Photochromic textile materials

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Abstract. Smart textiles are the materials that can perceive and respond to the changes in environmental conditions. Photochromic textiles, one of the smart textile products, can reversibly change their color by UV irradiation. Photochromic textiles have become more attractive with the increasing interest in functional textile materials. In this paper, the applications of photochromic dyes in textile industry, the problems experienced in the processes and general information about the solution possibilities of these problems are given.

1. Introduction

People’s expectations from textile materials are changing with the development of technology and accordingly, functional properties of textile materials have also become important beside their properties such as aesthetics, design and suitability to fashion. In this context, functional textile products increase the competitive power of the companies in the sector. The chromic materials, which are one of the functional textiles and can change colors with external factors, can be used to obtain smart textiles and also to get fashion effect.

Chromism is a general term used for color-changing materials and is used as a suffix. Chromic materials are also called "chameleon materials" due to their color changing properties caused by the effect of an external stimulus. There are various types of chromism according to the external stimulus (Table 1) [1].

Table 1. Chromism types [1]

| Chromism type     | External stimulus for changing of color               |
|-------------------|------------------------------------------------------|
| Thermochromism    | Heat                                                 |
| Photochromism     | UV radiation                                         |
| Electrochromism   | Electrical potential                                 |
| Solvatochromism   | Solvent polarity                                     |
| Piezochromism     | Mechanical pressure                                  |
| Cathodochromism   | Electron beam irradiation                            |
| Halochromism      | Solution pH                                          |
Chromism has been explored since 1900's and its main applications are in the field of photochromism, thermochromism and electrochromism, such as dye, cosmetics, plastics and many optical applications. In the textile industry, photochromism and thermochromism applications are generally used among these types.

2. Photochromism and its applications

Photochromic materials change from colorless when indoors to color when outdoors. Especially, photochromics change color in response to UV light. When the UV light source is removed, their color returns to their original state (Figure 1) [2].

![Photochromic compound (naphthopyran) and its photochromic reaction](image)

Figure 1. Photochromic compound (naphthopyran) and its photochromic reaction [2].

The most widely used class of photochromic dyes, along with many different classes, exhibit photochromism based on pericyclic reactions. These compounds, which show photochromism effect by the ring opening/closing reaction, are separated into 5 groups, spiropyran, spirooxazine, naphthopyran, diarylethene and fulgide [2, 3].

Photochromic eyeglasses are the most known photochromic products. These glasses get darker with the increase in the intensity of the UV light and thus the amount of light passing through the glass is reduced (Figure 2). Photochromic dyes can also be used at window glasses and, like the photochromic eyeglasses, with the increase in UV light intensity, the glass get darker and reduce the sunlight entering the building [4].

![Photochromic eyeglass at indoor (picture on the left) and outdoor (pictures on the right)](image)

Figure 2. The photochromic eyeglass at indoor (picture on the left) and outdoor (pictures on the right) [5].

The use of photochromic dyes in the optical industry is widespread, and the applications of these dyes are also available in the plastic and cosmetics industries. In addition, one of the commercial uses of these dyes is printing ink, which can be transferred to the materials such as cloth or paper by different processes such as screen printing, flexography, dry offset etc. with different effects [4].

The use of photochromic dyes in the textile field is based on the 1990's, and today there are some examples of commercial use [4, 6, 7]. Photochromic dyes can be added in the polymer matrix during the production of synthetic fibers and so, photochromic yarns can be obtained (Figure 3) [6]. These
dyes are also used by the fashion industry to obtain different effects such as photochromic t-shirts produced by printing method (Figure 4) [7].

![Before UV irradiation](image1.png) ![After UV irradiation](image2.png)

**Figure 3.** Photochromic yarns before and after UV irradiation [6].

![Before UV irradiation](image3.png) ![After UV irradiation](image4.png)

**Figure 4.** Photochromic t-shirt before and after UV irradiation [7].

Photochromic textile materials can be used as a UV sensor by changing the color depending on the amount of UV light in the environment. Thus, the person using the material would be warned that UV protection is required [4].

Photochromic dyes have also been used in the nanofiber production to obtain functional nanofibers. These dyes are incorporated into the polymer solution and then the nanofiber surface shows photochromic effect. Thus, sensitivity of photochromic dyes increase and the time necessary to respond to the UV irradiation reduce due to large surface area of the nanofibers. Photochromic nanofibers could find applications in fields such as optical data storage devices, optical sensors, processing media and functional components for smart surfaces [2].

3. The problems and solutions in the textile applications of photochromic dyes

In the studies on photochromic textiles, several problems have been encountered due to the sensitive structure of these dyes and their low water solubility [8-13]. The technologies such as encapsulation, sol-gel and electrospinning can be used to solve the problems in the textile applications of photochromic dyes [14-16]. The aims of these technologies are to provide the homogeneous distribution of the photochromic dyes in the solvent or carry the dyes in the polymer matrix. Thus, the use of photochromic dyes in textile materials can be improved with these alternative methods.

Encapsulation is a coating process of a core material with a shell material [17]. The encapsulation process provides advantages such as protecting the core from atmospheric conditions, increasing stability, improving processability, extending the shelf life of core material, etc. Along with many different encapsulation methods, methods such as in-situ polymerization, interfacial polymerization, emulsion-solvent evaporation and spray drying have generally been used to encapsulate photochromic dyes [15, 18-23]. Photochromic dyes based on spirooxazine, naphthopyran and diarylethene were used
as core materials and polymers such as ethyl cellulose, polystyrene, polyurethane, polymethyl methacrylate, melamine and chitosan were used as shell materials in these studies.

Sol-gel technology can be used as another application method for photochromic textiles [16, 24, 25]. Sol is the stabilized suspension of colloidal solid particles in liquid and gel refers to a web structure with a form between solid and liquid. Photochromic dyes can be applied on textile materials with sol-gel method which consists of application, drying and condensation steps. However, photochromic dyes are sensitive to high temperature and therefore the curing temperature of the photochromic sol-gel matrices is limited [26].

Photochromic dyes exhibit ring opening/closing reaction when exposed to UV light, and color change reactions may not occur due to their fatigue. Spiropyrans have relatively low fatigue resistance and the spiropyrans and naphthopyran derivatives which have higher fatigue resistance have become more important than spiroxazines. The use of different stabilizers such as hindered amine light stabilizers (HALS), antioxidants, UV absorbers, etc. can also improve the fatigue resistance of photochromic dyes [27].

4. Conclusion
The competition in textile industry is increasing and the production of high-value added materials is getting more importance. Smart textiles are the materials which are high-value added and therefore highly competitive. Photochromic materials have also become one of the remarkable products in this area, but the problems experienced in their applications restrict the use of these dyes in the textile industry. However, many different application methods have been studied to solve these problems. In this context, it is considered that the use of photochromic dyes in the textile industry will continue to be of interest by solving the problems experienced in the application.

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