Evaluation of Nickel/Palladium/Gold-Finished Surface-Mount Integrated Circuits

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ABSTRACT

Texas Instruments has introduced a refined version of its nickel/palladium (NiPd) finish for integrated circuit (IC) package leads. The enhanced version of lead finish is nickel/palladium/gold (NiPdAu).

TI has a long and successful history with the NiPd finish. There are more than 40-billion devices in the field with TI NiPd-finished leads. TI introduced the NiPd finish in 1989 and many papers and studies have been published on it. With the push for Pb-free electronics, TI decided to improve on the NiPd finish performance with Pb-free solders. The result is the NiPdAu finish.

In September 2000, results were published for solderability tests on NiPd-finished components using several Pb-free solder pastes that showed good performance. In that work, preliminary data showed the excellent performance of NiPdAu component lead finish with both a SnPbAg (control) solder and a SnAgCu (Pb-free) solder.

More extensive results are shown in this application report indicating good wetting performance of the NiPdAu-finished ICs (dual-inline and quad package styles) with both SnPbAg and SnAgCu solder alloys. Wetting balance tests showed quicker wetting time for NiPdAu-finish component leads versus NiPd and SnPb component leads. Visual inspection of solder joints made with NiPdAu-finished leads all gave acceptable wetting performance, based on industry-standard criteria. Cross-sections of the solder joints confirmed good wetting performance. Lead-pull test results were acceptable for all three component finishes with both solder alloys and two different Pb-free printed wiring board (PWB) finishes.

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Introduction

A nickel/palladium (NiPd) finish for integrated circuit (IC) leads was first introduced in the late 1980s.[1,2] To date (July 2001), more than 40-billion NiPd-finished IC packages are in the field. The four-layer NiPd structure is shown in Figure 1.

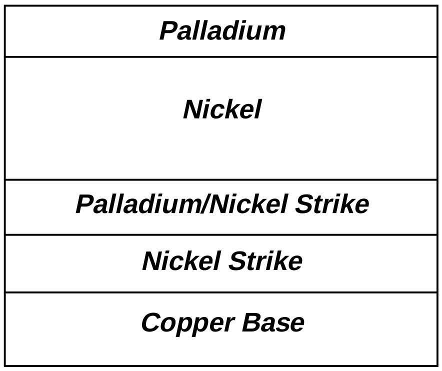

Figure 1. Metal Stackup for TI Four-Layer NiPd Structure

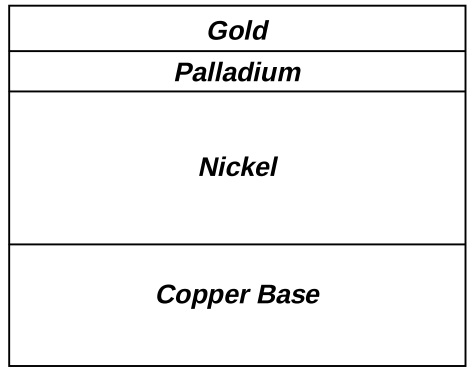

Figure 2. Metal Stackup for Three-Layer NiPdAu Finish

In the early 1990s, a nickel/palladium/gold (NiPdAu) lead finish was introduced in the Japanese market. This standardized three-layer NiPdAu finish is shown in Figure 2. Plating-layer thicknesses for TI versions of both finish systems are available upon request.

Since its introduction, many Japanese IC users have opted to use the NiPdAu finish. A key technical attribute of the NiPdAu finish is its enhanced wetting performance in solderability tests. This has made the NiPdAu finish preferred in the Japanese market. Faster wetting times in solderability tests may indicate improved wetting with the variety of Pb-free solder alloys currently being evaluated by the electronics industry.

With the interest in Pb-free processing that developed through the mid-1990s, the need for Pb-free package terminations became evident.[3,4,5,6,7,8,9] Because NiPd and NiPdAu are Pb-free finishes, use of either on components, in conjunction with a Pb-free solder alloy and organic solderability preservative (OSP) printed wiring board (PWB) pad finish, yields a Pb-free solder joint. Two previous studies have been performed to evaluate a Pb-free solder joint formed by using four-layer NiPd-finished IC components along with various Pb-free solder paste alloys and an OSP PWB surface finish.[10,11] A limited number of NiPdAu-finished units also were included in those previous studies for solder-wetting comparison.

Those studies showed that NiPd and NiPdAu finishes achieved equivalent, or better, lead-pull and temperature-cycle results versus SnPb plated component leads (control). Any difference in performance of the different lead finishes (SnPb, NiPd, NiPdAu) was merely visual.

The interest in use of the NiPdAu finish for component leads sparked its evaluation with the industry-preferred Pb-free solder alloy, SnAgCu, which is presented here.

Experiment

The Pb-free solder alloy chosen for this evaluation was 95.5Sn/3.9Ag/0.6Cu. This alloy has been recommended by the National Electronics Manufacturing Initiative (NEMI) as a “standardized Pb-free solder alternative.”[12] The decision was made to focus on performance of the NiPdAu finish components with the SnAgCu solder alloy because this alloy is becoming the predominant Pb-free paste being used.[13] The control paste chosen for comparison was 62Sn/36Pb/2Ag. Melting point and peak reflow temperatures used for the two paste alloys are shown in Table 1.

Table 1. Solder Alloys Evaluated

ALLOY	MELTING POINT (°C)	PEAK REFLOW USED (°C)
62Sn/36Pb/2Ag	179	225
95.5Sn/3.9Ag/0.6Cu	217	235

For the SnAgCu alloy, NEMI has indicated that:

> “use of the recommended alloys will raise the melting point by as much as forty degrees, which obviously has an impact on a number of the materials and steps in the assembly process, and affects companies throughout the supply chain.”[12]

Peak reflow temperature of 260°C has been mentioned as worst case across the industry for the SnAgCu alloy. For this evaluation a peak reflow temperature of 235°C was chosen to characterize performance of the SnAgCu alloy at a lower peak reflow temperature. Skidmore reported that the best results were obtained using a linear profile at 235°C peak when evaluating the solder alloy, flux chemistry, and profile.[14] Previous evaluations of SnAgCu solder alloy with NiPd-finished components indicated no difference in wetting performance between units soldered in a 235°C peak temperature and units soldered in a 260°C peak temperature.[11]

Test methods used in this evaluation included wetting balance, visual appearance examination, lead-pull, and solder-joint cross-section. The various components used in these tests are shown in Table 2.

Table 2. Components Used in Test

PIN COUNT	LEAD PITCH	PACKAGE DESIGNATOR	PACKAGE STYLE
20	1.27 mm	NS	Dual inline
176	0.4 mm	PBL	Quad
176	0.5 mm	PGF	Quad
208	0.5 mm	PDV	Quad

Wetting Balance Test

The wetting balance (meniscograph) test can be used to test wettability of IC leads. However, the wetting balance test is classified in ANSI/J-STD-002 as a “Test without established Accept/Reject Criterion.”[15] This test method is recommended for engineering evaluations only, not as a production pass/fail monitor.

