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Coloration of Polyamide-6, 6 Fabric with Carbon Black Nano Particle for Camouflage Textiles of Simultaneous Spectrum Probe in Visible and Near Infrared

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Abstract

Camouflage textiles on simultaneous spectrum probe in Visible-Near Infrared (Vis-NIR) have been explicated under optical mechanism of reflection and chromatic hue. Polyamide 6,6 (PA-6,6) fabric was experimented for liquid phase formulation and coloration in acidic medium of seven standardized P^H (0-6) with Carbon Black Nano Particle (CBNP). International commission on illumination (CIE) color value (L*, a*, b*), Kubelka-Munk (K-M) reflection and reflection (%) of CBNP dyed PA-6,6 fabric was investigated with optical condition of specular reflectance, color measurement spectrophotometer from 400 nm to 700 nm. The K-M reflection and reflection (%) of CBNP dyed PA-6,6 fabric was also measured with optical property of diffuse reflectance, Fourier transform infrared spectroscopy from 1000 nm to 2500 nm. Vis-NIR reflection (%) was observed comparatively lower for P^H 4 to 5. Similarly, K-M reflection of simultaneous spectrum probe in Vis-NIR was found higher for P^H 4 to 5. Raw CBNP and CBNP modified PA-6,6 fabric was also examined for oxidation property, aggregation property, coloring property and air permeability by scanning electron microscopy. Hence, this experimentation was only focused on color properties of CBNP modified PA-6,6 fabric in terms of camouflage textiles.

Keywords: Camouflage textiles; Carbon black nano particle; Polyamide-6,6; Coloration; Visible-Near infrared spectrums

Abbreviations: CBNP: Carbon Black Nano Particle; CIE: International Commission on Illumination; FM: Formulation; K-M: Kubelka-Munk; MIR: Medium Infrared; nm: Nanometer; PA-6,6: Polymide 6,6; NIR: Near Infrared; SEM: Scanning Electron Microscopy; Vis: Visible; T_g: Glass Transition Temperature; KBr: Potassium Bromide; mL: Mililitre

Introduction

TThe current limitation of camouflage textiles relates to chromatic and/or reflection matching for simultaneous spectrum probe against multidimensional Combat Backgrounds (CBs). There is limited solution and optical approach of adaptive camouflage textiles against CBs. Carbon Black Nano Particle (CBNP) has low reflection effect of simultaneous spectrums in Visible-Near Infrared (Vis-NIR). The combination of CBNP with synthetic dyes will minimize the intensity for camouflage textiles in simultaneous spectrums of Vis-NIR [1-4]. CBNP can be formulated with brown, olive, green and khaki colorants for improvement of camouflage property. Low reflection patterning will improve the camouflaging effect against multidimensional CBs in general. In literature, laboratory stage camouflage assessment is very limited for camouflage applications, but it is necessary to signify the optical properties of camouflage object against multidimensional CBs [4-10].

Engineering of CBNP for Camouflage Coloration

Liquid phase dyeing is a common process for textile coloration but CBNP based technical Formulation (FM) and camouflage coloration is still a new approach in terms of water bath dyeing [11-17]. Nitric Acid (NA) modified CBNP has liquid phase oxidation property for enhancement of low reflection chromatic hue. CBNP reduces the reflection in Vis-NIR for simultaneous concealment against Vis-NIR surveillance [1,4,16,18-22]. Research is limited to achieve low reflection property of polyamide 6,6 (PA-6,6) fabric in Vis-NIR spectrums[23-25]. CBNP treated fabric reduces reflection than synthetic dyes such as vat

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dyes [26]. CBNP is a self-agglomerate material due to existing van der waals forces. Raw CBNP has hydrophobic property. Oxidation and dispersing agents generates hydrophilicity on CBNP surface [27]. CBNP has different properties in terms of particle size, surface structure, surface size, P^H value and density. These properties of CBNP signifies the hydrophobicity, hydrophilicity and dispersibility for textile dyeing-coating-printing [5-8, 28]. Figure 1a shows the structure of CBNP.

Engineering of PA-6,6 Fabric Coloration with CBNP

PA-6,6-CBNP-NA-liquid phase dyeing has been assumed a Brownian movement pattern when dyebath temperature is higher than glass transition temperature Tg. The property of PA-6,6 fabric may follow a physical assumption of rubbery state in dyebath at high temperature. Molecular distance of PA-6,6 fabric increases and CBNP can penetrate inside the fabric. Therefore, a gradual percolation of CBNP into PA-6,6 fabric may formulate the coloration property [15,29-33]. In this experimentation, PA-6,6 fabric used for high temperature dyeing with CBNP, cited the structure in Figure 1 [4]. Figure 1b shows the structure of PA-6,6.

