EXTREME LONG TERM PRINTED CIRCUIT BOARD SURFACE FINISH SOLDERABILITY ASSESSMENT

Gerard O'Brien, Solderability Testing and Solutions Inc., Richmond, KY
Dave Hillman, Rockwell Collins, Cedar Rapids, IA

INTRODUCTION

Printed circuit board surface finishes are a topic of constant discussion as environmental influences, such as the Restriction of Hazardous Substances (RoHS) Directive or technology challenges, such as flip chip and 01005 passive components, initiate technology changes. These factors drive the need for greater control of processing characteristics like coplanarity and solderability, which influence the selection of surface finishes and impact costs as well as process robustness and integrity. The ideal printed circuit board finish would have good solderability, long shelf life, ease of fabrication/processing, robust environmental performance and provide dual soldering/wirebonding capabilities; unfortunately no single industry surface finish possesses all of these traits. The selection of a printed circuit board surface finish is ultimately a series of compromises for a given application.

KEY WORDS: Solderability, Surface Finishes

BACKGROUND

In 1993 Rockwell Collins introduced an avionics product which incorporated Chip On Board (COB) technology, that used a printed circuit board surface finish consisting of a dual electroplated gold configuration designed to satisfy both wirebonding and soldering process requirements. A gold plating thickness of approximately 30 microinches for solderability and avoidance of gold embrittlement issues was specified on the soldering pads. A gold plating thickness of approximately 60 microinches for wirebondability was specified on the bonding pads. The dual plating configuration was successful but substantially increased the cost and complexity of the printed circuit board due to the additional fabrication steps. A 1995-1996, investigation [1] evaluated a number of board surface finishes with the goal of qualifying a replacement surface finish for the dual plating configuration. The replacement surface finish needed to be wirebondable, avoid solder joint integrity issues associated with gold content and have a minimum 12 months shelf life. Table 1 lists the specific printed circuit board surface finishes that were assessed.

Table 1: Printed Circuit Board Surface Finishes Tested

Surface Finish	Plating Configuration
Electrolytic Gold/Nickel/Copper	Au = 3 µinch increments, Range: 3 -24 µinches
ENIG Electroless Nickel/Immersion Gold	Au - 2-4 µinch
ENIPIG Electroless Nickel/Immersion Palladium/Immersion Gold	Flash Au, Pd = 3 µinch increments, Range: 3 -24 µinches
Electroless Palladium/Nickel/Copper	Pd = 3 µinch increments, Range: 3 -24 µinches
Electroless Palladium/Copper	Pd = 3 µinch increments, Range: 3 -24 µinches
Immersion Silver/Copper	3 µinches
Immersion Bismuth/Copper	3-5 µinches
Note: Nickel thickness (when used) for all samples was 100-200 µinches	

The 1995/96 testing included solderability testing in accordance with the IPC-JSTD-002 specification, surface finish oxidation assessment using Sequential Electrochemical Analysis (SERA), and ball bond/wedge bond wirebondability testing in accordance with the MIL-STD-883D, Method 2011.7, test condition C procedures. The testing revealed that ENIPIG and the electroless palladium surface finish combinations achieved the desired solderability, shelf life and wirebondability goals. The ENIPIG surface finish was substituted for the dual gold plating finish configuration to reduce costs and to improve the overall product integrity.

Spare test specimens with the investigation surface finishes were produced for the study but were not utilized during testing. These specimens were placed in non-sealed polyethylene bags, stored in a 21ºC/30%-65% RH environment and promptly forgotten. The specimens were re-discovered in 2015 after accumulating 20 years of total storage time, thereby providing an opportunity to investigate extreme long term solderability of a well characterized set of printed circuit board surface finishes.

Test Specimen

The test specimen was a bismaleimidc-triazine (BT) laminate, 0.040 inches thick with 0.5 ounce copper outer layers sheared into 3x3 inch squares. These 3x3 substrates were electroplated with approximately 0.001 inches of copper prior to the application of each specific test surface finish. The test substrates that contained a nickel layer had approximately 0.0001 - 0.0002 inches of electroless nickel plating deposited. The 3x3 test substrates were diamond cut into 6 sections approximately 0.5 inches wide after plating for use in the 1995/96 evaluation. A total of 3-5 spare specimens that were 20 years old of each surface finish were available for the new solderability investigation.

Test Plan

A sample from each of the surface finishes and thicknesses was initially tested using a Metronelec ST88 wetting balance and following the protocol detailed in the IP CJSTD003C WAM1. These samples were tested using eutectic Sn Pb solder and using the prescribed test flux # 1. The test temperature was 235°C with a dwell time of ten seconds in the solder pot. Only two sample groups failed to produce positive wetting forces: the single thickness sample of immersion bismuth and the 3 microinch palladium over copper sample. Based on these initial screening results, additional samples were cut at random from the sample strips and were tested using the same test protocols. A number of selected samples were assessed using Focused Ion Beam (FIB) microscopy. A FEI Quanta 200-3D Dual Beam system with a gallium target ablation source and a maximum ablation rate of 0.5 microns/minute was used (Figure 1). A layer of platinum was vapor deposited onto the test samples prior to FIB analysis to prevent extraneous ablation damage. Sample assessment was also conducted using a Fischer Technologies XDV-SDD X-ray Fluorescence (XRF) system (Figure 2).

