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Printed and performance of temperature-responsive fabrics based on black thermochromic pigment

Abstract

The thermochromic pigments have been utilized in a variety of applications, including fashion design, textiles, gloves, military uses, and camouflage. While most of the research has focused on enhancing fastness proprieties, little attention has been given to optimizing the formulation of these pigments. This study aims to improve the fastness properties of thermochromic printed fabrics while optimizing the recipe by reducing the quantity of chemicals used. In this research, 100% cotton fabrics were printed with CHAMELEON thermochromic pigment, utilizing different quantities of fixer and slurry, including samples printed with and without these additives at a 3% shade concentration. Total number of three samples were printed using slurry and three without it. The printed fabrics were then dried at 100ºC and cured at 160ºC. Fastness tests were conducted following international standard methods, including rubbing fastness using a crock meter, lightfastness with a mercury lamp, and washing fastness using a Wascator. Results were visually assessed due to temperature deviations affecting spectrophotometer readings. The findings indicate that while the fastness properties of printed fabrics without slurry or fixer improved, as increase in fixer quantity resulted in decreased fastness properties. By optimizing the quantities of fixer and slurry, better fastness results were achieved for thermochromic printed fabrics without the use of slurry and fixer, instead utilizing a binder.

Keywords: thermochromic pigment, flat-belt screen printing, 100% cotton fabric, fastness properties

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Introduction

Thermochromic pigments exhibit color changes in response to temperature fluctuations, with the nature of this change being either reversible or irreversible, depending on the specific type of pigment utilized.[1,2] The thermochromic effect typically involves a reversible transformation in the color of fibers when they reach a designated activation temperature. As the temperature approaches this activation point, the color begins to fade, approximately 4°C below the activation threshold, transitioning through a range of colors until the original hue is restored upon cooling. These color-changing materials find extensive applications in various industries, including paints inks, dyes, and textiles.[3,4] Beyond traditional uses, thermochromic pigments are also incorporated into novelty items such as toys, dolls, and color-changing seals on beverage mugs that react to the temperature of hot or cold liquids.[3] Lecuo-dye thermochromic printed fabrics have been integrated with advanced technologies to create interactive textile displays, enabling new perspectives on the relationships between human behavior and the surrounding environment.[5] Thermochromic pigments are organic compounds that reversibly change color in response to temperature variations, which has led to their application in a wide range of functional and smart materials. In industrial and architectural contexts, thermochromic pigments have been explored for energy-related application, such as energy recovery in greenhouses, covered swimming pools, and membrane structures used in architectural textiles. For instance, when black thermochromic pigments are applied as coatings on roofing textiles below their transition temperature, they absorb incident solar radiation and appear black, subsequently releasing the absorbed energy in the form of infrared radiation to warm the interior environment. Above the transition temperature, the pigments lose their black coloration and reflect incident radiation, thereby helping to regulate indoor temperature and reduce heat gain.[6] In printing and packaging applications, the performance of thermochromic inks is strongly influenced by surface finishing treatments. These surface coatings not only affect visual appearance but also enhance rub resistance, which is critical for maintaining print quality during handling and transportation. Nevertheless, product appearance is influenced by multiple factors beyond printing techniques, substrate selection, and additives.[7] Moreover, the lightfastness of thermochromic colors varies depending on pigment composition, with stability decreasing as indicated by lower ratings on the blue wool scale, and with greater variability observed among different color formulations.[8]

Pigment

In wet-processing technologies, pigments represents a distinct class of colorants that differ fundamentally form dyes due to their complete insolubility in water. As a result, coloration of textile substrates using pigments is more technically challenging than conventional dying processes and requires specialized pigment printing techniques. Pigments are predominantly employed in textile printing rather than dyeing and typically exhibit particle sizes in the range of approximately 0.1-3 µm.[9] Pigments can be classified into natural organic, synthetic organic, natural inorganic, and synthetic inorganic categories based on their origin and chemical composition.[10] Natural organic pigments, derived from animal and plant sources, have limited practical application in textile due to their poor lightfastness and inadequate durability. However, with the exception of carbon black, many synthetic organic pigments exhibit limited stability and are prone to degradation or abrasion during use.[1] In addition, natural inorganic pigments are generally obtained by mining, washing, and grinding mineral-based materials, with most earth-tone pigments originating from iron-rich clays. Thermal treatment sometimes applied to modify their color, as exemplified by pigments such as raw umber, burnt umber, and burnt sienna. In contrast, synthetic inorganic pigments are produced through controlled chemical reactions or thermal process and are characterized by superior stability and lightfastness.[11]

