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Impact Of Photochromic Dyes On Colour-Changing Apparel

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ABSTRACT

The Journey starts with fibres and filaments, then yarns, and so on, and ends with finished garments entering the worldwide market. Back then, solar energy itself provided us with the benefits of vitamin D, improved immunity, strengthened bones, reduced high blood pressure, etc. Nowadays, too much UV radiation affects our bodies, so to protect our bodies from ultraviolet exposure, we started wearing clothes to protect our skin. Currently, to reduce apparel waste, we come up with the methods of mass-colourations and silica sol-gel coatings on photochromic pigments using a colourimeter, the usage of a spectrophotometer for spectral measurements, and colour intensity on cotton fabrics under UV irradiations. Tests are repeatedly making progress day by day to make a way for the production of colour-changing products such as dresses, T-shirts, curtains, accessories, *etc*. by the aid of screen printing, digital printing, *etc*., and also to be used as a danger indicator in place of protective textiles such as firefighters, nuclear technicians, *etc*. To conclude, by reducing the amount of usage of clothing that probably ends up in landfills, it is better to wear colour-changing natural cotton clothing instead of synthetic clothing under UV rays. Over the decades, this colour-changing apparel has assisted in the development of advanced textiles that respond to environmental changes, thus going to be a huge blow to the near-future trends in the fashion market. To summarize, it is preferable to wear colour-changing natural cotton clothes rather than synthetic clothing under UV radiation to reduce the amount of clothing used, which will most likely end up in trash. A decade from now, these colour-changing clothes will be a major blow to near-future fashion trends offering innovative possibilities for fashion and functional clothing.

KEYWORDS: UV radiation, mass-colourations, photochromic, colourimeter, intensity, protective, and market.

INTRODUCTION

In our daily lives, apparel keeps changing in our fast-moving fashion as our global solar radiation keeps changing. Apparel is another term for clothing or garments, includes types such as shirts, jackets, pants, dresses, and so on. Simply put, apparel is always in demand from Apparel and textile fashion industries. Apparels are made purely from a bunch of fibres then converted into yarns (staple and filament fibres), later made spool of yarns into a fabric and lastly, turn out as finished clothing garments for consumers that is ready for marketing purposes. Conserving nature for our future generation is easier said than done. The power per unit area that the sun provides in the wavelength range of the measuring device is known as solar irradiance. Solar radiation serves as the main energy source for most of the activities that occur in the atmosphere, hydrosphere, and biosphere.

The sun emits several distinct sorts of radiation. The Sun's optical spectrum emits rays consisting of infrared (IR), visible, and ultraviolet (UV) with a range of wavelengths starting from 200 nm and ending up at 1 mm (Dupont, E.; Gomez, J.; Bilodeau, D, 2013). However, UV radiation can be considered the most detrimental component of the solar spectrum (Ravanat, J.; Douki, T.; Cadet, J., 2001). The Negative effects of UV exposure can include skin redness, erythema, skin cell destruction, and even skin cancer (Serrano et al., 2013). The sun's harmful rays mostly damage the outer protective layer of our bodies' "skin," known as ultraviolet (UV) radiation. Since ultraviolet (UV) radiation is primarily categorized by wavelength, they may be divided into three sections, classified as UV-C, UV-B, and UV-A, according to their energy and wavelength.

Overall, UV radiation, including UV-A, UV-B, and UV-C rays, has both beneficial and harmful effects on living organisms, depending on the level of exposure and the specific wavelengths involved. Protection against UV radiation is important to prevent skin damage, premature ageing, and the development of skin cancer. A 1% decline in ozone would result in increased solar UVR at the earth's surface, possibly leading to a 2.3% rise in skin cancer rates. Our skin is shielded from different UV rays levels by garment colours. Simply put, various colours absorb sunlight at different levels of intensity. Consequently, the strength of UV radiation that will pass through the fabric and penetrate through the skin is influenced by the colour of the cloth. Wearing clothing helps shield us from the UV radiation that comes with sunlight, which is harmful to our health.