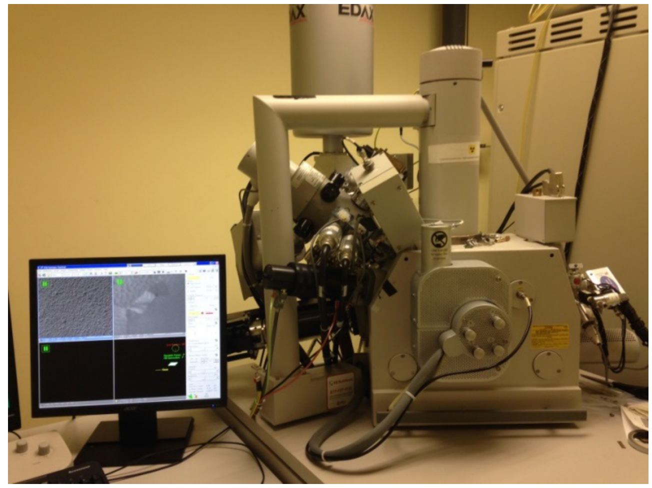

Figure 1: FEI Quanta 200-3A Dual Beam FIB System

Figure 2: Fischer Technologies XDV-SDD XRF System

RESULTS

Immersion Bismuth Surface Finish

Upon visual examination, the immersion bismuth surface finish test coupons appeared to be heavily oxidized. Wetting balance testing results showed no positive wetting forces were produced, further indicating that the bismuth surface finish had diffused into the underlying copper. Figure 10 illustrates the immersion bismuth wetting balance results.

Immersion Silver Surface Finish

The immersion silver surface finish test coupons exhibited some oxidation upon visual examination. Wetting balance testing results showed slow initial wetting times with final positive wetting forces (see Figure 11). These wetting balance values indicate degradation of the immersion silver surface but no negative impact of diffusion issues as were observed with the immersion bismuth surface finish.

Since current immersion silver surface finishes are typically 8-16 microinches thick, it was speculated that the original 3 microinch layer was consumed by oxidation and/or diffusion after 20 years of storage. XRF assessment measured 1.2 microinches of immersion silver while FIB assessment measured the immersion silver deposit closer to 2.4 microinches in thickness (Figure 3).

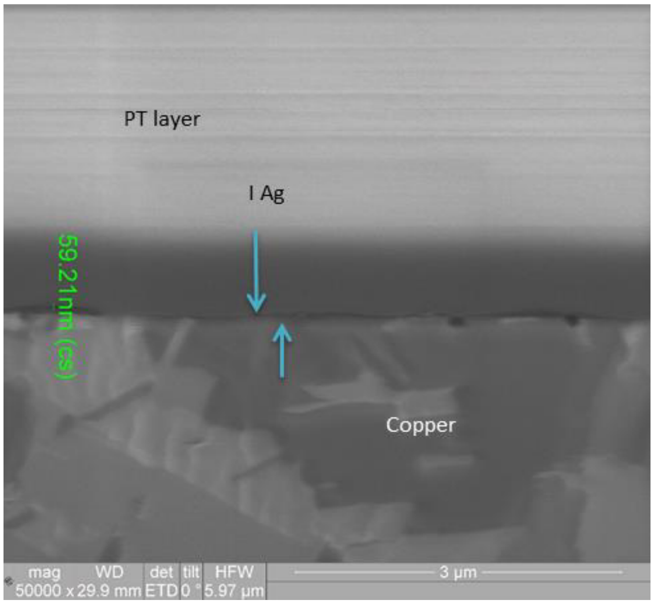

Figure 3: FIB Image of the Immersion Silver Deposit (50000X Magnification)

Electroless Palladium/Copper Surface Finish

The electroless palladium surface finish test coupons covered a palladium thickness range of 3-21 microinches and there was some coupon oxidation evident by visual examination prior to testing. The wetting balance testing results, shown in Figure 12, merge multiple tests for electroless palladium with increasing palladium thickness. The thinnest sample, nominally 3 microinches, was the only group that failed to produce positive wetting forces. The initial wetting times and final forces for the remaining sample groups are overall very consistent with palladium thickness, indicating no apparent negative impact on the protection of the underlying copper for palladium finishes in excess of 3 microinches.

FIB and XRF assessment were conducted to characterize changes in the electroless palladium layer after 20 years of storage. XRF assessment found no evidence of electroless palladium but FIB assessment measured the electroless palladium deposit at 0-0.3 microinches in thickness (Figure 4) for the 3 microinch electroless palladium sample. However, for the 6 microinch electroless palladium sample, the XRF measurement was 5.6 microinches and the FIB measurement was 4-6 microinches (Figure 5).

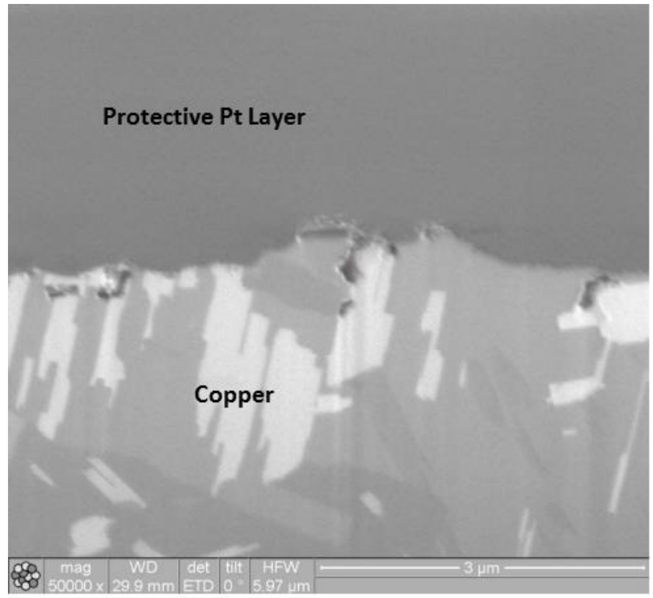

Figure 4: FIB Image of the Nominal 3 Microinch Electroless Palladium Deposit (50000X Magnification)

