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Comparative Assessment of Tone and Line Reproduction on Fabric Using DTF and Sublimation Transfer Printing

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ABSTRACT

Digital transfer printing technologies such as Direct-to-Film (DTF) and dye-sublimation printing are increasingly used for personalized textile production; however, the influence of textile surface structure and fibre orientation on the stability of tone and line reproduction remains insufficiently investigated. In this study, a comparative assessment of the reproduction of halftone and fine line elements on gabardine fabric using DTF printing with a white underbase, DTF printing without a white underbase, and dye-sublimation transfer printing is presented. A digital test scale containing cyan and magenta halftone areas and black line elements with different orientations was printed under identical resolution conditions (720 × 1440 dpi). Optical density measurements and relative information capacity loss were used as quantitative indicators of tonal and line reproduction. The obtained results showed that all investigated technologies provide stable reproduction in highlight tonal regions, whereas DTF printing with a white underbase provides improved colour field saturation in midtones and shadows compared to the other variants. Analysis of line reproduction demonstrated a significant influence of textile surface anisotropy, with relative spatial information capacity losses exceeding the reference threshold level of 15% in all investigated cases and reaching maximum values in prints produced without a white underbase. The results confirm the effectiveness of the white intermediate layer in improving the stability of reproduction of fine image elements on structured textile substrates and provide experimental data for the optimisation of digital transfer printing workflows.

KEY WORDS

DTF printing, dye-sublimation printing, textile printing, halftone reproduction, line reproduction, optical density, quality, information capacity loss

1. Introduction

The global market for digital heat-transfer textile printing technologies is demonstrating steady growth driven by the expansion of personalized apparel production, the rapid development of e-commerce platforms, and the transition of the textile industry toward short-run on-demand manufacturing models. Within this segment, dye-sublimation printing remains one of the leading technologies due to its high capability for continuous-tone image reproduction and its extensive application in sportswear, promotional textiles, and interior fabric products. According to estimates by Mordor Intelligence (2025), the global dye-sublimation printing market reached approximately USD 15.22 billion in 2025 and is projected to grow to about USD 28.05 billion by 2031 (CAGR ≈ 10.7 %). At the same time, Direct-to-Film (DTF) technology is rapidly expanding its application in the personalized textile production sector due to its capability to transfer images onto natural and blended fabrics without preliminary substrate preparation, which significantly simplifies short-run production workflows. According to Grand View Research (2025) the global DTF printing market was valued at approximately USD

2.72 billion in 2024, with projections indicating growth to around USD 3.92 billion by 2030 (CAGR ≈ 6 %). As a result, dye-sublimation and DTF printing technologies are increasingly considered complementary digital heat-transfer solutions for textile image reproduction, particularly in applications requiring flexibility in substrate selection and rapid production adaptation.

Textile materials represent anisotropic substrates with direction-dependent mechanical and surface properties. Therefore, the orientation of fibres relative to printed image elements may affect spatial reproduction stability, edge sharpness, and tonal uniformity. Despite the rapid industrial adoption of transfer technologies, the influence of fibre orientation on reproduction characteristics of printed elements remains insufficiently investigated.

Previous studies in the field of dye-sublimation textile printing have mainly focused on the influence of technological process parameters on image quality indicators such as colour strength, colour difference (ΔE), and print uniformity. For example, Toshikj et al. (2019) investigated the effect of total ink limiting levels and transfer paper properties on the colour strength and visual uniformity of sublimation prints on polyester fabrics, demonstrating that transfer media significantly affect final image quality characteristics. In paper (Özomay & Özomay, 2020) analysed the influence of temperature and pressing time on colour reproduction and fastness properties in sublimation transfer printing on polyester and nylon fabrics and confirmed that thermotransfer conditions directly determine the stability of colour coordinates and wash resistance. Other studies have addressed optimisation of thermotransfer regimes and material absorbency effects on optical density formation in sublimation printing processes, indicating that substrate properties play a critical role in determining the final reproduction quality of textile prints Repeta, Petriv & Kukura, 2025).

Printing technologies such as screen transfer and digital inkjet printing are widely applied for image reproduction on textile substrates (Lilić, Kašiković & Miketić, 2018: Stančić et al, 2020); however, most existing studies have focused primarily on colour fastness, adhesion behaviour and durability properties of printed layers rather than on spatial reproduction accuracy of fine image elements. At the same time, the rapidly emerging Direct-to-Film printing technology has been primarily investigated from the perspective of workflow efficiency, substrate compatibility, and production flexibility, whereas systematic studies addressing the reproduction stability of halftone areas and fine line elements on structured textile surfaces remain limited.

