# Evaluation of Stripped and Replated Component Termination Finishes

**Guhan Subbarayan, Robert Kinyanjui**

**Sanmina-SCI**

**Michael Baker**

**E-Certa**

## ABSTRACT

In this study, the termination finish of Small Output Integrated Circuit (SOIC) chip components were converted from Pb-free to Sn-Pb (backward conversion) and from Sn-Pb to Pb-free (forward conversion). The motivation for these conversions is due to a combination of factors such as the supply chain constraints on component availability and European Union's (EU) legislation on "Restriction of Hazardous Substances" (or RoHS). Additionally, components with 100% matte tin finish were converted to Pb-free Sn-3.5%Ag-0.5%Cu (SAC305) finish. This type of conversion would be necessary to avoid tin whiskers issue on matte tin finish components. The conversions were performed using a "Robotic Stripping and Solder Dipping Process".

After conversion, the parts were examined using x-ray fluorescence (XRF) to verify for RoHS compliance. Electrical and die visual investigation utilizing optical microscopy, DC pin to pin electrical testing and acid de-encapsulation were performed on one of the converted component (MC14111DW) to inspect for damage on die, after the conversion process. There were no opens or short circuits found during the electrical test. The die was undamaged after the conversion process.

As the final evaluation method, the converted parts were assembled on an actual PCB using both tin-lead and lead-free process. Three Printed Circuit Board (PCB) surface finishes namely Immersion Silver (ImAg), Organic

Solderable Preservative (OSP), and Electroless Nickel/Immersion Gold (ENIG) were evaluated. The microstructures of the converted components were normal in appearance and had well defined IMC both along the board and component interface. After microstructure analysis, lead pull testing was performed at 'as assembled condition' (AA) and 'after thermal aging' (ATA) to determine the mechanical reliability of converted component termination finishes with respect to the original termination finish. The results indicate that the converted component has almost the same pull strength as to that of the original component.

## INTRODUCTION

Electronic lead or component terminal finishes refer to the solderable finishes applied to lead-frames for ICs and terminations for discrete electronic components. Lead-frames are the metal tabs that electrically connect the chip die to the PCB. The predominant lead-frame termination finish today is a Sn-Pb alloy with typical nominal Pb content ranging from 7% to 37% Pb [1]. Due to RoHS legislation, the electronic component industry has been investigating Pb-free alternatives to the Sn-Pb terminal platings. Some commonly available Pb-free terminal finishes are Sn/(2-3)%Bi, NiPdAu, Matte-Tin, SAC305, Sn/2%Cu, and Au. While matte tin is the most commonly available among these finishes, there is a well-known phenomenon associated with this finish known as "tin whiskers" [2]. An important requirement for any Pb-free termination finish is to have good reliability in the solder joints made between the Sn-Ag-Cu alloy, PCB and itself. Metallurgical incompatibility between the Sn-Ag-Cu solder alloy and the terminal finishes could result in solder joint brittleness, low strength or poor thermal fatigue resistance, particularly following aging of the joint [3].

In this study, the existing component termination finish was stripped and replated with a new finish. Conversions from Sn-Pb to SAC305 (Pb-free), matte tin (Pb-free) to Sn-Pb, and matte tin (Pb-free) to SAC305 (Pb-free) were performed. These conversion processes will be necessary in the future for the following reasons. Due to a combination of the EU's RoHS legislation and supply chain constraints, some components will no longer be available with Sn-Pb termination surface finishes. However, contract manufacturers who build products for military and medical applications will prefer to continue using components with Sn-Pb termination finish to avoid the risk of tin-whiskers and other reliability issues associated with Pb-free process. In opposite scenario, contract manufacturers will face a requirement to convert from Sn-Pb termination finishes to Pb-free finishes to be compliant with RoHS legislation. There will also be a situation where there is a requirement to convert from matte tin (Pb-free) termination finish to some other Pb-free finish to avoid the risk of tin whiskers.

All the above mentioned conversions were performed by a “Robotic Stripping and Solder Dipping Process”. In this process, the existing outer termination finish of the component is chemically stripped, exposing the base metal. The component is then fluxed and the leads are dipped into a molten solder bath of the required coating to be plated. The entire process is performed automatically by a robot. Although this can be a very useful process, die and leads of the components are subjected to sudden thermal shock during the solder dip process. Therefore, there is a concern that that during this process, the die could be damaged or the mechanical reliability of the leads could be reduced due to stress buildup.

