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Smart textile framework: Photochromic and fluorescent cellulosic fabric printed by strontium aluminate pigment

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ABSTRACT

Smart clothing can be defined as textiles that respond to a certain stimulus accompanied by a change in their properties. A specific class herein is the photochromic and fluorescent textiles that change color with light. A photochromic and fluorescent cotton fabric based on pigment printing is obtained. Such fabric is prepared by aqueous-based pigment-binder printing formulation containing inorganic pigment phosphor characterized by good photo- and thermal stability. It exhibits optimal excitation wavelength (365 nm) results in color and fluorescence change of the fabric surface. To prepare the transparent pigment-binder composite film, the phosphor pigment must be well-dispersed via physical immobilization without their aggregation. The pigment-binder paste is applied successfully onto cotton fabric using screen printing technique followed by thermal fixation. After screen-printing, a homogenous photochromic film is assembled on a cotton substrate surface, which represents substantial greenish-yellow color development as indicated by CIE Lab color space measurements under ultraviolet light, even at a pigment concentration of 0.08 wt% of the printing paste. The photochromic cotton fabric exhibit three excitation peaks at 272, 325 and 365 nm and three emission peaks at 418, 495 and 520 nm. The fluorescent optical microscope, scanning electron microscope, elemental mapping, energy dispersive X-ray spectroscopy, fluorescence emission and UV/Vis absorption spectroscopic data of the printed cotton fabric are described. The printed fabric showed a reversible and rapid photochromic response during ultra-violet excitation without fatigue. The fastness properties including washing, crocking, perspiration, sublimation/heat, and light are described.

1. Introduction

Smart textiles are usually defined as garments that can sense and react to environmental conditions or external stimuli, such as light, pH, temperature, pressure, solvents of different polarities, mechanical or magnetic effects, chemicals, and electricity (Gashti & Eslami, 2015; Gashti, Ebrahimi, & Pousti, 2015; Gashti, Pakdel, & Alimohammadi, 2016; Parvinzadeh Gashti, 2014). For instance, smart clothes can release medication or moisturizer onto the skin, assist regulate the muscular vibrations during athletic activities, and even release materials able to control body temperature. Smart fabrics can also change their color, lighting up in patterns or even display pictures and video (Gashti & Eslami, 2015; Gashti et al., 2015, 2016; Parvinzadeh Gashti, 2014). Generally, there are three major components that must be present in smart garments including sensing, actuating, and controlling units. Production of smart clothes is generally based on the traditional textile manufacturing technologies, such as weaving, knitting, embroidery, and textiles finishing, coating and laminating. Textiles modifications or finishes, and miniaturized electronic devices can also generate smart garments or electronic textiles (e-textiles) that enable digital components to be embedded in such textiles imparting the ability to communicate, transform, and conduct energy (Gashti & Gashti, 2013; Nooralian, Gashti, & Ebrahimi, 2016; Ojuroye, Torah, Beeby, & Wilde, 2017).

Smart textiles that generate adequate responsiveness are prone to enhance their protective purpose as a consequence of an external stimulus such as pressure (Lee et al., 2015), temperature (Chowdhury, Joshi, & Butola, 2014), UV intensity (Gorjanc et al., 2017), pH (Rosace et al., 2017), or electrical field (Choi & Jiang, 2006). An example of smart textiles could be photochromic textiles that transform their color upon exposure to light (Cheng, Lin, Brady, & Wang, 2008). Photochromism is a photo-induced transformation process between two optical absorption states in which a compound in the solid state or in solution changes color when exposed to light and then reverts back to its original color upon removal of external light stimulus (Kawata & Kawata, 2000). This fascinating color-changing technology has received

