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Camouflage Assessment of Aluminium Coated Textiles for Woodland and Desertland Combat Background in Visible and Infrared Spectrum under UV-Vis-IR Background Illumination

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ABSTRACT

Aluminium powder (AP) formulated polyamide 6, 6 (PA 6, 6) knitted fabric, cotton woven fabric and hollow tubular polyester beg (HTPB) were experimented for spectral, chromatic, and imaging principle of woodland and desertland camouflage textiles in visible (Vis) and infrared (IR) spectrum under three-dimensional background illumination of ultraviolet (UV)-Vis-IR for concealment, detection, recognition and identification (CDRI) of target signature against selected combat background (CB) materials, and selected temperature was also trialled for IR radiation properties of target object (TOB)-CB in terms of CDRI. Cotton, PA 6,6 fabric and HTPB were coated and padded with AP powder formulated polyurethane (PU) based binder. Reflection profile of woodland CB and coated-padded textiles have been depicted in terms of multidimensional illumination properties of Vis imaging such as chromatic intensity, spectral reflection, Kubelka-Munk (K-M) reflectance, color rendering and photonic response related to surveillance imaging. A symmetrical chromatic value (L*, a*, b*) of AP coated fabric has been portrayed for concealment of target signature against woodland CB. Spectral reflection, chromatic illumination, K-M reflectance and scanning electron microscopy have also been critically confirmed five-time durability of color fastness to wash, tested by AATCC method 61-2013. HTPB-phase change material (PCM) formulation has been found temperature controllable effect of TOB in terms of heat energy at limited temperature, 30°C. Heat energy versus target concealment of IR imaging principle can be implemented for high-performance camouflage textiles design. The reflection profile of AP coated fabric can be applied for multidimensional camouflage coloration/patterning/HTPB-PCM based IR camouflage technology and direct applications of defence pavilion/tents/clothing against woodland/desertland CB. Therefore, the key phenomenon of this article has been focused on remote sensing properties of *Eucalyptus* tree, scientific name, *Eucalyptus Mannifera*, a common CB of woodland and AP formulated fabric for defence application against woodland and desertland CB in terms of CDRI of defence surveillance under consideration of laboratory and field trialling of woodland and desertland camouflage textiles assessment in Vis-IR spectrum. Therefore, a standardised methodology of camouflage textiles assessment for CDRI has been established under a new technique with conformist machine and technology which may be a new contribution to carry out further research and development for the fighting protection in combat environment under maintaining a standardized sequence from laboratory trialling to field experimentation in a limited timeframe of research.

Keywords: Camouflage textiles; Woodland/desertland combat background; Ultraviolet; Infrared; Phase change material; Hollow tubular polyester beg

1 INTRODUCTION

Reflectance profile of woodland combat background (CB) and desertland CB is very important parameters for defence target signature assessment of concealment, detection, recognition, and identification (CDRI) of target signature. Selection of right camouflage materials for woodland/desertland CB may signify the nearest reflection and chromatic behaviors of greenish leaves/dry leaves/tree bark/sand in comparison with treated textiles. Reflection profile of green leaves (Populustomentosa and Cedrusdeodara) and disperse dyes treated textiles have been experimented for assessment of woodland camouflaging[1]. The reflection profile of camouflage materials in laboratory trialling and implementation of standardized process of chromatic adaptation in visible (Vis) and infrared (IR) spectrum can signify the indication of CDRI progress for field experimentation. The accuracy of field trialling of camouflage textiles cannot be maintained properly under specific illumination of sunlight due to lighting angle and environmental issue, and other related properties because of interference of CB chromatic hue and the combination of color of known and unknown CB materials. The reflection profile of camouflage textiles is firstly measured with color measurement spectrophotometer, later it is demonstrated with infrared and photo simulation process of camouflaging[2]. The electromagnetic spectrums are replaced by changing the geometry of incident illumination. The geometry of incident illumination may be altered by weather, season, air, water, shadow, shape, moisture, material properties, specular components, diffuse components, etc. The properties of specular components surface (glossy,

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intensity, spatial) alter repeatedly due to angular phenomenon of illumination. The properties of diffuse component allow stable properties of object and background. As example, specified tree bark of woodland CB, Eucalyptus tree has different structural features, but spectral characteristics of tree barks are same in terms of cellulosic component and different chromatic hue due to different composition. Spectral symmetry can be considered for concealment of latest surveillance[3]. Reflectance profile of CB in Vis-IR ranges differs significantly. Reflectance profile of sand and soil accelerates in IR ranges than Vis ranges due to temperature deviation influenced by natural illumination. IR reflectance is declined when moisture of CB materials are reduced[4], so there is deviations of reflection in terms of properties of CB materials. A large number of experimentation has been conducted on aluminium powder (AP) in terms of electron, geometric, photonic and reflection, but CDRI concepts of AP reflection for special team in defence is still a new application of textile coloration under comparison with woodland and desertland CB[5]**.** Emissivity of CB-AP materials are the influencing fact for CDRI of AP treated textiles. Heat energy versus temperature is a medium for increasing/ decreasing of emissivity, it is a vital fact for CDRI versus AP treated textiles. The AP materials have been significantly designated for CDRI and reflection under multidimensional angle of illumination which is a regular problematic issue to conduct defense research on camouflage textiles under multidimensional CB and CDRI[6].

This concept of camouflage engineering for CDRI-AP treated textiles has been mainly concentrated on wavelength versus imaging signal versus selected woodland CB materials for CDRI of target signature. UV-Vis-IR is a major part of imaging signal captured by defence surveillance for target detection of opposition team. The sensor of hyperspectral/ infrared surveillance is also related to the broader wavelength covered by UV-Vis-IR spectrum. Hence the textile coloration for special force of defence need to consider in broader spectrum in UV-Vis-IR for camouflaging in terms of weapon, tents, location covering, soldiers dress and multidimensional target of protection.

2. EXPERIMENTAL DESIGN OF FABRICATION, TECHNICAL FORMULATION, AND CBS

2.1 Materials

130 GSM polyamide 6,6 (PA 6,6) knitted fabric; 310 GSM cotton twill woven fabric; AP, chem-supply Ltd. Australia; polyurethane (PU) based tubicoat (Pu-tubicoat), water insoluble, CHT chemical company ltd. Australia; PU and dimethyl formamide (DMF) were implemented for technical formulation and coloration in terms of coating-padding techniques. Green leaves, dry leaves, tree bark, scientific name, Eucalyptus Mannifera, Princes Park, Melbourne were used for chromatic and reflectance reference of woodland CB in laboratory stage and field trialling. Green leaves, semi-dried green leaves, dried leaves, dried tree bark were trialled as part of woodland CB materials. First samples of woodland CB were collected in Australian Summer, December-February 2020-21 and second samples of woodland CB were collected in Australian Spring, September-November 2021[7]. Dry sand was collected from Melbourne Sea beach as material of desertland CB. Hollow tubular polyester beg (HTPB), fabric type: woven, height:14 cm, width: 14 cm was collected from Amer-Sil KETEX private ltd, India. Eicosane, Sigma Aldrich was used as phase change material (PCM) for the measurement of thermal imaging of AP coated HTPB under specified temperature ranges. In field trialling of CDRI, aluminium foil paper (AFP) was used for background reflection measurement as polished surface of AFP in comparison with unpolished AP treated textiles.

