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Camouflage Fabric - Fabric for Today's Competitive Era

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ABSTRACT

Innovation is the foremost requirement of today's competitive era. Innovation refers to improving on an existing concept or idea using a stepwise process to create a commercially viable product. Food, clothing, and shelter are the basic needs of a human being. Clothing is made from textiles; with the help of textiles, the shelters are made more comfortable and attractive. Traditionally, fabrics are used for apparel and home furnishing purpose, but these days, application is diversifying in order to satisfy technical and protective functions. Camouflage fabrics are the ones most suitable for technical and protective purposes. Over the past few years, researchers have put emphasis on the development of camouflage fabrics for security measures for troops, and for activities intended to hide facts and mislead the enemy. Years of investigations have been invested into innovation in the manufacture of these fabrics which are providing the ultimate performance and reliability. In this review paper, an attempt is made to comprise principle, manufacturing techniques, properties and application. This paper also highlights the modern development and recent trends in the field of camouflage fabric. Camouflage and multispectral universal camouflage are the main areas of recent trends on camouflage fabrics. Camouflage fabrics are mostly used for hunting, survival prepper, tactical and military protective wears.

KEYWORDS

Camouflage fabric, Textile, Protective wear, Electrochromic fabrics

INTRODUCTION

The word camouflage is derived from the French word "camoufler" which means to disguise or hide from something. The phrase, which can provide the clear-cut definition, is: the tool used for breaking up the recognizable human form. Plants and animals show natural camouflage. A chameleon lizard changes its colour according to the surroundings and the leaves of *Corydalis hemidicentra* plant match the colour of the rocks [1]. Artificial camouflage can be obtained for concealing the personnel or the equipment from enemies. Textiles are playing the key role in generating artificial camouflage effects. Defence is the main sector which utilizes artificial camouflage produced by fabrics. Nowadays, most of the countries disburse a huge amount of their revenue, about 2 to 3 percent of the total defence budget, over the defence including vehicles, bombs, missiles and, most importantly, the attire of the personnel [2]. The main aim of camouflage is to help to hide the vehicles, the equipment and the personnel from the enemy to reduce the number of attacks from the enemy. Moreover, it might become difficult for the enemy to spot the vehicle and the

personnel. Camouflage fabrics were first used during the Second World War. A tremendous increase in use was seen after the war in Iraq in 1991 [3].

Several researches are going on to improve quality with lesser cost. The procedure for making a nature-raised fabric with eight layers is a recent development in the field of camouflage fabric, which is used for a special function called hunting research. The major manufacturers of the camouflage fabric are South Korea, China, Brazil, Indonesia and Turkey. Camouflage fabrics are used by most of the armed forces including army, navy, air force and para-military forces. It is estimated that more than 350 million meters of fabric is consumed worldwide annually. Camouflage fabric is produced in different patterns across the world. Russia uses a woodland type of pattern, Germany uses Flecktarn or a mottled camouflage type of pattern and the United State Air Force uses a digital tiger-stripe type of pattern.

PRINCIPLES OF CAMOUFLAGE:

The principle refers to the idea or the concept out of which this camouflage came into existence. The camouflage fabric works on six principles [4-5].

Resemblance to the Surroundings

Many animals and plants change their colour according to the surroundings, e.g. chameleon lizards or a plant named *Corydalis hemidicentra*. Thus, fabrics can be prepared in a way which makes them resemble the surroundings, thus making it more difficult to be spotted by the enemy [6].

Disruptive Colouration

The location and identity may be concealed through a colouration pattern which causes visual disruption because the pattern does not coincide with the shape and outline of the vehicles or the equipment [7].

Motion Dazzle

A pattern of contrasting stripes that degrade an observer's ability to judge the speed and direction of a moving object. This concept (Figure 1a) was used during the Second World War, when ships were painted to reduce the attacks from the submarines [8-9].

Counter Shading

It creates an illusion of flatness. In this, the upper part of the vehicle is painted in the darkest tone of colour and the lower part with a light colour, making the counter-shaded vehicle nearly invisible against a suitable background [10].

