

MORPHOLOGICAL ANALYSIS AND THERMOCHROMISM OF COMBAT FABRIC

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Abstract. The Malaysian Army uniform incorporates the "Malaysian Woodland Pattern" or "Corak Tentera Darat Malaysia" (CTDM), featuring various shades of green and brown to provide camouflage in the Malaysian environment. However, this camouflage fabric is static and does not adapt to changing surroundings. This study focuses on enhancing the camouflage properties of Malaysian combat fabric through thermochromism. The study was conducted by using thermochromic dye paste, which was designed to exhibit colour changes in response to temperature variations. This study used a range of thermochromic dye pastes, such as olive green (OG), black (B), and light brown (LB), to develop combat fabric that is widely used in Malaysia. The dye pastes were screen printed onto medium weight fabrics and were let air dry for 24 hours. SEM morphological examination revealed thermochromic dye particles firmly bonded to the fabric, providing critical insights into the material's composition and features. The EDX analysis conducted in this study provided the elemental compositions of the thermochromic fabric. In the current study, the thermochromic combat fabrics underwent colour changes in response to temperature variations, displaying distinct CIE L*, a*, and b* values. This characteristic is identified as thermochromism. Overall, the study explores advances in textile materials, particularly in military thermochromic properties.

Keywords: Morphological, thermochromism, combat, printing, development

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1. INTRODUCTION

Camouflage is one of the criteria used in military fabrics. It is a crucial component of forces trickery as it helps to remain hidden within distance from an enemy but at the same time, it permits armies to approach closer. Different patterns and colours are generally put into the fabric to produce the camouflage effect. The ability of camouflage to distort human figures, especially military forces with printed images of their surrounding environment has the potential to make one undetectable [1]. The major concern about standard camouflage fabric is the fabric is not capable of keeping up with the change of the particular nature because it has static or unchangeable colour features. Thus, the existence of thermochromic dye can help to conceal the concern mentioned before as thermochromic dye can be defined as the capability of dyes to shift colour due to the effect of the surrounding temperature [2]. The presence of thermochromic dyes makes it possible for a garment's or uniform's colour to blend in with the environment at a specific temperature [3].

The current research was influenced by the work of Vikova [4] and Karpagam [5], in which they invented chameleon-style printing and adaptable colour-changing systems. In contrast, the investigation focuses on the creation of colour-changing camouflage fabrics inspired by Malaysian forests. The Malaysian Army uniform, officially known as the "Malaysian Woodland Pattern" or "Corak Tentera Darat Malaysia" (CTDM), included a camouflage pattern designed for woodland environments in Malaysia. The CTDM typically includes various shades of green and brown to blend with the woodland environment. The pattern incorporates a mix of colours and shapes to provide effective concealment [6]. Unlike some high-tech materials or chameleonic organisms found in nature, current Malaysian combat fabric and camouflage patterns are meant to be concealed, they are not dynamic and do not change colour dependent on the surroundings. Due to this issue, this combat fabric might be less successful when the environments are experiencing rapid changes from dark to bright areas due to sunlight and heat. Therefore, the novelty of the project lies in its pioneering approach, which examines the feasibility of thermochromic dyes incorporated into military combat fabrics that are capable of undergoing colour changes due to temperature differences.

However, the challenges associated with employing thermochromic dyes include the understanding of morphological structures and the colour change effects (commonly referred as thermochromism) exhibited by the formulated thermochromic dye paste. To address these challenges, this study has established two objectives, 1) to analyse the morphological structures of fabric-incorporated thermochromic dye paste and 2) to evaluate the thermochromism of the resulting thermochromic fabrics. In our previous research [7], we prepared and examined several dye formulations that fulfil the colour requirements of combat fabric. For this investigation, the current study has selected the optimal thermochromic dye pastes for olive green (OG), black (B), and light brown (LB) from these formulations. These selected pastes were applied to medium weight fabric using the screen-printing technique. The screen-printing technique involves pushing ink through fine mesh holes [8]. The resulting thermochromic combat fabrics were then analyzed for both morphological features and thermochromism. By conducting this study, the camouflage effect on combat fabric was further improved, which will be advantageous to armed services and textile industries.

2. MATERIALS AND METHODS

Blended polyester-cotton Malaysian combat fabrics, weighing 201 g/m², were supplied by STRIDE (Science and Technology Research Institute for Defense), thermochromic dyes (Kolortek®, China), acrylic binder (Liquitex, USA) were the main materials used in this study.

