IMPLEMENTING PROPER PROCEDURES AND THE USE OF ADVANCED FLUX VERIFICATION TOOLS FOR A ROBUST WAVE SOLDERING OPERATION

Wojtek Antoniak[1] and Greg Hueste[2]

[1]Electronic Controls Design, Inc.

Milwaukie, OR 97222

[2]Speedline Technologies

Camdenton, MO 65020

ABSTRACT

This article examines **application** and **verification** techniques for flux deposition through spray fluxing in wave soldering processes, focusing on through-hole penetration and coverage uniformity. The work evaluates simple methods of spray fluxing verification processes to prevent solder defects and improve product quality.

The causes leading to defects of poor through-hole penetration are well documented in many publications (1,2).

FLUX BASICS

Flux is one of the most important materials used in the soldering process and, if applied correctly, has a significant impact on good solder joint reliability.

Flux used in wave and selective soldering processes is usually applied in liquid form, by means of spray. Flux removes oxides from joining materials/metals, protects against further oxidation during the soldering process and promotes wetting.

There are three basic types of soldering fluxes

- Alcohol-based
- VOC-free
- Water-soluble

Selection of the correct flux chemistry for a particular application depends on many factors, such as:

- The end product application and reliability requirement
- Flux application method (usually spray fluxing in conventional wave-soldering)
- Post-cleaning requirement, cleaning of residues due to their corrosive nature and/or post-soldering appearance

SPRAY FLUXING PROCESS

The most common form of applying flux on printed circuit boards (PCBs) is the spray fluxing method, where a liquid flux solution is sprayed onto the bottom of the PCB(s) by means of atomizing, jetting, or through the use of reciprocating or stationary ultrasonic-nozzles.

Like any tool, the performance of spray fluxers varies by manufacturer. The end user's objective is to have a spray fluxing system that offers:

- Long-lasting performance, free of defects and degradation over time, as well as compatibility with a variety of fluxes (Note: Some fluxing materials can be corrosive and may damage internal parts of a fluxer.)
- Easy set-up and maintenance

- Self-cleaning features and repeatability/performance over time
- Adequate controls and a design that provides good spray uniformity and through-hole penetration

There are three parameters influencing performance of any spray fluxer:

- Control of flux deposition
- Uniformity of spray
- Through-hole penetration

Flux Technical Bulletins/Data Sheets

Flux manufacturers provide guidelines regarding how their products should be used. Each flux will have its own unique document which includes the following information:

- Flux deposition range (amount of flux to apply) – the recommended value expressed in micrograms per square inch (typically ranging between 500-1,500 micrograms/inch square)
- Solids content
- Board top-side preheat temperature prior to soldering
- Recommended pre-heat profile
- Cleaning and touch-up guidelines
- Safety specifications

To ensure proper fluxing operation, the user must follow the flux manufacturer's recommendations and adjust the fluxer/machine to obtain the best soldering results.

Flux Deposition – Determining the Proper Volume

Through Flux consumption

- Assuming that overspray (flux loses) are negligible or could be calculated, sprayed flux could be diverted from a spray nozzle to a remote container for a controlled period of time, the volume of consumed flux calculated and then the flux deposit on the PCB calculated.

- The above method could be automated by employment of precise metering valves, flowmeters and/or positive displacement pumps (seen in some high-end fluxers). Such controls can provide the required information, guarantee consistent and optimal spray performance over time, but also significantly increase the cost of the machine.

Thorough Flux Deposition

The easiest way is to check flux deposition on a PCB is by calculating the weight of the product (PCB) before and after fluxing, than calculating the flux deposit (knowing product size and weight of flux on it). The results may be affected by the evaporation of flux (activators), the accuracy of weighing techniques and may not be as accurate, if not carried out properly.

