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Transfer of Ink-jet Printed Textiles for Home Furnishing into Production with Rotary Screen Printing Method

Abstract
In this work, a collection of decorative textiles for home furnishing was designed on a CAD CAM system, printed with an ink-jet printer, and transferred into production using rotary screen printing. The basic materials used were linen woven fabric and reactive dyes. Colorimetric measurements were carried out for the samples printed with both printing procedures. The reflectance values, CIELAB colour values and ΔE colour difference values were obtained and compared using two spectrophotometers. The colour fastness of the printed fabrics to washing, rubbing and artificial light was determined according to ISO standards. The research shows that an ink-jet printed collection can be transferred to rotary screen printing. The implementation of an ink-jet printing system in a traditional production process is recommendable for a traditional printer, because the sample collection can be prepared with significant savings in costs and faster turn-around.*

Key words: *ink-jet textile printing, rotary screen printing, reactive dyes, design of textile collection, CAD CAM system, colourimetry.*

Introduction

The textile printing market recorded a total production of around 25 billion m^2 of printed fabrics for 1996. As a dominant textile printing method, rotary screen printing represents 61% of the total production of printed textiles [1-2]. The increasing demand for environmental protection, short process runs, quick response times, and mass customisation in the textile industry has increased interest in ink-jet printing technology [3]. Digital textile printing has been recognised as a fast-growing part of the textile printing market, and recorded a growth from 745 to 12 454 printers in the period from 1998 to 2003 [4-5].

In recent years, considerable effort has been put into the development of the textile ink-jet printing field, with systems available for production, strike-off and sampling [3,6-9].

In a design process, digital printing technology saves time for design alteration, colourways and strike-off [10-11]. It has been established that, thanks to digital printing technology, designers can now reduce textile research and pattern design time by over 50% [12-13]. The designer can now see how a particular piece of fabric or garment will look in different colours and shapes without having to commit to a final product [12].

When an ink-jet is used for sampling and is transferred to traditional production, it is necessary to achieve a close resemblance to ink-jet printed fabrics and the final fabric print, and to obtain comparable colour characteristics and fabric handle [14-15].

The goal of our research was to prepare a sample collection using ink-jet printing, and then to transfer it to a production line

Figure 1. Designs prepared on a CAD CAM system (Designs by Mašenka Mikuž).

Figure 2. *Multiple colorways printed digitally using ink-jet printing (Design by Mašenka Mikuž).*

for printing with a rotary screen-printing method [16-17]. The exact transfer of colours was an important issue, and multiple colour measurements were performed on test samples with two different measurement systems. These systems use different measuring geometries and different measurement apertures, one with a specifically small aperture. Differences in measurement results were observed. The purpose was to evaluate whether a system with a small measurement aperture is suitable for the colour evaluation of printed textiles.

Preparing a collection

In this research, a decorative textile collection of home furnishing fabrics, including curtains, tablecloths and napkins, was printed on linen fabric. The designs were prepared according to the design trends in 2002/2003. The selection of designs was performed in several phases. In order to create designs that would be interesting for the end user, the members of the team had to collaborate closely in the selection process.

In the first phase, twelve different designs (Figure 1) were prepared, hand-drawn on paper and scanned with an Epson GT-10000+ scanner (Seiko Epson Corp.). Design repeats were prepared by a CAD CAM system with the advanced Socrates software (Sophis Systems NV). All designs were adapted for transfer to the rotary screen-printing process. Six colours were used (the maximum number of colours was set by the textile factory), and the height of the repeats was set to 64 cm in order to cover the circumference of the rotary screen stencil. This method enabled the collection to be transferred from digitally printed samples to traditional production.

Two preferred designs were selected in the second phase. Further modification (colouration) for the ink-jet printing process was performed with a CAD CAM system. Ten design colourways (30 × 40 cm) were then printed on linen fabric using an ink-jet printer (Figure 2).

