Optimising Stencil Thickness and Ink Film Deposit

An investigation about the preparation of thick film screen printing stencils and their influence on desired thick film ink or paste deposits.

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It is very important to control the thickness of the ink deposit in screen printing of functional pastes – especially in the field of printed electronics. In general, it is the height of the conductive tracks that can be altered in order to control the ohmic resistance since the specific resistance of the deployed material, the base area and the length of the printed structure are pre-defined. The aim of this investigation is to detect the most significant parameters that influence the ink film deposition in order to establish a dry ink film layer on the substrate which ranges between 80 to 100 microns.

1. Introduction

Screen printing is a process in which thick ink film deposits can be achieved on a wide range of substrates. This is a major advantage of this printing process compared to other processes such as Offset Litho, Flexography or Gravure. However, in order to produce a thick ink film there are several parameters that must be considered during the preparation of the printing form. These include: the type of screen mesh needed, the stencil material and the methods employed in stencil production. Additionally, there are the parameters and controls, which must be considered during the printing process itself. Some of these key parameters will be identified in this examination for further investigation within the field of thick film screen printing.

There are several aspects within the screen printing system which influence the characteristics of ink film deposition. Two primary influences are the screen mesh and the geometric stencil properties, representing the key elements in ink transfer and deposit formation. In addition, the rheological property of the printing ink is a key factor that can influence the thickness and fidelity of the printed film layer.

2. Problem Description

The possibility of producing high ink layers on the substrate is a major benefit of screen printing. The research projects at the Stuttgart Media University include printed sensors and thermocouples. In both applications thick ink film layers are required, e.g. to establish a non conductive spacer layer or a conductive track between such spacers. Controlling the most important influencing printing parameters is therefore a crucial requirement in order to obtain predictable results.

In screen printing the printed image is formed by forcing ink or paste to flow through a stencil, which is supported on fine woven gauze or screen mesh. The geometric properties of the stencil, mainly the emulsion over mesh (= EOM, see explanation in figure 1) value, influence the ink deposit especially when printing small structures. Commonly this impact of the stencil on the height of the printed structure will diminish if the structure is wider than 1.5 - 2.0 mm (this is being discussed later on. See figure 16). With increasing aperture the geometric mesh properties (mainly the theoretical ink volume Vth = mesh opening per area multiplied by the mesh thickness) govern the height of the printed structure [1].

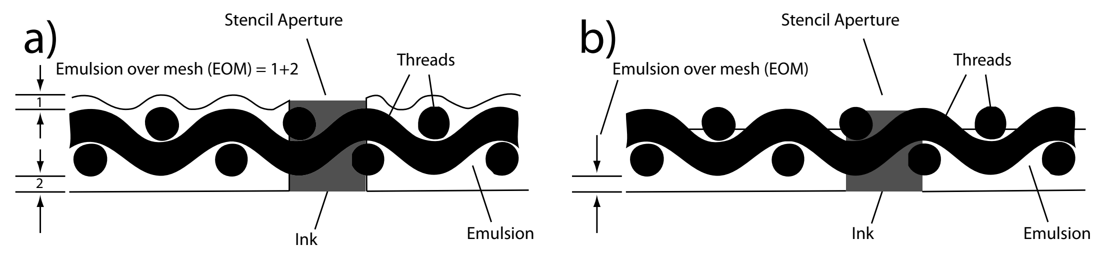
3. Materials and Parameters

In most screen printing applications the stencil thickness ranges from a few microns to some tens of microns. Besides some manual stencil preparation techniques mainly photosensitive (UV-sensitive) materials are used today. Two major photosensitive stencil systems are available:

- the liquid (direct) emulsion system and
- the dry capillary film system.

The choice of the system is determined by the nature of the printed product and by the production requirements such as the print run volume, the image fidelity, the edge definition (print quality) and the ink or paste type that is used.

Figure 1:
Cross-sections of a) an emulsion stencil and b) a capillary film stencil. The liquid emulsion encapsulates the mesh completely, as shown in a). The capillary film (basically consisting of dried photo sensitive emulsion) attached to the print side (lower side in the figure) penetrates the mesh, but does not fully encapsulate it. The capillary film therefore is not as firmly adhered to the mesh as the emulsion and thus withstands shorter print runs, only.



