SCIENTIFIC PAPERS
OF THE UNIVERSITY OF PARDUBICE
Series A
Faculty of Chemical Technology
17 (2011)

INVESTIGATION OF FACTORS INFLUENCING TONE REPRODUCTION IN SCREEN PRINTING

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Received September 30, 2011

Screen printing is one of the oldest printing processes. While its theory and tools did not change significantly, the technology underwent a considerable improvement during its history, and continues to develop in the 21st century as well. Screen printing allows deposition of a thick layer of ink onto the substrate, enabling the use of ideally any kind of substrate. In the case of this technology it is increasingly important to choose the right screen ruling according to the estimated viewing distance. Despite the significant technological development, halftone screen printing remains a challenge. Factors influencing quality are in close interaction with each other. For the optimal output it is necessary to control these factors more or less independently to produce high density screen prints in high quality. Tone values of the screen print are primarily influenced by the density of the mesh and thread weight. In practice the smallest dot will determine the usable highest screen ruling. In our research we investigated the effect of screen

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ruling on print quality. Test charts were printed on PVC and PP substrates using 36 l cm^{-1} and 60 l cm^{-1} screens ruling. Optical measurements were performed to determine density values, TVI curves, gamut volume to investigate the factors influencing tone reproduction quality. Magnified images were used to evaluate substrate-ink interaction.

Introduction

Since screen printing is a well-established and viable printing technology, it had been developing continuously and dynamically. Considerable development was brought by the appearance of UV inks and UV dryer units. A reasonably thick layer of ink can be deposited by this technology; this property makes it ideal for printing a wide range of substrates (wood, metal, textile, glass, paper, plastic). This unique printing process has the potential to penetrate to market segments other than the ones being traditionally in the scope of graphic industry, such as advertising. Technological development induces the demand for producing a wide range of tonal values. However, the ways toward this objective are seldom based on solid findings, but rather on experience and experiments [1,2]. Our research work focuses on the evaluation of the factors influencing print quality of halftones produced using two different screen ruling: 36 l cm^{-1} and 60 l cm^{-1}.

Experimental

Squeegee

The flexible doctor blade (or squeegee blade) has outstanding influence on the sharpness of the print, choosing the improper type of blade may become the source of many problems. Rectangular blades are ideal for producing sharp images. Another important feature of the blade is its hardness: for quality test prints at least 85-90 Shore hardness value is recommended. The hardness of the blade will influence abrasion resistance and chemical durability against solvents, as well as the extent to which the blade bends during printing [3,4]. A hard blade will produce sharper image and a thinner layer of ink on the substrate, indirectly influencing print quality. The applied blade was very hard (90° Sh) with rectangular profile.

Screen Printing Mesh

Resolution of the mesh is the capability of reproducing a halftone pattern with a given screen ruling (l cm^{-1}). Mesh count and the ratio of the thread diameter to the mesh-opening are primarily responsible for the optimum resolution. Meshes with larger mesh-opening than thread diameter are suitable for producing high resolution images. Thread diameter itself determines smallest printable dot size. This parameter has to be chosen carefully before raster image processing [5,6].

For our investigations prints were produced using PET 1500 150/380-31Y PW type high modulus, plain weave monofilament polyester mesh manufactured by SEFAR (Table I).

Table I Mesh properties

SEFAR monofilaments mesh	
Ruling, cm^{-1}	150
Tread diameter, μm	31
Mesh-opening, μm	29
fabric thickness, μm	37
Mesh tension, N cm^{-1}	12
Dot area, %	15-80
Smallest printable dot, μm	80-100

Rheological properties of the ink also play an important role in producing detailed halftone prints. As a unique feature of the screen printing process, rheological behaviour of the paste together with the mesh wettability properties will influence the print quality. In the case of printing small dots, the thread may block the dot opening preventing the paste from being transferred to the substrate. This problem is most likely to occur in highlight areas. Bounding regions of the tonal range are hard to implement with this printing process [7].

