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THE INFLUENCE OF THE TEXTILE SUBSTRATE COLOR ON THE CONTRAST OF THERMOCHROMIC PRINTS

Katarina Maričić, Nemanja Kašiković, Teodora Gvoka, Gordana Bošnjaković
University of Novi Sad, Serbia

Abstract
Thermochromic inks have attracted much attention due to their application in various fields, including the textile industry. The application of these colors in sports clothing enables the monitoring of the athlete's physiological state through the possibility of changing the color of the material under the influence of skin temperature. Due to the printing of thermochromic inks on textile materials used for visual control, there is a need to analyze the contrast of the printed elements. Contrast plays a significant role in visually highlighting shapes and details and also facilitates the recognition of printed parts and information on textile materials. Contrast analysis of thermochromic inks on different colors of textile materials plays a role in determining the optimal combination of base colors and thermochromic inks that will result in the most noticeable color change. This analysis allows designers and manufacturers to make good decisions about choosing the colors of textile materials when printing with thermochromic inks because, in this way, a high level of aesthetics and functionality is achieved. This work aims to compare and analyze the contrast of thermochromic inks on different colors of the substrate of different types of materials, as well as to determine whether the color of the fabric on which the thermochromic ink is printed affects the color contrast when it is changed, i.e., its discoloration and return to its original state. Magenta reversible thermochromic water-based leuco dye was used to print the samples. The work used textile materials for printing with different structures and different colors. The colors were chosen to be bright and to provide a good contrast with the magenta color so that their combination attracts the viewer's attention and can create a strong visual effect. Colorimetric and contrast analyses determined that the color of the substrate is dependent on the contrast value. In the case of polyester textile material, the white color of the substrate showed the highest contrast values. On the other hand, in the case of printed samples on a material made of a mixture of polyester and elastane, it can be concluded that the gray color of the substrate gives the highest contrast values. In conclusion, the research high-

lights the importance of choosing colors and materials to achieve optimal results in the design and production of textile materials with thermochromic inks.
Keywords: *contrast, smart textile, thermochromic inks*

Introduction

Thermochromic materials represent a type of functional materials that can change color, color intensity, or transparency due to the action of a thermal stimulus and belong to the group of smart materials. Color changes can be reversible or irreversible (Hakami et al. 2022, Jakovljević et al. 2022). An example of thermochromic materials is thermochromic inks, which have found their application in many areas. In this paper, the focus will be on their application in the textile industry.

Thermochromic inks contain microencapsulated active material and thermochromic pigments dispersed in a reactive binder (Jakovljević et al. 2020, Rožić et al. 2017). There are two large groups of these inks, leuco dyes and liquid crystals (Elmaaty et al. 2018). Thermochromic dyes that are most often used in the textile industry are leuco dyes, which are capable of reacting to temperatures from –15°C to 60 °C. A key feature of thermochromic inks based on leuco dyes is their capacity to dynamically change properties in response to varying ambient temperatures, making them optimal for use in textiles. Another group of thermochromic inks consists of liquid crystals, which provide a continuously changing color spectrum when exposed to temperature changes due to the selective reflection of a certain wavelength of light by the crystal structure (Guan et al. 2019).

Due to the possibility of developing new creative design solutions, color-changing smart textiles are attracting huge interest due to their interaction, responsiveness, and ultimate functionality. Thermochromic inks find applications as temperature indicators, components in wearable electronics, within medical contexts, for fashion design, and in protective uniforms and materials. (Shahid & Adivarekar 2020). Its use in modern sports is significant, as it enables monitoring and improving the athlete's results while protecting them from possible injuries. Thermochromic inks have also found their application in the fashion industry due to the possibility of providing dynamic visual effects in terms of changing the design and its adaptation to changes in the temperature of the environment or the body.

When it comes to colors on textiles, contrast plays an important role in visual impression and aesthetic design. A strong contrast between colors can attract attention and create an interesting and dynamic look by creating a striking and attractive visual composition. Calculating contrast can be useful for understanding the visual differences between two colors. This paper aims to highlight the importance of the contrast between the color of the textile substrate and the printed thermochromic inks, which represents a visual signal for monitoring a condition.

