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STENCIL PRINTING YIELD MPROVEMENTS

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ABSTRACT:
Stencil printing capability is becoming more important as the range of component sizes assembled on a single board increases. Coupled with increased component density, solder paste sticking to the aperture sidewalls and bottom of the stencil can cause insufficient solder paste deposits and solder bridging. Yield improvement requires increased focus on stencil technology, printer capability, solder paste functionality and understencil cleaning.

The wide range of required solder paste volume deposited on mixed technology assemblies is pushing traditional stencil design rules to their limit. There is a need for improved stencil, printing and materials technologies to increase the consistency of the deposit. Cleaning the underside of the stencil is a critical enabler to yield improvement. The purpose of this research is to study the wipe sequence, wipe frequency and wipe solvent(s) and how these factors interact to provide solder paste printing yield improvement.

Key words: Stencil Printing, Stencil Cleaning, NanoCoating, Under Stencil Wipe, Cleaning Agents

INTRODUCTION:
Understencil wiping has gained increased interest over the last several years. Changes in circuit design due to miniaturized components and highly dense interconnects have increased the importance of stencils being free of solder paste deposits in the wall of the aperture. In most stencil printing processes, dry wiping has been followed by vacuum assist in an effort to clean solder paste from aperture walls. As stencil apertures reduce in size, more frequent wiping is needed to assure that stencils are free of solder paste deposits.

To improve solder paste release, two technology approaches are being studied with higher levels of frequency. The first technology is a nano-scale hydrophobic, oleophobic and adhesion promoting coating.[1] The objective is to treat the metal stencil surface with a nano-coating to prevent solder paste from sticking to aperture walls. The second technology is to wet the understencil wipe with a solvent based cleaning agent. The cleaning agent dissolves the flux component within the solder paste to improve release of solder balls from aperture walls.

SMT PRINTING YIELDS:
Stencil printing is a critical step in the electronic assembly process. It has been reported that over 50% of SMT defects in the final assembly are due to factors involving the stencil printing process.[2] The key factors that must be understood are materials, equipment and tooling, personnel and environment, and operations and metrics.[3]

Numerous materials come into play within the stencil printing process. The most important material is the solder paste. Critical factors for the solder paste are the printing environment, metallurgy, viscosity, rheology, slump, particle size and distribution. The flux composition plays a significant factor in the rheology, viscosity, tackiness, residue levels, and how long the paste can be used within the process. This is commonly referred to as “response to pause.”

The stencil itself becomes increasing critical as the size of components decrease and the density of placements increase. Stencil factors of note are the stencil material, method of fabrication, aperture layout, thickness, aperture geometry, aspect ratio, aperture size, area ratio, taper and polish. Electroformed polished stencils with smoother aperture walls improve release. The recent innovation of coating the stencil to improve the repellence of the solder paste from the stencil wall is gaining significant interest.

The stencil printing machine is the enabler that provides both stencil printing accuracy and reliability. Stencil printers equipped with vision systems and metrologies provide feedback as to the yields and accuracy of each print. Process controls such as defect data collection, solder paste inspection tracking and optimal process settings helps the operator maintain a process with control limits.

Process parameters need to be established for the assembly in question. Stroke length, print pressure, print speed and print release from the stencil are typically dialed in using automated inspection operations. Cleaning frequency is established based on the board design and manufacturing environment or based on how well the board, stencil and paste are interacting within the print process. Print consistency is critical to achieving printing repeatability and reproducibility.

STENCIL RELEASE COATINGS:

High density and miniaturized circuit assemblies challenge the solder paste printing process. The use of small components such as 0201, 01005 and µBGA devices require good paste release to prevent solder paste bridging and misalignment.[4] When placing these miniaturized components, taller paste deposits are often required. To improve solder paste deposition, a nano-coating is applied to laser cut stencils to improve transfer efficiency.