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great attention in science to afford a variety of industrial products such as packaging, cosmetics, sunglasses and ophthalmic lenses, optical data storage, memories, optical switches, sensors and displays (Garai, Mallick, & Banerjee, 2016; Kunzelman, Gupta, Crenshaw, Schiraldi, & Weder, 2009). This intensified perceptibility of materials colored with photochromic or fluorescent colorants is an advantage in preparing colored advertisements, road and traffic signs, and information descriptions (Garai et al., 2016). The use of photochromism in textiles can offer innovative opportunities to accomplish smart garments capable of blocking UV radiation, sensing environmental changes, security printing, brand protection, sports clothing, fashion garments, clothing for special services such as fire brigades and the police, fabric-based electronic image displays, security barcodes, sensor systems, solar heat, light management and attractive decorations (Jamshaid & Mishran, 2014; Little & Christie, 2010; Otley, Invernale, & Sotzing, 2013; Qiu, Zhou, Lü, Zhang, & Ma, 2007; Rojas-Hernandez, Rubio-Marcos, Rodriguez, & Fernandez, 2018). Furthermore, photochromic effects can be applied in military clothing to provide camouflage that is responsive to light as an external energy stimulus (Hu, 2008). Stimuli-responsive and active protective garments have the advantages of their easy maintenance including washing and drying, extremely large specific surface and low specific weight with enhanced strength, tensibility and elasticity. Workability without altering the manufacture technology, potential incorporation of these types of sensors into structures of protective garments, in addition to their cost and accessibility, are also considerable advantages. Photochromic fabrics can be produced without compromising their comfort, easy care and hygiene. Therefore, this challenges researchers to develop new photochromic and fluorescent smart textiles (Arkhipova, Panchenko, Fedorov, & Fedorova, 2017; Christie, Morgan, & Islam, 2008; Luo, Tang, Zhu, Xu, & Qian, 2015).

It is possible to classify photochromic fibres into different groups: those which emit the color when activated by visible light and those which emit the color when activated by ultraviolet radiation. Photochromic fibres and/or fabrics made from different substrates (e.g., cotton, polyester, nylon, acrylic, wool, and polyamide) have been produced by different dyeing procedures through the incorporation of photochromic organic molecules, mostly spirooxazine-based colorants. Dyeing of garments using photochromic organic dyes results in a number of problems associated with the dyeing procedure such as dye degradation, limited interaction between dye and fibre matrix due to low dye uptake and decreased dye diffusion into the fibres, total inhibition of photochromism, constraints imposed by the hardness of the matrix, and low washing and light fastness characteristics. Some of these drawbacks can be overcome by processing dyes into pigments using microencapsulation processes; although this methodology tends to increase the stability of the photochromic compounds, it usually confers a certain harshness and stiffness on the fabric, compromising the comfort of the user (di Nunzio, Gentili, Romani, & Favaro, 2008; Fan & Wu, 2017; Fan, Zhang, & Wang, 2015; Feczkó, Samu, Wenzel, Neral, & Voncina, 2013; Peng et al., 2015).