[1] SBQ (stilbazolium quaternized) single component type of photopolymer

[2] Rz Value = Measure of surface roughness

Stencil Systems – Direct Emulsion

Direct emulsion stencils are produced by applying a light sensitive photopolymer emulsion on both sides of the screen mesh using a special coating trough. The achieved stencil thickness is determined by the type and quality of the emulsion, its viscosity, solids content, the coating trough velocity and the coating sequence (e.g. once on the print and twice on the squeegee side – in so called wet-on-wet application). Typical stencil thicknesses range between several to some tens of microns. After drying of the emulsion the coated screen which is in contact with a positive film image of the design (e.g. plot of circuit tracks) is exposed to an intense ultra violet (UV) light source. During exposure the UV light renders the exposed emulsion insoluble in water; the unexposed areas remain water soluble and are subsequently washed off with water, leaving the image areas of the screen/stencil open.

Stencil Systems – Capillary Direct Film

The Capillary Direct Film stencil system provides a precision-coated film of pre-sensitized photopolymer SBQ emulsion[1] (typically 18-80 µm thickness) supported by a polyester film base. The principle advantage of the capillary film is the more predictable thickness, a very low surface roughness (Rz value[2]) and the high acuity of edge definition. The ease of application is another advantage; in most cases capillary film can be applied to the screen with water – the water soluble coating adheres to the wet mesh through capillary action. If thicker films are required it is often recommended that the film is applied to the screen with a simultaneous coating of liquid photopolymer emulsion from the squeegee side which bonds the film to the screen and enhances stencil durability and resistance to breakdown during the washout stage. Once the film is dry the polyester support will be removed and the screen is exposed and developed in water in the same way as a direct emulsion stencil.

Parameter	Variable
Mesh	18/180, 32/70, 90/40, 90/48
Stencil Material	KIWO POLYCOL S 295 HV & XXL, Ulano CDF/QT Thick films
Squeegee Material	RKS Carbon reinforced blade, RKS Monoflex PR elastomer round blade
Machine Settings	Snap off distance and squeegee pressure were individually altered in order to achieve an optimised print result[4]
Parameter	**Constant**
Screen Mesh Tension	20 N/cm
print and flood stroke velocity	100 mm/s, 120 mm/s
Squeegee angle / hardness	75° / 75 Shore A
Printing Ink	Sun Chemical Conductive Graphite CHSN8002
Substrate	PET plastic film Melinex ST506, 175 microns

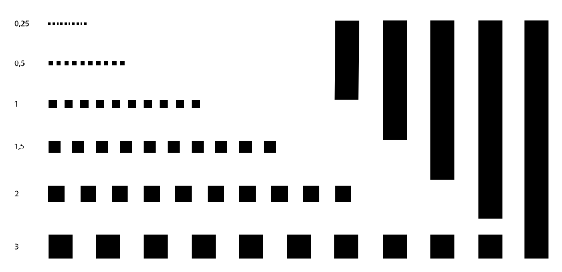
Table 1: Investigated parameters

Table 1 shows the parameters that were fixed during the print trials and those that were varied including their settings. In order to focus on the mesh and stencil parameters a single ink medium was selected as a constant for the purpose of this investigation. Commercial carbon-black ink was chosen as the preferred medium since it has proven suitable rheological properties. It is our view that the portability of the findings of this investigation to the application of other functional pastes will be feasible and helpful for further examinations in this field.

A similar investigation by Liepelt can be found in [2]. He discussed in his technical report the possibility of producing Braille text and tactile warnings in screen printing by means of thick stencils and UV-curable inks. Although he examined the thick stencil emulsion KIWO Polycol S 295 HV and the SEFAR PET 1500 32/70 screen mesh, similar to our investigation, only few parallels can be drawn. Our report deals with solvent based inks, but Liepelt used UV curing inks[3]. He was able to print tactile warnings but did not succeed to print Braille dots. According to DIN 32976:2007-08 a single Braille dot must be at least as high as 500 µm, whereas Liepelt only achieved a dot height of 200 µm.

