This paper was first presented at IPC APEX Expo in San Diego CA, USA, the 25th of February 2015.

Evaluation of Under-Stencil-Cleaning-Papers

Lars Bruno, Ericsson AB
Katrineholm, Sweden

Abstract
Solder paste screenprinting is known to be one of the most difficult processes to quality assure in Printed Board Assembly (PBA) manufacturing. An important process step in solder paste screenprinting is the under stencil cleaning process and one of the key materials in this process is the cleaning paper[1]. This, often neglected, material affects the cleaning process and thereby also the print quality. It is therefore important to perform tests of different cleaning papers before one could be chosen. This article describes how cleaning papers can be tested and it also tells how big differences it can be between different materials.

I. Introduction
The article has its roots in the need to improve the stencil cleaning during solder paste screenprinting, especially for small stencil apertures intended for fine pitch components.

When printing solder paste through very small apertures with low area ratios[2], the traction forces from the aperture walls will often be large enough to make much of the solder paste remain in the apertures. If this remaining solder paste is not removed, the deposited solder paste volume will be affected and potentially cause open solder joint, bridging and solder ball formation [2].

Examples of expected solder paste screenprinted transfer efficiencies[3] for different area ratios are given in figure 1.

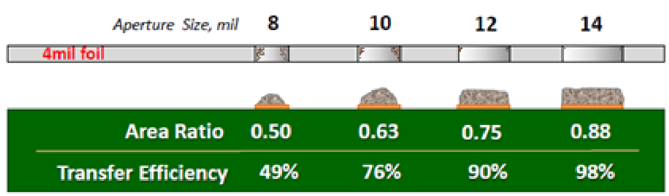

Figure 1 – Examples of expected transfer efficiencies for different aperture area ratios[4].

Photos of solder paste build up in apertures are given in figure 2.

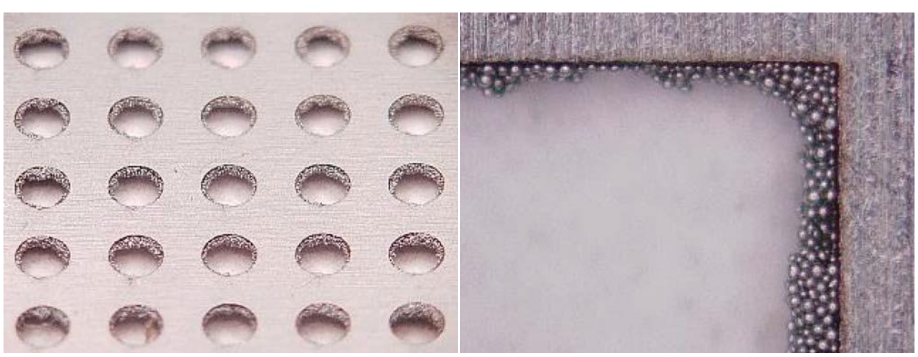

Figure 2 – Remaining solder paste in apertures [2].

[1] The materials in this report are called "paper", even though the fabric compositions in some materials do not contain any natural cellulose fibers, but instead/as well e.g. polypropylene, polyester and rayon.
[2] Area Ratio is the relationship between the aperture hole area and the area of the aperture walls. For a robust screenprinting process, a general rule is that this ratio should be at least 0.66 [1].
[3] Transfer Efficiency is the actual deposit volume divided with the theoretical volume if there is a 100% aperture release.
[4] Image courtesy of Alpha Stencils.

If the gasketing between the solder pads and stencil is not good enough or if the print pressure is too high, there is a risk that solder paste smears out on the bottom side of the stencil. This solder paste can then end up on the surface of a coming printed board and be a reason for solder balls and/or bridging between leads of fine pitch components. A description of solder paste smearing is given in figure 3.

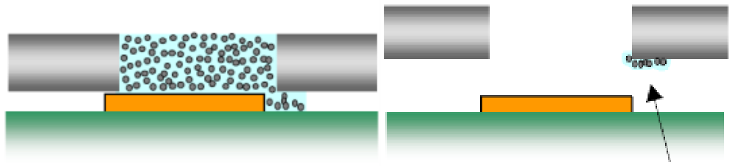

Figure 3 – Smeared solder paste under stencil[5].

In order to get a robust solder paste screenprinting process, both solder particles and flux vehicle need to be removed from the apertures and from the bottom side of the stencil.

A. The Stencil Cleaning Process within the Screen Printer

During solder paste printing, the stencil needs to be cleaned at certain intervals depending on the size, shape, pitch and wall evenness of the stencil apertures, as well as the characteristics of the solder paste. The status and type of screen printer cleaning unit are also significant for the choice of cleaning interval as is the cleaning agent, cleaning paper and the cleaning process parameter settings.

Most modern screen printers are equipped with an in-process automated under stencil cleaning unit. This stencil cleaning unit consists of a cleaning head, which often is connected to a vacuum system, and a unit designed to apply cleaning agent onto a part of a cleaning paper.

The cleaning unit is connected to a bar that moves it under the stencil during a cleaning stroke. The design of the cleaning head allows it to be risen towards the stencil bottom side during each cleaning stroke. The cleaning unit has a holder for a roll of cleaning paper that is setup so that fresh paper automatically could be forwarded over the cleaning head and then the used cleaning paper is rolled up on a second roll.

An example of a screen printer under stencil cleaning unit loaded with cleaning paper is given in figure 4.

Figure 4 – Under stencil cleaning unit with cleaning paper.

[5] Image courtesy of Koki Company Ltd.

Several different cleaning cycles can be chosen and they do most often contain one or several of the following cleaning strokes:

Wet cleaning stroke

- A part of the cleaning paper is wetted with cleaning agent.
- The wetted part of the cleaning paper is forwarded to the top of the cleaning head.
- The cleaning head is raised so that the paper gets in contact with the bottom side of the stencil.
- The cleaning head sweeps under the print area of the stencil.

Vacuum cleaning stroke

- The cleaning paper is forwarded so that a clean part of it is situated on the top of the cleaning head.
- The cleaning head is raised so that the paper gets in contact with the bottom side of the stencil.
- The vacuum is turned on.
- The cleaning head sweeps under the print area of the stencil.
- The vacuum is turned off.

Dry cleaning stroke

- The cleaning paper is forwarded so that a fresh and dry part of it is situated on the top of the cleaning head.
- The cleaning head is raised so that the paper gets in contact with the bottom side of the stencil.
- The cleaning head sweeps under the print area of the stencil.

The amount and types of cleaning strokes to be performed, as well as the cleaning interval, are programmed for each product. Note, that it exists other cleaning strokes than those mentioned above e.g. with oscillated cleaning head or forwarded cleaning paper during a stroke.

B. Consumable Materials Used in the Stencil Cleaning Process within the Screen Printer

Two consumable materials are used in the under stencil cleaning process within a screen printer, these materials are cleaning agent and cleaning paper.

The main reason to use a cleaning agent is that the solder particles are held in place on stencil surfaces by the flux vehicle and in order to make it easier to remove the solder particles, a cleaning agent is used to dissolve and reduce the flux resins [2]. Traditionally, IPA[6] has been the totally dominant cleaning agent for in-process under stencil cleaning, but nowadays water soluble cleaning agents are becoming more and more common.