The nano-coating chemically modifies the surface of the aperture allowing the solder paste to decrease its attractive forces to the metal surface.[5] Nano-coated stencils work in two complementary ways to reduce the adhesive force between the paste and the aperture. First, by adding the extremely thin coating, the roughness of the aperture is reduced. Additionally the coating fills in some of the "valleys" in the surface topology. This process decreases solder paste adhesion to the stainless steel stencil mesh.

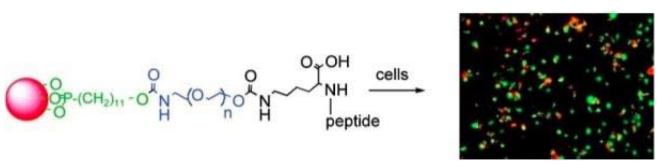

Figure 1: Nano-Coating Image and Structure Courtesy of Aculon[1]

The technology driving nano-coated stencils is the ability to repel the solder paste from the aperture wall. An extremely thin coating of a hydrophobic coating on the surface of the stencil has shown promise in improving fine pitch print yields.[4] The coating reacts with the stencil surface and aperture walls. The surface coating is roughly 5 monolayers thick.[1] The coating modifies the surface using a durable hydrophobic, oleophobic and adhesion promotion material.

WIPE FREQUENCY:

One question that continuously arises is how often should an understencil wipe be done? Many factors influence wipe frequency requirements. Generally speaking, miniaturized, high density designs require more frequent wipes because they present more opportunity for errant paste to remain in the stencil's apertures or stick to the stencil's bottom surface after separation. Wipe frequencies can range from every print on a highly miniaturized product to every 10-20 prints on a low density design.

Wipe frequencies and sequences are commonly determined based on printing yields and on board observations. Some are derived by DOE's while other from educated estimates. Most selections are product-specific, based on the solder paste formulation, PCB configuration and yield history. Stencil printers equipped with automatic underwipe systems offer users the option to program the order and speeds of the wiper passes using dry, vacuum, or solvent modes.

UNDERSTENCIL WIPE CLEANING SOLVENTS:

For higher pitch features, dry wiping the bottom side of the stencil works well. On larger feature prints, a small level of solder paste on aperture walls does not materially affect the printing process. As feature size reduces, chemical assist is often needed to dissolve the flux vehicle within the solder paste. Solder balls are released and collected within the wiping fabric.

Using a cleaning agent to wipe the bottom side of the stencil has some risk factors that need to be understood and anticipated. The risk of chemical assist wiping is the potential to contaminate the solder paste. To mitigate this risk, understencil wipe cleaning solvent must both clean and readily dry from subsequent dry wipe and vacuum processes.

The desirable properties of an understencil cleaning agents are (1) the ability to rapidly dissolve the solder paste flux vehicle, (2) material compatibility with the nano-coating and equipment, (3) non-flammable, (4) low odor and (5) sufficient volatility to rapidly evaporate and dry post cleaning. Deficiencies in any of these properties can reduce process repeatability and reproducibility.

The initial step in the understencil cleaning process is to match up the cleaning agent with the solder paste. Solder paste flux vehicles vary based on the technology applied. Poorly matched cleaning solvents with the solder paste will cause undesirable effects such as solder lump, insufficients and overall poor print quality. Solder paste flux packages that are non-soluble in the cleaning solvent have a tendency to repel. Instead of being attracted to the wipe fabric, the solder may smear onto the bottom side of the stencil.

For water soluble solder pastes, the flux vehicle is highly polar and readily dissolves within polar cleaning agents. Solvent – water cleaning agents rapidly dissolve polar activators, surfactants and other oxygenated solvents formulated into the solder paste. When formulated in the proper ratio, the cleaning solvent evaporates at a constant rate. This feature prevents tail solvents from being left behind that may contaminate the solder paste.

When the stencil is coated with nano-coating, the cleaning should not break or reduce the coating monolayer. Properly designed cleaning solvents improve the removal of solder paste out of fine pitch apertures, wipes easily off the stencil, does not streak or stain the stencil and readily evaporates.