The test form for the print trials is shown in figure 2. The test squares with an edge length between 1.5 and 3.0 mm were analysed, since only these structures were reproducible with all parameter setting variations.

Figure 2: Test form with square elements from 0.25 to 3 mm



[3]Unlike solvent based inks the UV curable systems have only few or no volatile parts. The volatile parts in solvent based inks (solvent blends) evaporate during the drying. Thus, the dry ink layer of solvent based inks is smaller than the wet ink layer while the wet and dry ink layer of UV inks is almost identical.

[4]In the majority of the cases the settings were the same. Only if the image had not printed completely the snap off and/or the squeegee pressure was altered in order to print the whole image. However, with some parameter combinations it was not possible to print a complete image, e.g the 300 microns capillary film on 90/40 and 90/48 mesh.

Screen Mesh Parameters

In screen printing the geometry and the type of screen mesh significantly influence the thickness of the ink film deposit. When printing solid areas the mesh itself is the dominating parameter. In this work 18/180, 32/70 and 90/40 as well as 90/48 (mesh count per cm / thread diameter in µm) screen meshes were used. Different theoretical ink volumes - while maintaining the mesh count - were examined using the screen meshes 90/40 and 90/48.

Mesh type	Mesh opening in µm	Thread Diameter in µm	Open area in %	Mesh Thickness in µm	Theoretical Ink Volume in cm³/m²
18/180 W[5] (PET 1000)	375	180	45,5	330	145,5
32/70 Y	240	70	58,7	117	68,7
90/40 Y	68	40	37,6	65	24,4
90/48 Y	55	48	24,6	78	19,2

Table 2: Mesh parameters. Excerpt from SEFAR PET 1500 data sheet

[5]W = white coloured screen mesh; Y = yellow coloured screen mesh

Squeegee Selection

In screen printing the squeegee performs a primary function in ink transfer. It is used to create the fluid dynamic pressure which forces the ink or print paste through the screen and stencil apertures and onto the substrate. There are a number of complex factors which affect this process including the squeegee blade type and edge profile as well as the squeegee angle and speed. The two squeegee types employed in this investigation differed in material composition and design. The RKS CARBON squeegee blade consists of a non-thermoplastic elastomer which is fused on a carbon-fibre reinforced plastic blade [3]. The shape of the elastomer print section is rectangular. The other blade used was a conventional elastomer blade with a rounded profile commonly deployed in printing thick ink films. The hardness of the squeegee blades was 75 Shore A in both cases.

4. Methods and Hardware

Stencil Production

The capillary direct films used were the Ulano CDF QT. This material was specifically designed for thick film applications and is available in film thicknesses up to 400 µm. The application of thick capillary film differs from more conventional capillary film products. It is necessary to apply a liquid emulsion (instead of water) to adhere the film to the mesh according to [4]. The investigation found that the stencil development and washout process can cause problems (washout failure and/or stencil breakdown). After discussing the problems with the supplier it was found that soaking the exposed film in warm water for ten minutes prior to washout enabled the unexposed image areas of the stencil to swell up and soften so that they would more readily dissolve and wash off with the application of a low pressure water jet or spray [5].

The liquid emulsions used for the investigation were KIWO Polycol XXL and Polycol S 295 HV. Both emulsions are produced especially for thick film stencil applications. The XXL emulsion is highly viscous; whereas the Polycol S 295 HV is more comparable to conventional emulsions. After initial trials the latter emulsion was preferred, primarily due to the ease of application with a coating trough.

During this process an additional special coating method was used that we termed ‘template blade coating’, details of which are given below.

Coating methods
Following a demonstration from the staff of the Application Technology Centre at Kiwo/Wiesloch we decided that the manual 'template blade coating' technique should be employed to apply the screen emulsion rather than the conventional coating with a coating machine. The advantage of the template coating is that having first sealed the screen mesh with a 1/1 coating of emulsion, a thick film of emulsion can be transferred to the print side of the screen in a single blade coating operation. The coating thicknesses that can be achieved by template blade coating are equivalent to those achieved by successive and time consuming coating and drying procedures carried out with a coating machine or by applying costly capillary films. As shown in figure 3a) for template blade coating the screen is sealed with emulsion first, as described above. A stencil area template (mask) is then produced from self-adhesive film (figure 3b). An acetate film with a thickness of 460 microns was found to be ideal for this purpose. The thickness of the film determines the thickness of the emulsion coating that can be achieved. Figure 4a) describes the emulsion coating into the aperture of the mask, leaving a thick stencil after drying and removing of the mask (figure 4d). Figures 5 and 6 show images of the complete process.