Thermochromic pigments

Thermochromic pigments are temperature-responsive materials that undergo a visible color change upon heating or cooling, enabling color modulation as a direct function of temperature.[12] Depending on their formulation, thermochromic pigments may exhibit either reversible or irreversible color transitions. Among the various types, lecuo-dye thermochromic pigments are the most widely used in textile and printing applications. These pigments typically consist of three essential components: a color former (leuco dye), a developer, and a solvent, combined in a carefully controlled microencapsulated system. The particle size of commercially available thermochromic pigments is generally < 6 μm for approximately 97% of the particles, facilitating uniform dispersion and printability.[4] In practical applications, thermochromic pigments are commonly incorporated into water-based resin binders and applied to white or neutral-pH textile substrates through printing processes. Within specific temperature ranges, these pigments transition from a colored state to a lighter or nearly colorless state. Initially, the color gradually fades as the temperature approaches the activation threshold and becomes almost colorless once the activation temperature is reached. The pigments remain in this colorless state until the temperature decrease below the transition range, at which point the original color is restored. This reversible color-change behavior is a defining characteristic of lecuo-dye thermochromic systems.[7] Thermochromic pigment slurries are available in a wide range of colors and activation temperatures to meet diverse application requirements. Standard activation temperatures typically include 15°C, 31°C, and 47°C, while custom formulations can be designed to activate across a broader temperatures range, from -10°C to 69°C.[13] The activation temperature is defined as the point at which the pigment has nearly completed its transition to a clear or light-colored state. The onset of color fading generally occurs approximately 4°C below the activation temperature, with intermediate color states observed within the transition range. Common standard colors include black, blue, magenta, green, orange and red, while customized shades such as purple, brown and turquoise are also available.[14]

Types of thermochromic ink

Thermochromic inks represent one of the major classes of color-changing inks developed since the 1970s and are characterized by their ability to undergo reversible color changes in response to temperature variations.[11] Previous study, thermchromic inks can be broadly categorized into two main types: liquid crystal-based systems and leuco-based systems.[15] Liquid crystal thermochromic inks exhibit high sensitivity to temperature fluctuations; however, their application requires highly specialized printing techniques, making them relatively complex and challenging to process. In contrast, lecuo-dye thermchromic inks are easier to handle and are therefore more widely employed, particularly in screen-printing processes. Owing to their ease of processing and versatile color-change behavior, lecuo-dye thermochromic inks have been extensively applied in a variety of consumer and industrial products, including textile applications, color-changing garments, interactive plastic items such as baby safety feeding spoons, coffee mugs, and toys. These inks are particularly well suited for use as visual temperature indicators, providing qualitative information such as cool, warm, or hot states.[15]

Liquid crystal thermochromic systems are typically employed in applications requiring high precision, as their color-change behavior can be engineered to respond within narrowly defined and programmable temperate ranges. Common applications include thermometers, liquid crystal display (LCD) screens, and novelty products such as mood rings. Owing to their liquid nature, liquid crystal used in textile applications are microencapsulated within aqueous solution to facilitate processing and improve stability. To maximize visual impact, these microencapsulated formulations are often applied via screen-printing, ensuring that the thermochromic materials remains predominantly on the fabric surface. The temperature range over which liquid crystals exhibit color changes can be precisely tailored to suit specific applications. The temperature interval between the onset of red colorations and the emergence of blue is referred to as the bandwidth, which can be designed to span from a narrow as 1°C to as broad as 20°C. The use of a black background is known to enhance color visibility, as it absorbs incident light and allows only the selectively reflected wavelength to be perceived. The thermochromic behavior of liquid crystals arises from temperature-induced changes in their molecular arrangement, which alter the wavelength of visible light reflected by the material. During operation, liquid crystal transition from a black state through the visible color spectrum and eventually return to back outside the active temperature range. Despite the functional advantages, liquid crystal thermochromic systems used in textiles are highly sensitive to soiling and contact with surface substances. This vulnerability is largely governed by the integrity of the microcapsule shell wall; degradations or rupture of the capsules can lead to the loss of active components and a consequent decline in thermochromic performance.[16] Lecuo-dye thermochromic inks are characterized by a distinct color-change behavior, appearing colored at temperatures below their activation threshold and becoming transparent or slightly colored when heated above the activation temperature. These inks are often blended with non-thermochromic pigments to enable controlled color transitions between different hues rather than a sample color-to-colorless change.[15]