2.2 Coating and Padding of PA-6, 6 and Cotton Fabric

4gm AP and 206 g PU-tubicoat were mixed in a beaker by electric blender. Formulated AP paste was coated on PA 6, 6 and cotton fabric. 2 g AP, 74 g PU-tubicoat and 200 mL distilled water were blended in 500 mL beaker for 30 min. The viscosity of solution was measured by automatic viscosity control, Norcross corporation, Newton, Mass, USA. Viscosity was found 10 centipoise assessed by shell cup 3.5. PA-6,6 and cotton fabric were soaked into AP solution for 30 min. The fabric was padded with laboratory padding mangle under high pressure of 22 kp/cm. Similar procedure was repeated for two times. The treated fabric was further padded with 2.5 % PU solution in dimethyl formamide (DMF) followed by two dip and two nip processes of padding. Fabric was dried in drying chamber at 120 °C for 30 min.

2.3 Coating of HTPB and Loading of PCM into the Selected Channel of HTPB

Figure 1, a thin layer AP was formulated by coating process, a modified process of coating but the process can be reversed by industry procedure like coating polyester fabric-hollow fabric design-injecting PCM into HTPB. A 19 channel HTPB, readymade was used for the experimental design of PCM versus thermal imaging of AP coated textiles. 9 channel HTPB was loaded by eicosane for thermal imaging and 10 channel was kept blank for heat energy deviation of eicosane loaded HTPB and eicosane unloaded HTPB for comparison of thermal imaging. HTPB before AP treatment also shown in supporting information, figure S_2 for clarification of HTPB preparation process.

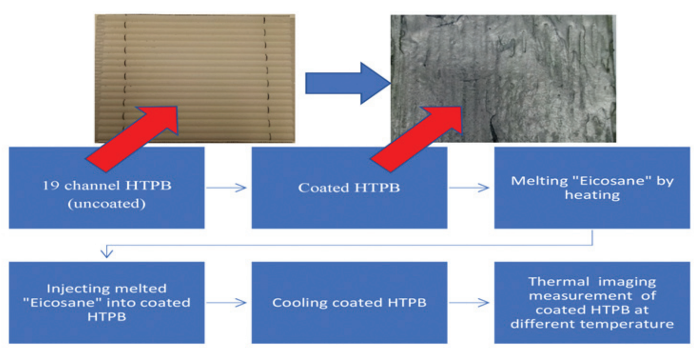


Figure 1. Methodology of thin layer AP coating on HTPB for PCM mechanism of thermal imaging.

3. METHODOLOGY OF TESTING AND IMAGING

PA-6, 6 and cotton fabric were scanned by colorflex EZ spectrophotometer, Hunter lab EasyMatchQC software under the conditions of viewing area geometry: 45°/0°, photometric reflectance: 0-150 %, port dia: 31.8 mm, view dia: 25.4 mm, light source pulsed xenon, number of layer of fabric: 2. TM4000/TM4000Plus, Hitachi, Japan and SC7620 sputter coater, Quorum, UK were used as set up of scanning electron microscopy (SEM) and the testing was conducted by 250 magnifications and 15kV. FLIR T440 camera, USA; IR lens, F = 18 mm; calibrated by national institute of standards and technology (NIST), USA was implemented for Vis (400-700 nm approximately)-IR (900-14000 nm approximately) imaging of target object (TOB)-CB materials. AP treated and untreated fabric strength was measured by Instron machine, capacity 5 kN, ISO 13934-1: 2013 (E), constant rate of extension. Color fastness to wash was conducted by AATCC test method 61-2013, ATLAS Launderometer. Fabric thickness was measured by digital thickness gauge, pressure 20 gm/cm^2.

3.1 Standardization of K-M Reflection for TOB-CB in Vis Spectrum

Kubelka-Munk (K-M) reflection of black, white, and green standard was implemented for standardization of color measurement and imaging of camera measurement for TOB-CB under standardized background color (black, green, and white) to minimize the interference of chromatic hue. Black standard was applied as higher K-M reflection from 0 to 1000, green standard was used as lower K-M reflection from 0.5 to 4 and white standard was also implemented as minor K-M reflection from 0 to 0.02.

3.2 Photometric Measurement in Vis-IR Imaging under UV-Vis-IR Background Illumination

Assessment of Vis-IR imaging was followed by a standard equation for the measurement of photonic response in UV-Vis-IR background illumination through imaging signal of AP treated fabric against woodland and desertland CB.

D/S = SSR

D = distance from the camera to the TOB

S = smallest target dimension of TOB

SSR = spot size ratio

Vis-IR-TOB-CB imaging was captured in a light cabinet (verivide) under protection of outside interference of light. D65 and UV background was illuminated from the source of light box and an artificial IR environment was created by 240V temperature controllable heater. A 45° (<50° has comparatively less variation of emissivity), angular distance of 76 cm and 60 cm was maintained for capturing image in general. The field trialling image of TOB-CB was around 180° angle with the observer. In terms of thermal sensor of thermal camera, the captured temperature has been mentioned by instantaneous field of view (IFOV) or distance to spot ratio. The accuracy of imaging mostly depends on imaging of emissivity which is influenced by materials properties versus distance-to-spot ratio. The standard of temperature deviation was captured from blue to red color signal under the region of black to white from low reflection to high reflection mechanism of chromaticity. In the area of black to white chromaticity, the region of blue identifies a minor photonic response to the thermal imaging, the region of green/yellow identifies a medium range of photonic response and consequently the region of red signifies a maximum thermal response to the imaging of TOB-CB.

3.3 Standardization of Camera Measurement and Chromatic Value Measurement for TOB-CB in Vis-IR Spectrum

Three standard tiles were used as machine standard of colorflexEZ, color measurement spectrophotometer. These color standards were used for chromatic accuracy of background of CB and AP treated textiles which signified the accuracy of testing and imaging without interference of CB reflection. Black tile was used as non-reflective background, white tile was used as reflective background and green tile was used as standardized chromatic hue as multidimensional CB color.

3.4 Standardization of IR Spot Temperature versus Temperature Deviation of TOB-CB for Chromatic Assessment in IR Spectrum

Spot temperature of thermal imaging is the average temperature of pixel in entire image, which is normally controlled by temperature deviation, minimum temperature, maximum temperature, these are automatically recorded by thermal sensor in terms of emissivity of TOB-CB and heat energy-radiation mechanism of thermal imaging. Spot temperature versus temperature deviation in IR imaging has been demonstrated in different combination of temperature generated by thermal sensor, which is graphically presented in supporting information, figure S_1.

4. RESULTS AND DISCUSSION

Established optical mechanism of CDRI has been demonstrated for color value, reflectance, color rendering and K-M reflection against TOB-CB. The common optical mechanism is derived as 1 = absorption of OB + reflection of OB + transmission of OB. If absorption of OB = 1, reflection of OB = 0 and transmission of OB = 0, the OB is depicted as zero reflection surface and oppositely if absorption of OB = 0, reflection of OB = 1 and transmission of OB = 0 which is considered for AP treated fabric surface. Kirchhoff's law defined as absorption of OB = emissivity properties of OB = photonic responses of OB in infrared wavelength, so the mechanism of AP treated fabric can be demonstrated by a standard relation, reflection of AP treated surface = 1- emissivity of OB, reflection-AP/TOB-CB is related to refractory oxide of AP treated textiles surface[6]. Reflection properties of AP is controlled by the mechanism of refractory oxides in Vis spectrum and photon energy is inversely proportional to its wavelength. AP is a semi-transparent substance due to properties of refractory oxides[8]. In general, green leaves, dry leaves, and tree bark of Eucalyptus plant shows low reflection in visible spectrum due to high absorption of chlorophyl, but the reflection is also related to leaf pigment, carotenoids, xanthophylls and anthocyanin. There is also deviation of reflection when different parts of tree generate different reflection due to having plant structure and the scattering properties of illumination. Reflection of woodland CB = absorption of coefficient + scattering coefficient + background reflectivity + optical properties of individual leaf, bark and cell + geometry of background + air cavity of cell wall + season of CB location + affected condition of plant by diseases, insects, nutrient and salinity conditions + shadows/moisture of surrounding area, soil and branches of tree[9]. Similarly desert CB is also related to the properties of sand and its reflection mechanism against target signature.