The wetting balance test measures the forces imposed by the molten solder on the test specimen as the specimen is dipped into and held in the solder bath. This wetting force is measured as a function of time and is plotted. A typical wetting balance curve is shown in Figure 3. Initially, the force is negative, indicating that the solder has not yet begun to wet the specimen and, in fact, shows a buoyancy effect. The force exerted by the solder approaches zero as the solder begins to wet the specimen. One commonly used performance measure is the time to cross the zero axis of wetting force, or t_0. This point indicates the transition from nonwetting ($F < 0$) to wetting ($F > 0$).

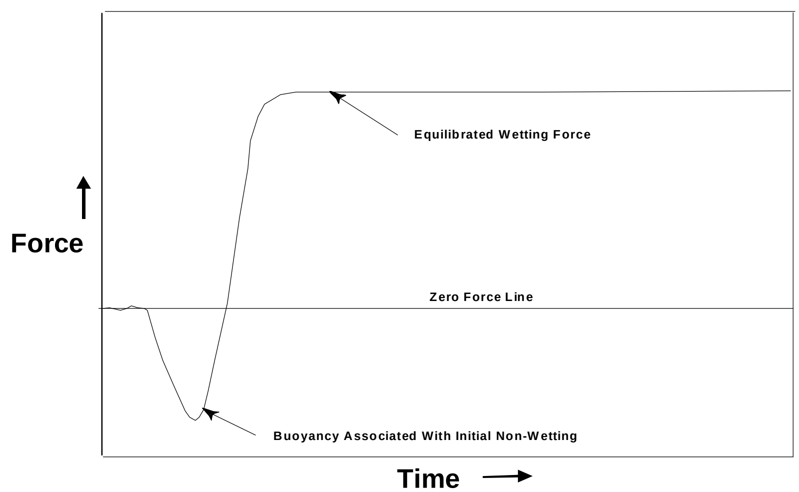

Figure 3. Typical Wetting Balance Curve

The wetting balance test was used to compare wetting performance of the three component lead finishes used in this experiment. The NS (dual-inline) package style was used for wetting balance tests. Samples of each component lead finish were tested and the wetting balance curve for the combined readings was plotted. Figures 4 through 6 show the curves for SnPb, NiPd, and NiPdAu, respectively. The three component lead finishes were tested with both SnPb and SnAgCu solder globules.

The two evaluation criteria are time-to-zero, t_0, and time to two-thirds maximum force, $t_{2/3}$. t_0 (as described previously) is the transition point from nonwetting to wetting, indicated when the force curve crosses the zero axis. Time to two-thirds maximum force is an arbitrary metric used to compare total wetting time between samples.

Notice that the wetting balance curves for the NiPdAu-finish samples (Figure 6) show quicker time to cross the zero axis and less variation in the maximum force when compared with SnPb and NiPd component finishes. Similar results were seen when a SnPb solder globule was used.

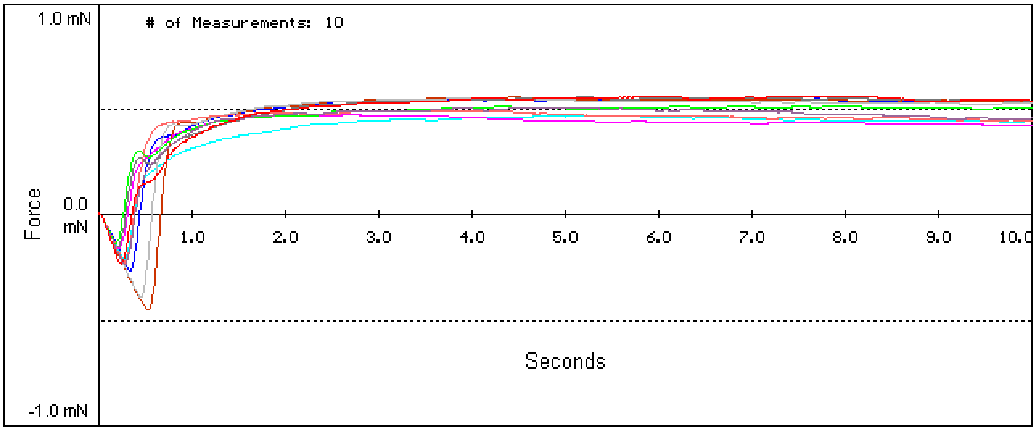

Figure 4. Wetting Balance Curves for SnPb Component Finish With SnAgCu Solder

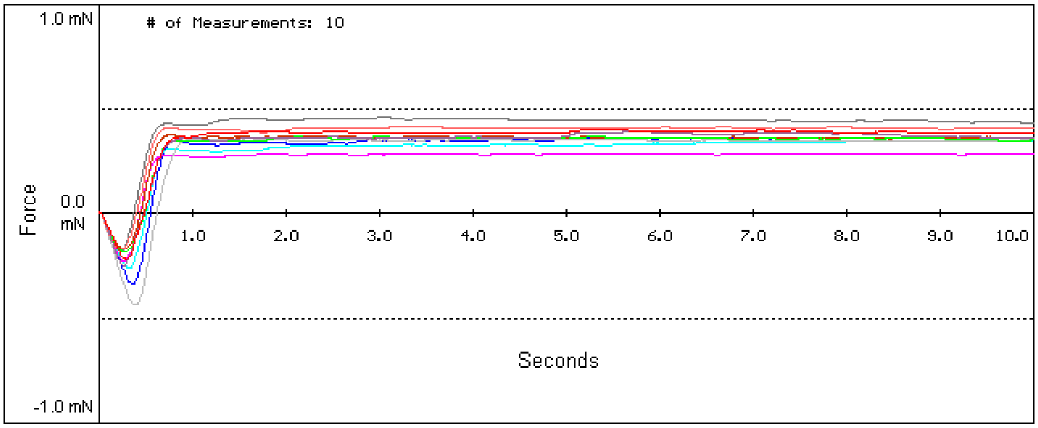

Figure 5. Wetting Balance Curves for TI NiPd Component Finish With SnAgCu Solder

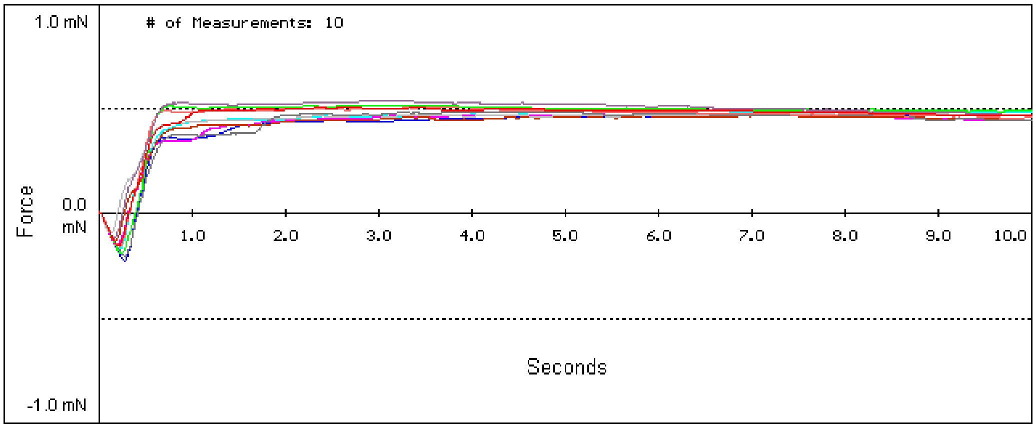

Figure 6. Wetting Balance Curves for TI NiPdAu Component Finish With SnAgCu Solder

A summary of the wetting balance data for the three component finishes, tested with both SnPb (235°C) and SnAgCu (250°C) solders, is shown in Table 3.