The objective of this research endeavor was to evaluate the converted components and to qualify this process. XRF analysis, electrical testing, die inspection, microstructure analysis and pull testing were performed on the converted components for the purpose of qualifying this process

## 2. Evaluation Methods:

Table 1 lists the Part Number, Manufacturer Part Number, Part Description, Original Termination Finish (before conversion), and Final Termination Finish (after conversion) that were used in this study. A sample size of 90 components for each part type was converted using this process

**Table 1: Components**

| Part Number | Manufacturer Part Number | Part Description | Original Termination Finish | Final Termination Finish |
|---|---|---|---|---|
| 1 | 12512 | SO16-3.8 mm | 100%Sn | SnPb |
| 2 | 12512 | SO16-3.8 mm | 100%Sn | Sn96 |
| 3 | 12512 | SO16-3.8 mm | 100%Sn | SAC305 |
| 4 | 12512 | SO16-3.8 mm | 100%Sn | 100% Sn (Same) |
| 5 | MC144111DW | SO16- 7.6 mm | SnPb | SnPb (Same) |
| 6 | 16085 | SO16- 7.6 mm | 100%Sn | SnPb |
| 7 | MC144111DW | SO16-7.6 mm | SnPb | SAC305 |
| 8 | 16085 | SO16- 7.6 mm | 100%Sn | SAC305 |
| 9 | 16085 | SO16- 7.6 mm | 100%Sn | 100% Sn (Same) |

This section is organized into three subsections. In the first subsection, the results of XRF analysis are presented. In the next section, electrical and die inspection results are presented. In the final section, microstructure analysis and pull testing results on converted components are presented.

### 2.1 XRF Analysis

X-ray based energy dispersive x-ray fluorescence (ED-XRF) is a commonly used tool for screening components for RoHS compliance. The XRF technique is a nondestructive method and gives real-time analysis information and can be used to analyze a wide variety of components. Table 2 shows the list of six RoHS banned substances and their maximum allowable limit in electronics assemblies. In addition to the RoHS substances, parts per million (PPM) for Sn and Ag was recorded in this study. A sample size of three components was used for the XRF analysis. Table 3, shows the average PPM values of the three readings for all the components in Table 1. The cells marked in red indicate that the composition exceeds the allowable limit, while green indicates that the composition is RoHS compliant.

**Table 2: RoHS banned substances and their corresponding maximum allowable limits**

| Banned Element/Compound | Chemical name | Maximum allowable limit (ppm) | Maximum allowable limit (percent weight) |
|---|---|---|---|
| Cadmium (includes metals and compounds) | Cd | 100 | 0.01 |
| Mercury (includes metals and compounds) | Hg | 1000 | 0.1 |
| Lead (includes metals and compounds) | Pb | 1000* | 0.1 |
| Chromium IV | Cr IV | 1000 | 0.1 |
| Bromine (Poly-brominated biphenyl) | PBB | 1000 | 0.1 |
| Bromine (Poly-brominated diphenyl ether) | PBDE | 1000 | 0.1 |

The Pb content was exceeding 1000 pm on part#1, 6 (Both converted from 100% Sn to SnPb) and part#5 (Original SnPb part). The other parts were within the maximum allowable limits and were therefore RoHS compliant.

**Table 3: XRF Analysis on Original and Converted Components**

| Part Number | Pb (PPM) | Hg (PPM) | Cd(PPM) | Br(PPM) | Cr(PPM) | Sn(PPM) | Ag(PPM) |
|---|---|---|---|---|---|---|---|
| ROHS Limit | 1000 | 1000 | 100 | 1000 | 1000 | - | - |
| 1 | 13172 | -128.2 | 104 | 8.76 | 384.1 | 986209 | 282 |
| 2 | 740.9 | -51.3 | 74.67 | 10.47 | 247.9 | 997927 | 1036 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 3 | 865.6 | -56.6 | 69.08 | 7.62 | 294.2 | 997934 | 904.5 |
| 4 | 647.8 | -37.24 | 30.2 | 16.5 | -279.3 | 999514 | 164.9 |
| 5 | 9283 | -68.46 | -68.4 | 5.64 | 201.77 | 990460 | 164.9 |
| 6 | 12582 | -72.3 | 0.936 | 67.3 | 12.9 | 987216 | 154.8 |
| 7 | 557.6 | -41.2 | -10.3 | 14.3 | 134.8 | 998519 | 840.1 |
| 8 | 918.2 | -68.56 | 66.39 | 18.84 | 243.4 | 997869 | 967.7 |
| 9 | 644.9 | -45.77 | 62.95 | 19 | 165.9 | 999103 | 68.1 |

**2.2. Electrical Testing and Die Inspection**

On part#5 (Part converted from SnPb to SAC305), electrical and die evaluation utilizing optical microscopy, DC pin to pin electrical testing and acid en-capsulation were performed. The purpose was to confirm that the die was in working condition after the hot solder dipping process. Three devices were submitted for analysis.

Pin to pin electrical testing was performed on the devices using an HP DC parametric analyzer to identify short or open circuited conditions. All pins were swept to Vss(Ground) from -2 to 2 volts with current limiting set at 1 mA. No open or short circuited conditions were detected at any active pin to ground. All current/voltage (IV) plots were very similar among devices.