In the apparel and textile fashion industries, typically under UV light, the photochromic plays a crucial role because these materials allow structural change in the molecules, leading to a reversible alteration in their optical properties, such as colour. This change occurs without the emission of UV rays from the material itself. The absorption of UV light by the photochromic molecules triggers the photochemical reaction responsible for the colour change, but UV radiation is not emitted because of this process. Future trends in colour-changing clothing may have the chance to be influenced by the ability of solar radiation to cause electromagnetically generated radiation, or UV rays, to change the colour of apparel. " There is no need for a reversible dress where there is a way to change into colourful attire the minute you wear it".

METHODS USED

1) MASS COLORATION OF miPP FILAMENT

miPP or polypropylene filaments are produced using metallocene catalysts which are a type of catalyst used in polymerization reactions to produce polymers with specific properties, such as improved strength, clarity, and thermal stability. The technologies were applied for the creation of photochromic textile materials. This involves bulk colouring polypropylene multifilament with colorimeter-assisted mass colouring methods. This colourimeter measures the amount of light that a substance absorbs or transmits at specific wavelengths to determine its colour. In this case, Lyondell Basell of Italy offered the Metallocene catalysts isotactic polypropylene (miPP) and they were produced with different concentrations of photochromic pigments to develop ultraviolet (UV) sensing materials.

Two types of miPP filaments, irrespective of pigment, were made using dried miPP chips under standard operating conditions only the manufacturer may specify. To create coloured filaments, 100% coloured miPP was first made into a ribbon\tape form. Combining photochromic pigments with dried chips of uncoloured miPP is done before the miPP begins to melt. Lastly, the coloured tapes are extruded, immediately run through a water bath then dried to create chips. To create coloured photochromic filaments, the air-dried coloured chips were vacuum-dried for 2 hours at 105°C. Later, they were combined with coloured chips at 4 different concentrations (0.55, 0.50, 1.50, and 2.50 of the chips (Wt.%)). Melt spinning, a laboratory-scale single-screw melt extruder with a 16mm diameter, 30 L/D ratio, and 2.66 $g.min^{-1}$ Melt Flow Index (MFI) was used for producing the filaments. Depending on the filament's shape after traversing the various cross sections, filaments were winded on grey cardboard with consistent tension and enough thickness, a vital step in the post-spinning process without the use of fluorescing chemical agents. As a result, 6 filament layers may be winded on the cardboard.

Instrument Used: The Colour strength (K\S) values of both exposure and reversion phases based on time and wavelength are used for the test.

2) SILICA SOL-GEL SYNTHESIS AND COATING ON PET FABRICS

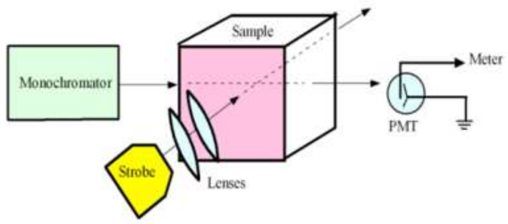
The second techniques were used to develop photochromic textiles is sol-gel coating, Therefore, Pre-treated, 100 % PET plain structured fabric was used for this study. PET fabric refers to fabric made from PET (polyethylene terephthalate) fibres. PET is a type of polyester that is commonly used in textiles due to its durability, wrinkle resistance, and moisture-wicking properties. Triacetoxyvinyl-precursor (TAS); Octyltriethoxyprecursor (OTES); Phenyltriethoxyprecursor(PhTES); aminopropyltriethoxy precursor (APS) and MPP (photochromic pigment). All the chemicals were purchased from Sigma-Aldrich, USA. Deionized water was used for the preparation of sol solutions (Aravin Prince Periyasamy, 2018). To guarantee adequate mixing, the MPP was added slowly to the prepared solution. Once mixed, the mixture is stirred to obtain a clear solution. After being dipped into the solution, 2 PET fabric pieces measuring 30 x 12 cm were removed vertically at a consistent pace of around 10 mm per sec^{-1}. After being let to dry naturally, the materials were treated for 10min at 110°C Celsius. Prior to measuring, the coated fabric was exposed to the atmosphere for a duration of 24 to 48 hours to guarantee total stabilization of the silica metrics continued by two washings in accordance with the regular washing method. As a result, the photochromic sol-gel fabric coated with APS precursor and with OTES precursor their effects shown in K\S values and the polarity of precursors affected the absorption spectrum of the coloured form of merocyanine resulting in ~40nm of hypochromic shift.