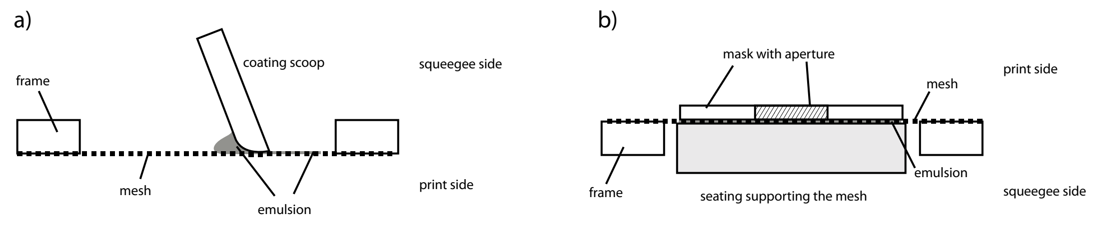


Figure 3:
a) coating the squeegee side; b) applying the template on the print side. The screen is set on a seating that supports the mesh

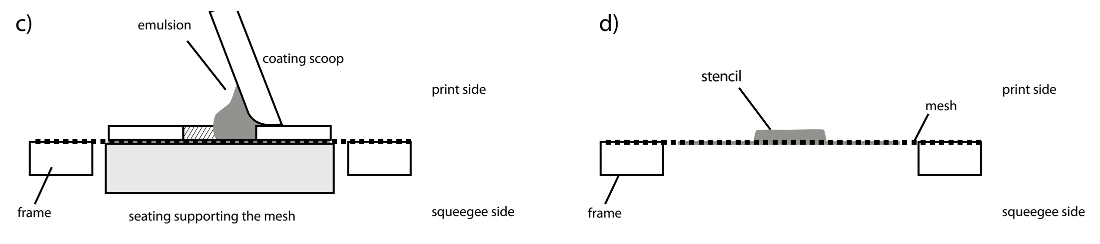


Figure 4:
c) Coating through the aperture in the template; d) resulting stencil thickness depending on the volatile parts of the emulsion and the thickness of the template.

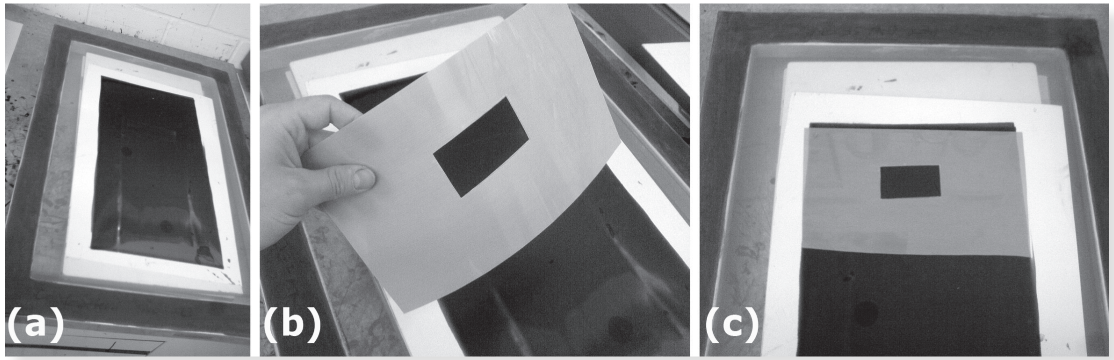


Figure 5:
The screen mesh is sealed with a 1/1 coating. After drying it is placed on a supporting platform with the squeegee side down (a). Afterwards, the template is applied (b). It is crucial to provide good contact between the template and the print side of the screen mesh to prevent the emulsion from flooding out beyond the templates aperture. An adhesive layer on the backside of the template is practical to make sure that the template is fixed absolutely flat and secure on the screen mesh (c).

