INVESTIGATION OF IMMERSION SILVER PCB FINISHES FOR PORTABLE PRODUCT APPLICATIONS

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ABSTRACT

Immersion silver is being pursued as a low-cost replacement PCB finish for both immersion gold/electroless Ni and selective gold/OSP in portable applications. Immersion Ag finish is touted both as a cost savings, yet reliable alternative to both ENIG and OSP. Hence, this study looked at the two of the most mature immersion silver plating chemistries in the market, as applied by several Motorola PCB suppliers and compared them to OSP and ENIG. Our study characterized the finishes for keypad popple contact resistance up to 500,000 cycles of actuation, electrochemical migration under humidity, BGA solder joint reliability, and wettability for Sn-Pb and Pb-free solder pastes. Plating process variation was evaluated by procuring samples with typical and 2x plating thickness while, environmental degradation was evaluated by aging boards in 85°C/85RH and flowing mixed gas. Recommendations for the applicability of the conventional and silver PCB finishes will be discussed in context of these results.

INTRODUCTION

With the push for lower cost and lead-free electronic products, the need to find alternate yet cost effective PCB finishes to replace HASL finish has gained considerable momentum[1,2,3,4,5]. Although several other lead free finishes such as organic solderability preservatives (OSP), selective gold, electroless nickel/immersion gold (ENIG), and electroless palladium, are available commercially, they are either a more expensive alternative or have well documented process related and/or reliability issues associated with them[4,6].

In this paper we are focusing on Immersion silver as an alternate finish for PCB surface. Two major suppliers of immersion silver technology promote it as an economic drop in replacement for OSP and ENIG without the elctromigration issues associated with electroplated Ag. Several published works have shown that silver is prone to electromigration and dendritic growth in presence of moisture and electric bias[7,8]. However, these studies concentrate on thick film-fired silver.

Even though both suppliers processes are similar in that they both plate silver onto copper with a co-deposited organic, they are different in their chemistries and processes. Table 1 shows their differences.

Supplier 1	Supplier 2
Acid based (pH=2)	Neutral (pH=7)
Thickness 10 – 40 µin	Thickness <6 µin
Drop in existing plating line	Needs specific Supplier equipment
Vertical or horizontal plating line	Horizontal plating line only

Table 1. Differences in supplier Immersion Ag plating processes.

For this study we compared PCBs finished with immersion Ag from two different suppliers against OSP, ENIG and electroplated silver (droplet test only). SIR and elctromigration tests were conducted in accordance to IPC and Bellcore standards by an independent laboratory. Furthermore, testing with exposure to extreme moisture and voltage (droplet test) was conducted in-house to gain a better understanding of dendritic growth and electromigration. BGA reliability was evaluated using the 3 point bend test while wetting and solderability was carried out using goop troop boards reflowed with several different solder pastes. Lastly, the finish was tested for keypad continuity applications by monitoring the changes in contact resistance for up to 500,000 cycles of metal popple actuation that mimicked the actual usage of the PCB surface. In order to access the process variations, samples from three PCB vendors, as well as from the chemical suppliers were procured and tested.

EXPERIMENTAL PROCEDURES

SIR and electromigration tests

Both Surface Insulation Resistance (SIR) and ElectroMigration (EM) tests were conducted at Trace Laboratories-East in strict accordance with IPC-TM-650 and Bellcore GR-78 specifications, respectively. The samples for these tests consisted of samples with 1x and 2x thickness from the vendors and suppliers. A set of 5 IPC B-25 coupons were tested in the as-received condition, after 1 reflow at peak temperature of 225°C, with rework flux only, and reflow at peak temperature of 225°C with application of two Sn-Pb and one Pb-free solder pastes, respectively. SIR coupons were tested for changes in resistance for up to 250 hours, while the EM coupons were monitored for 500 hours with periodic observation and recording of dendritic growth, if any. Bare Cu coupons were also run as a control.

Water droplet test

This test was designed to test the tendencies for electromigration of immersion Ag in presence of extreme moisture and voltage. Electromigration of metal species leads to dendritic growth resulting in short circuits was monitored and compared for immersion Ag as well as for Organic solder Preservative (OSP) and Electroless Ni over Immersion Gold (EniG) samples. IPC B-25 comb patterns were connected to a 50V DC source. A droplet of deionized water was carefully placed bridging adjacent metal lines and the subsequent change in potential difference was monitored across a 100kΩ resistor as a function of time.

Keypad contact resistance test

Change in contact resistance as a function of # of cycles of actuation were recorded using commercially available test equipment manufactured by Test Systems Engineering. The set up consisted of four platforms to hold the test samples and pneumatically driven actuators (pistons) to push the metal popples. Commercially available cellular phone keypads with immersion Ag finish from three vendors along with ENIG as reference were used. Metal popples were placed on the keypads and completed the electrical circuit when pressed by the actuators. Two wire contact resistance measurements were taken periodically to monitor the wear on the Printed Circuit Board (PCB) surface finish. Prior to testing, the keypad surfaces were subjected to various reflow and environmental conditions, including exposure to corrosive mixed gas flow (mixture of Cl_2, SO_2, NO_2 and H_2S) up to 96 hours, and aging at 85°C and 85%RH up to 96 hours, after 2 and 5 reflows, respectively.