The parts were de-encapsulated with fuming nitric acid to expose the die for inspection. The inspection was performed with high power optical microscopy and die marking. No anomalies were observed. Figure 1, shows an optical image of die (Part#5) with no anomalies.

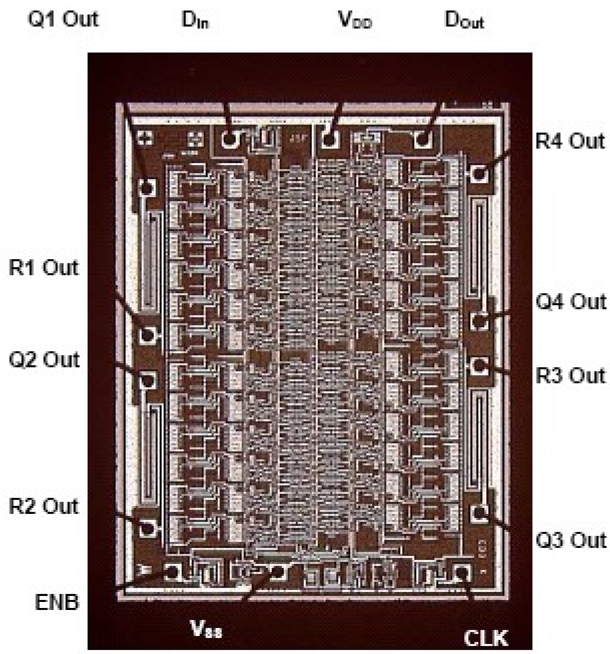


Figure 1: Optical Image of Die for Part#5

Ball bonds were intact and well placed on bond pads. Bond pads were free of contamination with no signs of corrosion present. Die fabrication process utilized a single level of aluminum metallization passivated by glassivation layer(s). No glassivation or metallization anomalies were evident.

### 2.3 Microstructure Analysis and Pull Testing

Components with Sn-Pb finish (Part # 1, 5, 6 from Table 1) were assembled on the PCB test vehicle, as shown in Figure 2. Components with Pb-free finish (Part # 2, 3, 4, 7, 8, 9 from Table 1) were assembled on the PCB test vehicle as shown in Figure 3. A sample size of three components were assembled for each part number type. The PCB dimensions were 6.5 inches by 10 inches.  It was 0.093 inches thick with 8 layers. Three PCB surface finishes, namely ImAg, OSP and ENIG were evaluated in this experiment.

