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Lead Free Process Transition Solder Paste Characteristic Assessment

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Abstract
The migration to Lead Free raw materials in the Electronics Industry will happen faster than the date proposed in the original draft of the legislation. A true Pb-free solution for product such as high end and volume server and desktop requires printed circuit boards and electronic packages to be totally free of lead and compatible with the higher processing temperatures.

Raw materials such as solder paste are under stringent characteristic assessment to fulfill optimal solder joint quality and reliability in mechanical strength and lower ionic and organic residue contamination. Characteristics such as printability, stencil life & cleaning, tackiness, slump, viscosity, wetting, solderability, copper mirror corrosion, thermal optimization, SIR/EM, ionic and organic contamination etc of both no-clean and aqueous solder pastes will be studied.

A SnAgCu (SAC) alloy is emerging as the industry standard and this paper focused on the 95.5Sn3.9Ag.6Cu alloy.

This paper describes the laboratory analysis and in-process printability assessment used to characterize a number of commercially available organic acid (OA) and no clean (NC) lead free solder pastes and compare them with Sn63Pb37 baselines. The goal was to cost effectively select the best performing Pb-free pastes for further analysis with the ultimate goal of selecting a viable Pb-free replacement for the SnPb paste currently in use.

Introduction
A large number of organic acid and no clean Pb-free solder paste formulations are commercially available and an effective method of narrowing the list of viable candidates was required. In-process printability testing and laboratory analysis were selected as the primary screening mechanisms. The SnAgCu (SAC) Pb-free alloy was fixed as follows:

Constituency: 95.5Sn3.9Ag.6Cu
Mesh: Type 3
Metals content: 88% to 90% by weight.

One paste supplier would only supply the 3.0 Ag SAC variation and this was included in the assessment. Previous studies have indicated the performance of the SAC alloy is relatively insensitive to changes in Ag between 3.0 and 4.0.

Solder Paste Criteria
Major solder paste suppliers were asked to submit one Organic Acid and On No Clean solder paste sample based on the following criteria:

a) Bellcore Compliant (NC)
    a. Passes Bellcore Testing after Aqueous Wash (OA)
    b. Testing by a recognized third party is preferred
b) Passes J-Std-004
    a. Copper Mirror Corrosion (High)
    b. Silver Chromate
    c. Flourides by Spot Test
    d. Typical SIR.
    e. Testing by a recognized third party is preferred
c) Passes J-Std-005
    a. Slump Test
    b. Solder Ball Test
    c. Testing by a recognized third party is preferred

d) Good Printability (down to .4 mm)
e) 4 hour stencil life (minimum), 8 hour stencil life (preferred)
f) 20 minute Idle Time (minimum), 40-60 minutes (preferred)
g) Hydrophobic
h) Robust in the ranges of 60 degrees F to 85 degrees F and 30% RH to 70% RH
i) Ease of stencil cleaning and misprinted board cleaning (recommended equipment and/or solutions are welcome)
j) Good tackiness to hold parts in place particularly during the GSM table movements
k) Excellent wetting
l) Robust Reflow Profile
    a. Air or N2
    b. Ramp to Peak or Ramp Soak and Spike
m) Minimal solder balling and beading
n) Minimal residue after reflow, cosmetically pleasing (clear is preferred)
o) VOC compliant (mandatory), VOC free (preferred)
p) 6 month refrigerated life, 5 day room temperature life
q) Minimal voiding on area array devices (<10% preferred, < 20% required)
r) Probe testable by bed of nails or flying probe (NC = no cleaning, OA = after cleaning)
    a. State the number of hours between assembly and test?
s) NC Residue can be removed, if desired, by cleaning (recommend chemistry and equipment)
t) OA paste can be cleaned in a DI Aqueous at 140 degrees F (maximum)
u) Paste cost comparable to industry standards
v) Minimal flux buildup in reflow ovens including exhaust ductwork
w) MSDS "Health and Reactivity Rating":
    a. 2 or less is mandatory
    b. 1 or less is preferred
x) OA cleaning is compatible with closed loop DI system

Solder Pastes Selected for Evaluation

The following samples in Table 1 were provided by major paste suppliers.