Reliability test

Three-point bend test to failure was conducted by assembling Glob Top Plastic BGA (1 mm pitch, 196 I/O) on a cellular phone controller boards. Flux-only attachment results in far fewer voids in the solder joint and allows for comparisons in the effect of the finish itself on void introduction in the joint. ENIG and OSP finish boards were also tested as controls. A span of 1 inch between the supports was used with a loading rate of 1mil/sec until failure, to record load as a function of displacement. To test the variations in reliability resulting from reflow and aging conditions, samples were subjected to 1 or 2 reflows, followed by aging at 150°C for 168 hours. Also, reflow profiles with two different peak reflow temperatures of 190°C and 215°C were employed to investigate the effects of process variation on the reliability. The aforementioned process variations were carried out to determine the effect of intermetallic layer thickness on the reliability of the solder joint, which in turn is dependent on reflow temperature and time, number of reflows, aging temperature and time after reflows.

Solder wetting and spreading

Goop Troop boards with immersion Ag finish from the three vendors, as well as samples with OSP and ENIG were used to study the wetting characteristics of the PCB surface finish. Using a 5 mil thick stencil and 132 mil diameter aperture, both lead-free and lead containing solder pastes were reflowed at a peak temperature of 225°C. After reflow the diameter of the solder sites were measured and compared to the original diameter to determine the wettability of the PCB surface by the solder paste. Tests were repeated with boards that were exposed to corrosive mixed gas flow (mixture of Cl_2, SO_2, NO_2 and H_2S) up to 96 hours and aging at 85°C and 85%RH up to 168 hours, prior paste printing and reflow.

RESULTS AND DISCUSSION

Finish appearance

The Supplier 2 finish is much shinier and silvery in appearance than the Supplier 1, which has a white matte appearance. With exposure to air reflows, the appearance of each stayed practically the same. However, after exposure to 85°C/85%RH the finish dulled a little for both supplier chemistries. The flowing mixed gas reacted with the finish and formed corrosion products as shown in Figure 1.

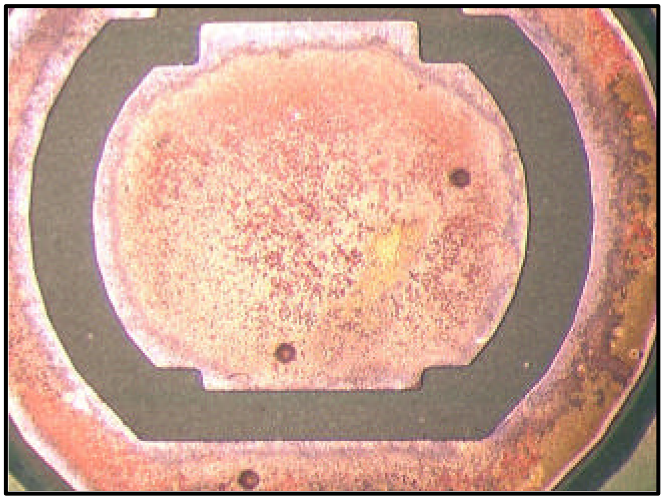

Figure 1. Macroscopic view of the immersion Ag surface exposed to mixed gas flow for 96 hours showing the tarnish and corrosion product.

SIR and EM tests

From the data supplied by the SIR laboratory, it is understood that all immersion Ag specimens supplied by the suppliers and vendors for both 1x and 2x thickness have passed the SIR test as regulated by IPC-TM-650. All samples with the exception of a sporadic few have either met or exceeded the reference resistance value of 10^8 ohms even after 250 hours of testing. Figure 2 is a representative plot of the resistance measurements as a function of time for both the control boards (bare Cu) as well as Immersion Ag samples. It is clear from the figure that all the samples have exceeded the minimum resistance value of 10^8 ohms through the entire duration of the test. Furthermore, all the samples with the exception of a very few have met the visual requirements at 10x magnification, i.e. no evidence of stains, dendritic growth, contamination or condensation on the comb pattern. This agrees with data reported by Intel[3] and Lucent[5]. The ones with a growth appeared to have condensation that contributed to the growth.

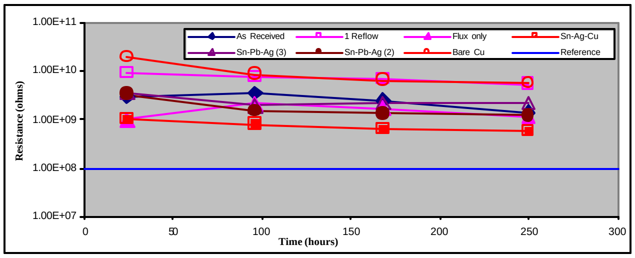

Figure 2. Surface Insulation Resistance (SIR) as a function of time for Supplier 2 samples (1x thickness).

All Electromigration samples met the Telcordia Technologies GR-78-Core, Issue 1, Section 13.1 average insulation and visual requirements. Also, no heavy corrosion or evidence of filament/dendritic growth that reduced conductor spacing by more than 20% was observed. A sample plot of insulation resistance as a function of time during EM testing for immersion Ag samples as well as bare Cu control boards are plotted in Figure 3. It is clear from the picture that Bellcore test requirements are adequately sufficed, i.e. $R_{final} > R_{initial}/10$ (final resistance values recorded after 500 hours of testing are greater than a tenth of initial resistance values recorded after 96 hours of testing).

