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Influence of Heating Temperature on the Ink Transfer to Polymer Substrates in the Retransfer Printing Process

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ABSTRACT

This study explores the effect of heating temperature on the ink transfer to Poly(vinyl chloride) and Poly(ethylene terephthalate) substrates in a specific retransfer printer. A notable correlation between heating temperature and solid color density was observed. The color density increases with heating temperature until reaching a critical threshold, typically around 140°C. Beyond this threshold, color density begins to decline due to ink penetration into the substrate, reducing ink film thickness on the surface of the substrates. This critical temperature is predominantly influenced by the properties of the ink rather than the characteristics of the substrate. The experimental study also reveals that variations in temperature-dependent ink transfer lead to noticeable color differences compared to standard references. An optimal temperature range of 120°C to 140°C was established, within which the process colors conform to the ISO 12647 standard, achieving ΔE values below 5. These results highlight the importance of maintaining appropriate ink transfer conditions to ensure precise color reproduction in printing processes.

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1. Introduction

Personalized intelligent cards have seen significant growth in the financial and retail sectors. These cards require the highest image quality for security, flexibility, and efficiency, which can be achieved through diverse card materials and a broad array of chip-encoding options [1].

Retransfer printing has emerged as a versatile and efficient technology for producing such cards, e.g., identification cards, credit cards, and access badges [2]. Unlike traditional direct-to-card (DTC) printers, which use a thermal head to transfer the image through a dye ribbon (often by sublimation) directly onto the card surface, retransfer printers carry out a two-step process. First, the image is printed onto the transfer film using a digital printing technology, such as dye-sublimation or thermal transfer. Then, the printed film is thermally transferred onto the plastic card. In this technology, the printhead never comes into contact with the cards. Thus, compared to DTC printing techniques, retransfer printing offers several advantages, including improved image quality, durability, and printability on a broader range of card materials [3], [4]. Retransfer technology provides a breakthrough beyond DTC printing and is expected to be 12 – 15% of the current printing market. The critical parameter of the ink-transferring process is the heating temperature. It is understood that this parameter directly affects the level of dye transfer to the substrate, resulting in color accuracy, density, and overall image quality [5] – [8]. Almost all research has been conducted on how the temperature influences the performance of the ink on the textile substrate. The literature identifies that the processing temperature can range from 138ºC – 300ºC [9], presenting a wide range of operations. However, the results can not be fully applied to plastic cards as the effect of temperature must comply with the substrate.

On the other hand, some works [8], [9] reported the level of dye penetration into the polymer substrate but did not describe how it influences ink performance on the substrates. Therefore, this study investigated the effect of temperature on the ink transfer to polymer substrates in the retransfer printing process. The study explores the fundamental processes that enable the industry to select an optimum condition, including materials, pressures, and temperature.

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2. Materials and Methods

2.1. Materials

The polymeric materials used to manufacture the printing substrate are Poly(vinyl chloride) (PVC) and Poly(ethylene terephthalate) (PET). The cards have a size (CR80) of 86 mm × 54 mm and a thickness of 0.76 mm. CIE LAB coordinates of two substrates are reported in Table 1. The measurements are described in the next section.

Table 1. *CIE LAB coordinates of the substrates*

Substrate	L	a	b
PVC	79.69	-0.04	-9.35
PET	87.57	-1.68	-1.14

2.2. Equipment and Printing Process

In this work, a Nisca printer PR-C201 was used. This printer uses retransfer printing technology, in which a high-resolution image is created directly onto the intermediate film by the sublimation process, where the dye materials at a solid phase (color ribbon) are transformed into a gas state when heat is applied [10]. The image is then transferred from the film onto the substrate by thermal bonding. Figure 1 shows the printer's working principles.