Photo Emulsion

The stencil form was created using CPS ULTRA COAT diazo-photopolymer emulsion. This type of “dual cure” diazo-sensitized emulsion is highly resistant against water and solvent based inks. Due to the high percentage solids, the optimum results can be produced using the 2 + 4 manual technique. The drying process of the stencil form was controlled accurately, the coated screen was kept in a dark place free of dust, with low humidity in horizontal position. It is crucial to prevent contraction of the emulsion which can be responsible for non-uniform surface areas [8]. Constant temperature (max. 30 °C) and good ventilation also improve the drying process. The thickness of the emulsion layer was measured by Elcometer 345 coating thickness gauge at five different locations; the average value was 43.25 microns.

Screen Printing Ink

ULTRAFORM UVFM, a UV curable ink for graphical screen printing applications was developed by Marabu corporation for plastic substrates. This flexible, fast curing ink is suitable for reproducing a wide range of colours. Generally UV curing screen printing inks are solvent free, have high mechanical and chemical resistance and short curing time [2]. Our test prints were cured with a 100 W UV lamp, travel speed inside the drying unit was approximately 27 m min^{-1}; the manufacturer's specifications allowed for 100-120 W power and 25-30 m min^{-1} travel speed. Before printing the next colour, test prints were stored properly for drying. The manufacturer's standard density values for process colours are: 1.4-1.5 D (Y), 1.4-1.5 D (M), 1.4-1.5 D (C), 1.8-1.9 D (K).

Printing Materials

We have chosen two plastic sheet substrates that are frequently used in industry: VIKUNYL PVC (#1) and VIKUPRON polypropylene (#2). Our test chart comprised of a 10 step CMYK wedge, RGB full tone patches, Arial and Times New Roman text 24-6 pt size. Test prints were produced with 36 l cm^{-1} and 60 l cm^{-1} screen ruling on a SVECIA PC semi-automatic flat-bed press; 10 copies were printed with both resolutions. To improve the appearance of the printed image, special screen angle values were applied: C (97.5°), M (157.5°), Y (82.5°), K (127.5°).

Methodology

Tone value increase (TVI), reproducible colour gamut and colour differences were measured on the test prints. We used X-Rite SpectroEye spectrophotometer (380-780 nm spectral range, a 0°:45° measurement geometry, 4.5 mm aperture diameter, D65 filter).

Results and Discussion

Properties of Plastic Substrates

The physical properties of the plastic substrates were investigated first. The surface smoothness was measured using a Beck instrument. The surface tension values were determined with a set of test pens (32-40 mN m^{-1}), both substrates passed the test at 36 mN m^{-1}. The substrate properties are listed in Table II. The PVC substrate

(#1) is heavier; it has a very smooth surface and optimum printability properties. PVC substrates are strong, rigid, and resistant to many organic and inorganic chemicals; they are usable typically in the 0-60 °C temperature range. The lighter PP substrate (#2) has a surface pattern. PP substrates are usually more rigid, endure higher temperatures (up to 100 °C) and also have a good resistance against chemicals.

Table II Substrate properties

Property	Foil #1	Foil #2
Caliper, mm	0.3	0.3
Weigth, kg m^{-2}	0.44	0.39
Smoothness, s	85.0	11.8

Tone Value Increase in CMYK Prints

The density values measured on different substrates vary to a larger extent than the values on the same substrate with different screen ruling. The best match with the digital proof was achieved in the case of the PP substrate with 60 l cm^{-1} ruling.

Table III Measured optical density values of CMYK process colours on substrate printed with 36 l cm^{-1} and 60 l cm^{-1} resolution

Prints	Optical density			
	C	M	Y	K
Proof	1.20	1.59	1.15	1.61
#1 (36 l cm^{-1})	1.14	1.62	1.16	1.47
#1 (60 l cm^{-1})	1.14	1.62	1.09	1.52
#2 (36 l cm^{-1})	1.17	1.61	1.30	1.47
#2 (60 l cm^{-1})	1.23	1.62	1.38	1.57

Density values of the magenta ink show the smallest variation and differ the least from the values of the proof.

Curves of tone value increase (TVI) were measured on the 10-100 % process colour tone patches of the test chart (Figs 1 and 2). Tone value increase was higher in the case of the PP substrate and with 60 l cm^{-1} ruling.

Magnified portions of CMY prints with 20 % dot area (Fig. 3) illustrate ink deposition on the surface, images of the PP substrate appear more blurred due to the more diffuse reflections from the less smooth, patterned surface.