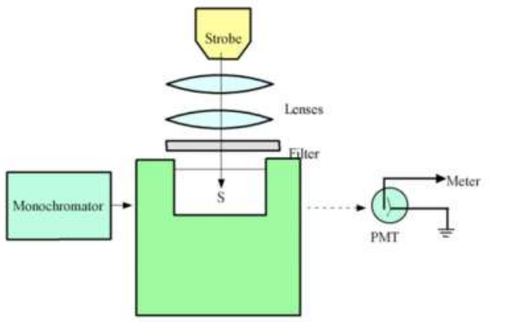
COLORIMETRIC MEASUREMENT OF PHOTOCHROMIC MATERIALS

This helps to deal with the measurement of photochromic surfaces and its problems that includes the intensity control and spectrum distribution of light sources, temperature, and exposure frequency respectively**.**

Spectral measurement: This is related to photochromic textiles, particularly in assessing and characterizing their colour-changing properties which involves the analysis of light across different wavelengths of the electromagnetic spectrum, typically in the visible range (400 to 700 nanometres) where human vision is most sensitive.

Instruments Used: Lateral illumination and axial illumination samples (S), PMT (Photomultiplier tube), Strobe, Lenses (L), Neutral density filter (F), Aluminium block, and Thermocouple are used to find the required results**.**





a) Lateral exposure **b) Axial exposure**

Since the sample in the cuvette is not turbid, the (PMT) tracks the amount of monochromatic light enters the (S). Before touches the sample, a flash from the strobe source is focussed by (L) and decreased by the (F). The sample is kept inside an aluminium bloc that allows water to circulate at a certain temperature. The thermocouple is used to monitor the sample's temperature directly. The analytical spectrophotometer is a useful tool in this process. A spectrophotometer allows for the measuring colour surfaces is as simple as adapting a Praying-Mantis accessory, that also allows for the measurement of photochromic surfaces by adding an irradiation light source. Using with textured surfaces, it is vital to use hemispherical illumination adaptation in the integrating sphere to include extra apertures for irradiation. This spectrophotometer system allows for the study of colour photochromic kinetics, the influence of exposure time, and heat sensitivity. The spectrophotometer's dual light source construction, that includes a shutter over the exciting light source, allows for continuous monitoring of photochromic colour change during reversion. If the halftime of the colour change is less than 500ms, such system with a pulsed discharge light can be utilized to assess the fatigue of a photochromic system. It is obvious to use an electronic shutter and continuous discharge light for fatigue testing of textile samples, which are frequently the slowest.

PROPERTIES OF PHOTOCHROMIC TEXTILES

Photochromism is a chemical process in which a compound undergoes a reversible change between two states having separate absorption spectra, i.e. different colour (P. Bamfield, 2001). When photochromic materials are exposed to light, especially ultraviolet (UV) radiation, their molecular structure undergoes a reversible transformation, resulting in a change in optical properties such as colour.

With exaggeration, in a photochromic system, when a fabric is exposed to UV rays (sunlight), the photochromic molecules themselves undergo reactions (allowing for the creation of dynamic colour-changing effects) that involve changes in structure, including unimolecular structure or bimolecular processes entirely depending on the specific characteristics and conditions of the fabric. Besides, those reaction mechanisms are initiated by the absorption of photons, which are packets of electromagnetic energy. When a photochromic molecule absorbs a photon (2 photons reacting with each other) of the appropriate energy, it enters an excited state (here takes place the excitation\ activation\ response time and relaxation\ reversion\ recovery time), triggering a series of changes in its molecular structure that lead to the reversible colour change. As a result, to make photochromic pigments, mixtures containing photochromic molecules are dispersed in a carrier material, such as a polymer matrix or solvent. These pigments are designed for use in various applications, including inks, coatings, plastics, textiles, and ceramics.

