Application Report
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Board-Mount Evaluation of Tin-Plated Component Leads

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ABSTRACT

The solderability performance of tin (Sn)-plated integrated circuit (IC) component leads is assessed in this paper, with nickel-palladium-gold (NiPdAu)-finished IC leads used as a control. The test methods were wetting balance and board mount. The wetting-balance test was done with eutectic SnPb (tin-lead) solder. Board-mount tests were done using tin-lead-silver (SnPbAg) and Pb-free, tin-silver-copper (SnAgCu) pastes under three different reflow conditions. Solder joints were inspected visually, lead-pull data was collected, and cross sections were made. The conclusion is that Sn-finished leads perform well with both Pb-bearing and Pb-free solder pastes. Their solder wetting performance is equivalent to the other Pb-free finish that was used as a control, NiPdAu.

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1 Introduction

The need for lead (Pb)-free electronics is well documented, with European legislation and the influence of Japanese market forces.[1, 2, 3] The industry has made strides in developing options to eliminate the major sources of Pb from electronic assemblies: the solder and the printed wiring board (PWB). A specific class of tin-silver-copper (SnAgCu) solder alloy has been embraced by the industry as an alternative to tin-lead (SnPb) solder.[4, 5, 6] Several Pb-free PWB finishes are available: organic solderability preservatives (OSPs), immersion Ag, and immersion Sn plating. The SnPb lead finish is the last and least-significant source of Pb in board-mounted integrated circuits (ICs). Texas Instruments (TI) has provided nickel-palladium (NiPd) and nickel-palladium-gold (NiPdAu) lead finishes as Pb-free options for more than 12 years.[7, 8, 9, 10] TI is now evaluating IC packages built with a matte tin (Sn) finish on the component leads.

The first package with matte Sn-finished leads evaluated by TI was the small-outline integrated circuit (SOIC). The bulk of SOICs supplied by TI are built using a NiPdAu finish on the component leads. Sn-finished SOICs were evaluated as another Pb-free option.

The work reported here focuses on board-level soldering performance of matte Sn-finished leads on SOIC packages. The data also is applicable to other packages built with matte Sn-finished leads. This study evaluates soldering performance of Sn-finished leads using three different reflow profiles and tin/lead/silver (SnPbAg) and lead-free SnAgCu solders.

Cross sections of the solder joints were made before and after temperature cycling. Lead-pull testing measured the strength of the solder joints. Wetting balance (meniscograph) data compared soldering performance of the matte Sn-finished leads with the different solder alloys. NiPdAu-finished leads were used as controls.

2 Components Evaluated

The IC package used for this evaluation was a small-outline integrated circuit (SOIC). Sn-plated units were built at an IC package assembly subcontractor external to TI. Internally built NiPdAu-plated units were used as a control. An isometric view of the SOIC package used in this evaluation is shown in Figure 1.

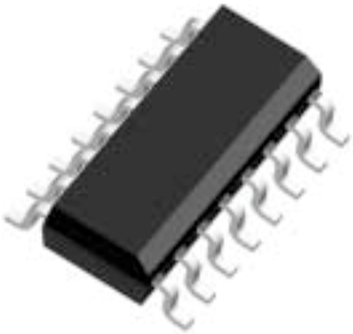


Figure 1. SOIC Package Isometric View

Features of the units evaluated are listed in Table 1.

Table 1. Component Details for Evaluation and Control Groups

	Evaluation	Control
Pin Count	16	16
Package Type	SOIC	SOIC
Base Metal	Copper	Copper
Finish	Sn (matte)	NiPdAu
Plating Thickness	10.9 µm	0.5 µm–2 µm (Ni), 0.02 µm–0.15 µm (Pd), 0.003 µm–0.015 µm (Au)
Grain Size	5.9 µm–17.2 µm	–

3 Evaluation Methods and Results

3.1 Wetting Balance

The wetting-balance test can be used to test solder wettability of IC leads. However, the wetting-balance test is classified in ANSI/J-STD-002 as a “test without established accept/reject criterion.”[11] This test method is recommended for engineering evaluations only and not as a production pass/fail monitor.

The wetting-balance test measures the forces imposed by the molten solder upon the test specimen when the test specimen is dipped and held into the solder bath during the test. This wetting force is measured by an electronic gauge as a function of time. A typical wetting-balance curve is shown in Figure 2. 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). A second point for comparison is the time $t_{2/3}$ needed until the wetting force reached 2/3 of the equilibrated wetting force. The wetting balance test method was used to compare the solder wetting performance of the Sn lead finish (see Figure 3) and the NiPdAu lead finish (see Figure 4).

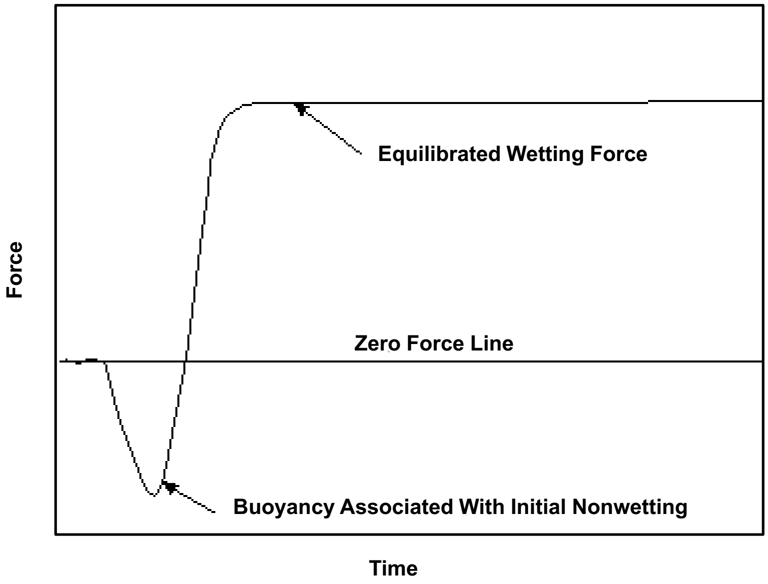
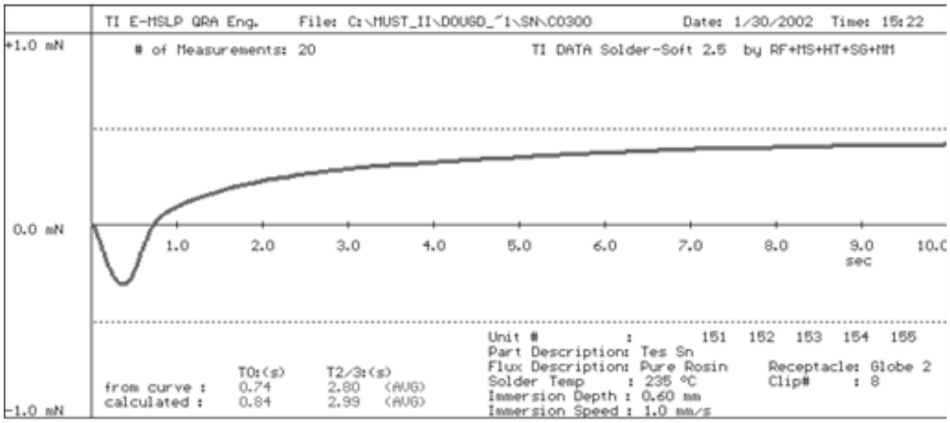