The visual appearance of the printed colourways was evaluated, as was the quality of the overall look after colour combination. A sample collection of six colourways was then printed on linen fabric using an ink-jet printer (at production-scale fabric width), and five metres of each colourway printed.

In the final phase, the textile factory selected two coordinate colourways for traditional production [16-17]. Both design colourways, design 'a' and design 'b', are presented (Figures 3 and 4) in this paper. A CAD CAM system was used to prepare the separation files (Figure 5) and colour tables (Figures 3 and 4) for both designs to be printed on the production line of the Tekstilna tovarna Prebold d.d. textile factory, Slovenia.

Experimental

Materials

Substrate: A scoured and bleached woven (plain weave) 100% linen fabric was used in our research (130 g/m^2, 22 threads/cm in warp direction, and 17 threads/cm in weft direction) produced by Tekstilna tovarna Prebold d.d.

Thickeners: The pretreatment of the linen fabric for ink-jet printing was performed with a low-viscosity alginate thickener CHT-Alginate NV (CHT R. Beitlich GmbH) with an 8%-8.5% concentration of solid content. The colour printing paste for rotary screen printing was prepared with a high-viscosity alginate thickener CHT-Alginate EHV (CHT R. Beitlich GmbH) with a 3%-4% concentration of solid content.

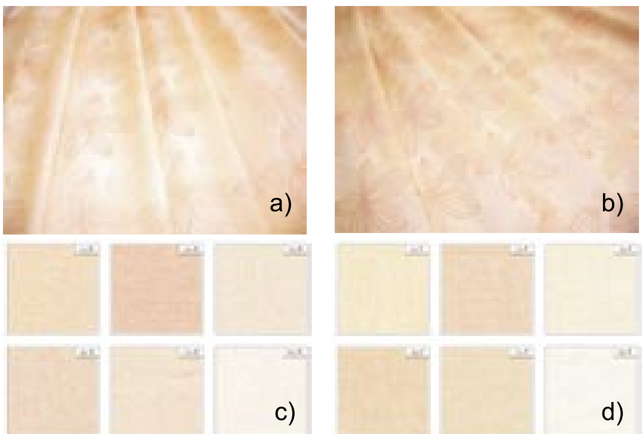

Figure 3. *Design »a« printed digitally using ink-jet printing (a) and the same design printed using rotary screen printing (b), color table printed using ink-jet printing (c) containing samples: 1a-B, 2a-B, 3a-B, 4a-B, 5a-B, 6a-B, color table printed using rotary screen printing (d) containing samples: 1a-P, 2a-P, 3a-P, 4a-P, 5a-P, 6a-P.*

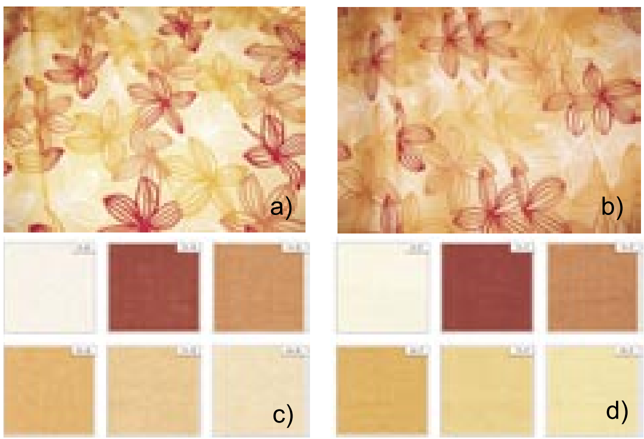

Figure 4. *Design »b« printed digitally using ink-jet printing (a) and the same design printed using rotary screen printing (b), color table printed using ink-jet printing (c) containing samples: 1b-B, 2b-B, 3b-B, 4b-B, 5b-B, 6b-B, color table printed using rotary screen printing (d) containing samples: 1b-P, 2b-P, 3b-P, 4b-P, 5b-P, 6b-P [15].*