Materials, Methods and Formulations of PA-6, 6 Coloration with CBNP

TThree types of laboratory grade CBNP from three different chemical companies were trialed for coloration of 130 gram per square meter (g/m^2) PA-6,6 fabric. CBNP was also used from Cabot corporation Ltd, USA. Laboratory grade 70% NA was used for acidic medium dyeing. Surface modification of CBNP was performed by NA oxidation [4,34]. CBNP-NA-water medium was dispersed by electric blender for 30 minutes and seven standard P^H (0-6) was set in CBNP dye bath by dropping technique of NA addition. Standardized dyeing process was applied for PA-6,6-CBNP-NA-water medium dyeing process without dispersing agent and binder [29,30,34-36]. Material and liquor ratio was kept around 1:18. Dyeing and coating formulations are individually cited in Table 1. Dyeing machine temperature was increased at 2˚C/min and temperature raised upto 100˚C and continued the run time of machine for 30 minutes. Figure 2 shows front view of laboratory dyeing machine (a), empty roller of sample dyeing machine before rolling fabric (b), rolled PA-6,6 fabric on roller surface before placing in dyebath (c), dyed PA-6,6 fabric on roller surface after removing from dyebath (d), CBNP dispersed solution without dispersing agent (e) [37], CBNP coating on fabric by laboratory coating machine, CBNP was encapsulated by polyurethane binder (f). Therefore, CBNP dyed samples were proceeded for structural properties, and camouflage analysis of electron imaging, color value and Vis-NIR reflection.

Testing Machines and Methods of Optical Analysis

CIE, color parameters (L*, a*, b*) were measured by Hunter lab reflectance spectrophotometer, Color Flex EZ; model, 45/0 LAV; under testing conditions with geometry, 45°/0°; viewing area, large; D65 illuminant/10°standard observer; room temperature, 18°C [4,23,38]. Colorflex EZ was used for the measurement of CIE color parameters of L*, a*, b* and ΔE; reflection (%) and Kubelka-Munk (K-M) reflection. Fourier transform infrared spectroscopy, PerkinElmer was used for assessment of reflection (%) and K-M reflection in .5 nm distance [3,38]. Hence, two different geometries of spectroscopic illumination such as specular and diffuse reflection were performed for measurement of Vis-NIR optical properties of CBNP modified PA-6,6 fabric.

Kubelka Munk Reflection Measurement in Vis-NIR Spectrums

K-M and Lord Rayleigh's law are related to refractive index versus wavelength based on assuming two different parameters. K-M theory is mostly defined for particle size and wavelength. As per K-M theory, scattering coefficients are constant throughout the sample of same particle size [39]. Therefore, Vis-K-M-specular reflection and NIR-K-M-diffuse reflection were tested for CBNP dyed and undyed PA-6,6 fabric [36].

Vis-K-M-specular reflection of untreated and treated PA-6,6 fabric samples were determined by K/S equation.

$$\frac{\mathrm{K}}{\mathrm{S}} = \frac{(1-R_{\lambda\max})^2}{2R_{\lambda\max}} \infty C_{CBNP}$$

Where, Where, K = coefficient of absorption, S = coefficient of scattering, $R_{\lambda\max}$ = reflectance of the substrate at maximum absorbance wavelength, C_{CBNP} = concentration of nano particle [19, 40-44].

NIR-K-M-diffuse reflection of untreated and treated PA-6,6 fabric samples were also measured by K/S equation [3].

$$\mathrm{K/S} = (1-\mathrm{R}\infty)2/2\mathrm{R}\ \infty\ C_{CBNP}$$

where K and S represents absorption and scattering coefficients respectively, and $R\infty$ denotes reflectance factor from fabric surface, C_{CBNP} = concentration of nano particle [32,75].

Scanning Electron Microscopy (SEM)

A table microscope SEM machine, TM4000/TM4000Plus, Hitachi, Japan and SC7620 sputter coater (Figure SI 2), Quorum, UK were used under 25 magnification, 100 magnification, 500 magnification; and 15KV power selection for each scanning. Three categories of acid modified raw CBNP and water modified raw CBNP were scanned by SEM. Acid and water diluted CBNP samples were simply dried in closed chamber at selected temperature and cooled before SEM scanning. RGB intensity of SEM image was measured by ImageJ software to signify oxidation property. The highest CBNP visible area of SEM image was selected by rectangular method, width = 15 pixels and height = 18 pixels under the distances from 0 to 15 pixels captured by ImageJ software. The standardized RGB intensity was followed from the value of 0 to 255. The plot profile of grey value was

Table 1: Seven standard P^H (0-6) in CBNP dyebath of PA-6,6 fabric coloration for formulation 1-7 and CBNP coating with formulation 8.

