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Board Finish Solderability with Sn-Ag-Cu

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Abstract
Lead-free soldering technology is still in its infancy with technical and cost issues posing major challenges for the industry. It is expected that soldering in a nitrogen atmosphere might overcome some of the technical barriers and provide soldered products comparable to those using conventional lead-containing materials processed in air. But quantitative data regarding the soldering behaviour of lead-free solders under various atmospheres are sparse. As part of an ongoing study on the effects of inerting on the solderability of lead-free alloys an examination has been made of the solderability, as measured in a wetting balance, of three common board finishes using a 95.5/3.8/0.7 SnAgCu solder. The board finishes used were ENIG, HASL, immersion silver and a copper OSP. To simulate typical lead-free soldering cycles the samples were subjected to multiple temperature cycles in a convection reflow oven before solderability testing using a Multicore MUST II tester. A peak reflow temperature of 250°C and an R flux was used for the ENIG and Ag finishes. The OSP finish performed poorly under these conditions and OSP testing was done using a 235°C peak temperature and a 0.5% activated R flux. During testing the atmospheres were controlled at levels of oxygen of 21% (air), 10,000, 1000 and 100ppm. Although inerting improved the solderability of all three finishes, there were differences between the individual alloys. Aging by multiple reflow cycles adversely affected the solderability of all finishes but the effects were less for ENIG than the other finishes.

Introduction
The continuing move to lead-free soldering requires technical solutions in a number of different areas. An areas that has not received much attention is that of the PCB finish. A number of finishes have been available for some time as alternatives to the ubiquitous SnPb solder levelled finish. These finishes have been developed to meet different needs than compliance with lead-free soldering, and have been driven by SM component yield issues. Fortunately the fact that lead-free finishes have been developed ahead of the lead-free issue means the industry has already alternative viable options to a SnPb finish on PCBs. While various PCB finishes have been included in various lead-free reliability evaluations, the solderability of the board finish has not been given serious consideration with lead-free solders.

Earlier work[1-5] has looked at the solderability of component finishes and pure copper, and has shown the wetting of these materials is poorer with lead-free. This reflects the higher surface tension of the lead-free alloys and the reduced ability to wet across terminations. To a significant degree this can be offset by two methods, increasing the flux activity or reducing the oxygen level. Increasing flux activity potentially creates SIR problems, and hence a valuable solution is nitrogen inerting. Inerting has been shown to be very effective in increasing the solderability with lead-free alloys to those seen with SnPb. Wetting of PCB pads is less problematic than with component terminations. With a print and reflow process the solder must wet along the component termination, but the amount of required spreading on a PCB pad is minimal. Hence the required level of wetting and spreading between components and PCBs is not the same, and so there has been less concern with wetting on PCBs. This work addresses this issue directly and quantifies the impact on PCB solderability when using lead-free alloys and the benefits of nitrogen inerting.

Solderability is typically measured using a wetting balance, and this approach was used here, but the technique was augmented by the use of spreading measurements. The degree of solderability from the spreading measurements was evaluated by printing solder paste dots with variable spacing and then measuring the degree of coalescence following reflow. Both wetting measurement approaches were used in carefully controlled atmosphere conditions.

The ageing of any PCB finish is a critical parameter and this was assessed in this study by exposing the PCBs to multiple reflows in air. By measuring the solderability of the finishes under the variously aged conditions the overall performance of the specific finishes was assessed.

Experimental

To realise the two tests a single PCB test vehicle (TB41) was designed, as shown in Figure 1. The board size was 30 X 15 mm and comprised 7 test pads for solderability testing, sized 3.8 X 1.90 mm, and 6 stripes of 25 x 0.5 mm for the dot test. Four surface finishes were applied to the PCBs, ENIG, HASL, Cu OSP (Glicoat SMD E3) and immersion Ag. The same laminate and copper etched board was used for all the finishes. All the finishes were applied by the same PCB supplier.

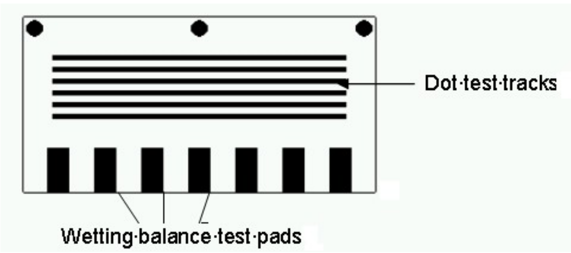

Figure 1 - Test Board

To age the solderable finishes and simulate multiple lead-free soldering profiles, samples with the ENIG, HASL and Ag finish were subjected to either 0, 2, 4 and 8 cycles in a five zone convection reflow soldering system. The reflow profile is shown in Figure 2, the peak temperature was 250°C. After 2 cycles of this profile the OSP finish did not exhibit any wetting at all. Therefore the peak reflow temperature was reduced to 235°C for all the OSP finished boards. The above was used to age the samples for the wetting balance tests, but for the spreading tests, all the tested samples were reflowed twice according to the same conditions.