Figure 2. Typical Wetting-Balance Curve

For the wetting-balance test, an automatic system with solder globule heat control, automatic immersion of the specimen into the solder globule, and an electronic gauge for recording the wetting force was used. The specimen leads were immersed in a liquid flux (25% pure rosin and 75% ethanol) prior to the test. The specimen immersion depth into the liquid solder globule (SnPb) was set to 0.6 mm for good thermal heat transfer of the 235°C solder bath into the specimen under test. The immersion speed was 1 mm/s.

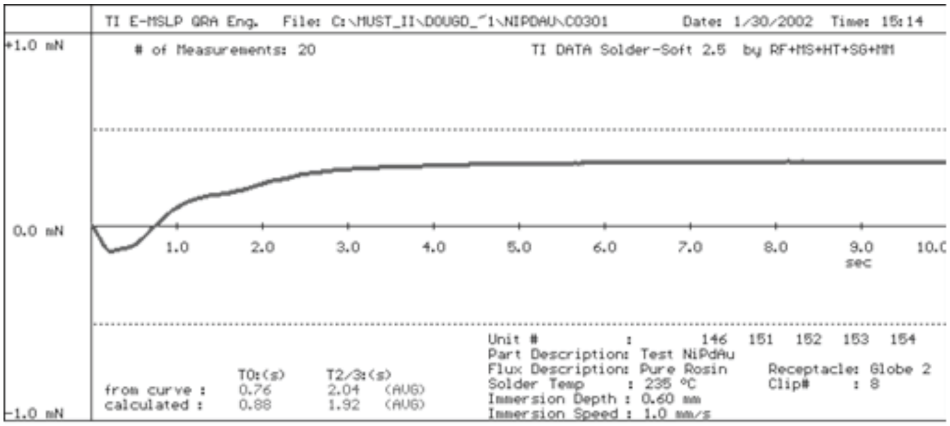


TI E-MSLP QRA Eng. File: C:\MUST_II\DOUGD_~1\SN\C0300 Date: 1/30/2002 Time: 15:22
# of Measurements: 20 TI DATA Solder-Soft 2.5 by RF+MS+HT+SG+MM

Unit # : 151 152 153 154 155
Part Description: Tes Sn
Flux Description: Pure Rosin Receptacle: Globe 2
Solder Temp : 235 °C Clip# : 8
Immersion Depth : 0.60 mm
Immersion Speed : 1.0 mm/s

	T0:(s)	T2/3:(s)	
from curve :	0.74	2.80	(AVG)
calculated :	0.84	2.99	(AVG)

Figure 3. Wetting-Balance Curve for Sn-Finished SOIC Component Lead



TI E-MSLP QRA Eng. File: C:\MUST_II\DOUGD_~1\NIPDAU\C0301 Date: 1/30/2002 Time: 15:14
# of Measurements: 20 TI DATA Solder-Soft 2.5 by RF+MS+HT+SG+MM

Unit # : 146 151 152 153 154
Part Description: Test NiPdAu
Flux Description: Pure Rosin Receptacle: Globe 2
Solder Temp : 235 °C Clip# : 8
Immersion Depth : 0.60 mm
Immersion Speed : 1.0 mm/s

	T0:(s)	T2/3:(s)	
from curve :	0.76	2.04	(AVG)
calculated :	0.88	1.92	(AVG)

Figure 4. Wetting-Balance Curve for NiPdAu-Finished SOIC Component Lead

The wetting balance results for the Sn-finished and the NiPdAu-finished SOICs showed equivalent results for the t_0 wetting time of ~0.8 seconds. Also, the $t_{2/3}$ results showed a good wetting performance of the tested lead finishes of the SOIC. The $t_{2/3}$ wetting time of ~2 seconds for the NiPdAu finish showed slightly quicker wetting performance than the Sn-finished SOIC. The measured differences, however, did not show any impact on the board-wetting performance, which is described in the following paragraphs.

3.2 Board-Mount Evaluation

3.2.1 Test Board

The double-sided PWB used has dimensions of 15.24 × 20.32 cm, with a thickness of 1.5 mm. The 35-µm-thick copper pads on the PWB have dimensions of 0.8 × 2.2 mm for the SOIC components. Finish on the copper pads is nickel-gold (NiAu), with the solder mask separating individual pads.

3.2.2 Solder Stencil

The solder stencil was a laser-cut stainless-steel mask, 150 µm thick. The solder paste was printed using a stainless-steel tool.

3.2.3 Component Placement

The components were placed with a mechanical placement tool using a microscope, which allows for accurate placement of the components into the printed solder paste on the test board.

3.2.4 Test Matrix

The Pb-free SnAgCu solder alloy chosen for this evaluation was 95.5Sn/4.0Ag/0.5Cu. This alloy has been recommended by the National Electronics Manufacturing Initiative (NEMI) as a standardized Pb-free solder alternative. The Sn/Ag/Cu class of alloys also has been recommended or suggested by IPC, ITRI, and NCMS.[4, 5, 6] The control paste alloy chosen was 62Sn/36Pb/2Ag. This is an SnPb paste with a small percentage of silver. The matrix of solder paste alloys, melting points, and reflow profiles used are shown in Table 2.

Table 2. Solder Paste and Reflow Profile Matrix

Solder Paste	Melting Point	Reflow Peak Temperature Range
62Sn36Pb2Ag	179°C	215°C–220°C
62Sn36Pb2Ag	179°C	235°C–240°C
95.5Sn4.0Ag0.5Cu	217°C	235°C–240°C
95.5Sn4.0Ag0.5Cu	217°C	255°C–260°C

Soldering evaluations were performed using three different reflow profiles. The profiles varied primarily by the targeted peak reflow temperature. Components were soldered to the PWB using a full-convection reflow process under a nitrogen atmosphere.

Temperature measurements were taken at four different locations on the PWB for each profile. The test PWB as well as the location of components and thermocouples used to set up the profiles are shown in Figure 5.

