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Study of the Influence of the Surface Roughness of Knitted Fabrics from Natural Fibres on the Light Fastness of Their Colours

Študija vpliva površinske hrapavosti pletiv iz naravnih vlaken na barvno obstojnost proti sončni svetlobi

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Abstract

The article examines the influence of the surface properties of knitted fabrics from cotton and wool of various knitted structures on the light fastness of their colours. The surface properties of knitted fabrics of single plain, 1×1 rib and French piqué knitted structures were evaluated by determining their roughness using a non-contact optical method for processing digital images of the knitted fabric's surface. The roughness profiles of the corresponding knitted fabric samples were obtained, and the main indicators of surface roughness were calculated: the profile height at ten points R_z and the arithmetic mean profile deviation R_a. Cotton knitted fabrics were dyed with the Bezaktiv Cosmos dye brand, which are bifunctional reactive dyes with monochlorotriazine / vinyl sulfone active groups, and wool knitted fabrics were dyed with acid dyes. The light fastness of the samples was evaluated after exposure to the Light Fastness Tester (Mercury-Tungsten Lamp) RF 1201 BS (REFOND) with a PCE-TCR 200 colorimeter. Colour measurements were averaged for each sample. Total colour difference (dE) was measured on the dyed cotton knitted fabrics samples after light exposure. According to the obtained roughness profiles of cotton and wool knitted fabrics, it can be concluded that the studied knitted fabrics are characterized by different roughness, which depends on their knitted structures. At the same time, a relationship was found between an increase in the roughness of knitted fabrics and the photodestruction of colours by reactive and acid dyes on cotton and wool knitted fabrics, respectively. The results show that the surface structure of knitted fabrics, that is the knitted structure, impacts the process of colour photodestruction and that the amount of dye that has undergone photodestruction increases with the increasing surface roughness of the knitted fabric.
Keywords: knitted fabric, knitted structure, roughness, photodestruction, light fastness.

Izvleček

V članku je proučen vpliv površinskih lastnosti strukturno različnih bombažnih in volnenih pletiv na barvno obstojnost proti sončni svetlobi. Površinske lastnosti pletiv v enostavni levo-desni, 1x1 rebrasti in francoski vezavi piké so bile ovrednotene z določanjem hrapavosti z brezstično optično metodo za obdelavo površine pletiv na digitalnih slikah. Dobljeni so bili profili hrapavosti posameznih vzorcev pletiv in izračunani glavni kazalci površinske hrapavosti: višina profila v

desetih točkah, Rz, in aritmetična sredina odstopanja profila, Ra. Bombažna pletiva so bila barvana z bifunkcionalnimi reaktivnimi barvili znamke Bezaktiv Cosmos, z monoklorotriazinskimi oziroma vinilsulfonskimi aktivnimi skupinami. Volnena pletiva so bila barvana s kislimi barvili. Barvna obstojnost pletiv na svetlobi je bila ocenjena po izpostavitvi vzorcev osvetljevanju v aparatu Light Fastness Tester RF 1201 BS (REFOND), opremljenem z živosrebrno-volframovo žarnico, in kolorimetrom PCE-TCR 200. Meritve barve so bile povprečne za vsak vzorec. Skupna barvna razlika (dE) je bila izmerjena na vzorcih barvanih bombažnih pletiv po izpostavljenosti svetlobi. Glede na dobljene profile hrapavosti bombažnih in volnenih pletiv je bilo ugotovljeno, da imajo pletiva različno hrapavost, ki je odvisna od strukture pletiv. Hkrati je bila ugotovljena povezava med povečanjem hrapavosti pletiv in fotorazgradnjo barve bombažnih in volnenih pletiv, obarvanih z reaktivnimi in kislimi barvili. Dobljeni rezultati prikazujejo vpliv strukture površine pletiv na proces fotorazgradnje barve in kažejo, da količina, razgrajenega zaradi delovanja svetlobe, narašča z večanjem površinske hrapavosti pletiva.
Ključne besede: pletivo, pletilske vezave, hrapavost, fotorazgradnja, svetlobna obstojnost