4.1 Structural Mechanism of AP Coated Fabric in Terms of CDRI-SEM Imaging

Figure 2, the structure of SEM confirms the higher percentage of AP deposition on the fabric surface. The magnification of SEM validates the existing of AP on PA 6, 6 (b, c) and cotton fabric (e, f) before and after five time washing.

SEM magnification clearly denotes that AP treated fabric surface has photon scattering effect due to smoothness, it has also been clarified that the minor percentage of photon signal to the imaging sensor when the concentration of PU-tubicoat-AP has been well cemented due to polymeric combination of AP on the fabric surface, and as a result, the breaking load of cotton twill fabric was increased from 770N (untreated fabric) to 1062N (AP treated fabric). AP creates stable oxide which is depicted as hard surface on textile materials. The mobility of photon signal may be minor due to larger particle size of AP which creates less reflection in UV-Vis-IR illumination and the combination may signify a confusing TOB to the observers. The whiteness area of SEM structure signifies that there is existence of PU on the fabric surface and PU effect is mostly declined by the AP deposition on the fabric surface, but the reflectance effect of PU has also been located very minor.

4.2 PCM Mechanism of AP Coated HTPB in terms of Heat Energy in IR Spectrum

Emissivity has relation between wavelength of radiation versus the angle of emission, the emissivity of water is

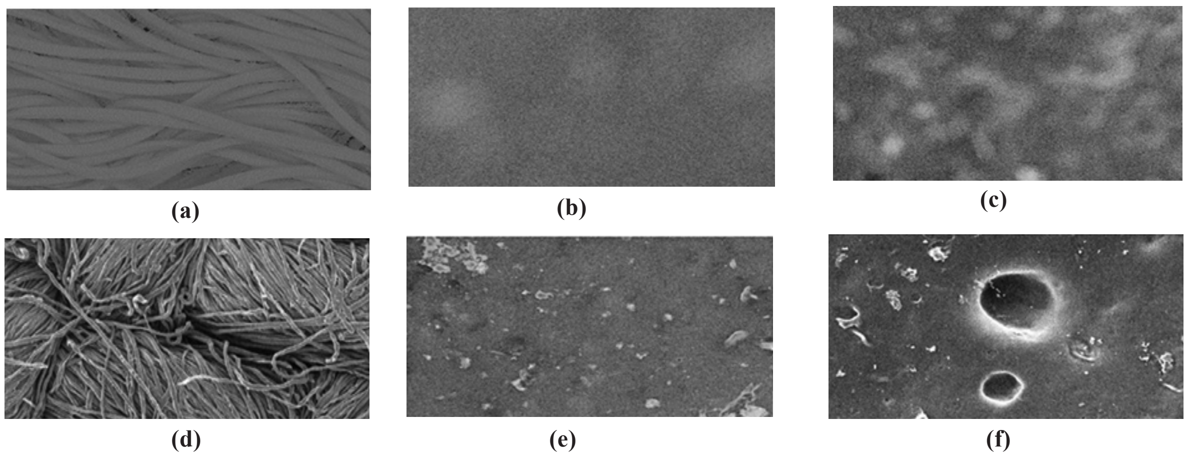


Figure 2. (a) Uncoated PA 6, 6 (b) AP coated PA 6,6 fabric (c) AP coated PA 6,6 fabric after five time washing (d) Uncoated cotton fabric (e) AP coated cotton fabric (f) AP coated cotton fabric after five time washing.

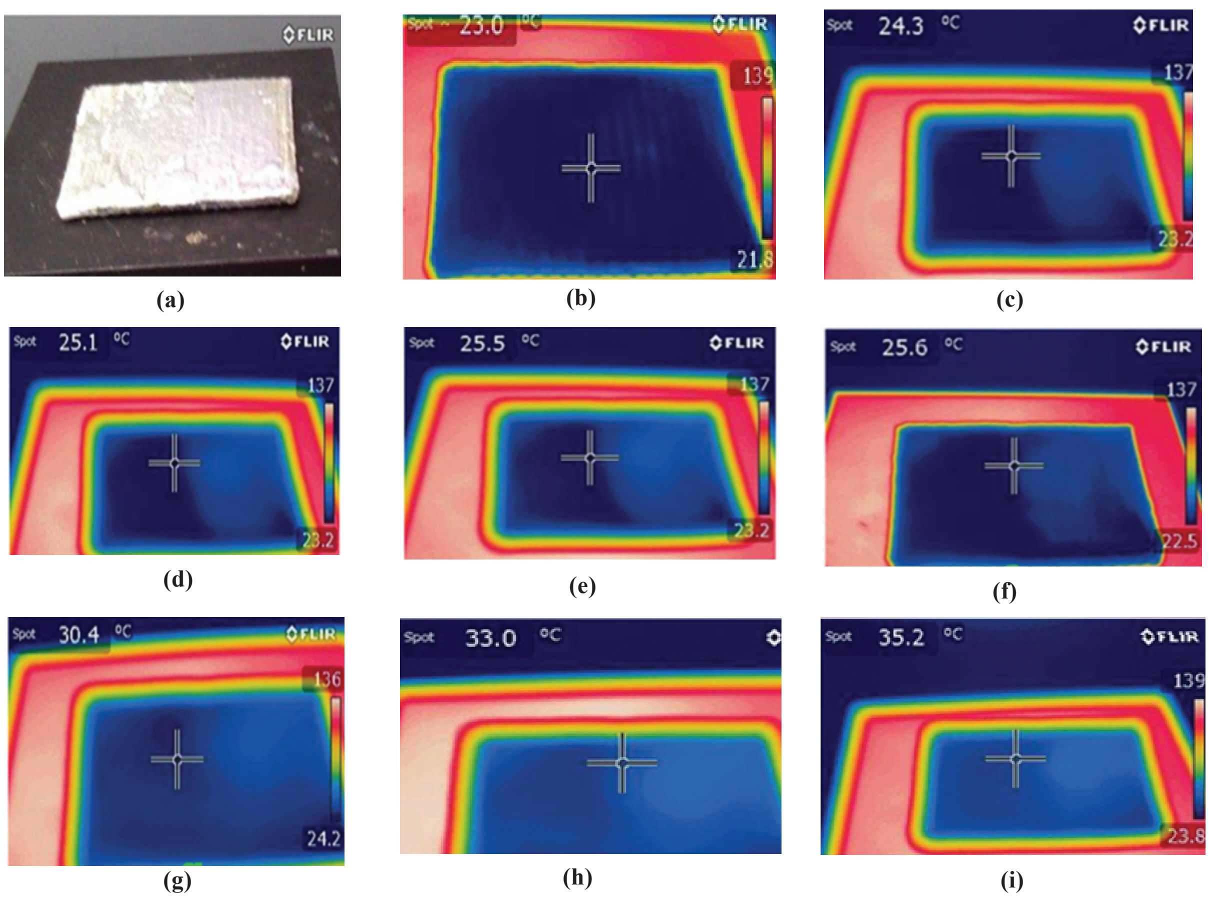


Figure 3. Temperature deviation of AP coated HTPB and PCM loaded HTPB from black to white chromatic hue in IR imaging for concealment mechanism of heat energy.

