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CO_2 laser treatment as a clean process for treating denim fabric

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ABSTRACT

In this study, a carbon dioxide (CO_2) laser was used for the colour-fading treatment of denim fabrics. Two types of denim fabrics were laser-treated: one was manufactured with low-twist yarn spun by torque-free ring-spinning technology, and the other was manufactured by conventional ring-spun yarn. Commercially available torque-free ring-spun cotton yarn was used to manufacture the denim fabrics. For comparison, one specimen of denim fabric featured torque-free ring-spun yarn in the warp direction and conventional ring-spun yarn in the weft direction, whereas another specimen featured conventional ring-spun yarn in both the warp and weft directions. The warp yarn of both specimens was dyed by the same indigo dyeing process. The denim fabric samples were treated with a CO_2 laser under the same conditions, and two laser processing parameters, namely, (i) resolution and (ii) pixel time, were used to adjust the laser power. After laser treatment, the colour properties (reflectance and colour parameters of the fabrics, such as the K/S value (the Kubelka-Munk function was used to represent the colour yield of the fabrics, where K is absorption and S is scattering) and CIE $L^*a^*b^*$ values) and dimensional stability of the denim samples were compared, and the results were analysed thoroughly. In addition, the colour-fading effect induced by CO_2 laser treatment was compared with that induced by conventional cellulase treatment. Experimental results revealed that CO_2 laser treatment is an effective alternative means of producing the colour-fading effect in denim fabrics if the processing parameters can be carefully controlled.

1. Introduction

The laser treatment of textile materials composed of synthetic fibres such as polymethyl methacrylate (PMMA) (Kawamura et al., 1982), poly (ethylene terephthalate) (PET) (Knittel et al., 1997a, 1997b; Wijayathunga et al., 2007), polyamide (nylon) (Akihiro and Kamata, 2004a, 2004b; Yip et al., 2006) and polypropylene (PP) (Akihiro and Narusue, 2004) has been developed over many years. As a rapid method that provides precision in processing, laser treatment is considered a clean process that offers low cost and low environmental impact because it is a water-free method (Zhao et al., 2010; Franco et al., 2010; PatentsALERT, 1997). With the use of laser processing, colour fading and patterns can be produced in textile materials by exposing the fabric to laser radiation of sufficient intensity to cause the photo-decomposition of the colouring agent while leaving the underlying textile material undamaged (PatentsALERT, 1997). Among the various laser-processing machines that are currently available, the CO_2 laser is the most suitable for textile materials (Kan and Yuen, 2008; Kan, 2012; Chan et al., 2009). CO_2 laser treatment has been applied in different areas of the textile industry in recent years (Ondogan et al., 2005a; Chow et al., 2012, 2011) as an alternative to conventional treatments such as stone washing, sand washing, snow washing, stone washing with enzymes and bleaching to achieve a faded look and worn-out effects (Dascalu et al., 2000; Ozguney, 2007; Tarhan and Sariisik, 2009). In comparing different conventional treatments (although enzyme treatment is a good method for treating textile materials (Vankar et al., 2007; Farooq et al., 2013; Aly et al., 2004)), previous studies have shown that with a precisely selected laser power, it is easy to induce certain design effects on textile surfaces by removing the dye present and altering colour quality values (Esteves and Alonso, 2007; Hung et al., 2013, 2011). In the case of denim, CO_2 laser treatment has recently been proved to be an effective method for fading the colour from the fabric surface in a short time, with the following advantages in terms of production (Card et al., 2006, 2005; Juciene et al., 2006):

(1) The laser beam enables the user to impart various visual features to textile surfaces of desired forms and designs (Petkov et al. 2008; Knittel and Schollmeyer, 1998).
(2) With the aid of a computer, it is not only possible to create a design but also to draw technical geometrical models of

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texture where the design is to be applied (Ondogan et al., 2005b).

(3) Laser designing allows for the short-time design of patterns with the required dimensions and intensities (Ondogan et al., 2005b).

(4) The wavelength and power of the laser beam applied may vary according to the nature of the surface texture where the design is to be created, and various adaptations are possible by making certain adjustments at the source of the laser beam as well as in the optical lenses (Bahners et al., 1992; Esteves and Alonso, 2007).

(5) This process is less hazardous to the environment as it reduces the use of chemical agents and water (Akihiro and Mochiduki, 2001; Akihiro and Ishihara, 2002; Akihiro and Mochiduki, 2003).

(6) Process flexibility allows for the replication of existing stonewash designs or the creation of new finish styles (Kan et al., 2010; Özgüney et al., 2009).

(7) The process can be applied to parts or assembled garments or on uncut material (Akihiro, and Kamata, 2004a; Akihiro and Kamata, 2004b; Akihiro and Narusue, 2004).

(8) By exploited the automated control of laser technology, the manufacturers can change a finish style to another without retooling (Dascalu et al., 2000).

(9) Micrographics can be applied to garments (Ondogan et al., 2005a, 2005b).

(10) The process allows for the replication of identical designs of standard quality and thus increases the added value (Ozguney, 2007).