Table 3. Wetting Balance Data

SnPb GLOBULE		
COMPONENT FINISH	**t_0 (s)**	**$t_{2/3\ MaxForce}$ (s)**
SnPb	0.41	1.16
NiPd	0.6	0.87
NiPdAu	0.31	0.61
SnAgCu GLOBULE		
COMPONENT FINISH	**t_0 (s)**	**$t_{2/3\ MaxForce}$ (s)**
SnPb	0.41	0.79
NiPd	0.49	0.62
NiPdAu	0.33	0.57

The wetting balance data indicates that the NiPdAu finish wet faster (t_0) than both the NiPd and SnPb component finishes. Time to reach two-thirds maximum force also was faster for the NiPdAu finish.

Soldering Evaluations

PWB Coatings

To evaluate Pb-free solder joints, two lead-free PWB coatings were used. The first was an OSP, (ENTEK® PLUS CU-106A). This coating is a substituted benzimidazole that can preserve the solderability of Cu through multiple soldering operations. The second pad coating used was a NiAu finish. The specification for the Ni and Au layers was 5-µm to 7-µm Ni and 0.09-µm to 0.11-µm Au.

Reflow Profiles

Reflow profiles used were based on inputs from the solder-paste vendors. In our evaluation, the reflow-profile temperatures were measured at the component lead. For the first run (SnPbAg control), the profile shown in Figure 7 was used. This profile reaches a preheat temperature of 120°C to 160°C for approximately 60 seconds before rising to a peak temperature of 225°C to 228°C.

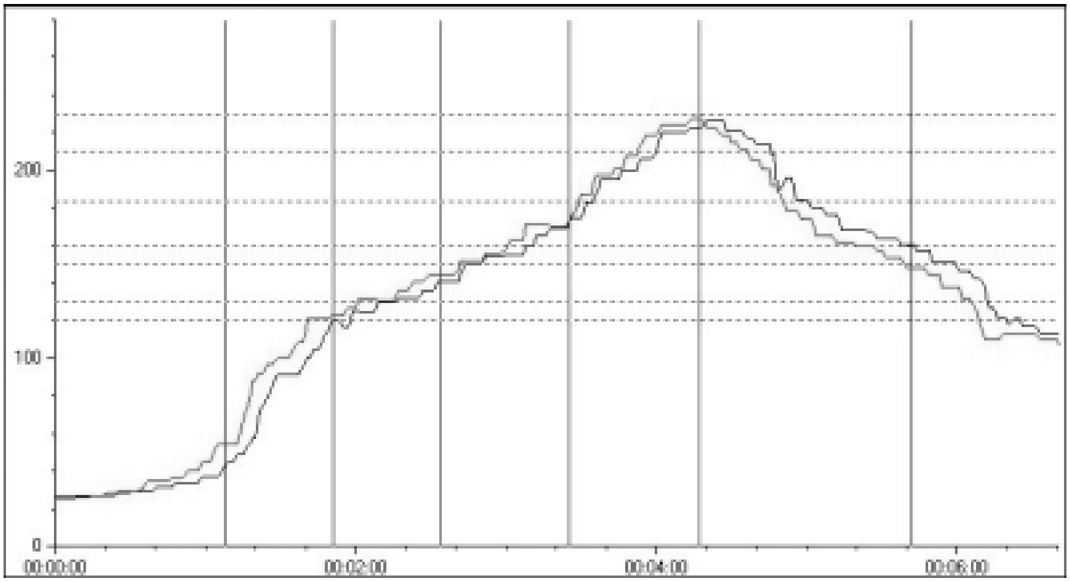

Figure 7. Reflow Profile for SnPbAg Solder Alloy

For the second run (SnAgCu alloy, 235°C peak), the profile shown in Figure 8 was used. This profile reaches a preheat temperature of 120°C to 170°C for approximately 100 seconds before rising to a peak temperature of 235°C to 238°C.

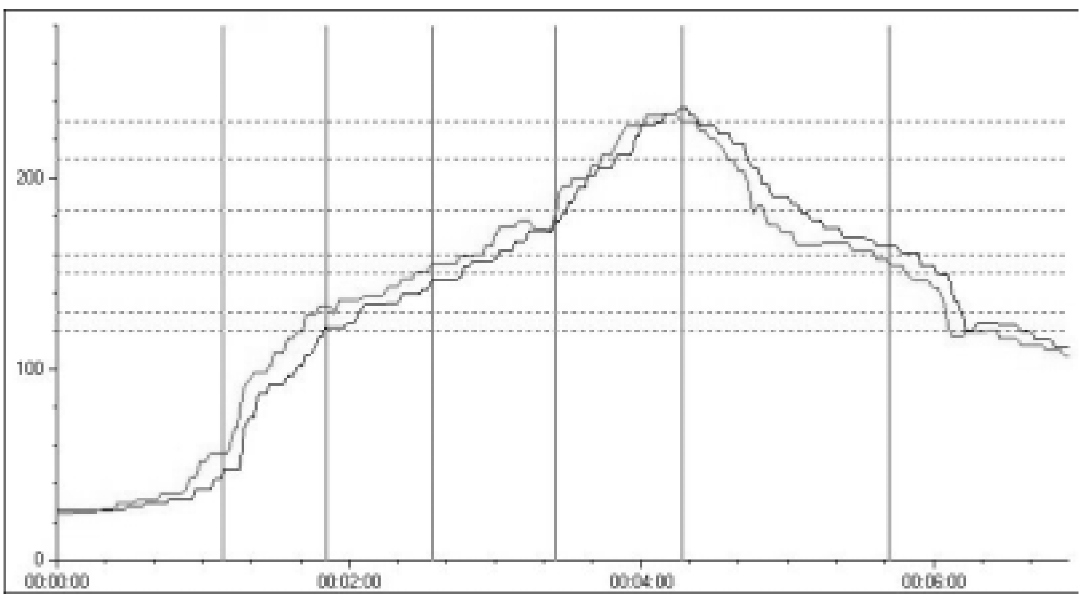

Figure 8. Reflow Profile for SnAgCu Solder Alloy

Test Equipment and Procedure

The solder paste was printed using a 150-µm, polished, laser-cut stainless-steel stencil. An optical alignment tool for manual component placement was used to align the device leads to the solder paste prints. Optical inspection of the printed solder paste on the board was performed to ensure adequate paste height and complete printing. For the reflow soldering process, a Rehm full-convection reflow oven was used with nitrogen (N_2) purge. Remaining oxygen (O_2) concentration was 500 ppm to 1000 ppm.

Performance Measures and Results

In this study, visual, mechanical, and reliability test methods were used to judge the performance of the solder joints. The methods used and results obtained are presented in the following paragraphs.

