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Evaluation of Two Novel Lead-Free Surface Finishes

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Abstract
Two new electrolytically plated lead-free surface finishes, satin bright tin on nickel and palladium-cobalt on nickel followed by gold flash coating, are evaluated for their wettability, bond strength, and voiding performance, and are compared with electrolytic nickel gold and OSP. Results indicate that Ni-Sn, although being sensitive to aging, and reflow atmosphere, solder alloy type, and variation in flux chemistry, it is the highest in wettability, one of the highest in lap shear strength, and the lowest in voiding. It performs better under long profile. The high sensitivity may be attributed to the relatively high reactivity of tin. Under most instances, the soldering performance is comparable with or better than the references OSP and Ni-Au. Ni-PdCo-Au is poor in wettability, fairly low in lap shear strength, and high in voiding. However, it is fairly stable, and its soldering performance is not sensitive to profile length, reflow atmosphere, aging treatment, and flux chemistry. It does seem to be sensitive to Bi-containing alloy in terms of voiding and lap shear strength. OSP is the poorest in wettability, but one of the best in lap shear strength. It performs best under long profile. It is not sensitive to reflow atmosphere, slightly sensitive to alloy type, but is very sensitive to aging and flux chemistry. Ni-Au is good in wettability and voiding, medium in lap shear strength. It is not sensitive to aging, flux chemistry, reflow atmosphere, slightly sensitive to alloy type and profile length.

Introduction
Due to environmental concerns and fears of being left behind, lead-free soldering has quickly taken the center stage of electronic industry.[1] Although global standardization on lead-free soldering may still be far away, consensus on choices of lead-free solder alloys has gradually been developed, with SnAgCu solders being the prevailing choices.[2,3,4] Unfortunately, the same can not be said about lead-free surface finishes. Since many surface finishes still suffer from significant processes constraints, the call for a robust finish chemistry keeps driving the industry towards developing new surface finishes. In this paper, two new electrolytic surface finishes, satin bright tin on nickel and palladium-cobalt on nickel followed by gold flash coating, are evaluated for their soldering performance. The evaluation parameters include solderability, bond strength, and voiding performance, and are compared to electrolytic nickel gold and OSP finishes. The effect of differing solder alloys, reflow profile, aging treatment, reflow atmosphere, and flux chemistry on soldering performance for each surface finish will be discussed.

Experiment
Materials
The effect of materials including surface finish type, solder alloy, and flux chemistry are studied using the following materials.

Surface Finishes
Two novel lead-free surface finishes, Ni-Sn and Ni-PdCo-Au, developed by Lucent EC&S were evaluated, with two commonly used Ni-Au and OSP also tested as references. The details of those four surface finishes are described below.

<u>Ni-Sn</u>
The Ni-Sn surface finish is a 120 μ inch layer of satin bright tin electrolytically plated on a 100 μ inch nickel layer which is electrolytically plated on the base metal copper. The tin layer is comprised of large grains, with organic inclusion less than 0.004 w/w %, and exhibits the lowest propensity for tin whisker development.

<u>Ni-PdCo-Au</u>
This surface finish is composed of a 100 μ inch nickel bottom layer, a 10 μ inch 80Pd/20Co (w/w) middle layer, and a 2-3 μ inch Au top layer. All three layers are electrolytically plated.

<u>Ni-Au</u>
This reference surface finish is composed of a 10 μ inch Au layer on top of a 100 μ inch Ni layer, with both layers being electrolytically plated.

<u>OSP</u>
A commercial Entek Plus Cu-106A.

Solder Alloys
Four lead-free solders, Sn42Bi58 (SnBi), Sn91.8Bi4.8Ag3.4 (SnBiAg), Sn95.5Ag3.8Cu0.7 (SnAgCu), and Sn96.5Ag3.5 (SnAg), were used, with eutectic Sn63Pb37 (SnPb) also included as reference.

Fluxes for Solder Pastes
Flux plays a dominant role in soldering, particularly for lead-free soldering.[5] Five fluxes for solder pastes were tested, as described below. Type 3 solder powder was used for all solder pastes in this study.

<u>NCXF</u>
A no-clean halide free flux, used for SnPb solder paste.

<u>NCX</u>
A no-clean halide-containing flux, used for SnPb solder paste.