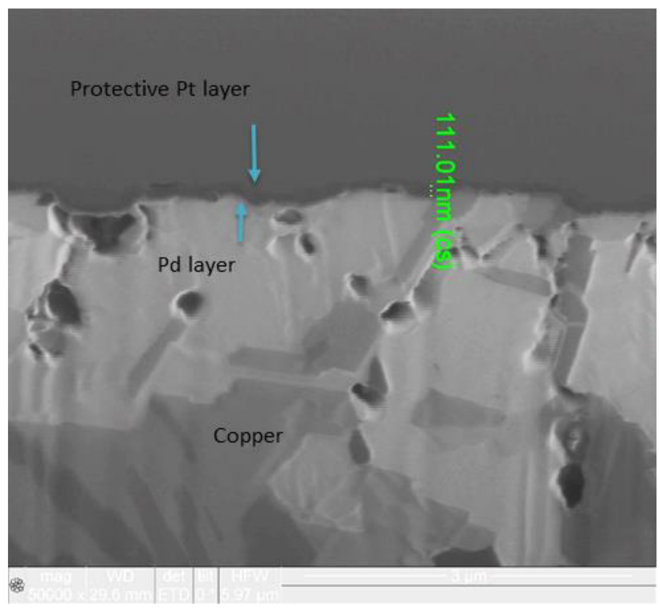

Figure 5: FIB Image of the Nominal 6 Microinch Electroless Palladium Deposit (50000X Magnification)

Electroless Nickel/Immersion Gold (ENIG) Surface Finish

The wetting balance test data for the ENIG surface finish are shown in Figure 13. The wetting times are somewhat slow and the rates of rise low, which is characteristic of ENIG with some age or stress on the deposit. The porous immersion gold deposit offers good protection to the underlying nickel but not enough to prevent the occurrence of some oxidation. However, the final wetting forces are excellent and meet the requirements of the soon to be released IPC 4552A specification. Increasing flux activity would have a dramatic impact on wetting times and rate of rise but little on the final wetting forces.

FIB and XRF assessment were conducted to characterize the changes in the ENIG plating after 20 years of storage. XRF assessment measured the immersion gold deposit at 4.9 microinches and the electroless nickel at 406 microinches. FIB assessment measured the immersion gold deposit at 2.4 microinches and the electroless nickel at 400 microinches (Figure 6).

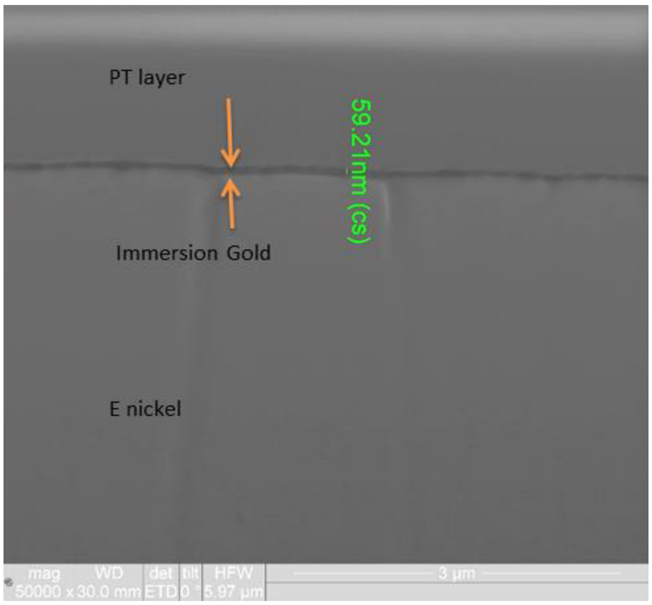

Figure 6: FIB Image of the ENIG Deposit (50000X Magnification)

Electroless Nickel/Electroless Palladium Surface Finish

The wetting balance test data for the electroless nickel/electroless palladium are shown in Figure 13. Overall this group exhibited excellent robustness with the majority wetting in less than 1 second. The rates of rise are good, which indicated the presence of only a minor oxide layer that was easily reduced by the rather inactive test flux # 1. The spread in the final wetting forces is relatively small with final forces somewhat lower than ENIPIG surface finish, but excellent overall given the age of the samples.

XRF assessment measured the electroless palladium at 5.11 microinches and the electroless nickel at 180 microinches with the FIB assessment measured the electroless palladium deposit at 2.6 microinches and the electroless nickel at 188 microinches (Figure 7) for the 3 microinch electroless palladium sample. For the 6 microinch electroless palladium sample, the XRF measurement was 5.95 microinches for the electroless palladium and 298 microinches for the electroless nickel with the FIB measurement at 2.1 microinches for the electroless palladium and 312 microinches for the electroless nickel (Figure 8).

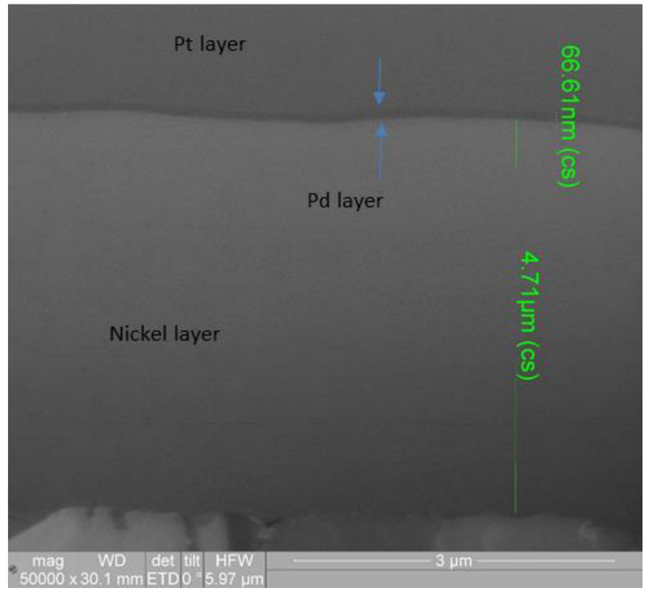

Figure 7: FIB Image of the 3 microinch Electroless Nickel/Electroless Palladium Deposit (50000X Magnification)