There are many conformational changes that can take place in the excitation process, which lead to changes in electronic absorption spectra, resulting in a visible colour change. If the changes are thermally reversible, after removal of the irradiation, which activates the changes, the system return to the state before irradiation and the induced absorption or colour spontaneously disappears. This was previously referred to as phototropism (Brown, G.H. 1971), and now more correctly as photochromism. Two chemical species showing a reversible transformation differ from one another not only in their absorption spectra but also in their physical and chemical properties.

Photochromic textiles possess several unique properties that make them distinct from regular textiles, some key properties of photochromic textiles:

- colour changing ability,
- reversibility
- durability
- customization options
- versatility
- innovative design potential

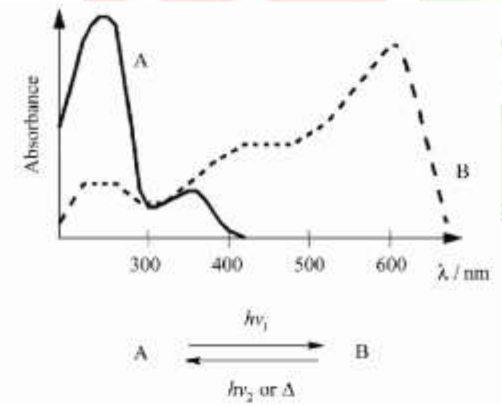
make them an exciting and promising material for various applications in the textile industry.

The major impact is to find the different drawing ratio on physical, mechanical, and optical properties of mass coloured photochromic polypropylene filament and the impact of the precursor on optical and physical properties of sol-gel photochromic coated fabrics can be used on cotton fabrics as well, although the processes and materials involved may vary from one another are as follows:

APPLICATIONS OF PHOTOCHROMIC

1) Test Reactions in Photochromic Textiles
2) Colour Surfaces Test in Photochromic System Measurement
3) Photochromic Dyes and Fluorescence Dyes Tests in Textile Industries.

1) TEST REACTIONS IN PHOTOCHROMIC TEXTILES



In Unimolecular reaction:

'A' specie (colourless or pale-yellow colour) is thermodynamically stable form then is transferred by irradiation to form a 'B' specie (yellow, red, violet, green or blue colour). This phenomenon is referred as positive photochromism.

In Bimolecular reaction:

When **λmax(A) > λmax(B),** Here, it is involving photocycloaddition reaction such that wavelength A max is greater than wavelength B max as a result, photochromism is negative or inverse. In general, the photochromic processes involve a one- photon mechanism (G. H. Brown, (Ed.), 1971 and A. V. El'tsov, Ed., 1990). The excited states of singlet (1A*), triplet (3A*), or both combine to generate B. Two photons absorbed can populate an upper excited state, which can also form B, the photoproduct.

End-Uses

- Developing a simple textile sensor which is sensitive to UV light and kinetic study of behaviour and using the technology of textile printing **by screen printing (PTP) using 5 photochromic pigments** to see the colour changes happens faster on apparel solely when the chemical structure of photochromic pigments is reacting at higher concentration level then recovers to the original colour.

- **In photochromic textiles, the preparation of a sensorial system can be used allowing the simple visual estimation of UV radiation amount.** (For example, a **simple rule scale** is designed by this system, where for comparison, there is a constant-colored part made from UV stable pigments or dyestuffs. Individual parts of the constant scale can be judged on having the same colour as the photochromic part at a specific UV radiation intensity. The observer will be able to estimate the UV radiation amount depends on a colour match between the photochromic colour changeable part and visual stable part of the textile UV sensor.

2) COLOUR SURFACES TEST IN PHOTOCHROMIC SYSTEM MEASUREMENT

In Shade intensity description, major present and future research is focused on the development of smart sensors with photochromic pigments, that may react under UV irradiation, it is crucial to offer an objective description of visual colour change for calibration purposes. The Kubelka – Munk function bases one possible solution on the spectrophotometric description of colour appearance (McDonald 1997).