1 Introduction

The roughness of fibrous materials is an important aspect of their quality and determines the surface properties and appearance of fabrics and knitted fabrics as well as products made from them [1, 2].
We have already examined the effect of the nature of the polymer matrix [3], preparation technologies [4, 5], chemical properties [6, 7] and dye concentration [8] on the light fastness of cotton and wool knitted fabrics colours. Despite the fact that the light fastness of colours largely depends on the chemical structure of dyes, in order to obtain comprehensive data, in this work, we planned to study the effect of structural characteristics of knitted fabrics from natural fibres on the light fastness of their colours. The irregularity of the surface of knitted fabrics of various knitted structures is proposed to be assessed by determining roughness indicators.
The roughness of material is characterized by the parameters given in ISO 4287:1997. Geometrical Product Specifications – Surface texture: Profile method – Terms, definitions and surface texture parameters [9]. According to these parameters, surface roughness is a set of surface irregularities with a relatively small step that is usually determined by its profile (Figure 1), which is formed in the cross section of this surface by a plane perpendicular to the nominal surface. In this case, the roughness profile is considered along the length of the baseline and is used to highlight the irregularities and quantify the parameters.
The assessment of surface roughness is based on the accepted reference system, in which the middle line of the profile serves as the baseline – this is the baseline *m*, which has the shape of a nominal profile and is drawn, so that the standard deviation of the profile to this line is minimal within the base length. The middle line of the profile is at the same distance from the lines of the peaks and valleys of the profile, which respectively pass through the highest and lowest points of the profile within the base length.
The main characteristics of the roughness profile are the height of its peak y_{pm} and the depth of its valley y_{vm}. These are the distances from the midline of the profile to the highest point of the peak and the lowest point of the valley, respectively.
To assess the surface roughness of fibrous materials, the height criterion R_z is common – the height of the profile at ten points [9]. It is the sum of the average absolute values of the heights of the five largest peaks of the profile and the depths of the five largest valleys of the profile within the length of the profile.
The criterion of the arithmetic mean deviations of the R_a profile, which is the arithmetic mean absolute value of profile deviations within the basic profile length [9, 10], is also significant for assessing surface roughness. Thus, to calculate the roughness parameters of knitted fabrics, it is necessary to obtain their roughness profiles.

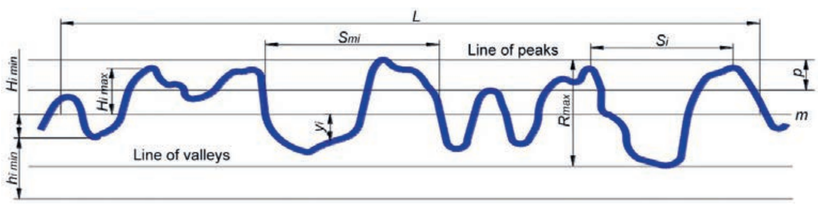


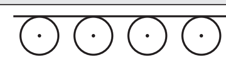
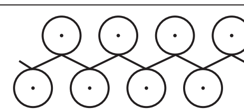
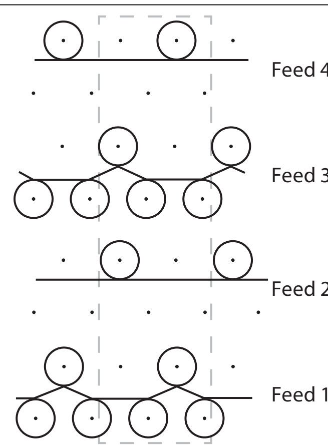
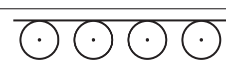
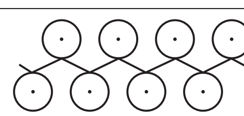
Figure 1: Roughness profile and its characteristics

Studies aimed at measuring and evaluating the profile characteristics of the roughness of textile materials using various devices are presented in [11, 12, 13], where all methods are divided into contact and non-contact. Contact methods for determining roughness involve a direct measurement of the relief of a textile material using a multidirectional tribometer [12], an optical multidirectional roughness meter [14], the so-called "vibrating blade" [15], and an inductive sensor converting displacement into an electric stream [16]. Non-contact measurement of roughness is performed using a variety of optical profilometer systems: Talysurf CCI 6000 [17], Micro Measure 3D Station [18], MicroXAM-100 and MicroXAM-1200 [19], Puotech 0918 [20], helium-neon laser [21, 22], triangulated laser technology [23], and microscopy and confocal microscopy [22]. However, these devices are expensive and not widely available.
The method for determining the roughness of textile materials using software products for processing scanned images, proposed in [24], does not require additional equipment and is available. Therefore, in this work, the determination of the roughness indicators of knitted fabrics was carried out in a non-contact way, that is by the optical method of processing digital images of the knitted fabrics surface in the JMicroVision 1.3.2 software environment.