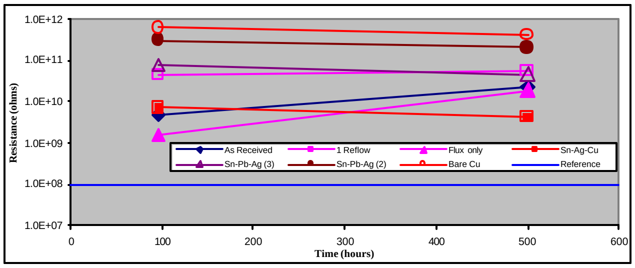

Figure 3. Electromigration (EM) data as a function of time for Supplier 2 samples (1x thickness).

Water droplet test

Results from the DI water droplet test indicated that all surfaces tested exhibit dendritic growth. It is clearly illustrated in Figure 4 in the case of immersion Ag PCB surface. Also, as can be seen from Figure 5, all surfaces experience a drop in potential due to electromigration and dendritic growth in presence of extreme moisture and bias, eventually leading to a short where the potential difference becomes zero. However, a closer look at the graph does indicate that OSP and ENIG surfaces have a slower rate of dendritic growth when compared with both the immersion Ag finishes.

Keypad contact resistance test

Keypads do not impose a severe requirement on the contact resistance performance of PCB finishes. Typically the threshold resistance value required of keypads to operate the radio is on the order of 25 kΩ or higher. Figure 6 illustrates the changes in contact resistance vs. # cycles of actuation of keypads for various surface finishes and subjected to 5 reflows prior to testing. As can be seen from the plot, all the samples are well below the arbitrary threshold value of 25kΩ even after 500,000 cycles of actuation. However, it is to be noted that the samples with ENIG are an order of magnitude or two lower in the contact resistance than the immersion Ag samples. Contact resistance values for samples treated to 5 reflows and exposure to 85°C/85 RH for 96 hours are shown in Figure 7. This graph too follows the same trend exhibited in Figure 6 with a slight increase in resistance, which still is far below the threshold of 25kΩ. Resistance measurements for samples subjected to 5 reflows and then exposed to mixed gas flow for 96 hours show a different trait (Figure 8). The resistance values for ENIG samples are unaffected while the immersion silver values start at higher resistance owing to corrosive layer on the surface (Figure 9), but decrease below the threshold of 25kΩ after actuation. This indicates that in

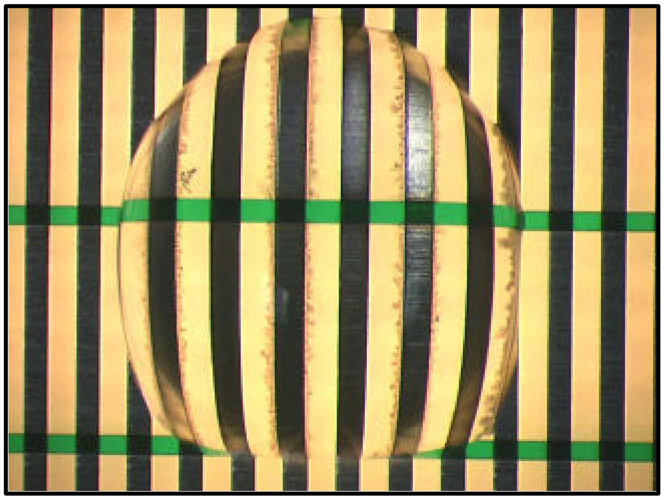

Figure 4. Macroscopic view of immersion Ag surface after 3 minutes of water droplet test. Note the dendritic growth on right side of the test coupon.

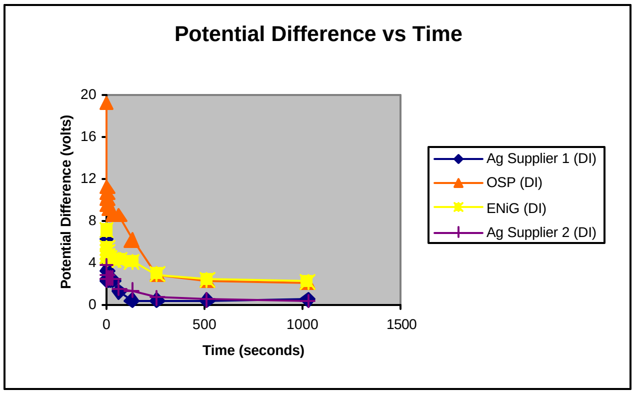

Figure 5. Plot of potential drop as a function of time during water droplet migration testing.

regular service, where the conditions are not as corrosive for extended periods of time, the degradation in performance might be minimal. Also, a close observation of keypad surface after actuation (Figure 10) shows a pock mark at the center where the popple made contact with the key pad during activation and grooves on the outer edge where the popple rests on the key pad. These areas actually provide a corrosion resistant area underneath the surface where the circuit can be completed at lower contact resistance upon actuation (Figure 11).