Thermochromic materials in textiles

In textile applications, thermochromic functionality is primarily achieved using two classes of materials: lecuo-dye thermochromic pigments and liquid crystals.[17] Both classes require microencapsulation prior to application in order to ensure thermal stability and protection from environmental effects. However, the color strength of lecuo-dye thermochromic pigments is relatively low-compared with conventional commercial pigments. This limitation arises from the inherently low dye content, which is approximately 2 wt% prior to microencapsulation and further reduced in the final encapsulated formulation. To compensate for this low color yield and to avoid pale shades, thermochromic pigments are often used at high loadings (approximately 15-30 wt%) in coating formulations. Such high pigment concentrations adversely affect fabric handle, flexibility, and overall comfort, which remains a critical challenge of textile applications. Commercial applications of lecuo-dye thermochromic pigments have been reported, most notably in T-shirts marketed under the Global Hypercolor brand in the early1991s. In these products, permanent background colors were combined with thermochromic pigments to achieve color-to-color transition rather than color-to-colorless effects. Despite their novelty, these garments exhibited poor fastness properties, particularly with respect to wash durability. Similar limitations have been observed in children's garments incorporating thermochromic effects intended to visualize changes in body temperature, as well as in denim fabrics designed to exhibit a temperature-induced faded appearance mimicking indigo wear patterns. Overall, although both lecuo-dye thermochromic pigments and liquid crystals have demonstrated functional feasibility in textile applications, their widespread adoption remains limited. Key challenge include inadequate wash and light fastness, high material costs and limited commercial availability. Nevertheless, these materials exhibit significant potential in the development of smart and responsive textiles, and ongoing research is expected to address current performance deficiencies and expand their commercial viability.[18]

Organic thermochromic pigments, which is reversible change color in response to temperature variation, also present promising opportunities beyond apparel applications.[1,19] In particular, their use in architectural and industrial textiles for energy management has attracted increase interest. For example, when a black thermochromic pigment is applied as a coating on textile membranes used in greenhouse roofs or covered swimming pools, the pigment absorbs incident solar radiation below its transition temperature, resulting in heat retention through infrared emission. Above the transition temperature, the pigment loses its black coloration, reflecting incoming radiation and thereby limiting further heat again. This adaptive behavior contributes to passive thermal regulation and improved energy efficiency in membrane-based structures.[20] Thermochromic materials have also been explored in baby garments, where color changes may serve as visual indicators of discomfort, illness, or abnormal body temperature. Such applications can be implemented either before garment manufacturing or as post-production coatings and prints using suitable binder systems.[21] The effectiveness of thermochromic coatings on textile substrates is influenced by the physical characteristics to the textile material, including fiber fineness and density. Thermochromic layers may be applied at various stages fiber, yarn, or fabric depending on particle size and substrate structure.[18]

In this study, focuses on the development of thermochromic pigment-printed 100% cotton fabric and systematically evaluates the influence of slurry and fixer concentration on color depth, rubbing fastness, washing fastness, and light fastness. By optimizing the printing formulation and process conditions, this study objectives to identify a simplified and effective approach for producing temperature-responsive cotton fabrics with acceptable fastness properties, thereby contributing to the advancement of functional and smart textile materials.

Experimental methodology

Material

A 100% cotton fabric was obtained from Gul Ahmed Textile Industries. Color Change Ltd. (UK) supplied the black thermochromic pigment slurry. The binder (77N), thickener (PTRV, BTF180), liquor ammonia, and fixer (Libra fix) were procured from a Popular Textile Industry. All materials were used as received without further purification.

Grey fabric assessment

The fabric mass per unit area (GSM) was determined in accordance with ASTM D3776. Fabric specimens were cut using a standard GSM cutter and subsequently weighed using an analytical balance to calculate the GSM value. The pH of the fabric was measured using a universal pH indicator. A few drops of the indicator solution were applied to the fabric surface, and the resulting color change was visually compared with the standard pH scale within a few seconds. The starch content of the fabric was evaluated using the TEGWA test. The TEGWA solution was prepared by dissolving approximately 10 g of potassium iodide in distilled water, diluting the solution to 800 mL with water, and subsequently making up the final volume to 1000 mL with ethanol. Two to three drops of the prepared solution were applied to the fabric surface, and the resulting color intensity was compared with the TEGWA scale to estimate the starch content.