Formulation-01 (Dyeing)	Formulation-02 (Dyeing)	Formulation-03 (Dyeing)	Formulation-04 (Dyeing)
CBNP: 0.5g	CBNP: 0.5g	CBNP: 0.5g	CBNP: 0.5g
Temperature: 100°C	Temperature: 100°C	Temperature: 100°C	Temperature: 100°C
Time: 30 min	Time: 30 min	Time: 30 min	Time: 30 min
P^H: 0, Nitric Acid	P^H: 1, Nitric Acid	P^H: 3, Nitric Acid	P^H: 3, Nitric Acid
PA-6,6 Fabric: 11g	PA-6,6 Fabric: 11g	PA-6,6 Fabric: 11g	PA-6,6 Fabric: 11g
Distilled water: 200 ml	Distilled water: 200 ml	Distilled water: 200 ml	Distilled water: 200 ml
Formulation-05 (Dyeing)	Formulation-06 (Dyeing)	Formulation-07 (Dyeing)	Formulation-08 (Dyeing)
CBNP: 0.5g	CBNP: 0.5g	CBNP: 0.5g	CBNP: 5g
Temperature: 100°C	Temperature: 100°C	Temperature: 100°C	5% solution of 70%
Time: 30 min	Time: 30 min	Time: 30 min	Nitric Acid: 1ml
P^H: 4, Nitric Acid	P^H: 5, Nitric Acid	P^H: 6, Nitric Acid	Tubicoat binder: 5g
PA-6,6 Fabric: 11g	PA-6,6 Fabric: 11g	PA-6,6 Fabric: 11g	
Distilled water: 200 ml	Distilled water: 200 ml	Distilled water: 200 ml	

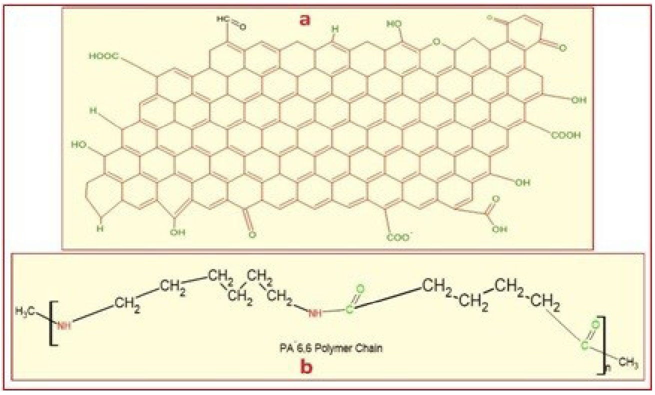

Figure 1: (a) structure of CBNP and (b) structure of polyamide 6,6.

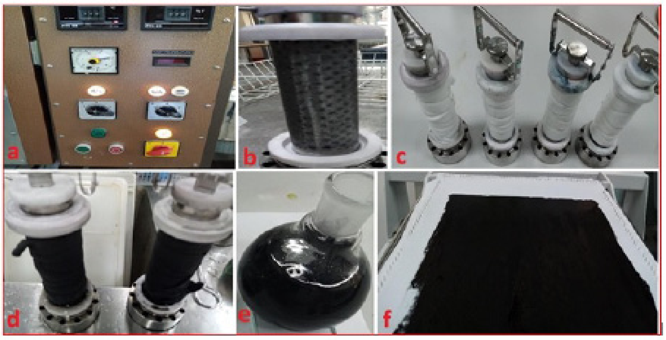

Figure 2: Experimental platform of CBNP formulation and coloration on PA-6,6 fabric.

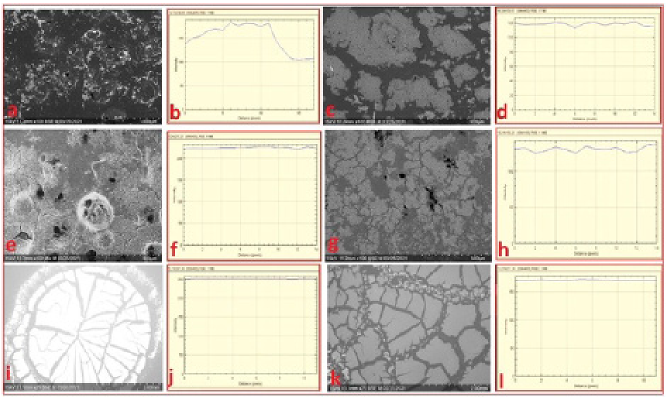

Figure 3: SEM morphology versus RGB intensity of water and acid modified raw CBNP to signify oxidation property.