Under stencil cleaning papers absorb flux and trap solder particles during the cleaning cycle. It is important that a cleaning paper is lint-free, has enough distances between fibers for vacuum cleaning and that solder particles are trapped and not released during the cleaning cycle. The cleaning agent shall wet out on a controlled area during the wetting of the cleaning paper and the cleaning paper shall not change its mechanical properties much when being wetted.

This report focuses on cleaning papers. All other materials, machines and settings used in the automatic under stencil cleaning process have been kept constant in each of the tests.

II. Methodology

The chosen cleaning papers were tested according to parameters that reflect performance during real under stencil cleaning. No standardized test method for cleaning papers intended for automatic under stencil cleaning exists.

The following tests and analyses have been performed:

- Fiber structure.
- Cleaning result in ordinary production.
- Ability to withstand sharp edge rubbing without leaving lint.
- Liquid absorption ability.
- Cleaning of heavy contaminated surface.
- Evaluation of where solder particles are entrapped.
- Vacuum cleaning ability of solder paste in small apertures.

[6] IPA = isopropyl alcohol

III. Tested Cleaning Papers

Three different cleaning papers were chosen for this test (named A, B and C in the report). They were chosen because of their differences in base material composition and fiber structure. The three tested cleaning papers are presented below.

- A, with 40% polyester and 60% rayon, uni-directional fibers[7], 50g/m^2
- B, with polypropylene, multi-directional fibers, non-woven fabric[8], 40g/m^2
- C, with cellulose and polyester, mostly uni-directional fibers[9], 68g/m^2

Photos with no magnification of the three cleaning papers are given in figure 5, figure 6 and figure 7.

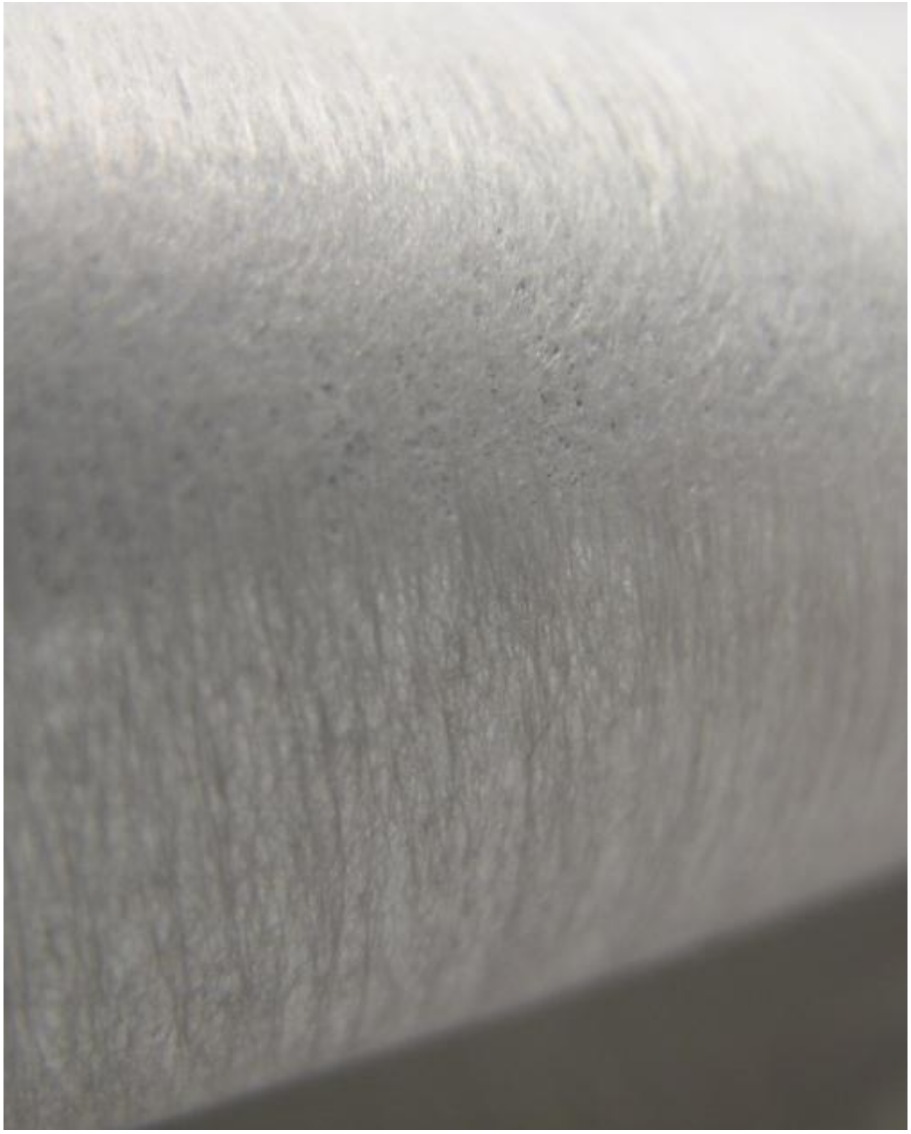

Figure 5 – Photo of cleaning paper A. Even surface with one predominant fiber direction.

As can be seen in figure 5, paper A has an even, very smooth and shiny surface and one predominant fiber direction. The fiber density defines the vacuum performance of the cleaning paper.

[7] Source: Data sheet from cleaning paper manufacturer.
[8] Ibid.
[9] Ibid.

Figure 6 – Photo of cleaning paper B. Wave formed surface because of regular imprints.

Cleaning paper B has a wave formed surface because of regular imprints.

Figure 7 – Photo of cleaning paper C. Even surface, darker “lines” with less material.

Cleaning paper C has an even, smooth surface and one dominant fiber direction. The fiber density is high and the cleaning paper gives a compact impression. There are “lines” with less material with regular intervals.

IV. Tests and Results

Below is a description of the tests, inspections and analyses that were performed on the three tested cleaning papers.

A. Fiber Structure

Small pieces of each cleaning paper were cut out and inspected using Scanning Electronic Microscopy (SEM)[10].

Cleaning paper A showed one dominant fiber direction and all fibers had about the same diameter. The fibers are often found in small bundles of 5-10 fibers, see figure 8.

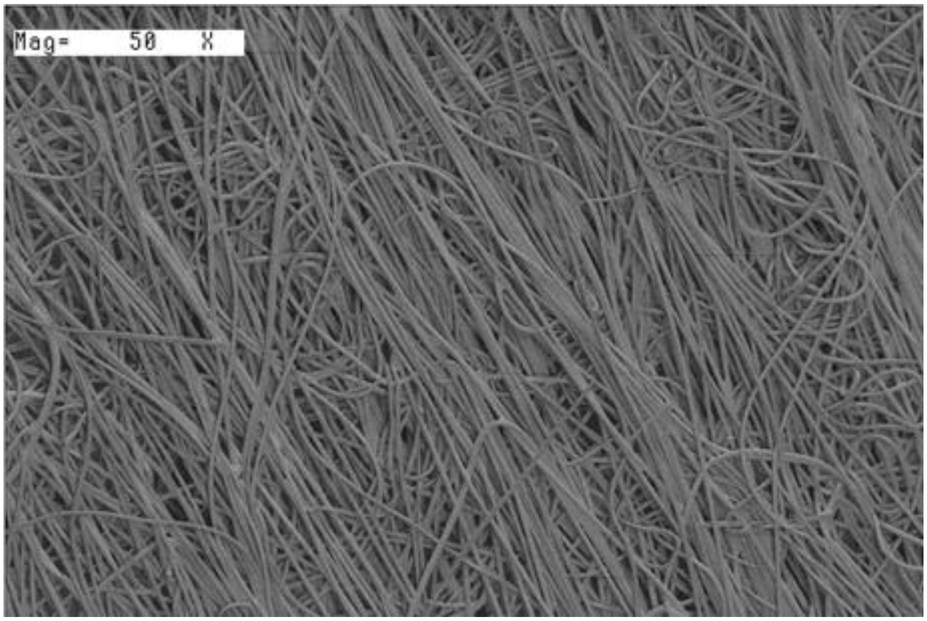

Figure 8 – SEM image of cleaning paper A. One fiber diameter and one dominant fiber direction.

