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Influence of Substrate and Screen Thread Count on Reproduction of Image Elements in Screen Printing

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Abstract:

The printing plate and its characteristics in the conventional printing techniques have a significant impact on print quality and image appearance. In screen printing, a weave of screen mesh i.e. a number of threads per cm, is the most important characteristic of the printing plate, hence the most relevant factor which defines printing quality. Print quality itself is a complex term that includes desired colour reproduction and satisfactory reproduction of image elements. In this paper focus was centred upon the reproduction of text and basic image elements (lines and dot structure) when printing on non-absorbent and absorbent substrates with different screen thread counts. The image element analysis led to the conclusion that using mesh with higher thread count does not significantly improve the reproduction of image elements. However, it is a very important parameter for text reproduction since low thread count may result in poor readability.

Keywords:

Line Area, Line Perimeter, Dot Roundness, Mottle, Screen Thread Count

1. Introduction

Estimating print quality is a demanding task since it implies the use of objective methods to define the perception of printed material (which is subjective matter). The quality of print products can only be measured by taking into consideration colour reproduction fidelity. This, however, is not enough to define overall, perceived quality as stated by Pedersen et. al. (Pedersen et al., 2011). In order to obtain a bigger picture of print quality, it is necessary to estimate the reproduction of image elements (dots, lines, solid ink areas), as the basic parts of any reproduction. It can be stated that the line and dot structure which can be produced in a particular printing process influence the appearance of an image substantially (Dhopade, 2009), which is why it is important to evaluate the reproduction of these elements, together with colour reproduction control. By analyzing dots and lines attributes, additional quality parameters like sharpness and artefacts could be defined as much as some non-desirable effects (ink bleeding, non-uniformity etc.).

A group of engineers from Torrey Research Group investigated the influence of different attributes on print quality in ink-jet printing, stating that attributes they emphasized could be used to evaluate quality of any imaging systems (Torrey Pines Research, 2003). As the most critical to the evaluation of prints, the authors defined permanence, edge quality, artefacts, resolution/addressability, linear tone scale/colour reproduction and solid area quality (Torrey Pines Research, 2003). Some of these parameters are also accentuated by Dalal et. al (Dalal et al., 1998). The authors divided quality attributes into two groups: fundamental quality attributes and stability and material quality attributes. Attributes from the first group are visually relevant and could be assessed for both coated and uncoated substrates. Some of the addressed are: text and line quality, micro-uniformity, macro-uniformity, adjacency, gloss uniformity, effective resolution etc.

The importance of evaluating defined quality attributes could not be disputed; hence many methods and algorithms had been developed in order to improve quality control. Kipman (Kipman, 1998) suggested that some tests that are easy to implement and could be useful to evaluate media dependent image quality issues. These tests include (Kipman, 1998):

- Dot Quality (including tests for dot placement accuracy and variations in dot formation)
- Halftone Quality (including tests for area coverage)
- Line Quality (including tests for sharpness and edge noise as well as detestability tests for negative lines)
- Text Quality (including tests for connectivity and edge degradation)
- Colour Quality (including tests for colour registration and CIE L* a* b* measurements)
- Smear/Overspray
- Spatial Resolution.

Image quality attributes are primarily defined for ink-jet printing and had been evaluated for other digital printing techniques and offset printing. In this paper the focus was placed upon the reproduction of image elements and text in screen printing. Despite the significant technological development, halftone screen printing still remains a challenge (Szentgyörgyvölgyi and Borbély, 2011). In the case of this technology it is increasingly important to choose the right screen ruling according to the estimated viewing distance (Szentgyörgyvölgyi and Borbély, 2011). The aim of this work was to evaluate the influence of screen thread count and substrate on the quality of image elements in screen printing. Two different substrates were used and printing was performed with 4 screen thread counts. We chose to evaluate some of the basic image elements attributes - line geometry, text readability, dot roundness and mottle. The reproduction of lines was estimated by measuring line area, while text readability was assessed on small letters in the same manner (measuring letter area and perimeter). Dot roundness gave us information about dot distortion during printing, while mottle was chosen to measure non-uniformity in ink application.

2. Theoretical background

Screen printing permits the control of ink film thickness by the diameter of the fibres that form the mesh, when the ability of mesh to conform to surface characteristics is unchallenged by any other direct printing process (Ingram, 1999). The factors influencing the quality in screen printing are in close interaction with each other (Niir Board, 2003). Tone values of screen print are primarily influenced by the density of the mesh and thread weight (Szentgyörgyvölgyi and Borbély, 2011), hence in order to control colour reproduction, these factors had to be controlled more or less independently.