Visual Appearance

Solder-joint appearance was documented to identify the wetting performance of the NiPdAu-finished components with both SnPbAg (control) and SnAgCu solder alloys. Samples were judged against criteria in IPC-A-610C for general electronic products, dedicated service electronic products, and high-performance electronic products.[16]

Visual Appearance Results for Dual-Inline Packages

Photographs of representative solder joints are shown in Figures 9 through 16 for the NS package style. All solder joints exhibited a heel fillet height of at least 1× the lead thickness and showed evidence of wetting to the sides of the leads. This performance would be considered acceptable for all three classes of products identified in IPC-A-610C.[16]

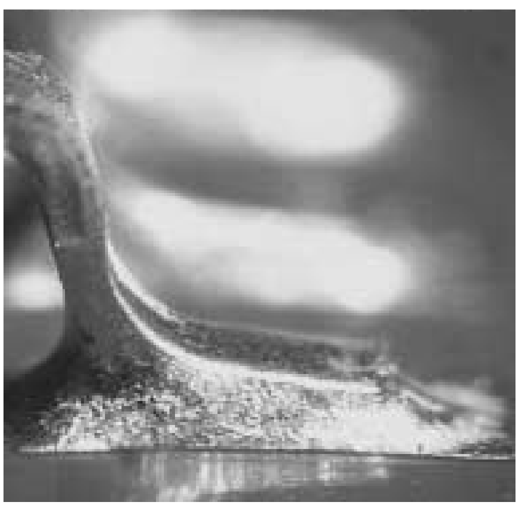

Figure 9. NiPdAu Finish NS, SnPbAg Solder, NiAu PWB Finish

Figure 10. SnPb Finish NS, SnPbAg Solder, NiAu PWB Finish

Figure 11. NiPdAu Finish NS, SnPbAg Solder, OSP PWB Finish

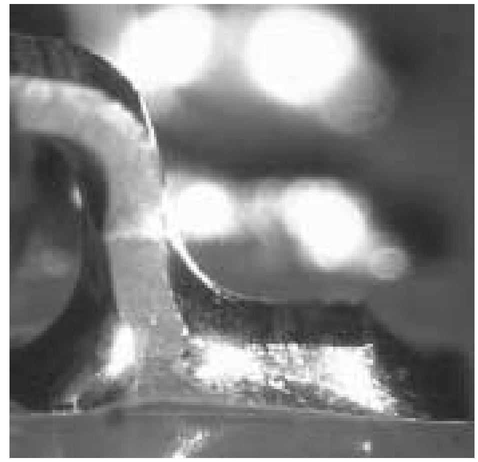

Figure 12. SnPb Finish NS, SnPbAg Solder, OSP PWB Finish

Figure 13. NiPdAu Finish NS, SnAgCu Solder, NiAu PWB Finish

Figure 14. SnPb Finish NS, SnAgCu Solder, NiAu PWB Finish

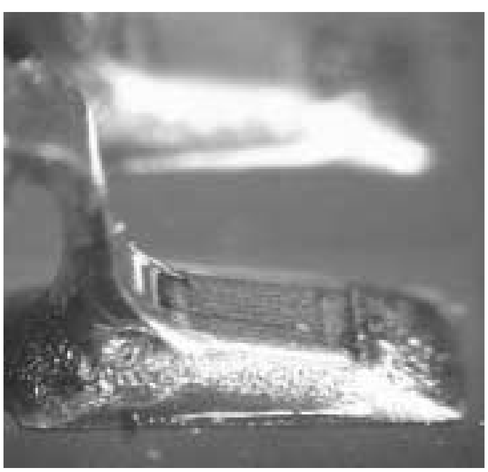

Figure 15. NiPdAu Finish NS, SnAgCu Solder, OSP PWB Finish

Figure 16. SnPb Finish NS, SnAgCu Solder, OSP PWB Finish

Visual Appearance Results for Quad Packages

Photographs of representative solder joints are shown in Figures 17 through 22 for the quad package styles. All solder joints exhibited a heel fillet height of at least 1× the lead thickness and showed evidence of wetting to the sides of the leads. This performance would be considered acceptable for all three classes of products identified in IPC-A-610C.[16]

Figure 17. NiPdAu Finish 176 PBL, SnPbAg Solder, NiAu PWB Finish

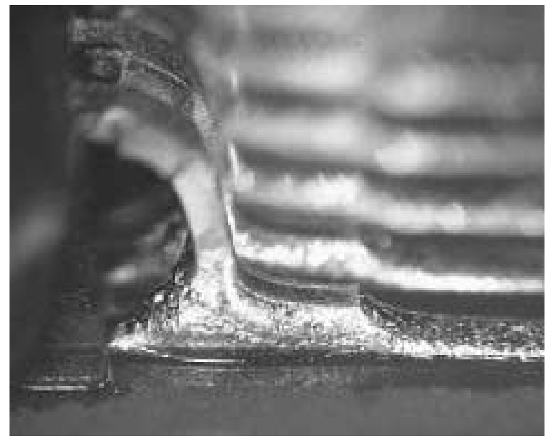

Figure 18. NiPdAu Finish 176 PBL, SnAgCu Solder, NiAu PWB Finish

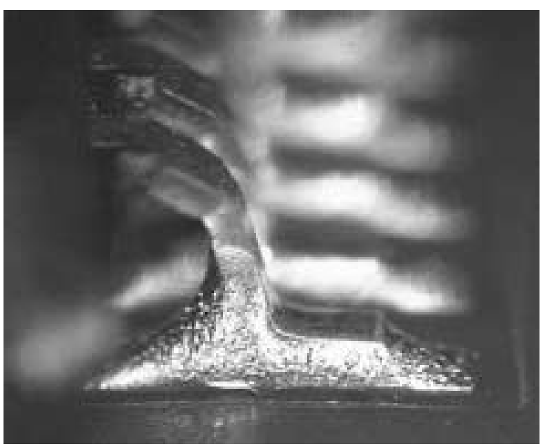

Figure 19. NiPdAu Finish 176 PGF, SnPbAg Solder, NiAu PWB Finish

Figure 20. NiPdAu Finish 176 PGF, SnAgCu Solder, NiAu PWB Finish

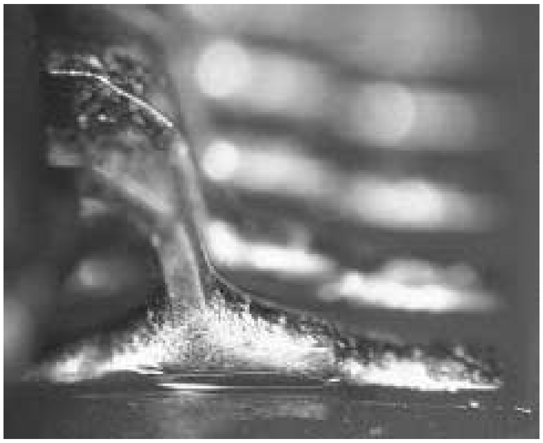

Figure 21. NiPdAu Finish 208 PDV TQFP, SnPbAg Solder, NiAu PWB Finish

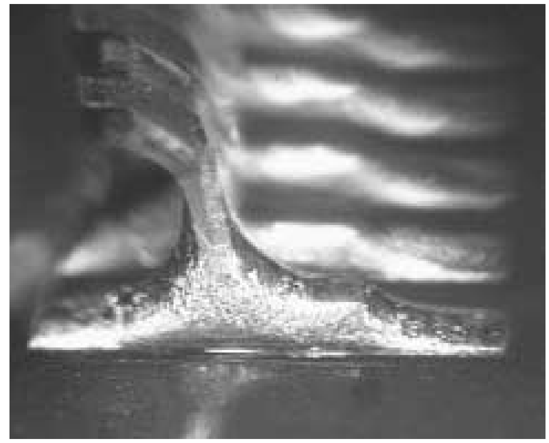

Figure 22. NiPdAu Finish 208 PDV TQFP, SnAgCu Solder, NiAu PWB Finish

Lead-Pull Test

Lead-pull testing determined the force needed to pull an individual IC lead from the PWB land pattern after soldering. First, to allow access to an individual lead on the PWB, all leads were cut near the package body. Next, with the leads separated from the package body, the PWB was fastened in a test fixture. Finally, the lead was pulled perpendicular to the PWB surface until it separated from the PWB. The rate of movement of the test device was 0.4 mm/second vertically to the board surface. The force needed to pull the lead from the PWB was measured and recorded. Lead-pull data was taken before and after exposure to temperature cycling.