There are two common weight test methods -- the wet and dry techniques -- which are used for different types of fluxes. The wet method is recommended for water-based fluxes (VOC-free) and the dry method is recommended for alcohol-based (VOC containing) fluxes.   Each method requires the weight measurements to be calculated using a scale/balance capable of measuring grams to three decimal places .000 – and the capacity to measure the full weight of the board. Many scales with high accuracy only measure to a 200 grams or less.

Wet Method (see Figures 1 and 2)

1. When using the wet method, a sample board and Ziploc® bag capable of accommodating the PCB are weighed prior to fluxing.

Figure 1 – Tools required to measure flux deposition on a board in wet method

2. The PCB is then fluxed and, following the last spray stroke, the PCB is immediately removed from the machine placed in the sealed Ziploc bag and weighed again.

3. The before and after weights are calculated along with the percent solid content and board size, and are then used to calculate the deposition weight (as shown in Figure 2).

	A	B	C	D	E
1	FLUX DEPOSITION CALCULATOR				
2					
3					
4	BOARD DIMENSIONS				
5					
6	WIDTH	5		SQ/IN	28.75
7					
8	LENGTH	5.75			
9					
10					
11	BOARD WEIGHT WET METHOD				
12					
13	BEFORE	39.599	GRAMS		
14					
15	AFTER	40.177	GRAMS		
16					
17	% SOLIDS	5.86			
18					
19					
20	MICROGRAMS SQ/IN			1178.115	
21					
22					

fx =((B15-B13)*B17/100)*1000000/E6

Figure 2 - Flux deposition weight - calculation formula for Wet method

The Wet test generally works best for VOC-free and water-based fluxes because it takes too long to evaporate the liquid component of the flux. It will indeed evaporate, but is bagged to prevent any loss.

Dry Method

1. A sample board is weighed prior to fluxing.

2. The board is fluxed and removed from the machine.

3. The board is placed flux side up on a table to allow all of the base/carrier (alcohol) to evaporate off the board, which should take approximately two to three minutes. Anything remaining on the board will represent a deposit of solids.

4. After alcohol evaporation, the board is weighed.

5. The before and after weights are measured along with the board size and are then used to calculate the deposition weight (as shown in Figure 3).

	A	B	C	D	E	F	G	H	I
1	FLUX DEPOSITION CALCULATOR								
4	BOARD DIMENSIONS								
6	WIDTH	5		SQ/IN	28.75				
8	LENGTH	5.75							
11						BOARD WEIGHT DRY METHOD			
13						BEFORE	38.125	GRAMS	
15						AFTER	38.158	GRAMS	
20						MICROGRAMS SQ/IN			1147.826

fx =(G15-G13)*1000000/E6

Figure 3 - Flux deposition weight – Calculation formula for Dry method

The dry test works well with any IPA-based flux because the IPA will evaporate quickly.

To obtain optimal soldering results, it may be necessary to adjust the amount of flux applied to the PCB. To do this, flow rate (the flux tank pressure) and/or the traversing speed of the fluxer head will have to be adjusted.

The flux deposition range recommended by the flux supplier is generally a fairly broad window and should be used as a guideline.

For optimal flux deposition, the lowest possible deposition of flux to deliver the best soldering results with an acceptable amount of residue left after soldering is required. Applying too much flux may affect the appearance of the product, and can leave excessive residues which may require cleaning or affect the reliability of the finished product if not cleaned. In addition, higher flux usage impacts operation costs, can affect conformal coating, surface resistance (SIR) and the like, and may increase the machine maintenance required.

The best way to determine how much flux should be applied is to initially deposit the maximum recommended flux volume, process the product and inspect the PCBs. Flux volumes can then be reduced until acceptable soldering results (top side solder penetration) along with acceptable flux residues are achieved.

Soldering results primarily depend on uniformity of the flux spray. If flux through-hole penetration is satisfactory, then good fillets should be achieved. To ensure minimal defects, spray uniformity, through-hole penetration and flux volume are equally important. Below is a DOE of a flux deposition and flux penetration) performed using a low solids, VOC-free (water-based), no-clean flux.