In particular, the combined influence of textile fibre orientation and transfer technology type on spatial reproduction characteristics has not yet been sufficiently analysed in comparative experimental studies.

Therefore, the present study aims to investigate the reproduction characteristics of halftone areas and fine line elements produced using dye-sublimation and DTF transfer technologies on gabardine fabric, taking into account the influence of textile surface structure and fibre orientation on optical density variation and line fidelity. The obtained results are expected to contribute to a deeper understanding of image formation mechanisms in digital heat-transfer textile printing and to support the optimisation of reproduction quality in personalised textile production workflows.

2. Methods

Printing of the test scale for evaluating the reproduction quality of tonal and line elements on textile material was performed using two digital transfer printing technologies: Direct-to-Film (DTF) and dye-sublimation printing. Both methods were implemented using the same image formation resolution of 720 × 1440 dpi (6 Pass mode), ensuring comparability of the experimental results with respect to halftone structure formation parameters.

Printing of the test scale using the DTF technology was carried out on an AINKJET DTF A-620 SUPER digital printer with DTK Ink pigment inks. Image formation was performed on an intermediate carrier – a polyethylene terephthalate (PET) film with a thickness of 95 µm, which ensures dimensional stability of raster elements during printing. After forming the color layer, a thermoplastic polyurethane (TPU) adhesive powder with a particle size of 80-200 µm was applied to the surface of the print, corresponding to standard DTF transfer conditions. The melting temperature of the adhesive powder was approximately 95-115 °C, providing effective thermal activation of the adhesive layer prior to image transfer onto the textile substrate. Image transfer onto the fabric was performed by heat pressing at a temperature of 165 °C for 15 s, ensuring sufficient adhesion of the polymer layer to the textile surface without significant deformation of raster elements.

Dye-sublimation printing of the test scale was carried out using a SureColor SC-F7200 digital printer with Epson Ultra Chrome® DS disperse inks. Image formation was performed on an intermediate carrier – Jasper sublimation paper with a grammage of 65 g/m², which ensures uniform transfer of the dye into the polymer structure of textile fibres during thermal diffusion. Image transfer onto the textile substrate was performed by heat transfer at a temperature of 215 °C for 30 s, corresponding to standard sublimation printing conditions and ensuring complete dye migration into the fiber structure of the material.

The use of identical printing resolution and standardized transfer conditions ensured the reliability of comparative

analysis of raster and line element reproduction when applying different digital textile printing technologies.

The print quality control test scale (Ryvak et al., 2014) consists of 44 functional blocks containing line and halftone elements intended for evaluating the accuracy of raster structure formation and the stability of tonal gradation reproduction in digital printing on textile substrates. The appearance of the test scale printed on the fabric is shown in Fig. 1.

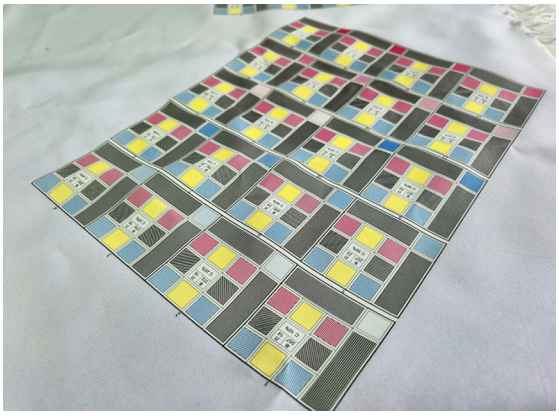
The scale includes line elements with screen rulings ranging from 14 to 100 lines/cm, arranged at standard screen angles commonly used in multicolor printing: 75° for magenta, 15° for cyan, 45° or 135° for black (Fig. 2).

Additionally, variants of element orientation are provided taking into account a possible 90° rotation of the substrate, allowing evaluation of anisotropic effects in line reproduction depending on the direction of the textile structure.

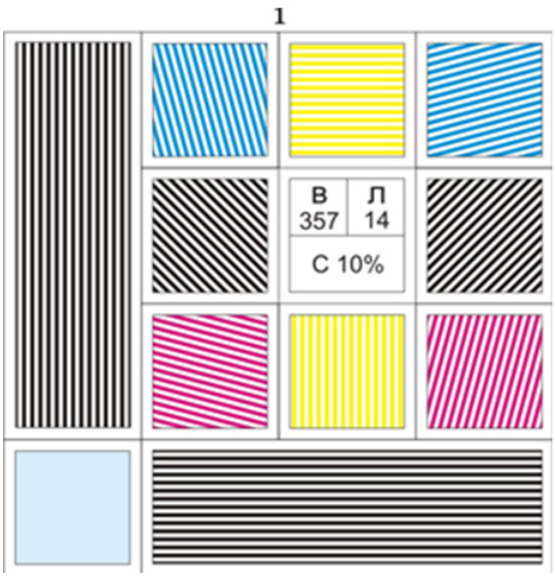
Besides line elements, the test scale includes halftone patches for each process color, corresponding to tonal coverage values of: 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 %.