2 Materials and methods

In the work, cotton and wool knitted fabrics of various knitted structures and surface density were investigated. Their main characteristics are given in Table 1.
Cotton knitted fabric was dyed with Bezaktiv Cosmos reactive dyes: Rot S-C, Blue S-C, Gold S-C, which are bifunctional reactive dyes with monochlorotriazine / vinyl sulfone active groups. Dyeing cotton knitted fabric was carried out using the exhaust dyeing method with a 1/50 solution rate. The mass of the knitted fabric sample was 1 g. The dye

Table 1: Characteristics of knitted fabrics

Raw material	Knitted structure	Surface density (g/m²)	Schematic representation of knitted structure
100% cotton	Single plain	150	
	1×1 rib	150	
	1×1 rib	280	
	French piqué	170	
100% wool	Single plain	420	
	1×1 rib	380	
	1×1 rib	450	

solution contained 1% dye and dyeing auxiliaries (30 g/l NaCl + 15 g/l Na_2CO_3). The dyeing was performed for 60 min at 60 °C, followed by applying overflow cold, hot washing, boiling soaping and cold rinsing procedures [25].

For dyeing the wool knitted fabric, the following acid dyes were used according to the corresponding dyeing methods: Acid Red 150 (method I), Acid Blue 92 (method II), Acid Green 27 (method followed by chroming). Dyeing technologies with acid dyes depend on their chemical structure. Dyeing of wool knitted fabric was carried out with the exhaust dyeing method. Samples of wool knitted fabric with a mass of 1 g and a liquor to fabric ratio of 50:1 were used. The dyebath contained 1% owf dye, 10% owf sodium sulphate, 4% owf acetic acid 30% (method I) or 4% owf ammonium sulphate (method II). Sodium sulfate and an acid agent (acetic acid or ammonium sulfate) were introduced into the total volume of water, heated to 40 °C , and knitted fabric samples were immersed in the solution. The treatment was carried out for 10 min. Then, the samples were taken out, the dye was added to the solution and the knitted fabric was immersed again. Next, the dye bath was heated to boiling point for 30 min. and dyed for 45 min. The dyed samples were washed with cold water and dried [26, 27].

The technology of dyeing wool knitted fabric with chrome dyes was followed by chroming. The liquor to fabric ratio was 50:1. The dyebath contained 1% owf dye, 10% owf sodium sulfate, 4% owf acetic acid. 30% Sodium sulfate, acetic acid and knitted fabric were introduced into the total volume of water at 30–45 °C, heated to boiling point for 45 minutes. Then, concentrated sulfuric acid measuring 1% of weight of the knitted fabric was introduced into the bath and dyed for another 20 min until the dye was completely exhausted. Afterwards, the temperature was lowered to 80 °C by adding cold water and a solution of potassium dichromate was introduced

Table 2: Indicators of light fastness of colours of the dyes used

Reactive dyes	Light fastness	Acid dyes	Light fastness
Bezaktiv Cosmos Rot S-C	4–5	Acid Red 150	4
Bezaktiv Cosmos Blue S-C	5–6	Acid Blue 92	4
Bezaktiv Cosmos Gold S-C	6	Acid Green 27	6

in the amount of 1% of the weight of knitted fabric. Chroming was carried out at boiling point for 20 min. Afterwards, the dyed samples were washed with cold water and dried [26, 27].

Table 2 shows the light fastness of colours obtained by the reactive and acid dyes used in the work as declared by the manufacturers [25, 28–30].