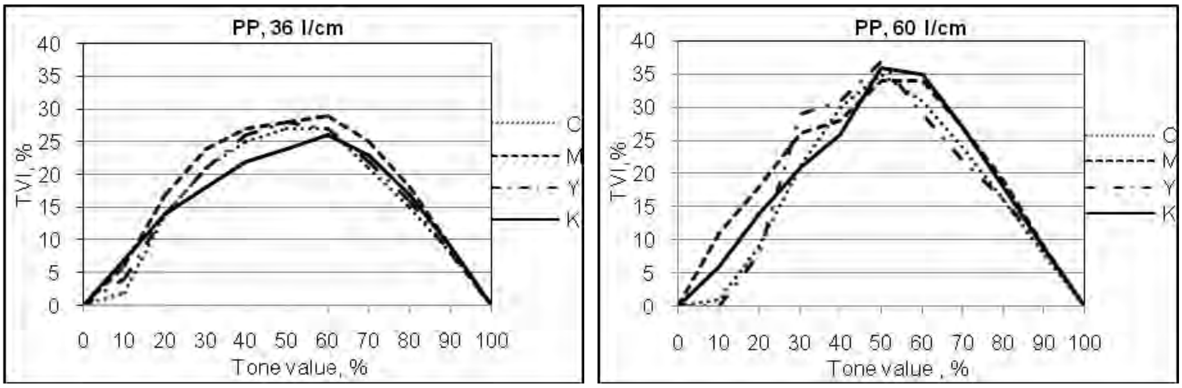

Fig. 1 TVI curves of process colours on PP substrate printed with 36 l cm^{-1} (left) and 60 l cm^{-1} (right) screen ruling

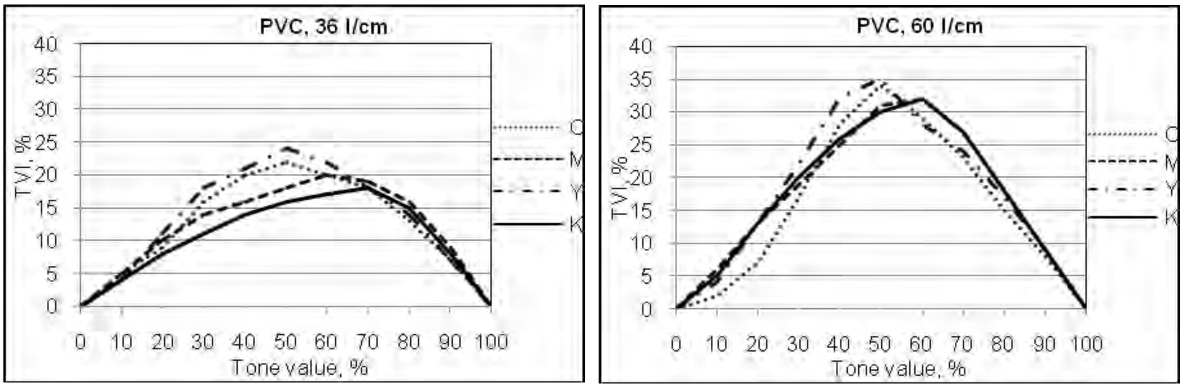

Fig. 2 TVI curves of process colours on PVC substrate printed with 36 l cm^{-1} (left) and 60 l cm^{-1} (right) screen ruling

Colorimetric Properties

We used the measured CIELAB values of the full tones of process colours (CMYK) to investigate colorimetric differences between our test prints. The print run comprised 10 individual prints produced by the same printing form. Average colour differences (ΔE^*_{ab}) between the test print process colour patches are shown in Table IV, the largest values are near the just noticeable threshold level. In the comparison of the average CIELAB values of the test prints (Table V) substrate #1 with 60 l cm^{-1} resolution was chosen as a reference, because it produced the highest chroma (C*) with both magenta and yellow colours. Differences are near threshold level, except for the case of yellow process colour where large differences occur, in agreement with the variations in density values. Table VI shows the differences between substrates printed with the same resolution and between prints on different substrates printed using the same resolution. Changing of the substrate or the screen ruling induces the largest shifts in yellow colour.