0.97[10] and oppositely emissivity of AP is lower although the emissivity properties of AP depends on molecular properties of AP. A thermal imaging variation has been observed between eicosane loaded part of channel-HTPB and unloaded part of channel-HTPB. As the emissivity of water is higher than AP under selected temperature range, so the process has limitation of stable camouflage design to minimize the temperature impact for concealment of target signature, but the process can be implemented for limited temperature range around 25°C to 30°C.

Figure 3a shows 19 channel-HTPB, 9 channel loaded with melted eicosane and 10 channel was kept completely blank. The eicosane loaded part of channel-HTPB shows the bluish hue without impacting temperature but the eicosane unloaded part of channel-HTPB shows the whitish color due to higher emissivity area compared to eicosane loaded part of channel-HTPB. At temperature 33.0°C, 35.2°C; eicosane starts to melt and the reflection of AP coated channel of hollow fabric increases very slowly in thermal image of 3b-3c-3d-3e-3f-3g-3h-3i (left part-eicosane loaded channel of HTPB. Oppositely, thermal image of 3b-3c-3d-3e-3f-3g-3h-3i (right part-eicosane unloaded channel of HTPB) shows whitish chromatic hue, the mechanism has been purely demonstrated the maximum heat energy and the reflection is comparatively higher. Therefore, PCM can be used for controlling IR temperature under minimum temperature range at below 30°C to minimize the reflection deviation between TOB-AP coated fabric and the technology can be implemented for camouflage product development of IR camouflage textiles of simultaneous formulation of UV-Vis-IR camouflage textiles.

4.3 Chromatic Profile of Woodland CB and AP Treated Fabric in Vis Spectrum

Figure 4, L* of AP coated PA 6, 6 fabric (68.36) and cotton fabric (56.93) are nearest of woodland CB. L* value of green leaves (40.18), dry leaves (53.2) and tree bark (45.14) are comparatively lower than untreated PA 6,6 and cotton fabric. Lightness value is also fluctuated by the structural properties of fabric and woodland materials. L*, a*, b* value trend to symmetrical chromatic value before washing and five-time post washing. Green leaves is showing higher greenish hue (a* = -6.73) due to presence of chlorophyll, dry leaves (a* = 1.88) and tree bark are remarking as reddish hue (a* = 13.87) due to existing of tannin in *Eucalyptus* plant materials [11]. Green leaves and tree bark shows blueish hue (b* =10.48 and 22.93) and dry leaves depicts highest blueish hue (b* = 25.20) due to possible presence of microscopic fungi on leaf surface. AP coated PA 6,6 exhibited a minimum value of greenish coordinate (a* = -0.29 and -0.23) before and after washing. AP coated cotton fabric also showed a minimum value of greenish hue (a* = -0.34 and -0.43) before and after washing. AP coated PA 6, 6 showed bluish tone (b* = 0.27 and 2.21) before and after washing due to existence of Al_2O_3 on fabric surface. AP coated cotton fabric appeared yellowish and blueish hue (-0.16, 2.99) before and after washing. Therefore, the color value of L*, a*, b* looks almost nearest chromatic coordinate between coated fabric and woodland background materials observed by CIE L*, a*, b*.

4.4 D65/10° Imaging of Woodland CB and AP Treated Fabric in Vis Spectrum

Figure 5 (f, g, h, i, j) denotes that AP treated fabric signifies a color tone of minor L* value and almost similar chromatic hue of green leaves, a core material of woodland CB in D65/10° imaging. In IR range, blueish tone of AP tends to replace by yellow/reddish/purple tone, green leaves are generally replaced to reddish/purple/yellowish color. Under transformation of IR, there is also possibility of matching woodland CB with AP treated textiles and it is also explained in subsequent explanation and mentioned in Fig. 8, 9 and 11 (a part of IR imaging).

4.5 Reflection Profile of Woodland CB and AP Treated Fabric in Vis Spectrum

Figure 6, reflection profile of AP for IR mechanism can be concluded as higher coating thickness of AP which depicts higher emissivity with minimum reflection, oppositely lower coating thickness of AP depicts minimum emissivity with maximum reflection, this photometric phenomenon generates a primary concept of lower reflection of raw whitish fabric of PA-6, 6 and cotton. Reflection profile of Vis mechanism has been demonstrated as higher coating thickness which signifies maximum oxidation and it is related to higher emissivity and minimum reflection, correspondingly lower coating thickness

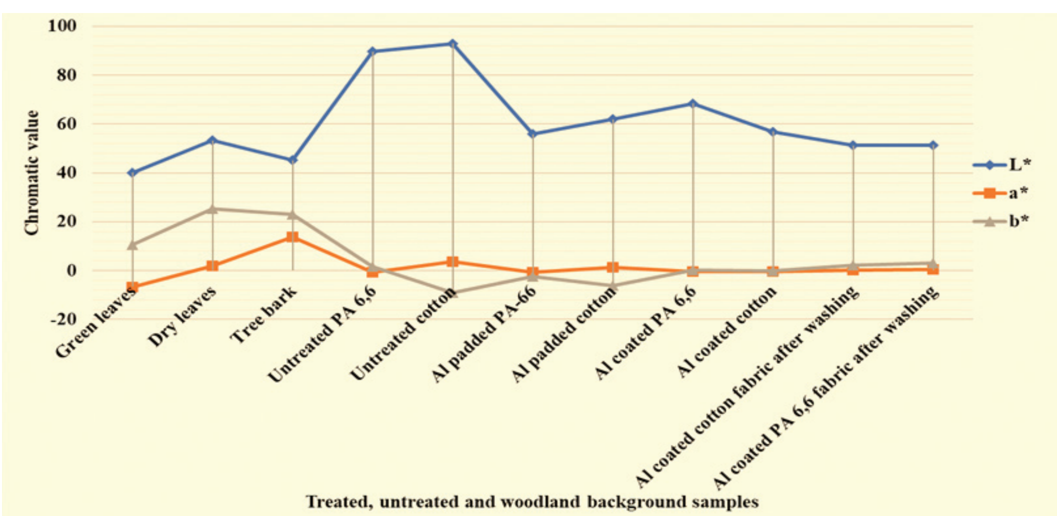


Figure 4. Chromatic value of AP coated-padded PA 6, 6, AP coated-padded cotton fabric and untreated fabric against woodland CB.

generates minimum oxidation, which is connected to lower emissivity and higher reflection. The intensity of AP reflection depends on oxide percentage of AP coated fabric. There is also reflection difference between AP coated and padded fabric due to deviation of AP deposition on fabric surface. AP coated fabric has higher percentage of Al_2O_3 rather than padded fabric which generates uniform reflection, and the mechanism is highly responsible for a smaller number of photonic responses to the remote sensing device. AP coated PA-6,6 fabric has reflectance with minor variation from 37 % to 38 % without washing and post washing from 17 % to 19 % at 400 nm to 700 nm. Similarly, AP coated cotton fabric has found less reflection which is 24 % to 25 % without washing and post washing from 16 % to 20 % at 400 nm to 700 nm.

to the surveillance imaging captured by digital camera/infrared camera/hyperspectral camera in terms CDRI.