<u>NCXLF</u>
A no-clean halide-containing flux, used for SnPb, SnAgBi, SnAgCu, SnAg solder pastes.

<u>NCLT</u>
A no-clean halide-free flux, used for low temp SnBi solder paste.

<u>WSX</u>
A water soluble halide-containing flux, used for SnPb, SnAgBi, SnAgCu, SnAg solder pastes.

Processes
The effect of process including reflow profile, reflow atmosphere, and aging history on solderability are studied using the following conditions.

Reflow Profile
All solder pastes were reflowed with a forced convection inline reflow furnace BTU NP70. All profiles exhibit a tent shape, with a peak temperature 30°C above the liquidus temperature of solder alloy. Three types of profile were used, with variation in reflow time. The time taken from ambient temperature to peak temperature was set at 3, 5, and 8 minutes for short, medium, and long profiles, respectively.

Reflow Atmosphere
Both air and nitrogen reflow atmosphere (with 20 ppm oxygen) were used in this study.

Aging Treatment
The effect of solderability on soldering performance was studied by modulating the oxidation level of testing substrates prior to depositing solder paste. The oxidation level was modulated by sending the substrates through BTU furnace 0 (condition 0) and 1 (condition 3) times using a medium reflow atmosphere, 245°C peak temperature, and air reflow atmosphere. The third conditioning procedure (condition 2) was to subject the coupon to an 85°C / 85% RH environment for 24 hours prior to soldering.

Response Variables
Three response variables were measured, including wetting, lap shear strength, and voiding. The experimental procedures for those measurements are detailed below. All tests were conducted with the use of 2 inch x 0.5 inch FR-4 coupons covered with copper foils with designated surface finishes.

Wetting
To the preconditioned FR-4 coupon is printed a single row of four ¼" circles solder paste using a stencil with 10 mil thickness, as shown in Figure 1. This coupon is run through the BTU on the designated profile and atmosphere for the given alloy. The spread diameter is then determined for each solder circle, with the average value representing the wetting performance of the given condition. Figure 2 shows an example of solder circle.

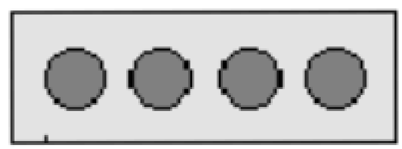

Figure 1 - Schematic of Wetting Sample

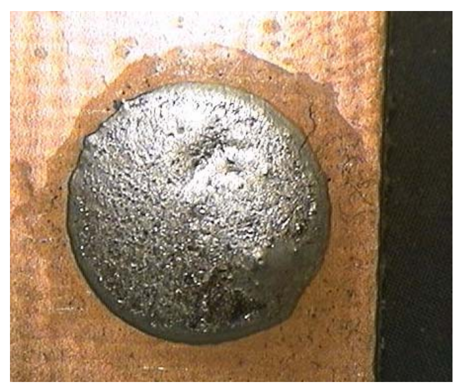

Figure 2 - Example of Solder Circle after Reflow

Voiding and Lap Shear Strength
On one end of a FR-4 coupon is printed a 0.5 inch x 0.25 inch solder paste using a stencil with 10 mil thickness. A second FR-4 coupon is placed on top of the solder paste, as shown in Figure 3. This sandwiched sample is run through the BTU on the designated profile and atmosphere for the given alloy. The voiding performance of the reflowed sample is then inspected with a X-ray inspection equipment followed by lap shear strength measurement with a MTS equipment. The voiding performance is expressed as area percentage of solder

joint. Figure 4 shows an example of X-ray picture of reflowed sample.

Results
Unless otherwise specified, all results are the average values of all systems studied.

