REPORT ON FIELD TESTS OF A DEVELOPMENTAL FABRIC TECHNOLOGY FOR CLEANING FINE-PITCH STENCILS

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ABSTRACT

A key step in the manufacturing of electronic circuit boards is understencil wiping, which removes excess solder paste from a stencil and prepares the stencil for the next printing cycle. Neither this process nor the stencil wipes used in it have significantly changed since the introduction of high-speed stencil printers in the early 1990s. As a result, costly stencil rolls have been an important aspect of a production process since their introduction.

In 2001, DuPont began a detailed study of the process and requirements for improving fine-pitch stencil cleaning. This research has proven that today's stencil rolls wipes deliver inadequate cleaning in fine-pitch applications. A large number of alternative materials were tested as replacement stencil rolls. A new standardize test to track fabric cleaning performance was designed and the methodology validated. Based upon these tests, a new stencil wiping fabric was found superior to existing stencil wipes. The new fabric was subjected to a lengthy series of field trials at facilities across the U.S., Europe and Mexico. Quantified results were obtained for analysis.

The result of these tests, on nearly 5,000 PCBs, confirms the hypothesis that improvements to the stencil wiping process are available which can significantly enhance product quality as measured by production yield while reducing production costs.

Keywords: stencil printing, solder paste printing, lead-free solder paste, fine-pitch surface mount processes

BACKGROUND

Since they were first introduced into the market in 1986, surface mount electronics have come to dominate the electronic assembly process world-wide. With over forty market segments, experts judge that total value of the electronics assembly industry was $648 billion in 2003 and will grow to $875 billion in 2008.[1] The vast majority of this huge output is in the form of surface-mount circuit boards.

The manufacture of surface mount PCBs requires stencils and stencil printers, and wipes to clean the solder paste off the stencils. There are a number of stencil wiping materials on the market today which can be generally summarized into three classes. The first group includes hydroentangled polyester-cellulose papers that do not contain any glues or binders. The second group contains less expensive polyester-cellulose materials which are made with binders. Lastly, a small number of stencil printers specify hard, thin polyester and/or polyester-rayon papers.

However, the electronics industry is rapidly pushing the limits of these stencil papers. First, the evolution of "fine-pitch" components adds a significant increase in complexity. The deposition of solder paste on fine-pitch boards is substantially more difficult and error-prone in a fine-pitch environment than when using older-style "fat" pitch surface mount boards. Another destabilizing innovation is the introduction of lead-free solder paste. Due to differences in viscosity and surface tension, no-lead solder paste requires greater precision in the printing process and the stencils are more difficult to wipe clean. A third major factor is the continuing downward pressure on costs, as operators continually seek new technologies that can pull costs out of the manufacturing process.

CONCEPTS

DuPont is one of the industry's largest providers of stencil-printing fabric on a world-wide basis. With a two-hundred year track record of innovation (the company has more than 18,000 active patents[2]) DuPont has an on-going program of monitoring markets and searching for opportunities for improvement. In 2000, the Contamination Control division developed an awareness that at least some of the production problems with fine-pitch electronics might be ameliorated by improvements in the stencil rolls.

This is not an intuitive discovery. The SMT production process is extremely complex. Some industry experts find a minimum of 39 process variables that must be controlled in stencil printing[3] and more than 200 in the entire SMT manufacturing process. It is clear, however, that the solder-paste printing process is the backbone of the assembly process. Process experts estimate that more than 50 percent of all surface mount manufacturing defects are caused by errors in the screen printing process.[4, 5] Informal discussions with other experts (who refuse to be quoted) push the actual number closer to 90%.

Oddly, the stencil paper itself is rarely regarded as a root cause of production problems. The more common tendency seems to be a focus on the type, quality and layout of the stencil itself. Other troubleshooting issues are improvements to the solder paste and elimination of irregularities in components packaging (i.e., coplanarity).[6] In one complex study on stencil printer optimization, ten different parameters were tested[7] but not one of the investigated parameters involved changing the stencil wiping paper. A typical report, documenting improved processes for wafer-bumping, simply summarized the situation with “Understencil wiping using lint-free cloths… is advised.”[8]

In fact, a lengthy review of 349 technical papers published since 1994 found not one author suggesting fault might be found with the stencil wiping paper. Similar results have been observed during field trials of stencil wiping rolls. The authors personally have observed experienced process engineers reconfigure and re-engineer processes to eliminate stencil printing problems, an completely overlook any issues with the stencil roll paper. Like death and taxes, stencil paper seems to be a given. But it does not need to be so.