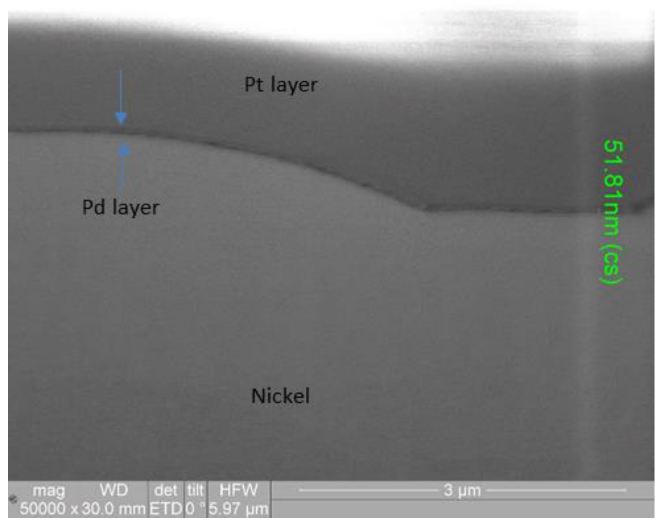

Figure 8: FIB Image of the 6 microinch Electroless Nickel/Electroless Palladium Deposit (50000X Magnification)

Electroless Nickel/Electroless Palladium/Immersion Gold (ENIPIG) Surface Finish

The wetting balance test results for the ENIPIG surface finish are shown in Figure 15. The use of immersion gold over the electroless palladium dramatically improved the robustness of the deposit. Wetting times were excellent at under 0.5 seconds, even after 20 years of storage. The rates of rise are also excellent to a final wetting force that meets the current requirements of the IPC 4556 ENEPIG specification. FIB and XRF assessment were not conducted on the ENIPIG surface finish due to sample quantity constraints.

Copper/Electroless Nickel/Electrolytic Gold Surface Finish

The wetting balance test results for the electroless nickel/electrolytic gold surface finish are shown in Figure 16. The thinnest nominal gold deposit was 5 microinches. The consistency of the group is excellent with the majority producing positive wetting forces in less than 1 second. The rates of rise to the final wetting forces are similarly excellent, indicating that the gold layer has protected the underlying nickel from passivation.

XRF assessment measured 5.8 microinches of electrolytic gold and 92 microinches of electroless nickel. The FIB assessment measured 3.6 microinches of electrolytic gold and 100 microinches of electroless nickel (Figure 9).

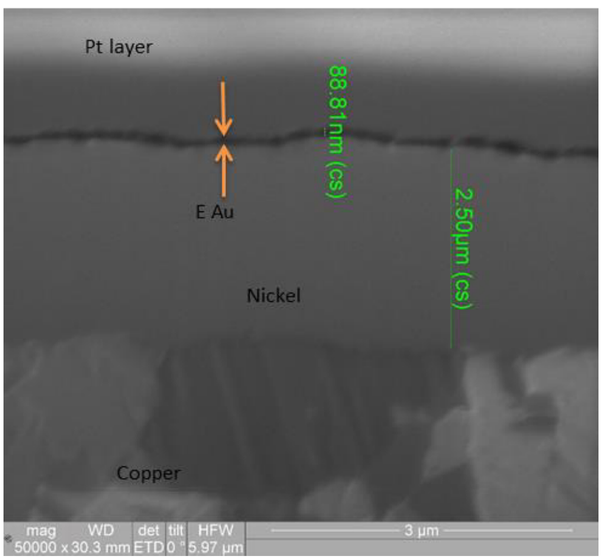

Figure 9: FIB Image of the Electroless Nickel/Electrolytic Gold Deposit (50000X Magnification)

DISCUSSION

Printed circuit board surface finishes have evolved during the past 20 years, so the surface finishes in the study are not "apples to apples" with surface finishes used by today's board fabricators. Modern board surface finishes are clearly better in terms of consistency/reproducibility, which makes positive solderability test results of these 20 year surface finishes reassuring. The following discussion points can be drawn from the data:

- The primary driving mechanisms for loss of solderability – oxidation and diffusion – were confirmed in the test results. FIB and XRF assessment revealed that the 3 microinch surface finish coupons were significantly degraded after 20 years of storage. The ability of different plating metallurgies and plating combinations to reduce surface finish oxidation and diffusion mechanisms was realized on the surface finishes tested.
- The immersion silver surface finish did surprising well despite its thinness. The IPC-4553 specification requires a significantly thicker plating to avoid the impact of storage and solder processing. The study testing results re-affirm the validity of the specification position/data covering the current immersion silver plating thickness requirements.
- The importance of having a nickel plating barrier to reduce the impact of diffusion was demonstrated. Nickel plating prevented the adverse effects of the copper diffusion on a number of the surface finishes.
- The importance of having immersion gold plating over the palladium plating to reduce the impact of surface oxidation/interface reactions was demonstrated. The immersion gold plating reduced the oxidation of the underlying surface finish and improved the solderability results.
- A storage condition of 21ºC/30%-65% RH in non-sealed polyethylene bags is not a particularly harsh environment, but is representative of many board storage environments used in industry today. The study test results are not representative of more severe board storage environments, but the results do demonstrate that properly processed, controlled surface finishes can have extremely long storage lives under specific conditions.