Flux Deposition DOE

Three target deposition rates were identified based on the flux deposition guidelines listed in the flux supplier's technical bulletin.

Low – 450 mg/in2. (Figure 3)

Medium – 950 mg/in2. (Figure 5)

High – 1500 mg/in2. (Figure 7)

The wet method, as described previously, was used to determine board weight for flux deposition.

Fluxer settings required to deliver the deposition rate for each target were determined. Once the settings were defined to meet the target deposition, weight tests were performed to ensure repeatability of the flux deposited.

A flux measurement system (ECD Fluxometer™) was used to determine through-hole penetration and uniformity for the low, medium and high deposition testing to verify fluxer performance at those settings. The critical indicators were evidence of good through-hole flux penetration and flux distribution/spray pattern.

VOC free, low solids water based flux		
4% Solids		
Target Deposition		
450 mg/in2		
Settings: 8 psi, 5 SF		
Run 1	445	
Run 2	473	
Run 3	449	
Run 4	441	
Avg	452	
Delta	32	

Figure 3 - Low Flux deposition. Target 450 mg/in2

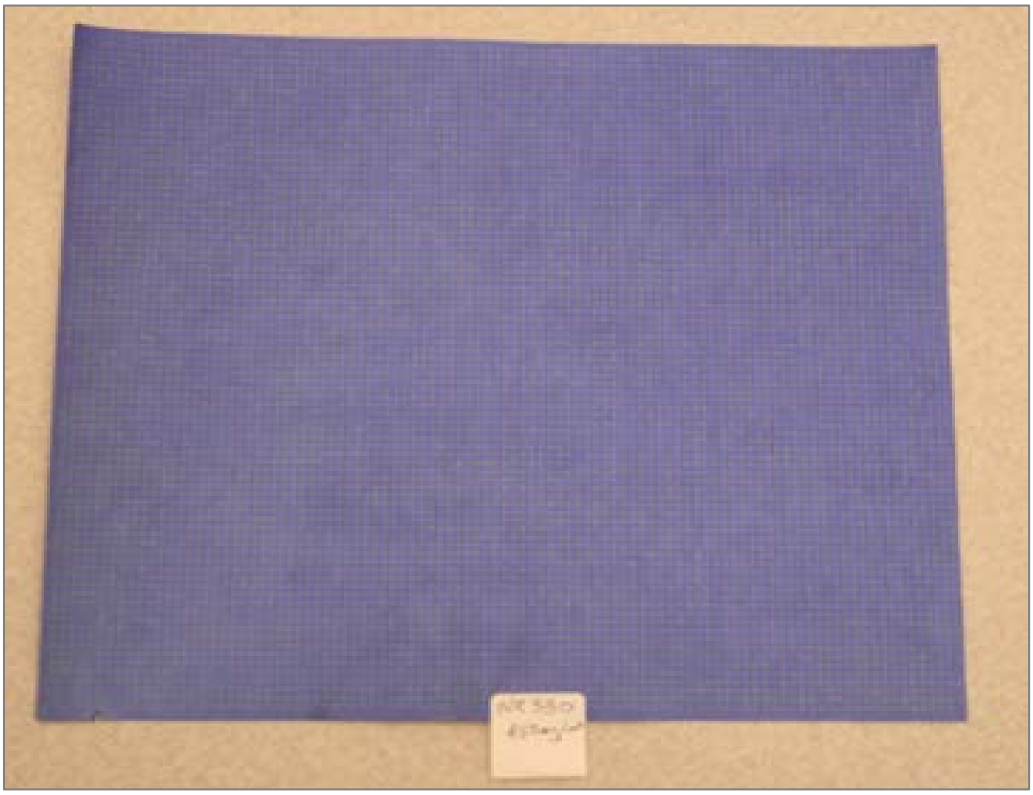


Figure 4 – Spray deposit target 450 mg/in2 using Fluxometer. Very good hole-fill and uniform flux deposition