Mimicry Principle

The mimicry principle tries to adapt not only the colour but also shape of the environment. The toad (Figure 1b) not only matches the colour of the leaves but also acquires the same shape as that of the leaves and becomes difficult to be identified by the enemy.



Figure 1. (a) Motion dazzle principle; (b) Toad between the leaves [3,9]

Continuation of the Pattern

Continuation of the pattern suggests that the personnel, vehicle, or equipment should be camouflaged in such a way that it appears in the continuation of the surrounding pattern or structure. The spider over the rocks is in continuation of the pattern made up by the rocks (Figure 2). Thus, it becomes difficult to be spotted by the enemy.

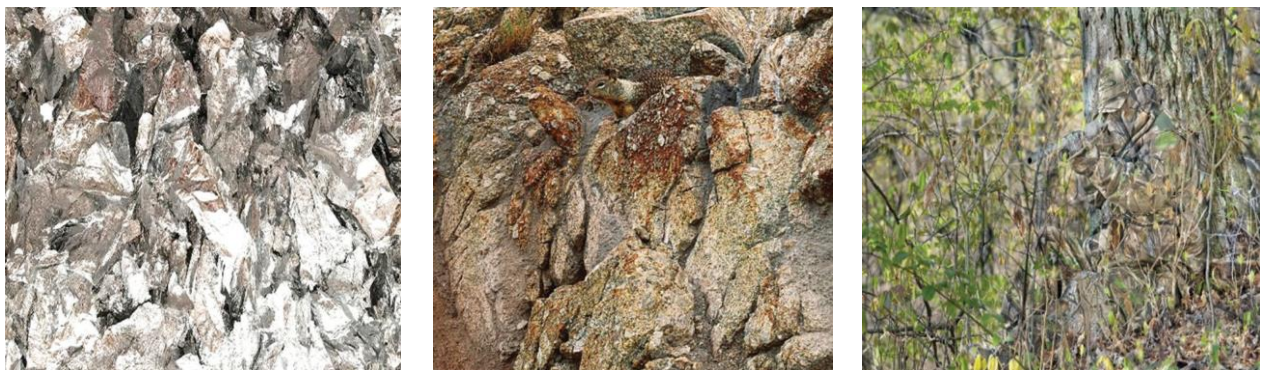


Figure 2. Continuation of the pattern of the rocks and a soldier difficult to spot in the forest [3]

REQUIREMENTS FOR MANUFACTURING THE CAMOUFLAGE FABRIC

For manufacturing the camouflage fabric there are two main substances: colour type and fabric type. Both organic and inorganic substances can be used to produce the camouflage fabric [2, 11]. Materials required for the preparation of camouflage fabric are as follows:

Colour Requirements

- Special or selected dyes like Procion MX and pigments like barium sulphate.
- Infrared absorbing pigment including both organic and inorganic materials, such as perylene black, phthalocyanine blue and organic materials includes ferric oxide, lead chromate, chromium oxide and isoindoline. These materials are incorporated into the printing paste.
- There are some infrared absorbing pigments which are incorporated into the polymer in the fibre forming process, such as carbon black.
- Infrared reflectance coatings, such as carbon compound coated over the synthetic fibres.

Fabric Requirements

- The prepared camouflage fabric should meet certain requirements before it is used for the defence purpose or any other application. The synopses of these properties are given below [11]:
- The fabric should possess high pilling resistance and should not generate the burr and snag.
- Tensile and tearing strength should be high, it may vary according to the end use application.
- Fastness regarding light, wash and perspiration should be good.
- The fabrics should possess the special functional properties, such as being flame retardant, waterproof, wind-proof, breathable and having antimicrobial properties.
- The fabric should be non-glaring.

MECHANISM FOR MANUFACTURING CAMOUFLAGE FABRIC

- The various properties of the camouflage fabric are described below with a brief description. These properties are listed as follows [12]:
- By changing the pH
- By changing the oxidation state
- By changing the bond arrangement
- By mechanochromism
- Due to the magnetic field

pH Change

Molecules can change colour dramatically in the presence of acids and bases as the camouflage fabric is dipped into solvents of different polarity. Change in the polarity causes the change in the colour.

