

AN INVESTIGATION INTO THE DURABILITY OF STENCIL COATING TECHNOLOGIES

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ABSTRACT

It is well documented that Nano coatings on SMT stencils offer many benefits to those assembling PWBs. With reduced standard deviation and improved transfer efficiency nano coatings can provide, there is also a cost. As PWB assemblers work to justify the return on investment, one key question continues to arise. What is the durability or life of these coatings and what can be done in the print process to maximize the life of the coatings? This paper addresses durability of the coatings in relation to the number of print cycles and underside wipe cycles applied as well as materials used on the underside wipe process. Different parameters will be applied and data will be collected. The results of this study will be summarized to help those using or considering the use of these nano coatings to improve their print process and suggestions will be given to maximize the life of the coatings.

Key words: nano-coating, SMT stencils, stencil cleaners, Phosphonate coating, FPN coating

INTRODUCTION

Miniaturization has been a large part of the SMT industry over the past several years. As demand for smaller devices continues to drive innovation those assembling these devices must respond by improving assembly practices, reducing rework and maintaining high yields. One method of improving the print process over the past several years has been the use of Nano Coatings on stencils to improve the print process. There are two main types of Nano Coatings being used on SMT solder paste stencils today which are Phosphonate and Fluoropolymer (FPN) nano-coatings (Figure 1).

Fluoro-Polymer Coating



Phosphonate Coating



Figure 1: FPN and Phosphonate Nano-Coatings on Stencils

Phosphonate coatings are based on self-assembled monolayer (SAM) technology. Phosphonate coatings are thin, essentially 1 molecule thick and are invisible on the stencil. FPN coatings are roughly 1000 times thicker than Phosphonate coatings due to the polymeric structure (Figure 2). FPN coatings are easy to see on the stencil and typically have a dye added to give a color to the coatings. Some FPN coatings also have a fluorescing dye added to aid in viewing the coating in the aperture walls.

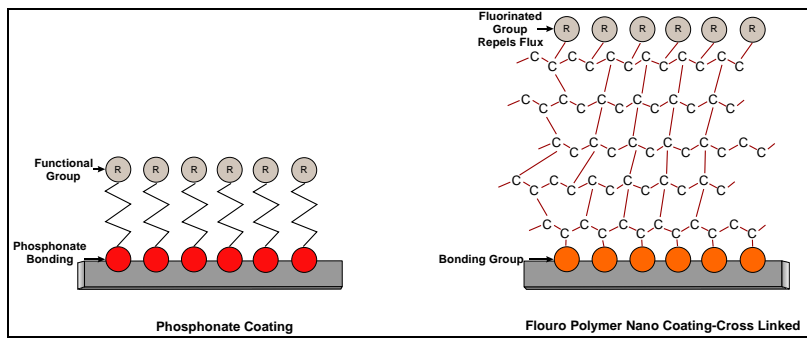


Figure 2: Phosphonate and FPN Nano-Coating Chemical Diagrams

A summary of the properties of these FPN and Phosphonate coatings is shown below (Table 1).

Table 1: Properties of FPN and Phosphonate Nano-Coatings

Attributes	Fluoro-Polymer Coating	Phosphonate
Application	Spray and thermal cure	Wipe on
Thickness	2-4 microns	1-2 nm
Visible on stencil?	Yes	No
Hydro and oleophobic	✓	✓
Reduces frequency of underside cleaning	✓	✓
Abrasion resistant	✓	Wears off
Chemical resistant	✓	Wears off
Re-coating possible?	No	✓
Solder paste volume	15 – 25% increase in TE	Slight decrease < 5%
Minimum Area Ratio	0.10 lower than foil	Same as foil

The major performance differences between these coatings has been documented in previous papers [1, 2]. Phosphonate based coatings are not visible on the stencil so it is difficult to see when they are worn off. When Phosphonate coatings do wear off they can be reapplied. FPN coatings are visible and can show damage or wear to the coating. FPN coatings are designed to be permanent and cannot be re-coated.

The focus of this investigation is on the durability and longevity of these two types of coatings. The question to be answered is how long do these nano-coatings last?