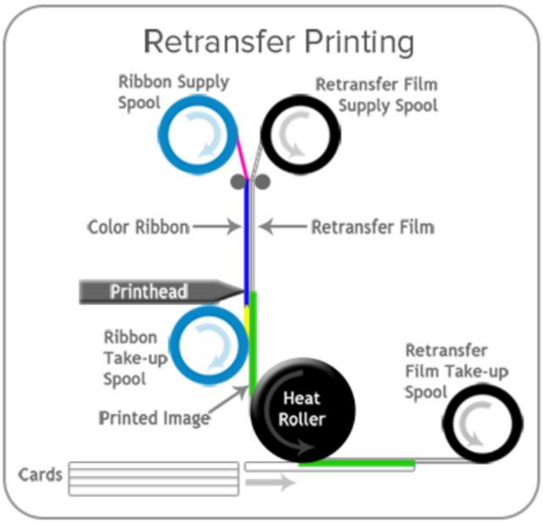

Figure 1. *Diagram of retransfer printing process in Nisca printer (Source:* [11]*)*

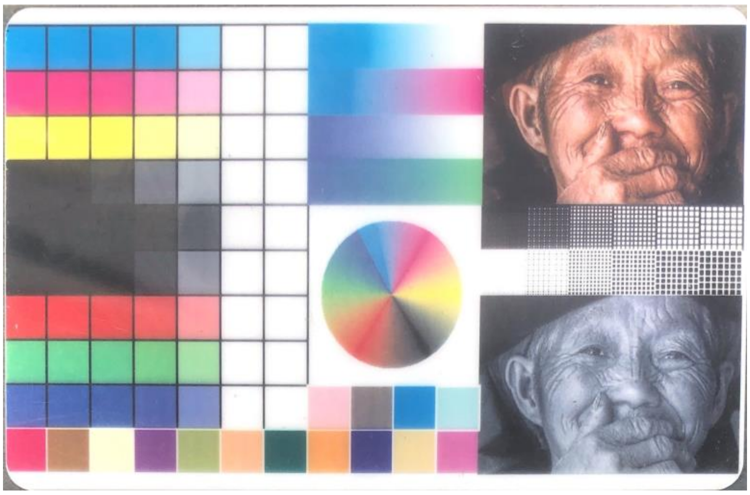

Figure 2. *Designed test target*

The PR-C201 printer offers a high speed, 600 dpi, 24-bit color. The dye sublimation inks (YMCKO color ribbon) are accommodated with the printer [10]. A test target was designed to evaluate the ink transfer (Figure 2).

This target consists of 4 solid ink patches, Cyan (C), Magenta (M), Yellow (Y), and Black (K), and three patches where solids are overprinted on each other: magenta on yellow (Red – R), cyan on yellow (Green – G), and cyan on magenta (Blue – B).

The printing process was set to the same parameters for all samples. The heating temperature was altered in the range from 100 to 200ºC.

2.3. Color reproduction characterization

2.3.1. Solid Ink Density

The thickness of the transferred ink film is evaluated by the solid ink density measured at solid ink patches. This method is based on the Lambert-Beer law, which states that the concentration of an absorbance is proportional to the absorption. According to that, the thicker the ink layer, the stronger the absorption, resulting in a higher color density.

The color density values were measured by an XRite DTP22 Color Digital Swatchbook Spectrophotometer, which had an accuracy of 0.02D. The measurements were conducted across three separate print samples produced under identical conditions, with the final results calculated as the mean of these trials.

2.3.2. CIE LAB color coordinates and color difference

The CIE LAB color coordinates of the printed samples were measured according to ISO 12647-1 standard on an XRite DTP22 Color Digital Swatchbook Spectrophotometer under D50 illuminant, 2° observer, 0/45 or 45/0 geometry, white backing.

In CIE LAB space (Figure 3), the lightness value, L*, varies from 0 (black) to 100 (white). The a* and b* coordinates correspond to the green-red and yellow–blue color axis, respectively, where negative values indicate a shift toward green and blue and positive values signify a shift toward red and yellow.

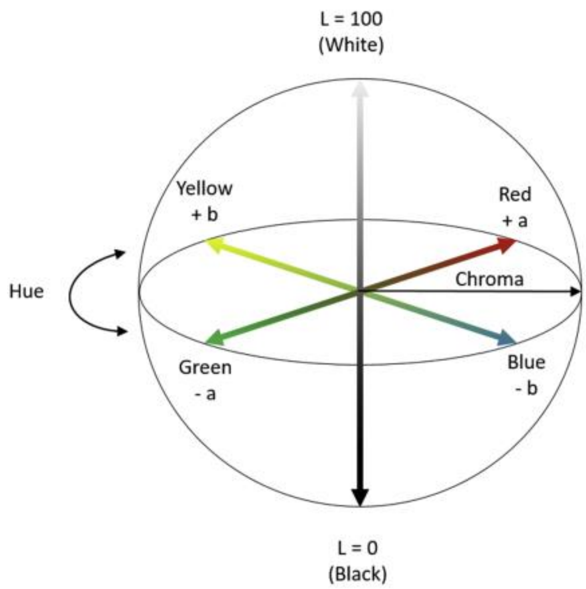

Figure 3. *CIE LAB color space diagram (Source:* [12]*)*

The color characteristics were calculated in the CIE LAB color model by following equations [12]