Bond Breaking

There are a number of systems that undergo reversible bond breaking and bond forming processes that result in dramatic colour change. For example: enol is colourless but on rearrangement of atoms it showed orange colour for the cis form, whereas for the transform it showed the red colour.

Oxidation State Change

Due to change in the oxidation state the colour of the fabric changes. For example: copper shows different oxidation state, such as 0, +1 and +2. With different oxidation states, different colours are observed, such as in 0-oxidation state as the molecules of the fabric are rearranged within the fabric structure the orange colour of the fabric is observed, while in the +1-oxidation state, the green colour is observed and in the +2-oxidation state, the blue colour. Moreover, migration of ions also leads to the change in oxidation state, thus colour is changed.

Mechanochromism

It basically works on the principle of sensing receptors. Sensing receptors sense the strain applied over the fabric and then change the colour of the fabric. For instance: green colour fabric when stretched alters the colour and finally becomes orange in colour.

Magnetic Field Effect

The colour of the fabric changes in the presence of a magnetic field. For example: if colour of the solution is red and when the magnet is pushed closer to the solution step by step, we can observe the colour changes, and the solution attains the blue colour when the magnet is in close vicinity of the solution.

CHROMIC MATERIALS AND MANUFACTURING TECHNIQUES

Chromic materials are also known as camouflage fibres, because they have the ability to change their colour according to external situations. Chromic materials are used to make the camouflage or colour changing fabrics. These materials are either applied in coating form or incorporated into the polymer structure. Chromic materials are classified on the basis of different external stimuli [13]. These materials are listed below:

- Photochromic: the external stimulus is the light
- Electrochromic: the external stimulus is the electricity
- Thermochromic: the external stimulus is the heat
- Solvatochromic: the external stimulus is a solvent
- Piezochromic: the external stimulus is the pressure
- Carsolchromic: the external stimulus is an electron beam

Photochromic Technique

Photochromism is a phenomenon in which the light as an external stimulus is used to facilitate changes in the molecular structure of a single chemical species without changing the molecular weight and reversibly produce two isomers with different colours (absorption spectra) [14]. This phenomenon is rarely used in textile applications. The main utilization of this technique is in the imaging system.

Photochromic dyes can be classified into two types from the viewpoint of thermal stability namely,

- T-type
- P-type

The general behaviour of P-type and T-type photochromic dyes are depicted in Figure 3.

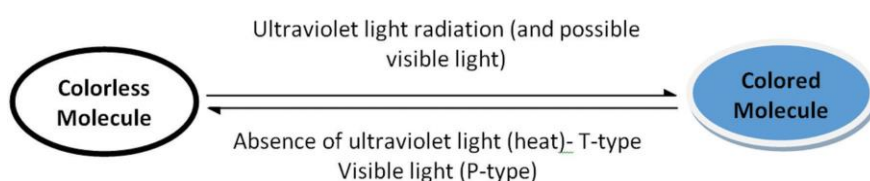


Figure 3. General behaviours of most commercial T-type and P-type photochromic colourants [15]

T-type

For the T-type dyes, the conversion process is driven by heat. The back reaction is caused thermally, although for commercial photochromic classes, visible light may also contribute. The rate of thermal fading is often expressed as "half-life" which is the time taken for absorbance to halve, once the activating light has been removed. For ophthalmic utility, a short half-life is desirable to stop vision being impaired when there is a sudden drop in light intensity [16]. Azobenzene, spirooxazines, naphthopyrans and spiropyran are the families of dyes that have had the greatest commercial and industrial importance. Such types of dyes are used in nail varnishes, which acquire colour in the sun, as well as in various other cosmetics and personal care products. This type of dye is used as a functional material, for example, in anti-counterfeit marking