2.1 Preparation of Thermochromic Dye Paste and Printing Process

The formulations of dye pastes, derived from various thermochromic powders with transition temperatures ranging from 15 °C to 40 °C, have been detailed in our previous study [7]. All formulations were prepared by mixing the thermochromic powders with an acrylic binder to form a thermochromic dye paste. The optimal thermochromic dye pastes for OG, B and LB were applied on top of medium weight fabrics using screen printing. The printed fabrics were then air dried for 24 hours at room temperature.

2.2 Morphological and Elemental Analysis of Thermochromic Fabric

The morphology and elemental analysis of thermochromic dyes on fabrics were analysed using scanning electron microscopy (SEM) (Hitachi TM-3000 SEM). The SEM assessment was conducted to observe the dispersion of thermochromic, paste-like dyes and their behaviour. OG, B and LB thermochromic dyes were applied on the medium weight twill fabrics to form thermochromic fabrics. The thermochromic fabrics and pristine fabric were cut into one cm square for SEM observation. Prior to the SEM analysis, gold was sputter deposited onto each sample. In this paper, 1000x magnifications and a 15-kV accelerating voltage were used.

2.3 Thermochromism Analysis

As the thermochromic dye pastes were formulated using distinct transition temperatures, it is crucial to comprehend the thermochromic behaviour of the fabric samples. Fabrics printed with the thermochromic dye pastes were subjected to heating on a hot plate within the temperature range of 25 °C to 40 °C, representing our local climate temperatures. The thermochromic colour changes were analysed based on the CIE L* a* b* values using a portable spectrophotometer (CS-10 digital handheld colourimeter) in response to heat. The CIELAB, or CIE L* a* b*, colour system, which represents the quantitative relationship between colours, is composed of these three axes linked together. On the colour space diagram, as illustrated in Figure 1, the L* is displayed as a lightness in the vertical axis with values ranging from 0 (black) to 100 (white). The a* value represents the red-green section of a colour, with a* (positive) and a* (negative) standing for the positive and negative values of red and green, respectively. The yellow and blue components are shown on the b* axis as positive and negative values, respectively [9].

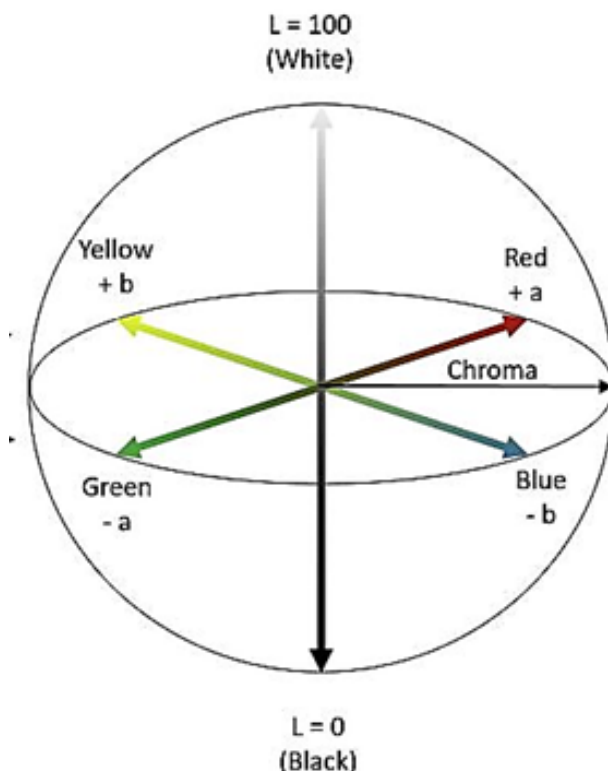


Figure 1: CIE $L^*a^*b^*$ graph modified and adapted from Ly et al. [9]

