SMTA 2001

Zero Defects Lead Free Soldering

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About the Author

Dr. Sammy G. Shina,

Sam Shina, PE, BSEE, BSM, MSCS, PhD, 19 Swanson Rd., Framingham, MA 01701, is the associate professor of Mechanical Engineering at the University of Lowell, College of Engineering. Professor Shina has spent 32 years in High Technology Companies developing new products and state of the art manufacturing.

His experience range from the process design and management of Automatic Printed Circuit Board (PCB) Fabrication, assembly and test; the introduction and management of CAE/CAD/CIM and manufacturing link processes. He is a graduate of MIT, Tufts and WPI.

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Project Team

UMASS Lowell-Industry Lead Free Consortium

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- **L. Harriman, C. Pace, Toxic Use Reduction Institute**
- **C. Pace , STEP Program**
- **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
- **M. Quealy, Scnieder Automation,** Andover, MA
- **G. Wilkish and B. Anderson, MACOM,** Lowell MA.

Umass Team

" This is the most systematic approach to lead free electronics assembly, that I have come across. Work initiated by UMass Lowell team is a positive step towards lead free process optimization."

Alan Rae
Director of Technology
Cookson Electronics

Experimental setup

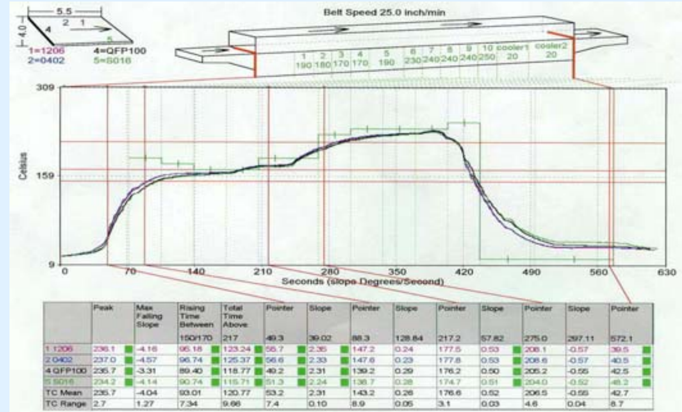
- **Lead Free: 54 Printed Wiring Boards (PWB's)**
  - **Two lead free surface finishes.**
  - **Lead free components.**
  - **lead free solders.**
- **Design of experiments; DoE**
  - **Orthogonal array L27.**
  - **one replication; 54 experiments total.**
- **Baseline: 12 Printed Wiring Boards (PWB's)**
  - **Two lead free surface finish**
  - **Lead finish components**
  - **Tin/Lead Solder**

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.

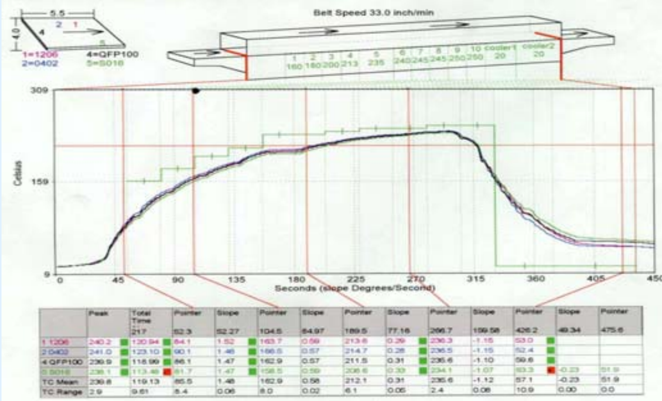
Soak Profile

(Sn/Ag/Cu with 120 sec above liquidus temp.)



Linear Profile

(Sn/Ag/Cu with 120 sec above liquidus temp.)



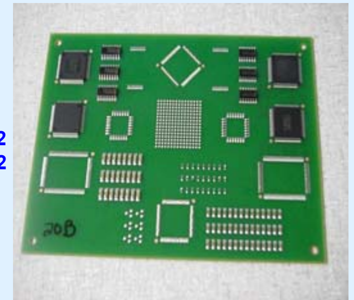
Test Vehicle: (Lead free components)

FR-4

size: 5.5”x4.0”

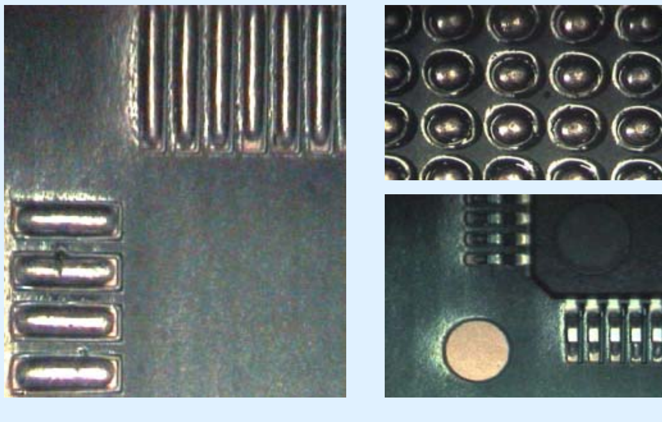
Passives
- 1206 - Qty 24
- 0805 - Qty 42
- 0402 - Qty 27

