Lead Free - Process, Reliability, and Options

Presented by
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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	205 - 213	Military/Aerospace	Panasonic
		Consumer	Hitachi
SnAgBiCu		Military/Aerospace	Panasonic (FA Controller?)
SnAgBiCuGe		Consumer	Sony
SnAgBiX	205 - 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
	Sn2.5Ag0.8Cu0.5Sb
	Sn0.7Cu
	Sn3.5Ag
	SnBiAg
	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

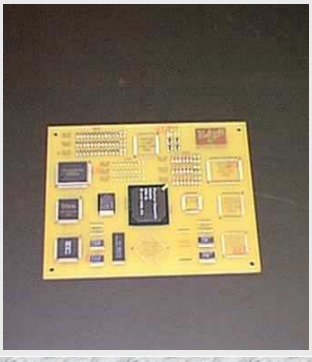
Lead Free-Research: Phase # 1

- 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;

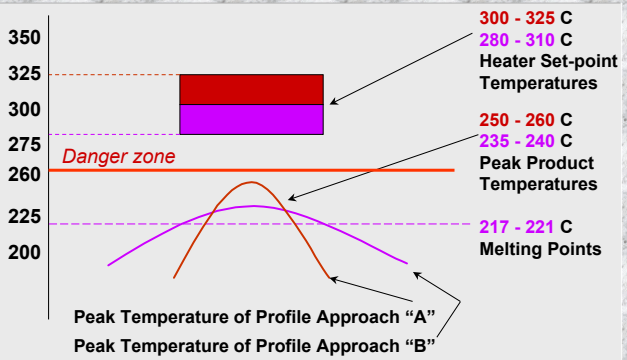
- Materials (Alloys):
  - Sn/Ag (96/4)
  - Sn/Ag/Cu (95.5/3.8/0.7)
- Flux:
  - Flux 1: No clean, high residue, high activity
  - Flux 2: No clean, low residue, medium activity
  - Flux 3: No clean, high residue, medium activity
- Profiles:
  - Low temperature conventional profile
  - High temperature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

Profiles:

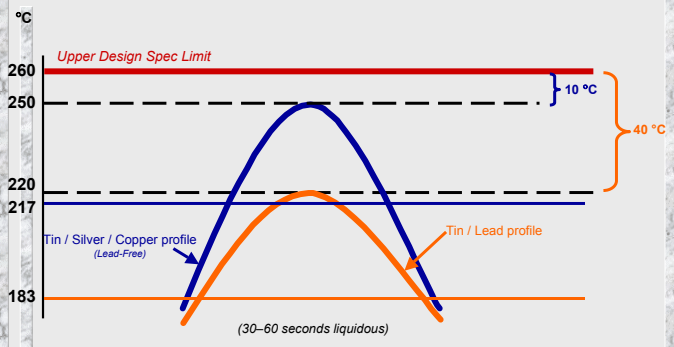
Nominal Reflow Requirements						
Profile	Preheat Ramp Rate °C/sec	Soak Temperature (150 - 170 °C)	Reflow Ramp Rate°C/sec	Peak Temperature °C	Time above liquidus 217°C	Profile Description
1	< 3	90 - 120 sec	< 3	230±5	60±15	**Conventional Low Temp**
2	<3	90 - 120 sec	<3	250±5	60±15	Conventional High Temp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

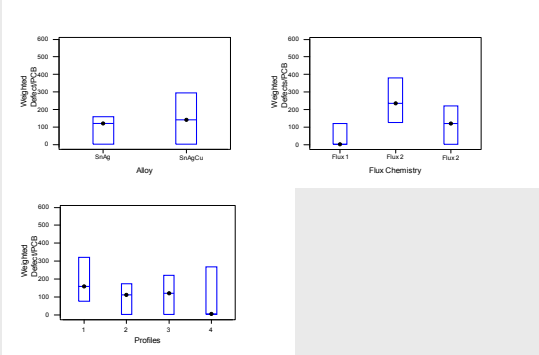
ANOVA Table For Randomized Complete Block Design

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%).

Circuit Assembly, April 2000.

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.

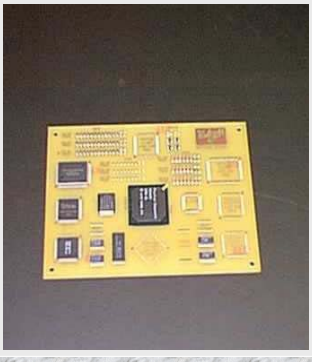
Lead Free-Research: Phase # 2

- **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	35.8827	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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