4.7 Relationship of UV-Vis-IR Illumination Background and TOB-Woodland CB under Controlled Illumination of Light Cabinet in Vis-IR Spectrum

Figure 8, Vis-IR reflection of AP treated fabric, green leaves, dry leaves and tree bark of Eucalyptus tree has been shown under three-dimensional standardized chromatic background of black-green-white reflection signal which are the common interference of CB, and furthermore the standardized backgrounds are considered for accuracy of chromatic reflection. Under three-dimensional background illumination of UV-Vis-IR, woodland CB and AP coated fabric have been demonstrated for clarification of reflection when every CB has multidimensional variation of background materials rather than common background materials of woodland/desertland. Under low temperature AP treated fabric looks blurred in IR range for detection and identification of target signature. UV light of AP coated fabric has been reflected more due to single side coating of cotton fabric as white part of opposite side fabric has been illuminated in maximum range of reflection. Green leaves-dry leaves-tree bark are completely invisible except the intensity of white background in UV illumination. AP coated fabric was compared with woodland background under three-dimensional chromatic variation of background in UV-Vis-IR illumination from black to white chromaticity of thermal imaging scale. Under UV illumination, green leaves, dry leaves, tree bark are almost invisible except white reflection of white background tiles. AP coated fabric is little bit blurred in UV light background. Under D65 illumination of IR imaging,

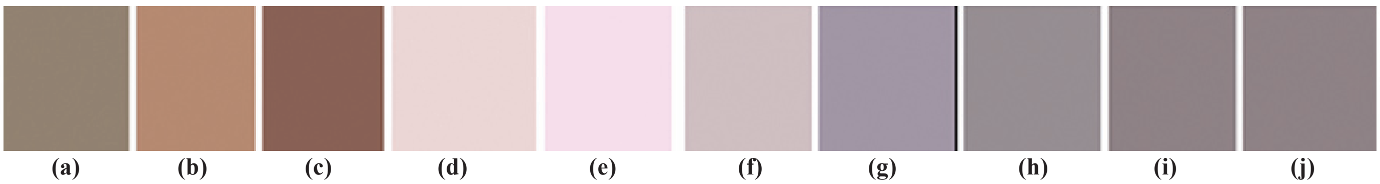


Figure 5. D65/10° imaging of green leaves: (a) Dry leaves (b) Tree bark (c) Untreated PA 6,6 (d) Untreated cotton (e) AP padded PA 6,6 (f) AP padded cotton (g) AP coated PA 6,6 (h) AP coated cotton (i) AP coated cotton after five time washing and (j) AP coated PA 6, 6 after five time washing.

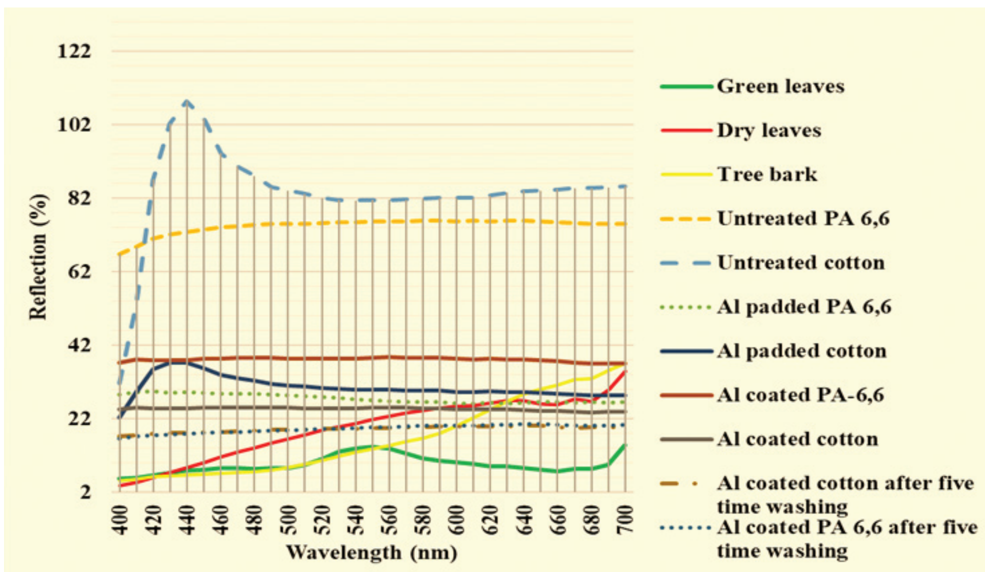


Figure 6. 0-150 % Reflection (machine standard) profile of AP treated fabric against woodland CBs.

4.6 K-M Reflection of AP Treated Fabric against Woodland CB in Vis Spectrum

Figure 7, the accuracy of K-M reflection of AP coated fabric has been found a new application for direct comparison with woodland CB materials. The scattering reflectance of green leaves, dry leaves and tree bark has been found higher due to surface roughness. It seems that the whole scattering area of woodland CB may differ from textile surface if the combat location is situated inside the area of woodland CB. Due to diffuse reflection of green leaves and tree bark; K-M reflection of woodland CB of Eucalyptus plant (green leaves, dry leaves and tree bark) has been found more variation due to structural deviation and existing pigment. The K-M reflection of AP padded-coated PA-6,6 and cotton fabric has been found significantly lower and straight signal of reflection due to opaque surface. The K-M reflection of AP-CB can identify the remote sensing parameters of chromophore which properties are directly related to electron energy versus photonic signal the chromatic appearance of AP treated fabric and woodland CB materials are almost symmetrical. UV background illumination of IR imaging, the chromatic appearance looks minor deviation in comparison with D65 image.

4.8 Simultaneous TOB-Woodland CB Assessment of AP coated Cotton Fabric under Woodland CB in Vis-IR Spectrum

Figure 9, a simultaneous reflection of green leaves, dry leaves and tree bark imaging signal versus AP coated textiles have been captured in the chromatic deviation of D65, UV and IR background illumination. The Vis spectrum image shows less reflection of lightness of AP coated fabric against woodland materials. AP coated fabric has brightly illuminated in UV background illumination when the imaging is compared with Vis and IR background. Under thermal imaging of IR at 46.6 ˚C and 33.9 ˚C, there is less reflection of AP coated fabric under woodland CB.

4.9 Assessment of TOB-Desertland CB Materials under UV-Vis-IR Background Illumination, a Lab Trialling under Standardized Black and White Background in Vis-IR Spectrum

Figure 10, the reflectivity of AP coated fabric is comparatively similar against desert CB in UV-Vis-IR background. The increasing of temperature range generates an

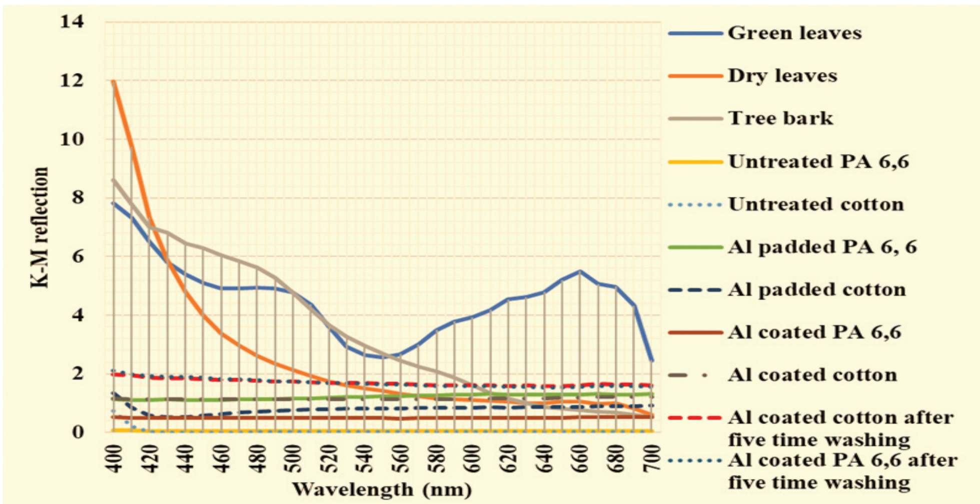
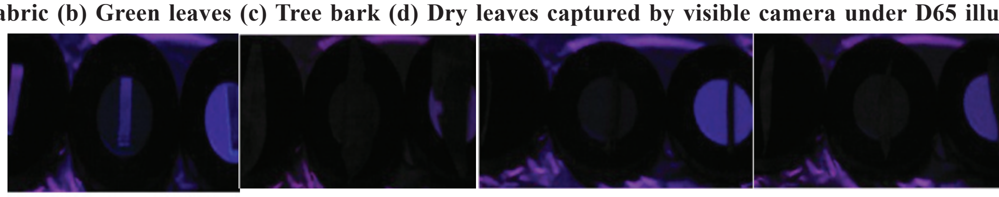
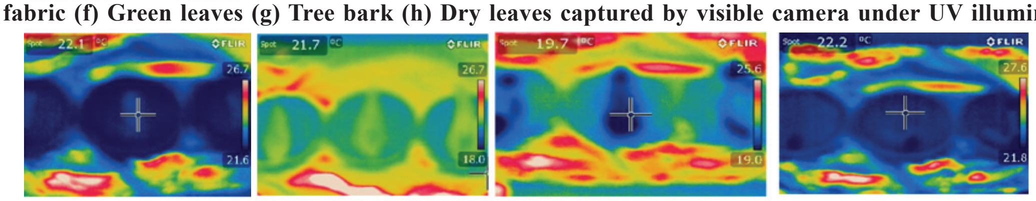