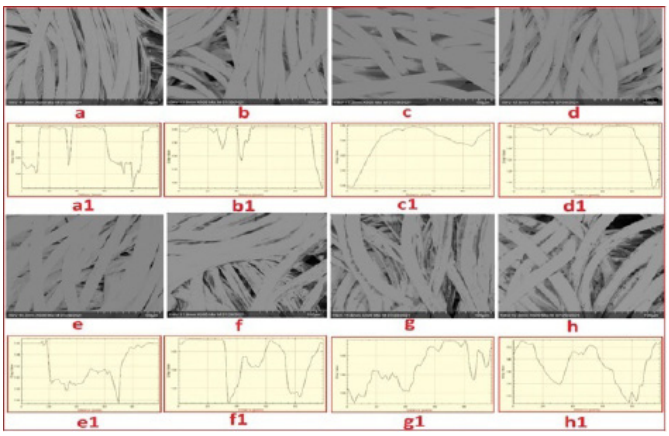

Figure 4: SEM morphology versus grey value intensity; undyed PA-6,6 fabric (a), CBNP dyed PA-6,6 fabric (b-h) and grey value intensity (a1-h1).

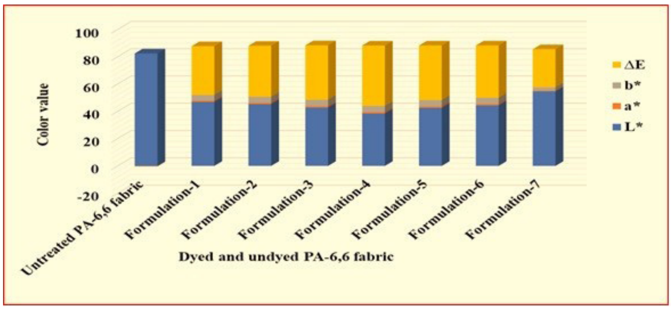

Figure 5: CIE color value of undyed PA-6,6 fabric and dyed PA-6,6 fabric with formulation 1-7.

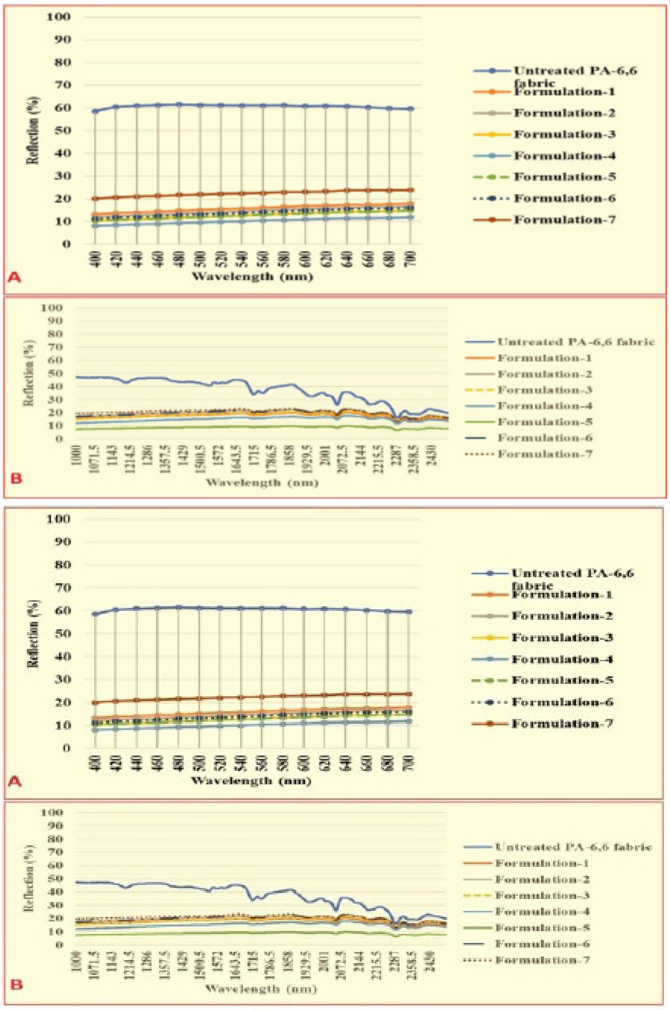

Figure 6: Vis-NIR reflection (%) of undyed and dyed PA-6,6 fabric with formulation 1-7 Assessment of K-M reflection in Vis-NIR spectrums.