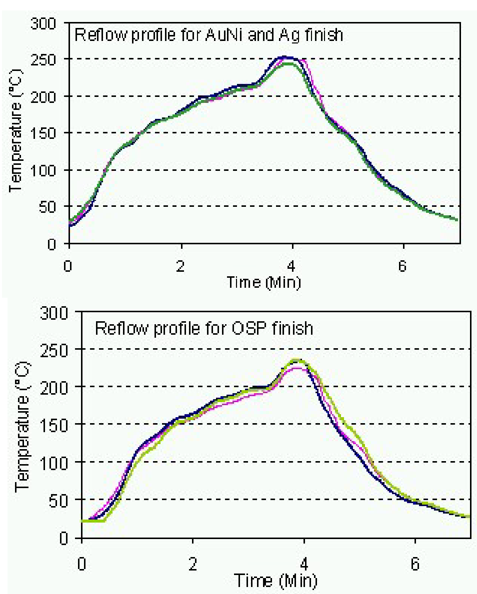

Figure 2 - Reflow Profiles for Ageing

Wetting Balance Measurements

The wetting balance was operated in the globule mode, with a solder pellet placed on the heated pin of the instrument where it formed a sessile drop. The wetting balance controller was modified so that it could drive two measurement heads, with simple switching between the two heads. One head was on the bench for normal ambient tests, whilst the second was located inside a glove box capable of operation at >5ppm partial pressure of oxygen (see). The glove box had two entry ports, both of which could be evacuated and back-filled with nitrogen to allow the introduction of samples with minimal disruption to the atmosphere. The oxygen levels were measured at the exit from the glove box, and were controlled using "Witt" gas mixing equipment. The Witt mixer was supplied with high purity nitrogen and bottled compressed air. Oxygen levels of 100, 1000, 10,000ppm and atmosphere were used.

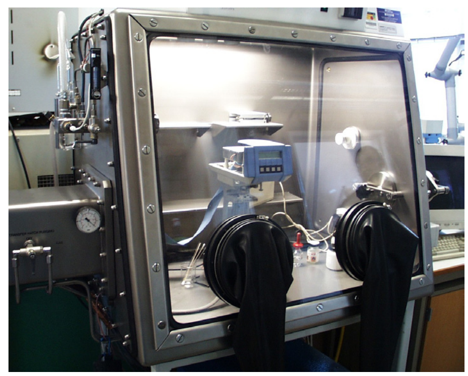

Figure 3 - Glove Box with Solderability Tester

SnAgCu solder (95.5/3.8/0.7) was used, in the form of 200 mg pellets. The solder temperature was 247°C, which represents a superheat of 30°C, a low value in a wetting test but useful for discriminating between different solderability levels. (The standard superheat in the wetting balance test for SnPb is 52°C). The immersion speed was 1 mm/s, the immersion depth 0.10mm, and no pre-heat was used. The fluxes used, were pure rosin for samples with ENIG, HASL and Ag finishes, and pure rosin with 0.5% halide for samples with OSP finish. The fluxes are in accordance with IEC 68-2-20 and were purchased from Multicore Solders as SM/NA and Actiec 5 respectively. The force data were acquired over a 10 second period. The boards were dipped at an angle of 45°. Six pads from two coupons for each combination were tested. The test results given are an average of the values for these 6 pads.

Spreading Measurements Using the Dot Test

The boards were stencil printed by hand using a DEK stainless steel mini stencil. The stencil design composed 6 tracks of square dots (0.5x0.5mm) placed with variable pitch as described in Table 1.

The gap between two adjacent stencil openings was increased by 50 μm. As the pitch increases the wetting potential can be assessed for each track by counting the number of uncoalesced dots of solder paste after reflow. The overall average from 6 tracks for each board gives a mean wetting value for either three boards with the ENIG, HASL and Ag finish or two boards of OSP finish for each recorded finish.