Fabric absorbency was assessed using the capillary rise method. Test specimens were marked at 10 cm intervals and vertically immersed in a Turkish solution for 2-3 to allow capillary action. The samples were then immediately ironed, and the absorbency was evaluated based on the height of liquid rise. The pilling resistance of the fabric was determined using a Martindale pilling tester in accordance with ASTM D4970. Circular fabric specimens were prepared using a standard pilling cutter and mounted on the tester plates. The samples were subjected to 1000 rubbing cycles under a specified load. Both single-plate motion (one plate stationary) and dual-plate motion (both plates moving) tests were conducted to assess surface fiber entanglement on the front and back sides of the fabric, respectively. Pilling performance was evaluated by visually comparing the tested samples with standard pilling rating cards. Fabric whiteness was measured using a spectrophotometer, and the whiteness index was recorded accordingly.

Pigment paste

The pigment paste was formulated using 9 wt% binder and an equivalent amount (9 wt%) of thermochromic pigment slurry, along with 1.7 wt% thickener (PTRV). The remaining components, as specified in the formulation recipe, were adjusted with deionized and distilled water. The mixture was initially blended manually in a beaker and subsequently homogenized using a high-speed mechanical stirrer for approximately 5 min to ensure uniform dispersion. The viscosity of each prepared paste for was maintained at approximately 80 cP at 22 ± 1ºC, as measured using a viscometer. This resulting paste was then used for printing, with thermochromic pigment concentrations adjusted according to the desired color depth (Table 1).

Table 1 Printing recipe for thermochromic pigment-printed 100% cotton fabric

Auxiliaries	R # 1	R # 2	R # 3	R # 4	R # 5	R # 6
CHAMELEON Pigment (Black)	3%	3%	3%	3%	3%	3%
Slurry	9%	9%	9%	-	-	-
Thickener (PTRV BTF 180)	1.70%	1.70%	1.70%	1.70%	1.70%	1.70%
Binder (77N)	9%	9%	9%	9%	9%	9%
Liquor Ammonia	1%	1%	1%	1%	1%	1%
Fixer (Libra fix) (ml)	-	1%	2%	-	1%	2%

Total solution for each recipe = 100ml

Printed fabric assessment

The color depth of the printed cotton fabrics was evaluated through visual assessment. Six independent assessors examined the samples using a standard color-matching booth under daylight illumination at a controlled room temperature of 18ºC-22ºC. Visual evaluation was adapted in this study because spectrophotometric measurement were

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found to be unreliable due to temperature-induced color variations inherent to thermochromic materials.

Rubbing fastness was assessed using a crock meter in accordance with ISO 105-X12. Printed fabric specimens measuring (25 x 5) cm were mounted on a rigid, flat metallic platform and secured with pins. A white crocking cloth (5 x 5) cm was attached to the abrading finger with a flat circular rubbing surface (16 x 25) mm diameter, and the samples were subjected to 10 rubbing cycles under a normal force of 9 N. Both dry and wet rubbing test were performed, and the degree of staining on the crocking cloth was evaluated using a standard staining scale.

Washing fastness of the thermochromic printed fabrics was evaluated following the ISO-105-CO2 standard. Fabric specimens measuring (4 x 10) cm were attached to adjacent white fabric and washed in a soap solution containing 5g/l detergent at a liquor ratio of 1:50. The washing process was conducted at 50ºC for 45 min using a high-temperature dyeing (HTD) machine. After washing, the samples were rinsed thoroughly with cold water and dried in a drying chamber for 2-3 min, depending on fabric quality. The washing fastness was subsequently assessed by visually comparing the washed samples with untreated printed fabrics using a standard staining scale.

The lightfastness of the thermochromic printed fabrics was evaluated in accordance with ISO 105-BO2. Test specimens with this dimension not less than (4.5 x 1) cm were prepared for analysis. Prior to testing, the humidity conditions of the xenon arc light exposure apparatus were adjusted according to the standard requirements. The specimens and blue wool reference standards were arranged, with an opaque cover placed across the middle third of both the specimen and the reference samples.