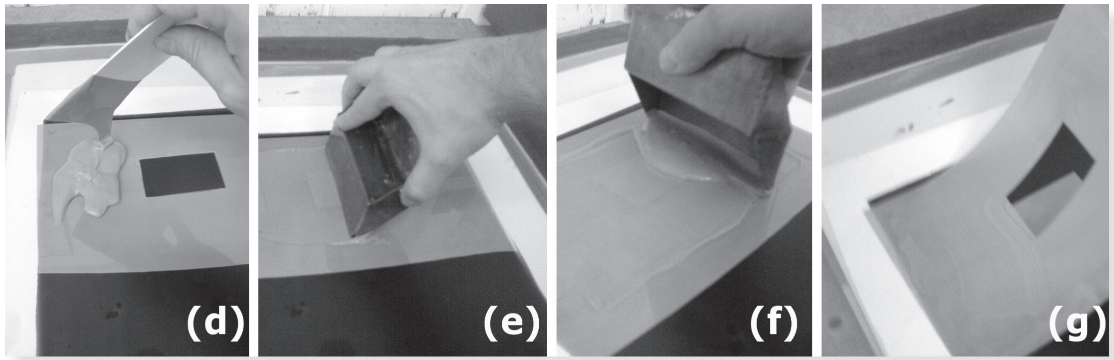


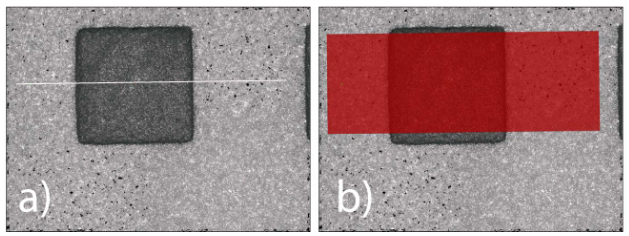
Figure 6:
An adequate amount of emulsion is placed on the template (d) and distributed by means of a coating trough or something similar (e). If the emulsion tends to blister, another few coating strokes may be necessary (f). A short standby time for levelling purpose and degassing of the emulsion is necessary before the template will be removed (g).

Microscopy
The printed samples were measured with an Alicona Infinite Focus Microscope [6]. This optical system provides 3-D topographical information either in true or false colour. The analysing software includes versatile processing of 3D-data such as profile and surface measurement. The following diagrams have been derived from these profile measurements.

5. The Results

In order to achieve statistical significance the measurements comprised of at least five different printed samples. The height of the printed tracks was measured by generating a 3D-profile across the printed square (along a single scan line as shown in figure 8 a) and analysing the profiles in the Alicona software. The width of the profile can be set between 1 and 999 pixels as shown in red in figure 8b). Averaging as many scan profiles as possible with the Alicona system leverages random noise and renders more smooth and reliable height values. The height of the profile was determined by choosing a line of best fit in the average profile as shown in figure 9.
The ink layer thickness values shown in the following figs. 10 to 16 are mean values obtained by the averaging method, always based on several measurement repetitions.

Figure 8:
a) single pixel (1.75 µm) scan line generating a profile across the printed square (ragged line in figure 9).
b) area of 999 parallel single pixel scan lines (1749 µm), generating an averaged profile (smooth line in figure 9).



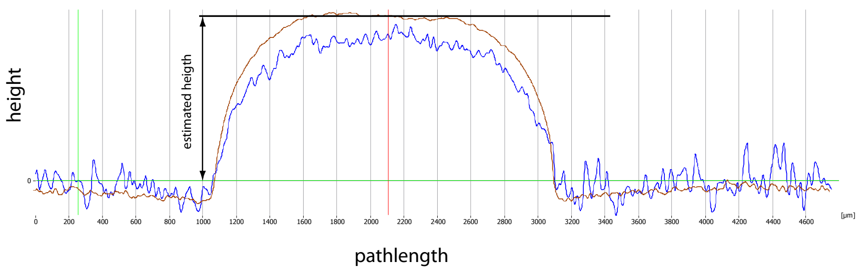


Figure 9:
single pixel scan profile (blue ragged line) and average (999 pixels) scan profile (smooth, red line).