The study of the surface roughness of knitted fabrics was conducted by obtaining roughness profiles of the corresponding knitted fabrics samples by processing digital images of the surface of knitted fabrics in the JMicroVision 1.3.2 software environment. Next, the main indicators of surface roughness were calculated: the profile height at ten points R_z and the arithmetic mean profile deviation R_a using formulas (1), (2), according to ISO 4287:1997 [9].

$$R_z = \frac{\sum_{i=1}^{5} y_{pmi} + \sum_{i=1}^{5} |y_{vmi}|}{10} \tag{1}$$

where y_{pmi} is height of the ith largest peak of the profile and

$y_{vmш}$ is depth of the ith largest valley of the profile.

$$R_a = \frac{1}{2n}\sum_{i=1}^{n} y_{pmi} + \frac{1}{2n}\sum_{i=1}^{n} |y_{vmi}| \tag{2}$$

where n is the number of selected points on base length.

The studied indicators were determined for samples of knitted fabrics walewise and coursewise.

The light fastness of samples was evaluated after exposure to the Light Fastness Tester (Mercury-Tungsten Lamp) RF 1201 BS (REFOND) with a PCE-TCR 200 colorimeter. The exposure time of the dyed knitted fabric samples was 320 hours. Colour measurements were averaged for each sample. Total colour difference (*dE*) was measured on the dyed cotton knitted fabrics samples after light exposure. Colour difference was calculated according to CIE 1976 L*a*b* equation (3):

$$\mathrm{dE} = [(dL)^2 + (da)^2 + (db)^2]^{1/2} \tag{3}$$

where *dL* is difference in lightness-darkness, *da* is difference in redness-greenness; *db* is difference in yellowness-blueness.

3 Results and discussion

The obtained profiles of the surface roughness of the cotton knitted fabrics samples of the studied knitted structures and surface density walewise and coursewise are shown in Figure 2.

According to the obtained roughness profiles of cotton knitted fabric, it can be concluded that the studied knitted fabrics vary in roughness, depending on their knitted structures. Knitted fabric with a single plain knitted structure has a uniform roughness of low values in both directions. For the rib, there is an increase in roughness coursewise. Piqué knitted fabric is characterized by high levels of roughness both walewise and coursewise.

Figure 3 depicts the roughness profiles of wool knitted fabric samples of the studied knitted structures and surface density.

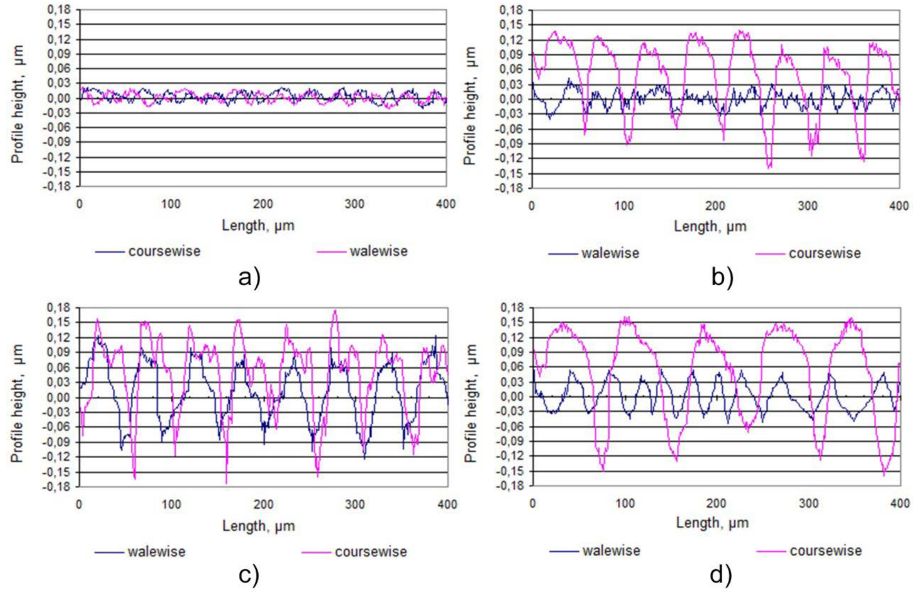


Figure 2: Roughness profiles of cotton knitted fabric samples: a) single plain; b) 1×1 rib 150 g/m²; c) French piqué; d) 1×1 rib 280 g/m²