Results and discussion

Thermochromic material are available in four primary forms, each designed for specific applications. The first form is thermochromic microcapsules in powder pigments, which are engineered primarily for use in non-aqueous ink systems and thermal resins. However, their applications extend beyond these systems to include toys and indirect food contact materials. The second form is thermochromic microcapsules in an aqueous-based dispersion, optimized for aqueous ink techniques. These materials, while primarily intended for such techniques, are versatile and have broader applications. The third form includes thermochromic inks available in various forms, such as screen-printing, flexographic printing, or spray applications. These inks are designed for use in water-based, UV-curable, and plastisol systems. They are particularly suited for a range of substrates, including textiles, plastic, ceramic and paper/board. The fourth form is thermochromic pellets, which are a blend of thermchromic compounds and polymer master batch carriers. These pellets are designed to be compatible with most plastic systems, allowing for seamless integration into plastic-based manufacturing processes (Figure 1).

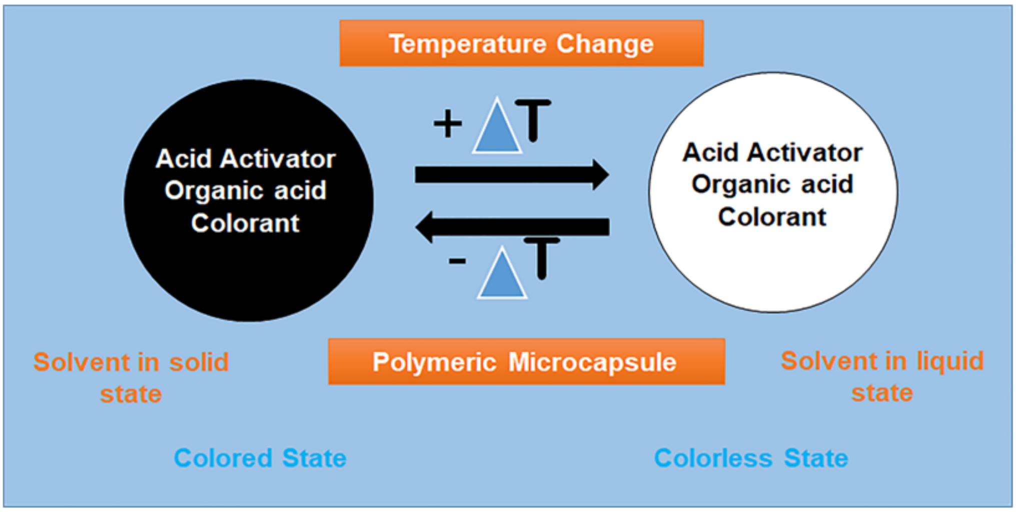

Figure 1 Schematic illustration of reversible color change mechanism of thermochromic pigment.

Chemistry of thermochromic pigment

Thermochromic pigments are typically composed of three essential components: an electron-donating, color former, an electron-accepting developer, and a color-change controlling agent. In practical terms, these pigments are formulated using an organic dye, an acid activator, and a low-melting solid, such as an ester or alcohol that functions as a solvent upon liquefaction. These components are commonly encapsulated within microcapsules to ensure stability and consistent performance. At temperatures below to the melting point of the solvent, the color former and developer remain in close contact, enabling electron interactions those results in the appearance of a visible color. When the temperature exceeds the solvent's melting point, the solvent liquefies and separates the color-forming components, disrupting electron interaction and consequently leading to a colorless state. The microencapsulation of these components is critical, as the thermochromic response is highly dependent on maintaining a precise and constant ratio among the three constituents, thereby protecting the system form external environmental influences. This microencapsulated thermochromic composition enables the development of commercial products with enhanced chromatic performance, offering a wide range of colors and higher color density compared to conventional thermochromic materials such as metal complex crystals and cholesteric liquid crystals. Moreover, the sharp and reversible transition between colored and colorless states contributes to their functional superiority. In textile applications, thermochromic pigments are typically applied to fibers, yarns, or fabrics through surface coating processes using appropriate binders.[22]