CONCLUSION

The study test results show that a variety of printed circuit board finishes subjected to a storage condition of 21ºC/30%-65% RH in non-sealed polyethylene bags maintained acceptable industry solderability test results after 20 years.

ACKNOWLEDGEMENTS

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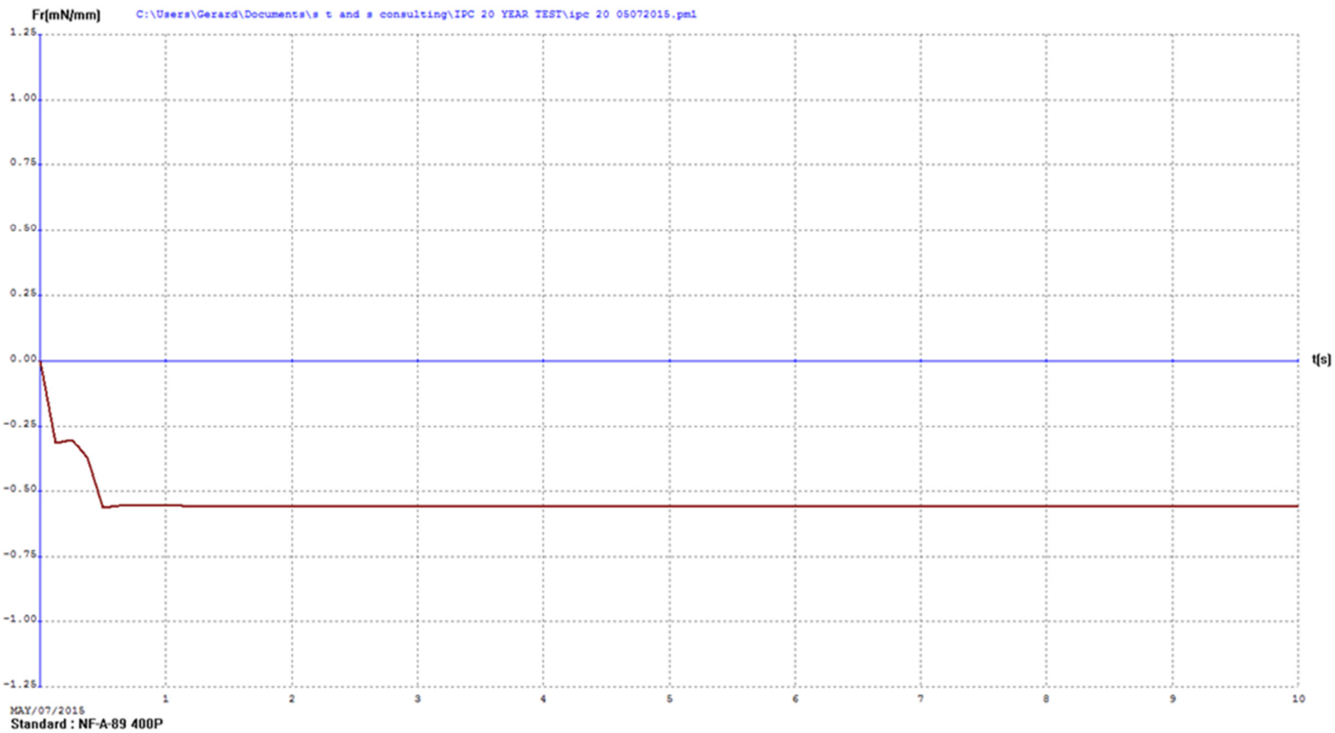