For cleaning paper B, most of the fibers have about the same diameter, but some of the fibers have melted together during the imprint heating. The imprints have an area of about 0.5mm x 0.3mm and are situated at about 1mm distance from each other. Cleaning paper B does not have any dominant fiber direction, see figure 9.

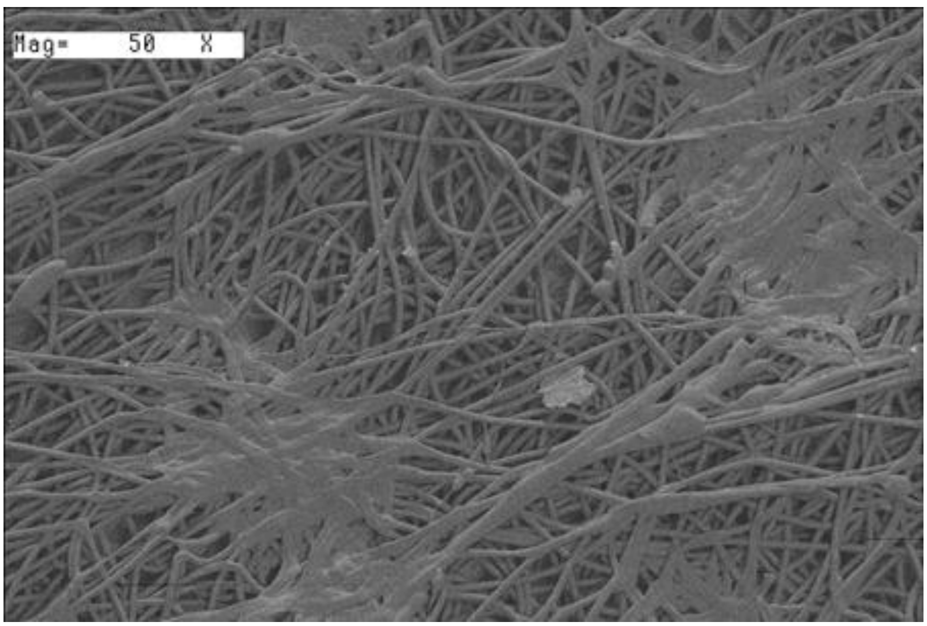

Figure 9 – SEM image of cleaning paper B. Imprints of melted fibers, no dominant fiber direction.

[10] All SEM analyses and SEM images in this document have been made by Kalevi Lehikoinen, Ericsson AB, Kumla, Sweden.

Cleaning paper C has two totally different types of fibers; cellulose and polyester. The cellulose fibers show a big variety of sizes and shapes, while the polyester fibers have the same round shape and diameter. There is one dominant fiber direction even though there are many fibers that do not follow this direction, see figure 10.

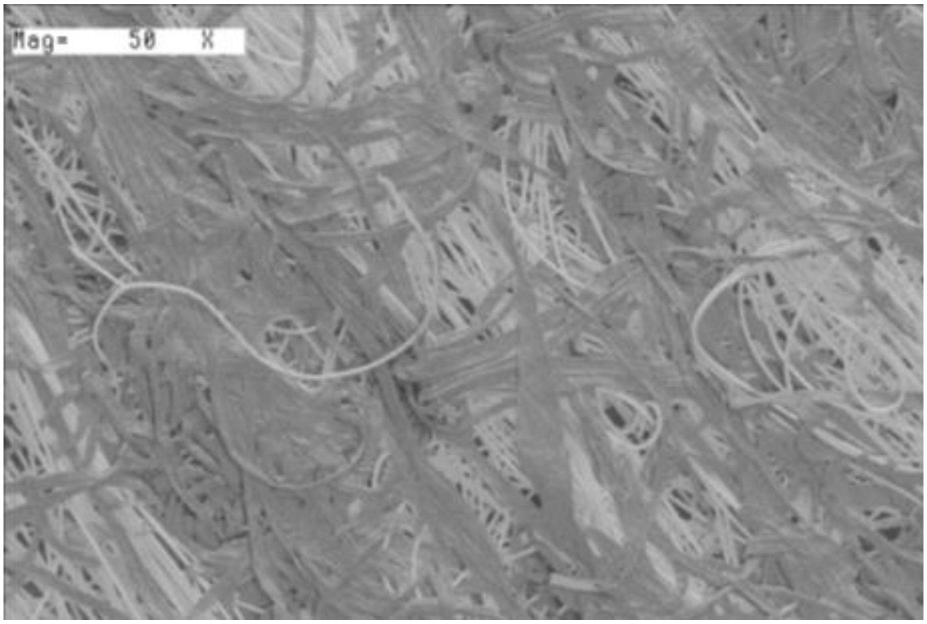

Figure 10 – SEM image of cleaning paper C. Different sizes and shapes of fibers.

The fiber forms, sizes and structures differ very much between the tested cleaning papers as do the materials of the fibers. How do these differences affect the cleaning performance?

B. Cleaning Results – Ordinary Production

All three cleaning papers were used during production of a "typical" PBA with standard pad sizes and component pitches. The smallest chip components on this board were 0402 and the smallest pitch 0.5mm. The stencil cleaning interval for this product was every 5th board and the cleaning cycle was Wet-Vacuum-Dry. Each of the three cleaning rolls was placed in the same screen printer, one at a time, and the stencil was inspected after ordinary automatic under stencil cleanings.

The results from these inspections were very good. No fluxes or solder particles were left on the bottom side of the stencil for any of the cleaning papers and it was not possible to see any differences regarding the amount of remaining solder paste in the apertures between the three cleaning papers.

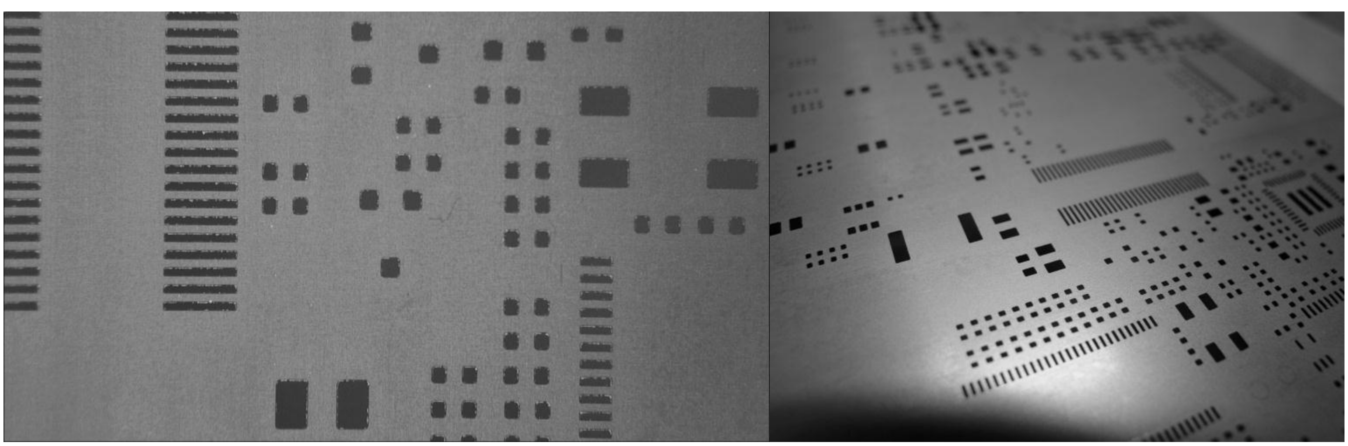

Figure 11 – Example of result after ordinary under stencil cleaning for one of the tested cleaning papers.