The reproduction of lines and dots is influenced by the properties of the printing plate (the mesh and the print-form making process), inks and substrates (Ingram, 1999). Screen thread count determines the smallest printable dot, while the ink viscosity determines dots regularity (low viscous inks creates irregular dots and fuzzy edges). Substrate absorption can affect colour strength and uniformity, but also the reproduction of dots and lines. When printing is performed on plastics, surface tension may impact the printability of the material (Ingram, 1999).

Pan et al. (Pan et al., 1998) investigated the effect of manufacturing process parameters on fine line reproduction when thick film deposition is obtained by screen printing. Four factors were investigated - print speed, squeegee hardness, squeegee pressure and snap-off distance. It was shown that squeegee hardness and print speed have the main influence on the quality of line reproduction. The higher is the squeegee hardness and lower the print speed, the better are the results (Pan et al., 1998).

By evaluating dots and lines appearance on printed material, sharpness and quality of image reproduction can be determined. Ink bleeding tends to make lines wider, hence estimating the line width changes could determine the bleeding degree. The evaluation of bleeding on small letters can give information about text readability. If ideal letter area and perimeter *deviates significantly* from measured values, it will indicate poor text readability.

Printed dot fidelity is determined by evaluating dot area and roundness (*Sarafano* et *Pekarovicova, 1999*). Dot roundness is very important parameter, since it represents the shape of the dot relative to a perfect circle. The ideal circular dot should be the one whose area is $\pi/2$ that of the corresponding square pixel. Printing a circular dot with diameter less than the diagonal of the square pixel at every addressed point will necessarily leave some area uncovered (Fleming et al., 2003). Similarly, if a dot is not perfectly round, its deviation can cause uneven ink coverage. Dot roundness is defined as (Fleming et al., 2003):

$$roundness = 4\pi\ (A/p2) \qquad (1)$$

where A is the area of the dot and p is its perimeter. The roundness is equal to 1 for circle, and is less than one for any other closed figure. The closer the roundness is to 1, the better is the quality of the dot. Fleming et al. (Fleming et al., 2003) stated that their analyses and interpretation are general and applicable to any printing processes where image quality is governed by the smallest printable dot. In screen printing, due to the technique itself, it is not expected that roundness reaches values as high as 1.

Macro non-uniformity is determined by measuring the mottle. Mottling is one of the most important defects in printing and can be defined as undesired unevenness in the perceived print density (Sadovnikov et al., 2005), or more precisely, as non-uniformity occurring on a scale greater than 1.27 mm. One of the causes for mottling is uneven absorption of ink into the substrate, producing a blotchy or a cloudy area (Dhopade, 2009). Degree of mottling can be defined by mottling index, which ideally should be 0. Mottling index or so called non-uniformity number (NU) is calculated from average of dots intensity above median (Ux) and those under median (Lx) by following equation (Muck et al, 2009):

$$NU = Ux - Lx \qquad (2)$$

Since the level of print non-uniformity is connected with intensity width span of picture dots, the larger the NU value, the bigger the mottling.

3. Methods and Materials

Two materials were chosen for printing substrates. They are categorized by their ability to absorb ink as non-absorbent and absorbent material. As an absorbent material matt coated paper, defined as type 2 according to ISO 12647-2:2004 (100 g/m2), was used. PVC foam (Forex) thickness of 3 mm was chosen as a non-absorbent substrate. Printing on both materials was conducted with inks based on nitro thinners (Sericol Trichromatic Plastijet TG).

Test image was created by means of Adobe Illustrator CS4 software, containing different elements used for print quality control as shown on Fig. 1. Test image dimensions was 29,7 x 42 cm. Elements assessed were lines (1 and 2 pt width), different text sizes ranging from 6-18 pt, micro and macro areas filled with black and area of 30% tonal value for black ink.

Screens with thread counts of 90, 120, 140 and 160 threads per cm were used for printing plates. Screen carriers were metal frames (58x84 cm), while the size of printing plates without a metal frame was 50x76 cm. Printing plates were made conventionally using linearized positive films. Maximum film density was 3.9, while minimum was 0,04. Film liniature was 5 times lower than the screen thread count and screen angles were set as: yellow 00, cyan 150, magenta 45° and black 750. As a photo sensitive coating we use Sericol Dirasol 915 emulsion. Exposure was performed with metal- halogen UV lamp (1000W), where the distance from lamp to screen measured 1 m. The exposure time for each printing plate was determined by using Autotype Exposure Calculator from Sericol. Table 1 summarizes different exposure times for each screen thread counts used for testing.