Target Deposition	
950 mg/in2	
Settings: 12 psi, 45 SF	
Run 1	948
Run 2	926
Run 3	908
Run 4	940
Avg	930.5
Delta	40

Figure 5 – Medium Flux deposition target 950 mg/in2

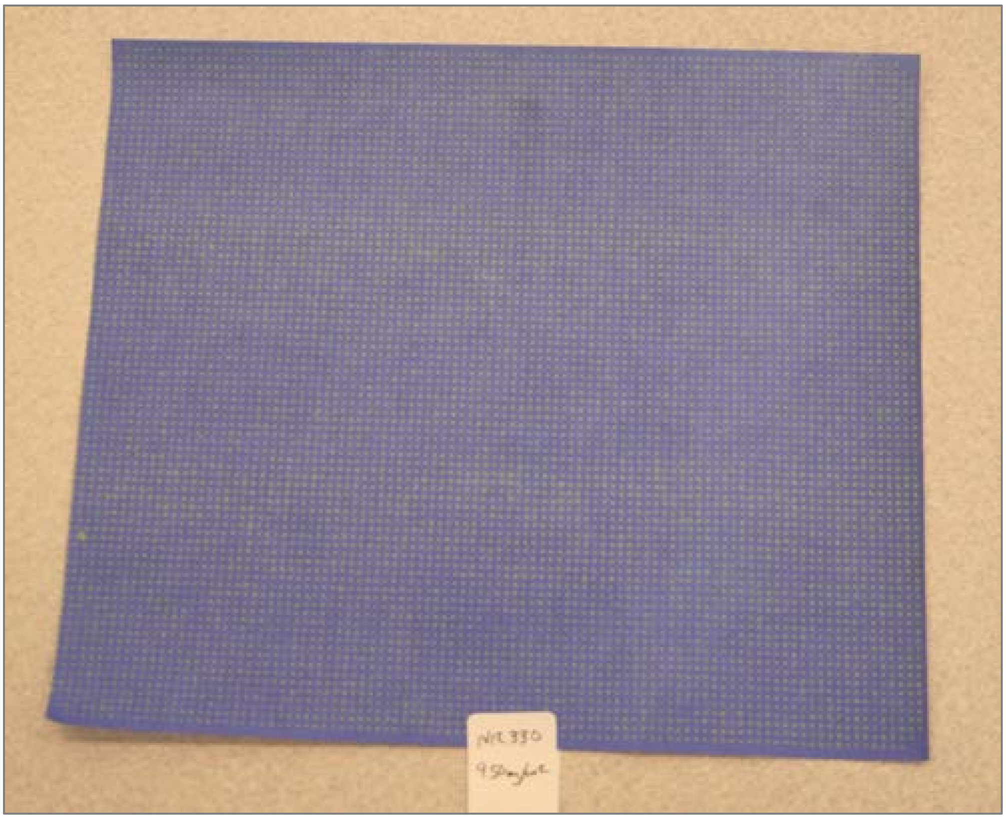


Figure 6 – Flux Deposition target 950 mg/in2 using Fluxometer. Very good hole-fill and uniform flux deposition

Target Deposition	
1500 mg/in2	
Settings: 12 psi/80 SF	
Run 1	1519
Run 2	1473
Run 3	1513
Run 4	1453
Avg	1489.5
Delta	66