Figure 7. K-M Reflection of AP treated and untreated fabric against woodland CB.

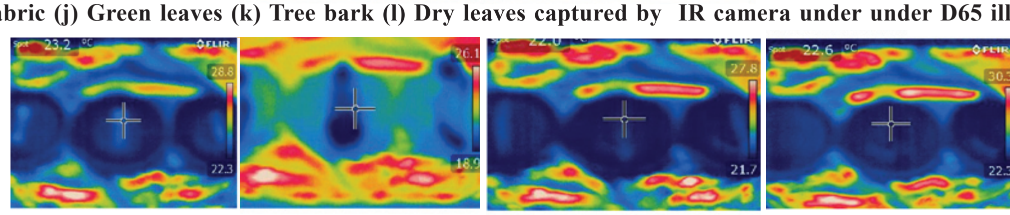
(a) AI coated fabric (b) Green leaves (c) Tree bark (d) Dry leaves captured by visible camera under D65 illumination



(e) AI coated fabric (f) Green leaves (g) Tree bark (h) Dry leaves captured by visible camera under UV illumination



(i) AI coated fabric (j) Green leaves (k) Tree bark (l) Dry leaves captured by IR camera under under D65 illumination



(m) AI coated fabric (n) Green leaves (o) Tree bark (p) Dry leaves captured by IR camera under under D65 illumination

Figure 8. Aluminium (Al) coated cotton fabric and woodland CB materials at 22.1 ˚C, 21.7 ˚C, 19.7 ˚C, 22.2 ˚C , 23.2 ˚C, 20.3 ˚C, 20.3 ˚C, 22.0 ˚C, 22.6 ˚C under temperature deviation from black to white chromatic hue in Vis-IR imaging.

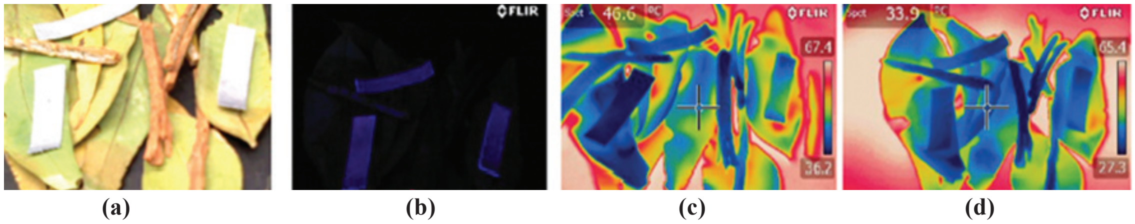


Figure 9. Scanned woodland CB materials and AP coated fabric in mixed combination under UV-Vis-IR background; Vis image of D65 background (a) Vis image of UV background (b) IR image of D65 background at 46.6 ˚C (c) IR image of UV background at 33.9 ˚C (d) Under temperature deviation from black to white chromatic hue in Vis-IR imaging.

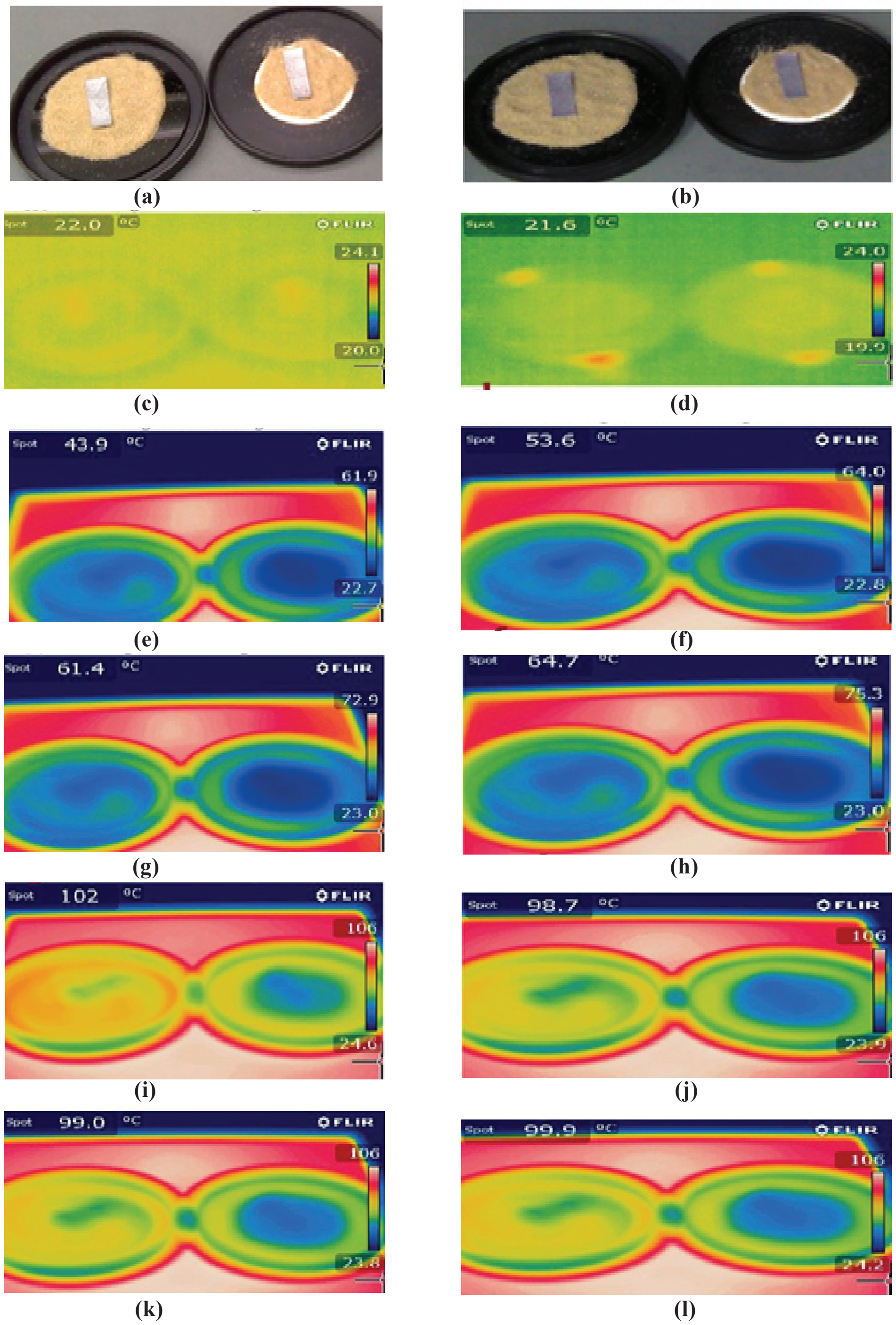
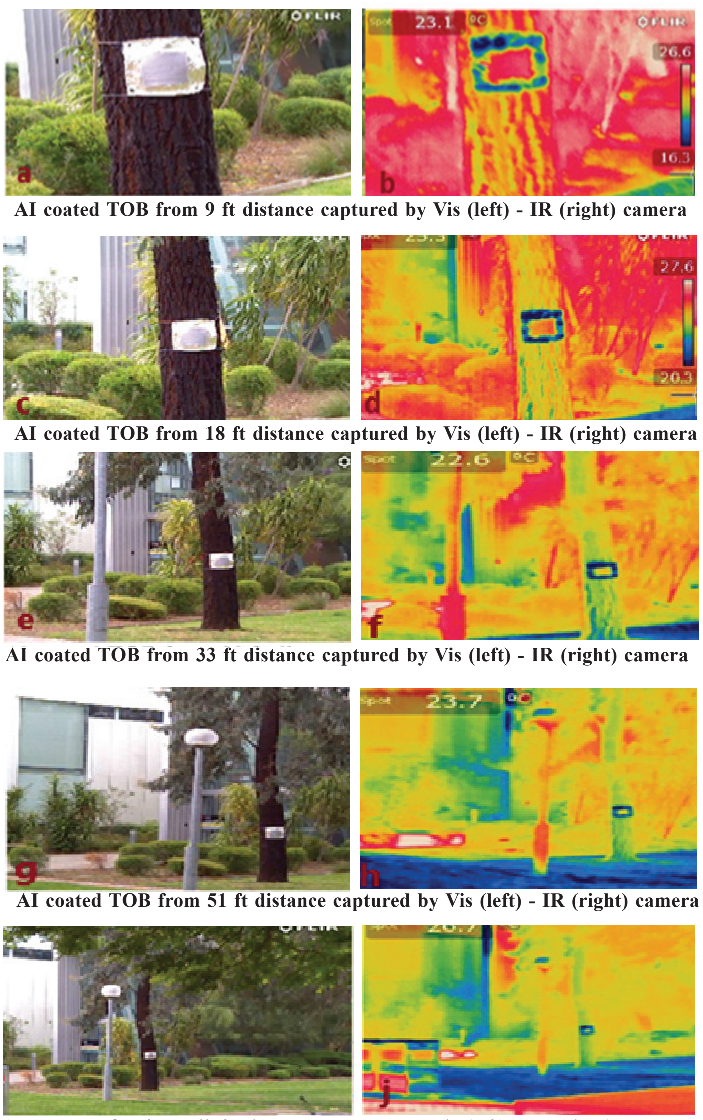