Figure 10: Immersion Bismuth Wetting Balance Results

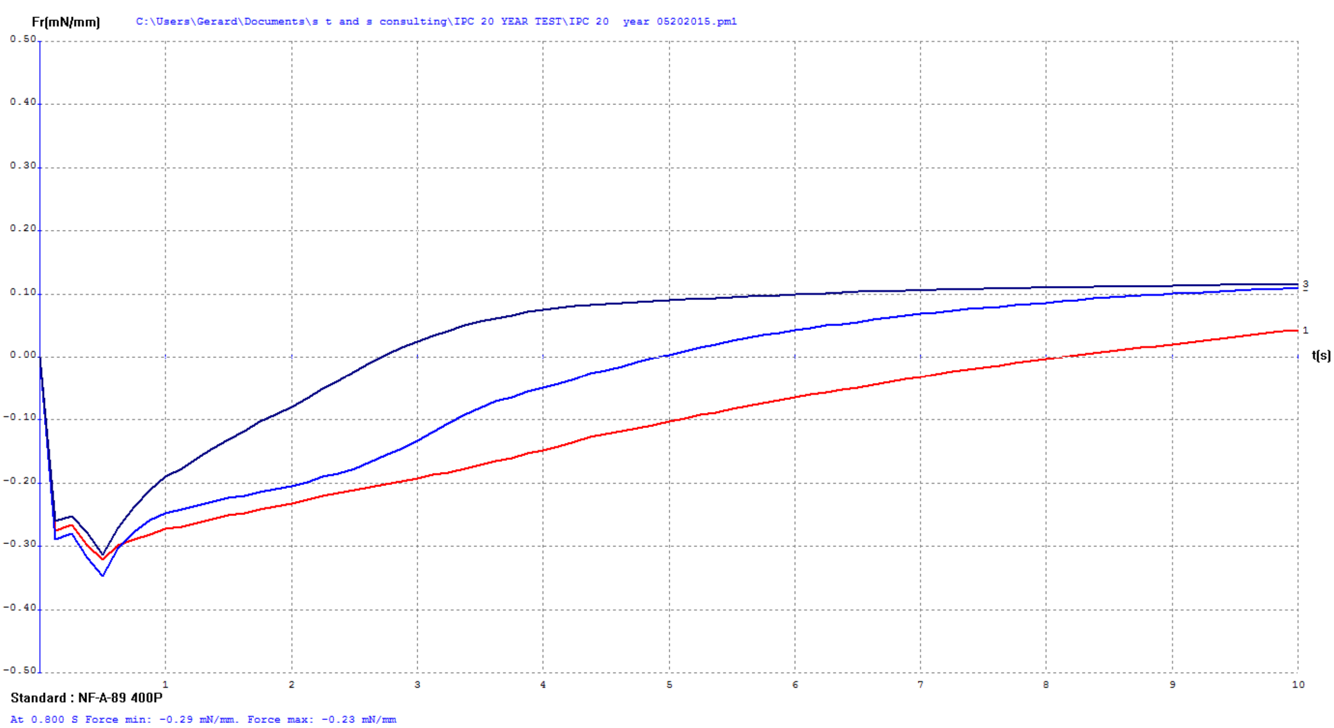

Figure 11: Immersion Silver Test Coupon Wetting Balance Results (3 Individual Test Coupons)

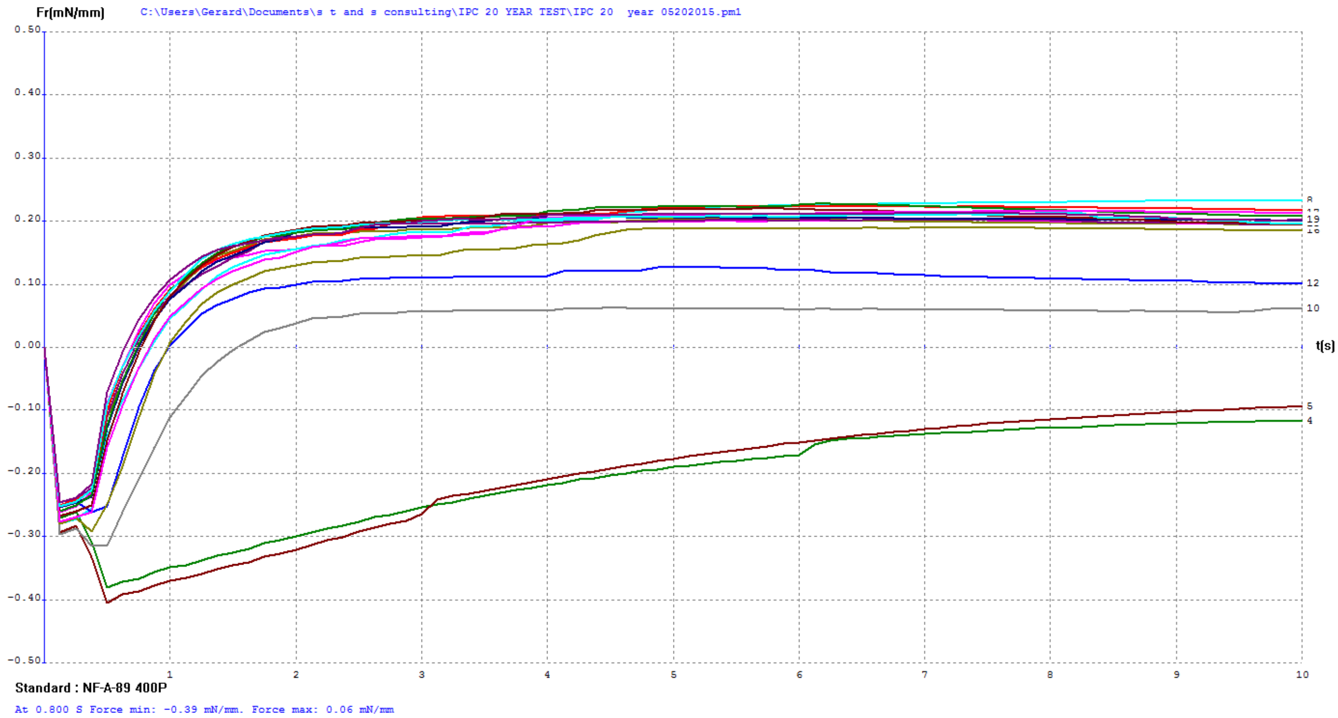

Figure 12: Electroless Palladium Test Coupon Wetting Balance Results (Test Coupons Covering 3-21 microinch range)