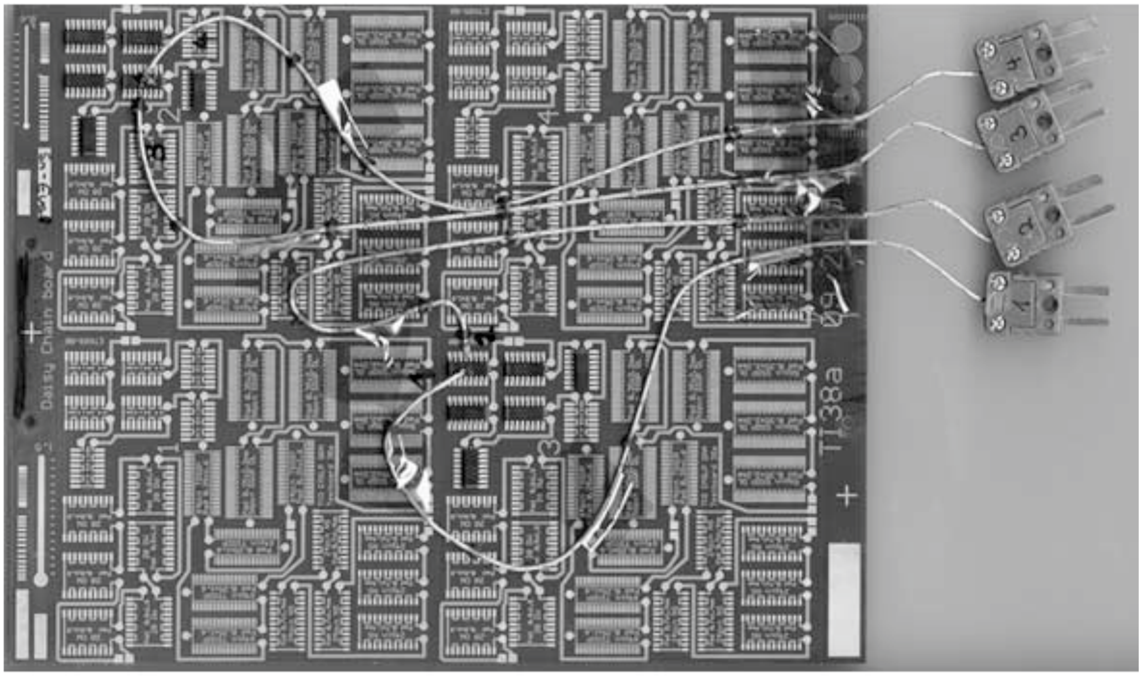


Figure 5. Test PWB With Thermocouples Attached

Thermocouples at locations 1 and 4 measured the *package surface temperature* on components located at the middle and corner of the PWB, respectively. Thermocouples at locations 2 and 3 measured the component *lead* temperature for components located at the middle and corner of the PWB, respectively.

3.2.5 Reflow Profile 1

The first profile (Figure 6) has a preheat zone of 150°C to 180°C for 40 to 60 seconds. The peak temperature range achieved with profile 1 is 215°C to 220°C. Temperature readings taken by thermocouples 1 and 4 are shown as a black line and a blue line, respectively. Temperature readings taken by thermocouples 2 and 3 are shown as a red line and a green line, respectively.

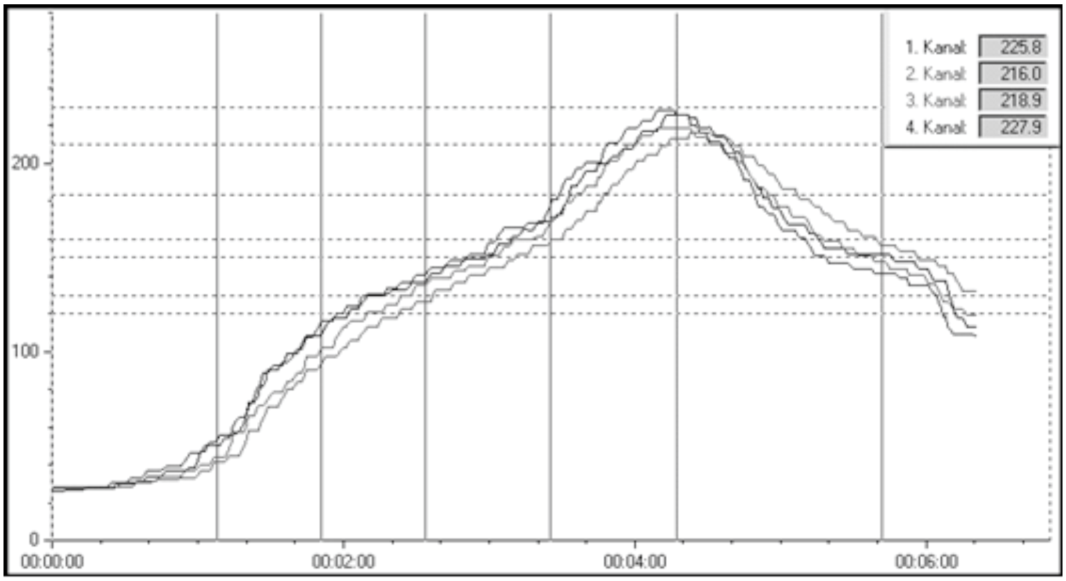


Figure 6. Reflow Profile 1 for SnPb Soldering Process

The liquidus point of eutectic SnPb solder (63Sn37Pb) is 183°C, thus the range of peak temperature for SnPb soldering processes is typically 215°C to 235°C. Profile 1 is intended to simulate the lower end of current SnPb reflow environments. The goal with profile 1 is to demonstrate soldering performance of the Sn-finished components in current (SnPb) soldering processes. Because the melt point of Sn is 232°C, it is critical that soldering performance of the Sn-finished components in a current SnPb soldering process be investigated.

The liquidus temperature of SnAgCu solder alloy is quoted as 217°C to 221°C. The minimum temperature used to reflow SnAgCu solder alloy in surface-mount applications is approximately 235°C. Thus, reflow of SnAgCu solder with profile 1 was not feasible. It is expected that customers using SnAgCu solder will operate with a minimum reflow temperature of 235°C.

3.2.6 Reflow Profile 2

The second profile (Figure 7) has a preheat zone of 150°C to 180°C for 40 to 50 seconds. The peak temperature range achieved with profile 2 is 235°C to 240°C.

