Characterization and optimization of an inkjet-printed smart textile UV-sensor cured with UV-LED light

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Abstract. For the development of niche products like smart textiles and other functional high-end products, resource-saving production processes are needed. Niche products only require small batches, which makes their production with traditional textile production techniques time-consuming and costly. To achieve a profitable production, as well as to further foster innovation, flexible and integrated production techniques are a requirement. Both digital inkjet printing and UV-light curing contribute to a flexible, resource-efficient, energy-saving and therewith economic production of smart textiles. In this article, a smart textile UV-sensor is printed using a piezoelectric drop-on-demand printhead and cured with a UV-LED lamp. The UV-curable ink system is based on free radical polymerization and the integrated UV-sensing material is a photochromic dye, Reversacol Ruby Red. The combination of two photoactive compounds, for which UV-light is both the curer and the activator, challenges two processes: polymer crosslinking of the resin and color performance of the photochromic dye.
Differential scanning calorimetry (DSC) is used to characterize the curing efficiency of the prints. Color measurements are made to determine the influence of degree of polymer crosslinking on the developed color intensities, as well as coloration and decoloration rates of the photochromic prints. Optimized functionality of the textile UV-sensor is found using different belt speeds and lamp intensities during the curing process.

Keywords: UV curing, digital inkjet printing, smart textile, photochromic

1. Introduction

Over the past decades, smart textiles and other high-end niche products have received increasing attention in research. Yet, a limited amount of products is on the market. Resource-efficient production processes like digital inkjet printing and UV-LED curing have large potential to make smart textiles and other textile niche products economically viable. These processes enable a textile production with minimized use of water, chemicals and energy and a minimized production of waste [1-6]. Furthermore, they make a small-batch production profitable [4, 6]. Resource-efficiency does not only make the production of products with high material cost economical, but also fosters sustainability and process flexibility, which gives the potential to innovate for the textile industry in European countries.
Recently, the number of research activities about the use and exploration of photochromic dyes in textiles increased [7-11]. Photochromic dyes can reversibly change colour upon irradiation with UV-light. Photochromic dyes, as in organic heterocyclic compounds, undergo isomerization triggered by

high photoelectric energy from a ring-closed colourless state to a ring-opened coloured state [12]. This study explores a resource-efficient production of a UV-sensing smart textile based on a commercial dye Reversacol Ruby Red, which is printed using digital inkjet printing and cured with UV-LED light. Hereby, the two functions of UV-light, as initiator for the curing reaction and as activator of the colour switching, are analysed. The production process of the textile UV-sensor is characterized and optimized in terms of its maximum developed colour intensity, reaction rates of coloration and reversion and degree of polymer crosslinking of the print on the fabric.

2. Experimental Part

Photochromic inkjet ink consisting of a UV-curable carrier and commercial photochromic dye Reversacol Ruby Red (Vivimed Labs, UK) was used to produce photochromic prints on plain-woven polyester fabric of 147 g/m^2 (FOV Fabrics, Sweden). Photochromic prints were produced by digital inkjet printing using a piezoelectric printhead; Sapphire QS-256/10 AAA (Fujifilm Dimatix, USA). Printing was made in multi-pass mode with 3, 5 and 10 passes at a resolution of 300 dpi. The prints were cured with a FireJet UV-LED lamp (Phoseon Technology, USA) with emission wavelengths of 380 to 420 nm and a maximum emission power of 6 W/cm^2. Curing parameters were varied by i) change in transportation speed of the print passing the UV-source, i.e. conveyer belt speed, and ii) intensity of the maximum UV-LED lamp power, i.e. lamp intensity. Conveyer belt speeds were either 50 mm/s or 300 mm/s and were combined with 1%, 25% or 80% of the maximum lamp intensity as shown in Figure 1.

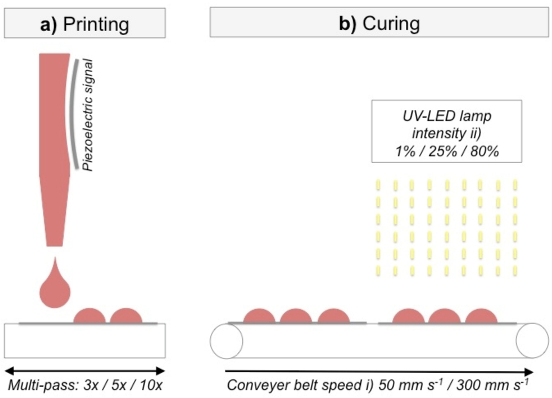

Figure 1. Production scheme of printing and curing of photochromic prints on polyester fabric.

To optimize the textile UV-sensor, the degree of polymerization of the UV-curable ink was studied by characterization of the thermal transition properties of the ink on the polyester fabrics by DSC. Photochromic UV-curable ink on polyester fabric was studied by heating from 25°C to 290°C and thereafter cooling to 25°C at a scanning rate of 10°C per minute. To determine the photochromic prints' colour performance, colour measurements were made using a custom-made LCAM Photochrome spectrophotometer (Technical University of Liberec, Czech Republic), which enables continuous colour measurements upon cycles of UV-activation and reversion [13]. Measures to characterize the sensor's functionality are the achieved colour yield ΔK/S, coloration rate and reversion rate upon isomerization between the uncoloured and coloured state.

3. Challenges and Conclusion

Digital inkjet printing and UV-LED curing are promising production processes for a sustainable, economic and flexible production of smart textiles. To produce a textile UV-sensor based on photochromic dyes with these processes, challenges the resulting functionality of the sensor. The

intensity of UV-light and speed under which the print passes the light source influences the photochromic dye during the curing process. We investigate the process and optimize the photochromic functionality; high colour yield, fast switching between colourless and coloured forms and optimal degree of polymer crosslinking to achieve sensor durability after washing.
We have found that high conveyer belt speed and low lamp intensity allow faster colour switching compared to stronger curing conditions and achieve high colour yields after washing despite a lower degree of polymer crosslinking.
To conclude, an optimized textile UV-sensor based on a commercial photochromic dye, Reversacol Ruby Red, can be produced resource-efficiently using digital inkjet printing and UV-LED curing.

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