$$\text{Hue } H^* = artg\left(\frac{b}{a}\right) \quad (1)$$

$$\text{Chroma } C^* = \sqrt{a^2 + b^2} \quad (2)$$

$$\text{Color difference } \Delta E_{ab} = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \quad (3)$$

Where ΔE_{ab} is the color difference and

$$\Delta L = L^*_{sample} - L^*_{standard} \,; \Delta a = a^*_{sample} - a^*_{standard} \,; \Delta b = b^*_{sample} - b^*_{standard}$$

It is expressed as a numerical value (ΔE_{ab}) representing the visual difference between the color standard and the sample.

In our study, the standard ink set colors were substrate-corrected by the Idealliance SCCA calculator, referred to as the tristimulus correction method, because the substrates selected for production do not match the reference (Table 2). The standard ΔE_{ab} tolerances for the solids of the process colors are less than 5.

Table 2. *Substrated corrected CIE LAB coordinates*

	PVC	K	C	M	Y	R	G	B	CMY
L*	79.69	13.56	45.95	39.61	74.55	38.76	41.3	20.56	18.97
a*	13.56	0.17	-31.72	63.04	-4.26	57.07	-55.54	16.04	-0.01
b*	45.95	-0.54	-47.59	-6.6	76.7	38.43	19.58	-41.51	-1.25

3. Results and Discussion

3.1. Temperature dependence of optical density

The measured optical densities of the primary colors printed at different temperatures from 100 – 200°C are reported in Table 3 and Figure 4.

Table 3. *Color density changes as temperature increases*

Substrate	T°C / Color	**100**	**120**	**140**	**160**	**180**	**200**
PVC	**C**	1.64	1.66	1.75	1.62	1.67	1.69
	M	1.83	1.86	1.98	1.85	1.86	1.82
	Y	1.2	1.5	1.52	1.49	1.39	1.45
	K	0	1.67	1.88	1.65	1.71	1.66
PET	**C**	1.24	1.24	1.34	1.31	1.34	1.36
	M	1.8	1.88	1.89	1.9	1.87	1.89
	Y	1.28	1.3	1.44	1.43	1.41	1.46
	K	1.7	1.73	1.75	1.75	1.71	1.74

The effect of temperature on the ink transfer to the substrates is more visible with PVC. Color density increases with temperature increasing and decreases after reaching a threshold. For example, with Cyan color, the density increases from 1.64 to 1.75 as the temperature rises from 100 to 140°C. Subsequently, it gradually decreases to 1.62 as the temperature rises to 200°C (Figure 4). For all colors, the threshold temperature values are around 140°C. This result can be explained by the heat absorption characteristics of the colorants transferred from the carrier to the substrate.

