Development of Responsive Camouflage Textiles Using Thermochromic & Non-thermochromic Colorants

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Abstract

Development of responsive camouflage textiles by coloration of electrically conductive plain woven cotton fabrics with thermochromic colorants was undertaken. Electrically conductive cotton woven fabrics were prepared by using 100% cotton yarns in warp and a core sheath nichrome-cotton yarn in weft. The fabric thus prepared was made conductive by joining the conductive yarns in a way so as to enable the current to pass through the weft yarns in parallel as well as series modes. The fabrics prepared were desized, scoured and dyed with thermochromic colorants and mixed thermochromic and non-thermochromic colorants. Passing current through the fabric generated heat, allowing the color of the fabric to be changed between two or more predetermined shades. To evaluate the camouflage textile in terms of performance and comfort, bending properties, moisture and air transport and thermal properties were measured and found satisfactory for using as defense application.

Keywords: *camouflage, conductive textile, core-spun yarn, thermo chromiccolorants, thermal comfort*

1. Introduction

Camouflage is an art unintentionally but favorably employed in nature to conceal the animals or object by pattern and/or color. Mankind learned basic camouflaging techniques from natural sources long before recorded history in order to conceal human beings, their possessions and even residences from human enemies as well as from animals. In more recent times, camouflage used on military equipment, became an essential part of modern military tactics, sharing a common intent of concealing people, clothing, armament and other accessories through the use of patterns which merge with a given background. For defense applications, the clothes are designed to mimic woodland and desert backgrounds. The patterns used for such military clothing is known as camouflage patterns, which mask the warrior with the background to deceive the opponent. However, the natural background changes markedly from place to place like desert or jungle, with the seasons, there being a predominance of green hues in summer, many of which disappear in winter. To cope with these changes,possibility of using thermochromic and / or photochromic dyes which may change colors triggered by a significant seasonal temperature change is being examined. Use of thermochromic colorants for development of camouflage /novelty articles is well established (D. Aitken, S.M. Burkinshaw, J. Griffith and A.D. Towns-Report-1996, M. A. Chowdhury, B.S. Butola and M. Joshi Report- 2012 ,R. M. Christie, S. Robertson and S. Taylor, Report-2007, T. L. Dawson, Report- 2010 R. R. Mather, Report-2001).Under normal conditions, the color depends upon surrounding temperature. If the surrounding temperature changes such that it passes through the activation temperature (TA) of the article colored with the thermochromic colorant, a color change from colorless to colored state or vice versa will take place (D.Aitken, S. M. Burkinshaw, Report-1996).

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However if the temperature remains above or below the transition temperature, no change in the color will take place. Here the trigger (stimulus) for color change is temperature, which is not under the control of user (In earlier approaches US Patent 6, 751, 831, 2004; US Patent 9, 767, 651, 2002; US Patent 6, 654, 096, 2003; US Patent 4,681, 791, 1987; US Patent 10, 095, 299, 2002; US Patent 5, 985, 381, 1999).

Thermochromic and non-thermochromic colorants were applied on textile goods for preparation of camouflage textile. But in those approaches camouflage effect was depended on surrounding environmental condition. There is no published literature where a positive stimulus has been made a part of the arrangement to bring out a change in color on demands.

In the current proposal, the authors propose to place the stimulus at the disposal of the user or the wearer of the garment having the camouflage pattern. This is proposed to be achieved by applying the thermochromic colorants or mixture of thermochromic and non-thermochromic colorants on an electrically conductive fabric. When current passes through the fabric, heat is generated and the temperature of the fabric rises irrespective of the surrounding temperature. Depending on the requirement, a specific color (or more colors) may be made to fade by raising the temperature of the fabric to a desired level by controlling the heat generated.