Lead-Pull Data for Dual-Inline Packages

Lead pull was performed on 20-pin SOP packages. Forty leads for each group were pulled to obtain an average pull force. The unit of measure for pull force is newtons (N). Figures 23 and 24 indicate the average of lead-pull values for the NiPdAu, NiPd, and SnPb-finished packages with SnPbAg and SnAgCu solder alloys. These data sets are for PWBs coated with OSP and NiAu, respectively. Data points for the non-temperature cycled units are diamond shaped; data points for the temperature cycled units are squares.

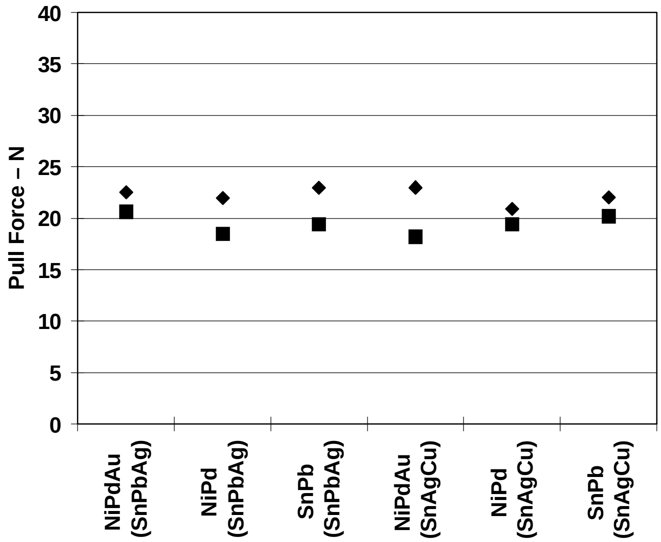

Figure 23. 20 NS SOP Lead-Pull Results, OSP Pad Finish, Before and After Temperature Cycling

The temperature-cycle excursion was –40°C to 125°C in 10-minute cycles. This was a thermal-shock test, with the boards being moved from a –40°C chamber to a 125°C chamber. There was no ramp between the temperature extremes.

For Figure 23(OSP PWB) and Figure 24 (NiAu PWB), essentially equivalent lead-pull results were seen for each lead finish before and after temperature cycling. The minimum lead-pull value specified by industry standards for non-temperature cycled samples (with the lead cross-sectional area of the leads tested here) is 10 N [17,18]. Data points for the non-temperature cycled units are diamond shaped; data points for the temperature cycled units are squares. All lead-pull values were above this minimum requirement.

The SEMI standard states that: "the average lead-pull force of the temperature cycled units shall be greater than half of the average lead pull force of the non-cycled units."[17] The lead pull values shown in Figure 23 and Figure 24 for temperature cycled units meet the industry-standard requirement.

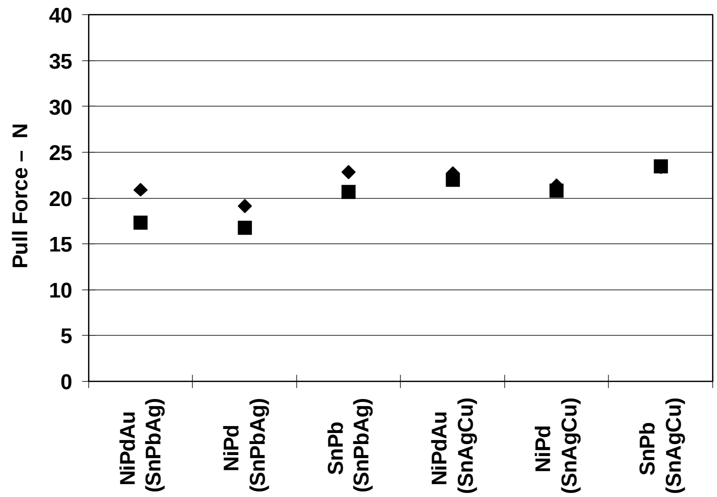

Figure 24. 20 NS SOP Lead-Pull Results, NiAu Pad Finish, Before and After Temperature Cycling

Lead-Pull Data for Quad Packages

Lead pull was performed on the three quad package styles listed in Table 2. Forty leads for each group were pulled to obtain an average pull force. For the three TQFP packages tested, the minimum lead-pull value specified by the SEMI standard for non-temperature cycled samples (based on the lead cross-sectional area of the units tested here) is 5 N.[17]

Figures 25 and 26 show the average of lead-pull values for the NiPdAu-, NiPd-, and SnPb-finished 176 PBL TQFP package with SnPbAg and SnAgCu solder alloys. These data sets are for PWBs coated with OSP and NiAu, respectively.

Data points for the non-temperature cycled units are diamond shaped; data points for the temperature cycled units are squares. This convention is followed throughout this section on lead-pull results.

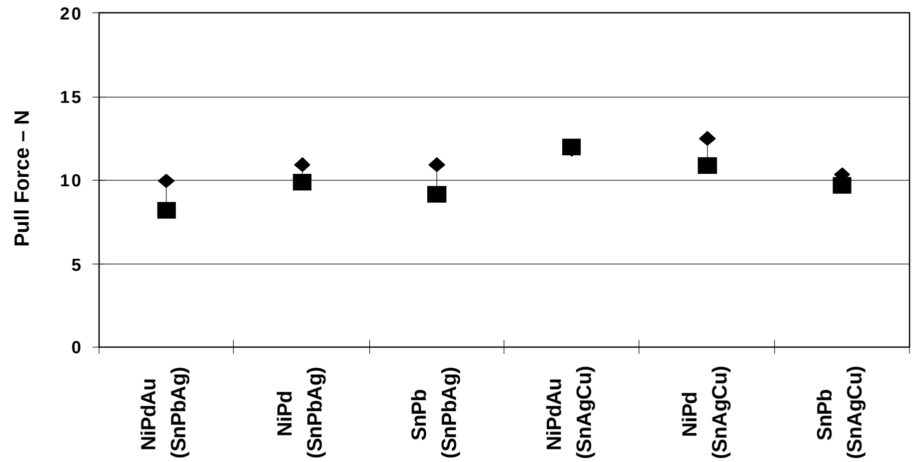

Figure 25. 176 PBL TQFP Lead-Pull Results, OSP Pad Finish, Before and After Temperature Cycling