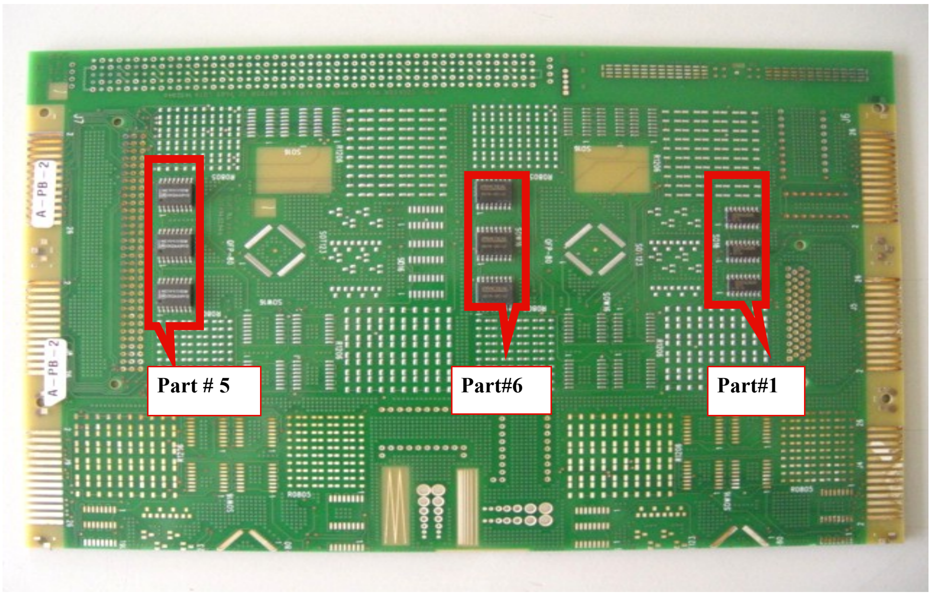


Figure 2: Sn-Pb components on PCB

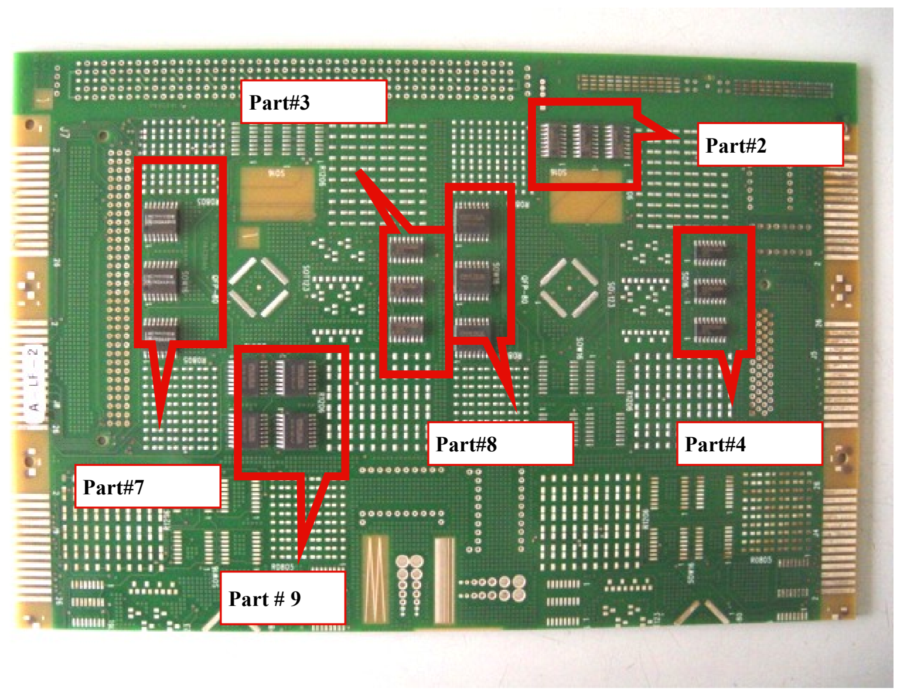


Figure 3: Pb-free Components on PCB

Three PCBs were assembled at each condition, as shown in Table 4. All the three boards were subjected to initial analysis. Then, one PCB was selected for time zero analysis. Another PCB was subjected to thermal aging at 150 °C for a time period of 10 days (240 hours). This was performed to accelerate the conditions that the solder joint would be subjected to in actual life cycle.

Table 4: Experimental Matrix

| Serial Number | PCB Surface Finish | Assembly Process | Number of boards assembled |
|---|---|---|---|
| 1 | ENIG | Pb-Free | 3 |
| 2 | OSP | Pb-free | 3 |
| 3 | ImAg | Pb-free | 3 |
| 4 | ENIG | Sn-Pb | 3 |
| 5 | OSP | Sn-Pb | 3 |
| 6 | ImAg | Sn-Pb | 3 |

**Assembly and Initial Inspection**

The Sn-Pb and Pb-free components were assembled with eutectic Sn-Pb and SAC305 solder pastes respectively. A 10 zone convection oven was used for reflow soldering both Pb-free and Sn-Pb assemblies. A Sn-Pb reflow profile was developed with a peak temperature 210 °C and Time Above Liquidus (TAL) of 90 seconds while Pb-free reflow profile was developed with a peak temperature 245 °C and TAL of 90 seconds.

After assembly, the boards were subjected to visual and 2D x-ray inspection to detect defects such as missing components, misalignment, bridging and tombstoning. Electrical continuity test was performed to compute the initial yield. Out of the 243 components tested, only 7 components failed due to opens, resulting in an assembly yield of 97%.

**Microstructure Analysis**

The 3.6 mm pitch SOIC components (Part # 1, 2, 3, 4) were used for cross-section analysis. For microstructure analysis, the selected parts were singulated from the boards and encapsulated in epoxy resin and prepared following standard metallographic procedures. Then, the samples were inspected under a high magnification microscope and SEM to evaluate solder joint quality and IMC growth. Microstructure of solder joints were examined at time zero and after thermal aging conditions. Microstructures of original and converted components were investigated. The IMC thickness for all the conditions was recorded as well.

The IMC for all the part numbers cross-sectioned (Part # 1, 2, 3, 4) showed normal appearance, acceptable thickness and was well defined along the board and at the component interface. Solder wetting, fillet and voiding were within the acceptable limits as per IPC 610D standards. There were also no cracks found in all the samples investigated. The microstructure of the part converted from matte tin to Sn-Pb termination finish (part#1) was consistent with that of a typical Sn-Pb solder joint [5, 6], as shown in Figure 4. The IMC composition was mainly $Cu_6Sn_5$ phase. Thermal aging produced an increase in growth of the IMC layer and the $Cu_3Sn$ layer became apparent, as shown in Figure 5.

The microstructures of converted Pb-free components (Part#2, 3) were similar in appearance as to that of original Pb-free component (Part#4) but quite different from Sn-Pb components. The IMC at the component interface had a scalloped shape as shown in Figure 6. Thermal aging produced increased growth rate of IMC for all Pb-free components at the component interface but not significantly at board interface.