2. Experimental

2.1 Material & Methodology

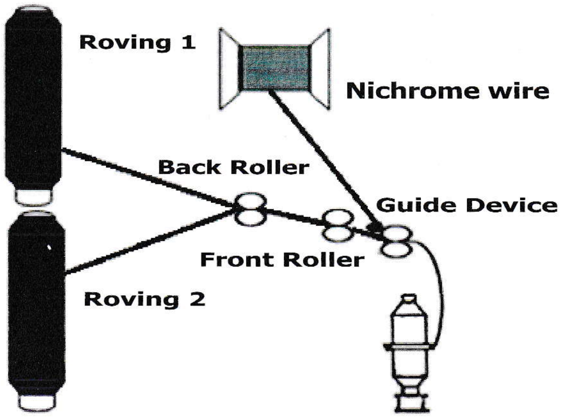

Figure 1: Schematic diagram of production of core spun yarn.

Figure 2: Optical microscopic picture of the core-spun yarn.

A conductive core-spun yarn was produced by ring spinning frame (Lakshi, India) using a Nichrome wire of standard wire gauge (SWG) 46 (resistance 480 ?/m) in the core and two cotton rovings of 0.92 & 0.97 Ne as sheath according to literature (O. Babaarslan Report-2001, C.W. Lou Report- 2005) A positively driven feed roller with special type of groove guide was attached to feed metal wire to the front roller of the drafting system. Schematic diagram of production of core spun yarn is shown in Figure 1.

A detail of the yarn production procedure was given in our earlier publication (M. A. Chowdhury, B.S. Butola and M. Joshi) The resultant count of the core spun yarn was 14 Ne. Microscopic view of the core-spun yarn is shown in Figure 2 which ensure that the core is properly placed at the centre of the yarn and the sheath cover the core as core is properly invisible in the Figure. Then 1X1 plain woven fabric was prepared on a sample rapier loom (CCI Tech Inc, Taiwan) using cotton yarns of English count 30 Ne as warp and 14 Ne core-sheath yarn as weft.

Table 1: Commercial Thermochromic Dyes.

Thermochromic colorant	24 mL
Non-Thermochromatic pigment	1 mL
Cationic agent (Americos AC NRL 9000)	10mL
Non-ionic dispersing levelling agent (Dispersol DX)	15 mL
Acrylic soft binder (Americos Acrylic Binder 16000)	20 mL
Water	30 mL

Table 2: Recipe for dyeing mixed thermochromic & non thermochromic colorant (For 100 mL dye solution)

Dye	Activation Temp. (^{0}C)
Americos Thermochromic Red	26
Americos ThermochromicBlue	25
Americos Thermochromic Green	22

The fabric was desized and scoured on a laboratory scale winch machine. A series of commercial thermochromic colorants were used has given in Table 1, supplied by Americos Industries Inc., Gujarat, India. Non-thermochromic pigments were supplied by Pidilite Pigments, India.

The fabric was then dyed with thermochromic blue colorants by continuous methods (padded at room temperature, dried at 80^{0}C for 3 min, followed by curing at 140^{0}C for 3 min). One sample was colored using combination of thermochromic red, green and blue colorants (having different activation temperature) at 1:1:1 ratio. Another sample was colored using thermochromic blue and non-thermochromic yellow pigment as given in Table 2.

Then the ends of the dyed samples were connected to obtain series and parallel connections. The circuit was completed by connecting two extreme ends to a digital multiple D.C. power supply, where it was possible to change and monitor the voltage (V) and current (A) digitally. Experimental set-up is shown in Figure 3.

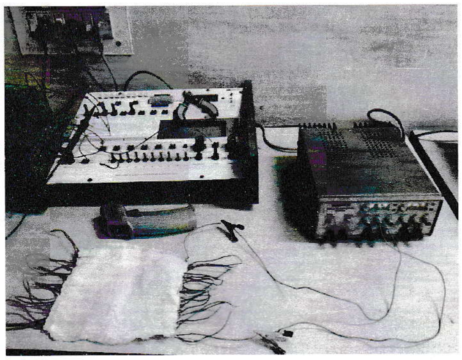

Figure 3: Experimental set-up for voltage and temperature measurement.