The use of the test scale provides comprehensive control of multicolor image reproduction quality in DTF and dye-sublimation printing technologies, since arranging raster elements at appropriate screen angles minimizes moiré formation and ensures reliable assessment of geometric raster structure parameters on textile substrates.

To compare reproduction capabilities of transfer printing technologies on gabardine fabric, a digital test scale containing cyan and magenta halftone patches and black line elements with decreasing widths and different orientations was printed using three variants: DTF transfer with white underbase, DTF transfer without white underbase, and sublimation transfer printing. Optical densities of halftone fields and minimum reproducible line widths



» **Figure 1:** *Appearance of the test scale*



» **Figure 2:** *First block of the test scale elements (screen ruling 14 lines/cm, line element size 357 µm, cyan tonal value 10 %)*

were measured to evaluate tonal and spatial reproduction performance. The theoretical tonal capacity of an amplitude-modulated halftone cell depends on the relationship between device resolution and screen ruling and can be estimated as:

$$N = \left(\frac{R}{L}\right)^2 + 1 \quad (1)$$

where R is device resolution (dpi) and L is screen ruling (lpi). This relationship describes the number of distinguishable tone levels within a halftone cell and is widely used in digital halftoning theory (Ulichney, 1987; Kipphan, 2001).

Based on this relationship, the equivalent information capacity per unit area of the reproduced halftone structure was estimated as (Ryvak et al, 2018):

$$I_e = I^2 \log_2 \left[\left(\frac{R}{L}\right)^2 + 1\right] \quad (2)$$

This parameter was used as an analytical indicator for comparative evaluation of reproduction performance of DTF and sublimation transfer printing technologies on gabardine fabric. The relative amount of loss of information capacity of prints can be determined by the formula:

$$\Delta I = \frac{I_e - I}{I_e} \cdot 100\% \quad (3)$$

I_e – theoretical information capacity;

I – actual information capacity.

Additionally, the influence of textile surface structure

was assessed by analysing the minimum reproducible line width at different orientations relative to the rib structure of the fabric.

3. Results and Discussion

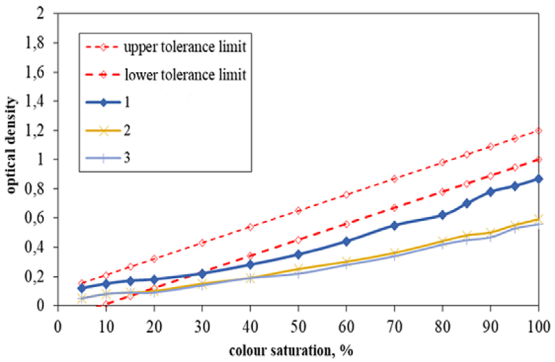
Since standardized reference values of solid ink optical density are not defined for textile transfer printing technologies such as DTF and dye-sublimation printing, the obtained density values were compared with typical pressroom control targets for offset printing on wood-free uncoated paper. According to common process control practice in compliance with ISO 12647-2 (2013) printing conditions, the recommended solid ink density ranges are approximately 1.00-1.20 for cyan, 1.05-1.25 for magenta, 0.85-1.05 for yellow, and 1.30-1.55 for black (Brotherhood Paper, 2026). Since ISO 12647-2 defines process control targets for offset lithographic printing on paper substrates, these density ranges were applied in the present study only as auxiliary comparative reference levels and not as normative quality criteria for textile transfer printing technologies such as DTF and dye-sublimation printing. The optical density of cyan and magenta imprints was measured using an X-Rite SpectroEye spectrodensitometer.

The results of optical density measurements for cyan and magenta halftone patches reproduced using sublimation transfer printing and DTF printing with and without white underbase are presented in Figures 3 and 4.

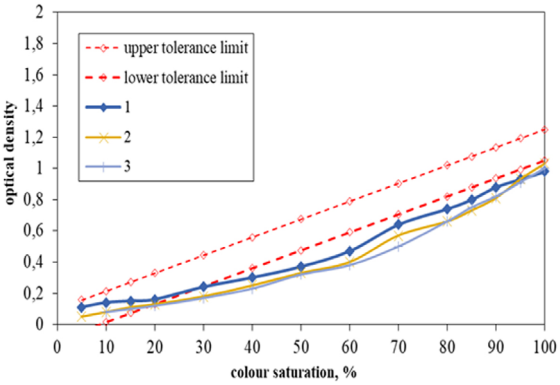
Analysis of the obtained data shows that in highlight tonal regions all three printing variants demonstrate optical density values within the reference interval typical for offset printing on uncoated paper. This indicates sufficient stability of tone reproduction at low coverage values regardless of the transfer technology used.