Table 1. Exposure time for each screen thread counts used

Screen thread counts (threads per cm)	Exposure time (min)
90	2,5
120	2
140	1,3
160	1

After exposing, printing plates were washed with water under pressure for 2 minutes and dried on a temperature of 39 °C for one hour.

Printing was performed on M&R Sportsman E Series, 6 colour screen printing press. Pan et

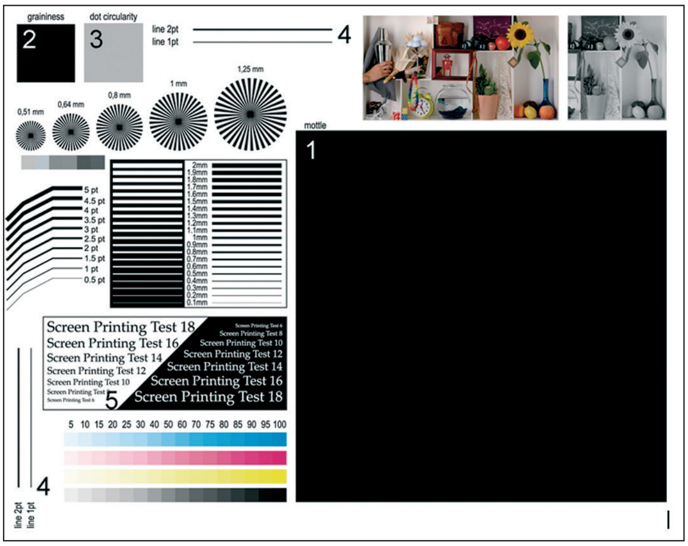

Figure 1. Test image used to evaluate reproduction of image elements (1 – area for macro non-uniformity control, 2 – area for micro non-uniformity control, 3 – element for dot circularity control, 4 – lines of 1 and 2 point width, 5 – text in positive and negative ranging from 6-18 pt)

al. (Pan et al., 1998) showed that four factors have significant influence on print quality in screen printing, so these factors were kept constant during printing on each material. Printing speed amounted to 15 cm per second, squeegee hardness - 80 Shore Type A, while pressure came to 275,8 x 103 Pa. Snap-off distance measured 4 mm.

After printing and drying, the elements of printed sheets relevant for further analysis were digitalized by Canon CanoScan 5600F scanner. Scanning resolution was set as 1200 spi and all auto functions were turned off. Substantial image elements were saved as separate tiff files and compared with the same elements from rasterized original test image. All values of importance were calculated within ImageJ software.

Line reproduction was assessed by measuring area of 1 and 2 point thick black lines. In this manner we determined the degree of bleeding for black ink. Bleeding was also defined on image segments containing text, where we assessed positive text size of 6 pt (for a comparison we use perimeter and area of letter "e"). Results of this comparison are a good indicator of text readability, since significant deviations in perimeter and area may result in poor readability.

Deviations in dot appearance were defined by measuring dot roundness on an image area covered with 30% black ink (25 x 25 mm). The roundness is obtained as a mean value of roundness of 10 dots, where dots to be measured are sampled randomly from the whole area of interest.

Macro-non uniformity (mottle) was assessed on 160 x 160 mm area covered with black ink (100% TV). So as to determine the non-uniformity number (mottling index), we use a plug-in for ImageJ software developed by Stanic, Muck and Hladnik (Muck et al.,2009). In order to determine the deviations from ideal reproduction visually, some of the image elements (text and dot structure) are also captured with Sibress Pit camera (elements were magnified 20 times). Results and discussion are given in the following chapter.

4. Results and Discussion

4.1 Line assessment

Results obtained from measuring a 2 pt thick line area, when printing is performed on PVC foam with different screen thread counts, are given in Fig. 2. If screen thread count increases, the line area increases too. The only exception was noticed when a mesh with 120 threads per cm was used both for 2 pt and 1 pt line (Fig. 2-3). The largest deviation from original for 2 pt line was only 1.68 mm2, and the differences between line areas, if different thread counts were used, are rather small (the largest deviation is only 6.78% of original line area). The largest deviation from original for 1 pt line was 44.52%.