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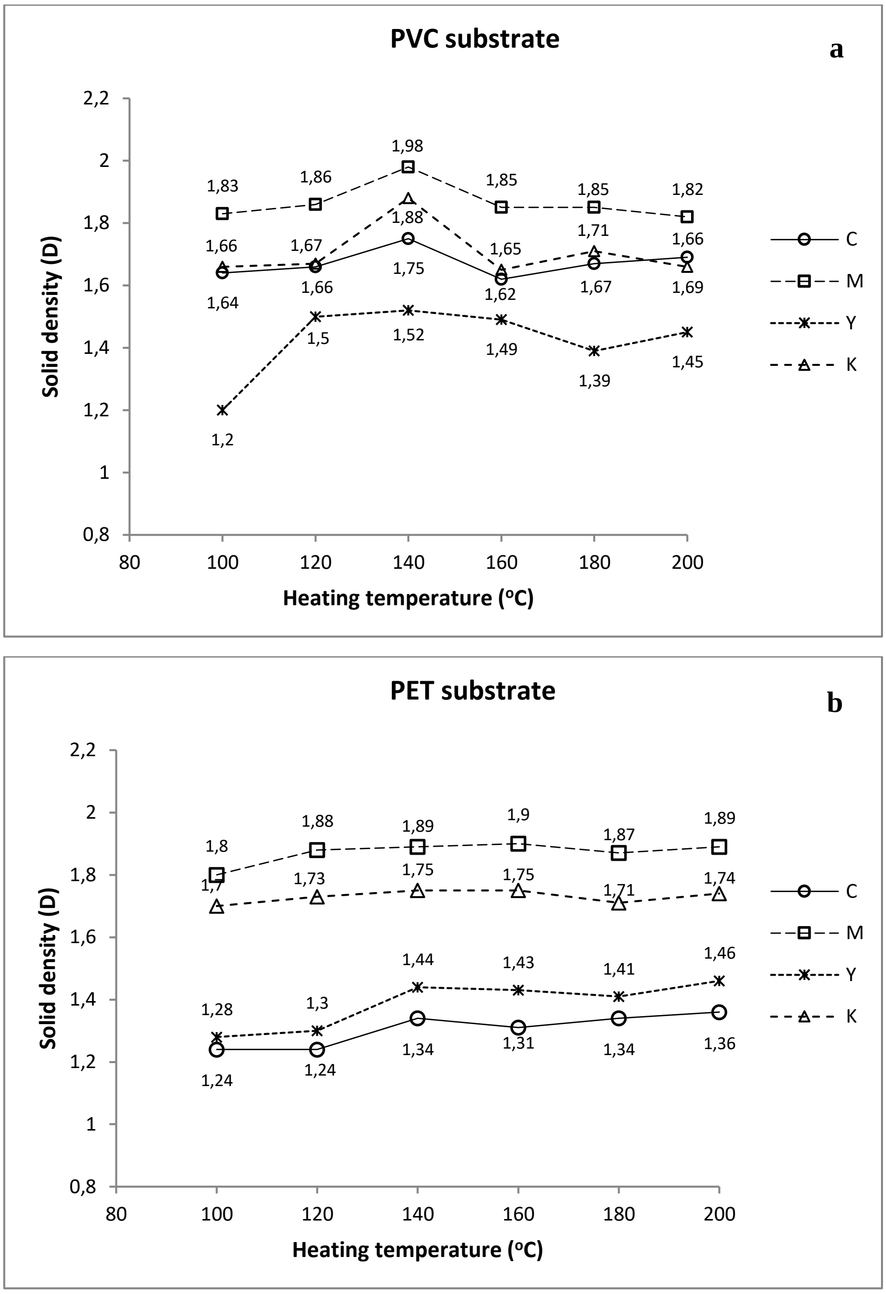

Figure 4. *Solid density as a function of heating temperature (a – PVC substrate, b – PET substrate)*

In the work of Hohne et al. [13], the differential scanning calorimetry (DSC) experiments of standard dye materials indicate that the endothermic peaks of the C, Y, K, and M dyes are 119oC, 130oC, 142oC, and 145oC, respectively. The dye materials start sublimating at these temperatures to transfer to the substrate, and the ideal working temperature for them is about 145oC [9]. Below this temperature, the ink transfer processes occur weakly, reducing the color density. At higher temperatures, color density may decrease due to ink penetration into the substrate, reducing ink film thickness on the surface and consequently lowering color density. This explanation is based on the research of Makenji et al. [9], which states that higher temperatures increase ink penetration into the substrate. The degree of penetration is contingent upon the structure and properties of the substrate material [14]. This observation suggests that ink penetration into PET substrates is more pronounced, reducing color density compared to PVC substrates, particularly for Cyan color. The impact of heating temperature on the ink transfer onto PET substrates is not as notable as on PVC. Nonetheless, a peak ink transfer at 140°C remains observable (Figure 4). These findings imply that temperature-dependent ink transfer is primarily dictated by ink properties rather than substrate characteristics.

3.2. Temperature dependence of printed colors

In this experimental series, samples of C, M, Y, and K colors printed on the PVC substrate were investigated at different temperatures. The measured CIE L*, a*, and b* values and deviations from the reference color (ΔE_{ab}) are presented in Table 4.