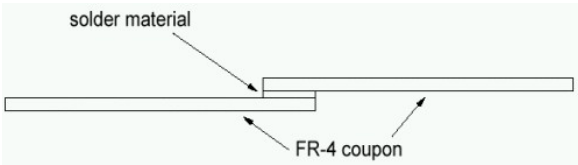

Figure 3 Schematic of Side View of Lap Shear Sample Layout

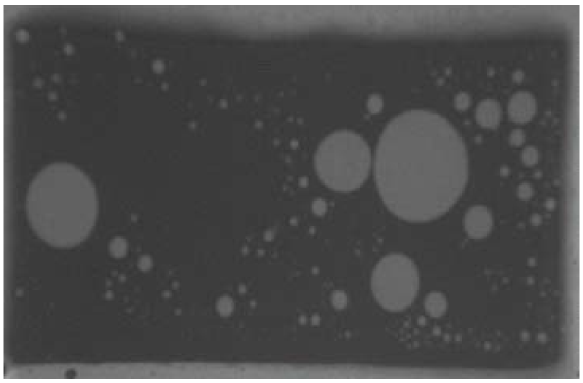

Figure 4 Example of X-ray Picture of Reflowed Sample

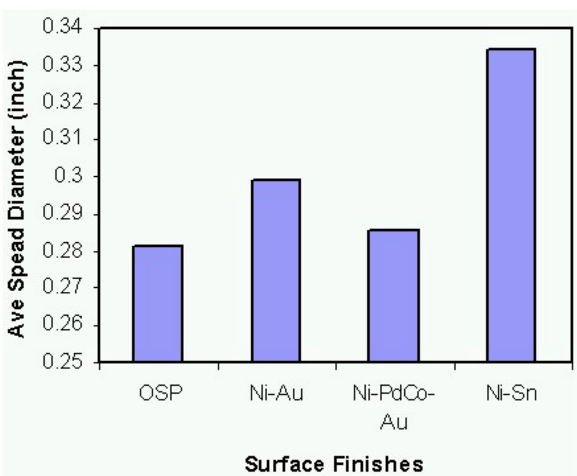

Figure 5 Effect of Surface Finish on Wetting

Effect of Surface Finish
The effect of surface finishes on soldering performance is studied by comparing the overall average performance for each surface finish.

Wetting
The effect of surface finish on wetting is shown in Figure 5. Ni-Sn exhibits the best wettability, followed by Ni-Au. Ni-PdCo-Au is slightly better than OSP, and both are considerably poorer than Ni-Au.

Lap Shear Strength
The effect of surface finish on bond strength is shown in Figure 6. Ni-Sn is comparable with OSP. Both are considerably better than Ni-Au which in turn is better than Ni-PdCo-Au.

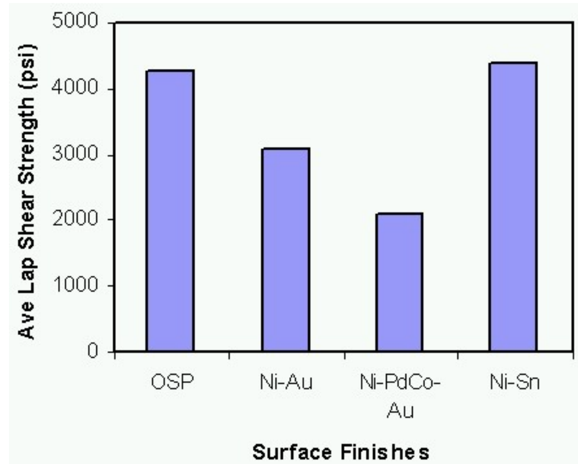

Figure 6 - Effect of Surface Finish on Bond Strength

Voiding
The effect of surface finish on voiding is shown in Figure 7. Ni-Sn is comparable with both Ni-Au and OSP. However, Ni-PdCo-Au is significantly poorer than the rest.

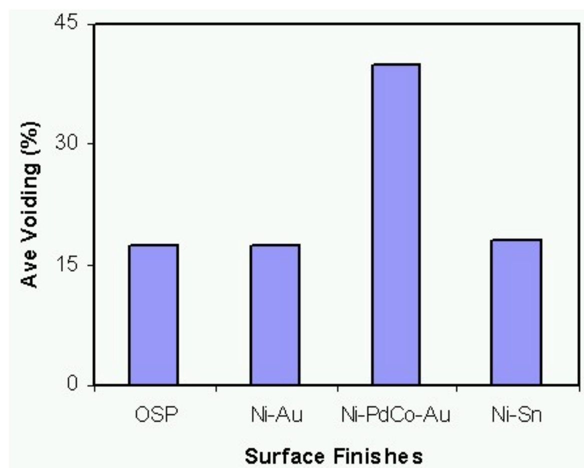

Figure 7 - Effect of Surface Finish on Voiding

Effect of Profile Length
Wetting
The effect of profile length on wetting is shown in Figure 8. Short profile results in the poorest wetting. This is attributed to a shorter fluxing time compared with a longer profile. Sensitivity of wetting toward profile length decreases in the following order: Ni-Sn > Ni-Au > OSP > Ni-PdCo-Au. However, it should be noted that further increase in profile length not necessarily causes a further increases in wetting, as reflected by comparing the wetting results of medium profile with long profile.