Figure 7 – High Flux Deposition Target 1,500 mg/in2

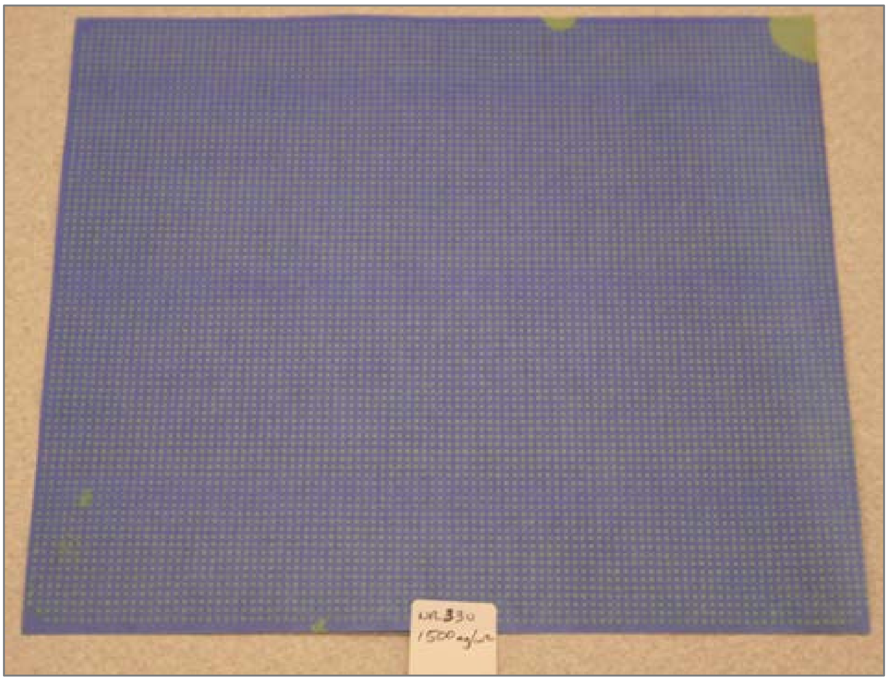


Figure 8 – Flux deposition 1,500mg/in2 using Fluxometer Very good hole-fill and uniform flux deposition

Soldering Defects - Insufficient Top Side Hole Fill

There could be many reasons for not achieving acceptable top side hole-fill in plated through-holes on printed circuit boards. Poor flux application, inadequate pre-heat, lack of contact with the wave, poor consideration of thermal relief in the board design, quality of plating, and contamination issues are some of the main contributors to insufficient top side hole fill.

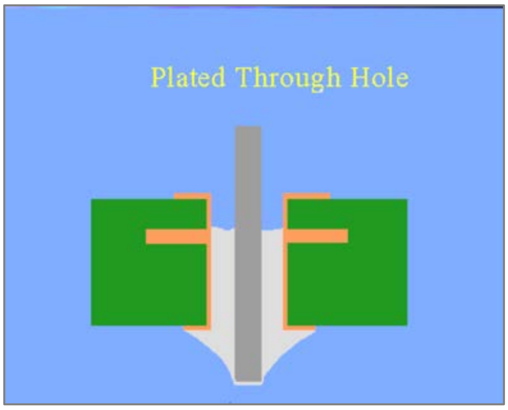


Figure 9 The solder wets the leads but fails to wet the surface of the through hole.

Insufficient top side hole-fill (Figure 9) is a common issue with wave-soldering processes and is generally the biggest challenge to overcome when soldering in a lead-free process. The leading causes of insufficient hole fill are inadequate application of the flux or a thermal issue (i.e. insufficient heating of the board, including the inner copper layers of the board). Determining which condition is causing the problem is critical and is why verifying flux coverage and penetration during the process development phase is essential.

The flux must be applied so that all exposed solderable surfaces are wetted by the flux. This includes not only applying flux to the bottom land, but also getting flux to wet the complete barrel, top land and the complete length of the pin.

If the spray fluxer is not set up correctly, then getting flux to all solderable surfaces may be challenging. Use of cardboard, printer paper or a glass plate may be effective methods to determine overall coverage of spray on the bottom of the board, but will not indicate how or if the flux penetrates to the top of the board.

Figure 10 represents a typical spray on a cardboard board/coupon and glass plate. While coverage is easy to see, overspray and through-hole penetration are not visible.

