Next Generation Chromatic Printing: Integration of Smart Colorants in Textile Substrates

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Abstract

Traditional textile colorants offer limited visual engagement due to their static properties. The rise of smart colorants—such as thermochromic, photochromic, hydrochromic, and phosphorescent (glow-in-the-dark) dyes—marks a significant shift in functional textile design. This study explores the application of these stimuli-responsive dyes on cotton and polyester/cotton fabrics. Employing optimized processing conditions and standard ISO-based fastness testing, the research validates the practicality of integrating multi-functional chromic effects into textiles. The findings show potential in wearable technology, interactive apparel for children, occupational safety wear, and mood-responsive fashion, paving the way for innovation in smart and functional garments.

Keywords

Smart Colorants, Thermochromism, Photochromism, Hydrochromism, Phosphorescence, Functional Textiles, Chromic Printing, Textile Chemistry

1. Introduction

The textile industry is witnessing a paradigm shift driven by the integration of smart and functional materials that elevate fabric performance beyond traditional aesthetics. Among these, **chromic materials**—substances capable of reversible color changes when exposed to specific stimuli such as heat, light, moisture, or UV radiation—are at the forefront of next-generation textile innovations. These dynamic materials have opened new avenues in interactive fashion, functional clothing, and wearable electronics.

Smart colorants such as **thermochromic**, **photochromic**, **hydrochromic**, and **phosphorescent (glow-in-the-dark)** dyes respond visibly to environmental changes, creating real-time feedback for the wearer or observer. For example, thermochromic dyes transition in color with temperature shifts, making them suitable for body-heat sensing apparel, while photochromic materials react to UV exposure and are increasingly applied in outdoor fashion and UV-protective wear. Hydrochromic dyes respond to water or humidity, ideal for rainwear or moisture-detection fabrics, and phosphorescent dyes store and release light energy, enhancing visibility in low-light conditions, which is valuable in safety gear and children's apparel (Harada et al., 2007; Fujiwara et al., 2004).

The potential of these materials lies not only in aesthetics but also in **functional and safety-driven applications**, including **healthcare diagnostics, mood-sensing clothing, military camouflage**, and **interactive children's wear** (Khattab et al., 2018; Wilk-Kozubek et al., 2024). Research by IOP Publishing (2019) emphasizes that combining multiple chromic responses within a single textile structure introduces challenges such as chemical incompatibilities and uneven fixation, but offers a richer and more engaging visual effect that cannot be achieved by conventional dyeing techniques.

Despite these advantages, industrial adoption has been limited due to concerns over **durability, wash fastness, and long-term stability** of smart dyes on textile substrates. As stated by Ludovic Gustafsson Coppel (2014), many of these chromic effects degrade after repeated washing or prolonged exposure, which necessitates further innovation in dye formulations and application techniques.

This study seeks to bridge that gap by exploring the practical integration of various chromic dyes into cotton and polyester-cotton blend fabrics under controlled printing and curing conditions. By employing standard ISO test methods for colorfastness, the research evaluates the performance and limitations of single and combined chromic dye systems. The work sets the stage for future developments in **responsive textiles** that serve both **functional** and **experiential** needs of consumers

2. Objectives

This study was designed with the following aims:

- To design textiles capable of transitioning between formal and informal appearances using chromic responses.
- To integrate multiple stimuli-responsive dyes into standard textile substrates, increasing interaction and appeal, particularly for younger consumers.
- To investigate the application of chromic colorants in non-fashion uses such as medical diagnostics and visibility-enhancing safety wear.

3. Materials and Methods

3.1 Substrates

- 100% Cotton
- Polyester/Cotton Blend

3.2 Smart Colorants Used

- Thermochromic dyes
- Photochromic dyes
- Hydrochromic dyes
- Glow-in-the-dark pigments (Phosphorescent)

3.3 Dye Combinations

- Thermochromic + Photochromic
- Photochromic + Hydrochromic + Phosphorescent
- All Four Combined (Full Spectrum)

3.4 Application Technique
• Screen/table printing
• Drying at 70–80°C
• Curing using dye-specific time-temperature profiles

4. Evaluation and Testing

Standardized Testing (ISO Methods):
- Colourfastness to Washing – ISO 105-C06
- Colourfastness to Rubbing – ISO 105-X12
- Colourfastness to Perspiration – ISO 105-E04
- Colourfastness to Water – ISO 105-E01
- Colourfastness to Light – ISO 105-B02

Tests were conducted in certified textile labs under the test report titled "CORRELATION SAMPLE" dated February 10, 2025.