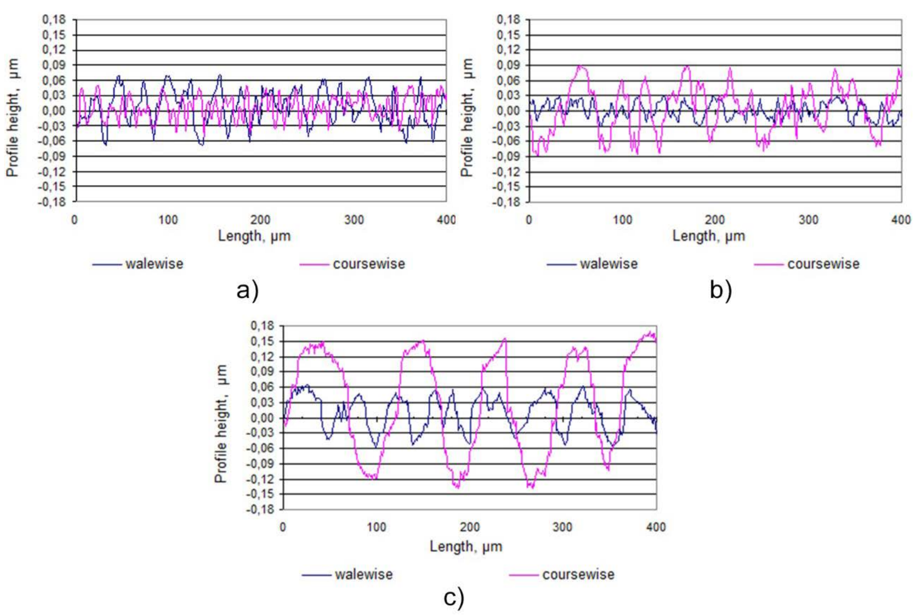


Figure 3: Roughness profiles of wool knitted fabric samples: a) single plain; b) 1×1 rib 380 g/m²; c) 1×1 rib 450 g/m²

Table 3: Influence of knitted structure and surface density on the roughness characteristics of cotton and wool knitted fabrics

Knitted fabric	Knitted structure and surface density	Profile height by ten points, R_z (μm)			Arithmetic mean of profile deviations, R_a (μm)		
		walewise	coursewise	mean	walewise	coursewise	mean
Cotton	Single plain	0.018	0.018	0.018	3.09	4.08	3.58
	1×1 rib, 150 g/m^2	0.029	0.122	0.076	6.39	6.36	6.38
	1×1 rib, 280 g/m^2	0.044	0.142	0.093	6.62	7.11	6.86
	French piqué	0.152	0.139	0.146	8.57	7.75	8.16
Wool	Single plain	0.030	0.047	0.039	7.12	7.25	7.19
	1×1 rib, 380 g/m^2	0.068	0.087	0.078	6.97	8.39	7.68
	1×1 rib, 450 g/m^2	0.089	0.099	0.094	7.56	9.12	8.34

The obtained surface roughness profiles of wool knitted fabric samples of plain and rib knitted structures, as in the case of cotton knitted fabrics, differ. The plain has a more uniform roughness walewise and coursewise on the canvas. The rib is characterized by a uniform surface walewise and an increase in roughness coursewise. For the rib, there is an increase in roughness coursewise, irrespective of the surface density of the knitted fabric.

Based on the obtained roughness profiles, the main roughness characteristics were calculated: the profile height at ten points R_z and the arithmetic mean profile deviation R_a. The research results are presented in Table 3.

The results of calculating the main roughness indicators R_z and R_a (Table 3), which characterize the unevenness of the knitted fabrics surface, show that the roughness of knitted fabrics from natural fibres depends on the knitted structure and increases in the series single plain < 1×1 rib < French piqué and with an increase in surface density. The plain knitted structure has a more uniform roughness walewise and coursewise compared to the rib knitted structure, but less uniformity compared to the plain knitted structure of cotton knitted fabric.

Figure 4 depicts the study results of the colours' photodestruction in knitted fabrics for 320 hours of insolation and the roughness indicators depending on the knitted fabrics' knitted structures.