Main Effects Plot

The results were analysed in accordance with the Design of Experiments (DOE) main effects plotting analysis. These plots clearly illustrate which parameters have a significant impact on the ink layer deposition. The parameters were altered at two levels. The two levels differ quantitatively – e.g. the mesh count 18/180 and 90/48 – or qualitatively – e.g. the squeegee material. The inclination of the line indicates whether the effect is a positive or negative response when the level changes from low to high [7]. The main plots are derived from the analysis of the printed 2mm squares. The y-axis shows the achieved ink layer thickness on the substrate; on the x-axis the two levels were plotted.

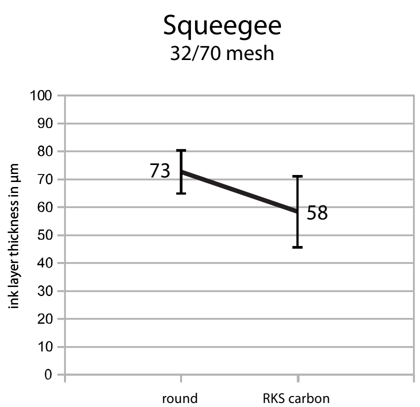


Figure 10:
Different squeegee blades printed with 32/70 screen mesh.

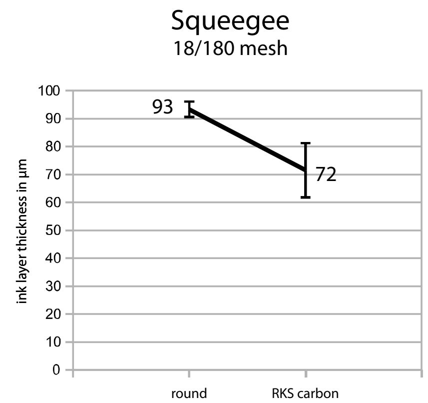


Figure 11:
Different squeegee blades printed with 18/180 screen mesh.

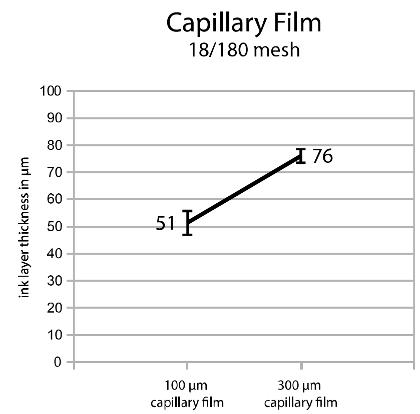


Figure 12:
Comparison between 100 and 300µm capillary film.

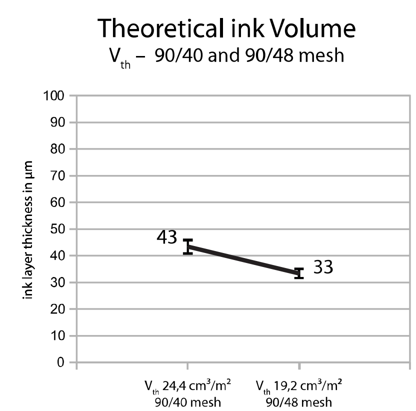


Figure 13:
Difference in theoretical ink volume at constant thread count.

Figure 10 shows the layer thickness achieved with the 32/70 screen mesh coated with Polycol S 295 HV emulsion (EOM 168 µm). The round squeegee produces a higher ink deposition, around 25% more than the RKS CARBON squeegee. However, in both cases the standard deviation is quite high. The coarser 18/180 (figure 11) screen mesh (EOM 247 µm), also coated with Polycol S 295 HV, basically shows the same behaviour as depicted in figure 10. In total, the amount of transferred ink is higher, but the difference between the round and the RKS CARBON squeegee is around 30%. The scattering of the results (represented by the standard deviation, the error bars in the plot) is lowest for the rounded blade and for the 18/180 mesh in comparison to the 32/70 mesh. Although the Vth is quite different between the 32/70 mesh and the 18/180 mesh (see table 2) the resulting larger thickness differs not as much as expected. It seems that the rather high EOM value superposes the influence of the V_{th}.