on bank notes, security printing such as passports where light responsive marks are marked as indicators of genuineness. Arresting photochromic effects can also be developed by incorporation of dyes into thermoplastics materials. Spirooxazines and naphthopyrans are used in mass colouration of polyethylene and polypropylene that have relatively low glass transition temperatures with flexible chains. That gives striking colour changes at inclusion levels of 0.3%w/w and less. Screen printing microencapsulated colourant is the most effective method of applying photochromic dyes because typical high crystalline polymers, such as polyester, hinder photochromism, while exhaustion dyeing technique tends to damage dyes. Photochromic effect can be incorporated to garments through the use of polypropylene thread that has been melt-spun with photochromic dye [14-16]. The general lack of robustness of T-type photochromic dyes prevents it from being used in particularly demanding applications where controlled switching between one or more states (coloured and/or colourless) is demanded [17].

P-type

For the P-type photochromic dyes, the process is driven by light irradiation and is not affected by the heat, remaining so until switched back by other wavelengths. A significant research both in academia and industry has been done in P-type photochromic dyes because of their potential as molecular switches [18]. However, much time, effort and money has been spent on developing P-type applications, yet it cannot be really commercially viable. Diarylethenes and fulgides are the families of dyes that have been investigated most in this connection. Fulgides are used in conventional colouration areas such as textiles and printing inks [19]. Diarylethenes offer a wide opportunity for the design of molecules whose optical characteristics can be switched in a controlled manner between persistent states. Great efforts have been made in P-type photochromic systems which stems from their potential use as functional colourants within the fields of optoelectronics, data storage, and nanotechnology [14]. Nanotechnology is a novel avenue because of its solid phase photochromism. In this context crystals of dihetarylethenes experience changes in shape, as well as colour, which results in molecular geometry variation during photochromic transitions. Such variation in particle dimensions forms the basis for light-driven actuators in nanomachinery. Molecules that switch optically are also utilized in the field of information technology because they could deliver memory systems with higher densities than those of current available commercial devices [19-20].

Thermochromic Technique

The word thermochromic is the combination of two words: thermos and chromic, where thermos means heat and chromic means colour change. When the chromic materials change colour due to the application of heat such type of fabrics are called thermochromic fabrics [21]. This phenomenon is referred to as thermochromism. For example, if we heat an iron bar in a furnace then it changes colour gradually from its black colour to red and then finally to yellow colour. This is because, as heat is supplied, atoms get excited and move to a higher state and then, to attain the stable state again, they emit light and thus it appears as if the colour is changed [22].

Nowadays, lens used on a sunny day provide protection to eyes but when exposed to cold weather they act as ski-goggles. Moreover, thermochromic prints are also used on the fabric, which changes colour when heat or temperature is changed.

The printed colour pattern (classic green and brown camouflage) mimics jungle motif design which transforms to desert colour motif on application of heat from external sources. Since thermochromic systems involve intramolecular transformations, it means that a large amount of energy is required to change the

colour. Thermochromic (TC) glazing (Pleotint, Ravenbrick, Solarsmart, etc.) can automatically modify its optical characteristics with respect to the external surface temperature, which governs a solar smart-phase transition or chemical reaction between two different states. The material looks transparent when the temperature is lower than the transition value and looks opaque at higher temperatures. The transition temperature range remains between 10 °C (maximum transparency) and 65 °C (minimum transparency). A wide range of organic and inorganic compounds in films of metal oxides, such as vanadium oxide, show the characteristics of thermochromism. These chromic materials are applied in two ways: [23-24]

- By using the leucodyes
- By using liquid crystal substances called cholesteric or chiral nematic systems. In this system the molecules form helices.

In both the cases the dyes are entrapped in microcapsules and are applied to the fabric like pigment in resin binder. Molecular rearrangements are done to change the colour of the fabric when the arrangement of the molecules is altered (e.g. spiro lactone).



Figure 4. (a) Hyper colour shirt, (b-c) Thermochromism principle [23-26]

Using leucodyes

These are organic carbon-based dyes or chemicals. As the leuco form changes to non-leuco form, its reflection and absorption rate changes. Thus, different colours are observed. Leucodyes can be used in thermal computer printed paper and in hyper colour T-shirts which change colour on touch. Leucodyes are simply applied with any of the printing method, generally with the screen-printing [22].

