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Impact of Laser Thermal Stress on Cotton Fabric

Abstract

The thermal processing of cotton fabrics poses a serious danger for these materials, especially such processes as singeing and burning patterns by laser. The impact of laser radiation on the colour change of dyed samples was evaluated.

Key words: cotton fabric, thermal stress, laser treatment, colour change.

Introduction

The aim of this study was the determination of the stress degree of cotton fabric after laser beam application on its surface. The beam intensity “duty cycle” and pixel time were changed to process the samples under different thermal conditions. Laser application is typical in the jeans industry, in which it is applied to cotton materials due to the material behaviour during thermal stresses.

Thermal processing can cause serious fabric damages and this paper introduces a process which is a typical example.

The action of a laser causes physical and chemical changes to polymer surfaces. It is possible to find a large amount of literature concerning UV laser treatment applied to synthetic fibres. Nevertheless, there are few references relating to the pulse CO₂ infrared laser only. The influence of CO₂ laser radiation on polyethylene terephthalate foils was observed by Dadsetan [1]. Dadbin et al. [2] investigated the surface modification of polyethylene film by CO₂ pulsed laser irradiation. Bormashenko et al. [3] demonstrated changes

in thin polymer films after the exposition of a CO₂ laser.

According to Ondogan et al. [4], by using a laser it is possible to create a worn look on denim, which could be an alternative method to conventional processes. From these results he stated that an infrared laser is a suitable tool for the decolouration of indigo-dye on denim fabric. In comparison with conventional techniques of processing denim fabric, a laser beam provides us with some advantages: it is environmentally friendly with respect to the consumption of chemical agents, has low water consumption, and offers flexibility of the process and replications of designs [5 - 8]. We tested the influence of a laser beam on different kinds of direct dyes to determine their stability.

Description of thermal processing

A Marcatex Laser (Garment Finish Kay, S.L., Spain) was used to cause thermal damage to cotton fabric. The laser is of the CO₂ pulse type. In *Figure 1* a photo of this laser is illustrated with a detailed de-

scription. CO₂ lasers are frequently used in a lot of industrial applications. The thickness of the evaporated layer starts in the micrometer range. Laser beams interact with fibres by local evaporation of material, thermal decomposition or changing the surface roughness. They are also quite efficient: the ratio of output power to motive power can be as large as 20% [9 - 11].

The main laser characteristics are mentioned below:

- Model Marcatex 150/250 flexi
- Average output power 150/250 watts
- Peak output power 230/400 watts
- Working frequency 50/60 Hz
- Wavelength of laser beam 10.6 micrometre
- Polarisation linear
- Time mode pulse.

The optical box belongs to one of most important parts of the equipment. It is illustrated in *Figure 2*, with a detailed description.

We investigated if it could be applied to yarns dyed by different kind of dyes. For all the experiment



Figure 1. Marcatex laser - used for the thermal stress of the substrate.

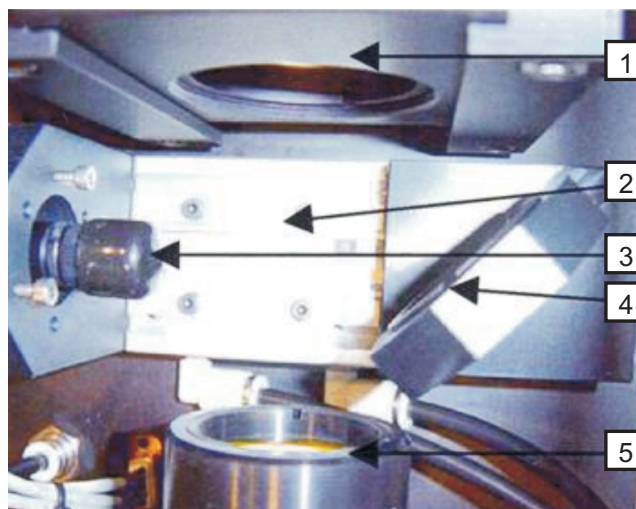


Figure 2. The optical box; 1) focusing lens, 2) cylinder, 3) marker diode, 4) marker diode mirror, 5) beam expander.