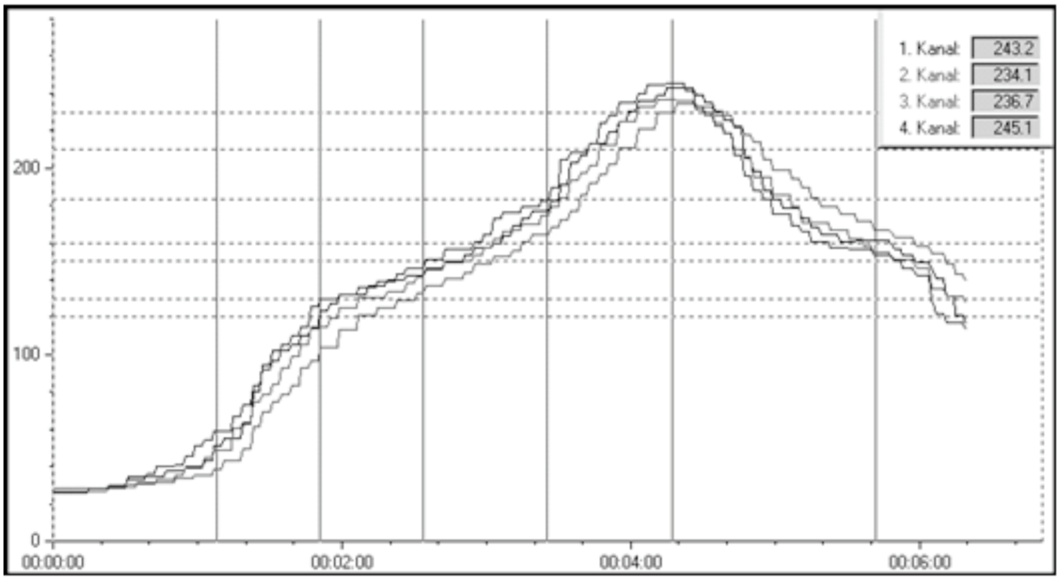


Figure 7. Reflow Profile 2 for SnAgCu Soldering Process, Low End

Profile 2 is intended to simulate the lower end of Pb-free SnAgCu reflow processes. The goal with profile 2 is to demonstrate soldering performance of the Sn-finished components in Pb-free (SnAgCu) soldering processes operating in the range of 235°C to 240°C peak temperature.

3.2.7 Reflow Profile 3

The third profile (Figure 8) has a preheat zone of 150°C to 180°C for 40 to 50 seconds. The peak temperature range achieved with profile 3 is 255°C to 260°C.

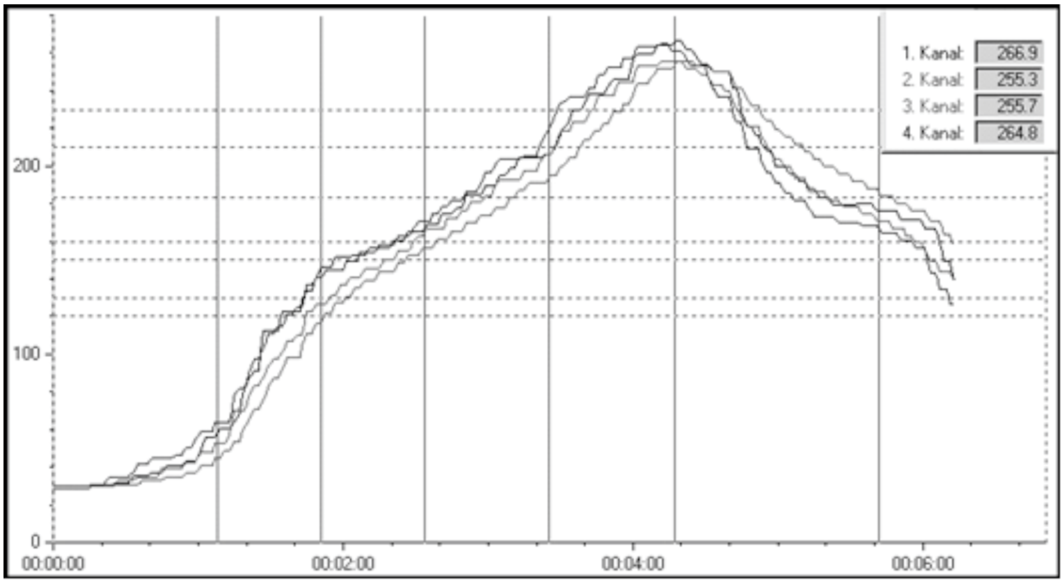


Figure 8. Reflow Profile 3 for SnAgCu Soldering Process, High End

Profile 3 is intended to simulate the upper end of lead-free SnAgCu reflow processes. The goal with profile 3 is to demonstrate soldering performance of the Sn-finished components in lead-free (SnAgCu) soldering processes in the range of 255°C to 260°C peak temperature.

3.3 Evaluation Methods

3.3.1 Visual Appearance

Solder joints formed were photographed to document visual solder wetting performance. Figure 9 and Figure 10 show typical wetting performance for the Sn-finished units with SnPbAg solder paste at 215°C to 220°C and 235°C to 240°C peak reflow temperatures, respectively. Figure 11 and Figure 12 show typical wetting performance for the NiPdAu-finished units with SnPbAg solder paste at 215°C to 220°C and 235°C to 240°C peak reflow temperatures, respectively.

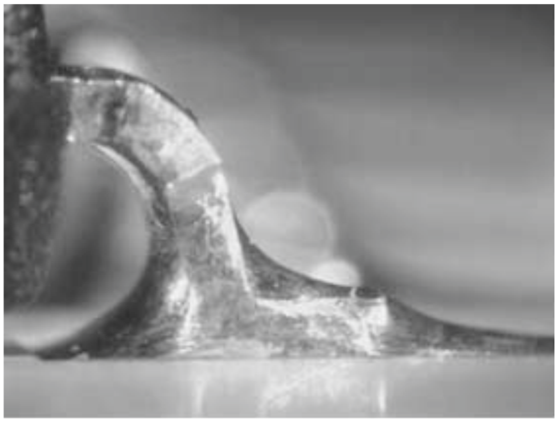


Figure 9. Typical Wetting of Sn-Finished Leads With SnPbAg Solder Paste, 215°C to 220°C Peak Reflow

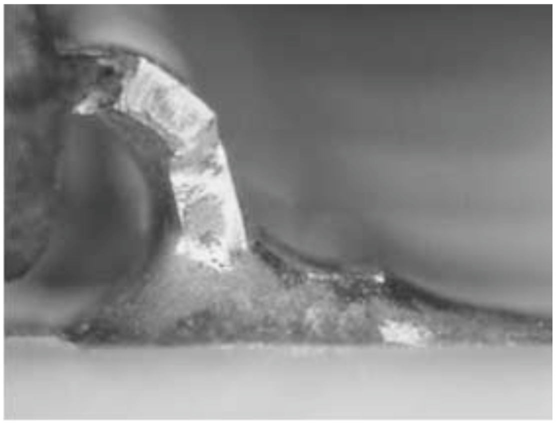


Figure 10. Typical Wetting of Sn-Finished Leads With SnPbAg Solder Paste, 235°C to 240°C Peak Reflow