Using liquid crystals

Liquid crystals are not purely solid but somewhat in liquid state. This phase is also called as nematic or smectic phase because molecules are roughly arranged. These are spherical capsules of smaller diameter than that of hair. There are two methods in which we can apply liquid crystals which are as follows:

1. By using liquid crystal capsules which can be incorporated into fibres by spinning technique. As they are locked into polymer fibres, fabric will not lose the colour on washing.
2. By coating the liquid crystal capsule over the fabric, which can be done either by direct spraying or by printing over the fabric. When the nematic material is presented against a black background its impact gets maximized. An example is the fabric used in medicine to detect arteries and veins – such type of fabric is prepared by spraying the capsules over the black bandage [22, 28-29].

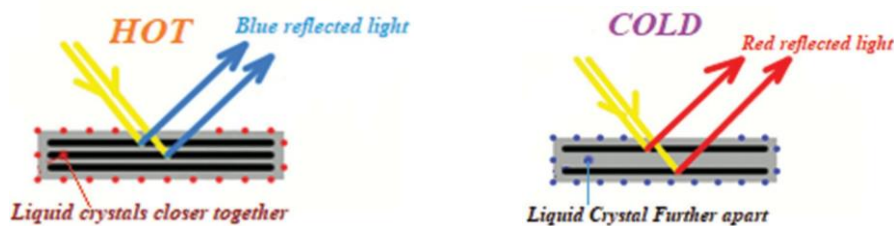


Figure 5. Effect of distance between liquid crystals layer on colour [29-31]

The effect of distance between liquid crystal layer is shown in Figure 5. The different medium has different reflection of light. It is observed from the Figure 5 that if one liquid crystal is used then there is narrow temperature range, but if we use multiple crystals the temperature range can be widened. The colour which is reflected by liquid crystal depends on the closeness of the crystals together.

Electrochromic Technique

When chromic materials change colour of the fabric due to the application of electricity or voltage such type of fabrics are called electrochromic fabrics [26]. This phenomenon is referred to as electrochromism. Electrochromism may also be defined as when a material is electrochemically oxidized, the reversible change in optical properties occurs. The colour change between a transparent or bleached state and coloured state or between two coloured states is thus displayed by such type of materials. However, the working definition of electrochromism has now been extended to include devices for modulation of radiation so that 'colour' means response not only by the human eye but also by the detectors at different wavelengths like near infrared, thermal infrared and microwave radiation. Electrochromic principle is used in glass windows of buildings, for anti-glare car windows, for sun-roof and rear vision mirrors [26-27].

There are three types of materials:

- Type1 - materials which in both oxidized and reduced form are soluble in electrolyte solution like 1,1-dimethyl-4,4'-bipyridinium.
- Type2 - these materials will form the solid film on the surface of the electrode like 1,1-diheptyl-4,4'-bipyridinium dictation in water.
- Type3 - these types of materials are in solid form in both oxidized as well as in reduced state like metal oxides and Prussian blue.

To make electrochromic devices, a seven-layer electrochemical cell with a rigid sandwich structure is formed. There are two conducting layers sandwiched between the two-substrate layer. Colour changes when there is charging and discharging of the electrochemical cells with a potential of 1-5 V. Five layer and four-layer electrochemical cells are also formed nowadays. To make the four-layer ECD:

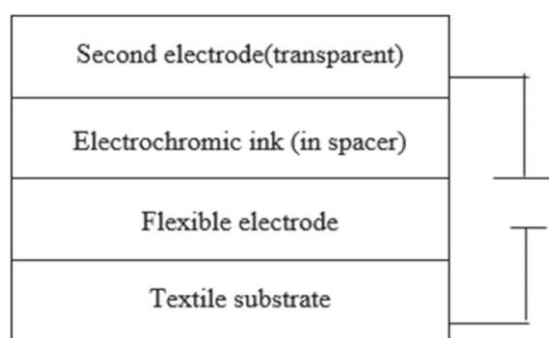


Figure 6. Basic design of 4-layer ECD

The first layer of the device is comprised of polyurethane coated polyester fabric, the conductive layer used is carbon black or silver, the electrochromic compound used is Prussian blue dispersed within a spacer fabric, the second electrode may be PET/ITO and the final layer is transparent, so that colour change may be easily detected. Nowadays, Prussian blue is being replaced by solid organic conducting polymers. As the charging and discharging occurs, the colour change is observed in the transparent layer of the ECD.