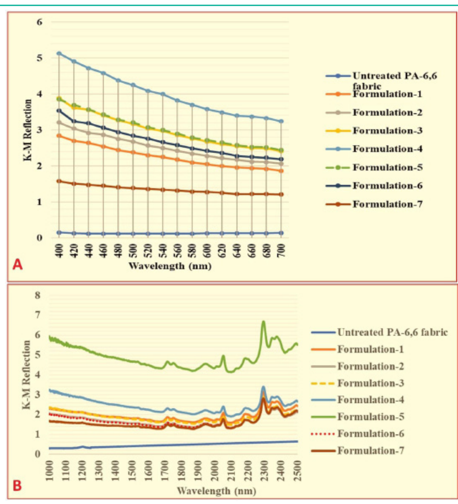

Figure 7: Vis-NIR-K-M reflection of undyed and dyed PA-6,6 fabric with formulation 1-7.

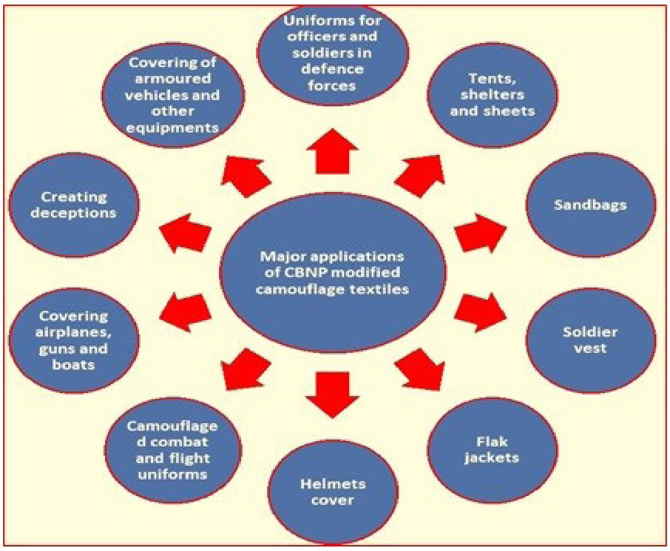

Figure 8: Expected applications of CBNP modified camouflage textiles.

also generated under the constant parameters of distances from 0 to 80 pixels captured by ImageJ software; area selected by rectangular method, width = 100 pixels and height = 100 pixels; the standardized intensity of grey value from 0 to 255. The intensity value of 0 denotes minimum intensity/black and the intensity value of 255 denotes maximum intensity/white [10].

It was almost unachievable to generate contrast electron imaging of CBNP dyed and undyed PA-6,6 fabric due to fine particle and lacking of structural deviation. For CBNP dyed and undyed fabric, a thin film thickness of carbon coating was achieved by sputter coater for SEM scanning. Additionally, SEM scanning without carbon coating was also trialed for CBNP dyed and undyed fabric for comparison of electron imaging shown in supporting information, figure SI 1.

Potassium Bromide (KBr) free Diffuse Reflection Measurement by Fourier Transform infrared Spectrometry in Near Infrared Spectrums from 1000 nm to 2500 nm

PerkinElmer is a common manufacturer of Infrared (IR) spectroscopy. This company has different model of IR spectroscopy with versatile configuration of sample port. Every sample port has different mechanism of scanning as directed in application note. In transmission mode, light directed through the sample and captured spectra by the system. So, KBr matrix is used for more accurate result as non-absorbing principle where internal particle is a major influencing factor for optical principle of transmission. KBr matrix is also suitable material for fixing sample in sample port for standardization of optical scanning. KBr is more likely implemented for sample measurement in Medium Infrared (MIR), 2500 nm-25000 nm. KBr is non absorbing material in MIR. Oppositely in reflection mode, light reflected from the surface of the target sample. Diffuse reflectance is a matter of structural geometry on surface area. So, KBr matrix is not a matter of invalid result where reflection of internal particle is very negligible influencing factor. Refractive index of KBr may also issue of reflection accuracy in NIR. As per K-M theory, scattering coefficients are mostly depends on particle size, not absorption. It is also predicted that if particle size is zero, scattering coefficient is also zero [39]. Absorption in the NIR is typically about 100 times weaker than MIR. The very weak absorptions in NIR are reported as small changes in refractive index. KBr is zero absorbance material which minimize the interference of reflection when absorbency is measured in MIR [47]. In this experimentation, CBNP is an IR absorbing material. The penetration depth of diffuse reflection is almost zero for high IR absorbing materials. Furthermore, this experimentation has been defined for coefficients of reflection. Machine has specific glass vial designed as sample port. In NIR spectroscopy, the core mechanism is glass sample port which is covered by sample cup to create reflection environment under a specified black standard termed as 'spectralon reflection'. Absorption and transmission of rays are not creating reflection of sample. These rays are not participating to make a spectral signal as diffuse reflection [39,47-49]. The whole mechanism is occurring underneath the glass vial. The sample port has sapphire/crystal window to capture reflection of sample. Therefore, KBr free measurement of CBNP dyed and undyed PA-6,6 fabric was experimented for diffuse reflectance measurement in NIR spectrums [4,50].