DEVELOPMENT

The search for a new fiber for stencil wiping is made more complex by the nonwoven manufacturing process, the sensitivity of the application to any form of residues, the stringent requirements for absorbency and the continuous demand for cost-effectiveness.

The objective of nonwoven technology is to produce a hybrid material: a substance with the strength, softness, and quality of a woven textile, but produced at the volumes, speeds and low costs of a paper. This is not an easy transition to make because there are major differences between paper fibers and textile fibers.

The fibers used to make paper traditionally are short, fine and easily react chemically with additives whereas cloth fibers tend to be large, long and chemically inert. The long, thick fibers of textiles leads to weaving and knitting manufacturing processes which give textiles their characteristic loose structure and stretch (“extensibility”). This contrasts to paper manufacturing processes in which the fibers overlap randomly and densely. This is why most papers are hard, stiff, smooth, dense and inextensible (without stretch) while most fabrics are soft, flexible, light and stretchy.

Most nonwoven materials use at least some natural fibers and many use some form of wood pulp because of its low cost, ease of use and chemical reactivity. Synthetic fibers offer more exotic capabilities since they can be longer, stronger, more uniform, and less compatible with water than natural fibers.

Some nonwoven materials use binders (glues) to hold the fibers in place. As measured by weight, binders can amount to 30% of some nonwoven products. The most common binder used in nonwoven fabric is a water-based "latex" emulsion, typically polyacrylate. Binders usually result in stiffer structures with little or no wet strength. Most of these binders are solvent-soluble and will begin to dissolve when exposed to the solvent carriers used in solder paste. For these reasons materials made with binders will not perform at an acceptable level in fine-pitch SMT applications.

Despite these limitations, a detailed search of opportunities produced a short-list of different fibers that had some potential as a replacement stencil wiping paper. These samples were procured from two main sources: companies which make fibers and wished to have their products considered as candidates, and different stencil roll fabrics plucked straight from the factories of electronics manufacturers that were using them. The typical sample was usually about five square meters of material. Pre-screening confirmed all of these candidate fabrics could be available in sufficient quantities, of sufficient quality, and at appropriate costs, to be a reasonable candidate as a stencil roll.

OPTIMIZATION OF FABRIC CHARACTERISTICS

There are four key parameters which define a typical high-performance wipe. These are (a) the raw tensile strength of the material, especially when wet, (b) the extractables which the paper might leave as residues, (c) the ability of the material to absorb contamination, and (d) the speed with which it absorbs the contamination. However, the trusted measurements of the first two of these parameters fail as accurate predictors of stencil wiping performance because of the microscopic nature of stencil wiping.

First, tensile strength reflects the dry, aggregate strength of the fabric. This is a vitally important characteristic. One of us (Abbett) has actually seen have seen cheap resin-bonded paper tear inside a stencil printing machine during use. Stronger paper will produce cleaner stencils.

But there is a subtle nuance to stencil wiping that is ignored by the standardized test. The measurement of tensile strength misses the fact that stencil wiping is performed microscopically, by each individual fiber. Laser-etched stencils have tiny, razor-sharp edges around the apertures. Microphotographs of stencils show these edges shredding individual fibers of a wipe and rolling the fibers into the solder paste while, at a macroscopic level, the overall wipe appears to be unaffected. So the optimal stencil wiping specification would be not just for a stronger fabric but for a stronger fiber ***inside*** a soft, absorptive fabric.

Another error is the measurement of absorption. Absorption is extremely important in stencil wipes. Most solder pastes use alcohol as a carrier for the paste. In addition, many users add other solvents to the cleaning process ("wiping wet"). So a superior stencil wipe needs to be highly absorbent.

But there is another issue. The standardized test method for measuring absorbency is ASTM D6651-01 which measures performance using different solvents. There was no data on the ability of the wiping materials to pick up and hold solder paste which is, of course, a granular solid and not a liquid. Considering this crucial parameter was suspect, a new, simple but standardized testing protocol for solder paste pick-up was devised. All prospective stencil wiping materials were subjected to the test.