3. RESULTS AND DISCUSSION

3.1 Morphological and Elemental Analysis of Thermochromic Combat Fabrics

Figure 2(a) depicts the longitudinal views of the pristine fabric sample. In the longitudinal views of the pristine fabric, the outer surface of the fabric exhibits a clean and smooth appearance. This smooth surface suggests that there is no visible deposition or accumulation of the thermochromic dyes on the surface. The SEM image in Figure 2(b) shows the thermochromic dyes cover the surface of the OG fabric. The existence of thermochromic dyes on the combat fabric is visible as compared to the pristine fabric which has a smooth surface. The surface for OG appears to be rough and the dyes are visibly adhered to the fabric in scattered and clumpy size. Aggregation of dye particles can result in a textured or rough appearance. Rozic et. al, reported that the change in fabric colour after heating is related to the change in size of the material molecules [10]. When OG is heated to 40 °C, it is anticipated that the dye molecules will undergo size changes, resulting in a shift from olive green to white. Upon cooling to 24 °C, the dye molecules are expected to revert to their original sizes, restoring the colour to olive green. Similar morphology was found on B and LB thermochromic combat fabrics (Figures 2(c) and (d)). It is obvious that the thermochromic dyes are present as aggregate, not perfectly spherical and are adhered to one another. This phenomenon may not have notable effects on the overall appearance and thermochromism of the fabric.

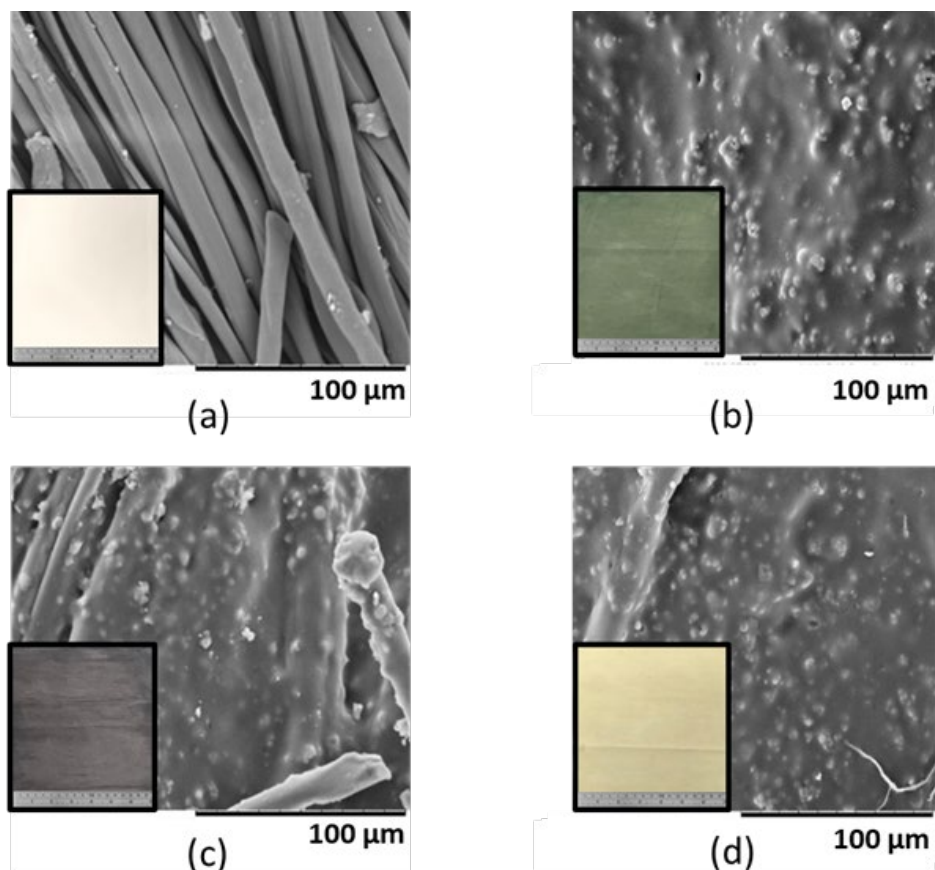


Figure 2: SEM images for (a) pristine fabric, (b) OG, (c) B and (d) LB fabrics

In a prior work by Civan and Kurama [11], the presence of carbon (C), oxygen (O), nickel (Ni), and iron (Fe) was confirmed, which was further validated by the EDX results of the thermochromic pigments. In our current study, we also detected these elements in the thermochromic fabric samples. Figure 3(a) to (d) illustrates the EDX spectra for pristine fabric, thermochromic OG, B, and LB fabrics, which all reveal the presence of C, O, Ni, and Fe.

Table 1 tabulates the weight percentages of C and O in the pristine fabric as 59.24% and 40.76%, respectively. In addition, the weight percentage of Ni and Fe in the thermochromic dyes varied depending on the fabric colour. For the OG thermochromic combat fabric, Fe and Ni were found at 0.02% and 0.04% weight percentages, respectively. In the case of the B thermochromic combat fabric, the weight percentages were 0.01% for Fe and 0.11% for Ni. Meanwhile, the LB thermochromic fabric exhibited weight percentages of 0.11% for Fe and 0.05% for Ni.