Figure 12 depicts the result when using capillary films of different thicknesses printed with the round squeegee. The observed increase of the ink layer thickness is about 50% whereas the thickness of the capillary film was tripled (the EOM was 43µm with the 100µm capillary film and 240µm with the 300µm film). The standard deviation is considerably small and implies reliable and more reproducible results.

In comparison with the result (93µm) of the template blade coated Polycol S 295 HV emulsion (figure 11) here the ink deposition is lower (76µm) although the EOM produced with the template blade coating technique (247µm) and the EOM generated by the capillary film (240 µm) was almost similar. The reason for this may be found in a different ink release of the different stencil systems since all parameters were kept the same during this investigation.

The results for two meshes differing only in the thread diameter and thus in the theoretical ink volume are shown in figure 13. The mesh with the higher theoretical ink volume Vth transfers more ink than the mesh with a thicker thread diameter and therefore a lower Vth. The ink deposition increases around 30% with the higher theoretical ink volume. This is as expected and in accordance with the well known Hagen-Poiseuille equation which describes the fluid flow of a viscous liquid through a pipe or a channel. See Riemer [1] for details.

$$\dot{V} = \frac{dV}{dt} = \frac{\pi r^4 \Delta p}{8 \eta L}$$

with

- $\dot{V}$ Volumetric fluid flow per second through a pipe in m³/s
- r radius of the pipe in m
- L length of the pipe in m
- η dynamic viscosity of the fluid in Pa•s
- Δp pressure difference between the entrance and the exit of the pipe in Pa

Although the Hagen-Poiseuille equation is valid for round pipes, only, it can be used as a first approximation telling us that the radius of a channel (which is represented by the mesh opening) has much more impact (in the fourth order) on the fluid flowing through it than the length of the channel, which is represented by the mesh thickness.

Influence on the Printed Track Profile
The profiles (cross-sections) of the printed lines measured with the Alicona Microscope indicate the influence of the various parameters on the printed structure. The slope at the edges of the lines is essential for good print quality.

The different squeegee materials produce different ink layer profile-shapes, as shown in figure 15. As expected, the round squeegee blade provides a higher ink deposition on the substrate (PET), which is reflected in a profile height that is 25% higher than the RKS squeegee. It shows that the print direction of the squeegee affects the shape of the profiles: the squeegee movement is from the left to the right. Accordingly there is an almost parallel slope (on the left hand side) but a differing slope on the right hand side after a profile length of around 0.25mm. Both squeegee materials provide a similar shape; however, they deliver different heights.

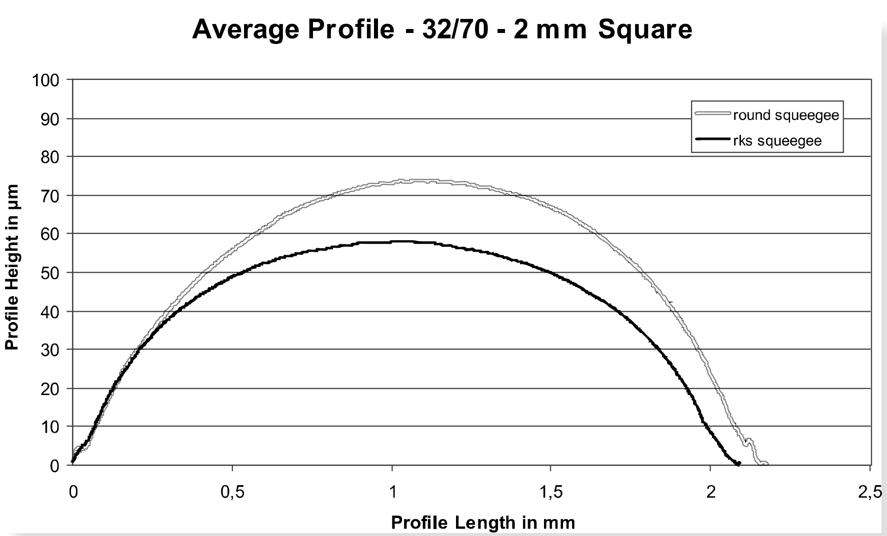


Figure 15:
Profiles of printed tracks (RKS vs. round squeegee) both aligned at the left edge.