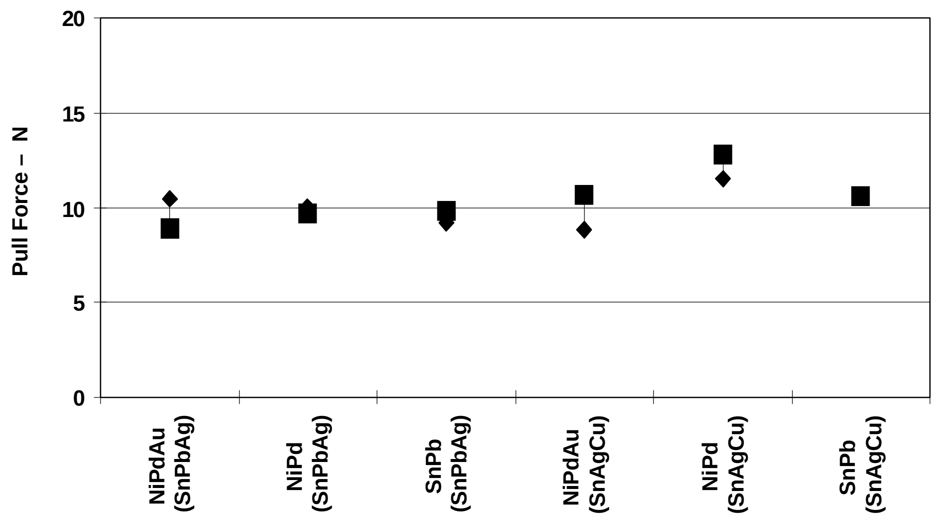

Figure 26. 176 PBL TQFP Lead-Pull Results, NiAu Pad Finish, Before and After Temperature Cycling

Lead pull results for the 176 PBL TQFP packages showed essentially equivalent lead-pull values for each lead finish before and after temperature cycling. All lead-pull values were above the minimum requirement of 5 N for non-temperature cycled units.[17]

Figures 27 and 28 show the results for the 176 PGF TQFP package and Figures 29 and 30 show the lead pull results for the 208 PDV TQFP package on OSP- and NiAu-finished PWBs with the solder pastes under evaluation. The results were similar to those seen in Figures 25 and 26 and the same conclusions can be drawn as to performance to the SEMI standard.

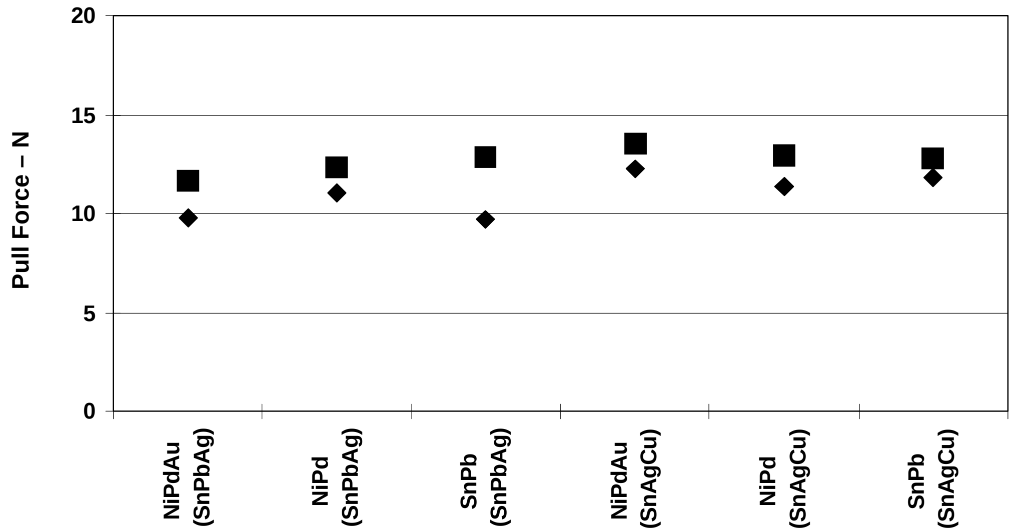

Figure 27. 176 PGF TQFP Lead-Pull Results, OSP Pad Finish, Before and After Temperature Cycling

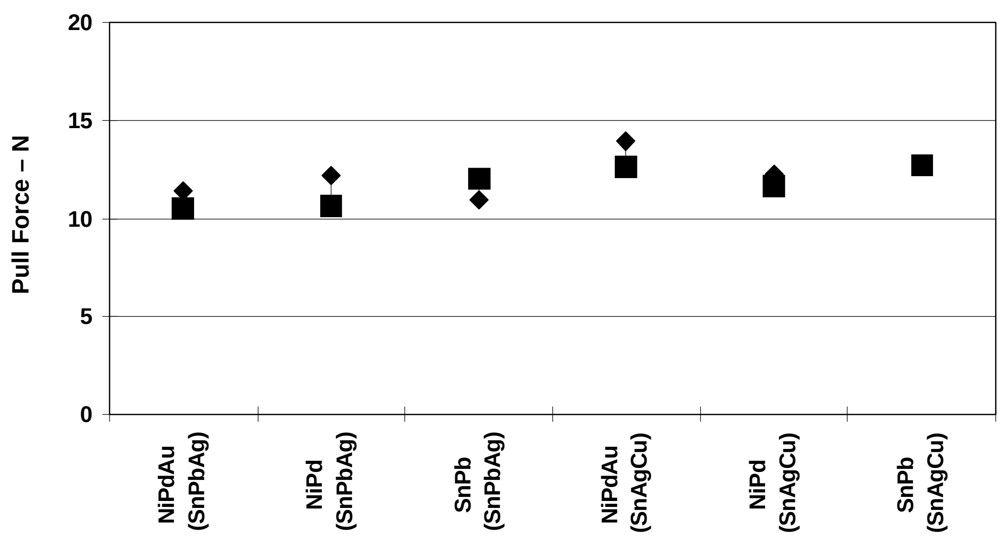

Figure 28. 176 PGF TQFP Lead-Pull Results, NiAu Pad Finish, Before and After Temperature Cycling

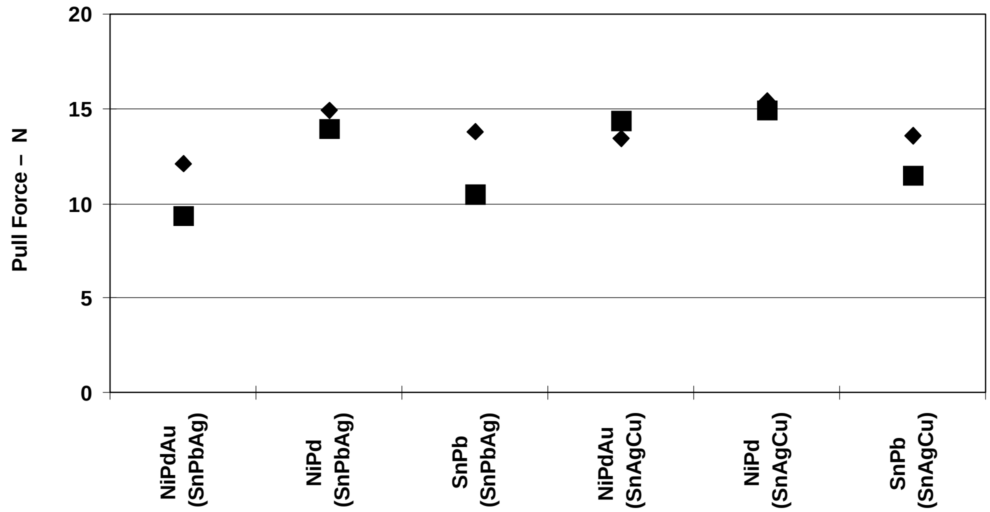

Figure 29. 208 PDV TQFP Lead-Pull Results, OSP Finish, Before and After Temperature Cycling