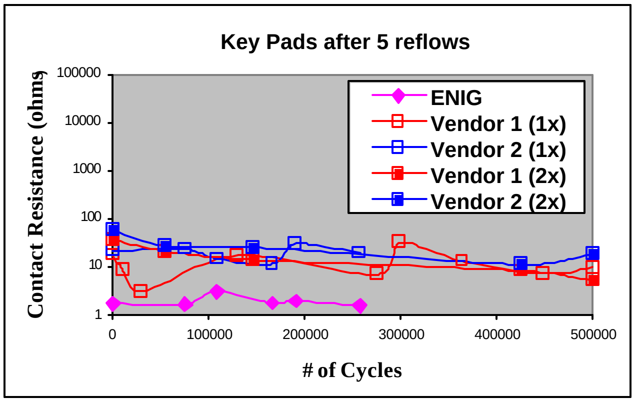

Figure 6. Keypad contact resistance data after 5 air reflows.

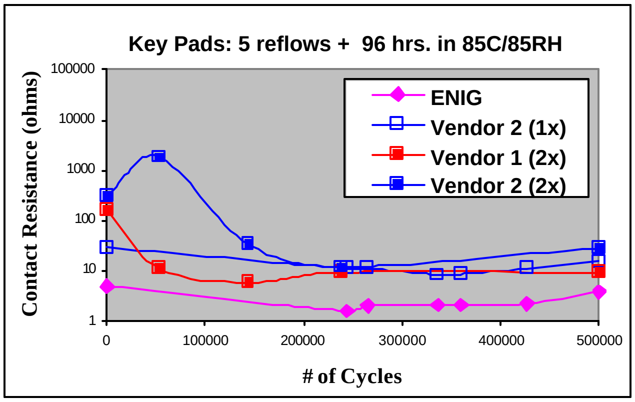

Figure 7. Keypad contact resistance data after 5 air reflows + 96 hours of 85°C/85RH.

Reliability test

The maximum load at failure of 196 I/O GTBGA in three point bend test for various finishes is shown in Figure 12. The plot shows that the OSP samples fail at higher loads than both the immersion Ag finishes with the Ag finish from supplier 1 having the lowest reliability. Also, as seen from the Tukey-Kramer comparison circles reliability of Ag finish from both suppliers is significantly lower than that of OSP. A cross-sectional view of the failed samples revealed that the failure occurred at the PCB/BGA interface near the intermetallic layer as shown in Figure 13. Also, EDS quantitative elemental analysis confirms the same results that show Cu and Sn in proportions closer to stoichiometric values of Cu_6Sn_5 intermetallic (Figure 14). As addition of small % of Ag is not expected to change the metallurgical structure of the solder joint, given that the solder already contains 2% silver by weight, two theories may explain why the silver boards exhibit lower strength. One, the immersion Ag finish causes a locally high level of silver at the interface which may cause a layer of Ag_3Sn to form and influence the strength of the interface. Two, the silver needs to be dissolved completely before the conventional Cu_6Sn_5 intermetallic layer can be established. Determining, if these or another theory is correct will need to be investigated further.

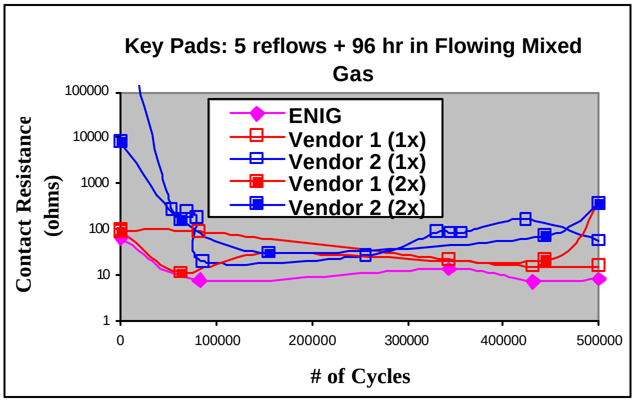

Figure 8. Keypad contact resistance data after 5 air reflows + 96 hours in flowing mixed gas flow.

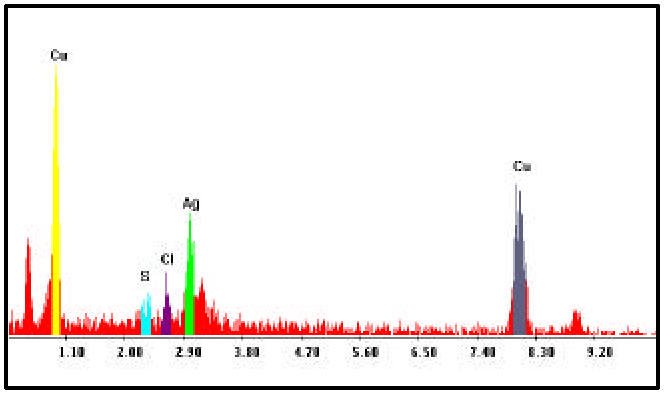

Figure 9. EDS analysis of the immersion Ag surface exposed to 96 hours of mixed gas flow, showing the S and Cl corrosion products.

Samples subjected to two reflows and aging of the solder joints lead to a lower reliability and is illustrated in Figure 15. This is probably due to an increase in intermetallic layer thickness[9]. Neither thickness of the Ag finish nor the peak reflow temperature has any significant bearing on the reliability. Figures 16 (a and b) and 17 respectively, illustrate this apparent lack of effect for the cases studied.