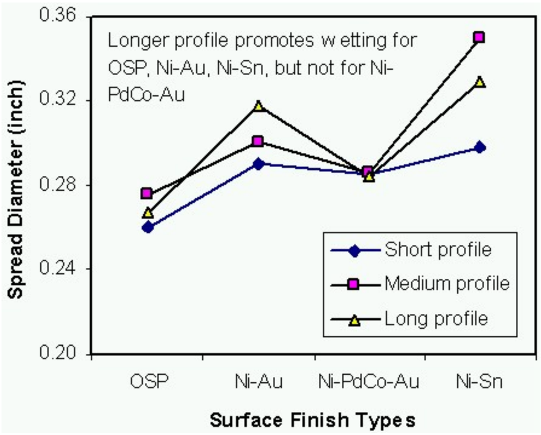

Figure 8 - Effect of Profile Length on Wetting

Lap Shear Strength

Figure 9 shows the effect of reflow profile length on bond strength. The lap shear strength increases with increasing profile length. Since a longer profile results in a better wetting, as discussed above, and a better wetting (or spreading) can result in a thinner bondline thickness, relation in Figure 9 suggests the lap shear strength may be a function of bondline thickness, and the shear strength increases with decreasing bondline thickness. A longer reflow profile may also promote a more intimate contact between solder and base metal, and consequently result in a higher shear strength. Ni-Sn appears to be more sensitive to the profile length than others, as shown by the wider data spread in Figure 9.

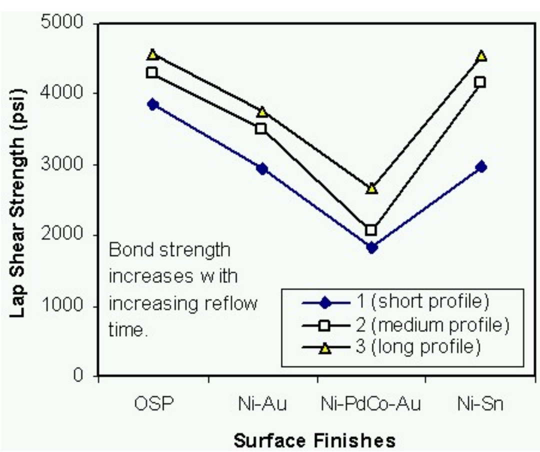

Figure 9 - Effect of Profile Length on Bond Strength

Voiding

The effect of profile length on voiding can be reflected by Figure 10. Although some data scattering is observed, generally the void content decreases with increasing profile length. This is consistent with the better wetting and higher strength associated with a longer profile discussed above. The sensitivity of voiding toward profile length decreases in the following order: Ni-Sn > OSP > Ni-PdCo-Au > Ni-Au.

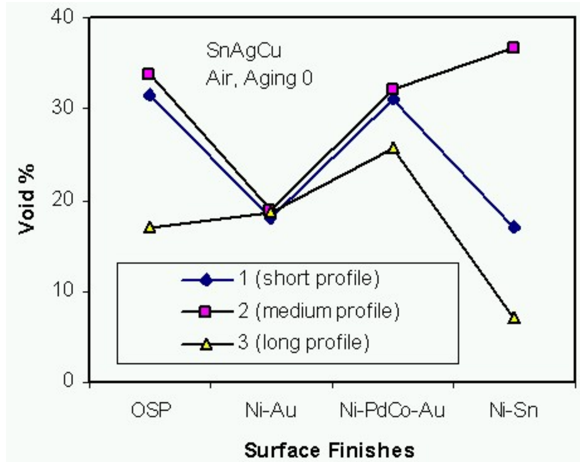

Figure 10 - Effect of Profile Length on Voiding for SnAgCu System with Aging 0 and Air Reflow Atmosphere

Effect of Reflow Atmosphere

Wetting

Figure 11 shows the relation between reflow atmosphere and wetting. Use of nitrogen provides a better spread for Ni-Sn system, but negligible effect for the rest three systems.