Table 1 - Stencil Description of Aperture Openings

Aperture No.	Pitch [mm]	Pitch [mil]	Gap [mm]	Gap [mil]
1	0	0	-	-
2	0.66	26	0.158	6
3	0.71	28	0.211	8
4	0.77	30	0.265	10
5	0.81	32	0.312	12
6	0.86	34	0.364	14
7	0.91	36	0.414	16
8	0.97	38	0.466	18
9	1.02	40	0.516	20
10	1.07	42	0.566	22
11	1.12	44	0.618	24
12	1.17	46	0.668	26
13	1.22	48	0.720	28
14	1.27	50	0.770	30
15	1.32	52	0.820	32
16	1.37	54	0.872	34
17	1.42	56	0.922	36
18	1.47	58	0.974	38

Figure 4 shows a test coupon after reflow. Two lead-free no-clean pastes were tested, Paste 1 and Paste 2. prior to printing the PCBs were aged by 2 passes in the 5 zone convection reflow oven in an air atmosphere. Two reflow profiles were used for the printed solder paste and were defined as being ‘hot’ and ‘cool’ see Figure 5. The reflow oven used was a Planar Products T-track batch reflow oven. The reflow oven was purged with liquid nitrogen from the start of the heating profile (50^0 C) to about 63^0 C and then switched to bottled nitrogen and compressed air which was mixed and controlled in Witt mixing equipment for all boards tested with nitrogen inerting. Four environmental conditions were tested: air, 10,000, 1000 and 100ppm oxygen.

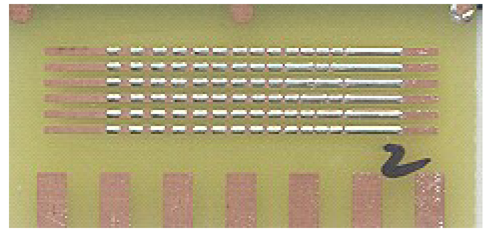

Figure 4 - Test Coupon after Reflow with Paste

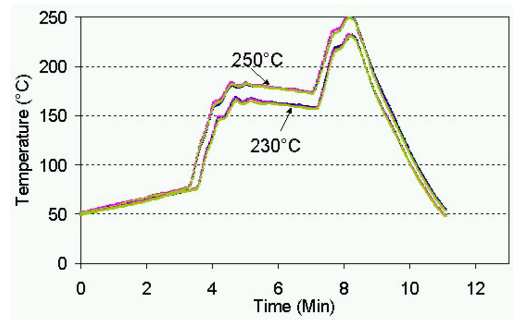

Figure 5 - Hot’ and ‘Cool’ Reflow Profiles for Processing the Solder Dots

Results

Wetting balance measurements

Figures 6 to 9 show the wetting time for the PCBs after aging with four reflow conditions in the 5 zone air circulating oven, and for four surface finishes.