2.2 Testing Procedure

The color of the fabric was measured as function of fabric temperature (which increased when the current was passed through the fabric). A reflectance spectrophotometer (GrytagMcbeth, Color Eye 700A) was used for colour measurement for illuminant D65 and 10° observer. A detail of the color measure ment procedure was given in our earlier publication and somewhere else (M. A. Chowdhury, B.S. Butola and M. Joshi, Coloration Technology, Accepted for publication; R. M. Christie and I. D. Bryant, Coloration Technology, Vol. 121, 2005, pp. 187-192). To find out the effect of voltage in heat generation and subsequent temperature rise, an 8 in x 8 in sample was taken and electrical circuits were prepared by joining the bands of wires both in parallel and in series manner with multiple D.C. power supply where it was possible to change and monitor the voltage (V) and current (A) digitally. When the current passes through it, due to the high resistance of Nichrome wire, heat is generated which raises the temperature of yarn and fabric. This temperature was measured by using an IR temperature sensor

(Raytek Mini Temp, USA) which was able to measure a minimum temperature difference of 0.5 0C. Experimental set-up is shown in figure 3. For meaningful comparison, different comfort and wicking properties of camouflage fabric were measured alone with a 1×1 plain woven fabric (60×60/20×20, GSM 160). Thermal properties of the fabrics were measured using Alambata instrument, Sensara, Czech Republic (figure 9). TEXTEST air permeability tester (FX3300), Switzerland was used to measure the air permeability at 98 Pa air pressure, as per the BS5636 test method. Moisture vapour transmission rate was measured by moisture vapour transmission cell. Wicking properties of fabric were measured in Gravimetric Absorbency Testing System (GATS), USA.

3. Results and Discussion

3.1 Effect of Voltage on Temperature Raise

The effect of voltage on temperature raise in series and parallel modes is illustrated in the Figure 4. It was found an almost linear relation existed between the voltage and temperature raise and the current requirement was much higher in series than in parallel. Only 20V electricity was enough to raise the temperature by more than 25°C in case of series connection where as this much of temperature can be generated by using only 11 V of electricity in case of parallel connection.

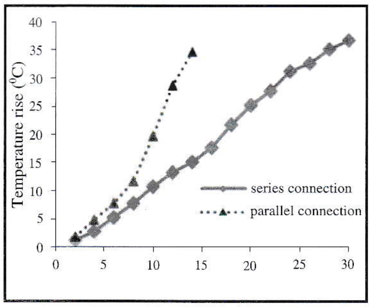

Figure 4: Effect of voltage in temperature raise in series and parallel connection.

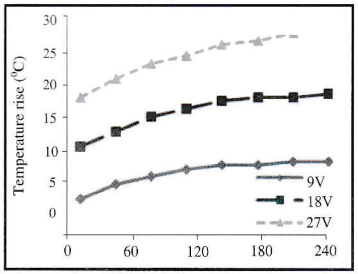

Figure 5: Effect of time of power supply on temperature rise in series connection.

3.2 Effect of Time of Power Supply on Temperature Rise

To find out the effect of time on temperature generation, fixed voltage of 9, 18 & 27 V was applied to the sample (8in x 8in) and the temperature rise was measured after 30 sec intervals. The connection was given in series and the experimental set-up was same as mentioned earlier. The result indicate that it required 4 minutes to generate 10^{0} C temperatures rise at 9V potential and after some time temperature rise become almost steady with time. But in case of 27 V, only 30 sec is enough to generate 18^{0}C temperature rise (Figure 5).

3.3 Effect of Temperature on Reflectance Spectra of the Sample Dyed with Thermochromic and Non-thermochromic Colorants

Reflectance spectra of the sample dyed with thermochromic blue color is given in the Figure 6. It can be observed that at lower temperatures maximum reflectance (? max) was found in the range of 450- 495 nm i.e. at blue region of the visible spectrum, which indicates that initial color of the sample was blue. A gradual shift of the reflectance curve was observed with the increase in temperature with maximum shift at 26^{0}C (Activation temperature, TA). At 28^{0}C temperature no peak was observed in blue region which indicates fading out of the color from the sample.

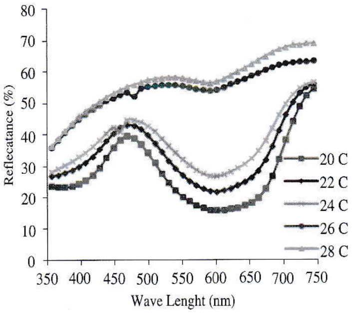

Figure 6: Effect of temperature on reflectance for blue sample.