Dyes: Commercially available reactive dyes from Ciba Specialty Chemicals were used in the printing processes. Ink-jet printing (CMYK system) was carried out with Cibacron MI water-based inks, with the standard set of four process colours: turquoise MI-700, red MI-400 (C.I. Reactive Red 24), yellow MI-100 (C.I. Reactive Yellow 95) and bMI–900 (C.I. Reactive Brown 11). The rotary screen-printing was performed with the following Cibacron P dyes: yellow P-6GS (C.I. Reactive Yellow 95), golden yellow P-2RN (C.I. Reactive Yellow 181), orange P-2R (C.I. Reactive Orange 13), orange P-4R (C.I. Reactive Orange 35), red P-BN (C.I. Reactive Red 24) and brown P-6R (C.I. Reactive Brown 11).

Textile auxiliary agents and chemicals: Urea and soda ash were used for the pre-treatment of the linen woven fabric for ink-jet printing. The colour printing pastes for rotary screen printing contained urea, soda ash and an oxidative agent. A non-ionic washing agent was used in the washing process.

Production of collection using ink-jet printing

The linen fabric was pre-treated in a textile factory on a Brückner foulard with a solution containing 15% thickener, 15% urea, and 3% soda ash. The wet pick-up was 70%, and the fabric was dried at 80 ^{o}C for 1.5 min. A PC system with the following software (ErgoSoft AG) was used for the ink-jet printing process: ColorProf for the printer colour calibration and making the colour profile, and TexPrint (RIP) for printing. In ink-jet printing, the deposition of ink is controlled by the printer colour calibration system and making the colour profile. At first, the maximum amount of ink was determined by testing the maximum ink uptake on the substrate. The maximum amount of ink is represented by the highest possible ink deposition on the substrate where the inks do not start to bleed. For the fabric used in our research, the maximum amount of ink was determined to be 200%. A sample collection and its colour tables were then printed using the Encad 1500 TX ink-jet printer by the DOD thermal technique method. All printouts were made at the following printing conditions: resolution 300 dpi, the CMYK system, 200% ink limit, bi-directional, six passes, standard head transition 4, and the standard optical density default. The printed fabrics were air-dried, and steamed at 15 m/min on a Vapolitermotex industrial Arioli steamer at 102 ^{o}C for 9 min in saturated steam. The steamed fabrics were washed at 75 m/min in a Goller industrial washing machine (five-step procedure) by cold rinsing (at 20 ^{o}C), followed by warm washing (at 50-60 ^{o}C), hot washing (at 80-95 ^{o}C) with an added washing agent (0.5 g/L), hot washing (at 80-95 ^{o}C) with an added washing agent (0.5 g/L), and cold rinsing (at 20 ^{o}C). The washed fabrics were then dried at 35 m/min on a Brückner conveyor dryer at 120 ^{o}C for 1.5 min. The same after-treatment for the printed fabrics was used in all the following procedures.

Production of collection using rotary screen printing

Two colourways, design 'a' and design 'b', were selected from the ink-jet printed collection for transfer to a job lot production using a rotary screen-printing process.

To ensure exact colour transfer, the colour tables for rotary screen printing were prepared according to the standard colour tables for printing with ink-jet printing (Figures 3 and 4). Preparation of the colour tables for rotary screen-printing was controlled colorimetrically using the Avantes measurement system (Avantes BV) with a Spectrocam 75 RE spectrophotometer, which has a measurement area of 1.5×2 mm, and uses 0 ^{o}(±5 ^{o})/45 ^{o} measurement geometry. The data was stored on a PC system with Avantes Spectrocam R75 software. All the samples were also measured using the Datacolor measurement system (Datacolor Int.) with a Spectraflash SF600+ spectrophotometer, which has a measurement area of ϕ9 mm and a measuring geometry d/8^{o}. The data was stored on a PC system with Datamaster software.