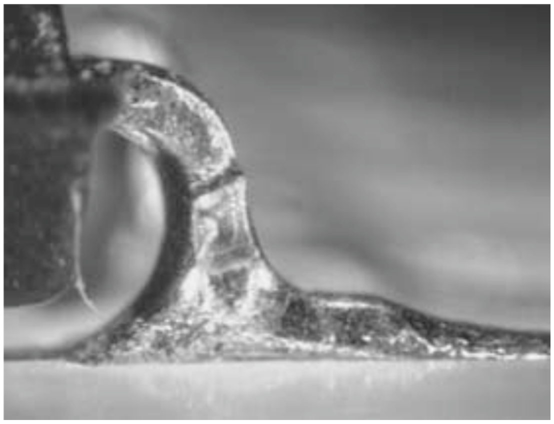


Figure 11. Typical Wetting of NiPdAu-Finished Leads With SnPbAg Solder Paste, 215°C to 220°C Peak Reflow

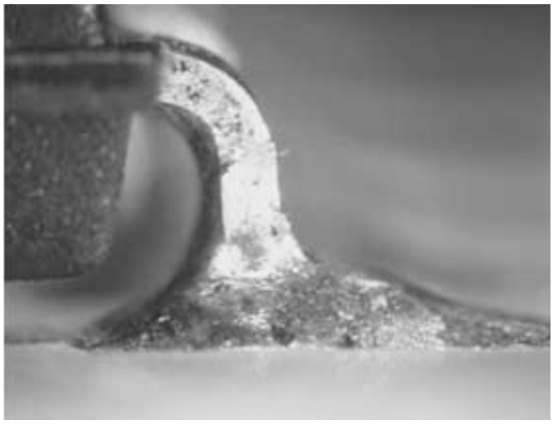


Figure 12. Typical Wetting of NiPdAu-Finished Leads With SnPbAg Solder Paste, 235°C to 240°C Peak Reflow

The solder joints formed with SnPbAg solder alloy and documented in Figure 9 through Figure 12 exhibited excellent heel, side, and toe filleting. Wetting height at the heel was at least equal to the lead thickness. This performance would be considered good for all three classes of products identified in IPC-A-610C for general electronic products, dedicated-service electronic products, and high-performance electronic products.[12]

Figure 13 through Figure 16 show typical wetting performance for the Sn-finished and NiPdAu-finished units with SnAgCu solder paste at 235°C to 240°C and 255°C to 260°C peak reflow temperatures, respectively.

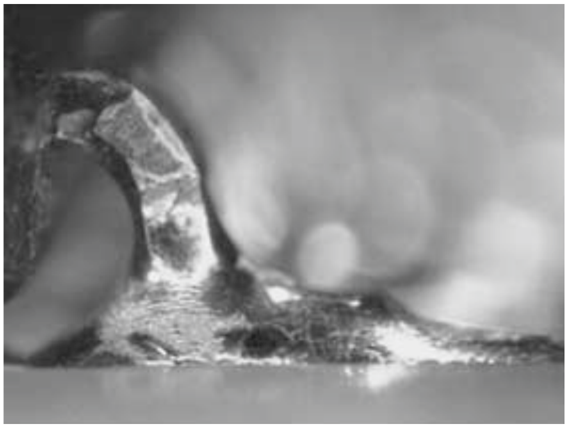


Figure 13. Typical Wetting of Sn-Finished Leads With SnAgCu Solder Paste, 235°C to 240°C Peak Reflow

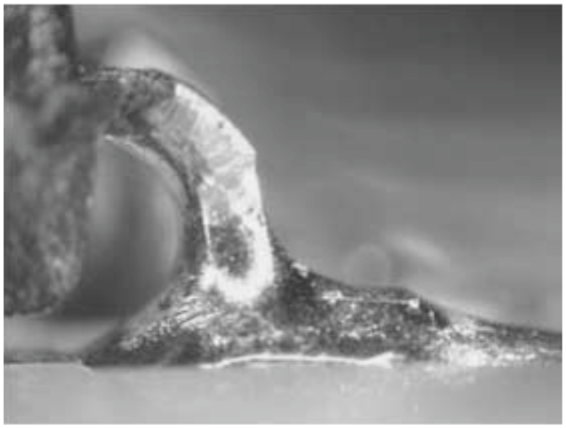


Figure 14. Typical Wetting of Sn-Finished Leads With SnAgCu Solder Paste, 255°C to 260°C Peak Reflow

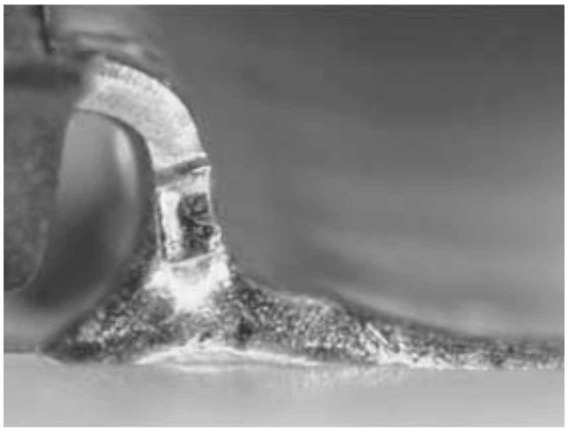


Figure 15. Typical Wetting of NiPdAu-Finished Leads With SnAgCu Solder Paste, 235°C to 240°C Peak Reflow

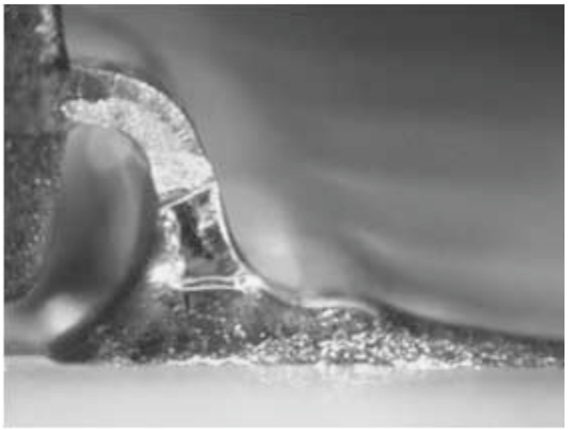


Figure 16. Typical Wetting of NiPdAu-Finished Leads With SnAgCu Solder Paste, 255°C to 260°C Peak Reflow

The solder joints formed by SnAgCu solder alloy and documented in Figure 13 through Figure 16 exhibited excellent heel, side, and toe filleting. Wetting height at the heel was at least equal to the lead thickness. This performance would be considered good for all three classes of products identified in IPC-A-610C for general electronic products, dedicated-service electronic products, and high-performance electronic products.[12]

3.3.2 Cross Sections of Solder Joints

Cross sections of the solder joints were taken to document the wetting on the underside of the leads. Figure 17 through Figure 20 show cross sections for the Sn-finished and NiPdAu-finished units, with SnPbAg solder paste reflowed with two different profiles.