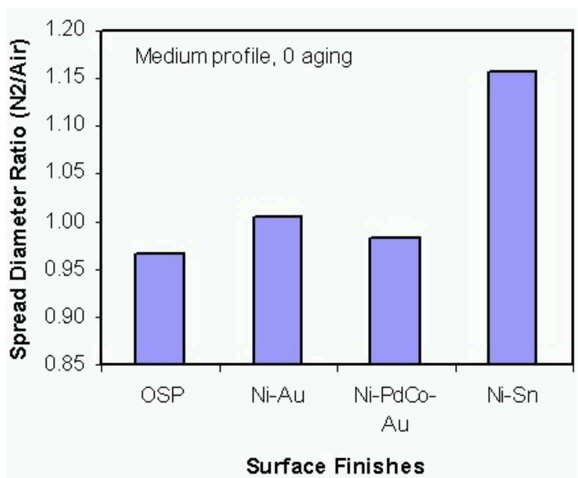

Figure 11 - Effect of Reflow Atmosphere on Wetting - A Ratio Value Greater than One Indicates a Positive Effect of Nitrogen.

Lap Shear Strength

Reflow atmosphere in general exhibits a slight positive effect on the lap shear strength of joints, as indicated in Figure 12.

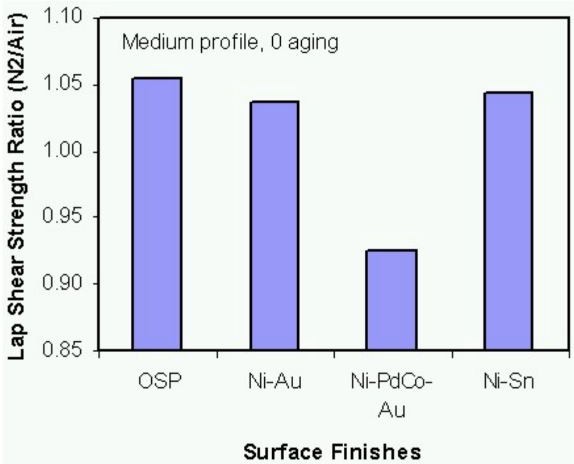

Figure 12 - Sensitivity of Lap Shear Strength Toward Reflow Atmosphere for System with Medium Profile and Aging 0 Treatment

Voiding

The effect of reflow atmosphere on voiding is shown in Figure 13 for a system with medium profile and aging 0 treatment. Except for Ni-Sn system, presence of nitrogen causes an unexpected adverse effect on voiding. Perhaps this phenomenon can be explained by bondline thickness effect. When reflowed under nitrogen, more solder may wick out from the sandwiched joint area, and possibly result in a thinner bondline thickness. A thinner bondline thickness has been reported to cause a higher voiding due to a greater difficulty for the volatiles to escape.[6]

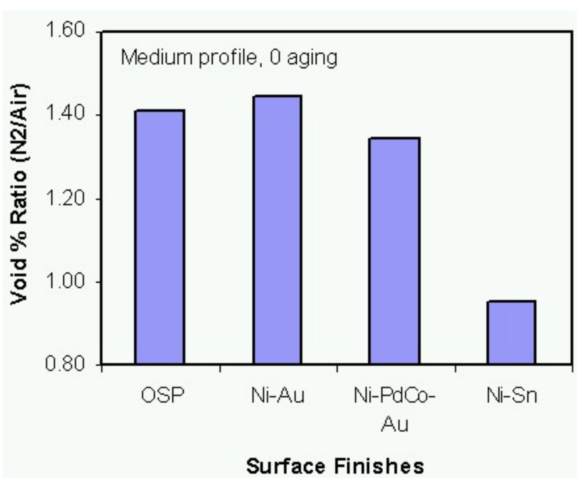

Figure 13 - Effect of Reflow Atmosphere on Voiding for a System with Medium Profile and Aging 0 Treatment

Effect of Alloy

Wetting

The effect of solder alloy on wetting is shown in Figure 14. SnPb solder generally wets better than the Pb-free alloys. Most of the Pb-free alloys are comparable in wetting, except that SnBi displays an exceptionally high spread for Ni-Sn system. Overall, Ni-Sn is more sensitive to alloy type than other surface finishes.

Lap Shear Strength

The effect of solder alloy on lap shear strength is shown in Figure 15. In general, the shear strength of alloys can be ranked as below: SnPb > SnAgCu, SnAg > SnAgBi, SnBi. Ni-PdCo-Au appears to be more sensitive to alloy variation, and the shear strength doubles when the solder is changed from SnBiAg to SnPb.