However, in midtone and shadow regions a noticeable divergence between the investigated technologies can be observed. In the case of cyan reproduction, density values obtained by sublimation printing remain closer to the lower boundary of the reference interval, while DTF printing with white underbase provides slightly higher optical density values due to additional reflection from the supporting white layer. At the same time, DTF printing without white underbase demonstrates reduced density values in darker tonal regions, which can be explained by partial penetration of the colour layer into the textile structure and increased influence of substrate anisotropy.

For magenta reproduction a similar tendency is observed. In highlight regions all printing variants demonstrate comparable behaviour, whereas in midtones and shadows density values decrease relative to the reference offset interval, especially in the case of DTF printing without white underbase. This behaviour



» **Figure 3:** *Optical density of cyan reproduction on prints: 1 – sublimation printing; 2 – DTF printing with white underbase; 3 – DTF printing without white underbase*



» **Figure 4:** *Optical density of magenta reproduction on prints: 1 – sublimation printing; 2 – DTF printing with white underbase; 3 – DTF printing without white underbase*

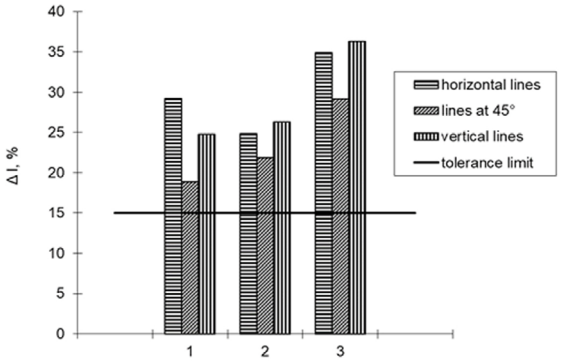
confirms that the presence of a white intermediate layer significantly improves colour field saturation stability during transfer printing on structured textile substrates.

Further analysis was performed for reproduction of line elements with different orientations relative to the textile rib structure in order to estimate the relative loss of image information capacity. The obtained results are presented in Fig. 5.

The largest loss of information capacity is observed for DTF printing without white underbase in horizontal and vertical line elements. At the same time, line elements oriented at 45° demonstrate improved reproduction stability, which confirms the anisotropic influence of gabardine fabric structure on spatial reproduction accuracy.

Both sublimation printing and DTF printing with white underbase demonstrate improved stability of line reproduction compared to the variant without white underbase. Nevertheless, in all investigated cases the relative loss of information capacity exceeds the reference threshold level of 15%, indicating the significant influence

of textile surface structure on spatial reproduction limitations in transfer printing technologies.



» **Figure 5:** *Relative loss of image information capacity in prints: 1 – sublimation printing; 2 – DTF printing with white underbase; 3 – DTF printing without white underbase*

4. Conclusions

A comparative experimental assessment of tone and fine-line reproduction on gabardine fabric using dye-sublimation transfer printing and Direct-to-Film (DTF) printing with and without a white underbase demonstrated that all investigated technologies provide stable tone reproduction in highlight regions under identical image formation resolution conditions.

The presence of a white intermediate layer in DTF printing improves the stability of fine-line reproduction compared with DTF printing without a white underbase, confirming its compensating role in reducing the influence of substrate structure on spatial image formation. At the same time, dye-sublimation printing demonstrated comparable or lower information capacity losses for certain line orientations, indicating that reproduction stability depends not only on the transfer technology but also on the orientation of structural textile elements relative to image features.
The analysis of line element reproduction showed that the relative loss of image information capacity reached 29.23% for horizontal lines, 18.8% for lines oriented at 45°, and 24.8% for vertical lines in the case of dye-sublimation printing. For DTF printing with a white underbase, the corresponding values were 24.9%, 21.8%, and 26.3%, respectively. The highest losses were observed for DTF printing without a white underbase, reaching 34.9%, 29.2%, and 36.3%.

Quantitative analysis of spatial reproduction accuracy showed that the relative loss of image information capacity exceeded the reference threshold level of 15% in all investigated cases and reached maximum values for DTF printing without a white underbase. This confirms the significant influence of the anisotropic rib structure of gabardine fabric on the reproduction of fine graphic elements in digital transfer printing technologies.

The obtained results provide experimental evidence of the importance of considering textile surface anisotropy and intermediate layer structure when selecting digital transfer printing workflows for personalised textile production requiring stable reproduction of halftone gradients and fine line elements.

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