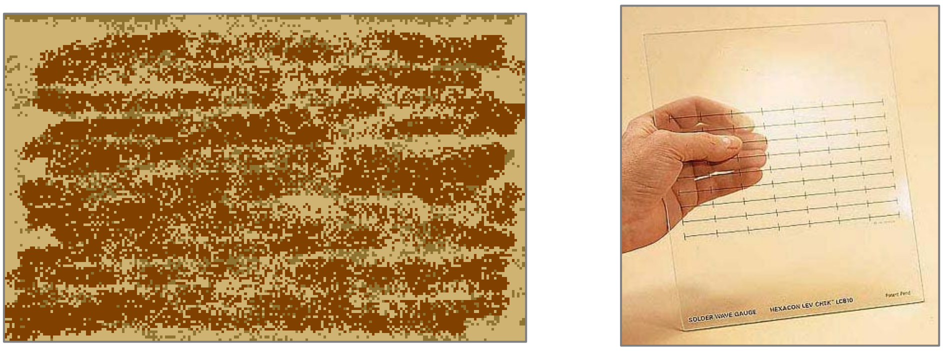
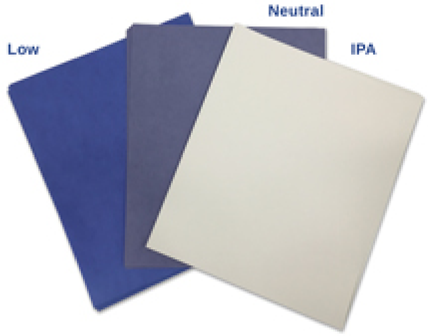


Figure 10 Cardboard and Glass plate test spray results

There are three types of flux-sensitive paper materials on the market (Figure 11) which can be used to check spray uniformity and coverage for both alcohol (IPA) and water-based fluxes. These papers are either thermal or litmus-based, offering different ranges of contrast after contact with flux solution.

	Test Paper		
Flux Type	IPA	pH Neutral	ph Low
No Clean IPA	Y	Y	N
No Clean VOC Free	N	Y	Y
Water Soluble	N	Y	Y
Rosin - Mil	N	Y	N
Contrast	**High**	**Medium**	**High**
Paper Medium	Thermal	Litmus	Brompheonal
Use with Flux pH	Alcohol	pH7 or less	pH4 or less
Start Color	**White**	**Blue**	**Blue**
Changes to	**Black**	**Pink**	**Yellow**



Test papers IPA/pH Neutral and ph Low

Figure 11 - Flux Sensitive papers characteristics

Using test papers allows good visibility and monitoring of the actual spray pattern produced by the fluxer. However, the paper alone will not determine if the spray fluxer is producing acceptable top side through-hole flux penetration.

FLUXOMETER (reference 3) is a tool widely used in the industry to check not only spray flux coverage but also topside through-hole flux penetration.

The tool consists of a frame/carrier, test mesh (a board with many plated through holes resembling PCB) and uses one of the flux sensitive papers.

The flux sensitive paper is placed above the test mesh/board with many plated through holes and placed in a carrier/frame

Figure 12 Fluxometer with flux sensitive paper.

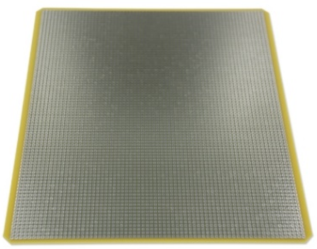


Figure 13 - Mesh test board (picture)

Figure 14 - Carrier (1) + Test mesh (2)

After processing the Fluxometer (ref 3) over a spray fluxer, flux penetrates through the holes in the mesh and leaves an imprint of the spray pattern on flux sensitive paper. Results are easy to understand (figure 15-20) and can be kept as a record of process verification.