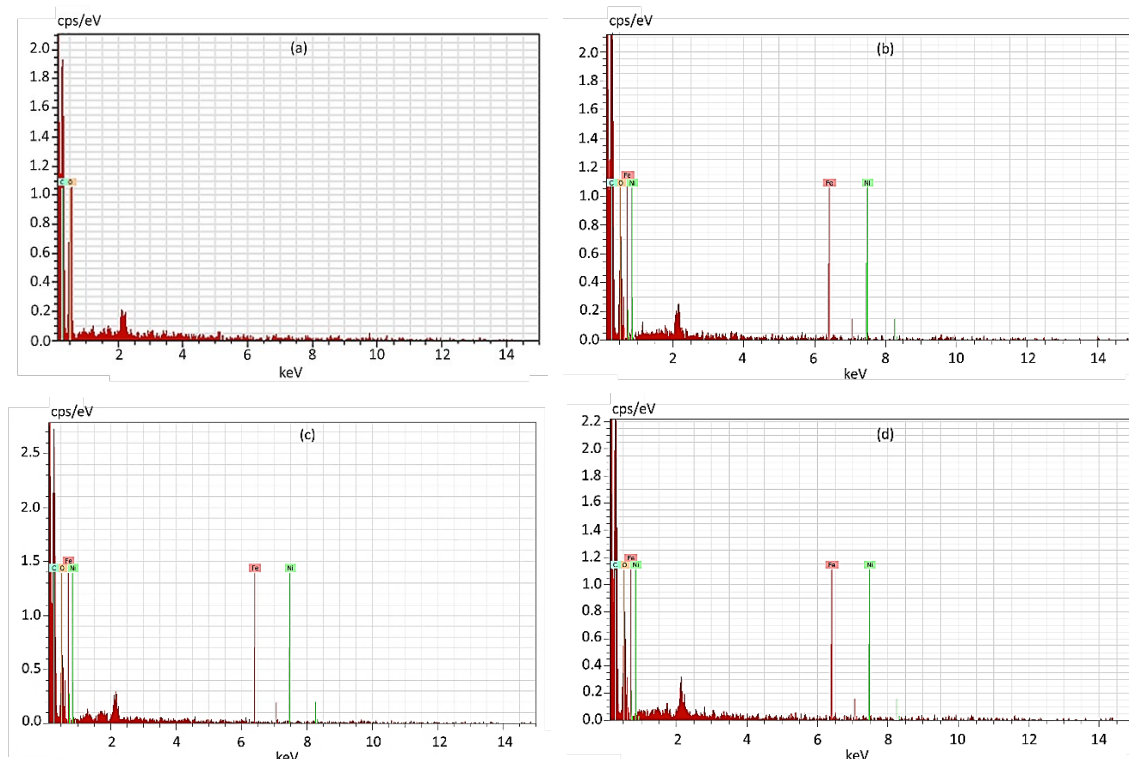


Figure 3: EDX spectra of (a) pristine fabric, (b) OG, (c) B and (d) LB fabrics

Table 1: Atomic weight percentage of pristine fabric, OG fabric, B fabric and LB fabric

Samples	Atomic weight (%)				Total
	C K	O K	Fe K	Ni K	
Pristine fabric	59.24	40.76	-	-	100
(OG)	70.71	29.23	0.02	0.04	100
(B)	70.39	29.49	0.01	0.11	100
(LB)	67.27	32.56	0.11	0.05	100

3.2 Thermochromism of Fabric Sample

In the present study, three thermochromic dye formulas which are OG, B and LB, respectively were applied on fabrics to form thermochromic combat fabrics. The fabrics were repeatedly heated with a hot plate and chilled to see the thermochromism phenomenon. In reaction to heating and cooling, the textiles' colour changed regularly. Figures 4 and 5 illustrate the thermochromism of the OG fabrics. At different temperatures, the changes of colours of the OG thermochromic combat fabric are visible. From the CIE $L^*a^*b^*$ values, the L^* value rises as the temperature rises (Figure 4). When the temperature approached 40 °C, the thermochromic combat fabric in olive green turned white or lighter colour similar to the colour of the pristine fabric. As a result, the fabric exhibited a high L^* value at 40 °C, indicating that the fabric becomes lighter at this temperature. As the temperature drops and reaches 25 °C, the L^* value