METHODOLOGY

The nano-coatings applied to stencils would essentially last forever if the stencils were never used. The lifespan of nano-coatings is determined by how quickly they are damaged through use and cleaning. There are two major ways in which stencil nano-coatings can be damaged or worn off, chemical damage and mechanical damage. Chemical damage can occur from the solder pastes and cleaning agents that are used. Mechanical damage can occur from abrasion due to circuit boards, squeegee pressure, underside cleaning and general handling. Both types of damage to nano-coatings are studied. Three commercially available nano-coatings were tested in this investigation. Two Phosphonate type coatings were evaluated. They are referred to as Phos-1, and Phos-2 in this paper. One FPN type coating was evaluated and it is referred to as FPN.

Chemical Damage to Nano-Coatings

Early studies for chemical compatibility with nano-coatings were conducted using a wet scrub tester (Figure 3).



Figure 3: Wet Scrub Tester

Wet scrub testing was performed using the ASTM D2486 method for paints and coatings. Scrub testing was run to 2000 cycles and repeated with a few different chemicals pumped over the surface. Dry scrubbing was done without chemicals as a baseline. Scrub testing was repeated using de-ionized (DI) water, isopropanol (IPA), and a rosin based liquid flux. The contact angle of DI water on the coated stencil surface was measured every 500 scrub cycles. A decrease in contact angle corresponds to a loss of hydrophobicity (Figure 4). The results from a previous study [1] are summarized and presented as part of this investigation.

Hydrophobic Surface		Hydrophilic Surface
High	Contact Angle	Low
Poor	Adhesiveness	Good
Poor	Wettability	Good
Low	Surface Free Energy	High



Figure 4: Explanation of Contact Angle and Hydrophobicity

Solder pastes contain a variety of ingredients which may chemically attack nano-coatings. Commercially available cleaning agents used for under-side cleaning and in stencil cleaning machines contain a variety of different chemicals. Solder paste and cleaning chemical formulas are proprietary but their main ingredients fall into certain chemical categories: solvents, surfactants, and acids/bases. Several chemicals from solder paste and cleaning agent formulations were chosen to be evaluated in this investigation.

Chemical exposure tests were run on stencil pieces coated with each type of nano-coating. The test methodology was fairly simple and intended to simulate multiple cleaning cycles. Testing involved immersion of the test pieces in each chemical for 48 hours at room temperature (20 – 22 °C). This immersion test simulates 192 cleaning cycles, assuming that each cleaning cycle is approximately 15 minutes. The test pieces were then rinsed in de-ionized (DI) water, dried, and evaluated for damage to the coatings. Coating damage was most easily evaluated by flooding the surface of each test piece with DI water and looking for signs of loss of hydrophobicity. Water droplets adhered to the test pieces in the areas where coating damage was present. Coatings that were un-affected by the chemicals retained their hydrophobicity and shed the DI water normally.

Mechanical Damage to Nano-Coatings

To understand what is causing mechanical wear one must understand the following:

- The FPN Coating is 2-4 microns thick on the bottom surface of the stencil and 1-2 microns on the sidewalls. This is a very thin coating that allows the manufacturer to successfully coat the aperture sidewalls as well as the bottom surface of the stencil without major changes to foil thickness and/or aperture size. Phosphonate coatings are approximately 1.4 nm thick [3] and do not coat the inside of the aperture walls.
- The FPN coating has a pencil hardness of 9H when fully cured. This hard durable surface is created for chemical resistance and durability. The pencil hardness of Phos-1 and Phos-2 coatings are not applicable as the coating is too thin to test using pencil hardness.
- When the sharp, thin edge of the squeegee pushes down against the stainless foil, over raised areas on the PWB, the friction between the coated side of the stencil and the uneven surface of the PWB eventually causes both types of coating to be worn away. In many instances this can be seen with PWB traces, venting patterns and even silkscreen rubbing off the coating in specific patterns as per the examples in Figure 5 below.
- In high volume applications, the coating chips or flakes off of the surface of the stencil around the apertures and in areas where there are no apertures. The amount of chipping or flaking varies depending on the process variables that are applied to the particular stencil. This can be seen below (Figure 5).