Examples of Fluxometer tests

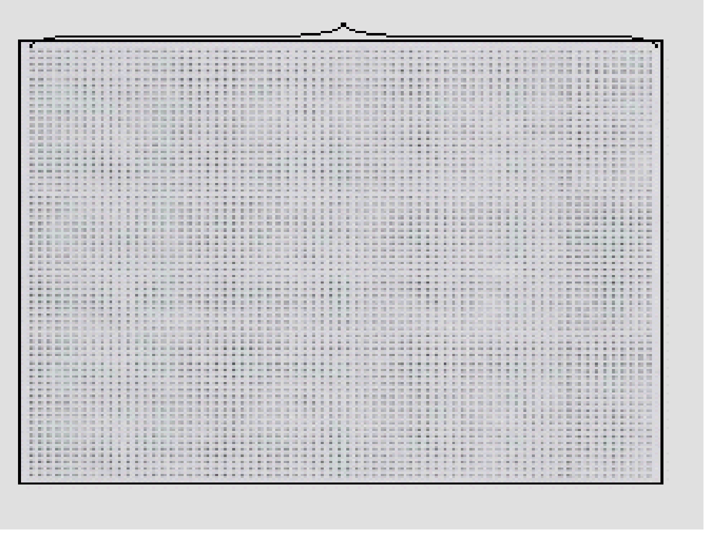


Figure 15 -Good flux penetration and uniform coverage, all holes are fill and flux penetrated through the mesh/holes

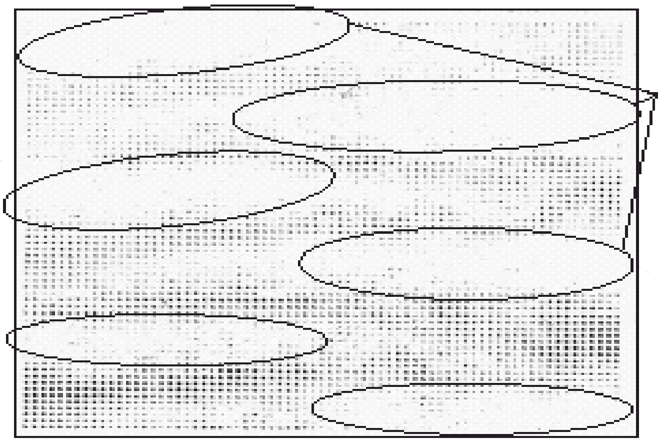


Figure 16 - Poor flux penetration and coverage. Flux did not penetrate in some areas

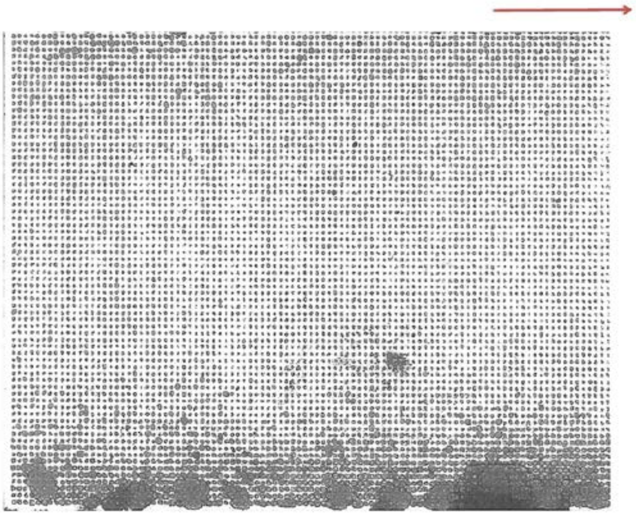


Figure 17 - Good flux coverage with acceptable through-hole penetration; overlapping spray at the front of the machine (bottom part) shows too much flux deposition.