To conduct the test, a series of brass test coupons were assembled. A test target roughly the size of a U.S. five-cent coin was inscribed on each brass coupon and before each test each coupon was cleaned with isopropyl alcohol. Each brass coupon was weighed on an analytical balance. After warming the solder paste to room temperature, the paste was spread evenly across the target zone using a spatula. The contaminated specification was arbitrarily defined as 0.25 g +/- 0.025 of solder paste (Figure 1a). The soiled coupon then was placed in a Gardner Abrasion Testing system (Figure 1b) such that it was held in place in center of scrub zone. The coupon was now ready.

To prepare the fabric for testing, a sample of the test fabric is wrapped around the small mounting device that fits into the abrasion machine. It is essential the fabric surface be flat and smooth, and free of wrinkles, visible lint or fibers. The mounting device is inserted onto the Gardner system, which is the silver rectangle in the center of the machine. The system automatically scrubs the brass test coupon for the desired number of cycles. When completed, the test coupon is removed and weighed. The result of the test is reported as a percentage of soil removed from the coupon.

The validation of the new test was conducted in various permutations. First, there were calibrating tests using known fabrics. Then a series of tests were performed varying the number of Gardner wiping cycles. Other tests were performed on different types of solder pastes. Still another series tested known papers dampened with solvent compared to cleaning without solvent. Once a standardized process was defined with reproducible results, finally all of the different new fabrics were tested.

Typical results are presented in Figure 2. The technical specifications and solder paste pick-up performance of two popular stencil wiping materials and the newly-developed material are compared in Table 1. The first three are the most commonly used stencil wiping fabrics on the market today; the fourth is the newly-developed material. The authors conclude there is substantial variation in the ability of different fabrics to remove solder paste, and some of the materials in use today are far from optimal.

Figures 1a and 1b

BRASS TEST COUPON SHOWING SOLDER PASTE SAMPLE (LEFT) AND GARDNER ABRASION TESTER (RIGHT)

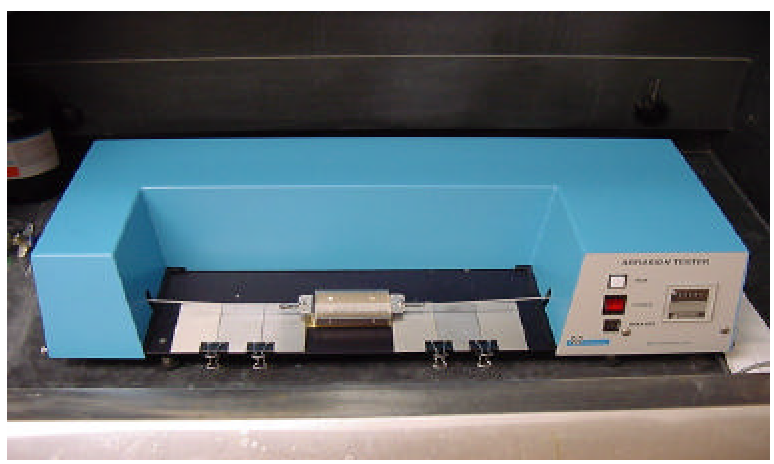
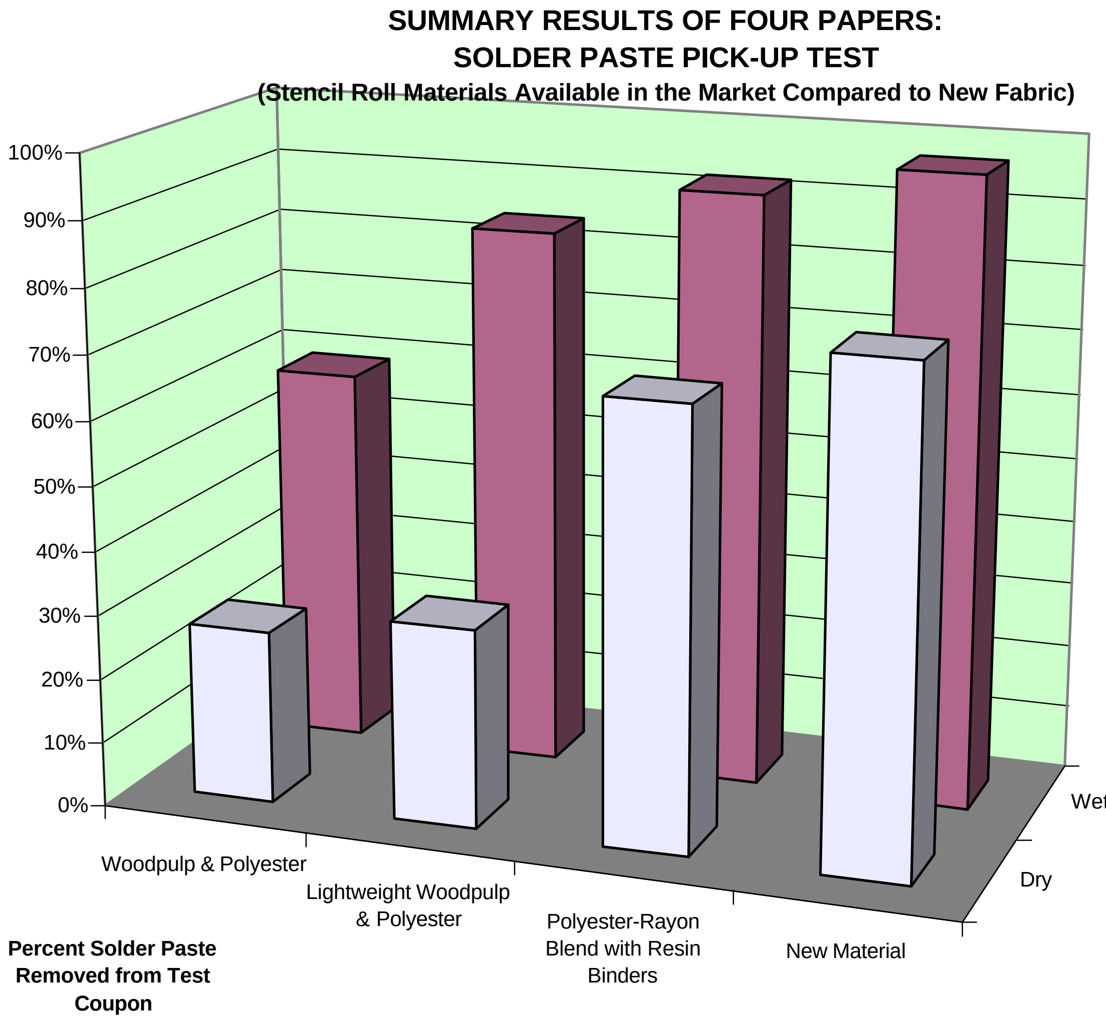