also drops, revealing the sample's original colour of olive green. When the temperature dropped, the a^* value changed to a negative value, which increased the intensity of the green colour. The b^* value, which expresses the yellow intensity this sample exhibits, stays positive as the temperature drops. The experimental result shows that during a multi-phase process involving both heating and cooling, the dye molecular structures undergo phase transitions. The dye molecular structures change when the thermochromic colourant is heated above room temperature. Similar observations were also reported by previous studies [10,12-15]. In addition, the study notices that the OG exhibits a noticeable alteration in its colouration, initiating a transition, as observed at a temperature of 29 °C. This temperature (29 °C) marks the starting point of the colour-changing process in the thermochromic OG sample, indicating its responsiveness to variations in temperature. This can be seen in Figure 4, where, at 29 °C, the $L^*a^*b^*$ showed a starting of drastic change of value.

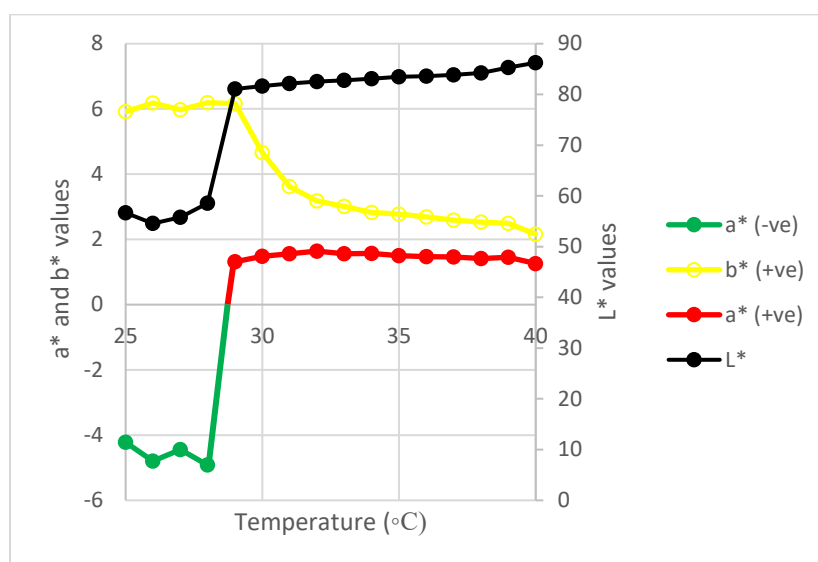


Figure 4: Plot of temperature versus $L^* a^* b^*$ values for OG thermochromic combat fabric

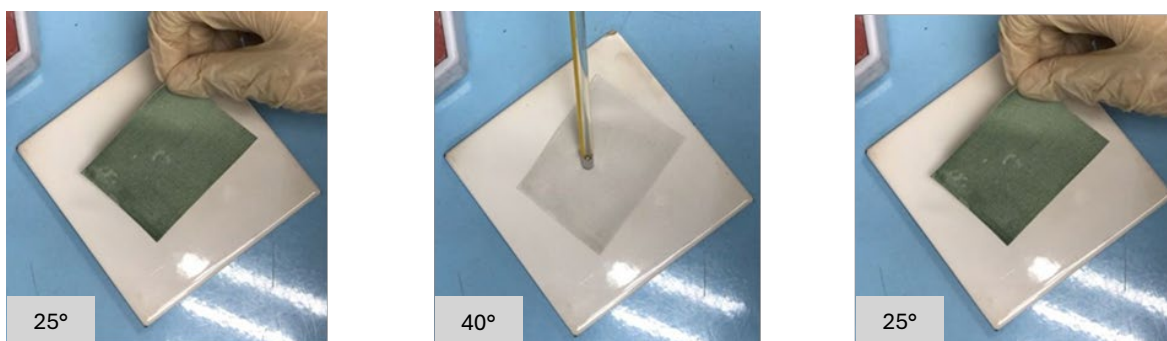


Figure 5: Photographs of reversible colour transformation of OG thermochromic fabric

For B thermochromic combat fabric, it underwent a transition from black to lighter red. At 40 °C, the fabric exhibits a high L^* value, resulting in the fabric approaching a lighter colour