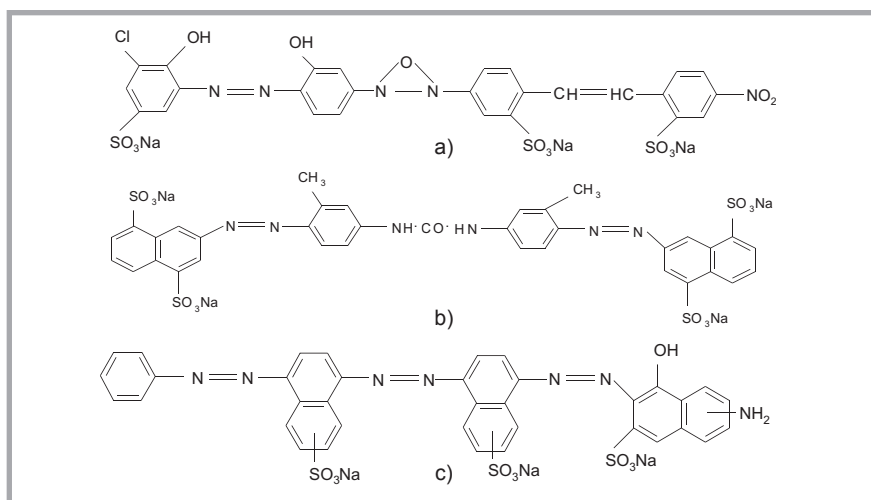


Figure 3. Direct dyes used for dyeing of cotton fabric: a) C.I. Direct Brown 103, C.I. Direct Yellow 50, c) C.I. Direct Black 56.

Table 1. Set-up of the Marcatec 150/250 Flexi EasyLaser laser machine

Duty cycle, %	Pixel time, μ s								
5	50	100	200	300	400	500	600	700	800
10	50	100	200	300	400	500	600	700	
20	50	100	200	300	400	500	600		

100% cotton twill-woven fabric with a fabric density of 32 threads/cm in the warp (linear density of the warp: 58.2 tex) and 14.8 threads/cm in the weft (linear density of the weft: 48.15 tex) was used for exposure to infrared laser radiation. The cotton fabric was dyed with direct dyes using a common technique. Three direct dyes were chosen for the dyeing of cotton fabric (Figure 3): C.I. Direct Brown 103 (Figure 3.a), C.I. Direct Yellow 50 (Figure 3.b) and C.I. Direct black 56

(Figure 3.c). The dyeing bath contained 0.5%, 1.5% and 3% of direct dye, 10 g·l⁻¹ sodium chloride (NaCl). The liquor ratio chosen was 1:50.

The dyeing was realized in a dyeing machine (Ahiba, Datacolor, Switzerland) with infrared heating at a temperature of 96°C for one hour. After that the samples were rinsed in water and dried in a laboratory drier (HS 62A, Chirana, Czech Republic).

Samples of non-dyed cotton were irradiated for comparison with the dyed cotton samples.

The thermal stress was caused by laser beam using various power setting parameters to achieve different stress conditions. For this experiment it was possible to use various set-ups of the laser machine. In this case two parameters were tested: the pixel time and duty cycle (see Table 1).

The “duty cycle” is synonymous with the power applied and represents the ratio of the laser time on (pulse width) and laser time off. Its maximum value is 50% for the equipment used. The pixel time is time used to mark each pixel of the image (in microseconds).

Measuring of remission values

Reflectance values of the samples were measured by means of a spectrophotometer (Datacolor 3890, Switzerland). K/S values were calculated from the reflectance values with the help of Kubelka-Munk theory, according to following formula.

$$K/S = (1-R)^2/2R$$

where:

K - the coefficient of light absorption,
 S - the coefficient of light scattering and
 R - remission, %