Solvatochromic Technique

When the colour of the material changes by changing the type of the solvent i.e. when using different solvents leads to different colours, such type of fabric is called solvatochromic fabric. This phenomenon is referred to as solvatochromism [31-32]. This occurs because different types of solvents have different effect on the ground state and the excited state of the electrons of the molecules in the fabric, so the size of the energy gap between them changes as the solvent changes. These materials show negative (hypsochromic) and positive (bathochromic) shifts.

Negative:

It is also referred to as the hypsochromic or the blue shift. The colour of the fabric changes to blue colour as the polarity of the solvent increases. An example of that is 4-(4-hydroxystyryl)-N-methylpyridinium iodide, which is red in 1-propanol, orange in methanol and yellow in water.

Positive:

It is also referred to as the bathochromic or the red shift. The colour of the fabric changes to red colour as the polarity of the solvent increases. An example of that is 4,4-bis(dimethylamino)fuchson, which is orange in toluene and red in acetone [32].

DEVELOPMENT OF CAMOUFLAGE COLOURS AND PATTERNS ON TEXTILE MATERIAL

Camouflage has been used for ages in the animal kingdom, as well as by humankind, to assist with hunting activities, as well as to assist in survival. The main purpose of the development of camouflage patterns and colours on textile material is to change the properties of a potential target so that it cannot be recognized, or to distinguish possible targets as those of your own and the opposite of your own, or identify the corporate image for a person or the equipment [33]. There are mainly two methods for developing camouflage colours and pattern on the textile material. One is blending, in which colours and patterns are used in such manner that they can blend with the nature. Disruptive pattern material (DPM) is the well-known example for a blended camouflage pattern used by the armed forces worldwide. Another method is disruption, in which the patterning is employed in such a manner that the observer's attention would not put emphasis on the shape of an object so as to reduce the probability of detection. Dye-sublimation heat transfer printing, fabrics inkjet printer and screen-printing process are common printing methods to produce camouflage patterns on fabric samples. Various researchers have been developing the camouflage pattern for the visible and the near-infrared radiation spectra on different fabric materials. Mehrizi et al. (2012) studied the effect of carbon black nanoparticles on the reflective behaviour of printed cotton/nylon fabrics in the visible/near-infrared regions [34]. The presence of carbon nanoparticles was found to cause significant decline in the near-infrared (NIR) reflectance of samples. Also, Mehrizi et al. used multi-walled carbon nanotube particles in the printing paste in order to simulate the desert and found considerable decline in the near-infrared

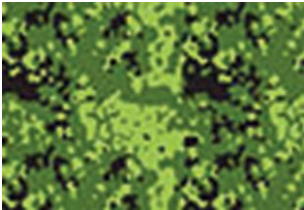
(NIR) reflectance along with an increase in the visible reflectance of the samples. A significant increase in wetting time was also found. Good crocking, washing and light fastness were found for all the samples [34]. Zhang et al. (2008) concluded that the reflectance of dye is affected by the constitution of dyes in the visible and the NIR region and dyed fabrics imitated the reflectance profile of the greenish leaf based on the NIR camouflage theory [35].

APPLICATIONS OF CAMOUFLAGE FABRICS

Camouflage finds its application mainly in the defence sector and a small proportion in various other sectors like in fashionable clothing industry, for decorative purpose etc. Camouflage uses in different sectors are briefly described below:

- In apparel grade: camouflage fabrics have existed for more than 75 years and have become very popular since 1990, after the operation Desert Storm in the Middle East by US Forces with NATO Alliances. Today most of the armed forces, including army, navy, air force and paramilitary forces, are using camouflage fabrics, as the fabric increased the safety factor for an individual soldier and the nature of the fabric improved the comfort level and the roughness. It is anticipated that total worldwide requirement of camouflage fabrics is more than 350 million meters annually. Approximately 35 million soldiers worldwide are using camouflage fabrics, which includes army, air force, navy, marines, coastal guards, paramilitary forces etc. [36].