This comparison showed that for apertures not smaller than 0.53mm x 0.48mm (21mil x 19mil) on 0.127mm (5mil) thick stencils, moderately contaminated stencil bottom sides and normal cleaning intervals, all three cleaning papers work well.

C. Ability to Withstand Sharp Edge Rubbing without Leaving Lint

In order to find out how well the three different cleaning papers could withstand cleaning over sharp aperture edges without leaving lint on the stencil, a wear-out test was performed.

This wear-out test was made such that each of the cleaning papers was rubbed 10 times forward and backward over an area with sharp stencil apertures. The stencil apertures can be seen in figure 12.

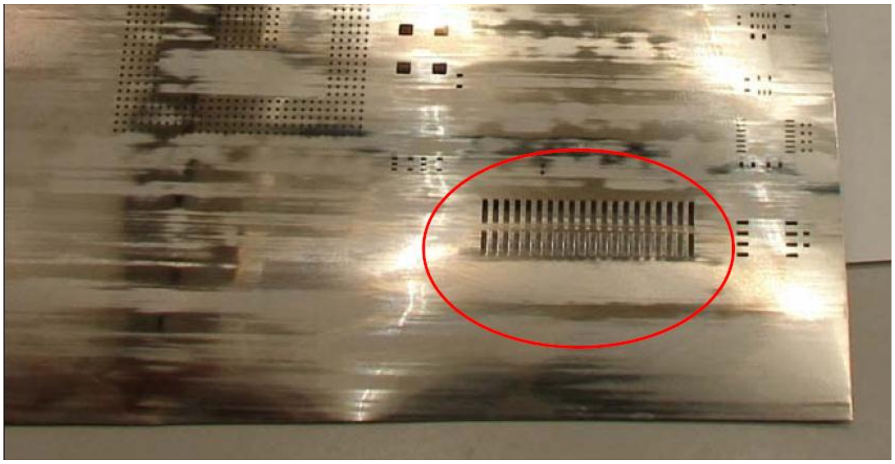

Figure 12 – Stencil apertures used for wear-out rubbing test.

After rubbing 10 times over the sharp apertures, parts of the cleaning papers were inspected in SEM and the results from this test can be seen in figure 13.

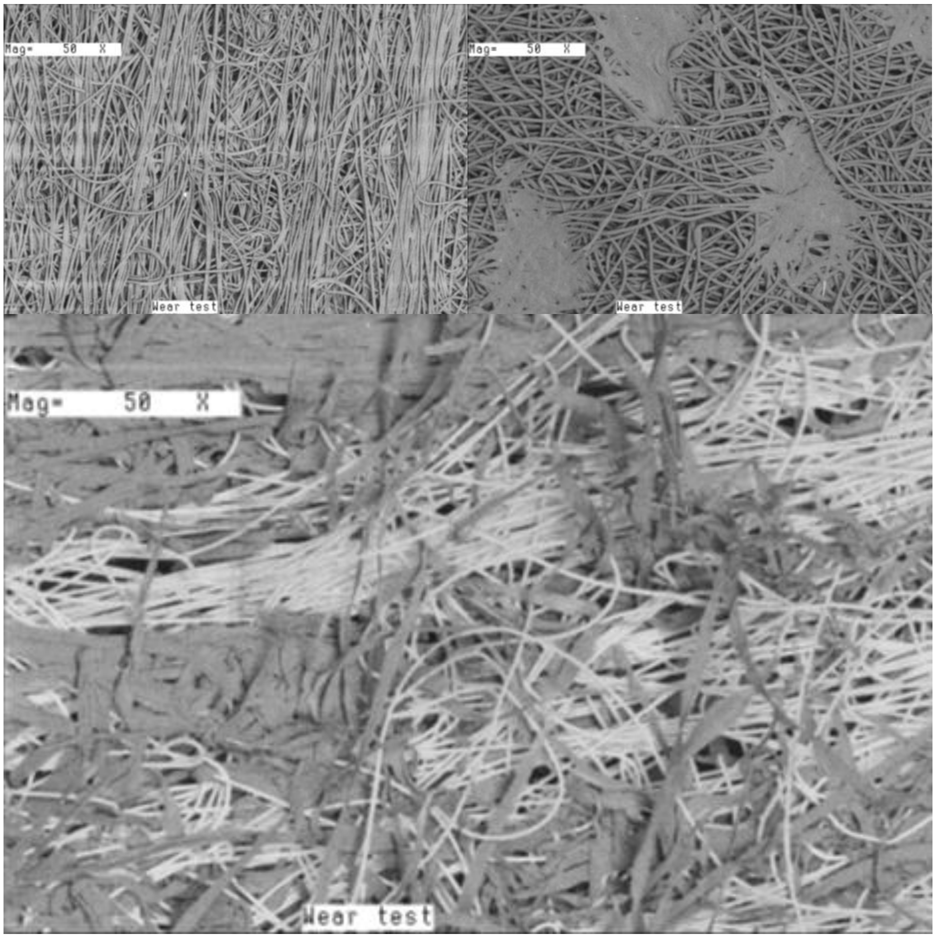

Figure 13 – Cleaning paper after wear-out test, A (upper left), B (upper right) and C (below).

Inspection of the stencil did not show any lint from any of the three tested cleaning papers. The SEM inspection discovered very limited fiber structure changes for the cleaning papers A and B, while cleaning paper C clearly had been affected by the rubbing. However, because no lint loosened from any of the cleaning papers, the results in this test are regarded as good.

D. Liquid Absorption Ability

In order to compare how liquid wets out and passes through the cleaning papers, a drop (~10µl) of the penetrant liquid Magnaflux SKL-SP1 was dripped on each of the cleaning papers. A white absorption paper had been placed below each cleaning paper in order to be able to find out how much of the liquid that leaks through.

The results from the liquid wetting test for cleaning paper A can be found in figure 14.

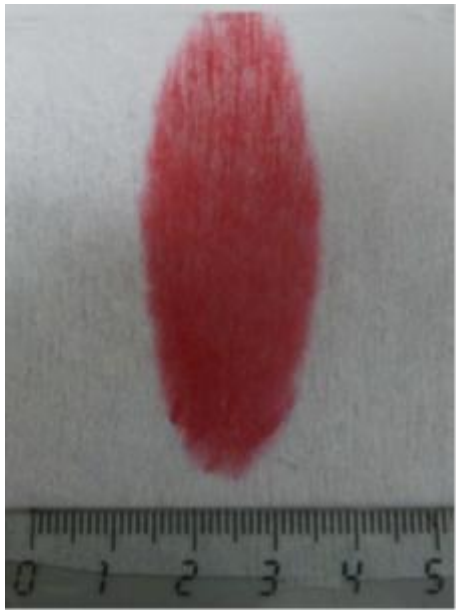

Figure 14 – Wetted area for cleaning paper A.

