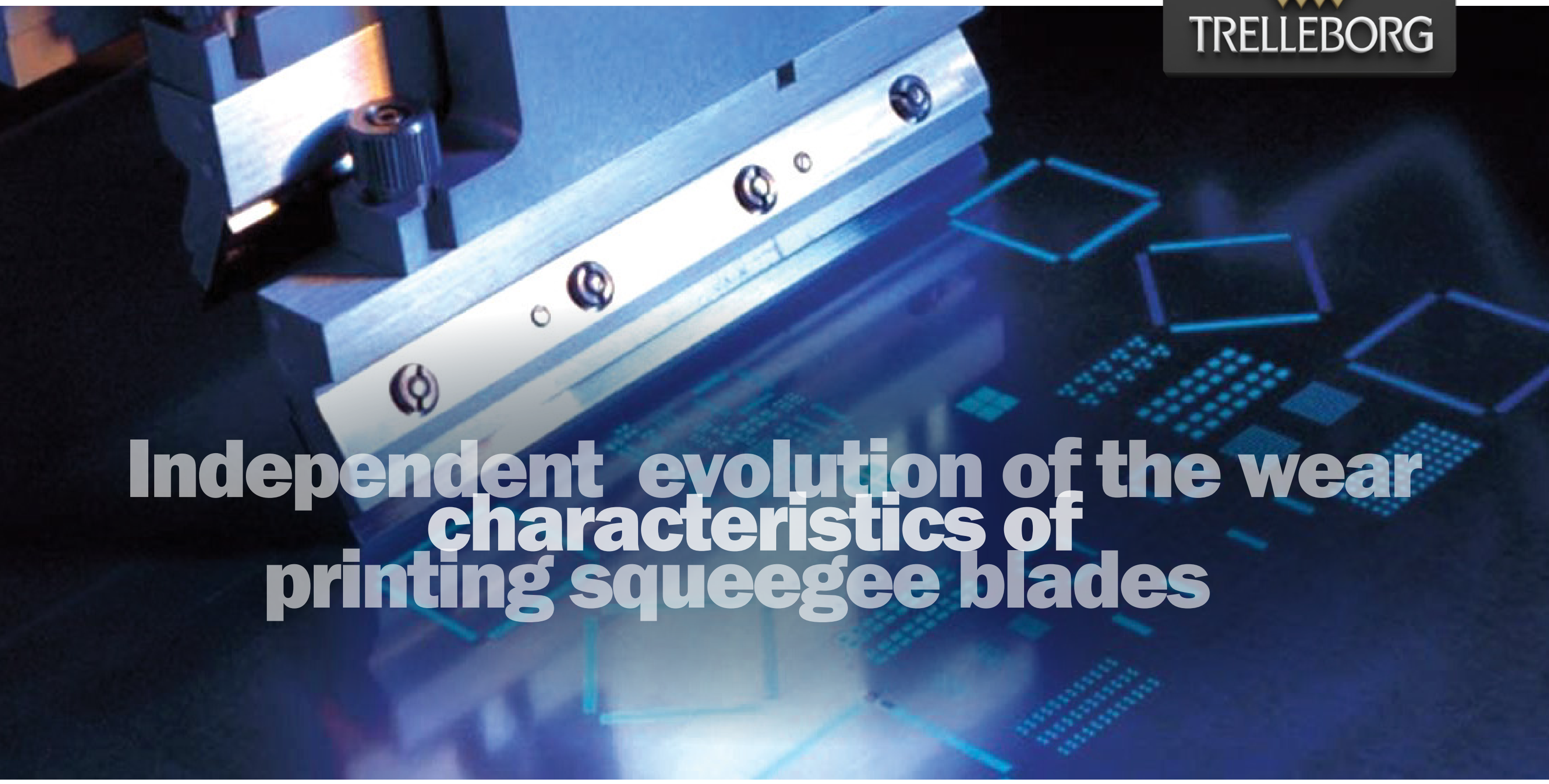


Independent evolution of the wear characteristics of printing squeegee blades

Unitex® Independent Report

Squeegee wear has an effect on the quality of the screen-printed product as well as the ink usage. There are cost implications from replacement of squeegees, increased ink consumption and rejection of printed product. This article details the development of a controlled accelerated wear procedure for squeegees and accurate measurement of wear using a microscope and image analysis techniques. It then describes how squeegees were then used to print in both worn and unworn states using a conductive silver ink, with the resulting printed samples analysed to compare the effect of wear on line geometry (and, hence, ink consumption) and electrical resistance for printed silver lines. Six different squeegee materials were used and obtained from commercial sources (Table 1).