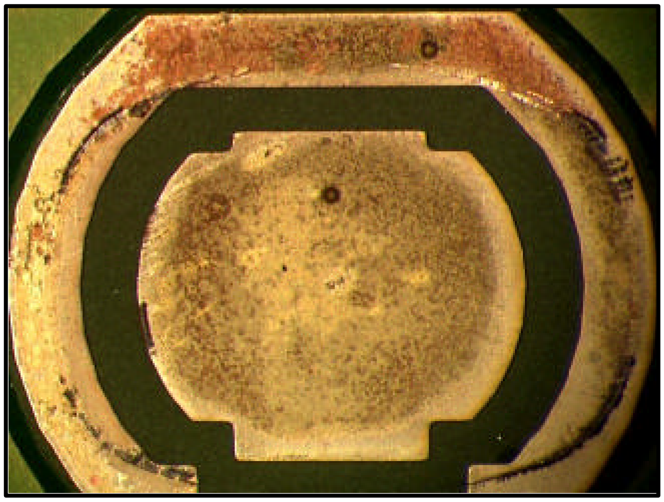

Figure 10. Low magnification picture of a keypad that under went 500,000 cycles of actuation. Note the pock-mark at the center made by the popple on actuation, and the groove on the edges where the popple rested on the ring.

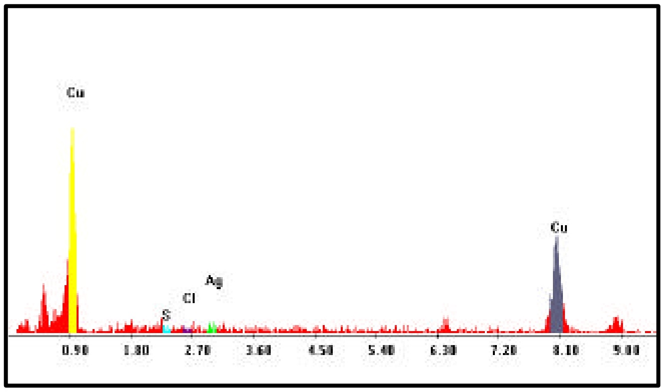

Figure 11. EDS analysis in the groove etched by the popple on the immersion Ag surface exposed to 96 hours of mixed gas flow, showing the Cu below the surface contacted by the popple during testing.

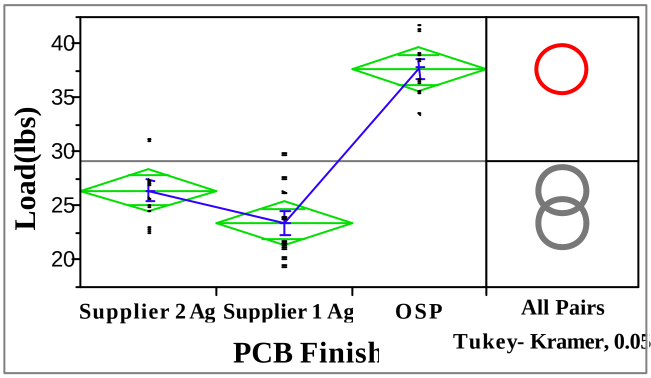

Figure 12. Maximum load at failure in 3 point bend test for various PCB finishes.

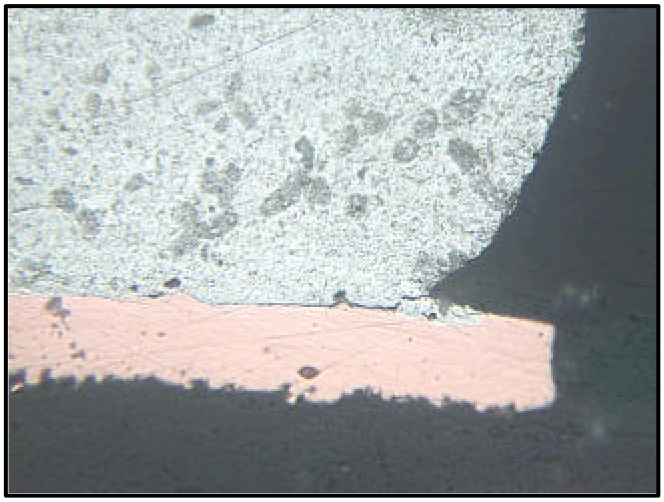

Figure 13. Cross section of the specimen subjected to 3-point bend test showing the failure at the BGA/PCB interface near the intermetallic layer.

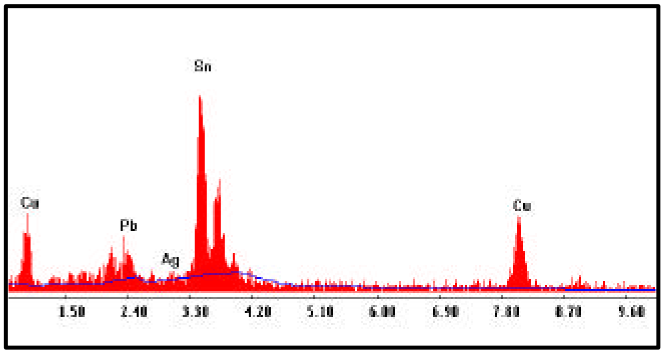

Figure 14. EDS analysis at the failed PCB/BGA interface confirming the presence of Cu_6Sn_5 intermetallic.