Stencil Influence on the Track Height
In figure 16 the impact of the stencil thickness (EOM) on the ink deposit is shown. The influence of the stencil can be well observed by comparing the smaller structure (1.5mm) with the wider one of 3.0mm width. Besides the appearance of pronounced shoulders at the edges (slope) of the 3mm-line it is clear that the height of the line profile also depends on the line width (see the difference between the 1.5mm and the 2.0mm line).

Thus, to achieve a good relation between the cross section of the track and its height it is advisable to keep the image structure (track) width below 3.0 mm. Even reducing the profile length from 2.0 mm to 1.5 mm improves the angle at the slope and generates a steeper slope. In figure 15 and 16 the profiles were aligned manually by editing and shifting the data in the spreadsheet software.

If possible, the image/track size has to be chosen with consideration because the height/width aspect ratio is greater the smaller the image structure is (in the investigated range of 1.5 to 3.0 mm), as shown in figure 17.

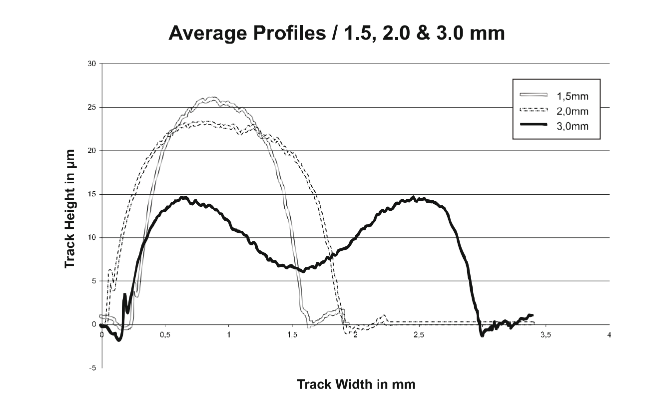


Figure 16: Stencil impact on the structure's height. Profiles aligned at the left edge.

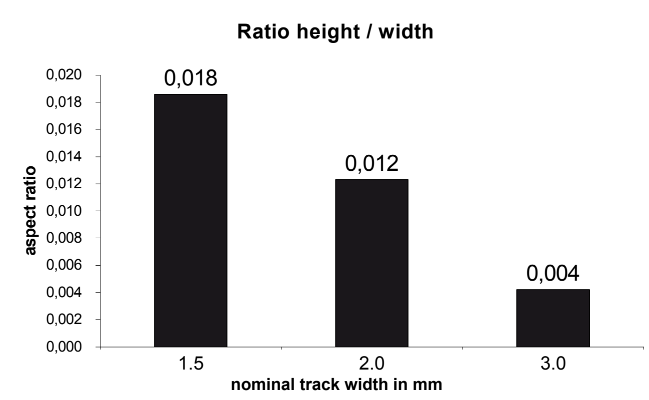


Figure 17: Aspect ratio of the structure's height and width.

6. Conclusion
In summary, the main effects plots show that a round squeegee in combination with a coarse screen mesh ranging from 32/70 to 18/180, coated with the POLYCOL S 295 HV emulsion shows the optimum ink deposition on the substrate. The maximum height of around 100µm – that was the goal of the investigation – could be achieved with the 18/180 screen mesh using the round squeegee shape (see figure 11).

We found that coating the mesh with the liquid emulsion is more user-friendly than the processing of the capillary film in terms of exposition and wash out. Especially the 'template blade coating' technique with the Polycol S 295 HV emulsion proved to be a quick and practicable method and yielded satisfying results for really thick EOMs.

The liquid emulsion and the capillary film are able to achieve EOMs in the same range, but the emulsion yielded a thicker ink deposition. It seems that the emulsion shows different ink release behaviour than the capillary film. This has to be verified in a successive project.

Overall, the high EOM helps to print a rather steep slope angle. The wider the track width gets the less steep is the resulting track height profile. Regarding the influence of the mesh geometry, a mesh with a higher theoretical ink volume Vth is preferred over a mesh with a higher overall thickness.

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