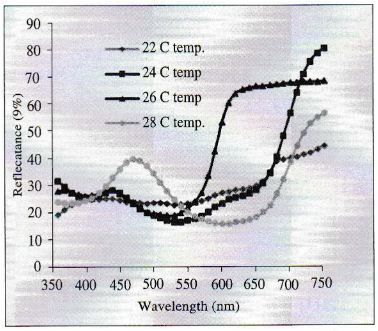

Figure 7: Effect of temperature on reflectance for sample prepare from mixing red, blue & green colorants at 1:1:1 ratio.

Reflectance spectra of a sample dyed with three thermochromic colorants (red, green and blue) having different activation temperature is shown in Figure 7. It can be seen that, at lower temperature (T<TA) all the three colorants are in color state. So the sample appears as grey. But with the increase of temperature, when it passed the activation of green color, sample appears as violet (? max 360 nm). Further with the increase of temperature the sample turns to red (? max 750 nm) and finally colorless. In Figure 8, the spectrum of a green colorant (obtained by mixing thermochromic blue colorant and yellow pigment) is shown. As can be seen, with increase in temperature, initially the green color becomes lighter (fading of blue colorant) and above the activation temperature of blue colorant (26°C), it becomes yellow as blue color fades completely but yellow color remains unaffected. The change in color thus obtained is reversible and is restored when the applied voltage is removed.

3.4 Bending Properties of Fabric

Bending properties of woven fabric composite materials are important because they govern many aspects of fabric performance, such as drape, handle, and they are an essential part of the complex fabric deformation analysis (H.U.Jinlian, Report-2008).

To use a fabric as a camouflage textile, it should be neither too stiff nor too limp. The bending stiffness of the fabrics was measured by Shirley stiffness tester which is based on the cantilever principle. Three specimens in both warp and weft ways were tested. Table- 3 provides average of the bending length, bending modulus and flexural rigidity of the tested fabric along with its grams per square meter (GSM) and fabric thickness of the prepared camouflage fabric and sample woven fabric. It is seen from the table that bending properties of the camouflage fabric is affected due to presence of metal wire in the core, though the fabric has considerable bending properties compared with sample fabric.

Table 3 : Bending Properties of fabrics.

Sample	GSM	Fabric thickness, t (mm)	Bending length, C (cm)	Flexural Rigidity, G (μNm)	Bending modulus, q (N/m2)
Camo-flage fabric	142	0.57	6.6	0.40	25924.05
Sample Fabric	170	0.8	7.4	0.68	15822.73

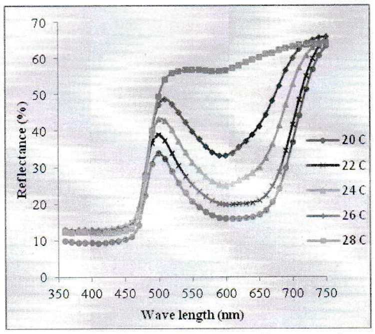

Figure 8: Effect of temperature on reflectance for sample prepare from mixing thermochromic blue & non-thermochromic yellow colorants.

3.5 Thermal Comfort of Fabrics

The human body is constantly exchanging heat with the thermal environment and it depends on the temperature difference between human body and surrounding environment. In general, clothing plays an important role in transmitting heat and evaporated sweat from the skin into the environment and by this it maintaining a heat balance between the skin surface and the surrounding environment. Thermal sensations commonly known as thermal absorbtivity or cool/worm feeling have been recognized as an important aspect of thermal comfort (Y. Li and A.S.W. Wong, Report-2006). The higher the value of thermal absorbtivity, cooler the feeling by the user. Thermal properties along with air permeability, MVTR and wicking properties are given in Table 4.

Though the camouflage fabric has little inferior thermal comfort properties in terms of thermal resistant and thermal absorbtivity compared to sample woven fabric, this is enough for military clothing purpose. Moreover if this kind of clothing is used during winter or colder region, this can provide addition worm to the user.