First, the reflectance values of the standard colour tables printed with ink-jet printing were measured using the Avantes system; then, the reflectance values of 2000 colour samples as collected in a production colour book, printed with dyes for rotary screen printing, were measured using the Avantes system.

Table 1. *The color printing paste recipe for rotary screen printing.*

	Ingredient	Concentration, %
Stock clear	Thickener (powder)	4.0
	Anionic agent	0.2
	H_2O	95.8
		100.0
Color printing paste	Stock clear	50.0
	Soda ash	1.5
	Urea	10.0
	Oxidative agent	1.0
	Reactive dye	X
	H_2O	Y
		100.0

Table 2. *Rotary screen printing process on a machine for sampling.*

Phase	Conditions
Printing	■ Rotary screen printing machine (J. Zimmer) ■ Rotary screen stencil: Penta Screen 125 mesh (Stork) ■ Printing speed: 5 m/min ■ Squeegee diameter: 12 mm ■ Magnet pressure: level 6 ■ No. of passes: 1
Drying	■ Drying chamber ■ T = 50°C, t = 10-15 min
Steaming	■ Industrial steamer Vapolitermotex (Arioli) ■ v = 15 m/min, T = 102°C, t = 9 min, saturated steam

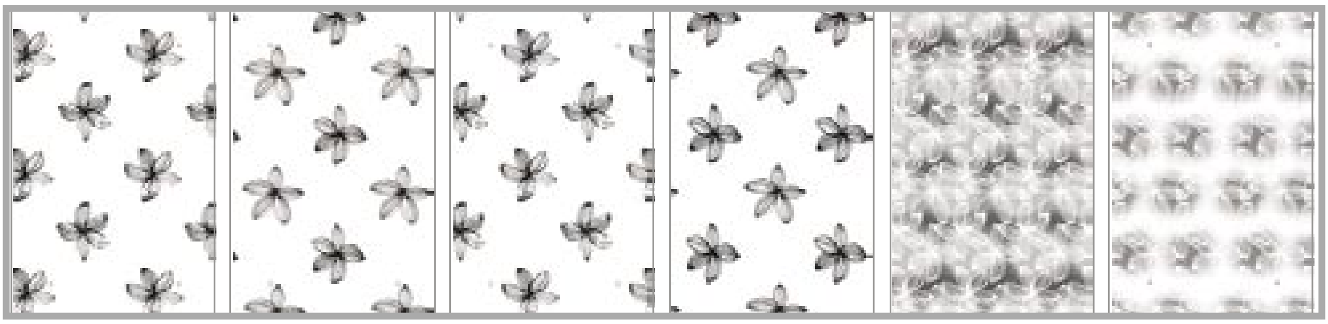

Figure 5. *Color separation files for designs 'a' and 'b': foreground colors from 1 to 4, background colors from 5 to 6, (from left to right).*

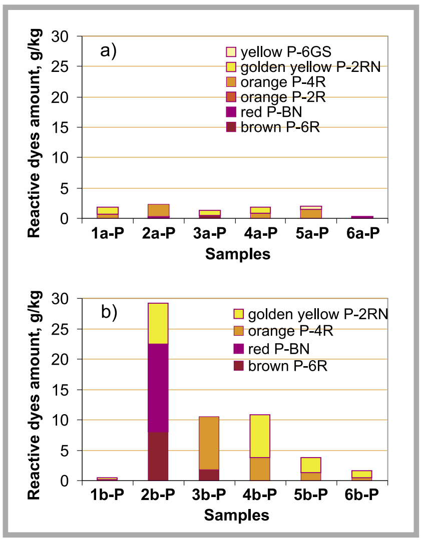

Figure 6. *Amount of reactive dyes in the color printing pastes for rotary screen printing process for design 'a' (a) and design 'b' (b).*

The results of these measurements were compared with the measurements of the standard colour tables. 40 colour samples showed $\Delta E^*<1.5$; recipes for these samples were then sent to the production department for sampling. These 40 colour printing pastes were prepared according to the production recipe given in Table 1. An anionic agent was added in the cold water and stirred, and then the alginate thickener was added and stirred for an additional 20 minutes. The maximum viscosity was reached after 60-120 min, to be used for mixing the colour printing pastes. These pastes were prepared in the following way. The dye was dissolved in hot water (Y), and then urea, oxidative agent and soda ash were added and stirred. The dissolved solution was then added to the clear stock.