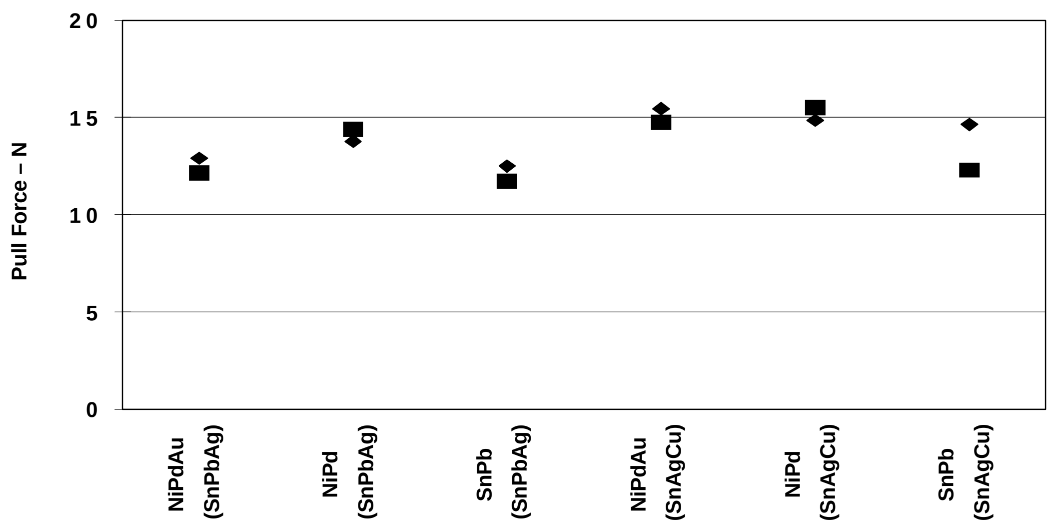

Figure 30. 208 PDV TQFP Lead-Pull Results, NiAu Finish, Before and After Temperature Cycling

Solder-Joint Cross-Section Data

Cross-Sections of Dual-Inline Packages

Figures 31 through 38 show visual cross-section results for NS dual-inline packages, both before and after exposure to 1000 temperature cycles of –40°C to 125°C. Cross-section results for the dual-inline units verified good solder wetting performance that passes industry-standard requirements.[16]