In photochromic pigments, changes in spectral characteristics before and after illumination they may be expressed by integral equation (1):

$$I = \int_{380}^{760} (K/S)_{\lambda} d\lambda$$

where I is the shade intensity; K/S is the Kubelka-Munk function; λ is the wavelength. In practice it is derived by integration using equation (1) expressed by the sum and the equation resulting to form (2):

$$I = \sum_{i=380}^{780} (K/S)_{i} \Delta\lambda$$

Δλ depends on the band pass of spectrophotometer. In photochromic substances, I depend on both time and intensity of illumination respectively.

The intensity of UV amount in spectrum is responsible for creation of colour effect and also shade intensity.

End-Uses

Photochromic materials are used most widely in ophthalmic sun-screening applications and also find applications in security printing, optical recording and switching, solar energy storage, nonlinear optics and biological systems (Crano & Guglielmetti 1999). The existing ranges of commercial products generally undergo positive photochromism, a light-induced transition from colourless to coloured due to a ring-opening reaction.

For spectral sensitivity tests, a special arrangement of the measuring system developed was used, which allowed the selection of variables bandwidth and dominant wavelength. Many photochromic substances are sensitive to dominant wavelength in spectrum evocating coloration (selective absorption) (Martina Viková and Michal Vik, 2016). In addition, the duration of the excitation and relaxation of the photochromic effect is significant and influences the colour of the materials used to make photochromic dyes for textile printing.

3) PHOTOCHROMIC DYES AND FLUORESCENCE DYES TESTS IN TEXTILE INDUSTRIES

Photochromic Dyes

- Photochromatic dyes are less common and do not work well with natural fibres, but they polymerize with synthetic fibres with ease. These dyes are impacted by UV radiation in addition to ongoing exposure to bleaching, detergents, and washing.
- Microencapsulation is a technique by which the photochromes are placed into a capsule-like carrier and then applied to the textile. Among various methods dyeing and printing are common (S. Aishwariya, 2018**)**.

Photochromatic Screen Printing

The screen's pore size ranges from 230 to 305. Sharp edge durometer squeeze is employed, and drying takes place at 310 to 320 degrees Fahrenheit for 30 to 90 seconds. Moreover, UV stabilizers were occasionally utilized on the test T-shirt.

Designs may be included into the primary design to provide subliminal messages or a logo with colour changes that only occur outdoors. Camouflage is a textile material that is bio-mimic from nature. It is made with chameleons from nature, as its colour changing capacity as inspiration. These dyes also used in footwear, furniture's, interior designing, security devices and packaging industry. They are used in hang bad, cap, knap sack, doll, night wear that is white during the night and other shades during the daytime (S. Aishwariya, 2018). These dyes are also utilized to signal danger and notify other members in case of protective clothing.

End-Uses

Therefore, photochromatic textured yarns are fashionable in California, while UV light-reactive curtains are becoming increasingly popular in Sweden. Solar inks are one of the leading manufacturers of textile applications, including smart textiles, home textiles, sports textiles, medical textiles, and geotextiles—where temperature variation is a crucial observational parameter.

Fluorescence Dyes

A natural compound called Flavin mononucleotide (bio-based flavin) often known as FMN, which has intrinsic fluorescence characteristics, also is a biomolecule that acts as a cofactor in various enzymatic reactions in living organisms, that is derived from vitamin B2 (riboflavin) and plays a crucial role in electron transfer processes in metabolism.

Photoluminescence does not directly alter the colour of the material. Instead, it refers to the emission of light by a material after being activated by an external energy source, such as ultraviolet (UV) or visible light. This emitted light usually has a distinguished colour guided by the energy levels of the material's electronic structure.

However, in some situations, photoluminescence can indirectly contribute to a perceived change in the colour or appearance of the material, particularly when combined with other factors or elements.

Fluorescence is a specific type of photoluminescence characterized by the rapid emission of light from some materials that absorb light at one wavelength (e.g., UV light) and then re-emit light at a longer wavelength (e.g., Visible light). These are functional dyes, and the emission light usually is of a higher wavelength than the absorbed light. (Y. Tang, et al., 2015.) For example, a white fabric containing fluorescent dyes may appear to change colour under UV light as the dyes emit visible light of a different colour.