Table 1 - List of Solder Pastes Evaluated

Vendor	Paste ID		
Vendor	Pb-free Organic Acid	Pb-free No Clean	Sn-Pb Baseline
1	OA-1	NC-1	n/a
2	OA-2	NC-2	n/a
3	OA-3	NC-3	n/a
4	OA-4	NC-4	n/a
5	OA-5	NC-5	Base No Clean
6	OA-6	NC-6	Base Organic Acid
7	not offered	NC-7	n/a
8	OA-8	NC-8	n/a
9	OA-9	NC-9	n/a

Notes: Vendor # 7 did not offer a lead free Organic Acid solder paste.

Laboratory Analysis

The following laboratory testing was conducted on the Pb-free pastes and their respective SnPb baselines. Changes were made to accommodate the Pb-free solder paste and are noted below.

<u>Viscosity Testing</u>

Malcolm Viscometer
10 rpm's for 3 minutes

Slump
IPC TM 650
Method 2.4.35
186 C for Pb-free/150 C for SnPb

Solder Ball
IPC TM 650
Method 2.4.43
244 C for Pb-free/208 C for SnPb

Wetting
IPC TM 650
Method 2.4.45
244 C for Pb-free/208 C for SnPb

Laboratory Results
The results are shown in Tables 2 and 3.

Table 2 - Laboratory Results for OA

Paste ID	Viscosity (cp)	Slump # of Space Violations	Solder Balling 1=good 4 =bad	Wetting (seconds)
OA-1	2760	1	4	61
OA-2	2170	6	4	180
OA-3	889	6	3	72
OA-4	1510	1	3	40
OA-5	3250	3	4	43
OA-6	1482	0	2	72
Not Applicable				
OA-8	2560	3	4	40
OA-9	3980	0	2	47
Base OA	1900	2	3	40

Table 3 - Laboratory Results for NC

Paste ID	Viscosity (cp)	Slump # of Space Violations	Solder Balling 1=good 4 =bad	Wetting (seconds)
NC-1	2570	0	2	48
NC-2	1930	11	1	91
NC-3	1611	4	2	41
NC-4	2380	0	3	95
NC-5	2170	3	2	39
NC-6	1359	0	3	112
NC-7	2370	0	2	46
NC-8	2170	8	2	41
NC-9	2600	2	2	48
Base NC	2150	0	2	16

Data from Table 2 and 3 indicated the Pb-free pastes did not perform any better in the laboratory as compared with their respective SnPb baselines. However, the data did not indicate any Pb-free pastes should be dropped from consideration.

NC-6 initially failed Slump Testing as seen in Figure 1. The root cause was traced to improper mixing of the paste at the solder paste vendors site. The vendor was allowed to properly mix additional samples and allowed to continue in the evaluation.

Figure 1 - NC-6 Slump Test

Representative results from the Wetting Test are seen in Figure 2. The Pb-free formulations exhibited significantly reduced wetting as compared with the SnPb baselines. However, because all lead free formulations exhibited the same phenomena, none were excluded from the printability testing.