Dependence of remission values for non-dyed cotton fabric on the wave-

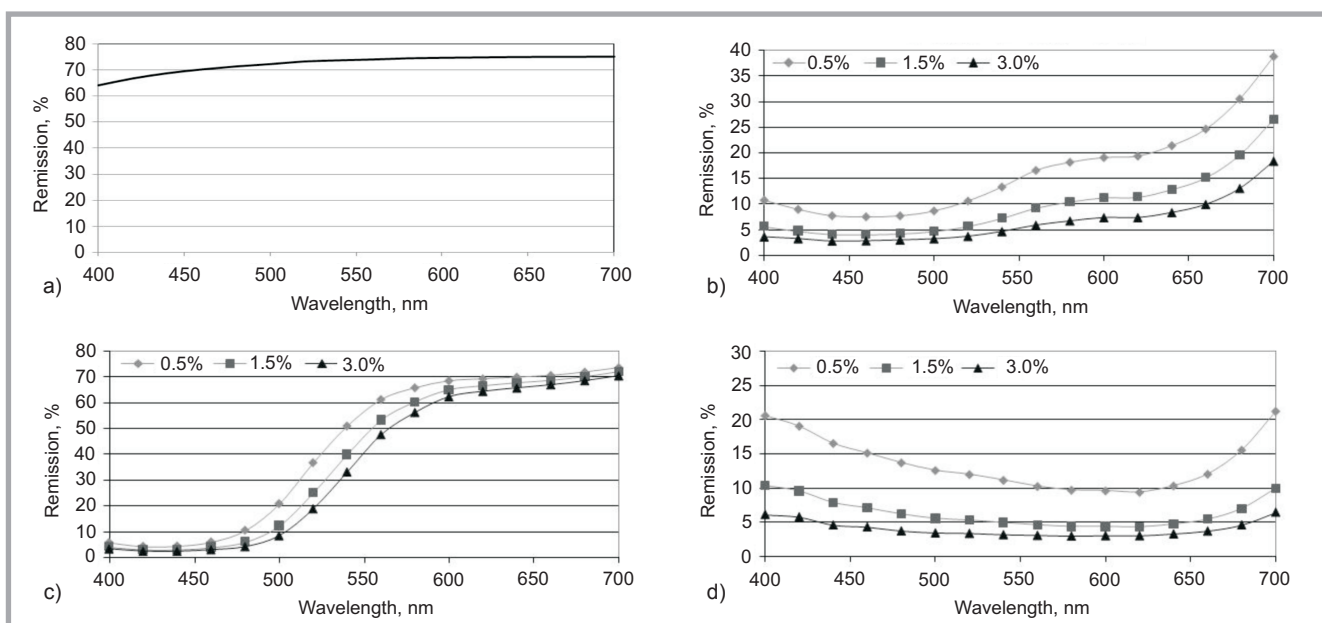


Figure 4. Dependence of remission values for non-dyed cotton fabric on the wavelength (a). Dependence of remission values for cotton fabric dyed with: b) C.I. Direct Brown 103, c) C.I. Direct Yellow 50, d) C.I. Direct Black 56 on the wavelength.

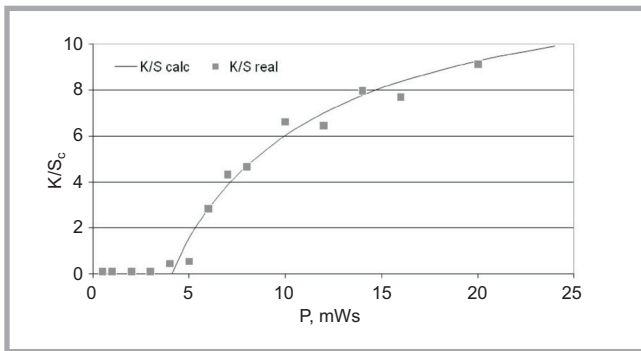


Figure 5. Dependence of K/S_C values of non-dyed cotton on the irradiation intensity P ; wavelength = 420 nm.

ton were connected with the irradiation intensity P in mWs.

In the range of P from 0 to 4 mWs, almost no changes in the non-dyed cotton fabric were noted (Figure 5). Above $P = 4$ mWs the yellowing of non-dyed cotton fabric occurs. At approximately $P = 24$ mWs non-dyed cotton fabric is severely decomposed by the heat effect of laser irradiation.

The colour changes in non-dyed cotton fabric were connected with the irradiation intensity P . A hyperbolic model was used for prediction of the yellowing of non-dyed cotton. The equation of linear regression is:

$$y = 2.0343 \cdot x + 0.0208$$

The coefficient of determination is equal to 0.8715.

In the case of dyed cotton, the behaviour of the fabric under laser irradiation is varied. Higher irradiation intensity causes bigger damage of cotton. At dyed cotton

length is presented on Figure 4.a. Dependences of remission values for cotton fabric dyed with: C.I. Direct Brown 103, C.I. Direct Yellow 50, and C.I. Direct Black 56 on the wavelength are shown on Figures 4.b, 4.c, 4.d respectively.

K/S values were also calculated for non-dyed cotton samples irradiated by infrared laser. In the quantification of the different parameters of laser irradiation, a new parameter P was suggested to de-

note the "irradiation intensity", which is defined by the following formula.

$$P = D/100 \cdot K \cdot T \cdot 1000$$

where

P - irradiation intensity in mWs

D - duty cycle in %

K - maximal power of the laser beam ($K = 200$ W)

T - pixel time in s.