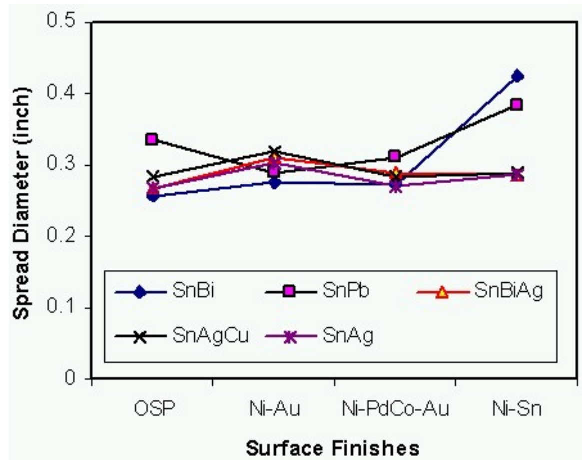

Figure - 14 Effect of Solder Alloy on Wetting

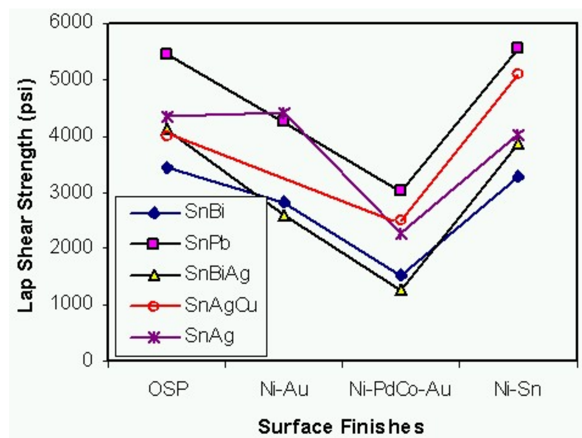

Figure 15 - Effect of Solder Alloys on Lap Shear Strength

Voiding

Effect of solder alloys on voiding is shown in Figure 16. SnAgCu and SnAg show a high void content, and is not sensitive to the surface finish type. SnPb exhibits the lowest void content. SnBi is also low in void content except in the case of Ni-PdCo-Au. SnBiAg exhibits an exceptionally high void content for Ni-PdCo-Au. The coincidence of high void content for both Bi-containing alloys suggests that Ni-PdCo-Au may be sensitive to the presence of Bi in terms of void formation.

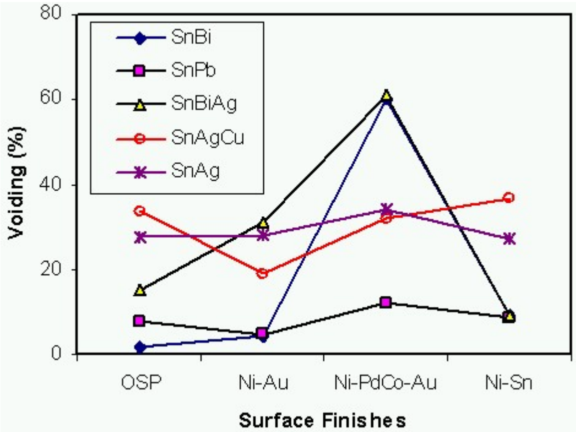

Figure 16 - Effect of Solder Alloys on Voiding

Effect of Aging on Wetting

Figure 17 shows the effect of aging on wetting. For Ni-Sn and OSP systems, aging treatment results in a considerable decrease in wetting, suggests that both finishes are sensitive to oxidation. Aging 2 shows comparable effect as aging 1, indicating the oxidation state may be stabilized after one pass through reflow furnace.