In different countries different types of camouflage fabrics are used. The various fabrics along with their users are described in Figure 7.

Digital camouflage (Canada) 	Tigerstripe (US Air Force) 	Digital camouflage (US Navy) 
Flecktarn (Denmark) 	Puzzle (Belgium) 	Lizard (France) 
Woodland (disruptive pattern camouflage) (Australia) 	Woodland (desert camouflage pattern) (Thailand) 	Flecktarn (for desert and semi-arid regions) (Germany) 

Woodland (Afghan army) 	Splinter (Sweden) 	Digital (M05) (Finland) 
Woodland (Poland) 	Woodland (Poland) 	Moro (Poland) 

Figure 7. Camouflage fabric associated with the user country [32, 38, 42]

- In decoration: e.g. the great fancy dress ball given by Chelsea Arts Club at the Albert Hall was based on the motion dazzle principle.
- Ships and aircrafts: ships are painted on the principle of motion dazzle camouflage or simply with camouflage pattern so that it might become difficult for the enemy to spot them. This principle was mainly used in the Second World War when painting the ships. Figure 8 shows the motion dazzle of a ship and an aircraft.



Figure 8. (a) Ship with motion dazzle principle (b) Aircraft with disruptive colouration [36-37]

- Land vehicles: Camouflage principle is used to disrupt the shape of the vehicle so that they may not get identified easily. The British army adopted a disruptive scheme for vehicles operating in the stony desert of the North African Campaign. Figure 9 shows the camouflage effect of vehicles in different geographical areas.



Figure 9. (a) Vehicle for desert area with stony desert pattern (b) Vehicle with stripe pattern [37-38]

- Electrochromic materials are used in glass windows of buildings, for anti-glare car windows, for sun-roof and rear-vision mirrors. Thermochromic prints are also used on the fabric which changes colour when heat or temperature is changed. Figure 10 shows the colour change due to thermochromic print highlighting the floral print on white background by changing from the black colour when heat is supplied.



Figure 10. Colour change due to thermochromic print highlighting floral print on white background by changing from black colour when heat is supplied [22]

EVALUATION OF CAMOUFLAGE FABRIC SAMPLES:

Performance of camouflage patterns on the fabric can be evaluated with the help of probability of detection (POD) and pairwise comparison methods. These techniques are described below.

Probability of detection

The probability of detection (POD) evaluation technique is mostly used for camouflage evaluation in a laboratory. In POD evaluation technique, firstly a number of observers at a time are observing at a number of targets at different locations. A predetermined path is used by the observer and the distances at which he sees the targets are noted [39]. The second version of this technique, the observer remains stationary at a specific location while the target moves closer. The third version is to photograph the object at different distances; the photographs are then shown to observers on a screen [40]. The probability of the detection of the target is determined by statistical methods. The North Atlantic Treaty Organization (NATO) has formulated an extensive guideline regarding the POD evaluation technique for camouflage evaluation [41]. The results can be predicted in graphical form in which distance from target lies on the x-axis and the probability of detection on the y-axis.

Pairwise comparison methods

The law of comparative judgment (LCJ) is the first pairwise comparison method for camouflage evaluation. It is a psychophysical tool for performance evaluation, developed by Thurstone and described by Torgerson (1958) in which different patterns are observed two at a time by a panel of people, and, with the help of statistical method patterns, ranked in terms of visible effectiveness [42-43]. The second pairwise comparison method is known as analytical hierarchy process (AHP). This method gives clear outcome in terms of how much more one pattern is visible in comparison to the other. The benefit of using these psychophysical methods, LCJ and AHP, is that a large number of people is not required for accurate and statistically significant outcome, as is for the POD evaluation method [44].