Accelerated squeege wear methodology

For an experimental investigation, it is not feasible to wear squeegees by printing due to the time it would take, wastage of both ink and substrate and the uneven and unpredictable wear that would result. Such a method might lead to lines and blemishes in the print which would not be evenly manifested. This necessitated the development of an accelerated wear technique. In order for the wear to be representative of that achieved through printing, wear was performed using a screen-printing press. However, rather than using printing to wear the squeegees, the trial used silicon carbide ('wet and dry') abrasive paper. This product was selected as it enabled a controlled and consistent means of wearing the squeegees and it was readily available in a range of carefully controlled grades.

The wear apparatus was designed specifically for this experiment (Figure 1). A stainless steel plate was attached to an aluminium screen-printing frame. Three different grades of silicon carbide abrasives were used; in order of declining roughness these were 1200, 2000 and 2500 grits (with 15.3, 10.3 and 8.4μm average particle sizes respectively). The silicon carbide sheets were cut into strips and placed side by side on the steel plate using a cushioned double sided tape. The full length of the sheets (280mm) was used and they were cut into strips so that all three abrasives could be used simultaneously. The worn squeegees could then be used to print three identical test images from the same screen in the ensuing print tests. The printing machine was a SveciaMatic SM.

In order to help lubricate the contact between the screen and squeegee and transport abraded particles away from contact area, a carbon paste screen ink was spread over the abrasive sheet prior to wear. Dry abrasion, or use of a low volatility solvent alone, was found to be much more damaging to the squeegee in preliminary tests. A flow coat was not used as it would most likely damage the abrasive and would suffer abrasion itself. A 10mm strip of squeegee material was attached to the adhesive tape at the end of the abrasive strips, where the squeegee lifted off after wear. The ink pooled at this point, as it was scraped along the abrasive sheet by the squeegee, and the strip allowed a reservoir of ink to form that would recoat the squeegee at the end of each wear cycle. This ensured that a covering of ink remained on the squeegee; rather than having dry contact.

The squeegee was then reciprocated over the abrasives to cause it to wear, with bands of different levels of wear across the width of the squeegee as a result of the different abrasive types. Fifty reciprocations of the squeegee were performed for each squeegee. Both abrasives and ink were discarded after each cycle of 50 reciprocations to ensure consistency between squeegees. Following wearing, the squeegees were cleaned and left for a minimum of 48 hours before wear measurement to allow any absorbed solvent to escape and swelling to subside.

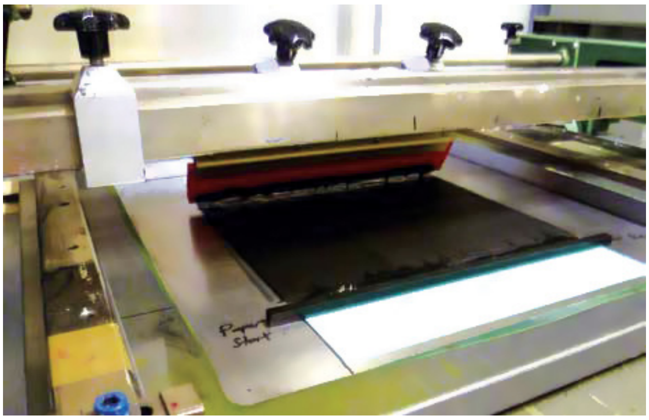
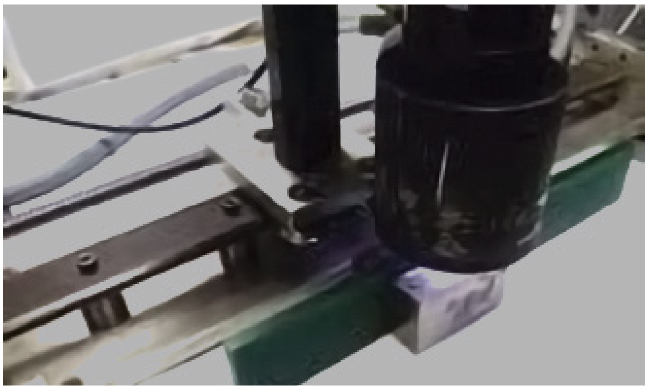