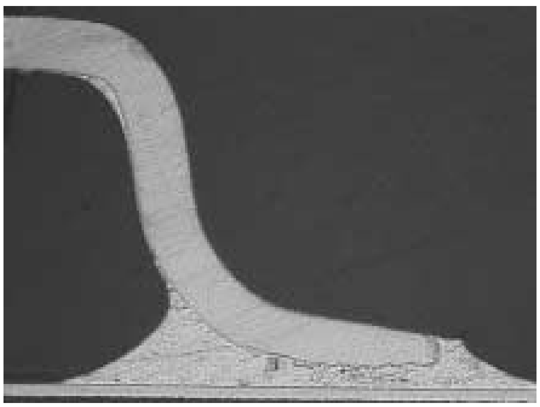

Figure 31. NiPdAu SOP, SnPbAg Solder, NiAu PWB Finish, 0 Temperature Cycles

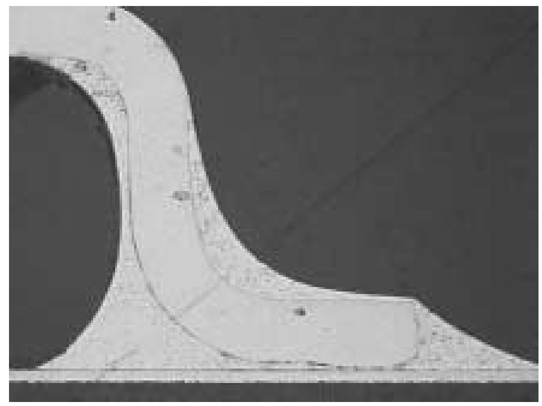

Figure 32. SnPb SOP, SnPbAg Solder, NiAu PWB Finish, 0 Temperature Cycles

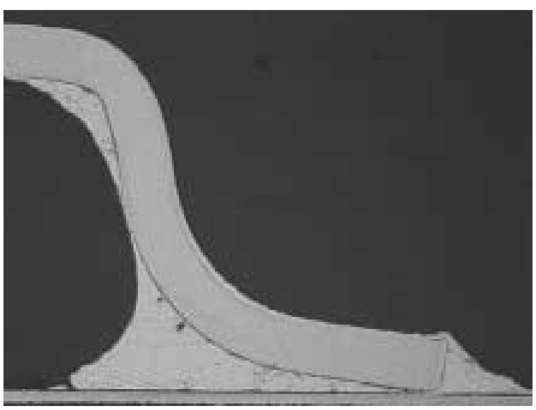

Figure 33. NiPdAu SOP, SnPbAg Solder, NiAu PWB Finish, 1000 Temperature Cycles

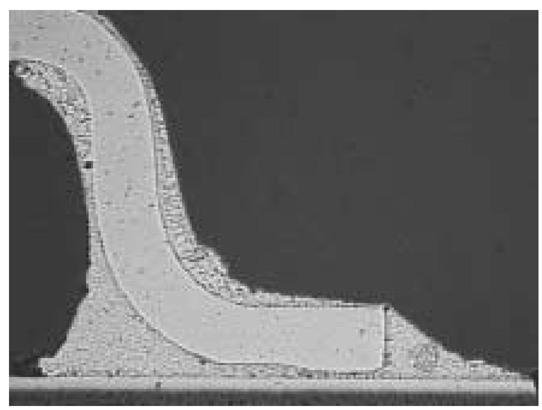

Figure 34. SnPb SOP, SnPbAg Solder, NiAu PWB Finish, 1000 Temperature Cycles

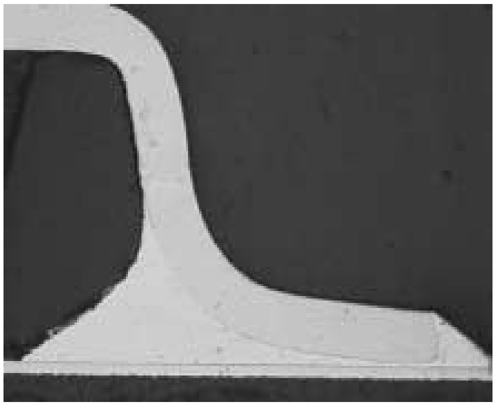

Figure 35. NiPdAu SOP, SnAgCu Solder, NiAu PWB Finish, 0 Temperature Cycles

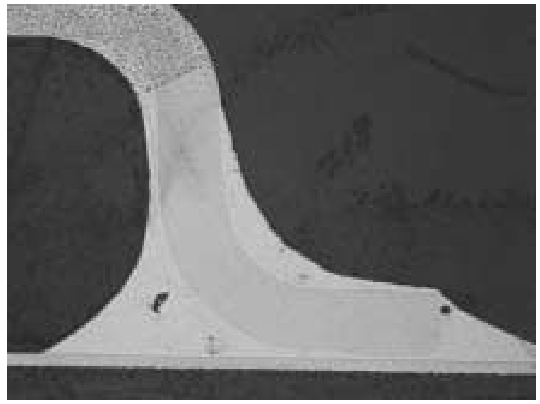

Figure 36. SnPb SOP, SnAgCu Solder, NiAu PWB Finish, 0 Temperature Cycles

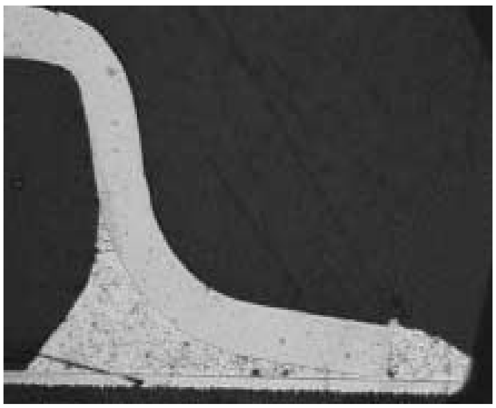

Figure 37. NiPdAu SOP, SnAgCu Solder, 1000 Temperature Cycles

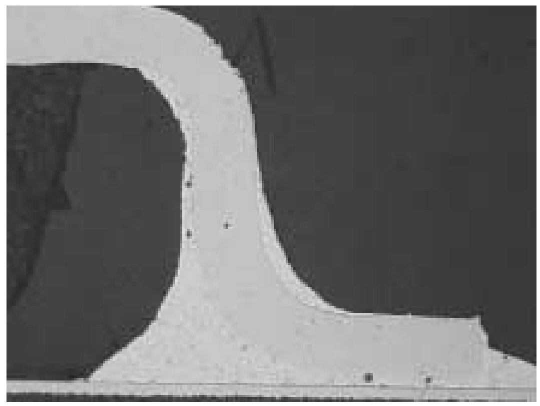

Figure 38. SnPb SOP, SnAgCu Solder, 1000 Temperature Cycles

Cross-Sections of Quad Packages

Figures 39 through 42 show visual cross-section results for TQFP packages prior to exposure to temperature cycling. Cross-section results for quad packages verified good solder wetting performance that passes industry-standard requirements.[16]

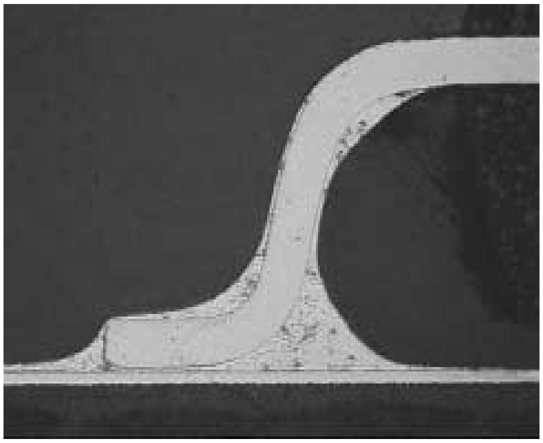

Figure 39. NiPdAu 208 PDV TQFP, SnPbAg Solder, NiAu PWB Finish, 0 Temperature Cycles

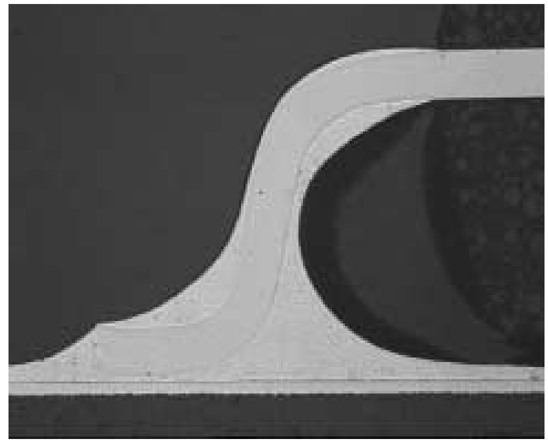

Figure 40. SnPb 208 PDV TQFP, SnPbAg Solder, NiAu PWB Finish, 0 Temperature Cycles

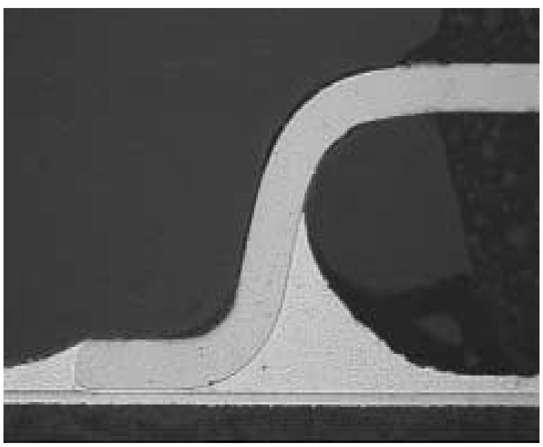

Figure 41. NiPdAu 208 PDV TQFP, SnAgCu Solder, NiAu PWB Finish, 0 Temperature Cycles

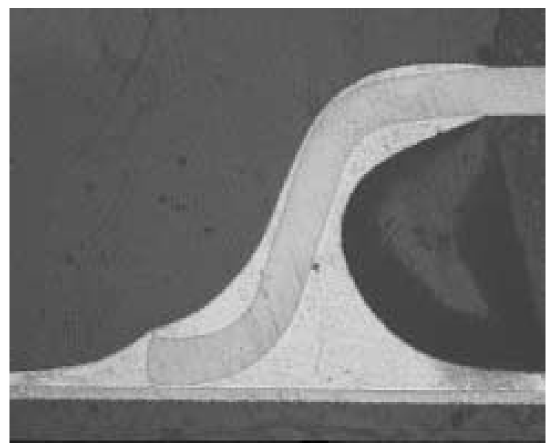

Figure 42. SnPb 208 PDV TQFP, SnAgCu Solder, NiAu PWB Finish, 0 Temperature Cycles

Cross-Sections Results

All solder joints exhibited a heel fillet height at least 1× the lead thickness and showed evidence of wetting to the sides of the leads. This performance is considered acceptable for all three classes of products identified in IPC-A-610C.[16]

Results/Conclusions

Wetting balance testing showed quicker wetting performance for the NiPdAu finish compared with NiPd and SnPb component finishes. This result was seen with SnPbAg and SnAgCu solder globules.

Visual appearance results and cross-section data indicate that an acceptable heel fillet of at least 1× the lead thickness was achieved for all three component finishes with SnPbAg and SnAgCu solder alloys.

Lead-pull results before and after temperature cycling were acceptable for all lead finishes when compared to the criteria set out in industry standards.

The evaluation demonstrates that lead-free soldering is possible with currently used peak reflow temperatures of 235°C to 240°C. Also, it was demonstrated that 260°C peak reflow temperature is not mandatory for SnAgCu lead-free solder alloy when state-of-the-art, full-convection reflow equipment is used.

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Alloy	**Supplier**
SnPbAg	Multicore
SnAgCu	Heraeus

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