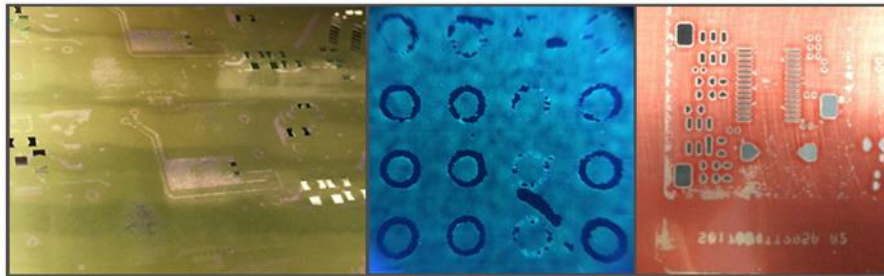


Figure 5: Damage to FPN Coatings

One method to investigate mechanical wear on nano coatings is to observe the coating after the stencil has been used in production. Below (Figure 6), one can see that the FPN coating is coming off of the surface of the stencil but the coating is still on the aperture walls.

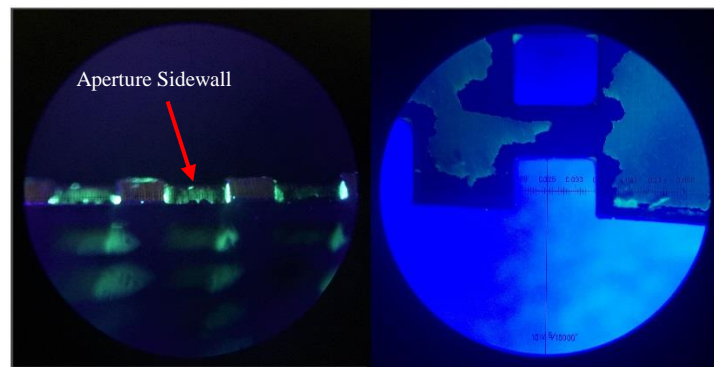


Figure 6: Cross Section and Surface Wear, 10,000 prints

Inspecting the retired stencil with 10,000 prints in the images above, the image on the right shows the coating has come off around the surface of the 15 mil apertures. After cross sectioning the same apertures, one can see the coating is still in the aperture walls (left image above). The UV tracer added to the coating fluoresces verifying the coating is still present.

When inspecting the mechanical damage to the coatings, the impact of both the downward squeegee pressure moving across the stencil on top of a non-planar board as well as the underside wipe material physically pushing up into the bottom of the stencil and moving across the stencil are both thought to contribute to coating wear. Each of these methods of mechanical wear were studied to further understand their impact.

It is widely believed that the type of underside wipe material can contribute to the deterioration of both Phosphonate and FPN nano coatings. To understand the impact of underside wipe on coatings, one stencil coated with Phos-2 coating and one stencil with FPN coating was used to print onto the test vehicle shown below (Figure 7). The test vehicle was made with 2oz copper and HASL finish to create a non-planer surface. Squeegee pressure was minimized to remove the variable of squeegee pressure while printing to obtain 1000 dry underside wipes.

One thousand underside dry wipe cycles using a popular midgrade, underside wipe material, were applied to both stencils on a commonly used automated stencil printer. A 30 Dyne/cm pen was used on the bottom side of both the Phosphonate and FPN coated stencils after the 1000 underside dry wipe cycles to determine if the coating was still present and active. 10 boards were printed with the Phos-2 coated stencil using a common no-clean paste, type 3 powder with a UV indicator added to the flux. Photos of the board side of the stencil were taken and compared to an uncoated stencil. Twenty boards were printed with the FPN coated stencils using the same no-clean paste and photos of the board side were taken.

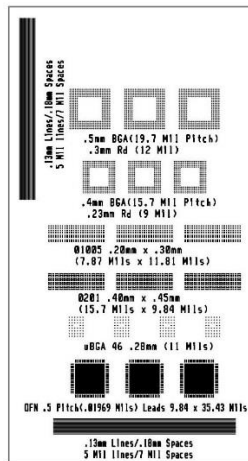


Figure 7: Nano-coating Durability Test Vehicle

The impact of squeegee pressure and speed is suspected to play a role in the degradation of the coating. One thousand dry squeegee prints were made on both the Phos-2 and FPN coated stencils, images were taken of the coating to see if there was any impact from 1000 dry squeegee prints to the coating. No underside wipes were used in this study and no solder paste was used to minimize the variables being observed. A common automatic printing machine was used with a squeegee pressure of 0.45 kg/cm (2.5 lb/in) and 40mm/sec squeegee speed. The test vehicle shown above (Figure 7) was used made with 2 oz copper and HASL finish.