Figure 2: measurement of squeegee wear and resulting microscope images



Squeegee number	Full details	Measured Shore A hardness \ (standard deviation)
1	Unitex® Ulon HP 500/4, Trelleborg Applied Technology, UK	74.2 (0.6)
2	Minoplain 9 x 50 x 1500 Blue (03MN-PLN-H-A09-50-1500)	76.0 (0.0)
3	Lumina L754/T G1 2000 Series G1 Medium blade	75.8 (0.4)
4	Serilor SR1 (50/09/75/SR1), 50 mm x 09 PO 75 SH. Fimor, France.	76.9 (1.2)
5	TG950:Printmor TS 9x50mm 75Sh GRN, BMP Worldwide.	78.7 (0.8)
6	Huayo, China	70.0 (0.8)

Table 1: squeegee types used in the testing

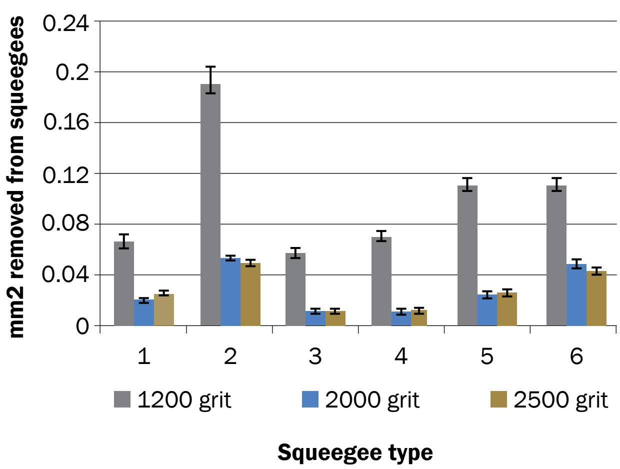


Figure 3: squeegee cross-sectional area removed after 50 wear cycles with different silicon carbide abrasives – error bars show standard deviations

Measurement of squeegee wear

Images of squeegee wear were captured using a Leica stereo microscope with a three chip CCD camera. The squeegees were measured from both the side and bottom of the squeegee. Wear was clearly visible as a band in the images and was evaluated using image analysis software (Image J 1.46r, U S National Institutes of Health). Rather than expressing two numbers to quantify wear, the cross-sectional area removed was calculated as a triangle from the worn width of the squeegee from both orientations as ½ a x b.

Squeegee wear findings

The amount of wear, in terms of cross-sectional area removed from the squeegee, is shown for the three wear bands (1200, 2000 and 2500) and for each squeegee in Figure 3. The roughest abrasive (1200 grit) gave the highest amount of wear, while the less rough abrasives (2000 and 2500 grit) gave less wear but were fairly similar to each other. For the roughest abrasive (1200 grit), the lowest amount of wear was observed in squeegee 3, followed by 1 and 4, though all three were broadly similar. Squeegees 6 and 5 gave more wear and performed similarly to each other. Finally, squeegee 2 showed significantly more wear than any of the other squeegees. For the 2000 grit abrasive, squeegees 3 and 4 gave the least wear, followed by 1, 5, 6 and finally 2. For the 2500 grit abrasive, squeegee 3 gave the least wear, followed by 4 , 5, 1, 6 and finally 2. For both 2000 and 2500 abrasives, squeegees 2 and 6 gave substantially more wear than squeegees 1, 3, 4 and 5. Overall, across all the abrasive types, the least wear was observed in squeegee 3.

Printing using worn and unworn squeegees

Unworn and worn edges of the same squeegee were printed sequentially, before moving on to the next squeegee. To alternate between unworn and worn edges, the squeegee holder was removed, rotated by 180 degrees and replaced in the printing press. All prints were performed on the same screen without changing over or cleaning between print cycles – with a control squeegee used to compare variation in print between the start and end of the series of print cycles. None of the printing parameters was altered and the ink was kept in excess to deter drying in the mesh. A gel type flexible silver paste was selected as it was stable over time and not prone to drying in. The substrate was 330μm Melinex 339 PET (DuPont Teijin Films). The screen used for printing consisted of three bands of identical test images which coincided with the different wear bands. A range of different line widths in both print direction (perpendicular to the squeegee) and at 90 degrees to the print direction was included. A total of ten prints were made for each squeegee configuration, giving a total of 140 prints. Including changeover time, this took less than two hours. The condition of the ink had not noticeably changed in that time.