The prepared colour printing pastes were printed on linen fabric using a rotary screen-printing machine for sampling, according to the procedure shown in Table 2. In this process, a 100%-coverage or 'pad' screen was used, and two running metres of fabric were printed for each sample.

All rotary screen-printed samples were then measured using the Avantes and Datacolor systems, and the results of the spectrophotometric measurements were compared with those of the standard colour table according to reflectance values, CIELAB values and CIELAB colour differences.

The colour tables from the best matching samples were prepared for rotary screen-printing of designs 'a' and 'b', and the collection was printed on the production line. Information about the dye amounts in the colour printing pastes is given in Figure 6.

Printing was performed at 17 m/min on the RD-IV 'Air-Flow' (Stork)rotary screen-printing machine, with 125 mesh rotary screens, a pass number of 1, and the squeegee position at 3, followed by drying in a Type DDII drying chamber at 17 m/min at 120-125 °C for 3 min [18].

Colour fastness tests

The quality of the printed samples in the colour tables for both printing processes was tested according to ISO standards; colour fastness to washing at 60 °C according to ISO 105-C03:1989, colour fastness to wet rubbing according to ISO 105-X12:1993, and colour fastness to artificial light according to ISO 105-B02:1994.

Results and discussion

Samples from the colour tables were compared; first their reflectance values, then CIELAB values, and finally the ΔE^* values.

As the measurement aperture of the Spectrocam 75 RE spectrophotometer is small, multiple readings had to be performed to ensure the repeatability of measurements. Each sample was folded to obtain two layers and placed in front of a white ceramic background. 25 readings at different locations were taken randomly for all ink-jet printed samples, and the averages of 25 readings were stored as the final measured values. The same measuring procedure was used for all rotary screen printed samples, 10 readings were used, and the averages of 10 readings were stored as the final measured values. All the samples from the colour tables were measured only once using the Datacolor colour measurement system and these measurement results were compared with those results obtained using the Avantes colour measurement system. The measurements of the ink-jet printed samples were used as standard values.

Reflectance values

All the samples were measured for reflectance values. Only the present reflectances from the best and worst matching samples for design 'a' are shown in Figure 7, and from the best and worst matching samples for design 'b' in Figure 8.

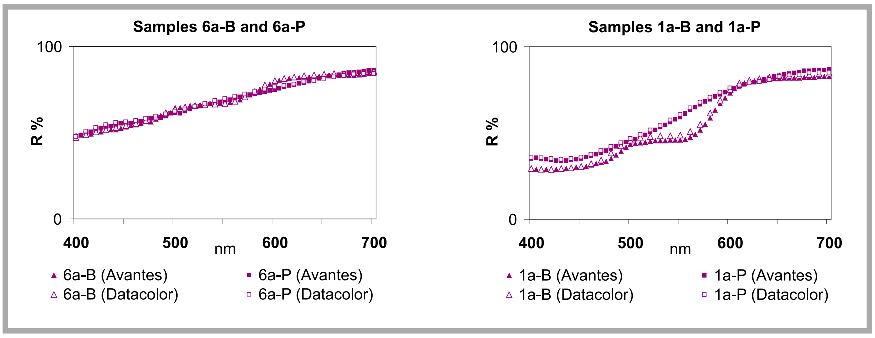

Figure 7. *Reflectance curves of best matching samples (a) and least matching samples (b) from ink-jet and rotary screen printing for design 'a'.*