The development of photochromic and fluorescent textiles using strontium aluminate pigments has been explored (T. A. Khattab, *et al.,* 2018). However, due to recent awareness, environmental concerns, and increasing regulations, many fluorescent dyes have been banned (X. Ye, *et al.,* 2018 A. Bafana, *et al.,* 2011). Hence, an eco-friendly fluorescent dye for textile applications would be necessary.

The connection between fluorescent dyes and FMN lies in their ability to interact with biomolecules and exhibit fluorescence. FMN is known to fluoresce when excited by UV light, emitting a characteristic blue-green fluorescence.

PHOTOCHROMIC AND FLUORESCENT TEXTILE DEVELOPMENT IN DIGITAL PRINTING

Digital printing is mainly an inkjet process with a series of print heads spraying the dye or ink onto the fabric (B. R. Ig and R. U. S. Se, 2011). Fluorescent dyes can be used in both inkjet and chromojet printing processes to create vibrant and eye-catching designs on textiles.

In our current study, FMN was printed on textiles using digital printing techniques such as inkjet and chromojet. The research work focused on the photophysical properties of FMN printed on woven textile materials such as using the help of spectroscopy analysis was cotton duck white woven (CD), mercerized cotton woven (MC)purchased from Whaley's (Bradford Ltd.) having textile weight170 gm^{-2} respectively and a 100% plain woven polyester (PET)textile of 160 $^{gm-2}$ provided by FOV Fabrics AB, Sweden.

Ink Preparation

Firstly, for inkjet printing, a 0.1% FMN by weight ink solution was made using 50% glycerol in an aqueous solution containing 0.3% Triton X 100. For chromojet printing, along with glycerol-based (GB), and water-based (WB) formulations utilizing deionized water with 0.1, 0.3, 0.5, 0.8, and 1% FMN by weight were prepared and were qualitatively analysed by observing them under UV light (370nm) in a closed dark chamber. As a result, we achieved the desired circumstances by maintaining and evaluating the viscosity of the ink formulation, allowing us to print FMN on both cotton (CD and MC) and PET (polyethene terephthalate present in polyester) textiles using the inkjet printing technique. Thus, this study indicates the link between printing formulations based on water and glycerol. The results showed that the FMN dye was adsorbed onto the textile fibre surface via hydrogen bonding and van der Waal's force of attraction. The OH group in the cotton substrate can connect with FMN's phosphate group.

Although specific UV and visible irradiated samples had low fluorescence intensity, samples printed with a greater concentration of FMN (0.8 and 1%) still displayed fluorescence effect even after extended UV and visible light irradiation.

Globally, polyester (PET) and cotton are the most produced and consumed textiles (J. W. S. Hearle, 2001.) due to their major industrial applications, hence the photoluminescent effect was studied on both cotton and polyester textile material.

CONCLUSION

As it is all known, photochromic dyes are sensitive to UV light at temperatures over 230°C, where they are extensively used in 3D printing and other applications. By using screen printing techniques with photochromic inks, designers can create custom photochromic clothing with unique colour-changing effects. These garments offer an interactive and dynamic element to fashion, responding to changes in light conditions and providing a visually engaging experience for the wearer. This concept for colour-changing apparel under UV radiation concludes that the cotton and polyester fabric colours affect UV rays' intensity that was transmitted through the fabric since photochromic pigments change colour more successfully in darker clothing on cotton fabrics. Nevertheless, cotton and polyester fabric made from photochromic, and fluorescence dyed fabrics offer a range of advantages, from enhanced visibility and safety to innovative design possibilities. By harnessing the unique properties of these dyes, designers can create garments that are both functional and visually captivating, pushing the boundaries of traditional textiles and fashion. Thus, the Colour changing apparel going to play a significant role in the upcoming near future trends in the fashion industries. These upcoming colour-changing garments will quickly spread throughout the globe and help the society free from dumping waste clothes in landfills as mass-produced products in the fashion industries.

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