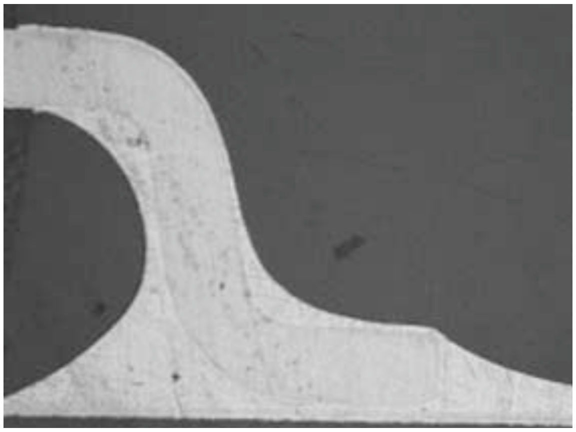


Figure 17. Cross Section of Typical Sn-Finished Lead With SnPbAg Solder Paste, 215°C to 220°C Peak Reflow

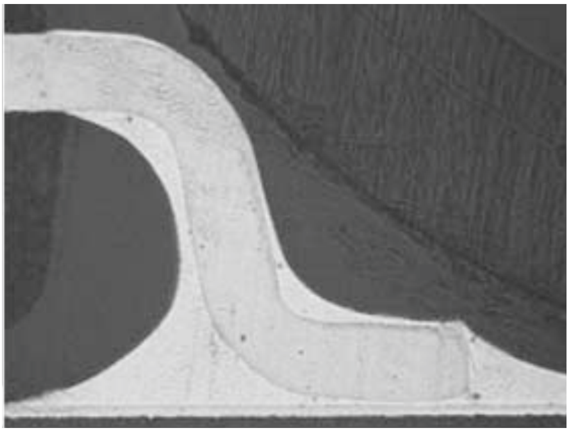


Figure 18. Cross Section of Typical Sn-Finished Lead With SnPbAg Solder Paste, 235°C to 240°C Peak Reflow

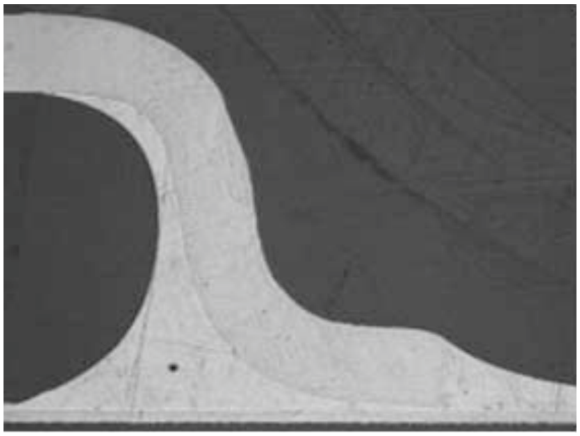


Figure 19. Cross Section of Typical NiPdAu-Finished Lead With SnPbAg Solder Paste, 215°C to 220°C Peak Reflow

Figure 20. Cross Section of Typical NiPdAu-Finished Lead With SnPbAg Paste, 235°C to 240°C Peak Reflow

Figure 21 through Figure 24 show cross sections of leads of the Sn-finished and NiPdAu-finished units, with SnAgCu solder paste reflowed with each of the two applicable profiles.

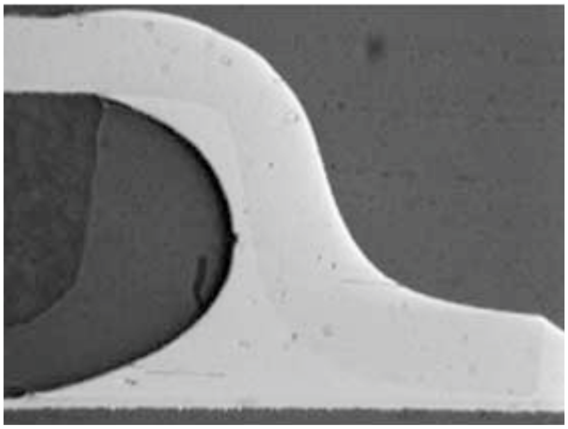


Figure 21. Cross Section of Typical Sn-Finished Lead, SnAgCu Solder Paste, 235°C to 240°C Peak Reflow

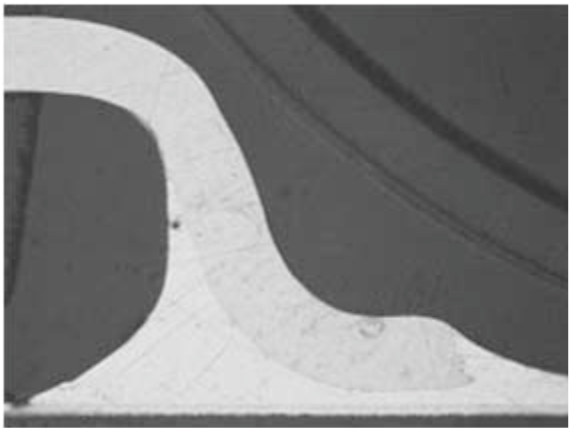


Figure 22. Cross Section of Typical Sn-Finished Lead, SnAgCu Solder Paste, 255°C to 260°C Peak Reflow

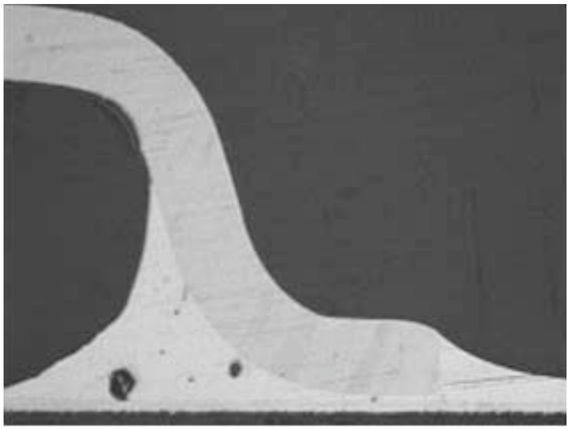


Figure 23. Cross Section of Typical NiPdAu-Finished Lead, SnAgCu Solder Paste, 235°C to 240°C Peak Reflow