When printing was performed on paper, the changing of the screen thread count had a larger impact on line areas. The trend of increasing the area in this case was almost linear (Fig. 4 and 5). Deviations from original were more noticeable - the larger was 16.13% of original line area for 2 pt line and even 56.46% for 1 pt line. These results are expected since paper is a more absorbent material than PVC.

4.2. Text readability

In order to evaluate text readability, we measured the area and perimeter of letter "e" size of 6 pt. When printing was performed on PVC foam, a significant degree of reduction in area values (comparing to the ones measured from original test image) was noticed (Fig. 6). The reduction is more obvious on lower screen thread counts.

The letter area was significantly reduced on paper prints as well (Fig. 7). There is no linear trend here – the increasing number of threads per cm did not necessarily increase the letter area. The reduction of the letter area results in poor text readability which can be seen on Fig. 8, where 6 pt text is magnified 20 times using Sibress Pit camera.

Different screen thread counts or the substrate did not affect letter perimeter significantly as can be seen from Fig. 9-10.

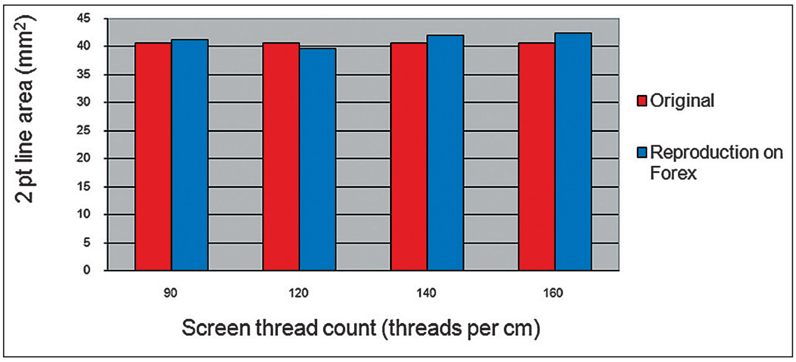

Figure 2. Areas of 2 pt thick lines printed on Forex with different thread counts

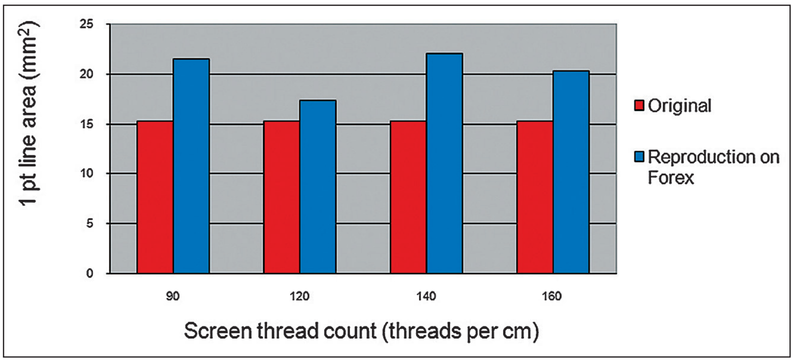

Figure 3. Areas of 1 pt thick lines printed on Forex with different thread counts

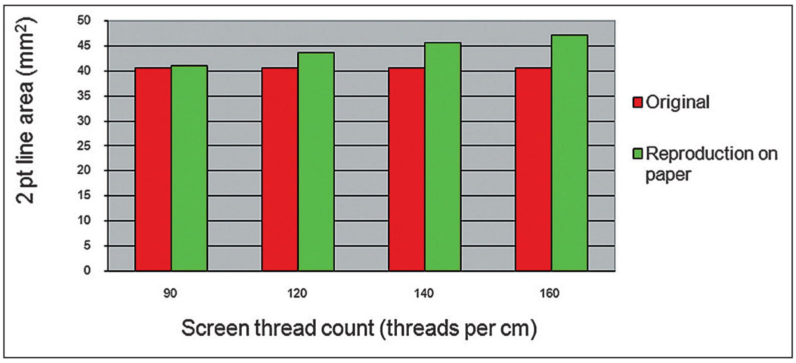

Figure 4. Areas of 2 pt thick lines printed on paper with different thread counts