Alternatively, photo-switchable textiles can be produced by simple technique called screen-printing using aqueous binder containing organic photochromic dyes, which prevents the problems related to dyeing and eventual incompatibility between the colorant and the substrate. The aqueous-based pigment-binder screen-printing method is a simple and cost-effective technique that can be processed to develop printing matrices, which are excellent hosts for both of organic and inorganic pigments. Pigment printing is not only the oldest but also the easiest coating technique as far as simplicity of application is concerned. More than 80% of the printed merchandise is based on pigment printing due to its apparent advantages, such as versatility and ease of near final print at the printing stage itself (Hoeng, Denneulin, Reverdy-Bruas, Krosnicki, & Bras, 2017; Pinto et al., 2016). Most of these coloration techniques use organic photochromic colorants which are characterized by low photostabilty and high cost compared to inorganic pigments. As a result, the photochromic fabric usually has poor properties that still need to be improved to satisfy consumer expectations, as the photochromic and fluorescent visual effects rapidly fade out with prolonged exposure to light, perspiration, heat, continuous washing, and rubbing (di Nunzio et al., 2008; Feczkó et al., 2013; Peng et al., 2015). The immobilization of inorganic pigment phosphor at low concentration onto binder-thickener printing matrix before their incorporation on fabric surface via screen-printing methodology can be considered as a potential strategy for the fabrication of photochromic fabrics with enhanced color-exchange properties, dye stability, and comfort. Oxide-based strontium aluminate pigment phosphor doped with divalent europium are extremely advantageous to provide photochromic and fluorescent functionalities to textile substrates while maintaining the original textile properties such as appearance, color fastness, handle, and touch. Up to now, there are different long-lasting luminescent materials have been developed as different primary color emitters, such as $CaAl_2O_4:Eu^{2+}/Nd^{3+}$ or $SrMgSi_2O_6:Eu^{2+}/Dy^{3+}$ for blue (Lin, Tang, Zhang, Wang, & Zhang, 2001; Yamamoto & Matsuzawa, 1997), $MgAl_2O_4:Mn^{2+}$ or $SrAl_2O_4:Eu^{2+}/Dy^{3+}$ for green (Matsuzawa, Aoki, Takeuchi, & Murayama, 1996; Wang, Jia, & Yen, 2003), and $Y_2O_2S:Eu^{3+},Mg^{2+}/Ti^{4+}$ or $CaS:Eu^{2+}/Tm^{3+}/Ce^{3+}$ (Smet, Moreels, Hens, & Poelman, 2010; Wang, Zhang, Tang, & Lin, 2003) for red. The $SrAl_2O_4:Eu^{2+}/Dy^{3+}$ has been verified to be an excellent long persistent phosphor due to its higher brightness, longer persistence time (> 10 h), with photo, chemical and physical stabilities (Kumar, Kedawat, Kumar, Dwivedi, & Gupta, 2015; Qin et al., 2013). In addition, the photochromic layer is nontoxic, non-radioactive, and can be recycled (Qiu et al., 2007; Rojas-Hernandez et al., 2018). Consequently, the fabrication of cost-effective high-tech textiles with tuneable photoswitchable properties, excellent fabric handle, high durability and improved fastness properties such as washing, perspiration, sublimation, crocking and light fastness through their printing with aqueous binder-containing inorganic pigment phosphor is an innovative approach, opening new horizons to the development of more effective and stable smart garments. To the best of our knowledge, the fabrication of light-responsive color changeable textiles employing screen-printing of aqueous binder and strontium aluminate pigment has not been reported. Herein, we report the design and application of strontium aluminate pigment on cellulosic fabrics by screen-printing for smart textile purpose.

2. Experimental details

2.1. Materials and chemicals

Desized, scoured and bleached 100% cotton fabrics (Plain weave) were supplied by El-Mahalla El-Kobra Company, El-Mahalla, Egypt. The fabric specifications were as follows: fabric weight 150 g/m^2, thickness 0.40 mm, micronaire (3.88 μg/inch), weft 30 yarn/cm, and warp 36 yarn/cm. The fabrics were scoured, by El-Mahalla El-Kobra Company, in aqueous solution having a liquor ratio of 1:50 and containing 2 g/L of non-ionic detergent solution (Hostapal; Clariant, Swiss), 5 g/L sodium hydroxide and 2 g/L of sodium carbonate at 90° C for 60 min to get rid of waxes and impurities, followed by rinsing in cold water, and finally dried at room temperature. The scoured cotton fabrics were bleached with hydrogen peroxide solution (20 ml, 35% H_2O_2), sodium silicate (2 g/L), sodium hydroxide (2 g/L) and 2 g/L of non-ionic detergent solution (Hostapal; Clariant, Swiss) at a liquor ratio of 1:50 for 1 h at 90 °C. Binder additive, thickener alcoprint PTP, and Reactive Red AEF were supplied by Dystar, Egypt. Strontium carbonate ($SrCO_3$), Aluminium oxide (Al_2O_3), Europium (III) oxide (Eu_2O_3), Dysprosium (III) oxide (Dy_2O_3) and Boric acid (H_3BO_3). All the raw materials employed in this experiment were supplied by Sinopharm Chemical Reagent Co. Ltd, China.

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