Measurement of printed silver lines

The dimensions of the printed features were measured using white light interferometry. This allowed a full three-dimensional surface profile to be captured, so that line width, print thickness and local surface variations could be evaluated. Lines of 400 and 600μm nominal width were measured both in the print direction and at 90 degrees to the print direction. A measurement area of 1.25 x 0.94mm was used. A sample surface profile is shown in Figure 4; the colour represents the height at that position, with the substrate blue and the line in green, with peaks in red.

Average line width and ink film thickness for each printed line were evaluated from the surface profiles using WCPCLine software written by WCPC. The software was able to use the roughness data for the substrate to precisely differentiate between ink and substrate. The electrical resistance of the lines was measured with a Keithley 2400 multimeter using the two-point probe technique. A probe was applied to the contact pads at each end of the printed tracks and the resistance recorded.

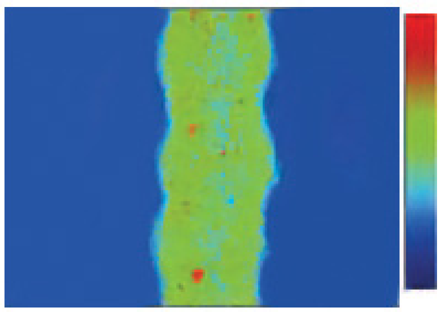


Figure 4: sample topographic profile of a 400μm screen-printed silver line

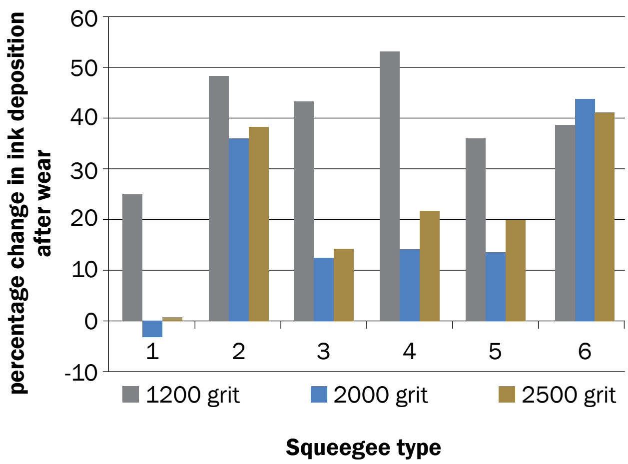


Figure 5: variation in ink deposition as a result of squeegee wear with different abrasives

Changes in ink deposition as a result of squeegee wear

The change in ink deposition as a result of wear is shown in Figure 5. Ink film thickness, line width and, hence, ink deposition generally increased with the amount of wear on the squeegee. However, the dominant factor in the deposition was the change in ink film thickness rather than the width of the line. This would lead to greater ink consumption and, therefore, cost/unit and an increasing likelihood of product failure or rejection. For the roughest abrasive, an increase in ink deposition and, therefore, ink consumption, of 25.5% was recorded for squeegee 1, while the other squeegees showed greater increases between 36.8% and 53.9%. For the mid roughness abrasive, squeegee 1 showed a small decrease of 3% in ink deposition due to wear while the other squeegees all increased deposition, in varying amounts, between 13% and 44.6%.

For the smoothest abrasive, squeegee 1 showed only a negligible change in deposition (+0.8%) while the other squeegees all increased deposition, in varying amounts, between 14.5% and 41.9%. The small reductions in deposition, mainly observed in squeegee 1 for 2000 and 2500 papers, were most likely within the inherent variability in the process and gradual drying in the mesh (demonstrated by the control prints).
The relationship between the amount of wear and ink deposition, while generally showing an increase in ink deposition with increased wear, was not straightforward (Figure 6). Squeegee 1 differed from the other squeegees, with substantially lower variation in ink deposition, even with comparable wear levels.