Table 4. *CIE LAB values of colors printed at different temperatures*

T°C		C	M	Y	K	R	G	B	CMY
100	L*	44.87	37.5	77.95	17.21	37.91	44.66	22.43	19.16
	a*	-26.25	66.76	-7.27	-2.35	57.01	-54.02	16.84	-1.07
	b*	-47.45	-9.28	73.7	-0.67	35.95	21.13	-45.98	-4.58
	ΔE_{ab}	5.58	3.41	5.44	4.44	2.62	4.00	4.91	3.50
120	L*	44.74	37.45	76.46	16.87	37.93	45.49	22.7	17.61
	a*	-27.07	66.91	-7.61	-2.78	57.46	-54.83	16.46	-0.93
	b*	-47.54	-9.08	74.97	-0.02	36.01	21.61	-45.82	-4.64
	ΔE_{ab}	4.81	5.08	4.23	4.46	2.59	4.71	4.83	3.77
140	L*	44.07	37.38	76.06	16.51	37.7	44.42	22.07	18.33
	a*	-27.99	66.93	-6.98	-2.59	57.42	-55.8	16.89	-0.52
	b*	-47.67	-8.68	74.75	0	35.11	15.72	-45.83	-4.76
	ΔE_{ab}	4.18	4.94	3.67	4.08	3.50	4.97	4.65	3.60
160	L*	45.37	37.48	76.63	17.21	38.16	45.44	22.86	18.78
	a*	-26.04	67.36	-7.56	-2.29	57.58	-54.96	17.5	-0.57
	b*	-47.34	-9.1	74.75	-0.36	36.43	15.89	-46.81	-4.86
	ΔE_{ab}	5.72	5.43	4.36	4.41	2.15	5.58	5.96	3.66
180	L*	44.8	37.39	76.8	16.84	37.97	44.67	22.15	17.07
	a*	-26.01	67.17	-7.38	-2.3	57.67	-54.83	17.16	-0.62
	b*	-47.67	-7.14	72.65	-0.8	36.13	15.51	-46.43	-2.34
	ΔE_{ab}	5.83	4.72	5.59	4.11	2.50	5.33	5.29	2.27
200	L*	44.59	37.55	76.69	16.92	37.8	44.49	22.39	17.85
	a*	-26.85	67.23	-7.46	-1.66	57.64	-55.24	16.37	-0.62
	b*	-47.85	-7.97	74.21	-0.95	36.5	-46.72	14.99	-5
	ΔE_{ab}	5.06	4.87	4.58	3.85	2.23	5.53	5.60	3.96
	$(\Delta E_{ab})_{TB}$	5.22	4.72	4.65	4.22	2.60	5.03	5.20	3.66

The variations in CIE L*, a*, and b* values with temperatures are found to be insignificant. When the temperature changes, the difference between colors (ΔE_{ab}) mainly comes from the variation in L* values due to the alteration in the amount of ink transferred onto the corresponding substrate, thus changing its density. As color density increases, L* decreases (see Figure 5). This result is consistent with Lambert-Beer's law, where increasing color layer thickness enhances light absorption.

The average color deviation from the standard (ΔE_{ab} value) is 5.22 when the temperature ranges from 100 to 200°C for color C. Corresponding figures for colors M, Y, K, R, G, and B are 4.72, 4.65, 4.22, 2.60, 5.03, 5.20, 2.6, and 3.66, respectively.

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The temperature range conducive to achieving the process colors meeting ISO 12647 standard with $\Delta E_{ab} < 5$ is 120–140°C (see Figure 6). This temperature range also corresponds to achieving optimal ink transfer levels.