Finally, a new hybrid type of stencil coating was examined that is currently in the R&D stage. The stencil aperture walls were coated with the FPN coating and the bottom or board side of the stencil was coated with the Phos-2 coating. This hybrid stencil was created to minimize the impact of the FPN coating wearing on the bottom surface of the stencil with a coating that can be easily reapplied. Images of the coating were evaluated after 50 prints with no underside cleaning.

RESULTS AND DISCUSSION

The results of chemical and mechanical damage to the nano-coatings are summarized below. Wet chemical scrub testing is summarized first, followed by chemical attack testing and then mechanical damage testing.

Wet Chemical Scrub Testing Data

Initial wet scrub tests were run with the FPN coating as compared to the Phos-1 coating. Contact angles were measured every 500 scrub cycles over 2000 scrub cycles total (Figure 8).

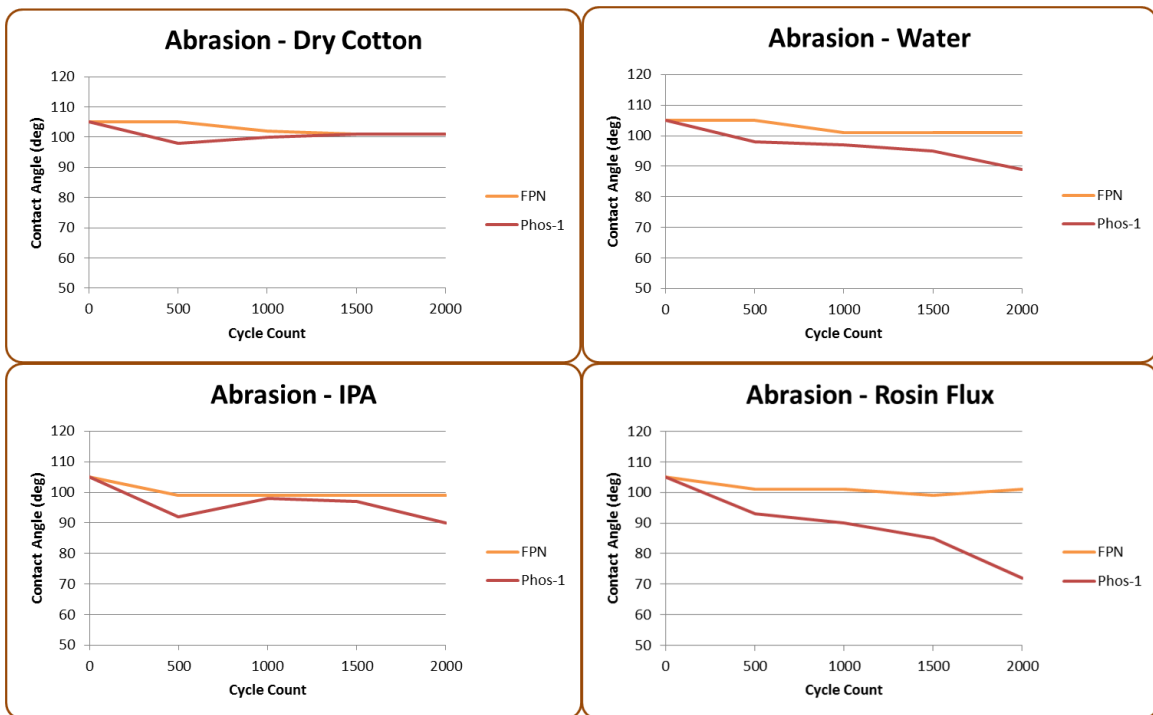


Figure 8: Contact Angle Over 2000 Scrub Cycles with Dry Cotton, DI Water, IPA, and Rosin Flux

Scrubbing with dry cotton showed very little change to the contact angle of both of the coatings. Scrubbing with DI water showed a decrease in contact angle for the Phos-1 coating. This indicates that the coating lost some hydrophobicity and was wearing off. Scrubbing with IPA showed a slight drop in contact angle for the Phos-1 coating. Scrubbing with the rosin flux showed the biggest change in contact angle for the Phos-1 coating and a significant loss of hydrophobicity was observed. The contact angle dropped slightly for the FPN coating in all of these tests, but the hydrophobicity was retained in all cases.