For no-clean solder pastes, the flux vehicle is much more complex. The flux component is designed with resins, activators, solvents and rheological additives. The problem is that the wide ranges of solder paste formulations are not overly consistent among solder paste suppliers or even formulation families. Therefore, it is challenging for a one size fits all cleaning solvent design to work on all solder pastes.

For many no-clean flux compositions, a water based understencil wipe cleaning solvent works buy may not be a good match for some flux compositions. On some no-clean compositions a solvent-based cleaning fluid that is properly balanced for cleaning and drying is the most optimal design. If the solder paste is designed for water cleaning, water based understencil wipe cleaning solvents may be an ideal match. Matching up with the cleaning solvent with the solder paste type is critical to achieving improved yields.

In many respects, the question an assembler should ask is will an understencil cleaning solvent improve yields and be worth the risk? When designed with the right properties, the cleaning agent is highly beneficial to the process and improves printing yields, and is no risk. The critical factor that an assembler must know and understand is that one cleaning material that works well for all solder pastes is not realistic. Solubility data is critical when selecting an understencil cleaning solvent. Paying attention to this level of detail prevents process risk.

SOLUBILITY TESTING METHODOLOGY:

Solubility testing exposes wet solder paste to a series of solvents with known solubility parameters. To evaluate the solubility of the solder paste with the cleaning solvent, wet solder paste is placed into a glass vial. Test solvents are added to the glass vials. The vials are placed onto a rotating wheel for 2-4 minutes to determine if the test solvent dissolves the flux vehicle. When the flux vehicle is soluble in the test solvent, the solder balls within the paste are released and freely disperse within the test solvent.

The wet solder paste is graded based on each solvent's ability to dissolve the flux vehicle (Table 1). The testing provides the formulator with insight into solvents that match up to the flux vehicle. This level of testing provides a predictive model for engineering cleaning agents that work to the design criteria.

Table 1: Wet Solder Paste Grading Scale

Score	Description
1	Solder Paste Easily Disperse
2	Most of the solder paste is disperse but small cluster adhere to beaker
3	Partially dispersed
4	Reluctant to disperse
5	Marginal interaction
6	No interaction

Score 1: Solder Paste easily dispersed

Figure 2

Score 2: Most of the solder is dispersed but small clusters of solder paste adhere to the side test vial side walls.