Methodology and equipment

Research methodology implies objective methods of investigation. The samples were printed using a manual screen-printing technique, with a 120 threads/inch screen, using a reversible thermochromic magenta color based on a leuco dye. Textile materials of different raw material compositions and different colors (white, beige, gray, yellow, and purple) were used as printing substrates. The first textile material used is 100% polyester and has a thickness of 0.405 mm. The other material used is a mixture of polyester (97%) and elastane (3%), while the thickness of the material is 1,070 mm. A total of 30 samples were tested, three samples each for all five different colors of two types of material, to obtain mean arithmetic values. The samples had to be heated to achieve a thermochromic ink activation temperature of 31°C. For this purpose, a stone slab was used, which was placed on an induction stove that heated it. When the stone slab reached a temperature of 50°C, samples were placed on it and heated for 2 minutes so that the ink would activate and lose its coloration. After heating, the samples were removed from the stone slab to cool down gradually and to monitor the process of returning the color to its original state. In time intervals of 10 seconds, the colorimetric values of the prints were measured to determine the current color of the print. The Techkon SpectroDens device was used for colorimetric measurements of the samples. During the measurement, the value of the standard observer was set to 2°, the standard illumination to D50, and the polarizing filter was turned off. The experimental conditions included an ambient temperature of 22°C ± 2°C, a relative air humidity of 40% ± 2%, and atmospheric pressure of 101kPa ± 1kPa.

Colorimetric testing obtained CIELAB values, from which mean arithmetic values were calculated for each tested sample during data processing and subsequently utilized to determine the absolute color difference. This analysis aims to determine how color has changed over time and what effect different colors of printing substrates have on it. The color difference value (ΔE^*) was determined using the CIE ΔE formula provided below, where ΔL^* signifies the difference in brightness, Δa^* indicates the difference on the red/green axis, and Δb^* indicates the difference on the yellow/blue axis.

$$\Delta E^* = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}}$$

The color difference values were categorized as follows: ΔE < 0.2 (not visibly different), ΔE between 0.2 and 1 (the color difference is noticeable), ΔE between 1 and 3 (the color difference is visible), ΔE between 3 and 6 (the color difference is clearly visible), and ΔE over 6 (obvious color deviations) (Kašiković et al. 2014).

The measured colorimetric values were also used for contrast analysis on samples of different colors. Contrast analysis provides additional guidance for fabric color selection when using thermochromic inks on textile materials. The formula for calculating the contrast is given below:

Figure 1 shows the experimental setup.

$$Contrast = \frac{Color\ 1\ Lightness - Color\ 2\ Lightness}{Color\ 1\ Lightness} * 100\%$$

Figure 1 shows the experimental setup.

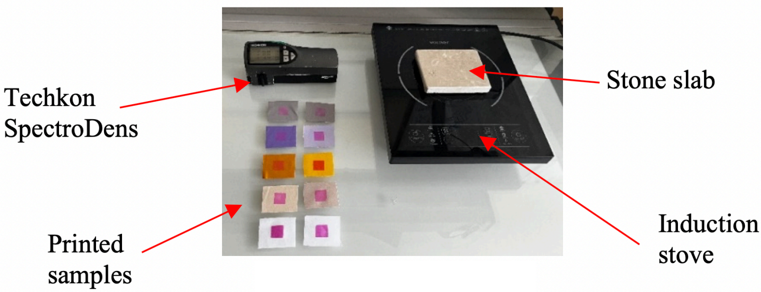

Fig 1. Experiment setup

Research results

Colorimetric analysis obtained CIELAB values, which were used to calculate the absolute color difference. The main goal of this analysis is to determine how the color of the print on different materials has changed over time. Figure 2 shows how the color of the samples on the beige substrate changed during cooling for one minute, with time intervals of 10 seconds each.