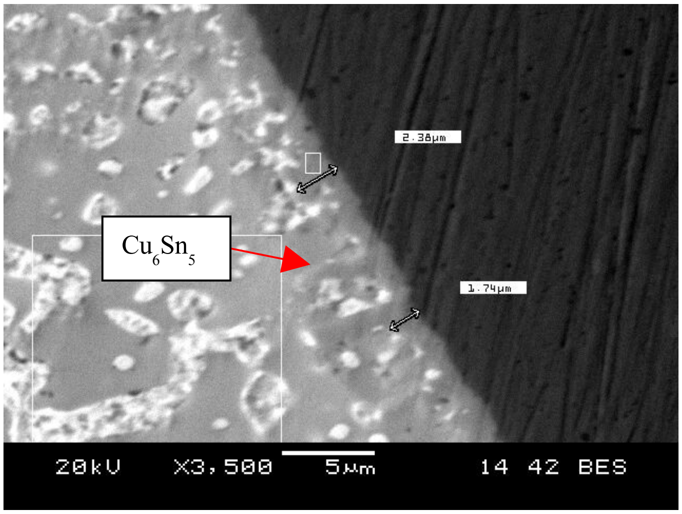


Figure 4: A representative SEM view of part#1 (Converted from 100% Sn to Sn-Pb termination finish) solder joint showing well defined IMC at as assembled condition

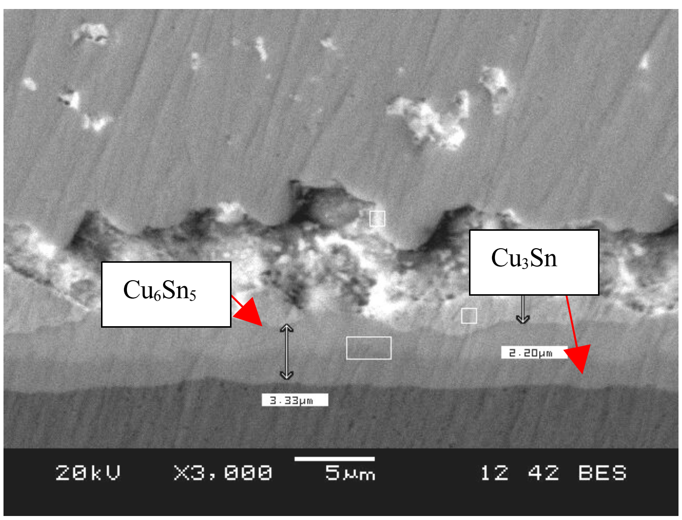


Figure 5: A representative SEM view of part# 1 following thermal aging (150 °C for 10 days) showing increased IMC thickness and appearance of $Cu_3Sn$ layer.

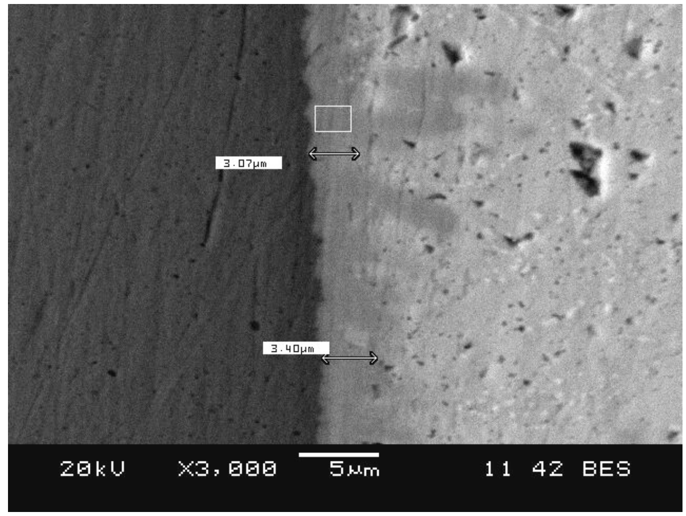


Figure 6: A representative view of part# 2 with Pb-free termination finish showing scallop shaped IMC at as assembled condition.

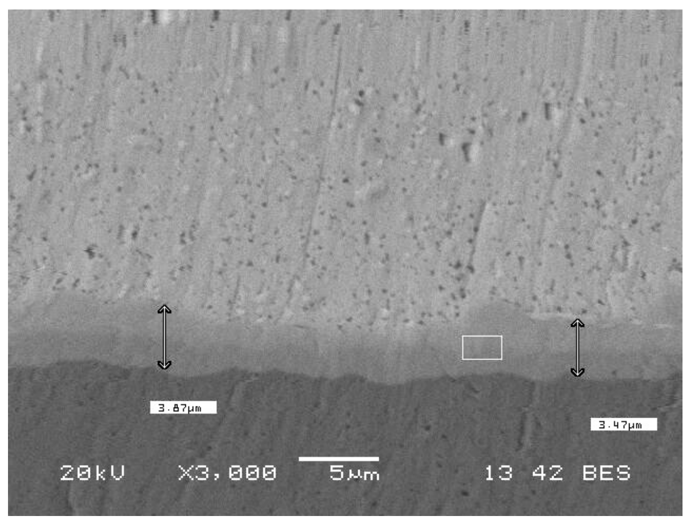


Figure 7: A representative view of part# 2 with Pb-free termination finish along board interface following thermal aging.