(Figure 6). As the temperature decreases and reaches 25 °C, a corresponding reduction in the L^* value is observed, exposing the fabric's original black colour (Figures 6 and 7). Enigmatically, the a^* value maintains a positive status when the temperature increases. This signifies the persistent presence of red intensity in the B thermochromic fabric. It is expected that when the temperature increases, the dye molecules will undergo a structural transition, leading to a certain arrangement or configuration. In this altered state, the molecules may absorb and reflect light corresponding to the red colour. In contrast, there is a noticeable shift in the b^* values, transitioning from positive to negative value. This shift causes a transition from blue intensity to yellow intensity in the fabric. In addition, the study observed a significant change in L^* and b^* values at 29 °C (Figure 6). These variations indicate a noticeable change in the fabric's colour at this temperature. However, the a^* value does not change dramatically at 29 °C. The a^* value consistently decreases as the temperature rises from 25 to 40 °C.

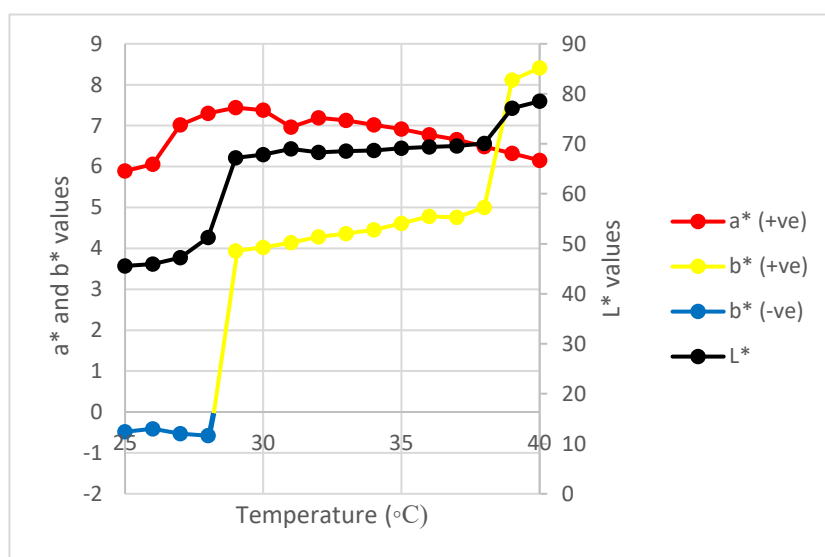


Figure 6: Temperature plot against L^* , a^* , and b^* values for B thermochromic combat fabric.

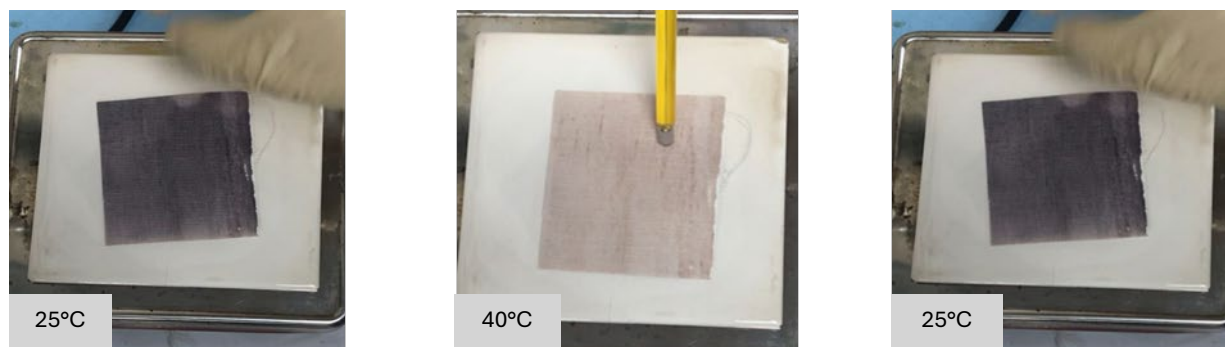


Figure 7: Photographs illustrating reversible colour transformation of B thermochromic fabric.