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Structure of leuco dyes

Leuco-dye thermochromic inks consist of a color former, a color developer, and a solvent, collectively referred to as the thermochromic composite, which is subsequently microencapsulated to protect the active components from environmental degradation.[15] In the non-heated state, the composite remains solid, allowing the color-former to exit in its colored form. Upon heating above the activation temperature, the solvent undergoes a solid-liquid phase transition, disrupting the interaction between the color former and the developer. This disruption induces a reversible structural change in the color former, resulting in a transition to its colorless form. The activation temperature of the therefore governed by the melting point of the solvent, which directly influences the thermal response observed in the present study. Lecuo-dye thermochromic inks may exhibit either reversible or irreversible behavior. Reversible systems displays a color-to-colorless transition when heated above the activation temperature, with full color recovery upon cooling, enabling repeated cycling without permanent degradation (Figure 2).

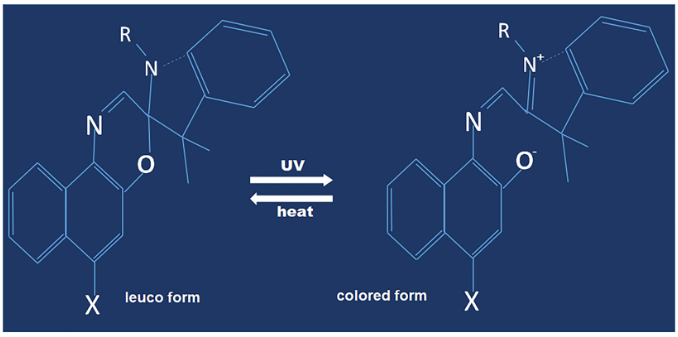

Figure 2 Schematic principle of reversible color transition in lecuo-dye thermochromic pigments.

In contrast, irreversible thermochromic inks undergo a one-way transition from a clear to a colored state when exposed to elevated temperatures. This transition typically initiates at approximately 65 °C and is completed around 90 °C, after which the color change is permanent.[23] Furthermore, the availability of leuco-dye thermochromic inks in various formulations, including solvent-based, water-based, UV-curable, and epoxy systems, allows their application across a wide range of substrates such as textiles, plastics, paper and metals.[22] This formulation versatility is relevant to the observed performance characteristics and supports the suitability of these inks for diverse functional and industrial applications.

Methodology of applying thermochromic ink

Thermochromic pigments containing leuco-dye color formers have been successfully incorporated in synthetic cellulose fibers during filament formation using the wet-spinning technique. In this approach, thermochromic pigments were dispersed in the cellulose spinning bath, and the resulting filaments exhibited clear thermochromic behavior, demonstrating the feasibility of bulk incorporation at the fiber formation stage. However, industrial fabrics containing thermochromic components have been developed for heat profiling of thermal processing environment, while nonwoven fabrics incorporating lecuo-dye thermochromic pigments have been developed via melt-spinning techniques. Additionally, waterproof apparel manufactured from flexible PVC sheets and other polymers substrates has been reported to exhibit temperature-dependent color changes, enabling visual monitoring of ambient temperature variations. More complex material systems have also been explored, including multilayer polymer composites fabricated by melt extrusion, in which one or more layers contain thermochromic materials combined with conventional polymer layers. These structures enhance durability and functional performance while retaining thermochromic responsiveness. However, despite their broad compatibility with textile fibers, thermochromic pigments exhibit low inherent affinity for textile substrates, making conventional dyeing processes ineffective. To address this limitation, a dyeing method based on the cationization of cotton fabric has been developed. In this method, cotton substrates are first treated with a cationic agent to introduce positive charges, followed by immersion in a dispersion of reversible thermochromic materials within a high-polymer medium.[18] In addition, effective fixation of thermochromic pigments on textile surfaces has been achieved using cross-linking agents, which promote bonding between the pigment and the fabric. This fixation s commonly applied through flat-belt screen-printing using a 180-mesh screen, resulting in uniform color development and improved durability.

Fastness properties of thermochromic pigment-printed fabrics

Thermochromic color change behavior

Figures 3A-3C display the thermochromic pigment-printed fabric below the activation temperature, where the fabric visibly retains its black coloration, confirming successful pigment fixation. In contrast, Figures 4A-3C show the same fabric above the activation temperature, exhibiting a clear color transition to white, indicative of the reversible thermochromic behavior inherent to the CHAMELLON pigment system. This reversible color change is consistently observed irrespective of the presence or absence of slurry in the printing formulation, demonstrating the robustness of the pigment's thermal response under different printing conditions.