As can be seen in figure 14, the wetting of cleaning paper A follows the main fiber direction. The wetting has an elliptical shape with the length ~60mm and the width ~30mm.

The results from the liquid wetting test for cleaning paper B can be found in figure 15.

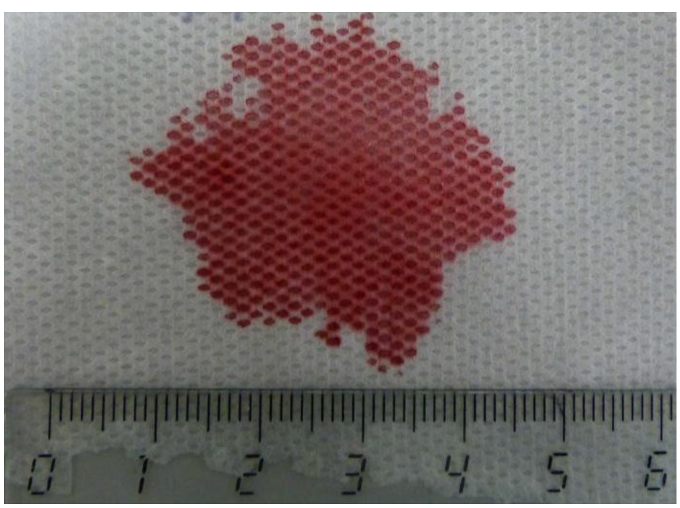

Figure 15 – Wetted area for cleaning paper B.

The wetting of cleaning paper B is the same in all directions and seems to go from one imprint to another. The “diameter” of the wetted area is about 30mm.

The results from the liquid wetting test for cleaning paper C can be found in figure 16.

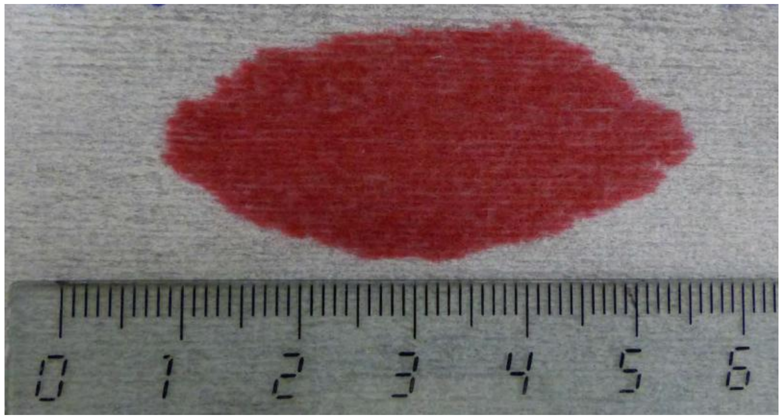

Figure 16 – Wetted area for cleaning paper C.

Cleaning paper C did also wet out along the main fiber direction. The wetted elliptical area has a length of about 45mm and a width of about 20mm.

The amount of penetration liquid that passes through the cleaning papers can be seen in figure 17.

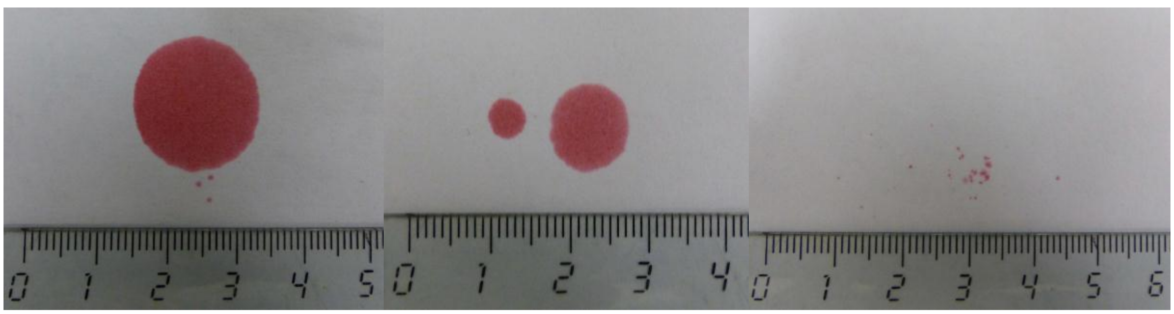

Figure 17 – Liquid that passes through the cleaning papers, A (left), B (middle) and C (right)

As can be seen in figure 17, cleaning paper C did nearly absorb all added liquid, while cleaning paper A left a circle-shaped dot with about 18mm diameter. Through cleaning paper B, liquid leaked that formed two (!) small circles with the diameters 4mm and 9mm.

It is difficult to tell the “optimum” wetting area and the amount of liquid that could pass through the cleaning papers in this test. However, it is necessary to know how each cleaning paper behaves in order to optimize the cleaning process parameters. It is also generally regarded as preferable if the cleaning agent stays on the fiber surfaces instead of being absorbed by the fibers. This makes it easier to transfer the cleaning agent to the stencil in order to dissolve the solder paste flux.

D.1 - Literature study – Liquid Absorption of Cellulose, Polypropylene and Rayon Fibers

A literature study was performed in order to try to understand the different liquid absorption behaviors of the tested cleaning papers.

Tests and theoretical analyses have shown that polypropylene does not absorb water into the fibers. The water is instead trapped in voids between different layers of polypropylene tape or between the fibers in polypropylene fabrics [4].

Cellulose, on the other hand, has very poor resistance to water absorption and water-saturated cellulose fibers swell and show a great loss in mechanical properties compared to dry samples [5].

The generated cellulose fiber rayon is also highly absorbent [6] and has the lowest elastic recovery of any fiber when wet [8].

The information above gives some understanding of why the tested cleaning papers behave so differently in the liquid absorption test.

E. Cleaning of Heavy Contaminated Surfaces

The cleaning papers' abilities to remove wet solder paste on stencils during automatic under stencil cleaning were compared by letting them clean a heavy contaminated stencil surface. The heavy contamination was achieved by printing solder paste on an area with no apertures on a bottom side of a stencil, see figure 18.

Figure 18 – Manual screenprinting of solder paste on bottom side of stencil

A 0.127mm (5mil) thick stencil with 42 square apertures with the size 3mm x 3mm were used in this test. The result from this manual screenprinting of solder paste is shown in figure 19.