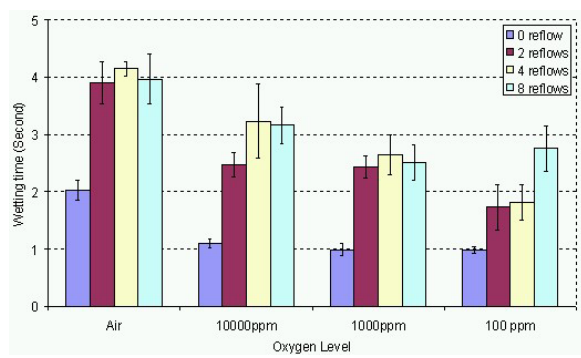

Figure 6 - The Wetting Time for ENIG Finished PCBs after Various Reflows

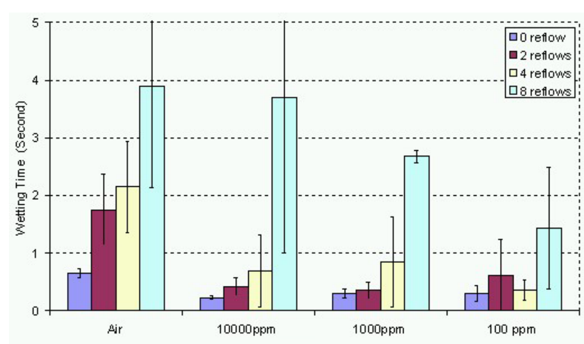

Figure 7 - The Wetting Time for HASL Finished PCBs after Various Reflows

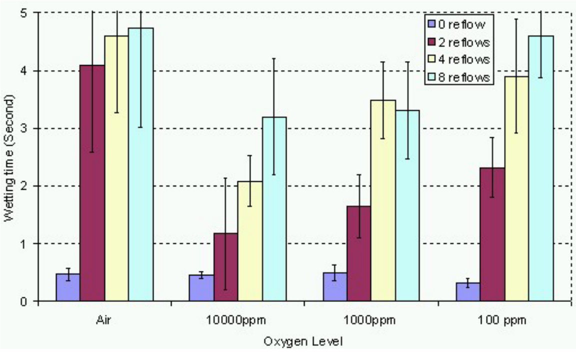

Figure 8 - The Wetting Time for OSP Finished PCBs after Various Reflows

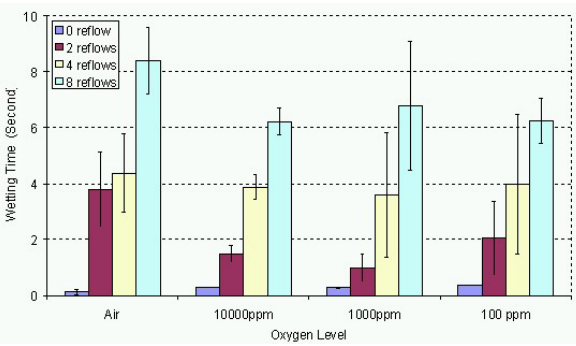

Figure 9 - The Wetting Time for Ag Finished PCBs after Various Reflows

All the results show the effect of ageing by multiple passes in the reflow oven. Interestingly for all finishes there is an overall reduction in wetting time with decreasing oxygen levels. This effect can be clearly seen in Figure 10 where the results are plotted only for the aged samples that have been reflowed four times.

Figure 10 shows the relative solderability of the finishes under these test conditions. The results clearly show that the SnPb HASL finish has superior solderability to the non-fusible coatings. The attribute of the coating melting at 183 °C with a 247 °C test is very apparent. However, even for the HASL finish the beneficial effect of nitrogen is very apparent. For the ENIG (AuNi) again the effect of nitrogen is significant, with broadly a factor of 2 reduction in wetting times, although the effect is not as strong with the as-received PCBs, as shown in Figure 6.

The OSP finish proved far more susceptible to ageing, and as mentioned before the ageing reflow profile was reduced and the flux activity increased. Hence, for the as-received PCBs good solderability was observed, but ageing had a significant effect. For ageing with two reflow passes the introduction of nitrogen had a marked effect. For ageing with four and eight reflows the solderability was generally poor for all conditions.

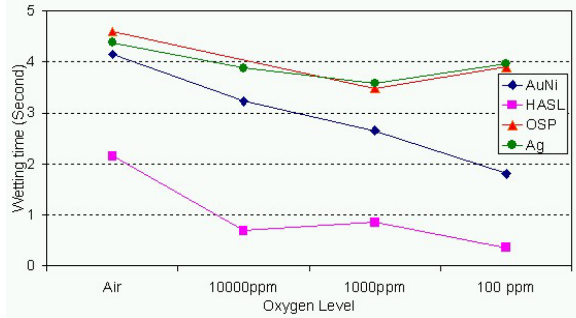

Figure 10 - Wetting Time for PCB Finishes after 4 Reflows

The Ag finish was far more robust than the OSP, but was still more susceptible to ageing than ENIG and HASL. For four and eight reflow passes there was no impact of nitrogen inerting, but for two reflows there is an important effect of inerting with a reduction of wetting

Overall from the wetting balance tests a positive effect of introducing nitrogen in reducing wetting times was observed for all the finishes when soldering with the SnAgCu alloy. From previous work on components a target value of 5000ppm oxygen was recommended, this value would clearly be of benefit, but perhaps a lower target of 1000ppm would be optimal.

Spreading Measurements Using the Dot Test

Results from solder spreading on the ENIG finish are shown in Figure 11 using paste 1. The legend refers to the ageing condition, and the reflow profile used in the soldering operation. A high number of uncoalesced dots indicate poor solderability, and the maximum numbers of dots are 18, as from Table 1. The results clearly show improvement in solderability with reducing oxygen levels.