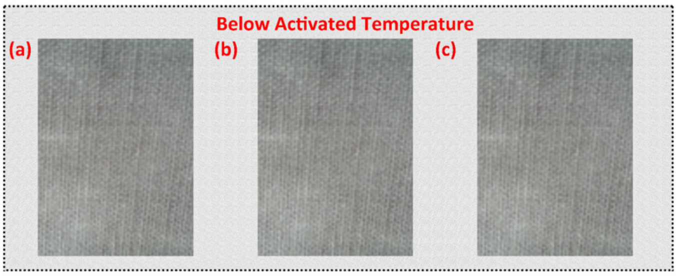

Figure 3 Appearance of thermochromic pigment-printed fabric at temperatures below the activation point.

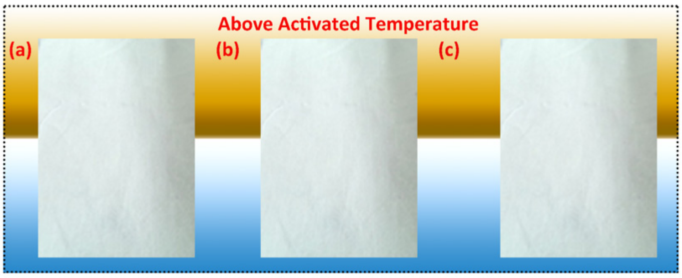

Figure 4 Visual response of thermochromic pigment-printed fabric at temperatures exceeding the activation temperature.

Effect of slurry and fixer on color depth

Visual examination under controlled illumination revealed that the color depth of fabrics printed with slurry remained essentially unchanged across varying fixer concentrations, as shown in Figures 3A-3C (Recipes 1-3). Similarly, samples printed without slurry but

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with different fixer content exhibited comparable color intensity, as illustrated in Figures 5A-5C (Recipes 4-6). These observations suggest that the binder primarily governs pigment fixation and color depth, with neither slurry nor fixer significantly influencing the visual color intensity of the printed fabric. Additionally, the use of a lower GSM fabric (136g/m^2) with an open pore structure likely facilitated pigment penetration, contributing to the uniform color depth observed across all formulations.

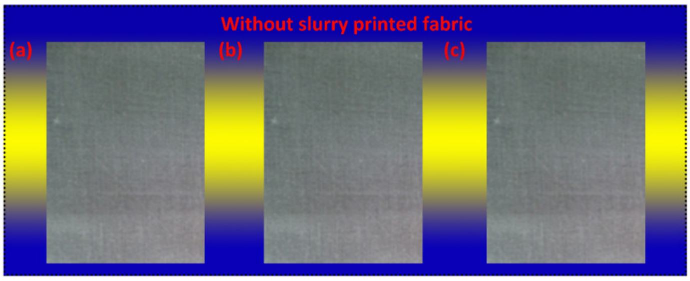

Figure 5 Surface appearance of thermochromic pigment-printed fabric printed without slurry.

Rubbing fastness

The rubbing fastness results, summarized in Table 2, indicate that dry rubbing resistance was uniformly high across all samples, with ratings mostly at 4/5 or 5. However, wet rubbing fastness was notably affected by slurry and fixer presence. Samples printed with slurry but without fixer (Recipe 1) demonstrated excellent wet rubbing fastness (rating 5). Increasing fixer concentration in slurry-containing samples (Recipes 2 and 3) led to a marked decline in wet rubbing fastness, with rating dropping to 3 and 2, respectively. A similar trend was evident in slurry-free samples, where fixer-free Recipe 4 achieved a wet fastness rating of 5, whereas Recipes 5 and 6, containing 1% and 2% fixer, registered lower ratings. These findings indicate that while fixer may enhance dry crocking resistance, its presence adversely impacts pigment adherence under wet conditions, possibly by interfering with pigment-fiber bonding when moisture is present.