Results and Dscussion

SEM Characterization of Raw CBNP under Heating and Cooling Mechanism to Signify Low Rreflection Property

Figure 3a, NA modified CBNP; figure 3b, RGB intensity of NA modified CBNP; Figure 3c, NA modified and oxidized CBNP after two-hour heating in closed chamber at 100°C; Figure 3d, RGB intensity of NA modified and oxidized CBNP after two-hour heating in closed chamber at 100°C; Figure 3e, water modified CBNP; Figure 3f, RGB intensity of water modified CBNP; Figure 3g, water modified and oxidized CBNP after two-hour heating in closed chamber at 100°C; Figure 3h, RGB intensity of water modified and oxidized CBNP after two-hour heating in closed chamber at 100°C; Figure 3i, water diluted CBNP before heating; Figure 3j, RGB intensity of water diluted CBNP before heating; Figure 3k, water diluted and oxidized CBNP after two-hour heating in closed chamber at 100°C; Figure 3l, RGB intensity of water diluted CBNP after two-hour heating in closed chamber at 100°C. Figure 3c, 3g; aggregation of CBNP reduces the surface area due to adsorption of nitrogen. Aggregated CBNP looks like blister in electron imaging. Heated CBNP blister looks comparatively darker than without heated CBNP blister, shown in figure 3c, 3g and 3k. CBNP looks darker due to the enhancement of COOH group on CBNP surface relates to the mechanism of heating-oxidation-COOH formation. NA treatment on CBNP may generate hydrophilicity of CBNP. The particle size of water modified CBNP is lower, shown in figure 3e and 3g and comparatively higher in acid modified CBNP due to hydrophilicity nature of NA modified CBNP shown in figure 3a and 3d. The tendency of aggregation is comparatively higher of acid modified CBNP due to fusing and covalent bond between molecule to molecule [31,34,51,52]. Particle size of CBNP also influences dye aggregation. Higher particle size has a tendency of higher CBNP aggregation due to hydrophilicity nature. RGB intensity of SEM image also signifies lower intensity of oxidized CBNP. RGB intensity of oxidized CBNP, 3d<RGB intensity of non-oxidized CBNP, 3b; RGB intensity of oxidized CBNP, 3h<RGB intensity of non-oxidized CBNP, 3f; RGB intensity of oxidized CBNP, 3l<RGB intensity of non-oxidized CBNP, 3j. Due to oxidation property of CBNP, the RGB intensity of heated CBNP was comparatively lower mentioned in figure 3d, 3h, 3l than the RGB intensity of without heated CBNP mentioned in figure 3b, 3f, 3j [31,53]. This evidence of CBNP oxidation supports for the applications of low reflection chromatic property. Chromatic aberration relates to electron energy. Every image has RGB chromatic hue. Figure 3 denotes the RGB intensity in the form of black and white chromatic hue. Figure 3 explained with ImageJ software for clarification. Therefore, CBNP oxidation and low reflection chromatic

property has been discussed by SEM. The optical theory of image formation between diffused reflection and scattered electron has almost similar action to form an image although the mechanical properties are completely different. Photon relates to reflection for optical imaging. Electron relates to electron imaging in SEM.