The infrared laser had a heat effect on the cotton fabric. The colour changes in cot-

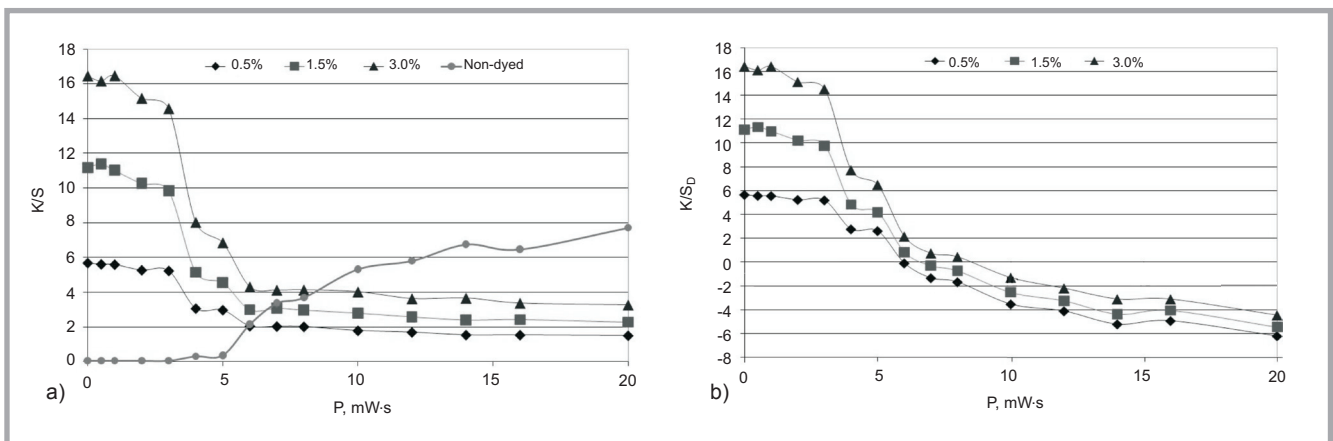


Figure 6. Dependence of K/S (a) and K/S_D (b) values for cotton fabric dyed with C. I. Direct Brown 103 on the irradiation intensity P ; wavelength = 460 nm.

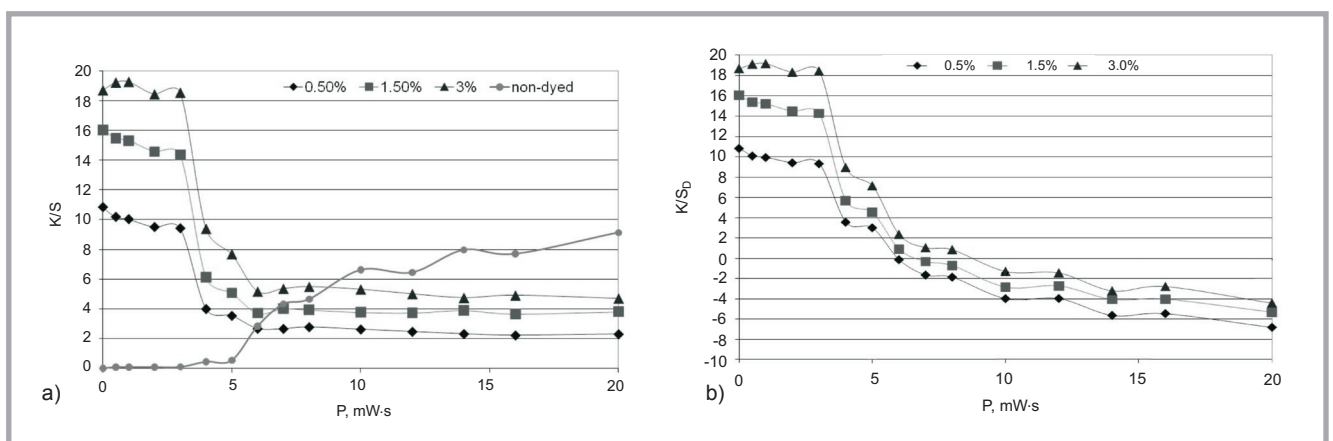


Figure 7. Dependence of K/S (a) and K/S_D (b) values for cotton fabric dyed with C. I. Direct Yellow 50 on the irradiation intensity P ; wavelength = 420 nm.