FIGURE 2



The new material is a hydroentangled, single fiber nonwoven fabric. Based on regenerated cellulose, the long, hard fibers are consistent and homogenous. When assembled into flat sheets, such as would be used to clean stencils, the material is softer, almost fluffy, in comparison to existing stencil roll materials. This open structure results in a fabric which is highly absorptive and scores very well on the solder paste pick-up test for non-liquid contamination.

FIELD TESTING FOCUSED ON YIELD ENHANCEMENT

Once a fabric was selected based on lab tests and manufacturability (which uses proprietary information not included here) a number of stencil rolls were prepared and field trials were conducted. More than 1,000 stencil rolls were consumed over two years in trials at seven large OEMs and subcontractors in North America and Europe.

One aspect of the new paper that showed great promise was the opportunity for a significant improvement in production yields. It is self-evident that the application of more solder paste on to the bare board will result in stronger solder joints and more reliable electronics. Partially- or completely-clogged apertures are the primary cause of insufficient solder paste. Improved cleaning of the stencil, it was hypothesized, should result in more solder paste on the boards and resultant increase in yields. [9]

This was explored during one of the preliminary field tests of the new fabric. Unable to directly and quickly measure the volume of solder paste deposited on the board, the average height of solder paste deposited on the solder pads (3-D measurement) was used as a surrogate in lieu of the more precise measurement of the solder paste transfer. At a large North American subcontractor, it was found that average height of solder paste deposited on the solder pads was

6.72% higher than with traditional stencils rolls. Figure 4 shows a summary of some of the comparative data.

Based on these findings, a longer test was conducted. Using an MPM Ultraflex 3000 stencil printer, the test fabric replaced a stencil roll made of rayon-and-polyester with resin binders. The solder paste was AIM NC251 "No Clean" material. The stencils were wiped wet using Multicore SC01 solvent. The test ran for two full shifts. Five different stencils, with apertures down to nine mils, on four different circuit board designs were tracked. Printing process quality were tracked using samples of the production boards measured with a 3-D inspection system outside the printer. The objective of the test was to measure the consistency of the printing process.