Figure 10. AP treated cotton fabric scanned under desert CB at 22 ˚C, 21.6 ˚C, 43.9 ˚C, 53.6 ˚C, 61.4 ˚C, 64.7 ˚C, 102 ˚C, 98.7 ˚C, 99 ˚C, 99.9 ˚C and deviation from black to white chromatic hue in Vis-IR imaging.

effect of detection of AP coated fabric surface due to the technical mechanism of heat versus mobility of AP molecules when the intermolecular deviation of AP surface looks like "water droplet" under visual scene of camera screen and the surface is fabricated accordingly at 43˚C, 53˚C, 61˚C, 62˚C, 102˚C, 98˚C. AP surface have been seen atomic vibration in high temperature. These variations of temperature versus mobility generates the reflection of detection but the dimension of reflection differs in eye-glance due to AP molecules variations of "water like droplet" and the TOB can be detected/recognized in high temperature variations, but it is not possible to identify target for the right attack of opposition team for exact decision making of TOB. Under D65-desert background, AP coated surface looks reflective, but UV-desert background AP coated surface looks blueish due to deviation of illumination, D65-UV. At 22˚C and 21.6˚C, the TOB-AP surface looks yellowish chromatic hue without identification of TOB-AP surface, it seems AP coated fabric is concealed under desert background at low temperature. But higher temperature generates blueish hue due to heating tendency at 43.9 ˚C, 53.6 ˚C, 61.4 ˚C, 64.7 ˚C, 102 ˚C, 98.7 ˚C, 99 ˚C, 99.9 ˚C, 102 ˚C, 98.7 ˚C.



AI coated TOB from 9 ft distance captured by Vis (left) - IR (right) camera

AI coated TOB from 18 ft distance captured by Vis (left) - IR (right) camera

AI coated TOB from 33 ft distance captured by Vis (left) - IR (right) camera

AI coated TOB from 51 ft distance captured by Vis (left) - IR (right) camera

AI coated TOB from 69 ft distance captured by Vis (left) - IR (right) camera

Figure 11. TOB-AP coated fabric assessment under woodland CB at different spot temperature-23.1 °C, 25.3 °C, 22.6 °C, 23.7 °C, 26.7 °C from black to white chromatic hue in Vis-IR imaging.

4.10 Field Trialling of Aluminium (Al) coated Cotton Fabric under Eucalyptus Tree and Surrounding Green CB Environment in Vis-IR Spectrum

Figure 11, under field trialling mechanism, there is an impact of multidimensional angular illumination under direct focusing of sunlight. The TOB is completely concealed in terms of chromatic deviation in surrounding CB. A polished aluminium surface, AFP was used in woodland background, it was almost visible due to shiny surface from 9 ft, 18 ft, 33 ft, 51 ft and 69 ft distance. AP coated fabric was found identification and recognition under woodland CB in Vis imaging when the detection was measured from 9 ft and 18 ft distance from target signature. Apparently increasing the distance was generated a gradual blurred image to the camera sensor when the target was measured from 33 ft, 51ft, 69 ft distance. Therefore, the partial assessment has been identified as identification = 9 ft distance, recognition = 18 ft distance, detection = 33 ft distance and concealment = 51/69 ft distance. The chromatic appearance of green leaves CB has also been observed a lower variation compared with AP coated cotton fabric. AFP has low emissivity; hence the surface shows high reflectivity in Vis-IR spectrum. Oppositely AP treated fabric-rough/unpolished surface has high emissivity which signify comparatively low reflection in Vis spectrum and significantly low reflection in IR spectrum. Figure 11(a), 11(b), green background tends to purple and reddish color at 23˚C under thermal deviation from 16.3˚C to 26.6˚C. The AP-TOB generates the chromatic signal of reddish hue which is matching with woodland CB color hue of green leaves. The tree bark color shows bluish chromatic hue which is replaced to yellowish hue and the minor percentage of greenish layer tends to reddish hue. The grass reflection of ground surface, surrounding of *Eucalyptus* tree has the tendency of chromatic hue from reddish/purple to whitish due to high reflection signal in IR spectrum. At the corner of Eucalyptus tree, the bluish and yellowish combination of grass has been illuminated as greenish area. The surrounding area of TOB has been generated a darker bluish tone due to quick heat generation on the surface of AFP. Figure 11(d), 11(f), 11(h), 11(j); when the target distance is gradually increased from 9 ft (23.1 ˚C) to 18 ft (25.3 ˚C)-33ft (22.6 ˚C)-51 ft (23.7 ˚C)-69 (26.7 ˚C). The woodland CB-green leaves and tree bark transfer the chromatic hue from reddish/purple to yellowish and still the chromatic hue between woodland CB and AP treated textiles have been found similarity under natural illumination falling sunlight at afternoon. Figure 11f, 11h, 11j; the surrounding grass of ground surface depicts the blueish hue because of heating of soil CB and the actual chromatic appearance of green grass has been influenced to make it blueish, dry grass has been visualized as blueish rather than reddish. Therefore, it has been demonstrated that AP coated textiles has been observed as the concealing tendency in IR spectrum in limited range of temperature (<30˚C) and the blurred chromatic hue of AP coated fabric has also been found in Vis spectrum.