Figure 3

Score 3: Partially Dispersed

Figure 4

Score 4: Reluctant to disperse

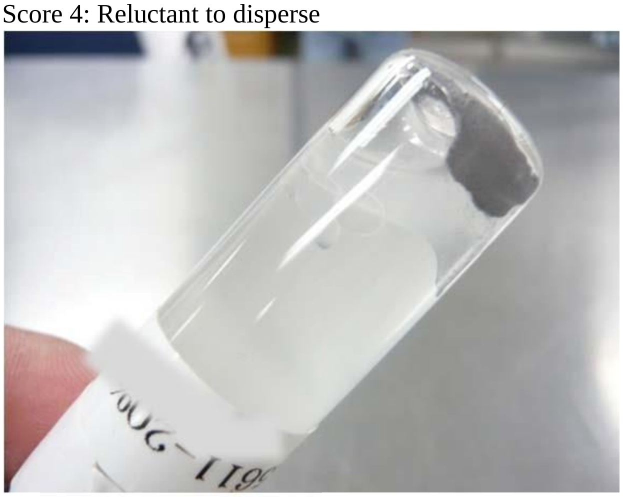

Figure 5

Score 5: Marginal Interaction

Figure 6

Score 6: No Effect

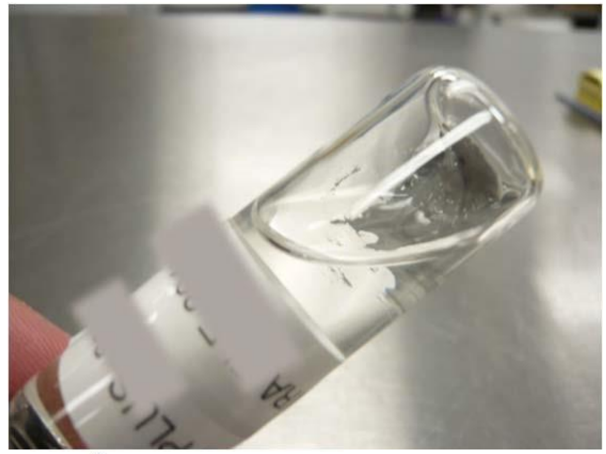

Figure 7

DESIGNED EXPERIMENT:
Seven understencil wipe cleaning agents were selected as the research solvents. The control solvent was IPA @ 100% concentration. One of the cleaning agents was a watersolvent azeotropic mixture, which allows the material to evaporate at a common rate. Five of the cleaning agents were solvent mixtures.

Nine solder pastes were selected for the study. Two of the solder pastes were tin-lead no-clean. Five of the solder pastes were lead-free no-clean. Two of the solder pastes were lead-free water soluble.

The first experiment was run to determine the solubility of the flux vehicle in each cleaning agent. Solubility testing as previously described was tested on the nine solder pastes used for this study. Figure 8 provides solubility of the nine solder pastes in the test solvents.

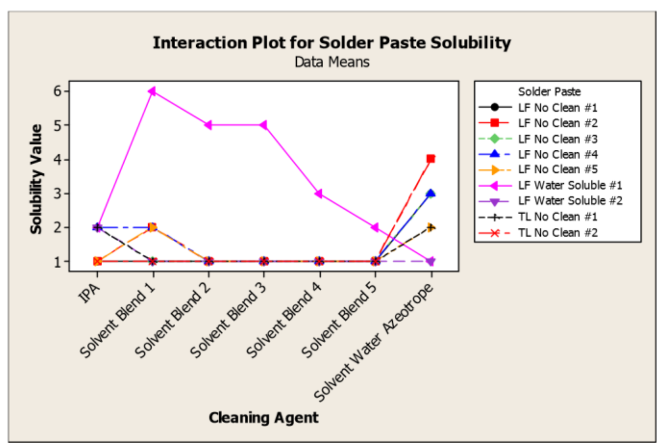

Figure 8: Solubility of the Wet Solder Paste in Cleaning Agents

The second experiment tested the cleaning solvent evaporation rate. Cleaning solvent was flowed onto stainless steel panels and allowed to air dry (Figure 9).

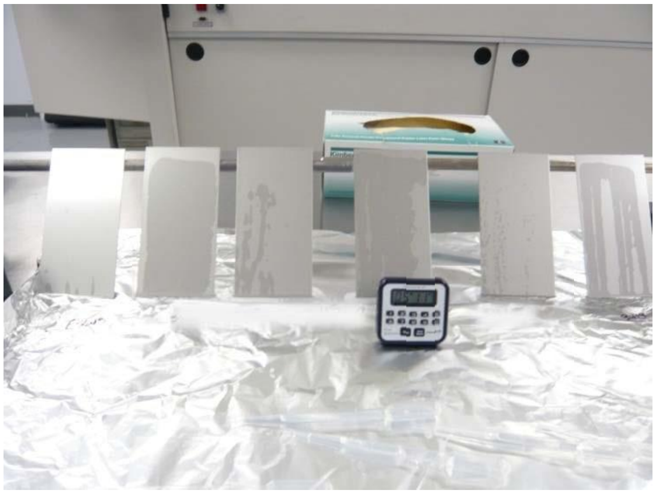

Figure 9: Evaporation Study

Short evaporation rates equate to faster drying. Most modern stencil printers equipped with understencil wiping follow the chemically assisted wipe with a dry wipe followed by vacuum collection and drying. Cleaning solvents that evaporate quickly are easily dried during the dry wipe and vacuum cycles. Cleaning agent that dry at slow rates may not adequately dry during the dry wipe and vacuum process. When this occurs there is the risk of cross contaminating the solder paste with the wipe solvent. If the bottom side of the stencil is still wet, a solvent film may be transferred to the board being printed, which potentially decreases yields. Figure 10 provides a summary of the evaporation times for the cleaning solvents within this study.