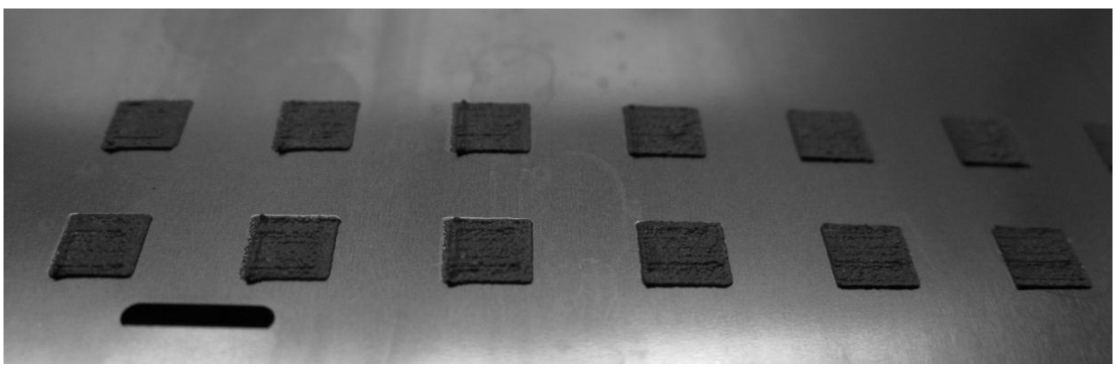

Figure 19 – Result from manual screenprinting of solder paste on bottom side of stencil.

After the manual printing of solder paste on a stencil bottom side with no apertures, the contaminated stencil was cleaned in a DEK Horizon 01i screenprinter with the following cleaning settings, see table 1.

Table 1 – Cleaning settings in screenprinter during test.

Cleaning agent	Dry clean speed	Wet clean speed	Vacuum clean speed	Advance of Cleaning Paper			
				During run	Before wet	Before dry	Before vacuum
DEK Pro XF	30mm/s	100mm/s	50mm/s	4mm	20mm	20mm	20mm

The boards were cleaned 10 times with the cleaning cycle Wet-Vacuum-Dry (osc[11]). The stencil was inspected after each cleaning cycle and the test was repeated once for each cleaning paper.

[11] osc = fast oscillation in x-y plane by the cleaning head during a cleaning stroke. In this test, oscillation was only used during the dry cleaning stroke.

The results after the first cleaning cycle are shown in figure 20.

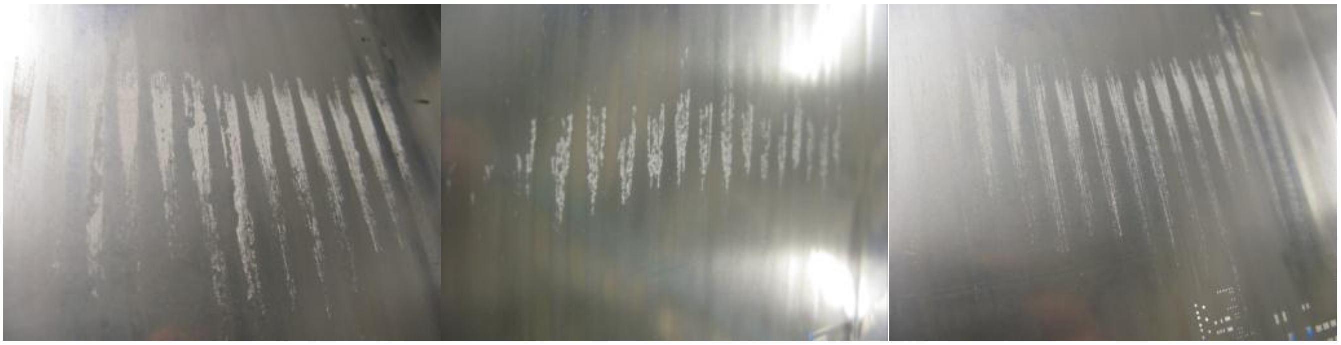

Figure 20 – Remaining solder paste after the first cleaning cycle, A (left), B (middle) and C (right).

As can be seen in figure 20, the solder paste was spread out equally (40-70mm lengths, very thin layer) after being cleaned once with the cleaning papers A and C. The length of the thin layer of remaining solder paste after the first cleaning cycle was about 25-30mm for cleaning paper B.

Photos after 10 cleaning cycles, at the end of the test, are given in figure 21.

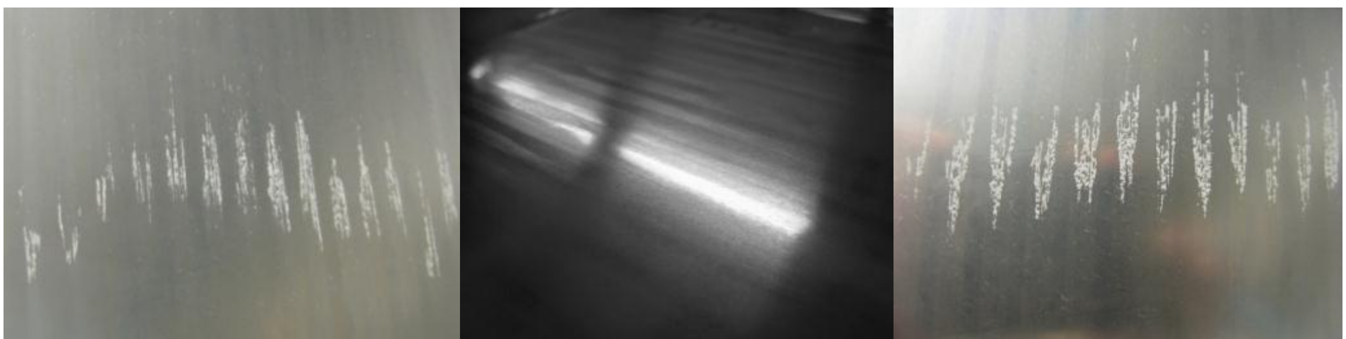

Figure 21 – Remaining solder paste after the 10th cleaning cycle, A (left), B (middle) and C (right).

The remaining solder paste after 10 Wet-Vacuum-Dry (osc) cleaning cycles was shown to be about the same for the cleaning papers A and C. The length of the thin layer of solder paste was about 25-30mm for both these cleaning papers. For cleaning paper B, the solder paste was nearly removed already after five cleaning cycles and no soldering particles or flux at all remained after 10 cycles.

Cleaning paper B clearly outperformed the cleaning papers A and C, that were judged as equal, in this cleaning of heavy contaminated surface test.

F. Evaluation of Where the Solder Particles are Entrapped

After the heavy contaminated cleaning described in the previous chapter, parts of the cleaning papers were cut out and inspected in order to find out where the solder particles had ended up.

SEM images of entrapped solder particles in the three tested cleaning papers are shown in figure 22, figure 23 and figure 24.

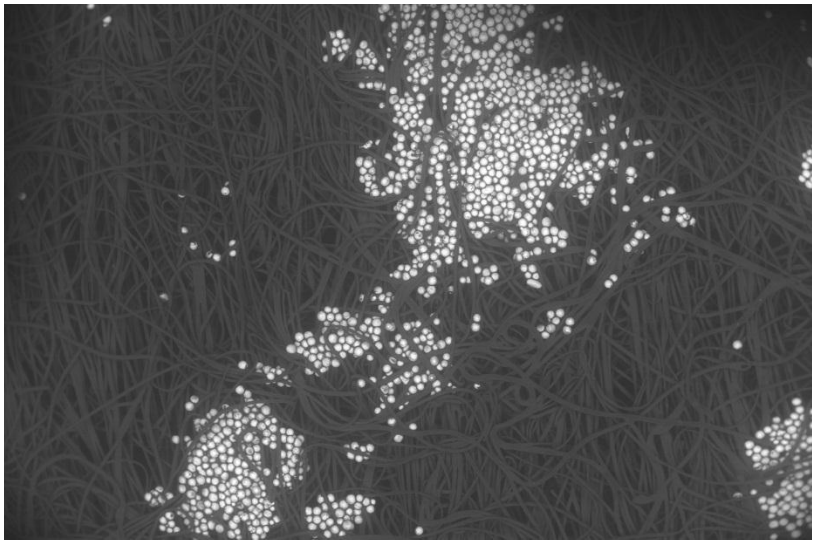

Figure 22 – Cleaning paper A, entrapped solder particles.