The results presented in Figure 4 show that with an increase in the roughness of knitted fabrics, the photodestruction of dyes by reactive and acid dyes on cotton and wool knitted fabrics increases, respectively.

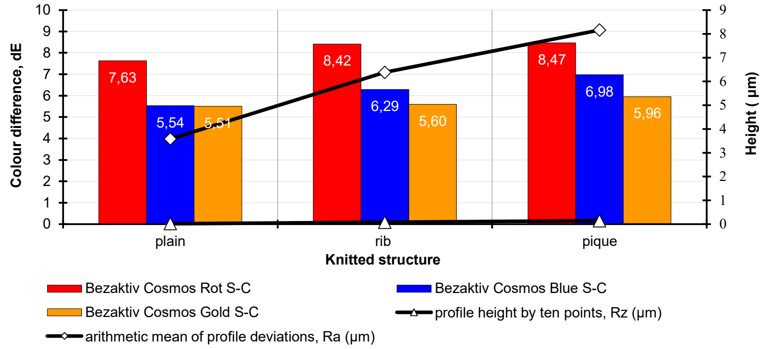
Figure 5 presents the study results of the photodestruction of knitted fabrics colours for 320 hours of insolation and the roughness indicators depending on the surface density of knitted fabrics.

Presented in Figure 5, the results indicate that with an increase in the surface density of knitted fabrics from natural fibres, the roughness increases and the photodestruction of reactive and acid dyes increases on cotton and wool knitted fabrics, respectively.

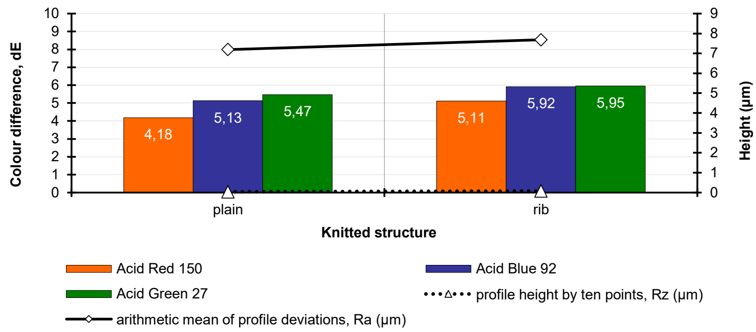
The obtained results confirm the impact of the surface structure of knitted fabrics, that is the knitted structure and surface density, on the photodestruction process of colours and show that the amount of dye that has undergone photodestruction increases with an increase in the surface roughness of the knitted fabric.

Taking into account the results of determining the surface roughness of knitted fabrics and the features of the photodestruction process of colours depending on their knitted structures, Figure 6 shows schematic images of the studied knitted fabrics and the mechanism of light exposure to them.

Thus, the studies on the roughness of knitted fabrics make it possible to determine the relationship between the light fastness of colours and the structural properties of knitted fabrics. The relatively uniform surface of a single plain structure knitted fabric distributes energy evenly and reflects more incident light than knitted fabrics with an uneven rough surface of 1×1 rib and French piqué knitted structures. Knitted fabrics with a more uneven rough surface- 1×1 rib and French piqué reflect less light, the incident rays are refracted and again fall on the surface of the knitted fabrics, which leads to a greater photodestruction of its colours.

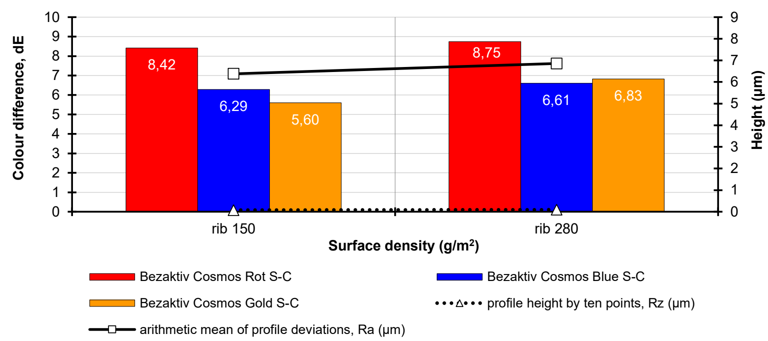


a)