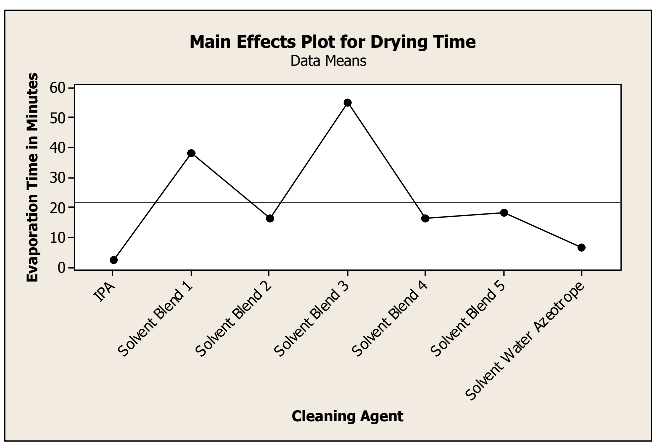

Figure 10: Cleaning Solvent Evaporation Rates

INFERENCES FROM DATA FINDINGS:

The desirable properties for understencil cleaning solvents are as follows:

1. Rapidly dissolve solder paste flux vehicle
2. Material compatibility with nano-coating and stencil printing equipment
3. Non-Flammable
4. Low odor
5. Non toxic
6. Sufficient volatility to quickly evaporate and dry

IPA is the most common wipe solvent used when a chemical assist wipe is used. The data infers that IPA was effective at dissolving the range of solder pastes selected for this research study. The negative with IPA is its low flash point and flammability. IPA vapors within the printer have the potential for a fire risk. From a health and safety standpoint, there are mixed reviews on IPA.

Solvent Blend #1 performed on par with IPA. The cleaning agent dissolved all solder paste flux vehicles with the exception of one of the water soluble lead-free solder pastes. The solvent blend has a lower vapor pressure, which reduces the flammability risk but required a longer time to dry.

Solvent Blend #2 performed better than IPA on the solder pastes in the study with the exception of the one water soluble lead-free solder paste. The solvent blend also has a slightly lower vapor pressure, which reduces the flammability risk. The drying time was slightly longer than the time to dry IPA.

Solvent Blend #3 performed better than IPA on the solder pastes in the study with the exception of the one water soluble lead-free solder paste. The solvent blend has significantly lower vapor pressure, which reduces flammability risks. The tradeoff is a significantly longer drying time, which may be an issue for understencil wiping.

Solvent Blend #4 performed better than IPA on the solder pastes in the study and slightly poorer on the one water soluble lead-free solder paste. The solvent blend also has a slightly lower vapor pressure, which reduces the flammability risk. The drying time was slightly longer than the time to dry IPA.

Solvent Blend #5 performed better than IPA on the solder pastes in the study and on par for the one water soluble leadfree solder paste. The solvent blend also has a slightly lower vapor pressure, which reduces the flammability risk. The drying time was slightly longer than the time to dry IPA.

Solvent Water Azeotrope performed well on the water soluble solder pastes and good on a number of the no-clean solder pastes. The performance on the no-clean solder pastes was slightly poorer than IPA but may be good enough. The solvent water azeotrope has the faster drying time with the exception of IPA. The one huge benefit is the nonflammability of the cleaning agent.

CONCLUSIONS:

Understencil wiping has gained an increase in interest over the last several years. Changes in circuit designs, such as miniaturized components, increased density of components, and new stencil technology need to decrease print defects as well as changes in and increased attention to employee safety and environmental regulations have driven renewed interest.

New understencil wipe solvents have been introduced recently to address these issues. Of all the cleaning agents tested, Solvent Blend #5 and Solvent Water Azeotrope provided the highest potential for understencil wipe cleaning solvents that replace IPA.

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