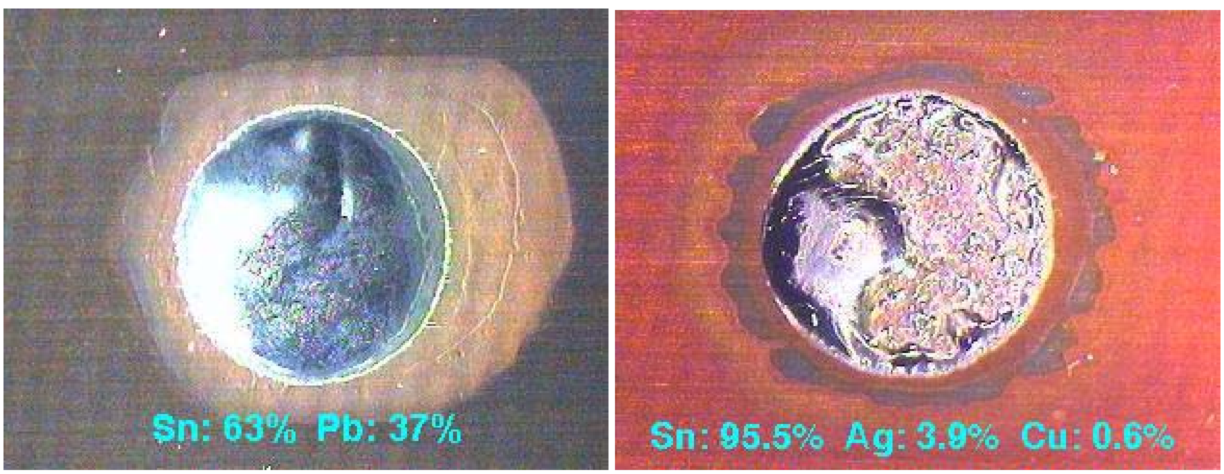

Figure 2 - Wetting Test

Figures 3, 4, 5 and 6 exhibit the range of wetting seen on the Pb-free pastes.

Figure 3 - OA-6 Example of Poor Wetting on OSP Coupon - Non-Wet and De-Wet Conditions Associated with this Paste.

Figure 4 - NC-6 Example of Poor Wetting on OSP Coupon - Non-Wet and De-Wet Conditions Associated with this Paste

Figure 5 - OA-4 Example of Good Wetting on OSP Coupon –

Note: None of the lead-free paste fell into the excellent wetting category (PB/SN baselines). Even the “good” wetting samples exhibited perimeter de-wet and some small pinhole artifacts

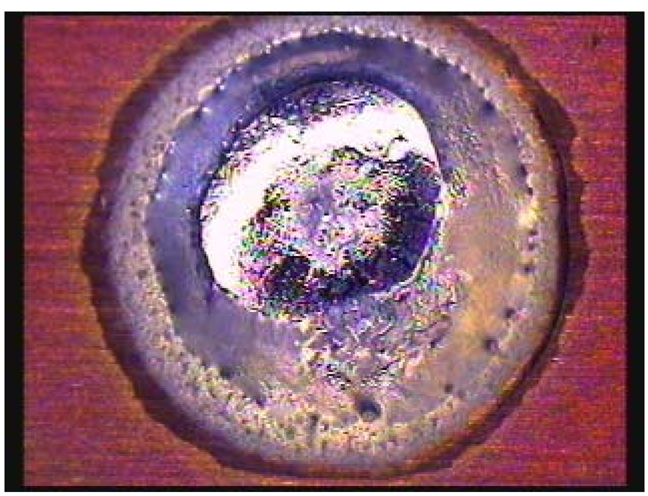

Figure 6 - NC-4 Example of Good Wetting on OSP Coupon.

Note: none of the lead-free paste fell into the excellent wetting category (PB/SN baselines) even the “good” wetting samples exhibited perimeter de-wet and some small pin-hole artifacts

Figure 7 - Baseline OA - Example of Excellent Wetting on OSP Coupon

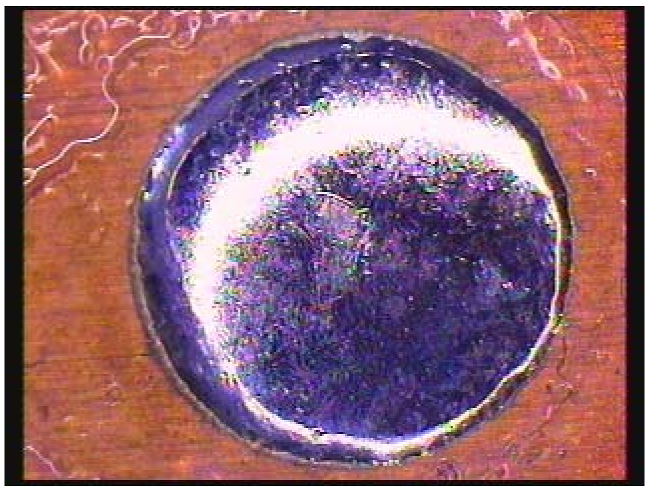

Figure 8 - Baseline NC - Example of Excellent Wetting on OSP Coupon

Figures 7 and 8 exhibit the superior wetting performance seen with the SnPb baselines. Profile optimization in an actual production environment is expected to improve the wetting performance of the Pb-free pastes.

Tables 4 and 5 summarizes the wetting results.