Figure 5 highlights some of the solder paste height results. The results are noteworthy, especially within a single board/stencil mix. All of the sampled boards exceeded the solder paste height specification. In addition, the variation around the average height of the solder paste was reduced (data not shown here). Importantly, follow-on visual inspection of the boards indicated no fibers, random solder balls or flux residues, further documenting the improvement in quality.

Finally, the test customer agreed to a long-term trial of high-speed production processes. The new fabric was placed in service on five SMT lines, using Indium 92J no-clean solder paste. All of the production was dedicated to the production of the same circuit board, and detailed comparative data was assembled. The abbreviated findings are shown in Figure 6. Yields, based on functional test results, improved using the new material, with only 59 defects found on in a production run of 2,095 boards, versus 216 defects found in a production run of 2,097 boards. This suggests that the new material will improve yields in the range of 1.7%-3.7%, based on a 95% confidence level. Because of this improvement in consistency and reliability, this subcontractor has implemented the use of the new paper on their fine-pitch boards.

CONCLUSIONS

This research has been able to confirm a number of important developments. In general, through the use of basic testing and analytical techniques, a new wipe fabric was developed that offered superior performance in laboratory tests and also demonstrated improved process yields in prolonged field trials. Related findings include:

(a) There are significant differences in the characteristics of stencil printer wiping papers, leading to substantial differences (for better or worse) in yields off the stencil printer.

(b) Current stencil wiping fabrics may be sub-optimal on the newer, denser, fine-pitch stencil designs.

(c) The new wipe, based on regenerated cellulose and developed using lab simulations of solder paste removal performance, made a statistically significant improvement in yield during field trials.

Table 1

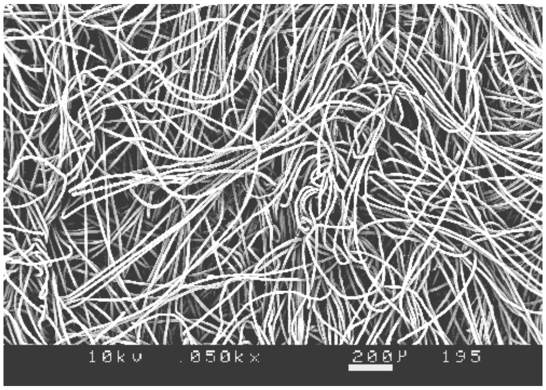
COMPARISON OF THREE CANDIDATE STENCIL ROLL FABRICS
(Dry Wiping Data Only Shown Here)

	New Paper (Developmental Specs) (See Fig. 3a)	Typical Nonwoven Paper (Actual) (See Fig. 3b)	An Example of Rayon & Polyester Paper with Glues (Actual) (See Fig. 3c)
Basis wt. (oz/yd^2)	1.87	1.56	1.11
Tensile Strength (lbs)	29	31	16
Thickness (mils)	15	12	11
Absorption (mL H_20/m^2):	3,910	2,900	2,064
Fiber Shedding (Particles >0.5 mm/m^2, $x10^3$)	127	1,130	50
Extractables IPA % (Total Burden)	0.20	0.07	0.98
Extractables H_2O % (Total Burden)	0.22	0.06	0.95
Solder Paste Pick-up	77%	61%	33%