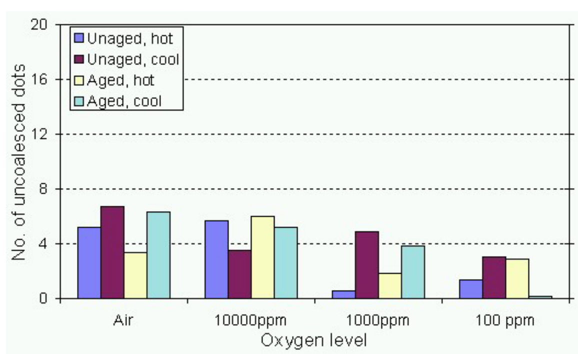

Figure 11 - Spreading Measurements for ENIG Finish and Paste 1

Overall the data did not show much difference between paste 1 and paste 2, hence the two sets were averaged for each finish. (See Figure 12.)

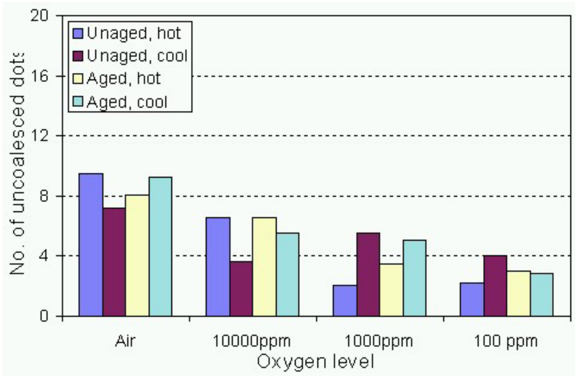

Figure 12 - Spreading Measurements for ENIG Finish, Averaged for Paste 1 and 2

The ENIG boards showed that there was a gradual improvement in solder spreading with decreasing levels of oxygen. (See Figure 13.)

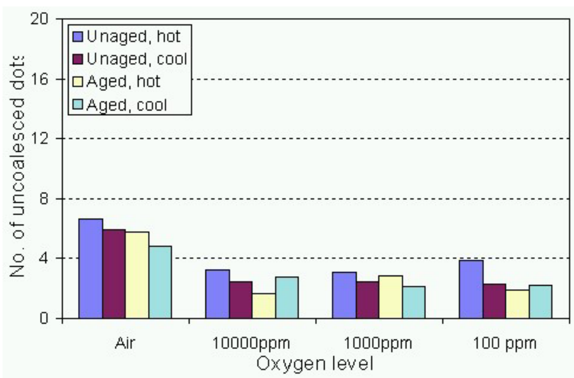

Figure 13 - Spreading Measurements for HASL Finish, Averaged for Paste 1 and 2

The HASL boards gave good results, which were significantly better than the Ag or OSP finish. A clear effect of inerting is seen. (See Figure 14.)

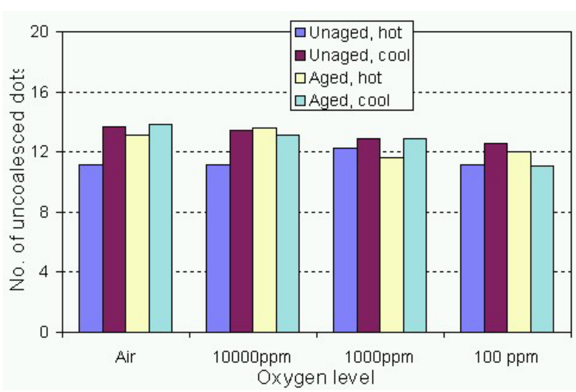

Figure 14 - Spreading Measurements for OSP Finish, Averaged for Paste 1 and 2

The OSP finished PCBs in general gave poor solder spreading for all conditions with little difference between air and nitrogen inerting. (See Figure 15.)

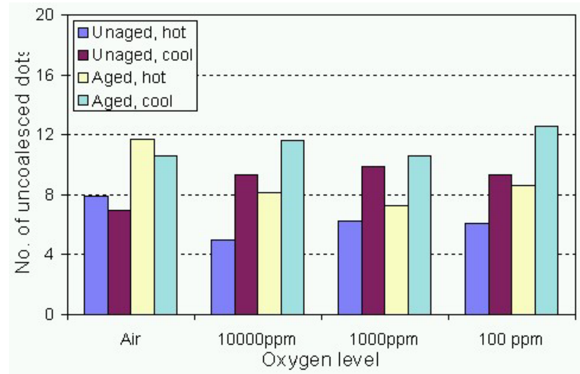

Figure 15- Spreading Measurements for Ag Finish, Averaged for Paste 1 and 2

The Ag finish boards showed little difference in solder spreading with nitrogen inerting or between paste one and two.

To summarise the data and draw more conclusions from the spreading data the effect of ageing was considered. The data were normalised across different oxygen levels and plotted for each PCB finish in Figure 16.