3.6 Air Permeability Test

Air permeability is a measure of the rate of flow of air passing perpendicularly through a given area of fabric at a specific pressure difference across the fabric test area over a given period of time (B. P. Saville, Report-2000).TEXTEST air permeability tester (FX3300) was used to measure the air permeability at 98Pa air pressure, as per the BS5636 test method. An average of 10 readings for each sample was reported. The area of the operation was 5 cm2 and the diameter of the sample holder is 1 inch. It is seen from the table that the camouflage fabric has slightly better air permeability compared to sample fabric. This may be due to the fact that the cover factor of the camouflage fabric is less than the sample woven fabric. So more air could be pass through the gap between the warp and weft.

Table 4: Different Comfort Properties of Fabric.

Sample	Air Permeability ($Cm^3/cm^2/s$)	MVTR ($g/m^2/24$ hr)	Absorption Capacity (gH_2O/g)	Thermal Resistance R, (m^2K/W)	Thermal Absorbitivity, b, ($Ws^{½}\ m^2K$)	Max. level of contact heat flux, q_{max}, (W/m^2K)
Camouflage Fabric	194.42	44.07	2.724	23.37	59.43	0.31
Sample Fabric	163.6	66.1	3.079	24.1	69.4	0.317

3.7 Moisture Vapor Transmission Test

Moisture vapor permeability (units =g m-2 hr-1) determines the resistance of a fabric to the transfer of water vapor or insensible perspiration emanating from the body. The manner, in which moisture is absorbed at the fabric inner surface, transported between the two sides significantly the wearer's comfort sensation, as the moisture is a much better heat conductor than air (B. P. Saville, Report-2000).

Due to the presence of metal wire in the core, moisture vapor transmission is lesser than the sample woven fabric. However, the moisture vapor transmission is acceptable in considering the nature of the fabric and application.

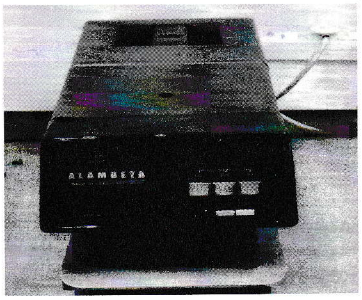

Figure 9: Alambata instrument.

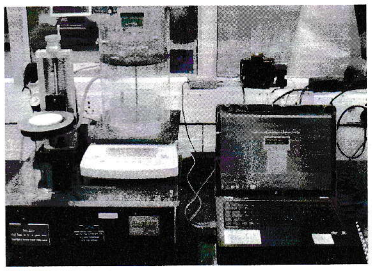

Figure 10: Gravimetric Absorbency Testing System (GATS).

3.8 Wicking Behaviour of Fabric

To make the wearer feel comfortable, the fabric worn next to the skin should absorb the perspiration from the skin surface and then transfer the moisture to the atmosphere. Wicking is one of the most widely used test methods for describing the ability of moisture absorption in fabrics (U. J. Patil, C.D. Kane and P. Ramesh, Report-2009, A. Das, M. Zimniewska and R.D. Mala, Report-2009).

The wicking behavior of the sample fabrics were measured in a Gravimetric Absorbency Testing System, GATS, USA (figure 10). Wicking property (in terms of absorption capacity) of the camouglage fabric was slighted affected due to the presence of metal wire in the core.

4. Conclusion

It was possible to manufacture a conductive woven fabric by having a 100% cotton yarn in warp and a core spun nichrome-cotton yarn in the weft. The conductive fabric responds to application of voltage across it by raising its temperature which depends on the kind of connection (series or parallel) and the voltage applied. When the fabric dyed with thermochromic colorants is heated by passing the current through weft yarns, its temperature increases and the color fades when the temperature increases beyond its activation temperature. By mixing thermochromic colorants having different transition temperatures or thermochromic colorants with non thermochromic pigments, it is possible to have fabric colors which change with change in fabric temperature. As it is possible to control the temperature of the fabric by controlling the voltage applied, the user can create a premeditated fabric color matching with a changing background. Camouflage fabric has slightly inferior bending and comfort properties compared to the normal woven fabric used in this purpose. However, these bending and comfort properties are acceptable in considering the nature of the fabric and application. This kind of approach could find their application in different defense end use like military clothing, military tent, artillery or vehicle cover etc. where these articles need to mimic with surrounding on demand.

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