Figure 3

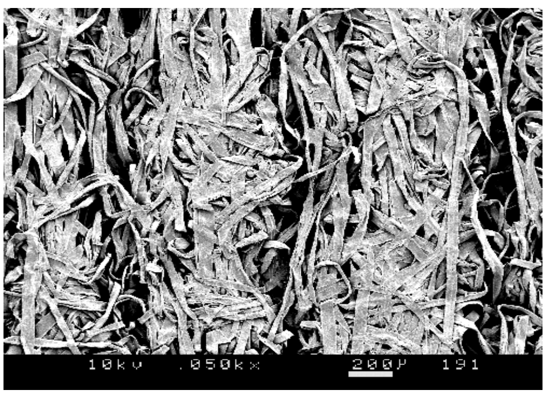
MICROPHOTOGRAPHS OF REPRESENTATIVE STENCIL WIPING FABRICS

Figure 3a



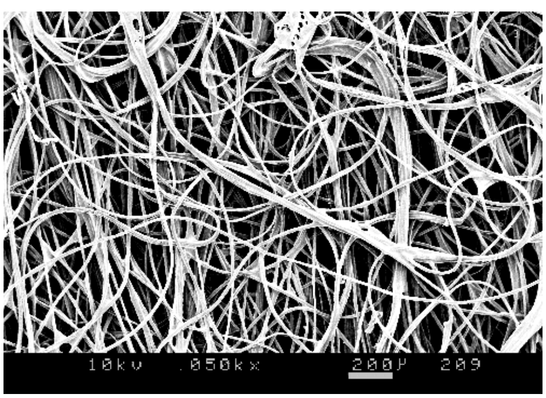
New stencil roll fabric has smooth, long, hard fibers. There is significant open space in the material to pick up and hold non-soluble contamination such as solder paste.

Figure 3b



Traditional stencil fabric is a two-layer hybrid material. A lower layer of polyester (not shown) is topped by absorptive fibers of cellulose. The polyester provides strength, while the cellulose enhances absorption. There is adequate open space in the material to hold solder paste, but the fragile cellulose fibers shred easily onto the stencil.

Figure 3c



A thin, hard stencil wiping fabric made from polyester and rayon, and bound together with glues. Open space is minimized by the glue that fills many voids. These glues can be extracted and the paper weakened by the solder paste carriers, and then can be deposited on the stencil, contaminating subsequent boards and boosting reject rates.