IC/Semiconductor
- LQFP120 - 0.0257 Pitch - Qty 2
- LQFP100 - 0.0157 Pitch - Qty 2
- SO14 - Qty 3
- SO16 - Qty 3



Visual Inspection

Wetting Performance



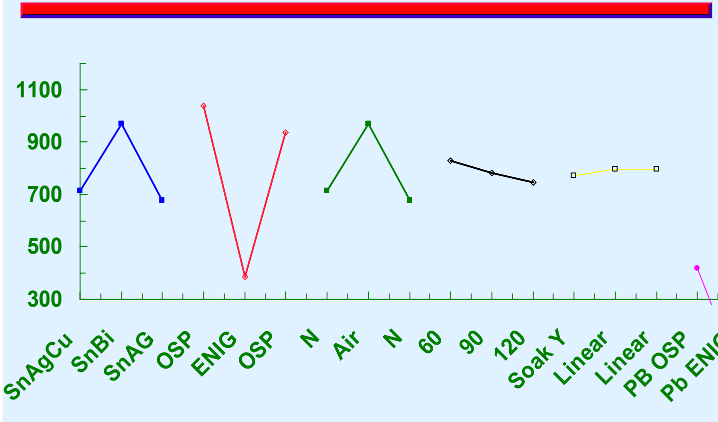
Visual Inspection

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

Lead Free Defect Results



Visual Inspection

Tin/Lead Baseline Defect 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

Visual Inspection

Anova 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

Pull Test on Ni/Pd SO14

Setup on Instron/ 45 is more desirable (+shear)

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

Visual + Pull

Conclusions

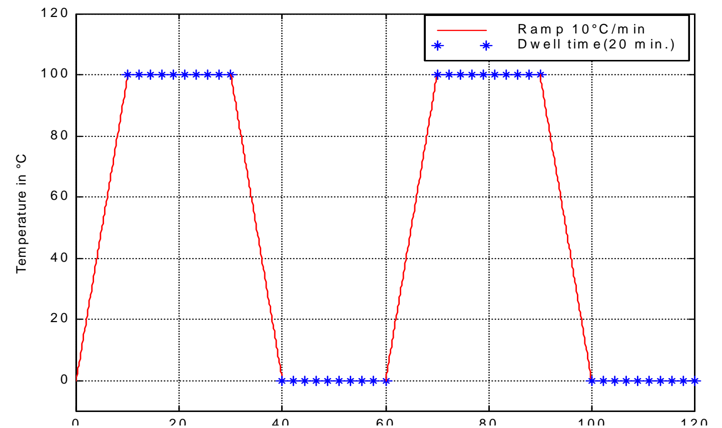
tors	Visual test	Percent contribution towards the variation of visual defects	Pull test	Percent contribution towards the variation of pull strength	Overall conclusio
der Paste Alloy	Sn/Ag/Cu or Sn/Ag	7.16%	Sn/Ag/Cu	42.89%	Sn/Ag/Cu
nponent Finsh	Ni/Pd	N/A	SO14 only	N/A	Ni/PD
B Surface Finish	ENIG	52.71%	OSP	7.43%	ENIG
rmal Profile	N/A	N/A	Linear	3.18%	Linear
e Above Liquidus	120 sec	0.57%	N/A	N/A	120 sec
low Environment	Nitrogen	10.72%	N/A	N/A	Nitrogen

Zero Defects Process

Comparison of Lead Vs Free

no.	Lead-Free PWBs	Visual Defect	Pull Strength	Tin-lead Baseline PWBs	Visual Defect	Pull Strength
1	5A	0	35.41	Pb 7	0	21.22
2	5B	0	31.83	Pb 8	0	22.27
3	6A	0	42.20	Pb 9	0	19.30
4	6B	0	30.77			
5	22A	0	27.96			
6	22B	0	31.49			
7	23A	0	29.01			
8	23B	0	34.98			
Average			32.95			20.93

Theoretical Thermal Cycling



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

Before and After Thermal Cycling

Conclusions

•For Zero Defect lead Lead Free Soldering and superior long term Joint Strength, use the following:

Materials

Lead Free Solder :	Sn/Ag/Cu
Surface Finish for PWB:	ENIG
Components Finish:	Ni/Pd

Processes

Reflow Profile:	Linear
Reflow Environment:	Nitrogen
Time Above Liquidus:	120 seconds

Future Work

•Consortium Working on 2nd phase:

Materials

New flux combinations with Sn/Ag/Cu
More component types (BGA, QFP's)
More Component finishes (Sn, SOP, Immersion)
More lead free PWB surface finishes

Processes

Reflow Environment: Nitrogen or Air

Benchmarked with Sn/Pb Lead materials Base

Cross Section of Zero Defect Test PWB 6A @ 10X Mag