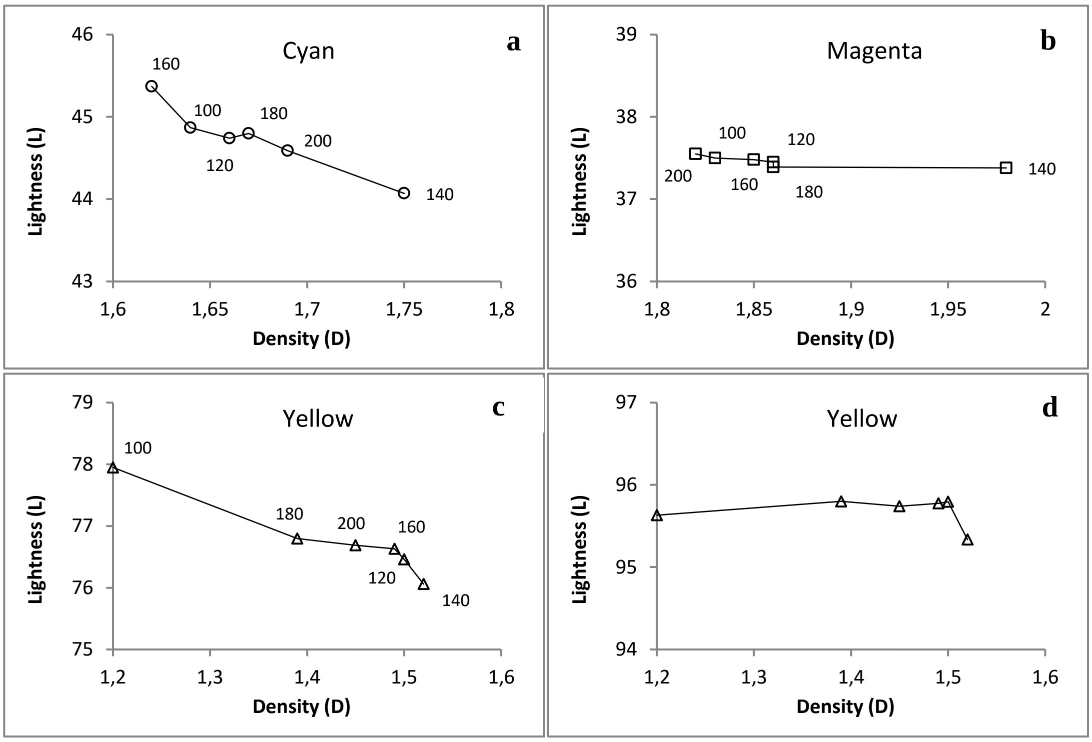

Figure 5. *CIE L* as a function of color density*

(a – Cyan, b – Magenta, c – Yellow, d – Black)

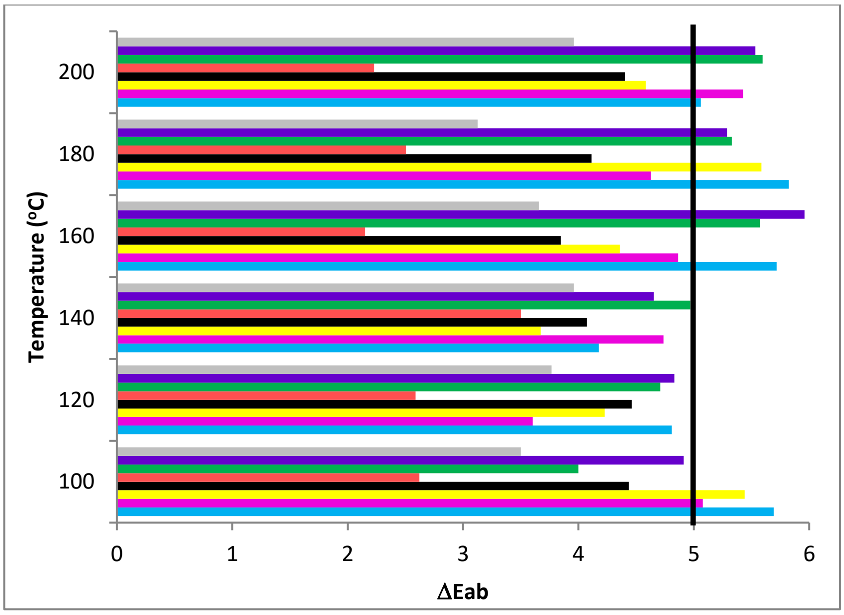

Figure 6. *The color difference between printed samples and the standard at different temperatures*

4. Conclusions

The effects of temperature on ink transfer to both PVC and PET substrates were investigated. The findings revealed a clear relationship between temperature and color density: as temperature increases, color density rises until it reaches a critical threshold, typically around 140°C, after which it declines. Importantly, this threshold is primarily dictated by the colorants' characteristics rather than the substrates' properties. This temperature-dependent ink transfer leads to color variations compared to the standard. The process colors meet the ISO 12647 standard with ΔE values below 5 at the temperature range from 120°C to 140°C. This range corresponds to optimal ink transfer levels, highlighting its significance in maintaining color accuracy and fidelity in printing processes.

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Conflict of Interest

The author declares no conflict of interest

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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2. Ostwald ripening and solubilization in alkane in water emulsions stabilized by different surfactants, Phys. Chem. Chem. Phys, 2004, 6(7).
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