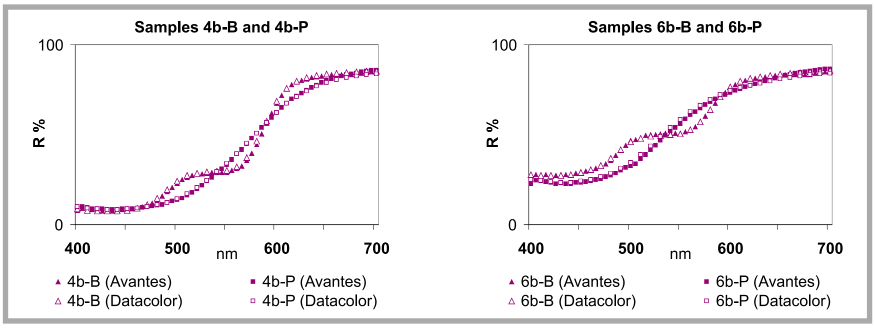

Figure 8. *Reflectance curves of best matching samples (a) and least matching samples (b) from ink-jet and rotary screen printing for design 'b'.*

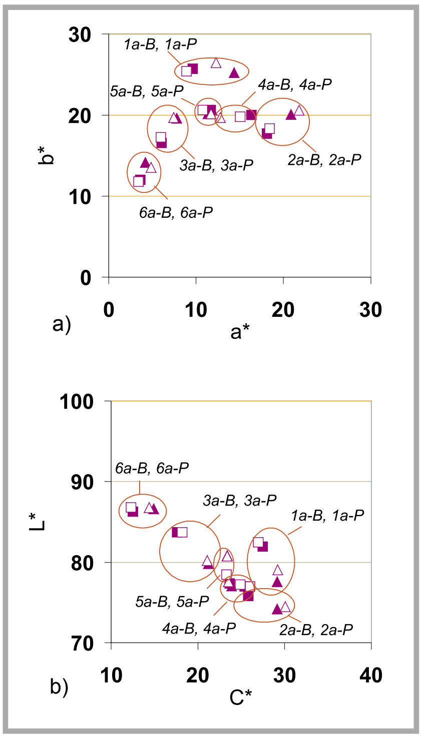

Figure 9. Positions of samples from ink-jet and rotary screen printing in diagram a/b* (a) and in diagram C*/L* (b) for design 'a'; ▲ - Ink-jet printing (Avantes), ■ - Rotary screen printing (Avantes), Δ - Ink-jet printing (Datacolor), □ - Rotary screen printing (Datacolor).*

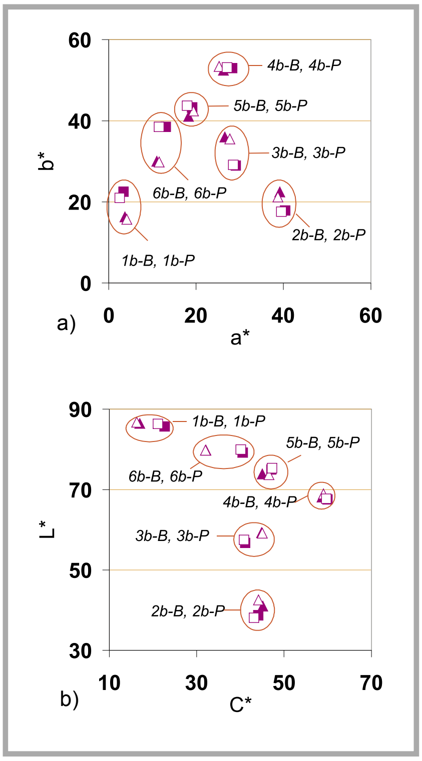

Figure 10. Positions of samples from ink-jet and rotary screen printing in diagram a/b* (la) and in diagram C*/L* (b) for design 'b'; ▲ - Ink-jet printing (Avantes), ■ - Rotary screen printing (Avantes), Δ - Ink-jet printing (Datacolor), □ - Rotary screen printing (Datacolor).*

Different curve characteristics were observed for the ink-jet and rotary screen-printed samples. It is assumed that this is a consequence of different dye characteristics and the different technological procedures of printing, namely the viscosity of colour printing pastes, different absorptions of the materials, different dye applications, etc [15]. The curve paths of the measured reflectances from the Avantes and Datacolor systems were almost identical.