Table 4 - OA Wetting Summary

Paste ID	Wetting Results
OA-1	Poor
OA-2	Poor
OA-3	Poor
OA-4	Good
OA-5	Poor
OA-6	Poor
Not Applicable	
OA-8	Good
OA-9	Good
Base OA	Excellent

Table 5 - NC Wetting Summary

Paste ID	Wetting
NC-1	Poor
NC-2	Good
NC-3	Good
NC-4	Good
NC-5	Good
NC-6	Poor
NC-7	Good
NC-8	Good
NC-9	Good
Base NC	Excellent

Printability Assessment

The Benchmarker II (Ref 1) was selected as a test vehicle. Solder paste printability assessments were conducted at 3 separate BEI facilities in an effort to improve the robustness of the selections given the differences in screen print equipment, processing techniques, and atmospheres (temperature/humidity) in the respective plants. Fifteen cards were printed with a 5 minute delay between each card. Additionally, a 1 hour delay was imposed after Card #10 to simulate a production line being down. Data was collected on Cards 2, 5, 8, 10, 12, and 15 which included the number of bridges, opens, and quality of depositions. The latter was given a score of 1 for preferred, 2 for acceptable, and 3 for unacceptable. Cards 2 and 8 were subjected to a hot slump in an in-line oven with a for 2 minutes time between 170 and 190 C and any increases in bridging was recorded. This test represents the performance of the paste just before going into reflow portion of the profile. Cards 5 and 10 were selected to a cold slump of 2 hours at 30 C/80%RH in an static oven and any increase in bridging was recorded. This test assesses the performance of the paste in extreme heat and humidity.

A numerical algorithm was created to weigh and calculate scores from all 3 BEI sites. Emphasis was given to selected print features and defects. The latter for example, included a higher weight for opens as compared with bridges due to the fact opens are more difficult to detect in a production environment.

The overall score appears in Figure 9 and Figure 10. The Printer Performance Ranking and Feature Ranking consider different groups of apertures on the card, the Slump Ranking includes hot and cold slump, and the Wait Ranking assesses the impact of the 1 hour delay print delay. In all cases, the lowest ranking indicates the better performing paste.