This scrub test was repeated comparing coatings from two different suppliers Phos-1 and Phos-2 (Figure 9). Both were scrubbed to 2000 cycles using IPA and the contact angle was measured after scrubbing.

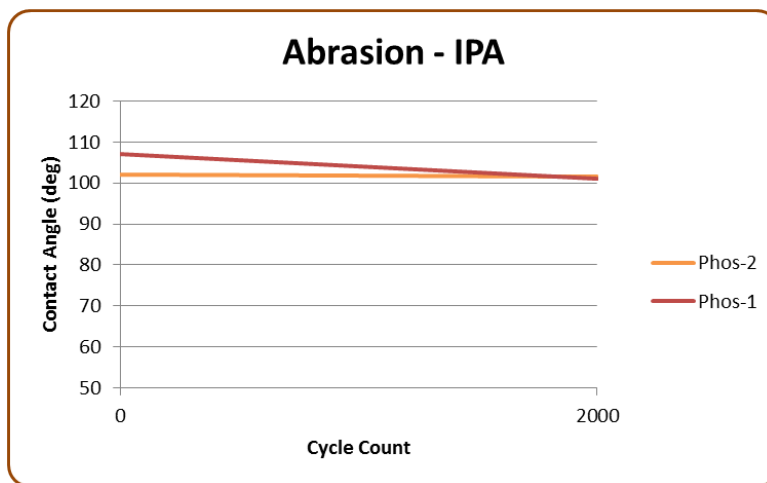


Figure 9: Contact Angle of Two Phosphonate Coatings Over 2000 Scrub Cycles with IPA

This test shows a slight decrease in contact angle for the Phos-1 coating while the contact angle for the Phos-2 coating did not change. Both coatings retained their hydrophobicity in this test. When running these type of abrasion / chemical resistance tests the data must be interpreted as a comparison of one technology to another within that particular test run. It is common for different batches / lots of monolayer phosphonate coatings to give slightly different contact angle results. Contact angles also change slightly from one stencil surface to another based on coating uniformity. Phosphonate coatings are applied manually which induces some variability in the uniformity of the coating.

This scrub testing is intended to show damage to the coatings within a relatively short period of scrubbing time. These tests were stopped after 2000 scrub cycles because damage to the coatings was observed within that number of cycles.

Chemical Attack Testing

A variety of chemicals may attack and damage nano-coatings. This damage can take the form of partial loss of hydrophobicity, visual change in the appearance of the coating, or complete stripping of the coatings. Visual changes are readily apparent for the FPN type coatings. Phosphonate type coatings are invisible and therefore it is difficult to determine when damage has been done to the coating. The chemicals used in these tests fell into three categories: solvents, surfactants, and mild bases. After testing the coatings were evaluated for damage by flooding the surface with DI water and looking for loss of hydrophobicity. Examples of DI water on a fresh coating and a damaged coating are shown below (Figure 10).

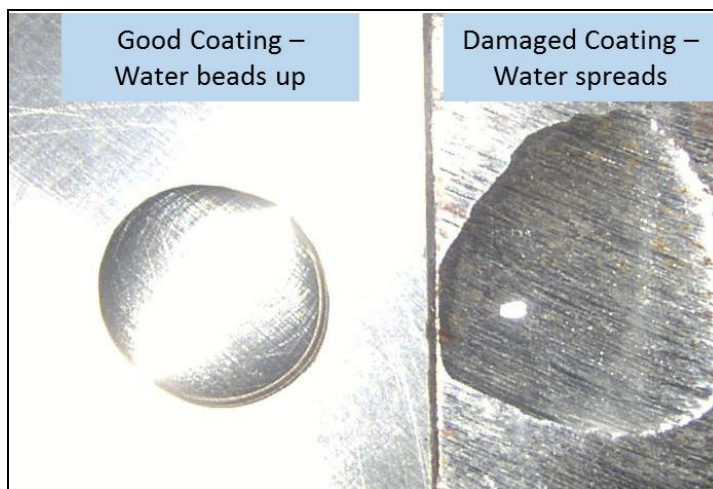


Figure 10: Fresh Coating (Good Hydrophobicity) and a Damaged Coating (Poor Hydrophobicity)

The results from chemical attack testing are shown below (Table 2). The chemicals that damaged the coatings are highlighted in yellow and the chemical that stripped the coatings is highlighted in red. The blank cells indicate that no damage was observed.