CIELAB colour values

The positions of the ink-jet and rotary screen-printed samples in the CIELAB colour space are presented in Figures 9 and 10.

It was observed that the differences between the measurements obtained using Avantes and Datacolor systems are small.

CIELAB colour difference ΔE*

The calculated colour difference values ΔE* for rotary screen-printed samples, compared to the standard samples, are presented in Figure 11.

On the Avantes system, the smallest colour difference for design 'a' was achieved for sample 6a-P (ΔE*=2.2), followed by samples with colour differences ascending in this order: 5a-P (ΔE*=3.5), 2a-P (ΔE*=4.5), 4a-P (ΔE*=4.7), 3a-P (ΔE*=5.1) and 1a-P (ΔE*=6.4). The smallest colour difference for design 'b' was achieved for sample 4b-P (ΔE*=2.2), which is followed by samples with colour differences ascending in this order: 5b-P (ΔE*=2.6), 2b-P (ΔE*=5.2), 1b-P (ΔE*=6.1), 3b-P (ΔE*=8.0) and 6b-P (ΔE*=8.7).

On the Datacolor system, the smallest colour difference for design 'a' was achieved for sample 6a-P (ΔE*=2.3) which is followed by samples with colour differences ascending in this order: 4a-P (ΔE*=2.4), 5a-P (ΔE*=2.6), 3a-P (ΔE*=4.5), 2a-P (ΔE*=4.8) and 1a-P (ΔE*=4.9). The smallest colour difference for design 'b' was achieved for sample 4b-P (ΔE*=2.2) which is followed by samples with colour differences ascending in this order: 5b-P (ΔE*=2.4), 1b-P (ΔE*=5.6), 2b-P (ΔE*=5.9), 3b-P (ΔE*=6.7) and 6b-P (ΔE*=8.6).
It is well-known from practical experience of ink-jet printing that ΔE* > 2 is not unusual, even using the same inks on the same fabric under identical printing conditions and after-treatment procedures.[19] The results of our research show that the same colour difference ΔE* > 2 also occurs when ink-jet prints are transferred to the rotary screen printing process.

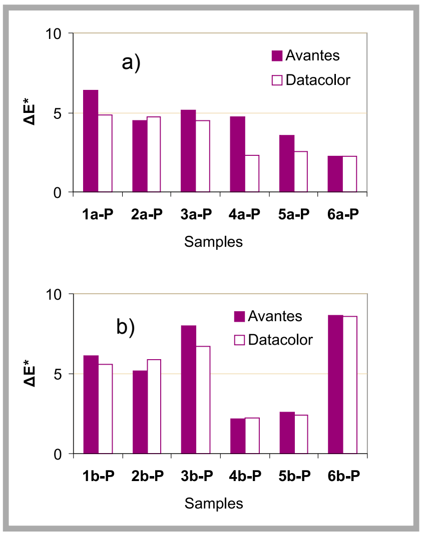

Figure 11. Color differences ΔE between ink-jet and rotary screen printed samples for design »a« (a) and design »b« (b).*

Results of colour fastness tests

The colour fastness to washing at 60 °C is 5 for all samples. The colour fastness to wet rubbing is 3-4 for ink-jet printed samples, and 4-5 for rotary screen printed samples. The colour fastness to artificial light is 3-4 for ink-jet printed samples, and 4-5 for rotary screen printed samples.