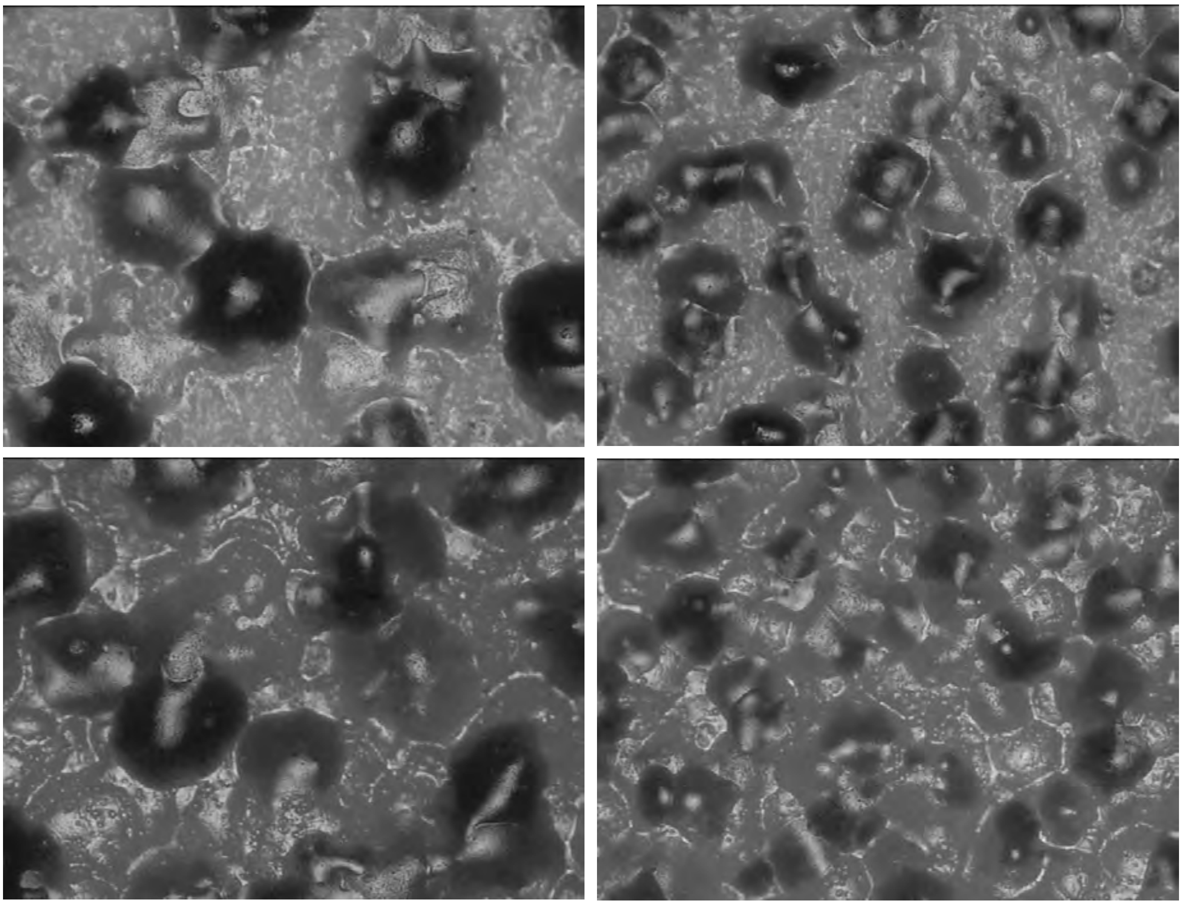

Fig. 3 Magnified images of 20 % CMY patch on PVC (upper row) and PP (lower row) substrates printed with 36 l cm^{-1} (left column) and 60 l cm^{-1} screen ruling (right column)

Table IV Average colour differences of process colour full tones between mean and 10 test samples

Prints	Colour difference (ΔE^*_{ab})			
	C	M	Y	K
#1 (36 l cm^{-1})	1.03	0.77	0.82	0.26
#1 (60 l cm^{-1})	0.80	0.29	0.44	0.33
#2 (36 l cm^{-1})	0.47	0.50	0.53	0.32
#2 (60 l cm^{-1})	0.25	0.34	0.49	0.20

Reproducible Colour Gamut

Printing materials, the applied technology, parameters of the printing process are all responsible for the reproducible colour gamut. In our case the variables were the substrate and the screen ruling, other parameters and components were kept con-