Figure 4

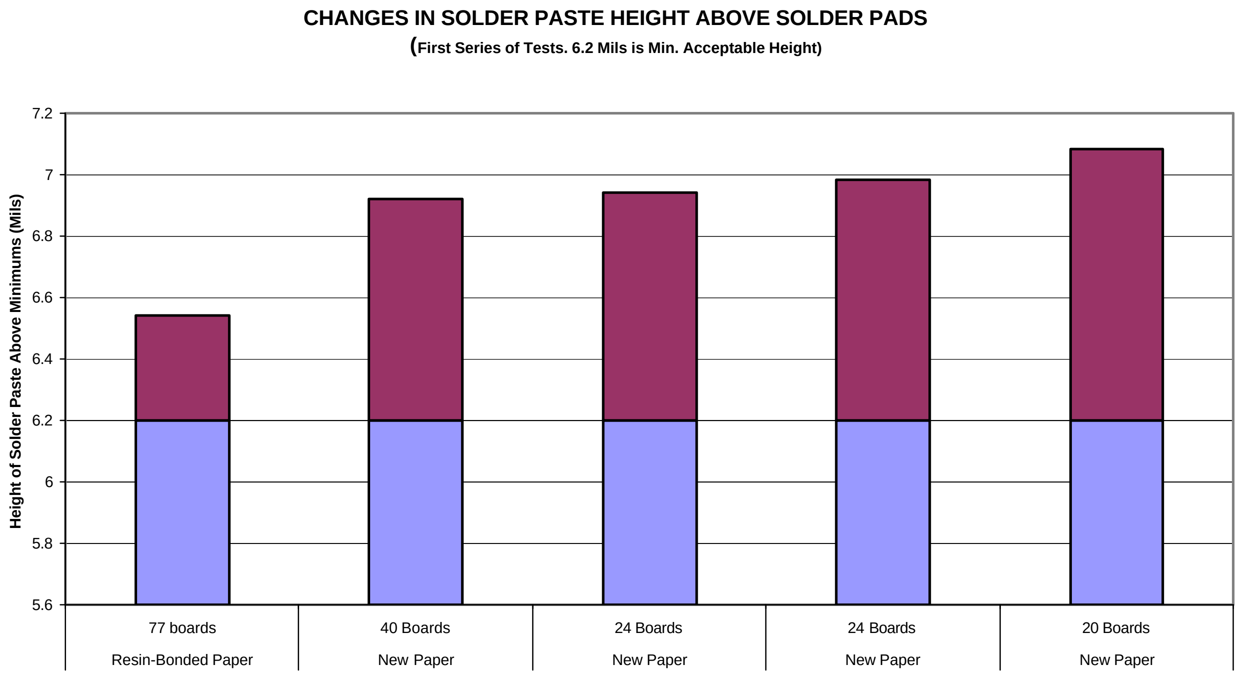


Figure 5

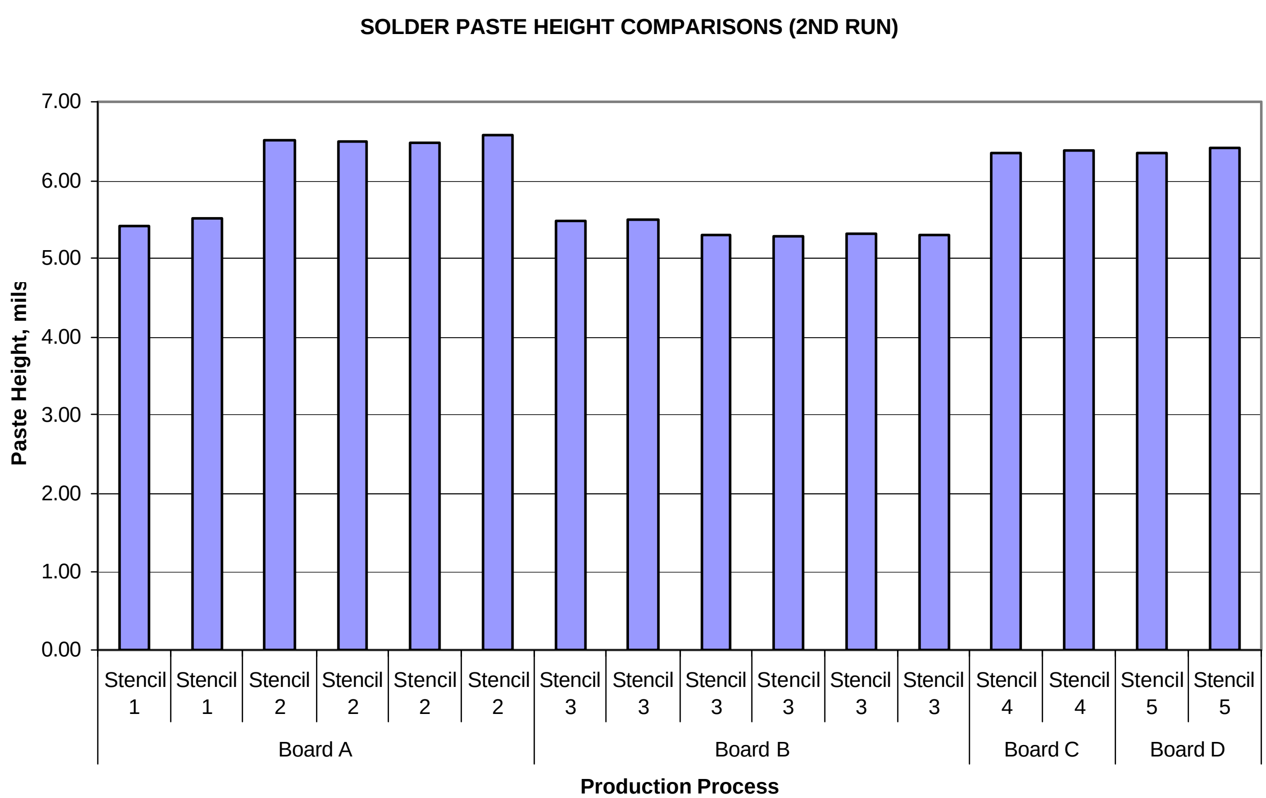
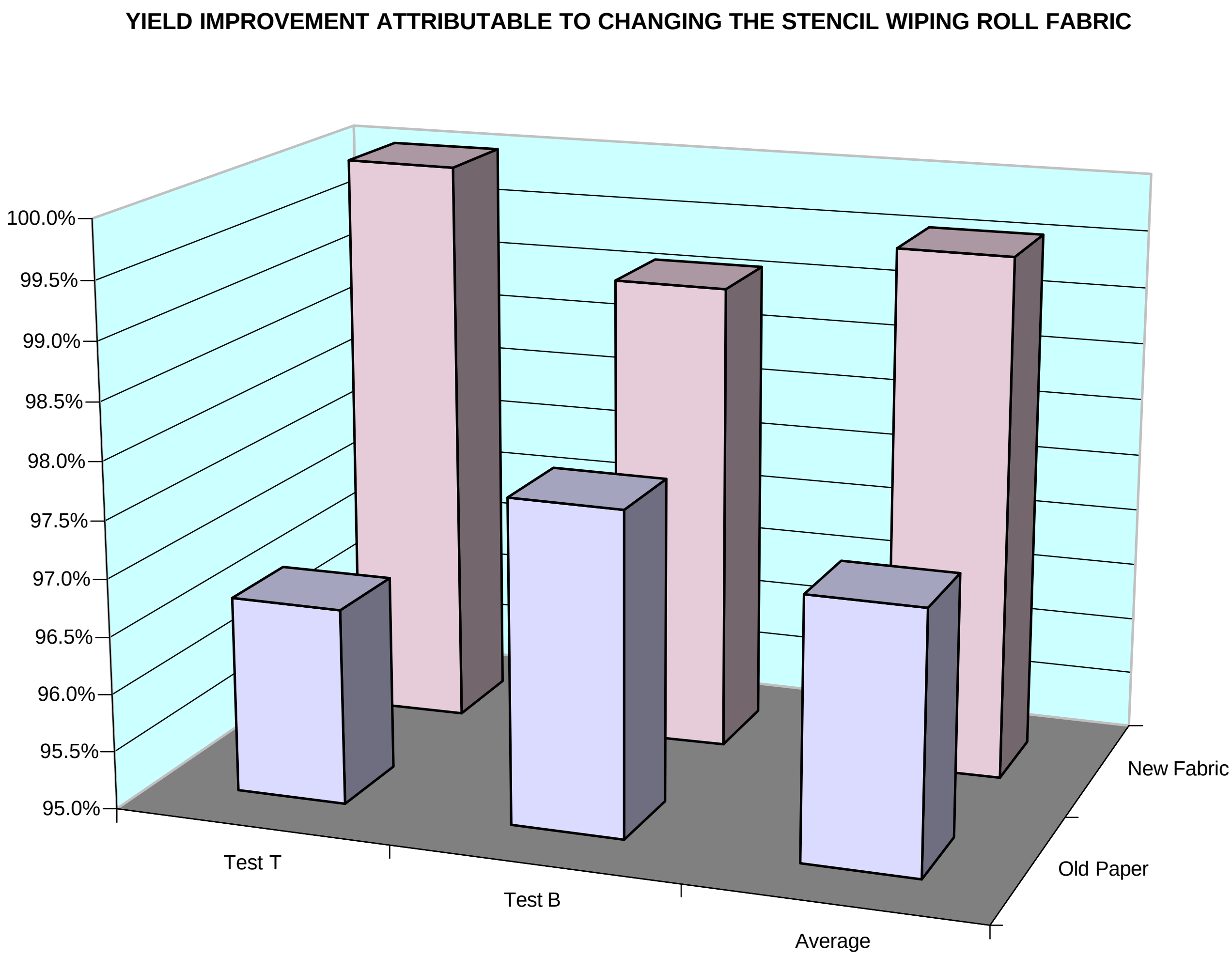