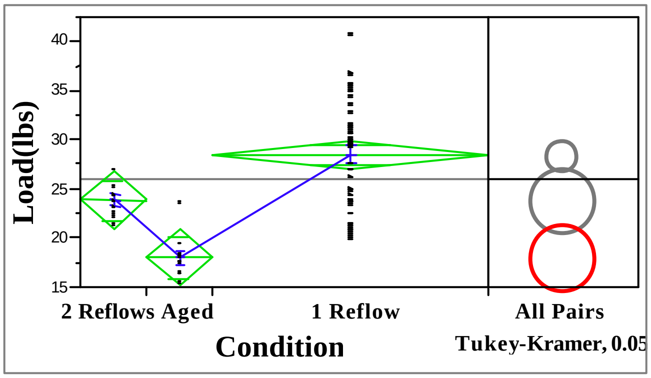

Figure 15. Plot of load to failure of Immersion Ag samples for various conditions tested in 3-point bending. Note the drastic drop in reliability for the aged samples.

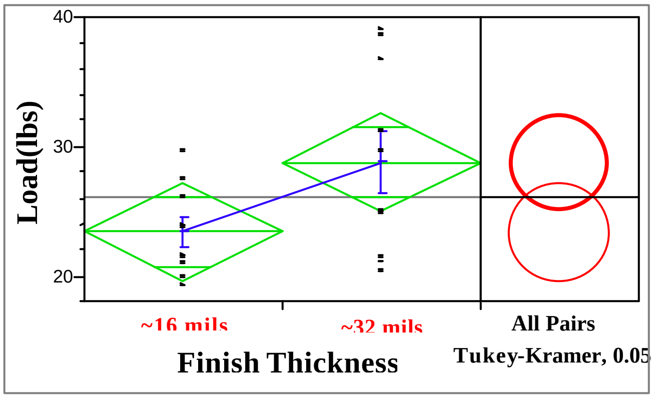

Figure 16a. Plot showing that the reliability of immersion Ag finish from Supplier 1 tested in 3-point bending is independent of the finish thickness.

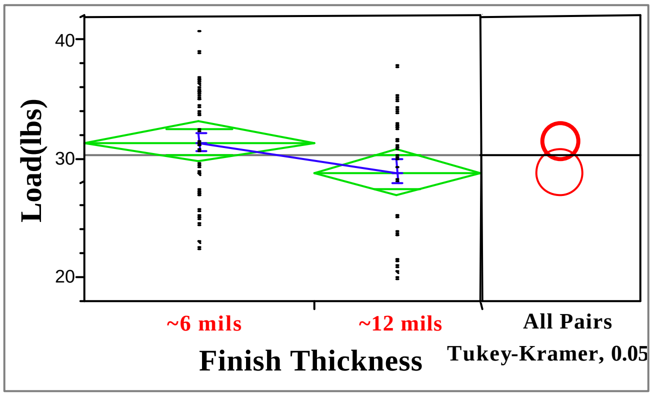

Figure 16b. Plot showing that the reliability of immersion Ag finish from Supplier 2 tested in 3-point bending is independent of the finish thickness.

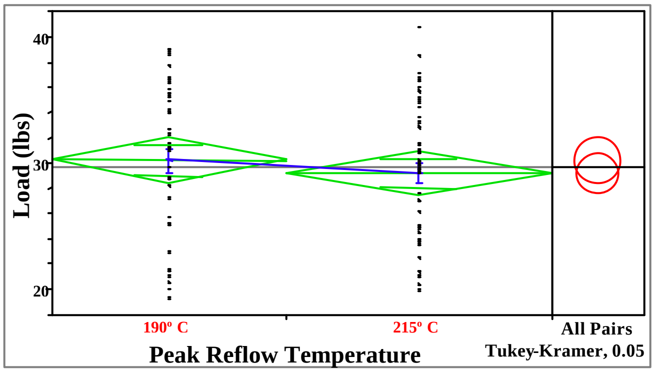

Figure 17. Plot illustrating that there is no significant effect of peak reflow temperature on the reliability of immersion Ag finishes tested.

Wetting and spread

Figure 18 shows the solder spread as reported by dimensional measurement for Pb-free and Pb containing solder pastes, reflowed over various immersion Ag surfaces. Also shown are the data for ENIG and OSP for comparative purposes along with reference/initial solder paste print diameter of 132 mils. It can be seen from the plot that all pastes have wetted and spread at least to the initial printed value of 132 mils in diameter, over all of the immersion Ag surfaces tested. In comparison, spreading on ENIG and OSP surfaces was to a greater extent. The same trend is true for samples exposed to 85°C/85RH for 168 hours, and samples subjected to corrosive mixed gas flow for 24 hours prior to paste printing and reflow. This is clearly illustrated in Figures 19 and 20, respectively. However, all finishes with the exception of OSP exhibited dewetting, i.e. shrank in wetting diameter when they were exposed to mixed gas flow for 96 hours prior to paste printing and reflow. This is shown in Figure 21 and the large error associated with the measurements is due in part to a very spotty and uneven wetting exhibited on the corroded surface (Figure 22). Figures 23, 24, 25 and 26 are plots of wetting for solder pastes Sn-Pb-Ag (1), Sn-Pb-Ag (2), Sn-Pb-Ag (3) and Sn-Ag-Cu, respectively on various PCB finishes and reiterate the aforementioned observations from the solder paste perspective. A closer observation of Figure 26 indicates that wetting of Pb-free paste Sn-Ag-Cu over OSP is slightly below the reference. This is expected as Sn-Ag-Cu alloys exhibit much larger wetting angles on Cu substrates than Sn-Pb solder alloys and inhibit spread during reflow[10].