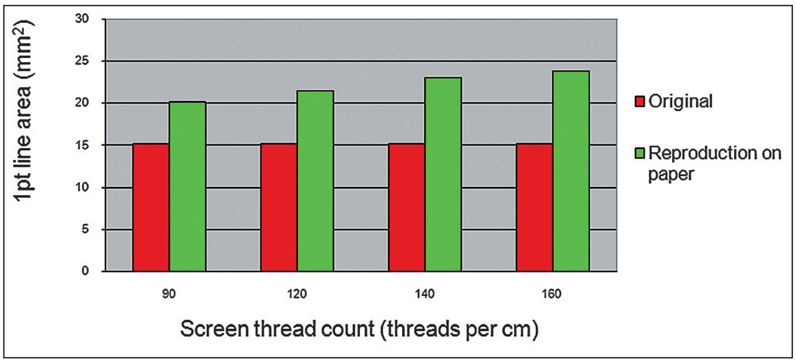

Figure 5. Areas of 1 pt thick lines printed on paper with different thread counts

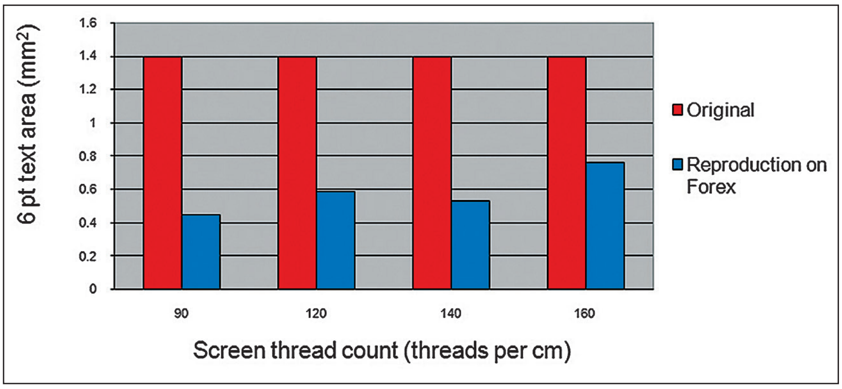

Figure 6. Areas of 6 pt letter e printed on Forex with different thread counts

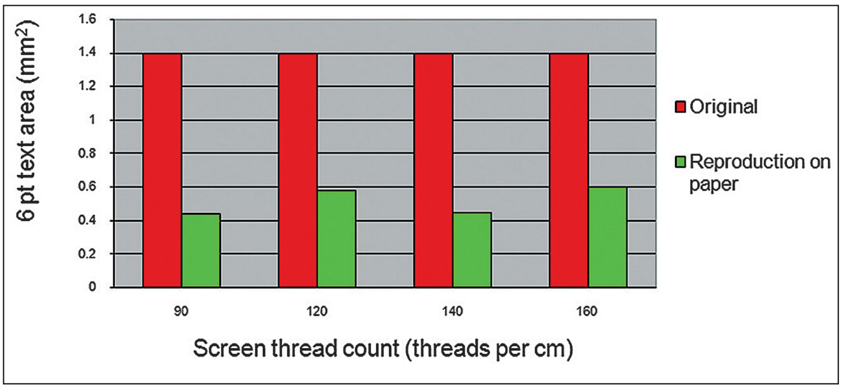

Figure 7. Areas of 6 pt letter e printed on paper with different thread counts

Figure 8. 6 pt text printed on paper (magnified 20 times)

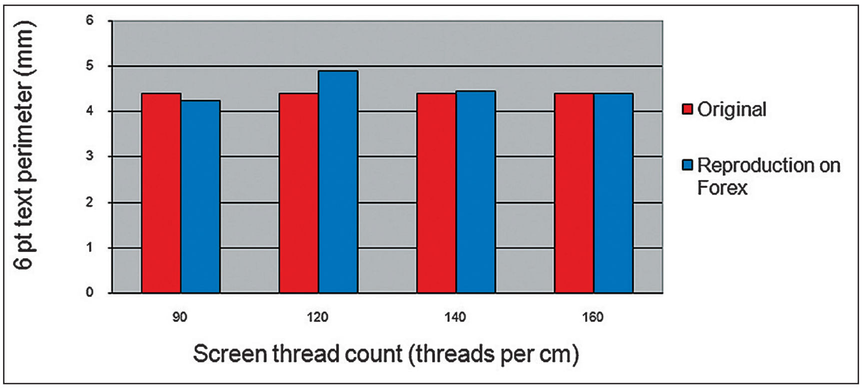

Figure 9. Perimeter of 6 pt letter e printed on Forex with different thread counts