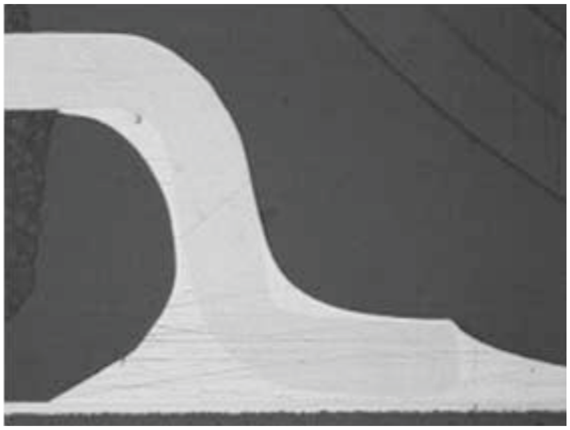


Figure 24. Cross Section of Typical NiPdAu-Finished Lead, SnAgCu Solder Paste, 255°C to 260°C Peak Reflow

3.4 Lead-Pull Test Method and Results

3.4.1 Lead-Pull Test

Lead-pull testing determined the force needed to pull a lead from the PWB land pattern after soldering. First, to allow access to a lead on the PWB, the leads were cut near the package body. Next, with the leads separated from the package body (see Figure 25), the PWB was fastened in a test fixture. Finally, the lead was pulled perpendicular to the PWB surface until it separated from the PWB (see Figure 26). The rate of movement of the test device was 0.4 mm/s 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.

The temperature cycle was –40°C to +125°C, in 30-minute cycles. This was a thermal-shock test, with the boards being moved from a –40°C to 125°C chamber. There was no ramp between the temperature extremes.

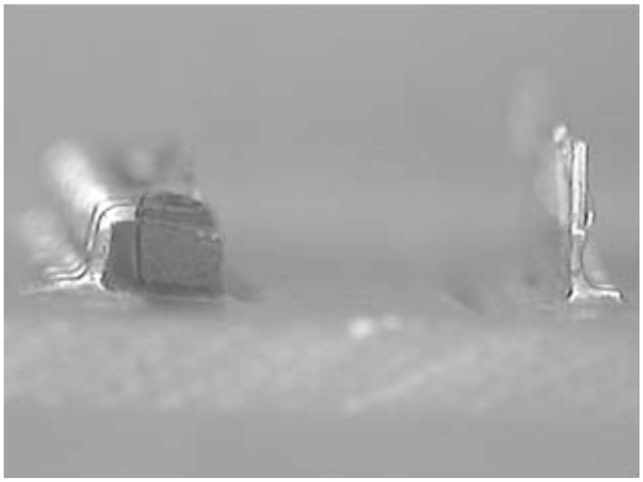


Figure 25. Leads Bent Up for Pull Test

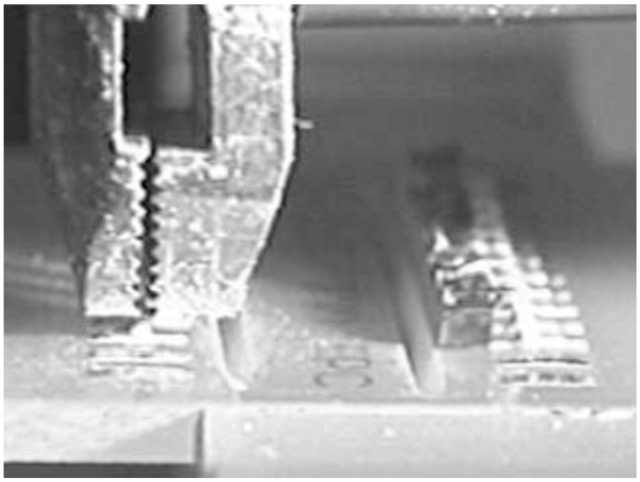


Figure 26. Leads Pulled Vertical to PWB

3.4.2 Lead-Pull Data

Lead pull was performed on Sn-finished and NiPdAu-finished leads. Forty leads from each group were pulled to define an average pull force. Pull force is measured in Newtons (N).

Figure 27 gives average lead-pull values for the Sn-finished and NiPdAu-finished packages, with SnPbAg solder alloy for the defined reflow conditions. This data set is for PWBs with OSP coating and includes data for both non-temperature-cycled units and units after temperature cycling.

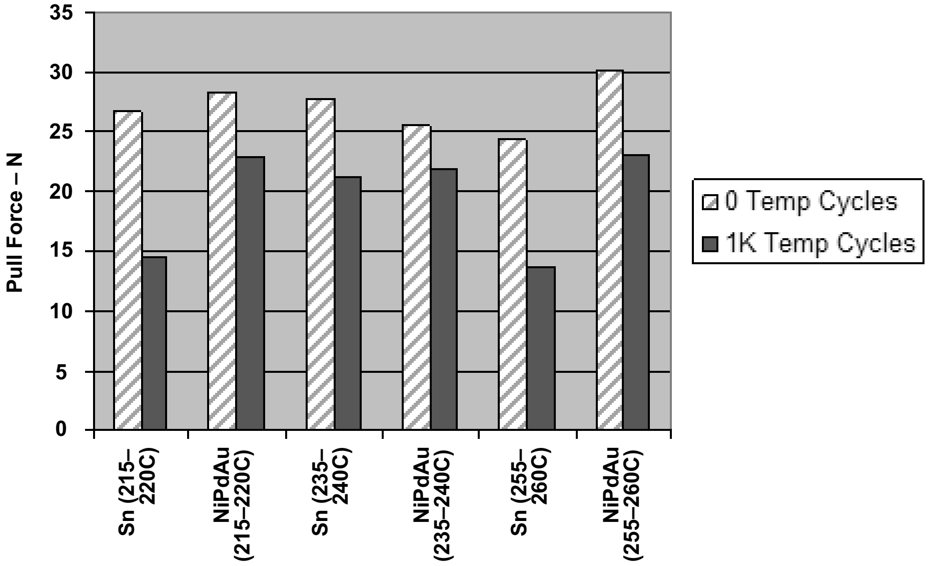


Figure 27. Average Lead-Pull Values for Sn-Finished and NiPdAu-Finished Units, SnPbAg Solder Alloy

The minimum pull force specified for non-temperature-cycled units, per the industry-standard specification, is 10 N. The industry-standard requirement for the temperature-cycled units is that the average lead-pull force shall be greater than half of the average pull force of the non-cycled units.[13, 14] Both Sn-finished and NiPdAu-finished units meet the industry standard requirement for non-cycled and temperature-cycled units when using SnPbAg solder.