The average IMC thickness across the component interface and board interface is shown in Table 3 and graphically plotted in Figure 8. The four columns in Table 3 represent the following:

C1 – IMC thickness (μm) at component/solder interface at as-assembled condition.

C2 – IMC thickness (μm) at component/solder interface after thermal aging at 150 °C for 10 days.

C3 – IMC thickness (μm) at board/solder interface at as-assembled condition.

C4 – IMC thickness (μm) at board/solder interface after thermal aging at 150 °C for 10 days.

Table 5: Average IMC Thickness

| Part Number | C1 | C2 | C3 | C4 |
|---|---|---|---|---|
| 1 | 2.06 | 3.15 | 2.11 | 2.17 |
| 2 | 3.24 | 6.05 | 3.22 | 3.34 |
| 3 | 3.40 | 6.01 | 3.89 | 3.27 |
| 4 | 2.34 | 3.73 | 3.64 | 3.67 |

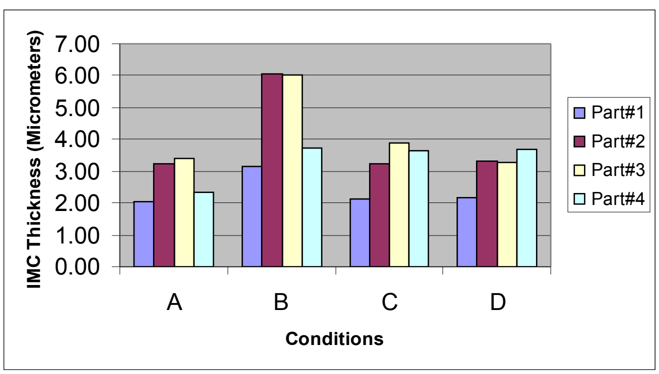


Figure 8: Graphical illustration of Table 5

IMC layer at the component/solder interface was slightly wider than at the board side for both as-assembled and thermally aged conditions. Additionally, the growth rate of IMC with thermal aging at the component interface was higher than at board interface for all the component types. Pb-free components had a thicker IMC layer compared to Sn-Pb components. The growth rate of IMC along the component/solder interface due to thermal aging for converted Pb-free components (Part#2, 3) was higher than that of the original component (Part#4).

## Lead Pull Testing

Lead pull testing was conducted to investigate the pull strength of leads and evaluate the mechanical reliability of the original and converted components. It is a superior method compared to ball shear test, to identify failures of weak interfaces [4]. The testing was performed on a Chatillon TCM 201-SS, DFE-100 equipment. Testing was performed with the following parameters: test speed 0.3 inch/minute and maximum test load of 50 Kgf. Figure 9 illustrates the setup of the pull tester used in this study. Pull testing was performed on the SOIC 7.6 mm pitch components (Part#5, 6, 7, 8, 9).


Figure 9: Setup for Pull Testing

A sample size of three components was pulled at each condition. A total of 96 components were subjected to pull testing. The pull strengths of three PCB surface finishes, namely ImAg, OSP and ENIG were also compared.

Figure 10 is a box plot based on the pull test results for Part#5, 6, 7, 8, 9. For all part numbers, the mean pull strength decreased after thermal aging. This was expected as aging increases the thickness of IMC and makes the solder joints brittle.

The highest mean pull strength was recorded for Part#6 (Converted from 100% Sn to SnPb) at “As-Assembled (AA)” condition while the lowest mean pull strength was also recorded on part#6 at “After Thermal Aging (ATA)” condition. Sn-Pb components had slightly higher mean pull strengths than Pb-free components before and after conversion. A statistical t-test was conducted using MINITAB to determine if there is any significant difference between the different part types. Only part #6 showed a significant decrease in the mean pull strength after thermal aging.

The pull strength of the part converted from SnPb to SAC305 component (Part #7) was almost same to that of the part before conversion (Part #5), at both AA and ATA conditions. There was not much significant difference between pull strengths of original 100% matte tin component (Part#9) and after it was converted to SAC305 finish (Part#8), at both AA and ATA conditions. However, the pull strength increased significantly at AA condition, when original 100% matte tin component (Part#9) was converted to SnPb finish (Part# 6). In contrast, the pull strength decreased significantly at ATA condition, when original 100% matte tin component ( Part#9) was converted to SnPb finish (Part#6), as shown in Figure 10. All these data indicate that mechanical strength was not considerably affected during the conversion process.