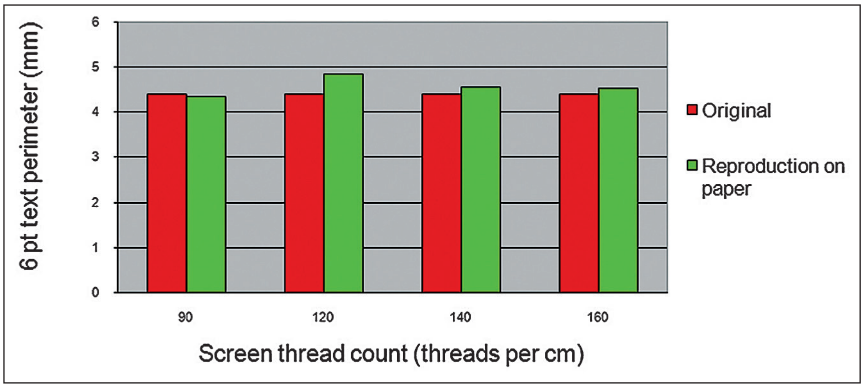

Figure 10. Perimeter of 6 pt letter e printed on paper with different thread counts

4.3 Dot roundness

Dot roundness was measured on areas of 30% TV for black ink. Obtained values for each material and screen thread counts are given in Table 2.

Table 2. Dot roundness values

Dot roundness				
threads/cm	90	120	140	160
Forex	0.884	0.906	0.884	0.875
Paper	0.866	0.664	0.869	0.867

Increasing screen thread count did not affect dot roundness significantly. For paper prints the largest deviation from ideal case was noticed when a mesh with 120 threads/cm was used, while for PVC prints, this liniature provided the best results.

From the results given in Table 2 it can be concluded that the substrate affected dot roundness, more circular dots being obtained when printing was performed on PVC. Differences are rather small and it was to be expected that dots reproduced on these substrates had approximately the same shapes. This, however, was not confirmed visually. From the images showing dot structures detected with Sibress Pit camera (Fig. 11) it is evident that dots printed on Forex and paper do not have the same shape. Differences in measured and observed roundness could be explained with the method used for calculating roundness value. Though dots reproduced on paper are perceived as more circular, the raggedness of the dots leads to higher perimeter and hence lower roundness value. Roundness values obtained from measuring dots areas and perimeters are still a significant fact, since the dots with ragged structure do not contribute to the good reproduction of image details.

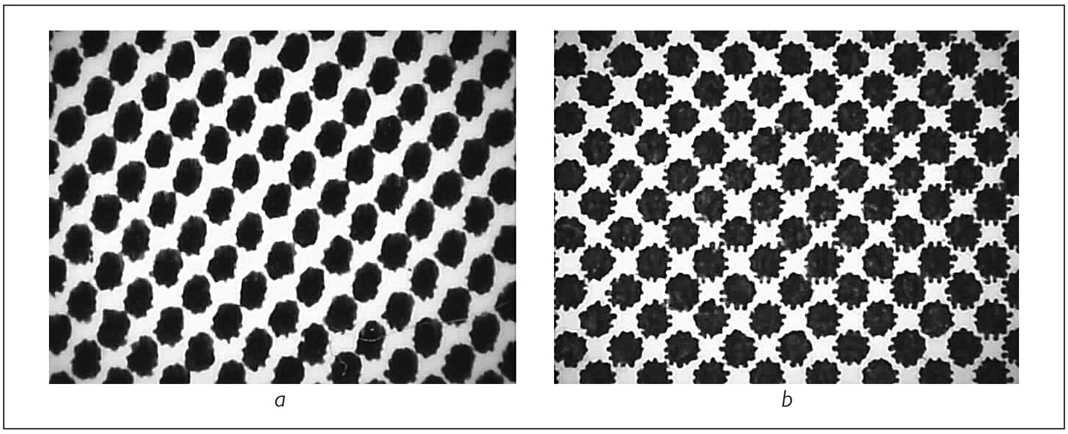

Figure 11. Dot structure of 30% TV detected with Sibress Pit camera. Substrate: a – Forex, b – paper