5. CONCLUSION

This experimentation of AP coated textiles has been mainly conducted by the mechanism AP reflection technology of CDRI in woodland and desertland CB in Vis-IR spectrum under the illumination background of UV-Vis-IR. This subsequent trialling generates a concept of AP-woodland-desertland CB under proposing a standardized method of CDRI-Vis imaging-thermal imaging which can be implemented for

CDRI/camouflage materials research and its implementation for defense protection, a potential branch of technical textiles in terms camouflage engineering. The combination of AP treated patterning in UV-Vis-IR can be used for woodland CB in winter season/casual season for concealment of target signature when the temperature variation is less. The fabrication of AP textiles/PCM loaded textiles technology can be used for defence tents under simultaneous protection of heat and concealment. Similarly, the clothing textiles can also be implemented by HTPB-PCM as the range of body temperature has minor impact for IR-CDRI when the highest range of body temperature of a healthy man is around 36°C ± 2°C, approximately. The temperature of human tolerance limit is considered as simultaneous concealment of Vis-IR imaging. When the temperature is more than 30°C, the AP-HTPB-PCM treated target is detected due to temperature deviation between woodland background/desertland background and AP treated textiles.

In concluded point, the CDRI methodology of AP treated textiles versus combat background has been critically approached, experimented and tested under selected measurement process for camouflage materials versus methodological identification and investigation of defence professional in terms of laboratory and field trialling to get the accuracy of CDRI results in terms of cost and time minimization which are denoted as SEM imaging of TOB-CB materials for electron response of materials, chromatic and reflection measurement between combat materials and textile materials, UV-Vis-IR background measurement and imaging, heat radiation versus temperature versus PCM mechanism and camouflage materials identification under UV-Vis-IR spectrum.

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SUPPORTING INFORMATION, FIGURE S$_1$

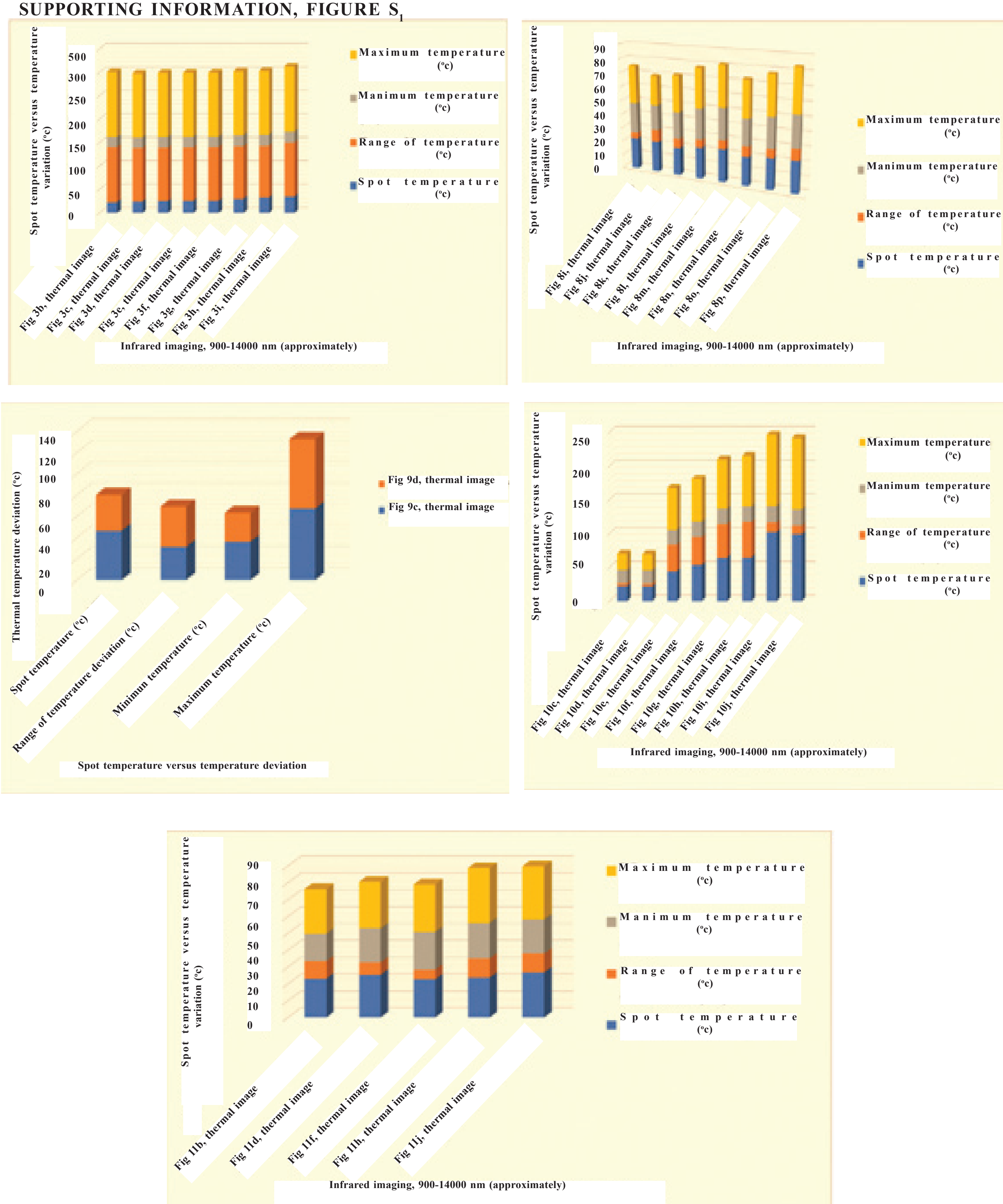

Figure S$_1$. Spot temperature versus range of temperature deviation, minimum temperature and maximum temperature in infrared imaging captured for this experimentation mentioned in Fig. 3 (b, c, d, e, f, g, h, i), 8 (i, j, k, l, m, n, o, p), 9 (d, c), 10 (c, d, e, f, g, h, i, j), 11 (b, d, f, h, j).

SUPPORTING INFORMATION, FIGURE S_2

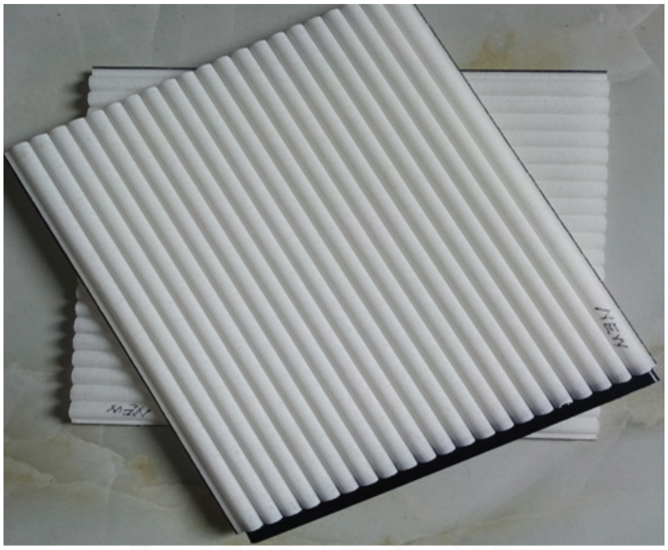

Figure S_2. Hollow tubular polyester beg (HTPB) before AP treatment