Figure 6



REFERENCES

1 "Research Announcement," Electronic Trend Publications, July 2004

2 Dupont Corp. web site, http://dupont.t2h.yet2.com/t2h/page/homepage as of Nov. 18, 2004

3 Richard Clouthier, "The Complete Solder Paste Printing Process: Stencil Aperture Area Aspect Ratio," SMT Magazine, January 1999

4 "Paste Printing," Assembly Magazine, April 1, 2003

5 Bob Ries, "3-D Post-Printing Inspection", Circuits Assembly Magazine, June 1998. Interestingly, Mr. Ries attributed 60% of the total production defects to solder paste/printing defects.

6 SMT Magazine, "Web Exclusive", March 22, 2002

[7] John V. Stevenson and Derek Drabenstadt, "Stencil Printer Optimization", SMT Magazine, November 1999

[8] Mike Bixenman and Charlie Pitarys, "Cleaning Guidelines for Fine-pitch Stencil Applications", SMT Magazine, June 2001

[9] A brief editorial comment from the authors, stepping outside of the wiping issue: During this testing procedure, it became obvious that there is a need for rapid, reliable measurement of the ***volume*** of solder paste on a bare board. No real-time method exists today which can cost-effectively perform this task. A slow but useful surrogate is the measurement of solder paste height (a 3-D measurement) across a sample of production boards. The faster 2-D inspection – available on almost all modern stencil printers – also is an adequate but cruder monitor of the stencil printing success. It is the opinion of the authors that no company should attempt fine-pitch printing without, as a minimum, automatic 2-D inspection of all boards. This single change will drive up yields (although also drive up mis-print rates) as measured at Functional Test.