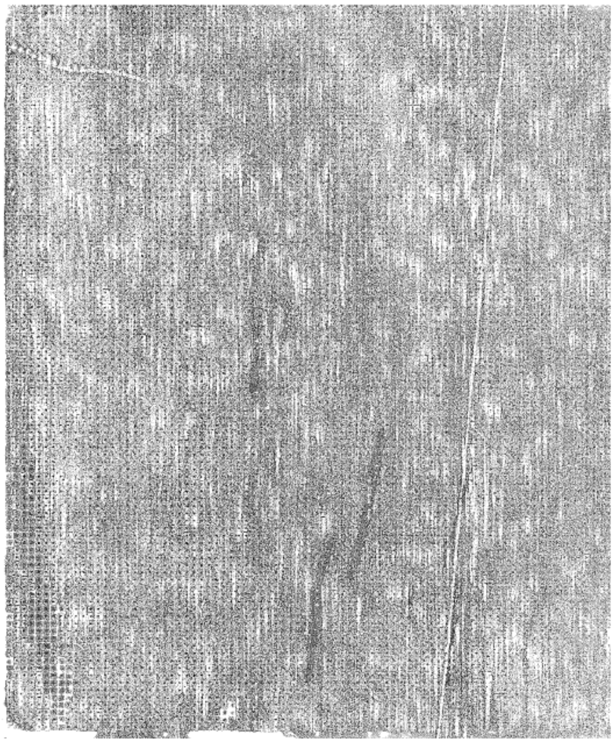


Figure 18 - Heavy flux deposition, leading to high flux usage. Increased costs and potential post-cleaning requirements.

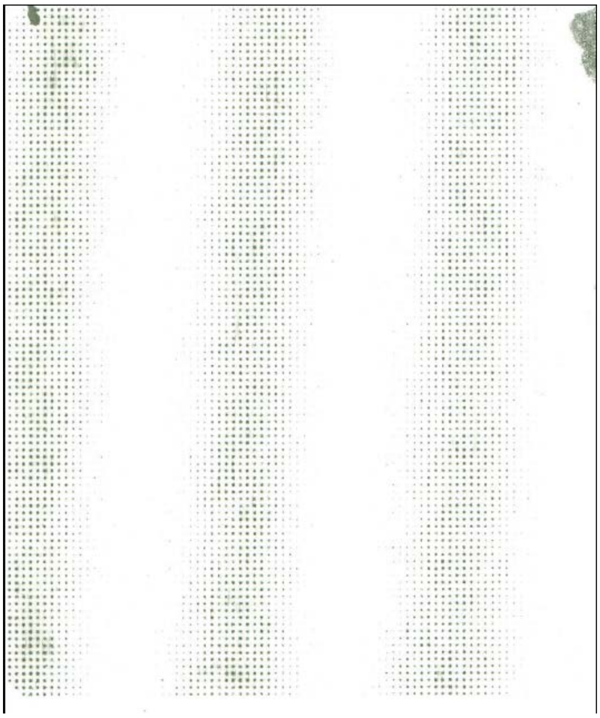


Figure 20 -Missing spray coverage – no spray on return stroke. Light deposit and hole fill.

CONCLUSIONS

Flux plays a major role in a successful soldering operation by removing oxides, acting as an oxygen barrier preventing further oxidization and promoting wetting.

The correct process development and set-up of every spray fluxer is critical for a robust, reliable wave soldering process and should not be neglected.

While finding the optimal flux deposition rate can be troublesome as it may require testing and be time consuming, verification of spray coverage and topside flux penetration is easy, leading to the elimination of potential guesswork related to the analysis of soldering defects.

Employment of thermal and litmus sensitive papers together with tools like Fluxometer (ref. 3) provide easy setup and troubleshooting techniques of various spray fluxing applications, including: y coverage/spray patterns, topside hole-fill, benchmarking and monitoring of flux application over time, discovery of incorrect setups leading to missing/under/over spray, and clogged nozzles leading to defect-free soldering, among others.

References:

Ecd.com,. 'ECD Fluxometer® | Maximizes Yields And Reduces Rework ...'. N.p., 2015. Web. 27 Oct. 2015.

Epectec.com,. 'Inconsistent Or Poor Hole Fill On A PCB - Wave Soldering Defects'. N.p., 2015. Web. 27 Oct. 2015.

Kirby, Ken. Flux Application For Lead-Free Wave Soldering. 1st ed. Web. 27 Oct. 2015.