Table 2 Assessment of rubbing fastness (dry and wet) of thermochromic pigment-printed fabric

Sample code	Dry rating	Wet rating
Recipe 1	5 ± 0.1	5 ± 0.1
Recipe 2	5 ± 0.1	3 ± 0.2
Recipe 3	5 ± 0.1	2 ± 0.3
Recipe 4	4/5 ± 0.2	5 ± 0.1
Recipe 5	4/5 ± 0.2	4 ± 0.2
Recipe 6	5 ± 0.1	4 ± 0.2

Washing fastness

As detailed in Table 3, washing fastness assessments show that fabrics printed without fixer but with slurry (Recipe 1) maintain excellent resistance to staining after washing (rating 5). This introduction of fixer at 1% and 2% concentrations (Recipes 2 and 3) slightly reduced washing fastness to a good level (rating 4), indicating diminished durability. Remarkably, similarly high washing fastness was observed for the slurry-free and fixer-free sample (Recipe 4), confirming that slurry and fixer are not prerequisites for wash durability. Increasing fixer content in slurry-free samples (Recipes 5 and 6) further decreased washing fastness, confirming the detrimental effect of fixer on wash performance. The data suggest that fixer may promote pigment migration or destabilize pigment-fiber interactions during laundering, leading to increased fabric staining.

Table 3 Washing fastness performance of thermochromic pigment-printed fabrics

Sample code	Bleached fabric	Staining
Recipe 1	5 ± 0.1	5 ± 0.1
Recipe 2	4 ± 0.2	5 ± 0.1
Recipe 3	4 ± 0.2	5 ± 0.1
Recipe 4	4/5 ± 0.2	5 ± 0.1
Recipe 5	4 ± 0.2	5 ± 0.1
Recipe 6	¾ ± 0.3	4 ± 0.2

Lightfastness results

Table 4 reveals that lightfastness ratings, based on the blue wool scale, vary primarily due to the presence of slurry. Samples printed with slurry (Recipes 1-3) achieved a rating of 3 and exhbited noticeable fading after 2 hours of xenon arc light exposure. Conversely, slurry-free samples (Recipes 4-6) displayed improved photostability with a rating of 4 and delayed fading to 3 hours. The fixer concentration does not appear to influence lightfastness significantly. These results underscore that slurry may accelerate photo degradation of thermochromic pigments, potentially by increasing their exposure or reactivity to ultraviolet radiation. Strategies such as UV absorbers could be incorporated to further enhance lightfastness in future formulations.[18]

Table 4 Lightfastness ratings of thermochromic pigment-printed fabric (blue wool scale)

Sample code	Left side		Right side	
	Blue wool scale	Hours	Blue wool scale	Hours
Recipe 1	3 ± 0.2	2	3 ± 0.2	2
Recipe 2	3 ± 0.2	2	3 ± 0.2	2
Recipe 3	3 ± 0.2	2	3 ± 0.2	2
Recipe 4	4 ± 0.1	3	4 ± 0.1	3
Recipe 5	4 ± 0.1	3	4 ± 0.1	3
Recipe 6	4 ± 0.1	3	4 ± 0.1	3

Conclusion

In this study, 100% cotton fabric was printed using hand screen-printing techniques, both with and without slurry. The comparison of these two methods revealed that printing without slurry and fixer yielded superior results. The primary focus of this study was to optimize the printing formulation, with secondary objectives including applications for curtain, table covers in ICU rooms, aprons, and fashion design. Previous studies aimed at improving lightfastness utilized a UV observer in conjunction with slurry; however, this research achieved similar results without the use of slurry, effectively optimizing the formulation. In earlier work, synthetic binder such as Bricoprint Binder SF20E, Perapret PU New, and LA-B 1096 BASF were predominantly used, alongside a thickener known as Magnaprint Clear M04, with pigment paste formulations containing 10% binder, 4% thickener and the remainder as water. In this study, a natural binder (77N) was formulated, complemented by an eco-friendly thickener (PTRV BTF 180) at a reduced concentration of 1.7%. This adjustment minimized the amount of thickener used, achieving the necessary viscosity of 80 cps by decreasing the thickener content from 4% to 1.7%. Samples were printed with varying quantities of fixer, dried at 100 ˚C, and cured at 160 ºC for 90 second. Colorfastness properties, including wash fastness, rubbing fastness, and light fastness, were evaluated according to international standards. While previous research predominantly focused on enhancing fastness properties using slurry and various chemicals, this study successfully improved fastness properties without slurry, utilizing thermochromic pigment. Ultimately, the optimization of slurry and fixer was achieved, resulting in better result outcomes compared to formulations that included slurry.

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Conflicts of interest

The authors declare no conflict of interest.

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