Deposition of inks on the substrate

The deposition of water-based inks on the fabric was determined for the inkjet printing process in further tests. Fabric samples (30×30 cm) were weighed before and immediately after ink-jet printing (wet printouts), to establish the deposition of ink for every colour for both designs (i.e. the amount of ink required to print 1 m^2 of fabric) for a 100% coverage print on the linen substrate, under the previously mentioned printing conditions. The results of these tests are shown in Figure 12, representing the total amount as well as the parts of each ink used. The part of each ink was determined based on the data stored with the digital image file (TIF) of a printed colour (i.e. obtained with Adobe Photoshop software within the channel values), and determined based on the density curves for all four print channels (C, M, Y, K).

The largest ink deposition was measured for sample 2b-B in design 'b' (L*=38.09,

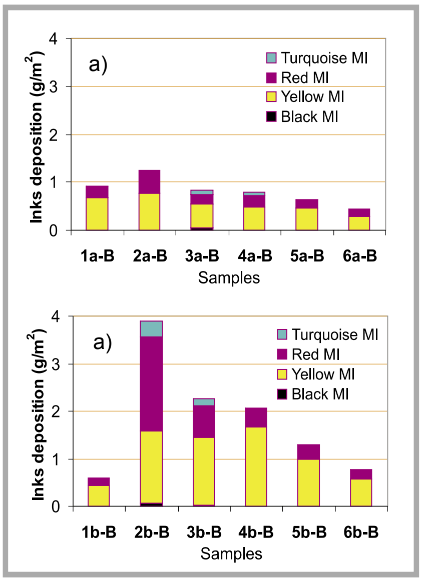

***Figure 12.** Deposition of the inks on the substrate for the ink-jet printing process for design »a« (a) and design »b« (b).*

C*=44.16), with 3.9 g/m2 of ink at 125% of ink deposition (channel values: C=11%, M=63%, Y=49% and K=2%).

Summary

This paper presents the preparation of a decorative home furnishing fabrics textile collection. The results show that an ink-jet printed textile collection can be transferred directly into a rotary screen-printing process. It shows that ink-jet printing is suitable for making sample collections in production.

Colour separation files can be prepared with a CAD CAM system and designs can be transferred from ink-jet printing to the rotary screen-printing process. The optimum match between the standard and target print is presented in industry as ΔE*<1.5, but the results from our printed collections show that the design can also be printed with a greater colour difference. This is due to the granular (pixel-like) appearance (ink drops) of ink-jet prints, while the appearance of rotary screen prints is uniform; however, visually comparable designs can be achieved with ink-jet printing and rotary screen printing especially for darker colours where more drops are applied, thus forming an equally coloured area which is more similar to rotary screen prints. Prints obtained under industrial conditions with rotary screens show some differences compared to ink-jet prints, due to a small degree of overlapping of the colour areas (1 mm), such as often occurs during rotary screen printing process when 'tight fitting' designs are printed, while this is not the case in ink-jet printed designs where all colours are "applied" at the same time._The Avantes colour measurement system is suitable for the colorimetric evaluation of printed samples, but an optimal number of measurements must be determined prior to final measuring. The ink-jet print resolution and characteristics of fabric structure should be taken into account. The quality of prints determined by ISO standards show that both ink-jet and rotary screen prints have excellent colourfastness properties to washing, but ink-jet prints are less resistant to wet rubbing and artificial light. Some additional information regarding the results of ink deposition tests with the ink-jet printing process is also presented in this article. For the substrate used in this research, the maximum ink uptake was 200% and the maximum ink deposition was 6.25 g/m2.

Conclusing

- Using the ink-jet printing process in the phase of preparing a sample collection brings many benefits to a textile factory; significant cost savings for screens and colour printing pastes, and a shorter time cycle for collection production, from two months to two weeks [16].
- It can also be concluded that the ink-jet printing system is a very reliable and efficient system for printing sample collections, and textile designs can be printed with a high degree of repeatability.

Acknowledgment

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