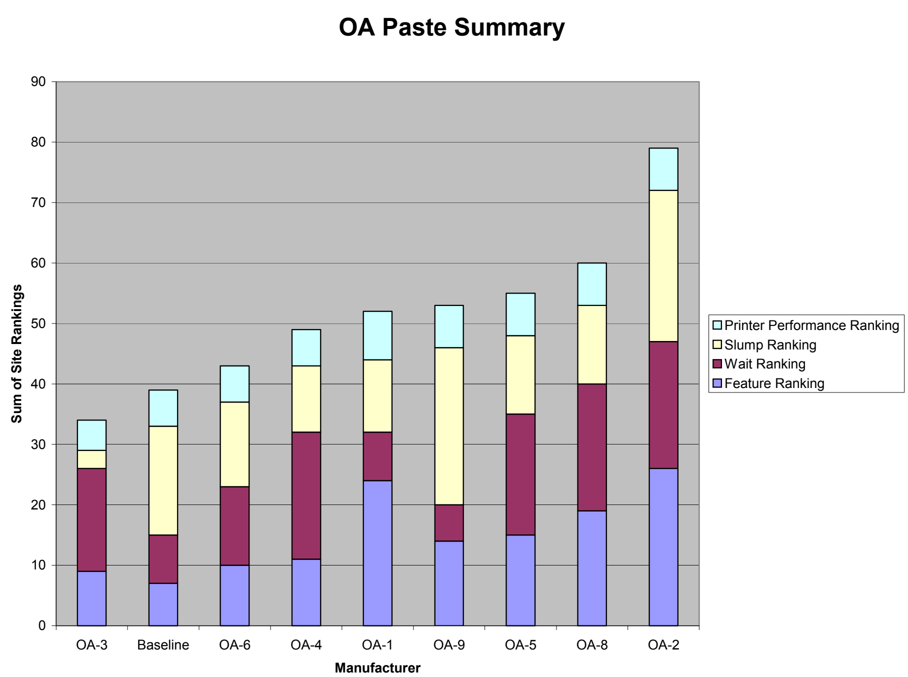

Figure 9 - OA Paste Summary

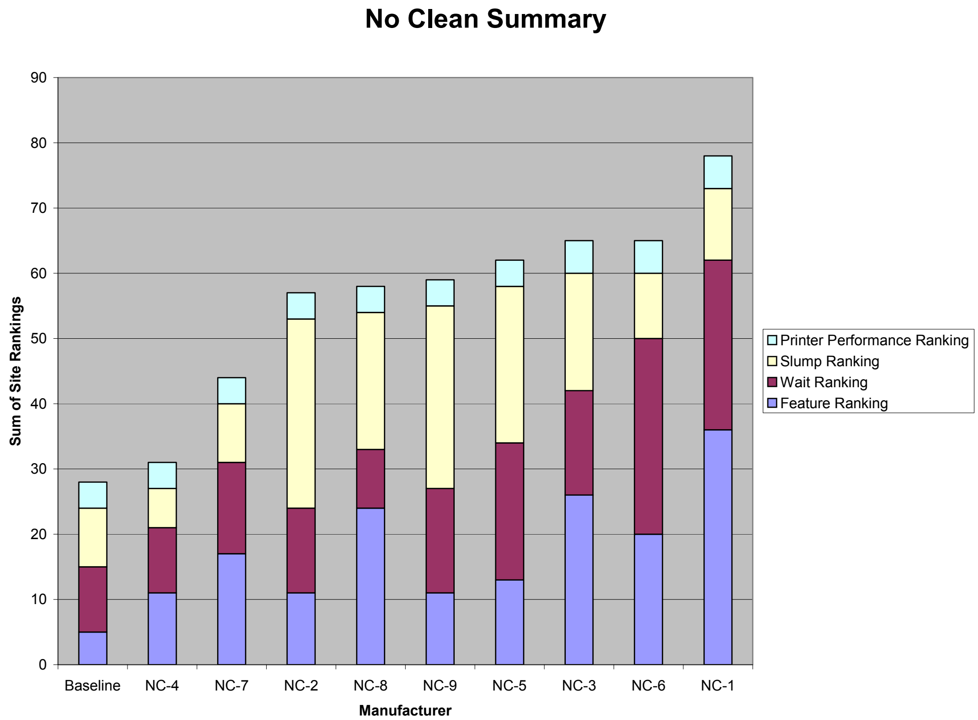

Figure 10 - No Clean Paste Summary

Note: Representative Hot Slump numbers, based on production experience, were used for the OA and NC baselines.

One OA Pb-free paste outperformed the OA baseline but none of the NC Pb-free pastes outperformed the SnPb baseline while several OA and NC Pb-free pastes came close to their respective baselines. The top 5 OA and top 5 NC Pb-free pastes, along with their respective baselines, will be subjected to additional analysis on the Benchmarker II board which will include assembly and test. Assessment criteria will include assembly defects, wetting, solder balling, BGA voiding, ICT probeability, SIR , and Ion Chromatography. The top performing Pb-free pastes will be subjected to additional analysis which will include joint cross sections, vibration, mechanical shock, and thermal cycling.

Soldering of PQFP 208 and BGA 196:
The NC-7 paste, which was the second best performing Pb-free No Clean Paste, was selected to solder the PQFP 208 and BGA 196. The following oven parameters applied:

<u>Oven Parameters for the PQFP 208 and BGA 196:</u>
Ramp to Peak Profile
1-2 C per sec Ramp
Peak Temperature = 245 C
Time above 218 = 70 seconds
10 Zone Convection Oven
Nitrogen Atmosphere

A cross section of the PQFP208 appears in Figure 11. The joint meets IPC Class 3 criteria and the reduced wetting performance seen in the laboratory work does not appear to have a detrimental impact on the joint.

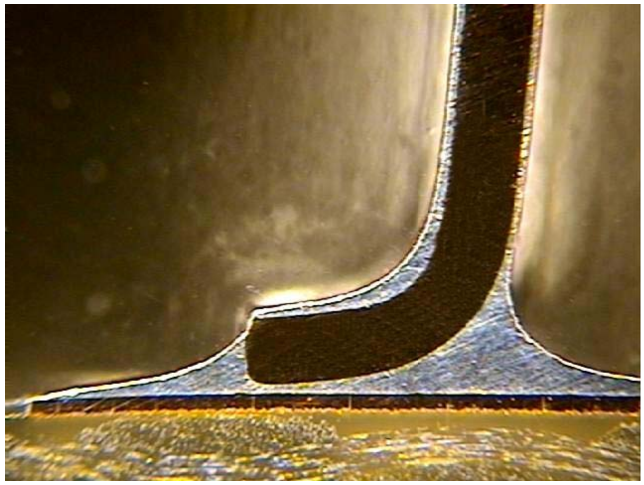

Figure 11 - PQFP208 /NC-7 Pb-free Paste
The joint meets IPC Class 3 Preferred Criteria.