Structural Characterization of PA-6,6 Dyed Fabric with CBNP

Figure 4, structural differences relates to the deviation of dyed fabric surface. In general, nano-dyed fabric shows minor deviation in SEM scanning due to unchanging of fabric structure [54]. Figure 4a, SEM morphology of untreated PA-6,6 fabric; Figure 4a1, SEM morphology versus grey value intensity of untreated PA-6,6 fabric; figure 4b, CBNP dyed PA-6,6 fabric with FM-1, P^H:0; figure 4b1, grey value intensity of CBNP dyed PA-6,6 fabric with FM-1, P^H:0; figure 4c, CBNP dyed PA-6,6 fabric with FM -2, P^H:1; figure 4c1, grey value intensity of CBNP dyed PA-6,6 fabric with FM-2, P^H:1; figure 4d, CBNP dyed PA-6,6 fabric with FM-3; P^H:2; figure 4d1, grey value intensity of CBNP dyed PA-6,6 fabric with FM-3, P^H:2; figure 4e, CBNP dyed PA-6,6 fabric with FM-4; P^H:3; figure 4e1, grey value intensity of CBNP dyed PA-6,6 fabric with FM-4, P^H:3; figure 4f, CBNP dyed PA-6,6 fabric with FM-5, P^H:4; figure 4f1, grey value intensity of CBNP dyed PA-6,6 fabric with FM-5, P^H:4; figure 4g, CBNP dyed PA-6,6 fabric with FM-6, P^H:5; figure 4g1, grey value intensity of CBNP dyed PA-6,6 fabric with FM-6, P^H:5; figure 4h, CBNP dyed PA-6,6 fabric with FM-7, P^H:6; figure 4h1, grey value intensity of CBNP dyed PA-6,6 fabric with FM-7, P^H:6. The electron imaging of dyed fabric is not standardized way for adsorption of CBNP measurement on PA-6,6 fabric surface. Electron image of dyed and undyed PA-6,6 fabric is not able to compare clearly due to minor structural deviation. There is enormous lacking of significant deviation between dyed and undyed PA-6,6 fabric when structural deviation of knitted fabric looks almost unchanged after dyeing. Hence, it is so tough to identify the deviation of electron imaging between treated and untreated PA-6,6 fabric due to smooth surface [1,55]. The fluctuation of grey value intensity in electron imaging has also been shown in figure 4b, 4d, 4f, 4h, 4I, 4l for more clarification and signification. The highest variation of grey value intensity of dyed PA-6,6 fabric is noted around ±14 compared with undyed PA-6,6 fabric under the fluctuation of selected pixel area. Oppositely, the lowest variation of grey value intensity of dyed PA-6,6 fabric is also remarked around ±15 compared with undyed PA-6,6 fabric under the fluctuation of selected pixel area. Accordingly, it can be noted that FM-1, FM-2, FM-3, FM-4 have minor presence of CBNP; and FM-5, FM-6, FM-7 have maximum presence of CBNP due to optimum level of acidic P^H. PA-6,6 fibre forming polymer has free volume in the polymer chain which may retain CBNP through diffusion technique in dyebath when temperature of dyebath raises above Tg [29]. Under this consequence of electron imaging of dyed and undyed PA-6,6 fabric, the air permeability may have in acceptable range without blocking the significant area of fabric pore for clothing comfort. Minor structural deviation in electron imaging signifies the finer particle size which may increase the air permeability. The property of air permeability is the core requirement for defence uniform [1].

Figure 5, comparison of CIE color value of undyed PA-6,6 fabric and CBNP dyed PA-6,6 fabric with FM-1, P^H:0; FM-2, P^H:1; FM-3, P^H:2; FM-4, P^H:3; FM-5, P^H:4; FM-6, P^H:5 and FM-7, P^H:6. L*, a*, b* values are slightly lower for FM-04 and higher for FM-7 due to deviation of existing CBNP on PA-6,6 fabric surface. Color difference, ΔE is almost similar of all formulated CBNP dyed PA-6,6 fabric rather than FM-1, FM-2 and FM-7 [27,42]. The reaction may happen between -$CONH_2$ group of PA-6,6 and COOH of oxidized CBNP at selected temperature, 100°C. The supporting information has been cited in table SI 3.

Chromatic Assessment of CIE L*, a*, b* and ΔE from 400 nm to 700 nm

Assessment of Reflection (%) in Vis-NIR Spectrums

Figure 6A, comparison of reflection (%) of undyed PA-6,6 fabric and reflection (%) of CBNP dyed PA-6,6 fabric with FM-1, P^H:0; FM-2, P^H:1; FM-3, P^H:2; FM-4, P^H:3; FM-5, P^H:4; FM-6, P^H:5; FM-7, P^H:6. The reflection (%) looks similar when PA-6,6 fabric was dyed with CBNP, FM 1-7. FM-4, P^H:3 looks comparatively lower reflection (%) than FM-1, 2, 3, 5, 6, 7. In general, reflection (%) of CBNP dyed PA-6,6 fabric has low reflection property when -$CONH_2$ group of PA-6,6 is modified by the chromatic property of COOH presence in CBNP. It is a suitable property for camouflage formulation of PA-6,6 fabric [1,21,56]. The supporting information has also been cited in table SI 1.