(11) The texture formed on a fabric does not wear out or deform, unlike the textures formed by the sanding and stoning processes (Ortiz-Morales et al., 2003).

(12) Designs are not limited to two-dimensional figures. A deliberate deformation is created on a textile surface that enriches a given design's visual features. Thus, three-dimensional surface designs can be created (Ondogan et al., 2005a, 2005b).

(13) The process is capable of transferring all types of pictures, writings, figures, designs, special logos and characters onto clothes with the desired appearance, dimensions and density (Ondogan et al., 2005a, 2005b).

(14) The process enables "quick response" and "just-in-time production" as it is a flexible model that can rapidly respond to various demands in competitive international markets. Products can be sold immediately after laser treatment as the laser processing is a dry treatment that does not require rinsing (Ondogan et al., 2005a, 2005b).

(15) The cost of small quantities of products is lower when compared with that of products generated by conventional methods (Dascalu et al., 2000; Maryan and Montazer, 2013).

(16) The processing equipment is safe to use and easy to repair and maintain (Dascalu et al., 2000).

(17) The process allows for around-the-clock production (Dascalu et al., 2000; Ondogan et al., 2005b).

(18) The process is able to create different layers of the same colour shade on the fabric, which is difficult to achieve manually (Kan et al., 2010).

(19) The process is easy to implement as any two-dimensional designs can be created using AUTOCAD, PHOTOSHOP or CORELDRAW and can be input to the laser-control software directly for treatment afterwards (Ondogan et al., 2005a, 2005b).

Clearly, CO_2 laser treatment provides an effective means and alternative for cleaner production in the denim colour-fading process (Kan and Yuen, 2008; Kan, 2012). In fact, a number of laser machines have been sold in Asian factories for the daily production of colour-faded denim (Cheung, 2012, 2013). Table 1 shows the comparative advantages offered by laser processing over conventional wet chemical processing for denim colour-fading.

In textile fabrics, the degree of twist or torque in the yarn affects the final fabric properties, such as skewness, which affects the dimensional stability of the fabric (Murrells et al., 2003; Khedhor et al., 2009). Traditional methods for reducing residual torque involve the permanent setting of yarn or the physical balancing of yarn by two-plying, but these methods are too expensive. Recently, a novel torque-free ring-spinning technique was developed for producing low-twist yarn on a ring-spinning system with a yarn-torque-reduction device that modifies yarn structure and reduces twist to a great extent without affecting the yarn strength (Tao et al., 1997a, 1997b; Wong et al., 2004). Torque-free ring-spun yarn possesses similar tenacity, elongation and evenness to conventional ring-spun yarn. In addition, the mechanical properties of denim fabric produced by this torque-free spinning technique are similar to those of conventional denim fabric (Wong et al., 2004; Hua et al., 2004). Recently, few studies have reported the effects of CO_2 laser treatment on the colour properties and dimensional stability of denim fabric manufactured from torque-free ring-spun yarn. In this study, denim fabrics manufactured from conventional ring-spun yarn and torque-free ring-spun yarn with the same indigo dyeing process were treated with a CO_2 laser under the same conditions, and their colour properties, such as reflectance, K/S value and CIE $L^*a^*b^*$ values and dimensional stability, were evaluated.

2. Experimental section

2.1. Denim fabric

Two samples of 100% singed, desized, pre-skewed and pre-shrunk (2% in warp and 1% in weft) with 3/1 right-hand twill cotton denim fabrics were obtained from Central Textiles (H.K.) Ltd., Hong Kong (specifications in Table 2). The warp yarn of the two denim samples was dyed with pure indigo dye (C.I. Vat Blue 1) (supplied by a dye manufacturer in China) by performing 11 dips (with 50% pick-up per dip) at a speed of 21 m/min during the dyeing process. The major difference between Fabric 1 and Fabric 2 was the amount of twist and bulkiness in the warp yarn. Herein, yarn twist is defined as the number of twists per 1 cm of yarn, and bulkiness is represented by the yarn diameter. The warp yarn in Fabric 1 was conventional ring-spun yarn, whereas Fabric 2 was manufactured using torque-free ring-spun yarn. As indicated in Table 2, the warp yarn of Fabric 2 had lower twist and higher bulkiness. The two fabrics were conditioned under standard atmospheric conditions of 20 ± 2 °C and a relative humidity of 65 ± 2% before further treatment.

Table 1
Comparison of the advantages offered by laser processing over conventional wet chemical processing (Kan and Yuen, 2008; Kan, 2012; Cheung, 2012, 2013).

Process consideration	Conventional wet treatment	Laser treatment
Handling and storage of chemicals	Yes	No
Preparation of chemicals and baths	Yes	No
Water usage	Heavy	None or very low
Raw materials consumption	High	Relatively low
Drying and heating operations	Yes	No
Number of process steps incurred	Single/multiple	Single
Energy consumption	High	Low
Sequential effluent treatments	Yes	No
Environmentally costly	Yes	No
Equipment footprint	Large	Small