The Intermetallic layer (3000X) of the PQFP208 is seen in Figure 12.

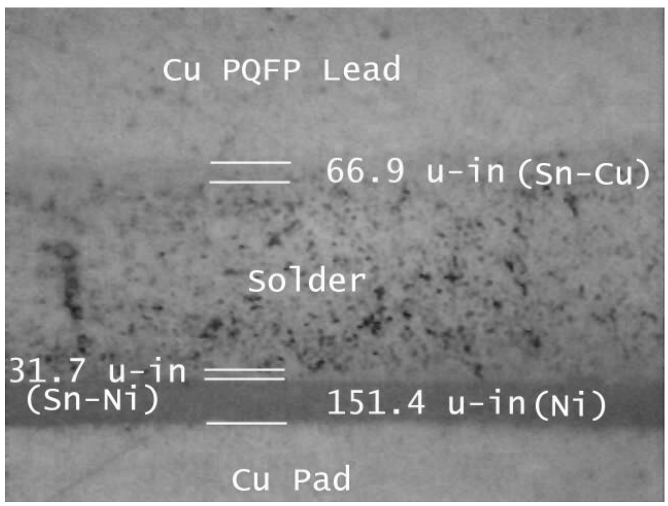

Figure 12 - Close up of Figure 11 Showing Intermetallic Layers and Bulk Solder

A cross section of the BGA196 joint appears in Figure 13.

Figure 13 - BGA 196/NC-7 Pb-Free Paste
The joint exhibits excellent wetting to the PCB pad and minimal voiding.

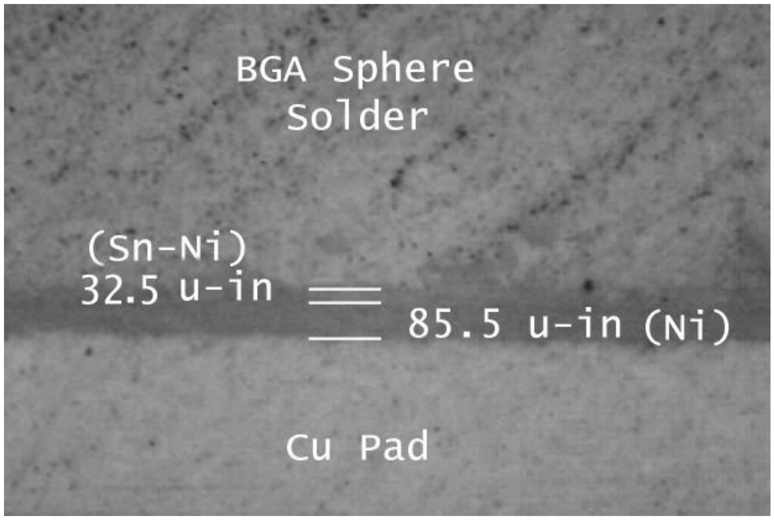

Figure 14 - 3000X View of Figure 13 Showing the Intermetallic Layer

Summary and Future Work

Laboratory Analysis and Printability Assessments were used to compare a number of commercially available Pb-free pastes with a SnPb baseline and select the higher performing pastes for additional analysis using the Benchmarker II Test Vehicle.

A larger test vehicle will also be designed to validate the performance of the top performing Pb-free pastes. The test vehicle will include mixed technology, a thicker board, higher pin count BGA's, and press fit connectors and include additional testing such as In-Circuit Test, 4 point bending, and the assessment of the installation of press fit connectors immediately adjacent to BGA's.

Acknowledgements

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References

(1) "Defining Solder Paste Performance via Novel Quantitative Methods", Richard Lathrop, Apex 2003 Proceedings.