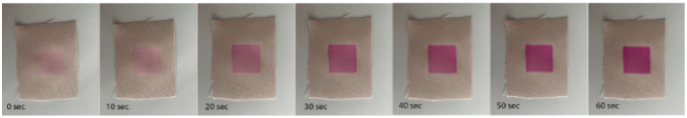

Fig 2. Display of color change in a time interval of one minute

Figure 3 graphically presents the color differences for the samples of different polyester colors. It can be noticed that the color change of the prints over time is not the same for all colors of the substrates and that the color change values increase as the print cools down, that is, as it recovers its coloring. The biggest color changes were recorded on prints printed on a yellow substrate, where the color difference was 50.94. The smallest color changes were measured on a print on a white substrate and amounted to 35.78. Also, considering that a color difference of more than five is considered a massive difference, with all prints in the first two intervals, the color difference is very noticeable. On the third and fourth intervals, all colors except yellow have a color difference of 1.49 to 3.02, which are characterized as very small and medium color differences. At all other intervals, with white, beige, gray, and purple, the color difference is very small, while with yellow, the difference is medium and can be noticed even by an untrained eye.

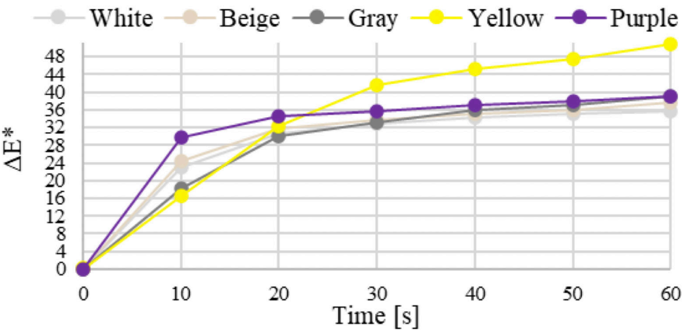

Fig 3. Comparative display of changes in absolute color difference over time for different colors of polyester textile materials

Prints on textile material made of a mixture of polyester and elastane require a longer cooling time to restore the color because the material has a greater thickness. Figure 4 shows how the color of the samples on the beige substrate, made of a mixture of polyester and elastane, was changed during cooling.

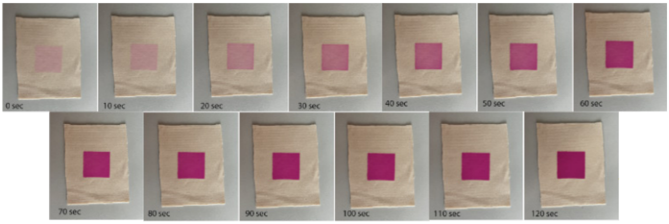

Fig 4. Display of color change in a time interval of two minutes

Figure 5 shows the color changes on prints printed on different colors of textile material made of a mixture of polyester and elastane during a time interval of 120 seconds. It can be seen on the graphic that even in this case, the color change is not the same for all samples. The most significant color changes were recorded on prints printed on a beige substrate, where the color difference was 49.57. The slightest color change was measured on the print on the purple substrate and was 27.05. By analyzing the other prints, it can be seen that the color change decreases with the change in material color from beige to white, yellow, and gray to purple.

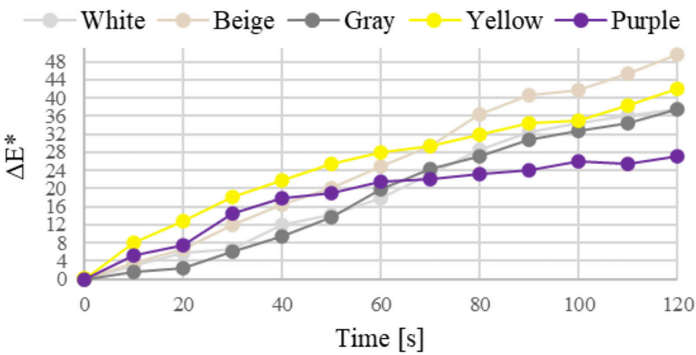

Fig 5. Comparative display of changes in absolute color difference over time for different colors of polyester-elastane blend textile materials

Contrast measurement is an important feature when choosing the color of the substrate for printing with thermochromic inks, as it enables the desired level of visibility of color change to be achieved. To calculate the contrast, the lightness values measured during the colorimetric measurement and the appropriate formula for calculating the contrast were used. The comparison is always made with the color of the substrate because it is important to monitor the contrast in relation to the substrate over time. The goal of the contrast analysis is to determine which substrate color for printed samples with magenta thermochromic ink gives the best contrast values when changing color. Figure 6 shows graphically the changes in contrast during the cooling time interval of the print on polyester samples.