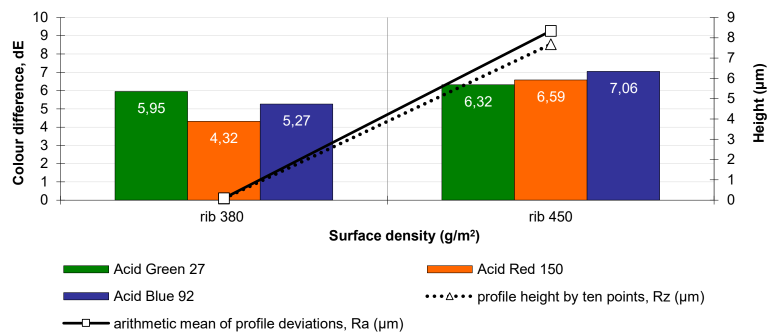


b)

Figure 4: Influence of knitted structure on surface roughness and photodestruction of colours: a) cotton knitted fabrics dyed with reactive dyes; b) wool knitted fabrics dyed with acid dyes



a)



b)

Figure 5: Influence of surface density on surface roughness and photodestruction of colours: a) cotton knitted fabrics dyed with reactive dyes; b) wool knitted fabrics dyed with acid dyes

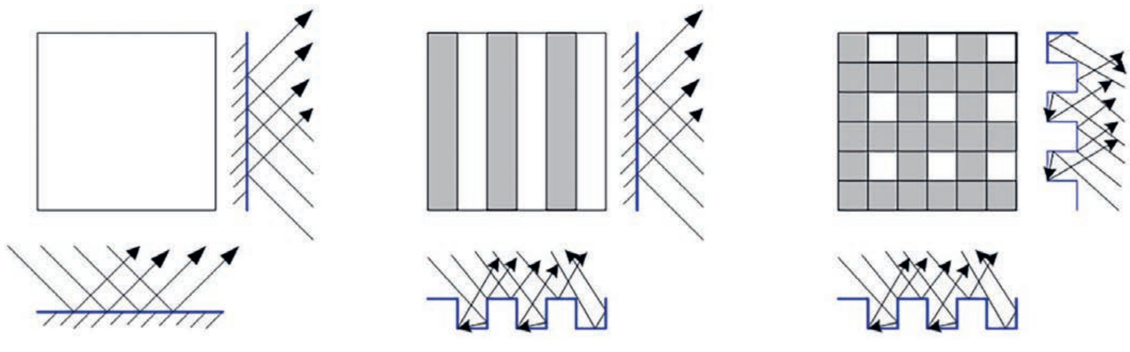


Figure 6: Mechanism of action of light on knitted fabrics of different knitted structures: a) single plain; b) 1×1 rib; c) French piqué

Therefore, on the basis of the obtained roughness profiles by calculating the main characteristics of roughness – the profile height at ten points R_z and the arithmetic mean deviations of the profile R_a – it has been found that for the studied knitted fabrics, the photodestruction of colours increases with the increasing roughness in the series single plain < 1×1 rib < French piqué and with an increase in the surface density of knitted fabrics. Based on the conducted research, we can conclude that knitted fabrics with an uneven rough surface structure necessarily need light-protective treatment.

4 Conclusion

Studies on the dependence of the light fastness of knitted fabrics from natural fibres on the structure of knitted fabrics have showed that the type of knitted structure and the surface density of knitted fabrics have a significant impact on their light fastness. The research of the effect of knitted structure and surface density on the photodestruction kinetics of colours of knitted fabrics from natural fibres showed that both for cotton and wool knitted fabrics, the light fastness of colours increases in the series French piqué < 1×1 rib < single plain and with a decrease in the surface density of the studied knitted fabrics.

On the basis of the obtained roughness profiles and the analysis of the calculated basic characteristics of roughness, it has been found that for the studied knitted structures of knitted fabrics, the increase in roughness coincides with a decrease in the light fastness of colours in the series single plain < 1×1 rib < French piqué. Thus, based on the conducted studies of the effect of the structure of knitted fabrics from natural fibres on its light fastness, it is possible to claim that knitted fabrics with an uneven rough surface structure require a protective treatment that will ensure their light fastness.

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