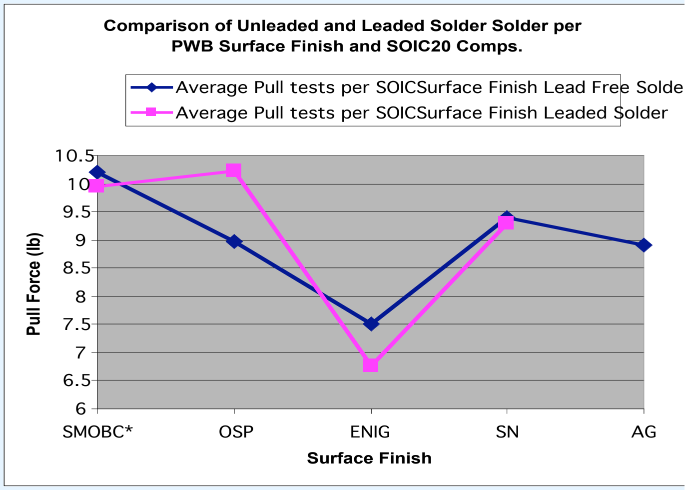
Pull tests
Average Analysis - QFP



Pull tests
Average Analysis - SOIC







QFP - SMOBC PWB Finish X (C solder, pb free) X (B solder, leaded) QFP - OSP

Pull tests Multiple Range Tests

Multiple Range tests – Homogenous GroupsCo

Pull test Conclusions - 1

The selection of materials and process affects the pull strength of the solder joints for the QFP and SOIC components tested, using components with Nickel/Palladium/Gold finish:

- .The pull forces are dependant on the footprint of the components used Thus pull forces in the SOIC were significantly higher that QFP.
- .The PWB surface finish has a significant effect on the pull test of the leads. Of the five PWB finishes (SMOBC, OSP, ENIG, Matted SN and Imm AG), ENIG was significantly lower than the other finishes in both IC's pulled. OSP was significantly higher in QFP and SMOBC/HASL was significantly higher in SOIC.
- .The solder suppliers were not important in the pull tests for the two IC types. Supplier B was slightly higher in QFP and significantly higher in SOIC 20.
- .Nitrogen was significantly higher than air reflow for QFP,
- Nitrogen not significant for SOIC.

Pull test Conclusions - 2

Comparison of unleaded solder pulls to leaded solder pulls in QFP and SOIC, using components with Nickel/Palladium/Gold finish.

- This comparison was difficult since the baseline leaded PWBs were made with a single process: that of being soldered in air with leaded solder from supplier B, and the silver surface finish baseline was not available. The data indicated that the difference is not significant in most cases when using the same solder supplier (B) for unleaded and leaded solders.

Pull test Conclusions - 3

Interchangeability of leaded and unleaded components and solders in SOIC and tin plated components pull tests.

This is an important issue for electronic component suppliers and customers, concerned about keeping a dual set of materials for different markets around the world as the technology transitions from leaded to lead free soldering. The data indicates that for the set of 7 conditions analyzed in Table 6, with 21 pair-wise tests, there is no significant difference in the pull test results. Note that the baseline condition of leaded solders and component-finishes, and the ultimate condition of lead free solders and component-finishes were not tested.

Other than lead Free

Capstone Projects at UMASS