5. Results and Discussion

The durability of the smart colorants was evaluated through standardized tests assessing color retention and physical integrity under common textile stress conditions such as rubbing, perspiration, washing, water immersion, and light exposure. Across 15 different dye configurations—ranging from single chromic systems to complex multi-functional combinations—the test results revealed consistent trends in performance.

Single dye applications such as thermochromic, photochromic, hydrochromic, and glow-in-the-dark systems scored highly in fastness parameters. Each recorded ratings of 3–4 or 4 across all ISO tests, corroborating findings from previous studies (e.g., Harada et al., 2007; Wilk-Kozubek et al., 2024) which highlighted the stability of isolated smart dyes under standard processing conditions.

In contrast, multi-dye combinations such as Thermochromic + Photochromic + Hydrochromic exhibited reduced ratings (as low as 2–3 in perspiration and washing). This is attributed to potential antagonistic interactions between dye chemistries and non-uniform fixation profiles. IOP Publishing (2019) supports this observation, noting that mixed chromic systems often face solubility conflicts and substrate incompatibility.

However, these limitations are balanced by the enhanced aesthetic and interactive visual effects achievable with such dye blends. Their novelty positions them well for applications in children's fashion, branding, mood apparel, and visibility-enhancing garments (Khattab et al., 2018).

Thus, while single dye systems excel in durability, the pursuit of multi-functional apparel must involve strategic selection, careful pre-treatment, and improved crosslinking agents to maximize fixation and minimize color migration or degradation over time.

6. Conclusion

Smart colorants offer a revolutionary approach to textile printing. This study demonstrates the feasibility of incorporating thermochromic, photochromic, hydrochromic, and phosphorescent dyes into common substrates. While multi-functional dye systems exhibit slightly lower durability than single-dye applications, the aesthetic and functional benefits justify their continued development. These textiles hold strong potential across multiple domains—interactive fashion, children's wear, healthcare diagnostics, and safety wear.

7. References

1. Ludovic Gustafsson Coppel, Society for Imaging Science and Technology, 2014, pp. 242–246.
2. Jun Harada et al., American Chemical Society, 2007, pp. 16216–16221.
3. Md. Ibrahim H. Mondal, Textiles: History, Properties, Performance and Applications, Nova Science Publishers, Inc., 2014.
4. I. Cabral et al., 'Dynamic colour in textiles: combination of thermo, photo and hydrochromic pigments,' IOP Publishing Ltd., 2019, pp. 1–6.
5. Shafia Siddiqui et al., Pakistan Journal of Social Sciences, 2023, pp. 381–388.
6. Magdalena Wilk-Kozubek et al., Polymers, MDPI, 2024, pp. 1–17.
7. H. Bouas-Laurent et al., Pure and Applied Chemistry, IUPAC, 2001, pp. 639–665.
8. Bikash Garai et al., Chemical Science, 2016, pp. 2195–2200.
9. Junji Zhang et al., Advanced Materials, 2013, pp. 378–399.
10. Helmut Gorner, 'Photochromism of nitrospiropyrans: effects of structure, solvent and temperature,' The Owner Societies, 2001, pp. 416–423.
11. P. S. Hariharan et al., 'Tunable Fluorescence and Nanofabrication Studies,' JPCC, 2015, pp. 9460–9469.
12. Tawfik A. Khattab et al., Carbohydrate Polymers, 2018, Vol. 195, pp. 143–152.
13. Toshikatsu Fujiwara et al., American Chemical Society, 2004, pp. 4035–4038.
14. Morita Yasushi et al., Annual Report of Osaka University, 2008, pp. 15–17.
15. Anitha Patlolla et al., The Royal Society of Chemistry, 2012, pp. 7028–7035.
16. Hélène Sérier-Brault et al., Hal Open Science, 2020, pp. 1–24.
17. Angela G. Rincon et al., J. Phys. Chem. Letters, 2010, pp. 368–373.