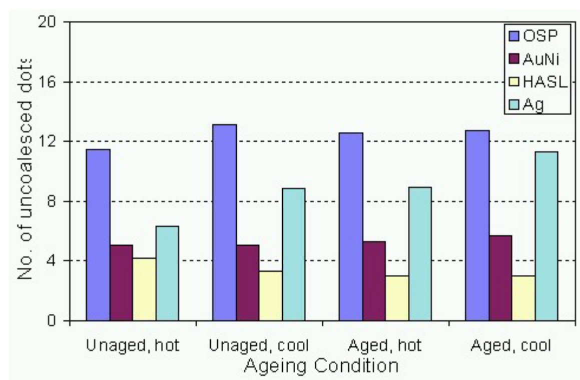

Figure 16 - Effect of Ageing after Normalising Across Different Oxygen Levels

This shows that a very similar response is seen for the different PCB finishes, with only the Ag finish showing a progressively poorer solderability with ageing. To visualise better the effect of ageing the data was averaged across the different ageing conditions and these results are plotted in Figure 17.

Figur 18 shows that inerting has a clear effect on solderability for the ENIG and HASL finish, with a small effect on OSP, and no significant influence on the Ag finish. The results in Figure 17 agree very closely with the results seen in.

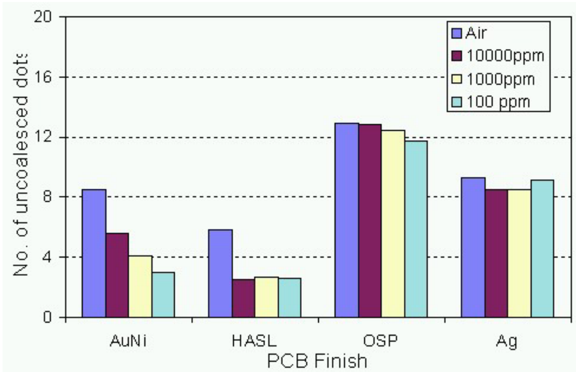

Figure 17- Effect of Inerting on PCB Finishes

Conclusions

Overall there was a clear benefit for inerting, although the magnitude of the effect was PCB specific. Both the balance and spreading measurements revealed that the effect of nitrogen inerting on wetting was very dependent upon the board finish. For the ENIG finish there was a improvement in solderability with decreasing oxygen level. For the HASL finish there was significant improvement from air to 10,000ppm, but little change at lower oxygen levels. For the OSP and Ag finishes a benefit of inerting was observed but this tended to be under specific conditions and not across all the measurements.

With the dot test, wetting over unfluxed areas is problematic, and the flux vehicle is critical in affecting spreading, and can be more important than nitrogen. Only on the ENIG finish, which presumably doesn't age significantly, does the solder spread increase with reducing oxygen levels. It is possible that nitrogen will have a more marked effect in wave soldering were all the surfaces are pre-fluxed.

Solderability was dramatically influenced by ageing in the reflow process for all 4 finishes, and proved a successful method for ageing the samples. The increased reflow cycles caused a significant reduction in solderability of the HASL, OSP and Ag finishes, but for the ENIG finish the effect of multiple reflows on solderability was less important.

The wetting balance and solder dot spread measurements agreed very well and ranked the PCB finishes and the effect of inerting in a similar fashion. This important result gives confidence in using either technique on its own to characterise solderability.

References

1. C. Hunt and D. Lea, "Solderability of Lead-free Alloys", Session P-MT2, Paper 3, Proceedings APEX2000, January 2000.
2. S.M.Adams, P. Stratton and C. Hunt, 'Atmosphere Effects on the Comparative Solderability of SnAgCu and SnPb Alloys", Proceedings SMTA/Nepcon East, Boston, June 2001.
3. Sean Adams, Paul Stratton and Chris Hunt, 'Evaluation of the Comparative Solderability of Some Lead-free Alloys", Proceedings IPC Annual Meeting, SO4-4, 2001
4. Christopher Hunt, Deborah Lea, Sean Adams and Paul Stratton, 'Evaluation of Solderability of Lead-free Alloys in Nitrogen", Session SO4-4, Proceedings APEX2002, January 2002
5. Christopher Hunt and Deborah Lea, National Physical Laboratory, Sean Adams, BOC Gases, Evaluation of the Comparative Solderability of Lead-Free Solders in Nitrogen –Part II, Session SOL2, Proceedings of SMTA International Conference, September 22 - 26, 2002