Table 2: Chemical Attack Results for the Nano-Coatings

Chemicals	Chemical Type	Phos-1	Phos-2	FPN
Isopropyl alcohol	Solvent	Damaged		
n-butyl alcohol	Solvent	Damaged		
Hexylene glycol	Solvent			
Propylene glycol	Solvent			
Dipropylene glycol	Solvent	Damaged	Damaged	
Dimethyl esters (Dibasic ester)	Solvent	Damaged		
Ethylene glycol monobutyl ether	Solvent	Damaged		
Diethylene glycol monobutyl ether	Solvent	Damaged		
Triethylene glycol monobutyl ether	Solvent	Damaged		
Diethylene glycol monohexyl ether	Solvent	Damaged	Damaged	
Propylene glycol methyl ether (1-methoxy-2-propanol)	Solvent			
Tripropylene glycol n-butyl ether	Solvent			
D-Limonene (orange oil)	Solvent	Stripped	Stripped	Stripped
Non-ionic block copolymer surfactant 50 g/L	Surfactant			
Octylphenol ethoxylate surfactant 50 g/L	Surfactant			
Monoethanolamine (100 g/L pH 11.60)	Mild base			
Potassium carbonate (100 g/L pH 11.50)	Mild base			
Tetrapotassium pyrophosphate (100 g/L pH 10.40)	Mild base	Damaged		

The majority of the chemicals tested were solvents. These solvents or similar compounds are used in stencil cleaners and solder paste fluxes. The Phos-1 coating was damaged by many of the solvents tested including isopropanol (IPA). The Phos-2 coating was damaged by two of the solvents tested. The FPN coating was not affected by the majority of the solvents with one exception, D-Limonene (orange oil). D-Limonene stripped all three coatings completely. Two surfactants were tested and neither affected the coatings. Three mild base solutions were tested at fairly high concentrations (100 g/L) in order to show the possibility of chemical attack. In general, the coatings were not affected by these mild bases with the exception of Phos-1 which was damaged by the pyrophosphate solution.

The intention of this chemical attack testing was to show that nano-coatings are not compatible with every solder paste or stencil cleaner. Some chemicals will shorten the life of the nano-coatings through chemical attack. It is recommended that nano-coating users check with their suppliers to ensure that the nano-coating is compatible with the materials that come into contact with the stencil.

Mechanical Damage Testing

Squeegee testing in the company lab did not supply conclusive results as to how many print cycles the coatings could withstand before durability degrades. Several mechanical factors play a role in how many prints can be completed prior to nano coatings showing signs of wear and it is the combination of these factors that determine the stencil coating life. Some of these factors are:

- Squeegee pressure and speed.
- Flatness of the PWB surface
- Board support
- Under stencil wipe material
- Stencil wash method and interval

When 1000 underside dry wipe cycles were applied to both Phosphonate and FPN coated stencils using a mid-grade commonly used underside wipe material, both types of coatings passed a 30 Dyne/cm pen test. This test is commonly used to test Phosphonate coatings and verify that the coating is still present on the underside of the stencil. After passing the 30 Dyne/cm test, 10 boards were printed with the Phos-2 coated stencil using type 3, no-clean paste with a UV indicator added to the flux and no underside clean cycles. The images below (Figure 11) are taken from the board side of the Phos-2 coated stencil with UV light. One can see that there is very little flux/solder paste on the underside of the Phos-2 coated stencil indicating again that the Phosphonate coatings are present and preventing flux and solder paste from adhering to the underside of the stencil after being exposed to 1000 dry wipe cycles. It is easily seen that the uncoated stencil after 10 prints would cause bridging.