Figure 6B, comparison of NIR-reflection of undyed PA-6,6 fabric and CBNP dyed PA-6,6 fabric with FM-1, P^H:0; FM-2, P^H:1; FM-3, P^H:2; FM-4, P^H:3; FM-5, P^H:4; FM-6, P^H:5; FM-7, P^H:6. NIR-reflection is comparatively lower for FM 1-7 and remarkly lower for FM-5. CBNP can be formulated for NIR camouflage textiles in terms of low reflection property of CBNP material. Due to lower reflection property of CBNP, the reflection of chromatic compound was not identified by the spectra from 1000 nm to 1700 nm. The reflection of hiding amide group, -$CONH_2$ was remarked for FM, 1-7. The bending of reflection spectra of untreated PA 6,6 fabric was completely hided for 1200 nm, 1573 nm, 1536 nm and 1750 nm due to the smooth layer of CBNP chromatic compound (COOH, C=O) on the polymeric layer/chain of amide group, -$CONH_2$ existing in PA-6,6 fabric. The reflection (%) at 1715 nm, 1946 nm, 2052 nm, 2185 nm, 2293 nm, 2375 nm were comparatively lower for CBNP modified PA-6,6 fabric due to chromatic intensity of CBNP on PA 6,6 fabric. The supporting information has been cited in figure SI 3-11 and table SI 5.

Assessment of K-M Reflection in Vis-NIR Spectrums

Figure 7A, comparison of Vis-K-M reflection of undyed PA-6,6 fabric and CBNP dyed PA-6,6 fabric with FM-1, P^H:0; FM-2, P^H:1; FM-3, P^H:2; FM-4, P^H:3; FM-5, P^H:4; FM-6, P^H:5; FM-7, P^H:6. K-M reflection is higher of dyed PA-6,6 fabric; FM-04. The K-M reflection was gradually decreased when the fabric was trialed with higher P^H and lower amount of NA. -$CONH_2$ group of PA-6,6 fabric is modified by the chromatic property of existing COOH in CBNP. The supporting information has been cited in table SI 2.

Figure 7B, NIR-K-M reflection of undyed PA-6,6 fabric and CBNP dyed PA-6,6 fabric with FM-1, P^H:0; FM-2, P^H:1; FM-3, P^H:2; FM-4, P^H:3; FM-5, P^H:4; FM-6, P^H:5; FM-7, P^H:6. Comparison of NIR-K-M reflection is higher for FM-04, and comparatively lower for other formulated PA-6,6 fabric. Higher K-M reflection value identifies the coloring property of CBNP on PA-6,6 fabric. The K-M reflection was gradually increased when the existing -$CONH_2$ compound of PA-6,6 has been modified by COOH and C=O compound of CBNP. The symmetric bending of spectra has been identified and gradually modified for K-M reflection at 1700-1800 nm, 2000-2100 nm, 2200 nm and 2295 nm. The supporting information has been cited in table SI 4 and figure SI 12.

Conclusion

The theory and approach of simultaneous concealment in Vis-NIR is not still established for camouflage applications. There is ongoing research for Vis camouflage and NIR camouflage individually. There is technical difficulties for development of simultaneous camouflage textiles due to deviation of optical response in Vis-NIR spectrums. The low reflection property is a crucial and common unit of camouflage property against multidimensional CBs in Vis-NIR spectrums. Therefore, low reflection property of CBNP modified dyed fabric has been logically explained in terms of reflection %, K-M reflection in Vis-NIR spectrums. Therefore, figure 8 shows the summarized applications and scope of CBNP modified camouflage textiles for defence applications in Vis-NIR spectrums although modification of chromatic materials and achromatic design depends on specific combat environment.

CBNP has coloring property of PA-6,6 fabric under standardized matching of P^H in liquid phase oxidation and coloration. CBNP has lower reflection property for simultaneous concealment in Vis-NIR against combat background. The lower reflection property of CBNP dyed PA-6,6 fabric has been supported by the chromatic mechanism of electron imaging; Vis-NIR-reflection (%); Vis-NIR-K-M reflection and CIE L*, a*, b* values. CBNP can also be combined with different dyestuff for color matching against selected combat background. CBNP liquid phase coloration has the feasibility for clothing comfort of defence professional in terms air permeability. This clothing comfort property can be applied for design of defence uniform in addition to camouflage formulation and coloration.

Author Statements

Declaration of Conflicting Interests

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Data Availability

All data generated or analyzed during this experimentation are included in supporting information, Table SI 1-5 and Figure SI 1-12.

Author Contribution

Sole-authorship of Engr. Md. Anowar Hossain

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