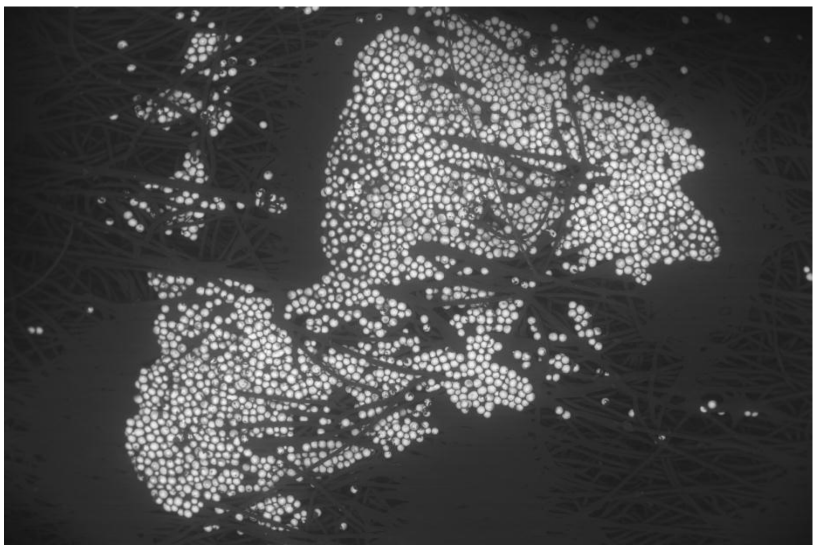

Figure 23 – Cleaning paper B, entrapped solder particles.

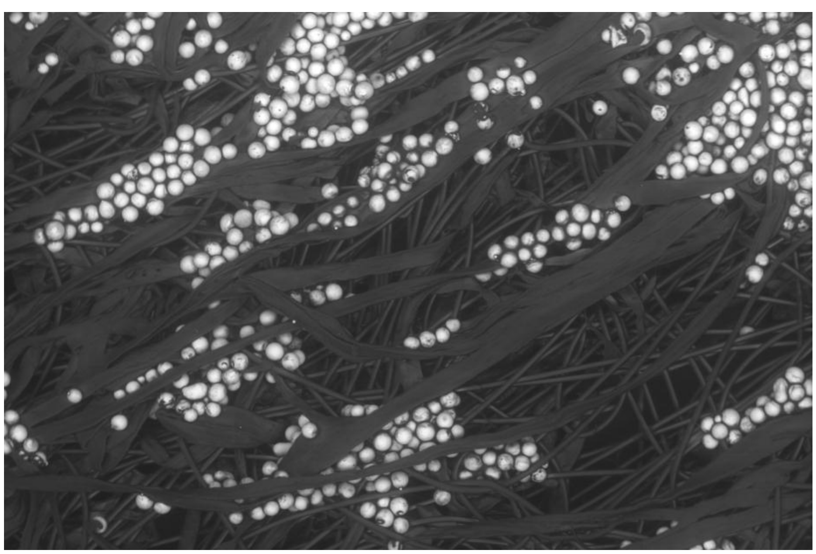

Figure 24 – Cleaning paper C, entrapped solder particles.

The pictures above show that most of the solder particles in these extremely contaminated cleaning papers end up into coherent groups on the cleaning papers' surfaces. However, many of the single particle, or smaller groups of particles, find their way in between the fibers and by doing this, the risk that they are being released during the cleaning process decreases. This is a likely behavior during cleaning of less contaminated stencils.

The three cleaning papers have similar behavior regarding entrapment of solder particles with the exemption that cleaning paper B can catch an extra amount of solder particles in its imprints and that the solder particles need to find ways around the big and flat cellulose fibers in cleaning paper C.

G. Vacuum Cleaning Ability of Solder Paste in Small Apertures

In order to find out how well the cleaning papers work in the vacuum cleaning process, a vacuum cleaning test of small apertures, intended for 01005 chip components, was performed.

The screenprinter, stencil and solder paste used in the test are shown in table 2.

Table 2 – Machines and materials for vacuum cleaning test.

Screen printer	Cleaning agent	Stencil material	Technology	Stencil thickness	Aperture size	Solder paste
DEK Horizon 01i (2009)	DEK Pro XF	Stainless Steel	Laser cut	0.1mm (4mil)	0.22mm (8.5mil) square	Senju M705-GRN360-MZ-5, Type 4

The apertures were completely filled with solder paste by manual printing from the stencil's top-side and gentle removal of the surplus solder paste on the stencil's bottom side, see figure 25.

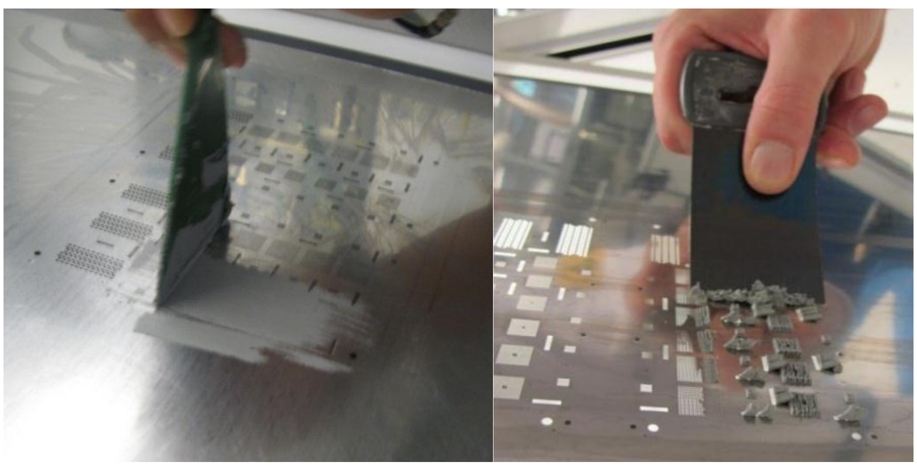

Figure 25 – Filling of small apertures prior to vacuum cleaning test.

One example of the result from the complete filling of the small apertures intended for 01005 chip components is given in figure 26.

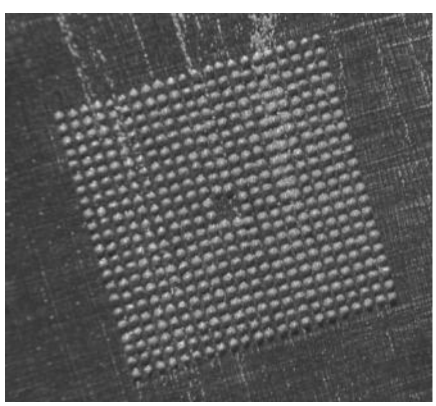

Figure 26 – 100% filled apertures for vacuum cleaning test (one site intended for 240 pcs of 01005 chip).

After having filled four sites, each with 480 apertures, with solder paste and controlled that all apertures were completely filled, one Wet-Vacuum-Vacuum-Vacuum cleaning cycle was performed and after this, the stencil was inspected. This procedure was repeated once for each cleaning paper.