Figures 8 and 9 show a plot of temperature versus L^* , a^* , b^* values for LB thermochromic combat fabric and photographs of reversible colour transformation of LB thermochromic fabric. As depicted in both figures, the LB thermochromic fabric samples underwent distinctive

changes. As the temperature approached 40 °C, the thermochromic combat fabric in light brown transitioned to a white or light shade parallel to the colour of the pristine fabric. The positive a^* and b^* values for the light brown thermochromic combat fabric shown the presence of red and yellow intensity, respectively. Conversely, with the temperature dropping to 25 °C, the L^* value decreased, unveiling the fabric's original colour of light brown. When the temperature decreased, the a^* value stayed positive, signifying the presence of red intensity in the spectrum. Simultaneously, the b^* value also remained positive, indicating the enduring yellow intensity in the LB thermochromic combat fabric as the temperature decreased. Furthermore, at 29 °C (Figure 8), this study notices a notable and abrupt shift in the b^* value, indicating a considerable change in the colour of the fabric at that particular temperature. On the other hand, there were no significant changes observed in the L^* and a^* values at 29 °C. To summarize, the thermochromic OG, B, and LB consistently respond to temperature changes, making them suitable for applications in camouflage because of their colour-changing behaviours.

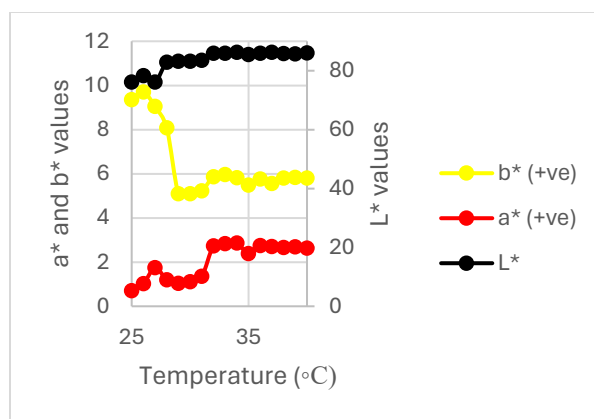


Figure 8: Plot showing temperature for LB thermochromic combat fabric against L^* a^* b^* values

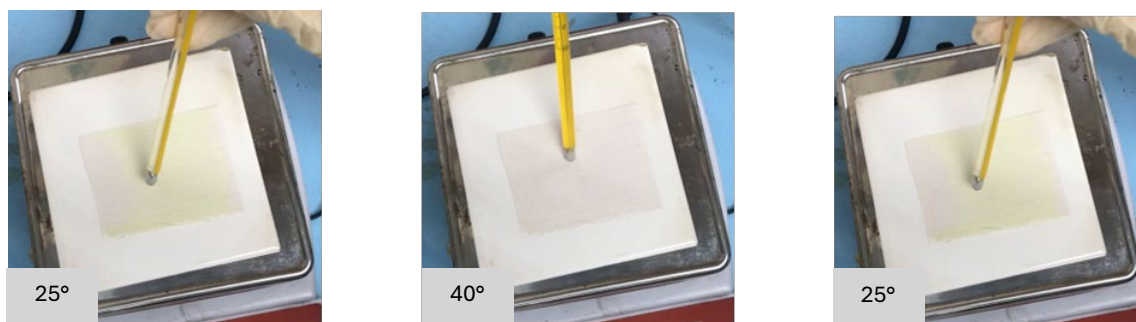


Figure 9: Photographs exhibiting reversible colour alteration of the LB thermochromic fabric

4. CONCLUSIONS

The uniqueness of the study lies in its discussion of incorporating thermochromic dyes into military combat materials. This innovation enables these combat materials to undergo colour changes in response to temperature variations. From the SEM analysis, the thermochromic dye particles were visible in the sample of OG, B and LB fabrics. The surface for OG, B and LB appears to be rough, and the dyes are visibly adhered to the fabric in scattered and clumpy size. The thermochromism of the fabrics throughout this study demonstrates a significant finding in developing combat fabrics. The fabric exhibited different values throughout the CIE L*, a* and b* colour space as the temperature either increased or decreased. This indicates that the thermochromic dyes are successfully applied onto the fabric as they showed a shift in colour as the temperature increased and reverted to the original as the temperature back to 25 °C. Moreover, a comprehensive study on the thermochromic fabric's colourfastness is essential. This study may help to ensure the thermochromic fabric preserves its colour stability and effectiveness throughout its lifecycle.

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Author Contributions

All authors contributed toward data analysis, drafting and critically revising the paper and agree to be accountable for all aspects of the work.

Disclosure of Conflict of Interest

The authors have no disclosures to declare

Compliance with Ethical Standards

The work does not compliant with ethical standards

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