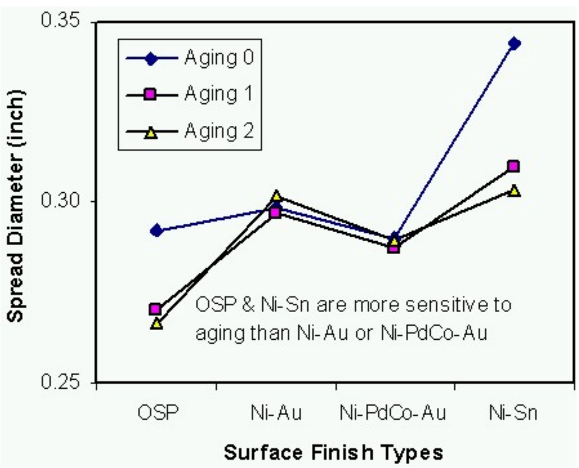

Figure 17 - Effect of Aging on Wetting

Effect of Flux Chemistry on Wetting

The effect of flux chemistry on wetting is shown in Figure 18 for system with SnPb alloy, medium profile, air reflow, and no aging treatment. Both Ni-Sn and OSP are sensitive to the variation in flux type. The sensitivity toward flux type can be ranked as below: Ni-Sn > OSP > Ni-Au, Ni-PdCo-Au.

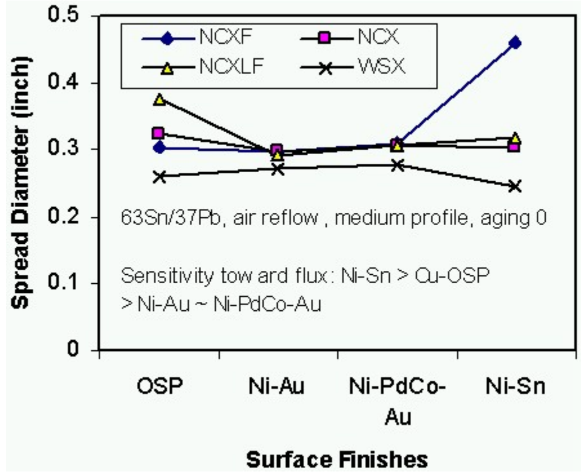

Figure 18 - Effect of Flux Chemistry on Wetting

Discussion

In general, it is expected that solder joints with a higher void content will display a lower joint strength. This relationship can be used to review and validate the trends observed in this study. A system with SnBiAg is examined, with relationship between void content and lap shear strength shown in Figure 19. In general, a good correlation can be observed, with lap shear strength decreases with increasing void content, thus confirmed the findings in this work.

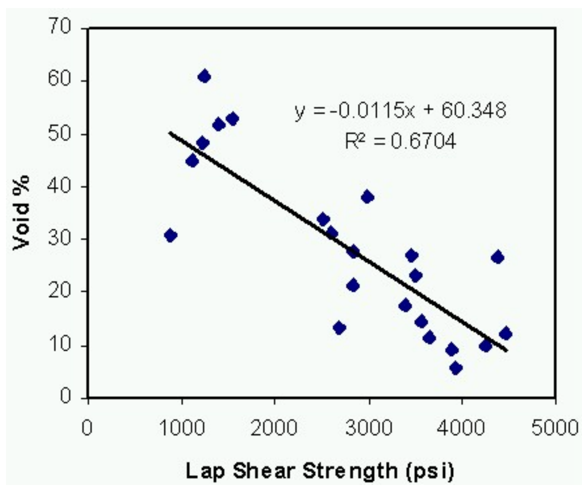

Figure 19 - Relation between void content and lap shear strength for SnBiAg system.

Conclusions

The newly developed electrolytical satin bright tin Ni-Sn by ECS, although being sensitive to aging, reflow atmosphere, solder alloy type, and variation in flux chemistry, it is the highest in wettability, one of the highest in lap shear strength, and the lowest in voiding. It performs better under long profile. The high sensitivity may be attributed to the relatively high reactivity of tin. Under most instances, the soldering performance is comparable with or better than the references OSP and Ni-Au.

Another newly developed electrolytical Ni-PdCo-Au is poor in wettability, fairly low in lap shear strength, and high in voiding. However, it is fairly stable, and its soldering performance is not sensitive to profile length, reflow atmosphere, aging treatment, and flux chemistry. It does seem to be sensitive to Bi-containing alloy in terms of voiding and lap shear strength.

OSP is the poorest in wettability, but one of the best in lap shear strength. It performs best under long profile. It is not sensitive to reflow atmosphere, slightly sensitive to alloy type, but is very sensitive to aging and flux chemistry.

Ni-Au is good in wettability and voiding, medium in lap shear strength. It is not sensitive to aging, flux chemistry, reflow atmosphere, slightly sensitive to alloy type and profile length.

Acknowledgement
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Rererence

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