The result for cleaning paper A is given in figure 27.

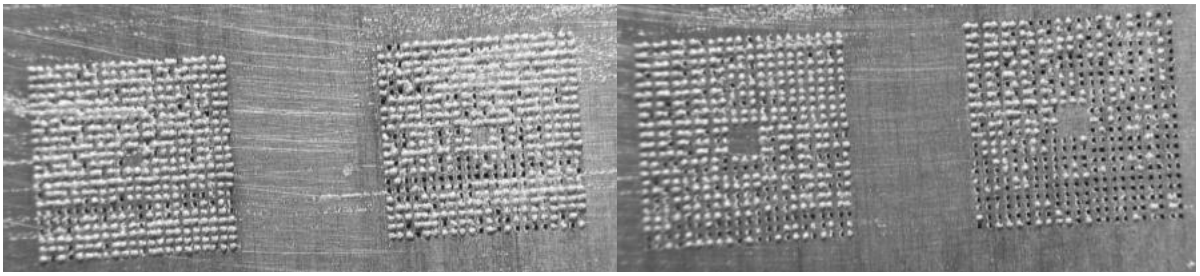

Figure 27 – Vacuum cleaning results for cleaning paper A.

The result for cleaning paper B is given in figure 28.

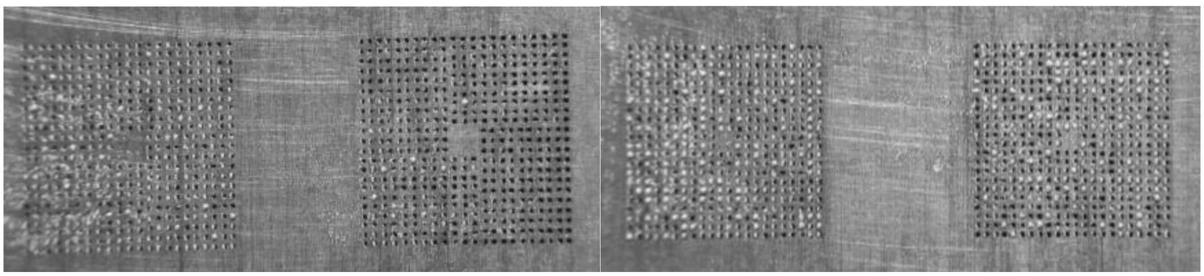

Figure 28 – Vacuum cleaning results for cleaning paper B.

The result for cleaning paper C is given in figure 29.

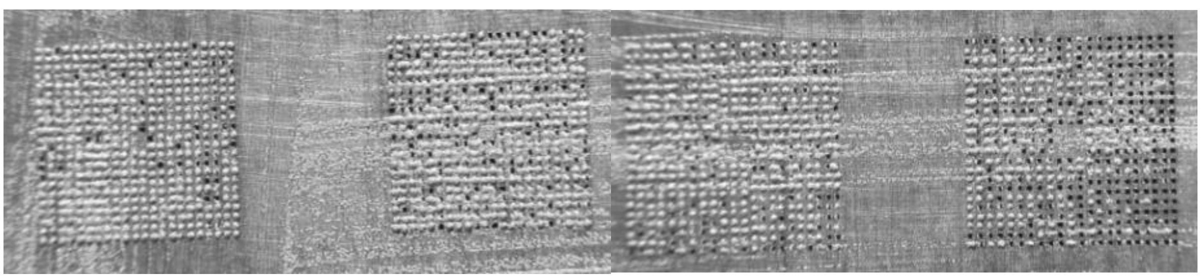

Figure 29 – Vacuum cleaning results for cleaning paper C.

Even though the results are rather uneven, it is very clear that cleaning paper B provides the best conditions for vacuum cleaning of small apertures of the three tested cleaning papers. Cleaning paper A and C do not perform as well as B and are considered as being equal in this test[12].

V. Conclusion/Summary

This comparison of three different under stencil cleaning papers clearly shows that there are big differences in fiber materials, fiber structures and fiber densities between the tested cleaning papers and that these differences significantly affect the cleaning performance.

Cleaning paper B performs best in this comparison. This cleaning paper has a fiber material that does not absorb any liquid which prevent the fibers from swelling and to change mechanical properties. The random fiber structure in combination with the slightly rough surface makes it good at removing solder paste from stencil surfaces. There is also sufficient space between the fibers to ensure a good vacuum performance.

[12] Please note the solder paste smearing on the stencil surface, especially after cleaning with cleaning paper C.

The smooth and shiny surface of cleaning paper A with its uni-directional fiber structure gives less friction towards the stencil than cleaning paper B and it is therefore more difficult to efficiently remove solder particles and flux from stencils' bottom sides. The fiber density in cleaning paper A is also higher than for cleaning paper B, which makes vacuum cleaning more difficult.

The cellulose fibers in cleaning paper C absorb much cleaning liquid, swell and weaken its mechanical properties. The thickness of the cleaning paper and the high fiber density in combination with the flat cellulose fibers make it difficult to vacuum clean small apertures. The even and smooth surface with one dominant fiber direction of cleaning paper C makes it more difficult to remove solder particles and flux from stencil surfaces compared to cleaning paper B.

For cleaning of stencils that have been contaminated in ordinary production with apertures intended for 0402 chip and 0.5mm pitch CSPs[13], QFPs[14], QFNs[15] and bigger, all tested cleaning papers work well, but it is likely that the cleaning intervals could be prolonged by using cleaning paper B compared to A or C. For cleaning of stencils with apertures intended for e.g. 01005 chip or 0.3mm pitch CSPs, the choice of cleaning paper B will mean a great advantage for the cleaning and thereby the print quality results.

This study shows that it is very important to evaluate under stencils cleaning papers in a controlled way in order to find the most suitable product. Appropriate tests to be performed in the evaluation are, as well, suggested.

VI. References

[1] IPC-7525B, Stencil Design Guidelines

[2] IPC-7526, Stencil and Misprinted Board Handbook

[3] IPC-7527, Requirements for Solder Paste Printing

[4] The water absorption behaviour of all-polypropylene composites and its effects on mechanical properties, 2009, H Deng, C.T. Reynolds, N.O. Cabrera, N-M Barkoula, B Alcock, Queen Mary University of London, Great Britain and T Peijs, Eindhoven University, the Netherlands

[5] Comparison of water absorption in natural cellulosic fibres from wood and oneyear crops in polypropylene composites and its influence on their mechanical properties, 2004, Ana Espert, Fransisco Vilaplana, Sigbritt Karlsson, Department of Fibre and Polymer Technology, Royal Institute of Technology, Sweden

[6] Textiles (9th ed), 2001, Sara J Kadolph and Anna L Langford, Prentice Hall

[7] Classification & Analysis of Textiles - A Handbook, 2003, Karen L LaBat and Carol J Salusso, University of Minnesota

VII. Acknowledgement

The author would like to thank the following colleagues that have contributed to the development of the methods, performed tests and reviewed the article:

Ericsson AB, Katrineholm: Sofie Johansson, Bilgehan Simsek, Byron Meza
Ericsson AB, Kumla: Leena Korhonen, Kalevi Lehikoinen
Ericsson AB, Kista: Anne-Kathrine Knoph, Benny Gustafson

---

[13] CSP = Chip Scale Package
[14] QFP = Quad Flat Package
[15] QFN = Quad Flat No-lead