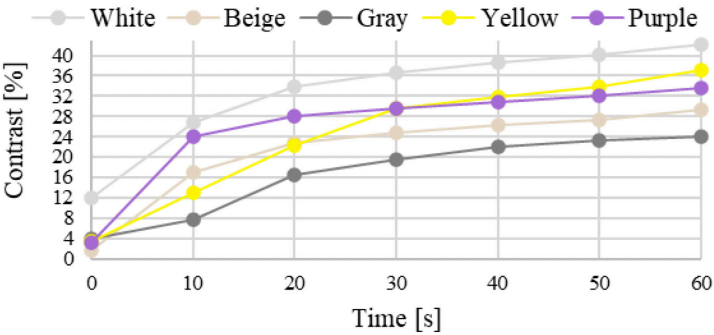

Fig 6. Graphic representation of contrast on samples printed on polyester textile material

Analyzing Figure 6, it is noticed that the contrast is the lowest at the first measurement interval, after which it increases drastically at the second and third measurement intervals for all colors of the substrate. After the third measurement interval, i.e., after 20 seconds of cooling the prints, the contrast values gradually increase. With the white substrate, a growth of about 2 % is observed at each subsequent time interval. The yellow substrate color at the fourth measurement interval still has a drastic increase in contrast by 7 %. Although there are significant increases in contrast over time, especially compared to the initial state, the contrast results are lower compared to the white substrate color. In the case of a print on a gray substrate color, after the third measurement interval, the contrast increases by 1 %, which is the smallest contrast change during the measurement time and the least noticeable change.

Figure 7 graphically presents the change in contrast over time for samples made of a mixture of polyester and elastane. It can be seen that all colors except yellow and purple have contrast values that increase over time. In the case of the print on the gray substrate, the highest contrast was recorded at the beginning compared to all other samples, but it also had a constant increase in contrast. The yellow substrate color in the first three measurement intervals gives the lowest contrast values compared to other colors, so it is not a good choice for contrast monitoring during color activation. The graphic shows that, in addition to gray, a purple substrate color can be used when following the mention of color around the activation temperature and in the first few seconds after heating the print. However, after reaching the activation temperature, the lowest contrast is expressed on the purple color of the substrate.

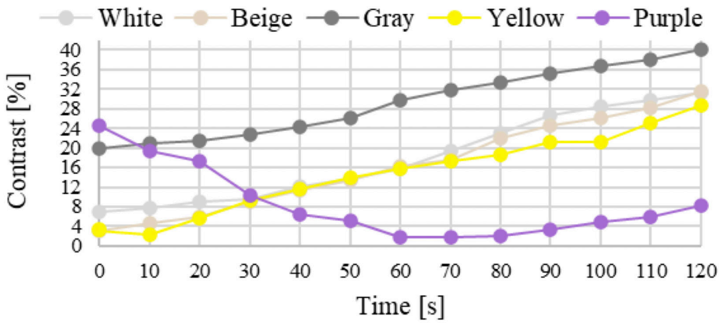

Fig 7. Graphic representation of contrast on samples printed on a polyester-elastane blend textile material

Conclusions

1. Contrast analysis of thermochromic inks on different colors of textile materials plays an important role in achieving the desired visual effects and functionality. A graphic representation of the contrast on different colors of the substrate of two different textile materials enables a clear view and comparison of the color contrast on different textile materials.
2. The highest contrast values on the polyester textile material within a 60-second time interval are given by the white color of the substrate, while the gray color of the substrate gives the lowest contrast values.
3. For samples printed on polyester and elastane blend textile material, it can be concluded that the gray color showed the best contrast both at the beginning and at the end of the measurement. Therefore, it gives good contrast results during both the cooling and heating of the print. Additionally, the white and beige colors are good because they have a constant and relatively even increase in contrast, while the yellow and purple colors of the substrate have variable contrast values during the cooling of the print, so they are not the best choice if a consistent change in contrast is desired.

Acknowledgment

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