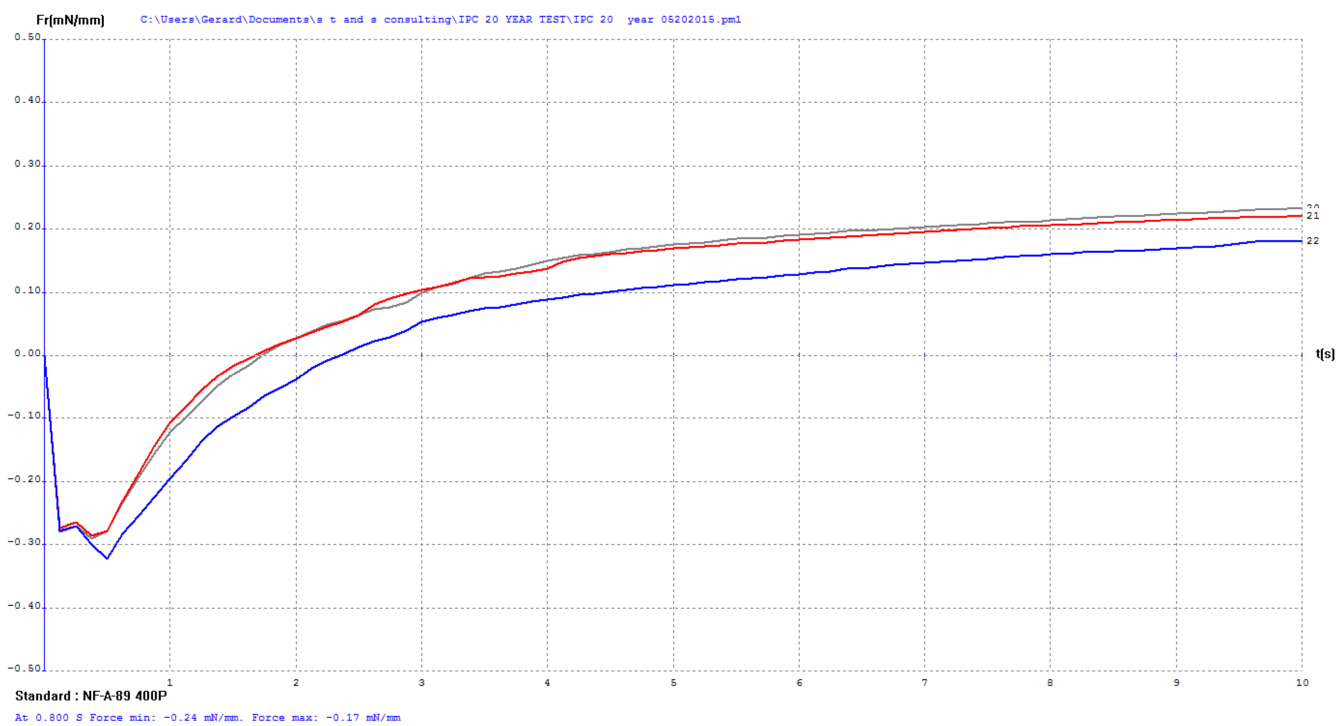

Figure 13: ENIG Test Coupon Wetting Balance Results (3 Individual Test Coupons)

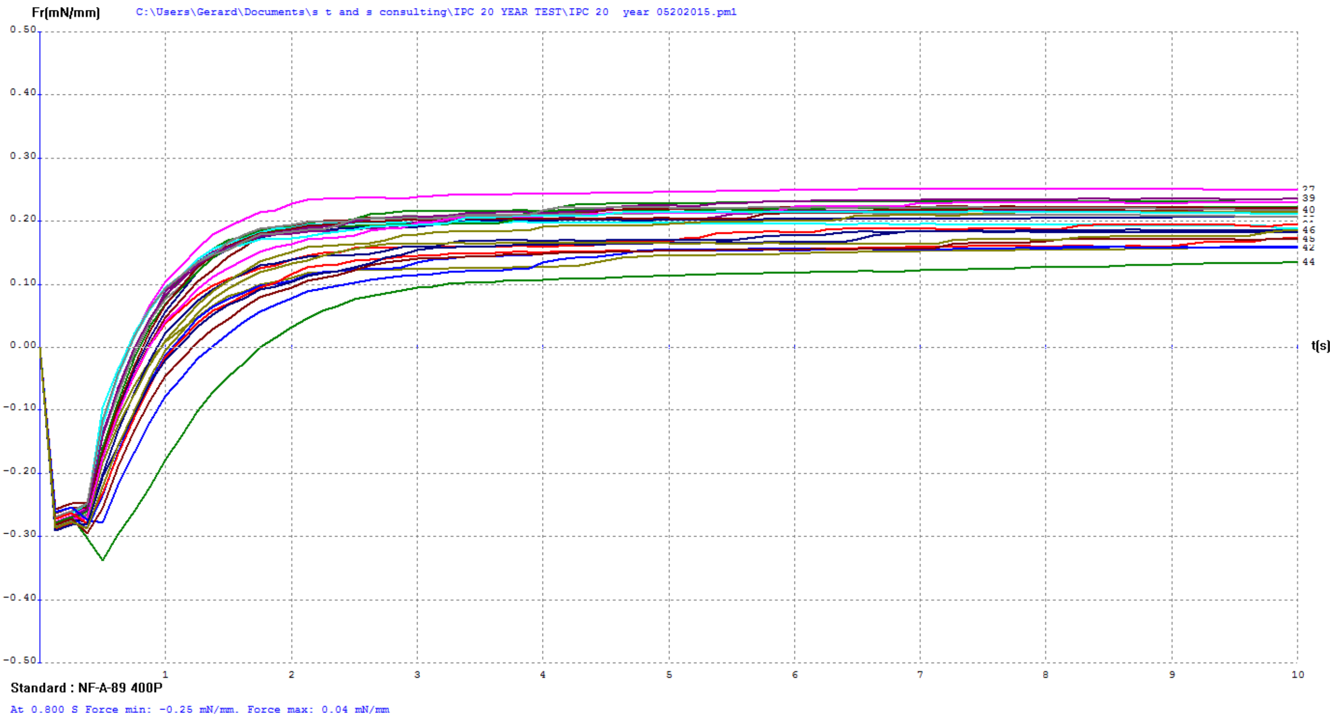

Figure 14: Electroless Nickel/Electroless Palladium Test Coupon Wetting Balance Results