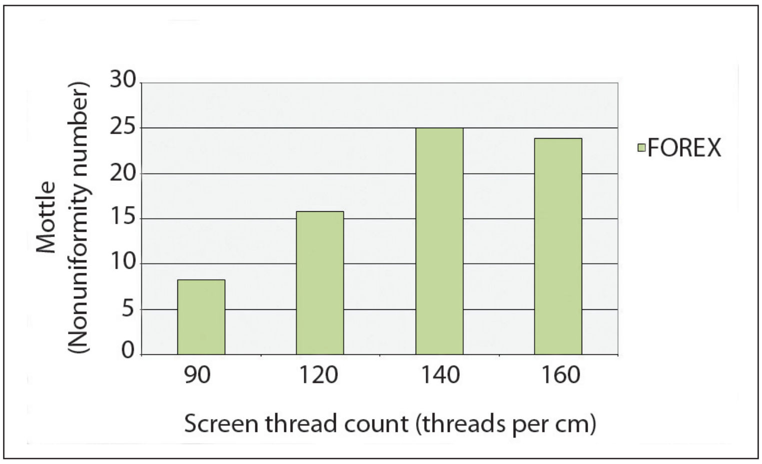

Figure 12. Degree of mottle for Forex prints

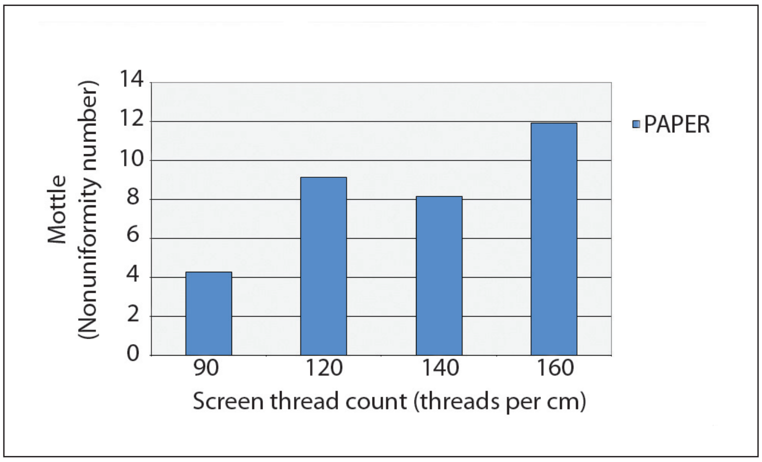

Figure 13. Degree of mottle for paper prints

4.4 Mottle

Degree of mottle was defined with a non-uniformity number. Mottle index increases with increasing screen thread counts as seen on Fig. 12-13. Comparing NU numbers for paper and forex, higher values were obtained for Forex prints.

5. Conclusion

This paper provides the assessment of influence of screen thread count and substrate on the reproduction of image elements in screen printing. Using the forms with four different thread counts, prepared in the same manner, we perform test images printing on two different substrates - paper and PVC. By using a software for image analysis, line reproduction and text readability were evaluated, and the changes in dot structure and macro non-uniformity defined.

The changes in line area led to conclude that ink bleeding occurs for every substrate used (area values were higher than ideal case). With the increase in screen thread counts, line areas increased as well – non-linearly for forex and linearly for paper. Hence, it was concluded that mesh liniature did not affect the reproduction of lines in the same manner for different materials.

Text readability assessment showed that letter areas and perimeters decreased from ideal case for both substrates used. This results in poor readability, which can be improved if higher screen thread counts are used.

Dot roundness assessment showed that the increase in screen thread counts did not significantly affect dot shape. When different substrates were used, dot roundness values failed to predict perceived dot shapes. This indicates that dot roundness evaluation method was not appropriate for dot shape evaluation. However, it is a good indicator of dot regularity, and can be used to predict the quality of image details.

By increasing the number of thread counts mottling index increased for non-absorbent substrate (PVC) and varied non-linearly for absorbent material (paper). Non-uniformity was more noticeable for PVC prints.

Taking all results into account, it can be concluded that the use of higher screen thread counts for non-absorbent substrate does not significantly change the reproduction of image elements. The only exception are solid colour areas, where higher screen thread counts results in lower uniformity. For paper prints it was noticed that the use of higher thread counts increased the bleeding. The evaluation of text readability showed that higher screen thread count contributes to better reproduction for all materials used. It was also noticed that dot roundness was not a meaningful parameter for assessing deviations in dot shape in screen printing, but that could be used in order to predict the reproduction of image details and artefacts. In order to confirm these insights, further testing should be performed and more substrates with the same absorption power should be evaluated.

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