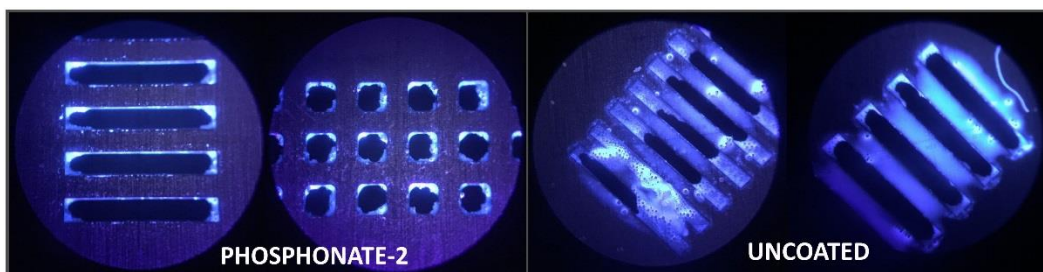


Figure 11: Phos-2 Coating, 1k Dry Wipes versus Uncoated, 10 Prints/No Underside Wipe

After passing the 30 Dyne/cm test, 20 boards were printed using the FPN coated stencil with type 3, no-clean paste. The left image below (Figure 12) is taken from the coated side of the stencil prior to printing paste after 1000 dry underside wipe cycles. Small areas can be seen with no coating present indicating the coating is coming off in small areas during the 1000 dry wipe process under UV light. No UV light was used in the right image below after printing 20 boards with no underside clean cycles. When UV light was used, the entire image fluoresced making it difficult to see flux and paste residue. One can see that there is very little flux/solder paste on the underside of the stencil in the right image below indicating again that the FPN coating is present on the surface after 1000 dry wipe cleaning cycles and then 20 prints with no underside wipe.

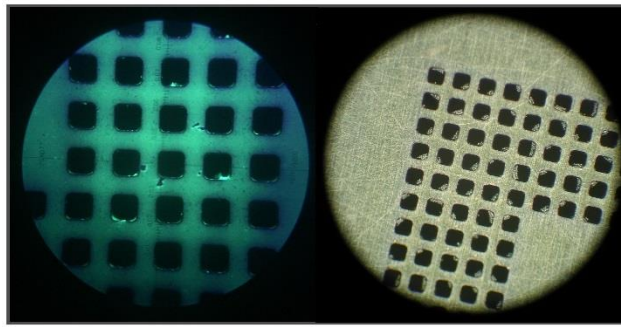


Figure 12: FPN Coating, 1000 Dry Wipes (left), 20 Prints with No Underside Wipe (right)

The squeegee test consisted of 1000 dry squeegee prints and were made on both the Phos-2 and FPN coated stencils. Since the Phos-2 coating is clear and contains no fluorescing dye, wear damage could not be seen in the images. Images of the FPN coated stencils after 1000 dry squeegee prints are shown below (Figure 13).

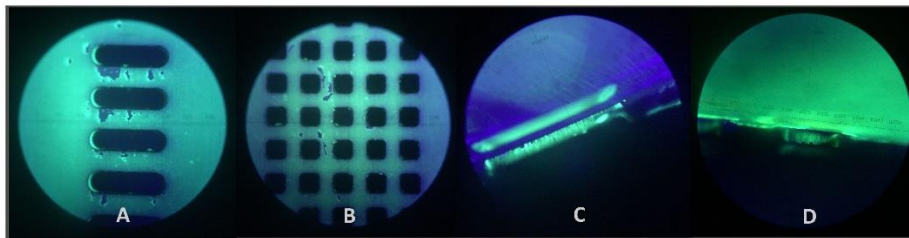


Figure 13: 1000 Dry Prints, FPN Coated Stencil

In image A and B above (Figure 13), damage can be seen in the FPN coated surface of the stencil. When apertures were cross sectioned, however, the coating was still intact inside the apertures. This can be seen in images C and D above with the coating fluorescing in the aperture walls indicating that the coating is still intact.

By observing both the squeegee testing images and the underside wipe images above, one can come to the conclusion that both the underside wipe process and the downward pressure and movement of the squeegee blade across non-planer PWBs contribute to coating wear during the print process.