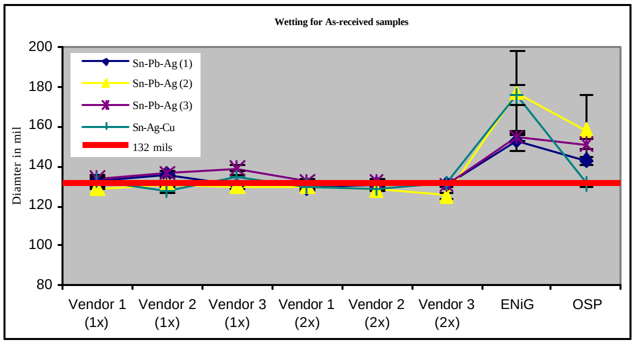

Figure 18. Wetting data of Sn-Pb-Ag and Sn-Ag-Cu solder pastes over various surface finishes in As-received condition.

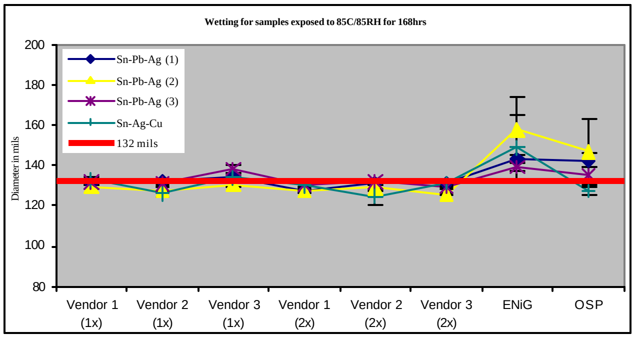

Figure 19. Wetting data of Sn-Pb-Ag and Sn-Ag-Cu solder pastes over various surface finishes exposed to 85°C/85RH for 168 hours.

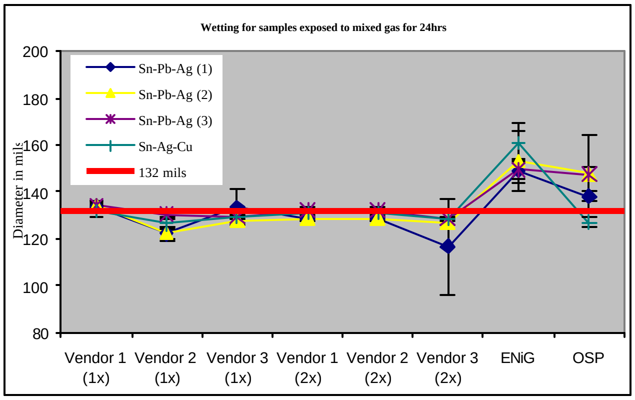

Figure 20. Wetting data of Sn-Pb-Ag and Sn-Ag-Cu solder pastes over various surface finishes exposed to flowing mixed gas for 24 hours.

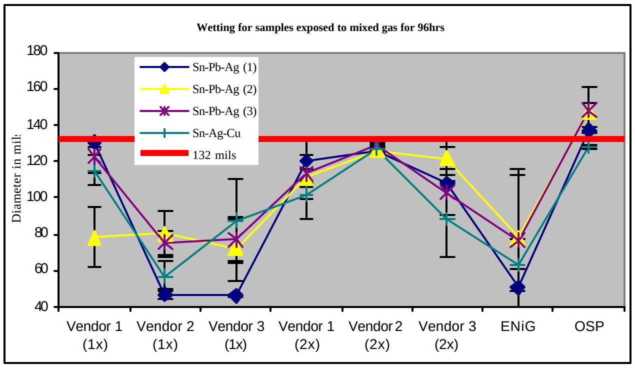

Figure 21. Wetting data of Sn-Pb-Ag and Sn-Ag-Cu solder pastes over various surface finishes exposed to flowing mixed gas for 96 hours.

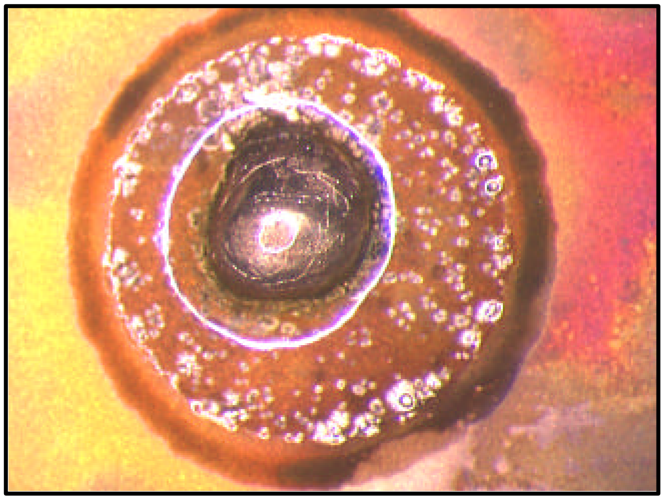

Figure 22. Spotty and uneven wetting phenomenon exhibited on the corroded surface created by exposure to mixed gas flow for 96 hours.