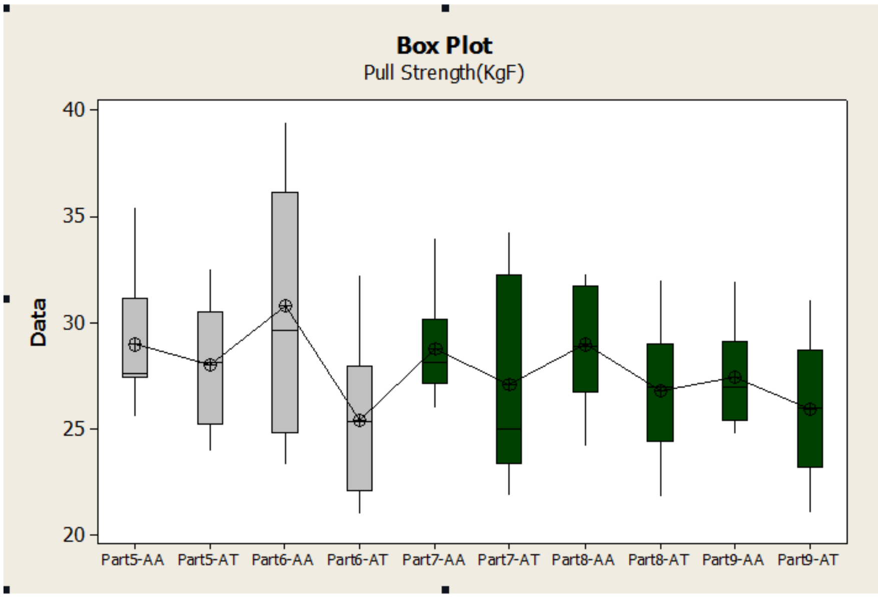


Figure 10: A box plot comparing mean pull strengths of all part numbers. Parts with SnPb termination finish is shown in grey, while parts with lead-free finish are shown in green.

Figure 11 is a box plot showing pull testing results for SnPb component finish with three different PCB surface finishes, namely, ImAg, OSP and ENIG. Among all PCB surface finishes ENIG has the highest mean pull strength before aging, however, after aging, ENIG has the lowest mean pull strength. After conducting a t-test, the statistical analysis showed that the mean pull strength of ENIG did decrease significantly after thermal aging, while aging did not significantly affect the mean pull strength for ImAg and OSP PCB surface finishes. A similar trend was also observed for lead-free parts, as shown in Figure 12.

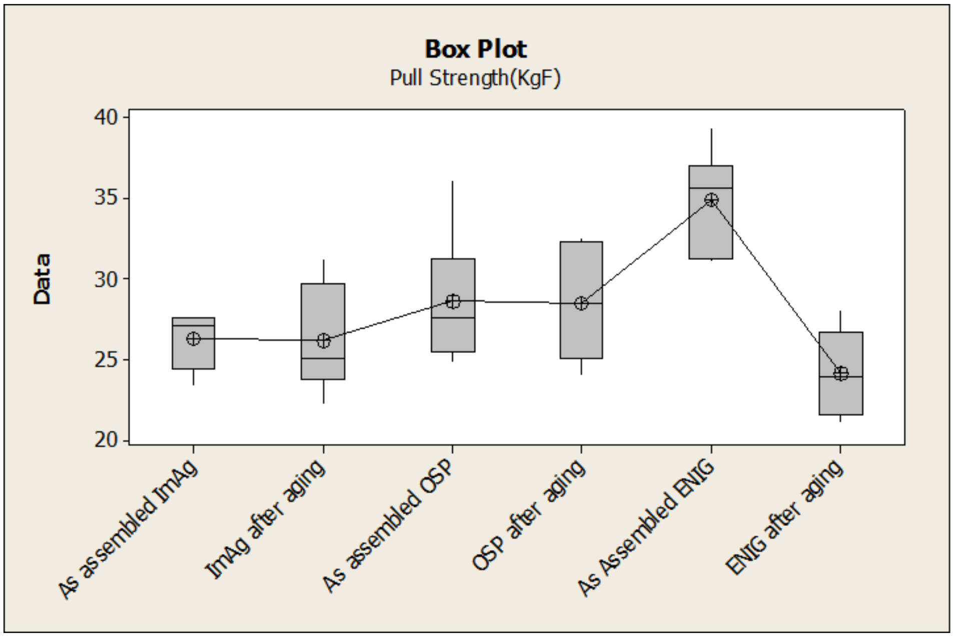


Figure 11: A box plot showing mean pull strengths for SnPb parts with ImAg, OSP and ENIG PCB surface finishes at AA and ATA conditions.