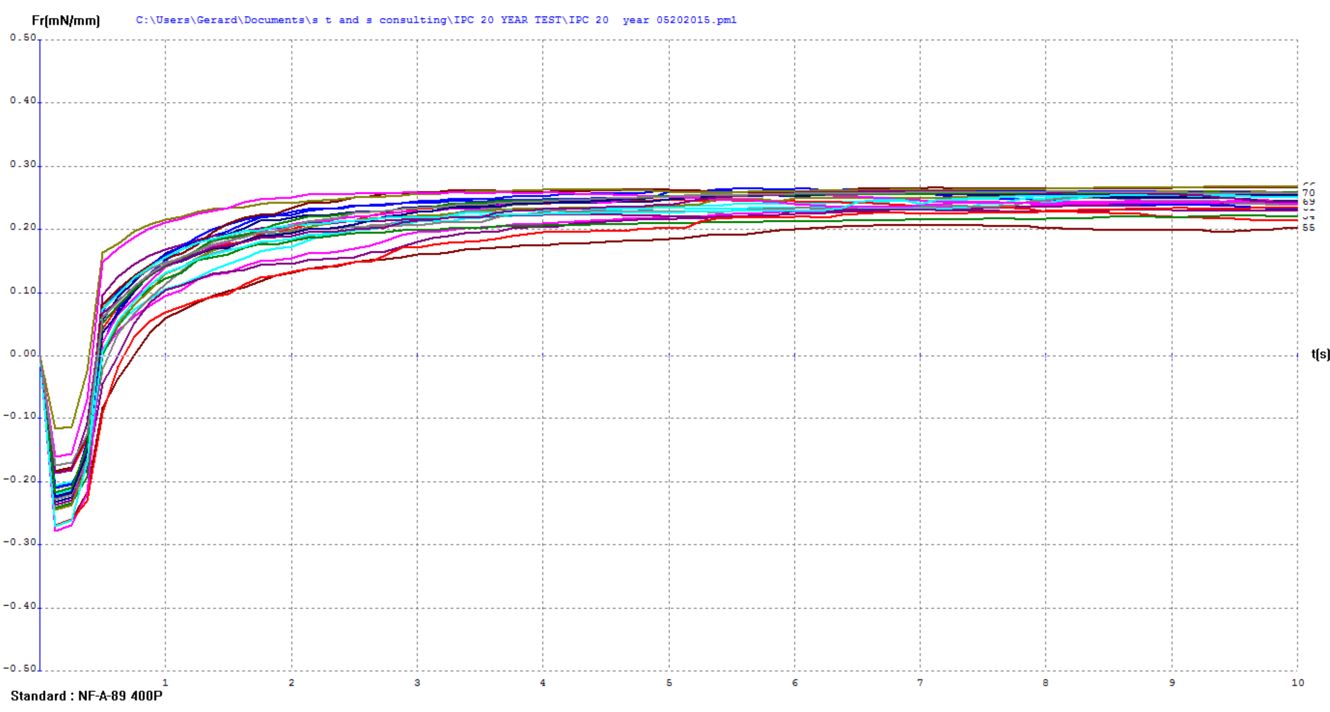

Figure 15: ENEPIG Test Coupon Wetting Balance Results (3-24 microinch coupons)

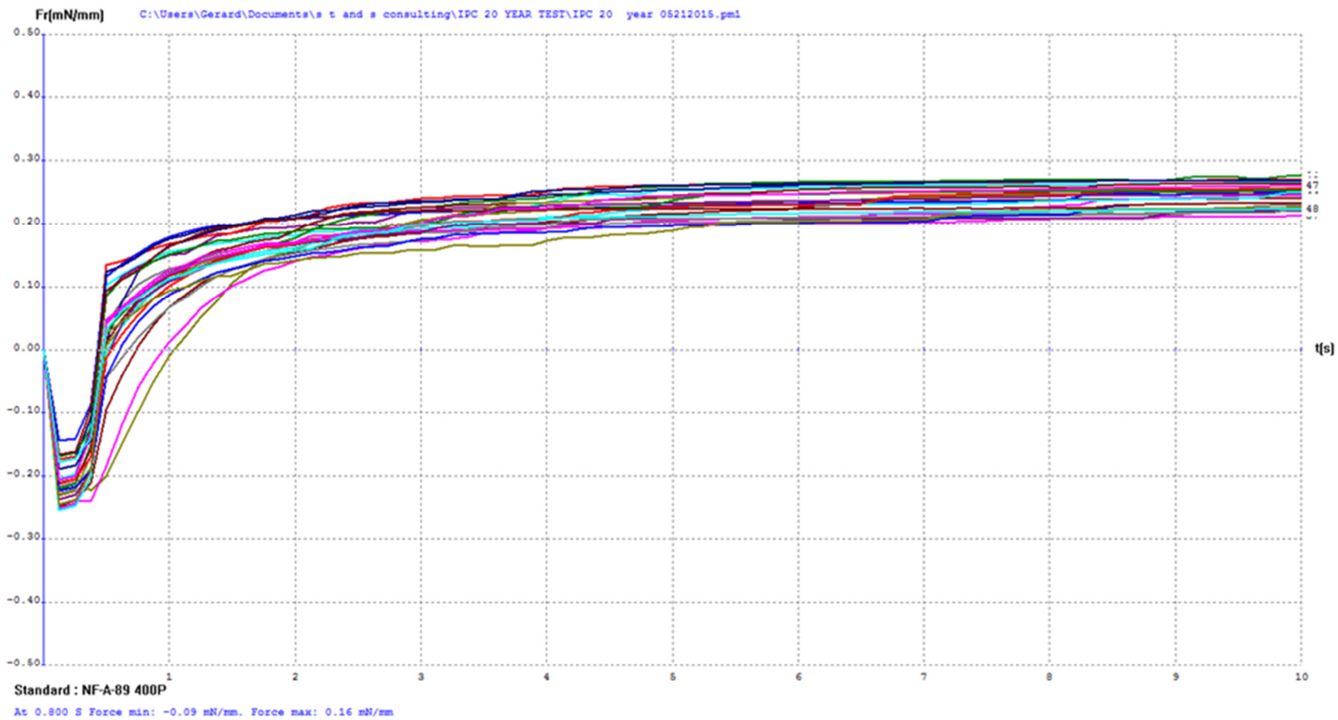

Figure 16: Electroless Nickel/Electrolytic Gold Test Coupon Wetting Balance Results