Figure 28 gives average lead-pull values for the Sn and NiPdAu finished packages, with SnAgCu solder alloy for the defined reflow conditions. This data set is for PWBs with OSP coating and includes data for both non-temperature-cycled units and units after temperature cycling.

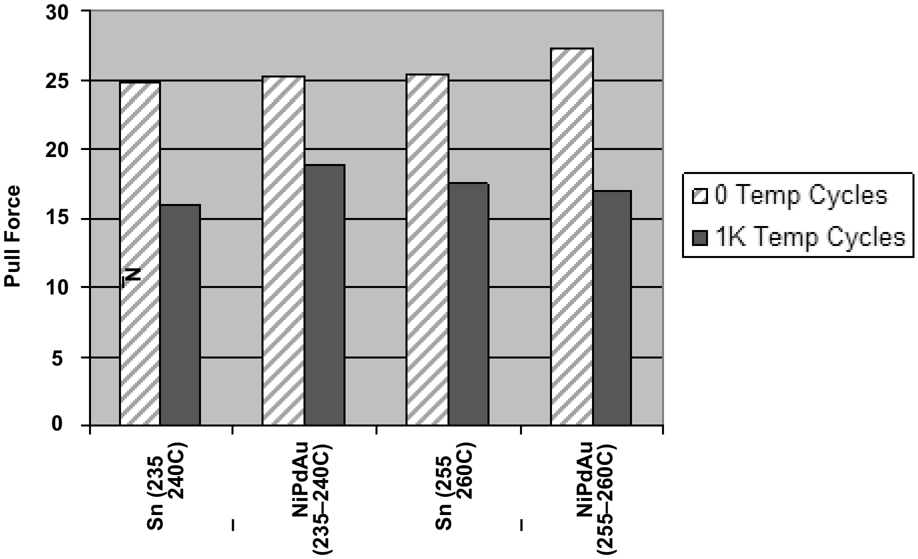


Figure 28. Average Lead-Pull Values for Sn-Finished and NiPdAu-Finished Units, SnAgCu Solder Alloy

Both Sn-finished and NiPdAu-finished units meet the industry-standard requirement for noncycled and temperature-cycled units when using SnAgCu solder.

3.5 Lead-Pull Failure Mode

It is important to understand the failure mode seen during the lead-pull testing. There are four possible modes of failure in this test method. In mode 1, the component lead, solder, and PWB pad remain intact, and the PWB Cu pad is pulled away from the PWB base laminate. In mode 2, the interface between the PWB Cu pad and the solder gives way. In mode 3, the joint breaks within the solder, leaving solder on the PWB Cu pad and the component lead. In mode 4, the lead peels away from the solder, leaving the bulk of the solder attached to the PWB Cu pad.

The lead-pull failure modes were recorded for the Sn-finished and NiPdAu-finished units tested. More than 95% of the lead-pull failure modes for the Sn- and NiPdAu-finished units tested were mode 1 (see Figure 29 and Figure 30). The Cu pad lifted from the PWB base laminate before failure of any other interface. Figure 29 and Figure 30 show typical lead-pull failure modes where the Cu PWB pads have been lifted from the PWB. A small number of units showed mode 3 failure, with the joint failing within the solder. No mode-4 failures were noted, indicating that the bond between the lead and the solder is stronger than the bond between the PWB pad and the PWB substrate, in most cases.

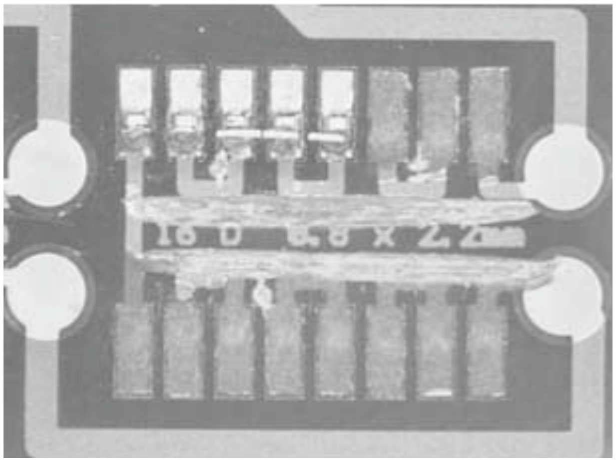


Figure 29. Typical Lead-Pull Failure Mode

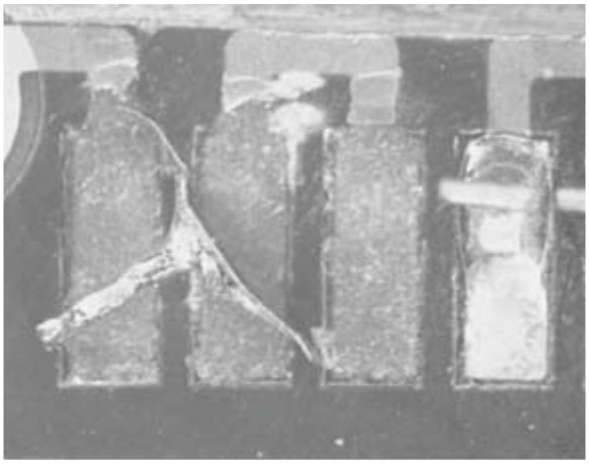


Figure 30. High Magnification of Typical Lead-Pull Failure Mode

4 Conclusions

This evaluation has demonstrated excellent solder wetting performance for Sn-finished components with both SnPbAg (current) and Pb-free (future) soldering processes.

Specifically, for the Pb-free solder paste (SnAgCu) and for the Pb-bearing solder paste (SnPbAg) for the three appropriate reflow profiles:

1. Lead-pull data for as-built and temperature-cycled units showed passing results with both solder pastes.
2. Lead-pull data showed that the weak point in the joint was not the lead/solder interface.
3. Cross sections of as-built joints showed excellent wetting to the bottom of the lead and excellent heel and toe filleting for both pastes under appropriate reflow conditions.
4. Visual inspection of solder joints showed acceptable and equal performance for both solder pastes.
5. Wetting-balance data, using SnPb solder, showed that t_0 and $t_{2/3}$ for Sn-finished leads were equal that for NiPdAu-finished leads.

The Sn-finished leads will perform well with both Pb-bearing and Pb-free solder pastes. Their solder wetting performance is equivalent to the other Pb-free finish that TI uses, NiPdAu.

5 References

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Revision History

Changes from Original (October 2002) to A Revision **Page**

- Changed temperature in *Lead-Pull Test* section from +25°C to +125°C. 13
- Deleted outdated links item 5 and 6 in the *References* section. 16

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

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