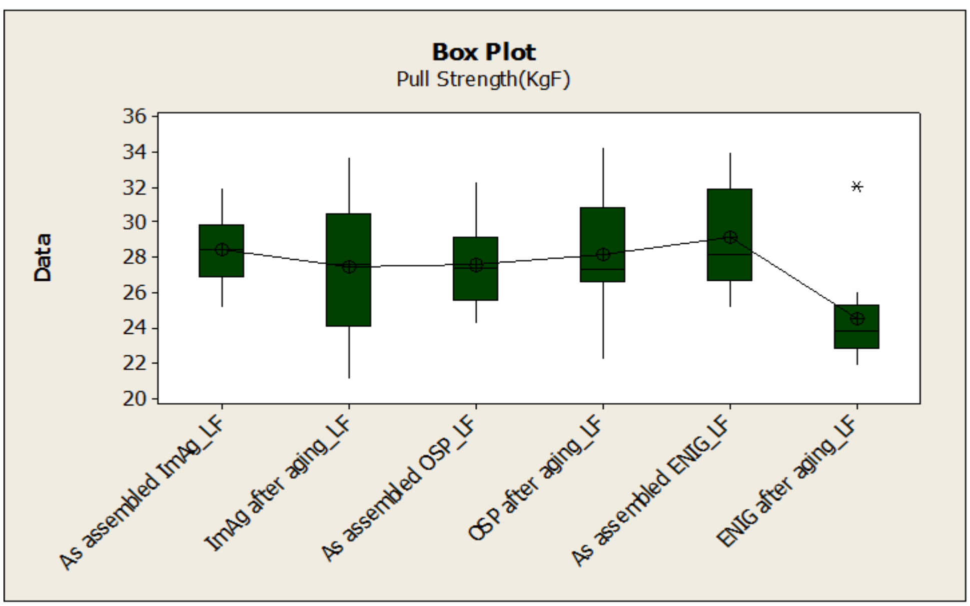


Figure 12: A box plot showing mean pull strengths for lead-free parts with ImAg, OSP and ENIG PCB surface finishes at AA and ATA conditions.

Figure 13 shows the three types of failure modes observed during the pull testing. At as-assembled condition, the percentage of failures due to broken leads, lifted pads, and lifted leads were 43%, 29%, and 28%, respectively. This implies that the weakest link of the solder joint at 'as-assembled' condition is within the bulk of the solder joint which is a normal characteristic of a good interconnection. After thermal aging, the percentages of failures due to broken leads, lifted pads, and lifted leads were 22%, 16%, and 62% respectively, which implies that the weakest link of the solder joint is at the interface between the component lead and the PCB. The reason for this weak interface is due to aging which increases the IMC thickness, making the interface layer brittle and weak.

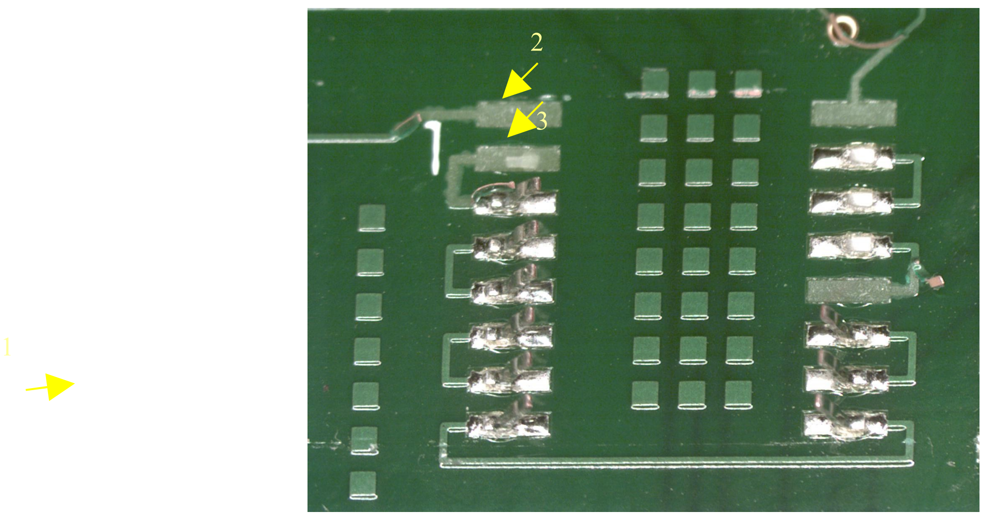


Figure 13. A representative view from a component after pull test, showing different failure modes: (i). Broken leads, (ii). Lifted pad and (iii). Lifted lead

## 3.CONCLUSIONS

The "Robotic Stripping and Solder Dipping Process" can be a very useful process to convert one termination finish to another desired termination finish. In this study, the converted components were evaluated using three methods. The XRF analysis proved that all the components converted to Pb-free were RoHS compliant. The electrical testing performed on die showed no failures. There were also no anomalies found on the die by optical inspection.

The converted components were assembled on an actual PCB test vehicle and evaluated. Initial analysis showed few defects and the yield of the assembly was 97%. The IMCs for all the converted components (SnPb and Pb-Free) were normal in appearance and of acceptable thickness. They were well defined both along the board and component interface. There were no cracks found in all the samples investigated.

The pull testing results indicate that mechanical strength was not affected significantly during the conversion process. Among PCB surface finishes, ENIG had the highest mean pull strength before aging. However, after aging, it had the lowest mean pull strength. This trend was observed for both SnPb and lead-free parts.

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