Table V Colour difference values of average test prints, substrate #1 with 60 l cm^{-1} resolution was chosen as a reference

Prints	Colour difference (ΔE^{*}_{ab})			
	C	M	Y	K
#1 (36 l cm^{-1})	1.15	1.64	4.61	0.93
#1 (60 l cm^{-1})	-	-	-	-
#2 (36 l cm^{-1})	1.09	1.69	6.77	1.81
#2 (60 l cm^{-1})	1.89	0.60	1.23	2.63

Table VI Colour difference between prints on different substrates with the same resolution (upper rows) and between prints with different resolutions on the same substrate (lower rows)

Prints	Colour difference (ΔE^{*}_{ab})			
	C	M	Y	K
#1 – #2 (36 l cm^{-1})	0.97	3.02	2.59	1.36
#1 – #2 (60 l cm^{-1})	1.89	0.60	1.23	2.63
#1 (36 l cm^{-1} – 60 l cm^{-1})	1.15	1.64	4.61	0.93
#2 (36 l cm^{-1} – 60 l cm^{-1})	1.58	1.10	5.70	0.96

stant. For accurate comparison of reproducible colour ranges the device- dependent three dimensional colour solids have to be calculated. In our study we used only the primary and secondary colours of four colour printing (C, M, Y and R, G, B) to demonstrate boundaries of the achievable ranges in a^*, b^* chromaticity diagram. This way differences in L^* dimension are not considered, but our results show a close match of brightness values as well as of gamut boundaries (Fig. 4).

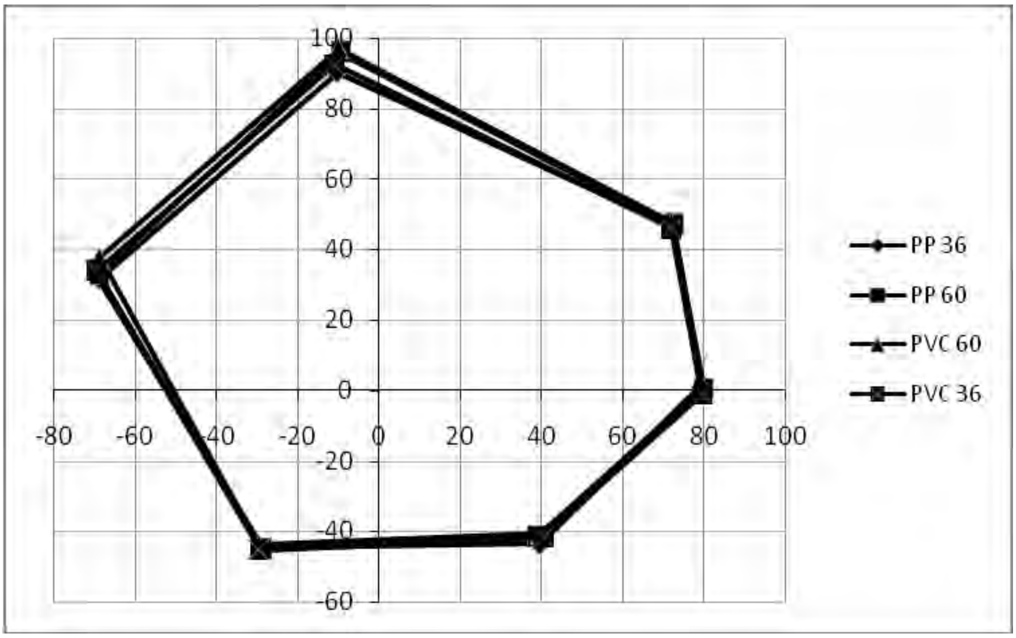

Fig. 4 Illustration of reproducible colour gamut in *a**, *b** chromaticity iagram in case of the two types of screens and substrates

Conclusion

In our study we investigated screen prints on two types of plastic substrates, printed on the same press with two different screen rulings. We found that with higher screen ruling higher TVI values were produced, as well as in the case of the less smooth polypropylene substrate with surface pattern. Density values of the yellow colour varied considerably relative to the other process colours, this behaviour reappeared in the colorimetric data. Switching between substrates and screen ruling caused only threshold level colour differences. Significant changes were not experienced in reproducible colour gamut.

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