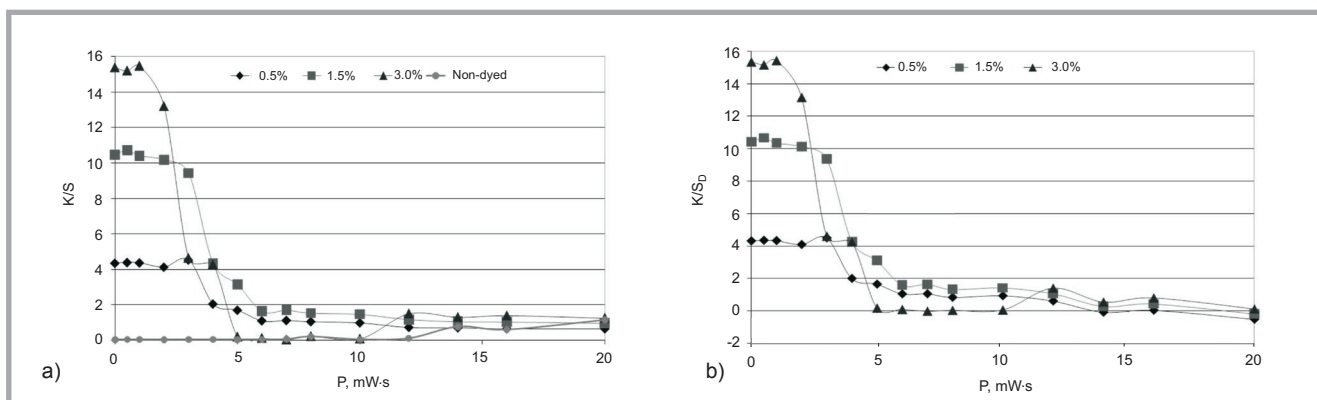


Figure 8. Dependence of K/S (a) and K/S_D (b) values for cotton fabric dyed with C. I. Direct Black 56 on the irradiation intensity P ; wavelength = 560 nm.

material the irradiation causes decomposition of dye - decolorization.

Low irradiation intensity cause the decolorisation of cotton, which is exhibited by decreasing K/S values after laser irradiation. The dyestuffs show varying stability during laser irradiation. The behaviour of some dyestuffs is similar after laser irradiation, such as in cotton fibres – in this case the decolorisation of the dye is accompanied by the yellowing of the cotton.

To separate the influence of the yellowing of cotton from the decolorisation of the dyestuff in fibres, the idea of combining these two processes was adopted. If the processes are independent, then cotton yellowing can be separated. Dye decolorisation is given by the formula:

$$K/S_D = K/S - K/S_C$$

Where K/S is the value of the dyed sample measured (Figures 6.a, 7.a, 8.a), and K/S_D is the K/S value caused by the dye (Figures 6.b, 7.b, 8.b). K/S_C is equal to the yellowing of cotton by laser irradiation (Figure 5). All K/S values were measured within the wavelength of the maximal light absorption of the dyestuff tested.

The stability of the test dyestuff in cotton was different.

- C.I. Direct Brown 103 (Figure 6) was stable up to $P = 3$ mWs for 0.5% dye, $P = 1$ mWs for 1.5% and 3% dye.
- C.I. Direct Yellow 50 (Figure 7) was stable up to $P = 1$ mWs for 3% dye. The depth of the colour shade slowly decreases for 0.5 and 1.5% dye.
- C.I. Direct Black 56 (Figure 8) was stable up to $P = 3$ mWs for 0.5% dye,

$P = 2$ mWs for 1.5% dye and $P = 1$ mWs for 3% dye.

Almost no changes in K/S values are observed for parameter P from 0 to 1 mWs. The decomposition of the direct dye of cotton fabric occurs at an irradiation intensity P in the range of 1 - 6 mWs. Infrared laser radiation affects cotton fabric above an irradiation intensity P of 6 mWs, whereby yellowing, browning and damage to the cotton fabric occurs.

Conclusion

Minimal irradiation intensity causes visible colour changes to dyed cotton samples, which depend on the dye concentration in fibres (on the depth of shade, respectively). Samples with higher dye concentrations (deeper shades) need lower irradiation intensity to induce colour changes. In the case of the samples observed, colour changes start in light shades of $\frac{1}{2}$ irradiation intensity in comparison with deep colour samples dyed with the same dye. This concentration effect is linked to the light flowing through the fibre system with different absorption properties.

The values of K/S_D calculated are minus in the case of higher irradiation intensity ($P = 6$ mWs and more). This observation can be explained by the protective properties of dyes in cotton. Dyes probably decompose at lower temperatures or the products of dye destruction are able to reduce the oxidation process of cotton by laser irradiation.

Acknowledgment

This work was supported by research project IGS-FT-TUL199/2009.

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Received 07.01.2009 Reviewed 29.10.2009