RECENT DEVELOPMENT AND FUTURE TRENDS

Today camouflage is playing a passive role in the requirement of concealment and deception. Nanotechnology is playing a major role in the future development of camouflage systems on the fabric. Modern technology gives the capability to scientists, engineers and researchers to modify the properties of substrates and surfaces at the molecular level, thereby having the advantage of exploiting (and controlling) certain characteristics of materials and surfaces. Significant research has been contributed to textiles with electrochromic properties for colour change through electric stimulation. Wheaton et al. (2010) gave the concept of using an electrochromic process to change colour panels. The colour of plastic/textile hybrid panels can be changed from yellow to green [45]. It is also investigated that specular reflections are still a problem. Wearable flexible displays are also proposed as an alternative for active camouflage (cloaking) on the textile material. A special material known as metamaterial with special properties is developed by Duke University. These materials are able to 'bend' electromagnetic energy around the target in such a manner that the target will be physically present but would not appear to be there. Thermochromic pigments can change colour depending on the temperature of the textile material. Heated panels are being made for camouflage pattern and colours. New developments in thermochromic pigments/dyes have been made stable enough to be used in commercial and consumer markets.

Earlier camouflage fabrics were made solely from heavy cotton twill. This heavy fabric can be quite durable, but it is also hot to wear and becomes heavier when wet. After this, the fabrics were prepared from synthetic fibres, but they were unable to absorb sweat. Moreover, pure synthetics are shiny and reflect infrared light. The more effective solution was blending cotton and synthetic fibre which resulted in stronger fabric without increasing weight. Nylon and cotton blends became increasingly common in military uniforms.

Nowadays, knitted polyester scrim composition provides increased tensile and tear strength. Moreover, the fabric is flexible and used for all kinds of application like uniforms, tents, helmets, straps to carry weapons etc. The recent development in camouflage fabric is nature-raised fabric which is used for special hunting purpose. This is a special type of fabric which has a different procedure and special properties, such as special textures which refract the light, thus breaking up reflection and stopping the glare or the shine. These types of fabrics are prepared through eight layers and procedures, each of which has a special function and finally makes it suitable for the hunting purpose. The fabric is comprised of natural shapes from nature [45-46]. Active camouflage and multispectral universal camouflage are the area of recent trends on the camouflage fabrics. A system that changes the colour or patterns to match the environment in real time is known as active camouflage. Best example of such research are retroreflective objects which appear transparent. The traditional approach to camouflage design is a semi-random placement of colour and shape to disrupt the target's true shape, or camouflage patterns that were attempting to mimic natural camouflage to hide an object in the visible spectrum; in both cases these designs actually go too far in random patterns or specific mimicry to provide a better camouflage. Multi-spectral camouflage is being used as a counter-surveillance technique to conceal objects from detection across several parts of the electromagnetic spectrum at the same time. Multi-spectral camouflage also tries to simultaneously hide objects from detection methods such as infrared, radar, and millimetre-wave radar imaging. The emergence of new infrared camouflage and countermeasure technologies in the context of military operations have paved the way to enhanced detection capabilities. Camouflage devices such as candles (or smoke bombs) and flares are developed to generate either large area or localized screens with very high absorption in the infrared spectrum.

CONCLUSION

The principles of camouflage are growing at a fast rate and increasing day by day. The main users of camouflage fabrics are hunters, including game watchers, and the military. Most of the studies focus on the positive aspects of camouflage in the defence sector. But at the same time, if the enemy uses camouflage fabric, it might become difficult for us to spot the enemy. The camouflage fabric creates an illusion for the observer and as a result the camouflaged object becomes blurred or unrecognizable. Furthermore, the cost of the camouflage fabric is higher than the normal grade fabric but if the production of camouflage fabric increases then the cost might decrease. The principles of camouflage are also used for decoration purposes which results in value addition.

Researchers are focusing on developing camouflage for known challenges, but as modern warfare dictates, textile manufacturers and researchers must now plan for the unknowable challenges.

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