For squeegees worn with the roughest, 1200, abrasive, there was a reduction in line resistance for all lines due to the increase in ink deposition from the worn squeegees. The lowest reduction in line resistance was observed in Squeegee 1, with an average 21% reduction in line resistance across all lines. This was followed by squeegees 5, 6, 2, 3 and 4 with overall reductions of 29 to 37%. These trends mirrored the patterns seen in the printed line geometry; the greater the increase in ink film deposition, the greater the reduction in resistance. For the mid roughness abrasive, squeegee 1 showed a small increase of 3% in line resistance due to wear, due to reduced ink deposition, while the other squeegees all showed a reduction in resistance, in varying amounts between 12.7% and 37.8%. For the smoothest abrasive, squeegee 1 showed only a very small increase in resistance of 1.5% while the other squeegees all gave reduced resistances, in varying amounts between 17.8 and 32.3%. The resistance data highlights the changing electrical properties due to worn squeegees. When used in electrical products, such variations in conductivity might lead to unpredictable behaviour. Properties of other functional layers such as dielectrics and insulators would be affected similarly in terms of capacitance, resistance etc. This would lead to a higher failure and rejection rate for the products.

The relationship between the ink deposition and the reciprocal of the measured line resistance is shown in Figure 7. While the worn squeegees gave a general increase in ink deposition, which gave a reduction in line resistance, there was no deviation from the relationship which would suggest a reduction in the performance of lines printed with the worn squeegees. Print defects, such as broken lines, would lead to higher than expected resistances. This highlights the benefit of a controlled wear methodology rather than testing squeegees worn through printing which might suffer nicks or other uneven damage and cause broken lines.

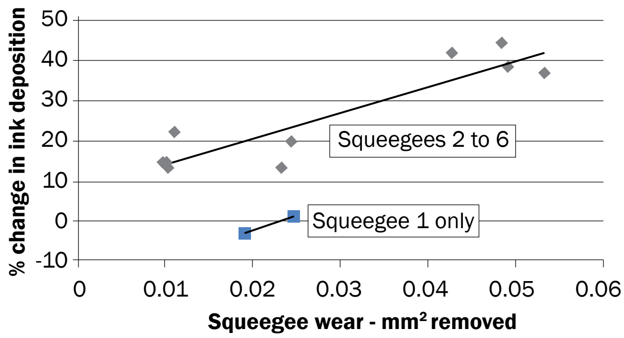


Figure 6: relationship between squeegee wear and change in ink deposition for 2000 and 2500 abrasives

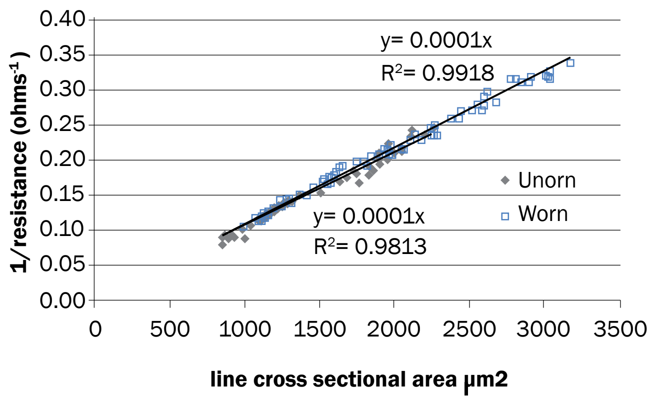


Figure 7: correlations between ink deposition (line cross-sectional area) and line resistance

Conclusions

This investigation highlighted differing wear characteristics, and hence longevity, for a range of squeegees. Squeegee wear led to increases in ink transfer and thicker printed lines. This would lead to greater ink consumption and therefore cost/unit and an increasing likelihood of product failure or rejection. Squeegee 1 (Unitex® Ulon HP 500/4 from Trelleborg) was the best performing in terms of maintaining consistency in the print after wear, with a marked contrast between its performance and that of the other squeegees, suggesting a greater lifespan and lower ink consumption than other squeegees.

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Trelleborg Applied Technologies delivers innovative and reliable solutions that maximize business performance to meet your needs. Our dedicated and highly skilled staff are always on hand to provide seamless process support from initial idea, through to delivery and beyond.

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