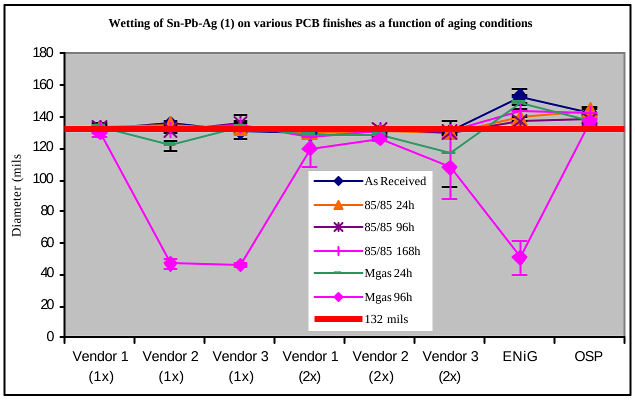

Figure 23. Wetting data of Sn-Pb-Ag (1) on various PCB finishes as a function of aging conditions.

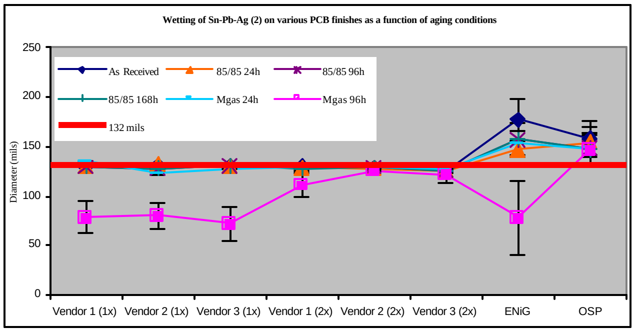

Figure 24. Wetting data of Sn-Pb-Ag (2) on various PCB finishes as a function of aging conditions.

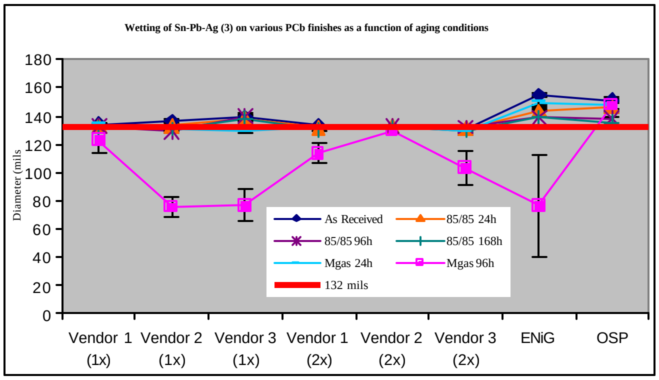

Figure 25. Wetting data of Sn-Pb-Ag (3) on various PCB finishes as a function of aging conditions.

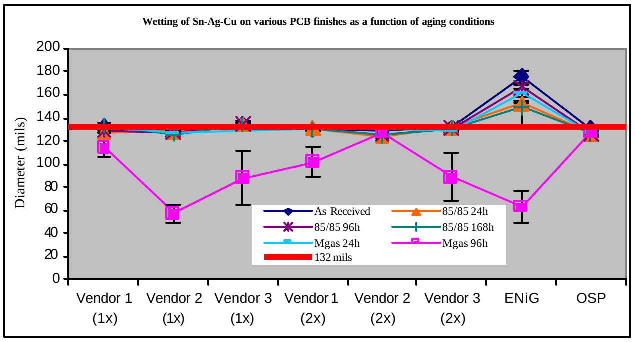

Figure 26. Wetting data of Pb-free paste Sn-Ag-Cu on various PCB finishes as a function of aging conditions.

CONCLUSIONS

The following conclusions could be drawn based on the findings of this study:

1) Immersion Ag surface finish performs adequately in the SIR and EM tests and is not readily prone to dendritic growth in presence of high humidity. However, ENIG and OSP are superior in the water droplet conditions simulating condensation and are less likely to electromigrate under those circumstances.
2) For keypad applications in portable products, immersion Ag finish is a viable alternative to ENIG as it performs adequately under normal conditions with extended exposure to corrosive atmosphere being the exception.
3) Immersion Ag/BGA solder joints appear to have lower load levels at failure than OSP and ENiG finishes in the as-reflowed condition. The effects of silver thickness and peak reflow temperature are insignificant on the reliability. However, solid state aging and multiple reflows lead to a lowering of failure load.
4) Wetting and spreading of both Pb containing and Pb-free solder pastes over the immersion Ag surface are adequate even when the surface is mildly corroded. ENIG and OSP exhibit greater solder spread than immersion Ag finish for all testing conditions studied, but the silver was more consistent. Also, if subjected to corrosive environment for extended periods of time ($\geq$ 96 hours flowing mixed gas), wetting deteriorates drastically for immersion Ag and ENIG finishes.

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