The final stencil nano coating that was tested was an R & D hybrid coating. The coating consisted of an FPN coating applied to the stencil aperture walls and the Phosphonate-2 coating being applied to the underside of the stencil. The advantage given by this new technology is the Phosphonate-2 coating provides a non-stick surface on the bottom of the stencil and the FPN coating gives solder paste printing benefits on the aperture walls. When wear occurs the Phosphonate-2 coating could be easily reapplied to the bottom of the stencil by the user. The images below (Figure 14) show the board side of the stencil with coating fluorescing on the apertures walls where the FPN coating is present.

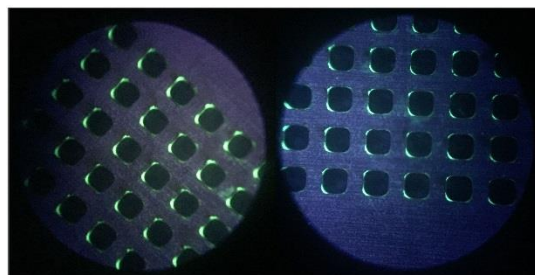


Figure 14: FPN Coating in Aperture Walls, Phosphonate on Board Side of Stencil

To test the effectiveness of the R & D stencil coating, 50 consecutive prints were completed with no underside wipes between the prints using the previous test vehicle and a solder paste including the UV dye in the flux. The images below (Figure 15) show the bottom of the stencil after 50 consecutive prints with no underside wipes along with images of the 0.4mm micro BGA prints onto copper clad.

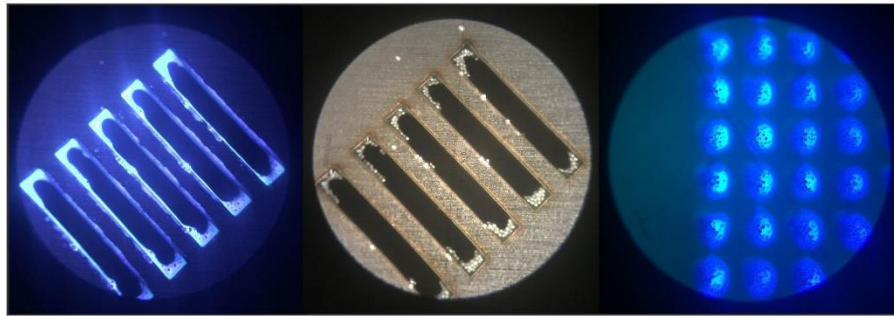


Figure 15: FPN Coating in Aperture Walls, Phosphonate on Board Side, 50 Prints, No Underside Clean

Minimal flux and paste are visible on the underside of the stencil after 50 prints with no under stencil wipe and no bridging is present in the paste deposited on the copper clad. Durability studies were not done on this particular stencil in that the Phosphonate coating durability along with FPN durability findings in this study will apply here as well. This coating technology is currently under evaluation.

Recommendations to Extend the Life of the Nano-Coating

The following are general guidelines to extend the life of nano-coatings on stencil.

1. Use solder pastes and stencil cleaners that are chemically compatible with the nano-coating.
2. Reduce the frequency of under-side cleaning to minimize both abrasive and chemical damage.
3. Minimize squeegee pressure and use proper board support to minimize mechanical damage.
4. Use nano-coatings that are more resistant to chemical and mechanical damage.
5. Re-coat Phosphonate based nano-coatings as needed to maintain the board side stencil coating.

CONCLUSIONS

Nano-coatings provide many benefits to the solder paste printing process including improved transfer efficiency, decreased standard deviation in the print process, reduced need for underside and stencil cleaning and reduced occurrence of bridging. These benefits last only as long as the nano-coating remains functional and since these coatings are nanometers to a few microns thick, users must understand they do not last indefinitely. Damage to coatings can occur thru both mechanical and chemical processes applied to the stencil during the assembly process, and once damage begins, it continues at an increased rate until the stencil no longer out performs an uncoated stencil. There are ways to extend the life of the nano-coating on the stencil and to ensure excellent print performance by following the recommendations above. Finally, new technology is being studied to combine both types of nano-coatings into one technology that will offer the best benefits of each type of coating and possibly improve the overall durability of the coating.

ACKNOWLEDGEMENTS

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