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Impregnation of Microencapsulated Aroma Oil on Ramie Blended Terry Textile and its Bending Rigidity

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Abstract
An aroma agent containing eucalyptus essential oil was used for the development of a smart terry textile. The performance of terry woven fabric with microcapsules in relation to varied amounts of binder as well as the weft density of the fabric was evaluated. By SEM analysis it was confirmed that microcapsules really covered the terry textile. The bending rigidity and coefficient of anisotropy of samples modified with microcapsules and untreated ones were assessed. Due to additive components such as microcapsules and binder, the bending rigidity of terry fabric increased by even 5.1-12.8 times in the weft direction and by 5.3-14.0 times in the warp direction compared with grey ones. The research developed an analysis and empiric mathematical model suitable for predicting of binding rigidity as well as designing new terry fabrics with required binding properties.

Key words: *aroma oil, bending rigidity, binder, concentration, microcapsules, terry textile.*

Introduction

Presently textile products are required to perform extra properties and offer active functionality like microcapsules (MCs) containing carbon nanofibres [1], and some of them have come to be known as smart textiles [2]. The potential applications of microencapsulating also include insect repellents, dyes, vitamins, antimicrobials, phase change materials and specific applications like antibiotics, hormones and other drugs [3], covering such fields like agriculture, pharmacy, food, cosmetics, textiles, paints, adhesives, coatings, etc. [4].

Aroma products with microcapsules could be applied to almost all industrial products, such as papers, plastics, paints, scented stamps, cellular phones, greeting cards, as well as textiles, thereby creating scented clothing [5]. There are various essential oils which have found their place in aroma therapy, providing skin glowing, moistening, refreshing and other wellness effects [6]. Many companies have continued their interest in microencapsulated fragrances [3] that emit the natural aroma of flowers, fruit, herbs, perfumes, etc. Such products continue to sell well, particularly in hosiery, gloves, socks, scarves, ties, handkerchiefs, curtains, cushions, sheets, toys, and other products. Furthermore modified textiles are used for specific purposes like first-aid, clinical, and hygienic as well as for improving the barrier effect against pathogens and their carrier medium [7, 8].

Natural fibres such as cotton, flax, bamboo and ramie [9-12] are favourable for various textiles with microcapsules, including cosmetic ones, but some man-made fibres like lyocell [7], polyamide [13] or blended textiles like wool/polyester [14, 15] are also used. According to [6], applying microcapsules on polypropylene, acrylic fibre surfaces are also obtained.

Microcapsules are mostly evaluated in terms of particle size, morphology, shell material composition, fragrance intensity [16] as well as particle size distribution and encapsulation efficiency [1, 9]. The size of microcapsules with perfumes generally varies form 1 to 10 μm [14, 16], but some authors confirm an interval between 1 and 100 μm with a mean size of 27 μm [13].

Some investigations have been made on materials without any treatment; but the binder plays an important role in the performance of the active product, influencing the adhesion to the textile subtract [15]. Fabric coated with 35 wt.% of microcapsules added relative to the coating binder showed an energy storage capacity of 7.6 Jg^{-1}, high durability and adequate stability after washing, rub fastness and ironing treatments [17].

Some mechanical impacts: the washing/laundering test, ironing test and rubbing test [2, 17-19] of textiles with microcapsules, were performed and the quality of the textile evaluated. For evaluation of the handle of cotton and lyocell knits treated with MCs containing *Citrus unshiu* essential oil (MIC-CUEO), some mechanical properties were investigated including the bending rigidity, shear stiffness, and frictional coefficient [20]. The research concluded that the knits tended to be more resistant against bending after treatment with MIC-CUEO. In order to improve the handle of dyed cotton fabrics with microcapsules [19], a softener was treated in a simultaneous step with MCs or in a separate step after the dying procedure. It was found that after dying and microcapsule treatments, the stiffness of the fabrics increased very slightly, i.e. from 1.43 till 1.52 cm. Yet the sample which was treated with softener in a separate step was stiffer compared with that treated with softener simultaneously. [21] presents a new method of measuring the bending rigidity of fabrics and its application for the determination of their anisotropy. The way of measuring the anisotropy of bending rigidity on circular samples described can speed up and improve the quality of investigations in the field of the influence of the textile structure on bending rigidity and, consequently, on draping as wrinkling of the textile. Nevertheless the thickness of the textile tested is important. Moreover materials whose thickness does not exceed 1.5 mm can be bent using the device.

Microcapsule concentration levels in study [22] were 5, 10, 25 and 40%, calculated from the weight of microcapsules to that of the acrylic binder. It was found that the bending rigidity of plain weave PES fabric with microcapsules was more than 400% greater with 40% concentration compared with the control. With nonionic surfactant, for a 25% concentration, the bending rigidity declined (no surfactant, 0.00272 $N \cdot cm^2/cm$, 0.5% surfactant, 0.00228 $N \cdot cm^2/cm$). For primary handle values of treated fabrics, as the

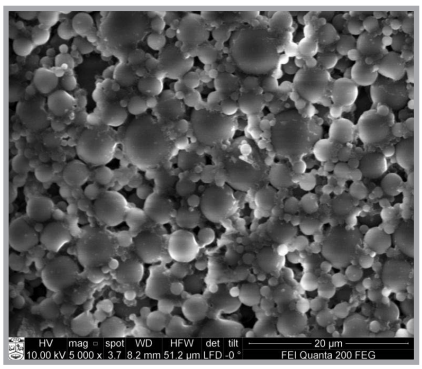

Figure 1. *Scanning electron microscopy photographs of the microcapsules with Eucalyptus essential oil, 5000 x magnification.*

concentration increased, the values of Koshi (stiffness), Shari (crispness), and Hari (anti-drape) increased. The performance and hand properties of polyester knit fabrics treated with PCM microcapsules were investigated in [23]. The fabrics treated become stiffer and more inelastic in bending with an increase in the add-on. It was found that the bending stiffness and bending hysteresis of modified knit fabrics increased by 0.001715-0.00250 N·cm^2/cm and 0.00169-0.00201 N·cm^2/cm, respectively, as the add-on was increased from 5.3 to 22.9%.

Although there is a great demand for smart home textiles, there are very few investigations on terry textile treated with microcapsules, as well as comprehensive research on the quality of such products in relation to various factors. Supposedly this is due to the irregular structure of terry textile, the variety in warp and weft components, and the complexity of production. Especially there is a lack of investigations on predicting the peculiarities of terry fabric quality in dependence on the impregnation process and materials used. Despite the fact that the processes of application of MCs as well as the binder are very important factors influencing textile with microcapsules, only some studies on the bending properties of such products are presented in the literature.

In order to understand the bending rigidity of terry fabrics treated with microcapsules, as investigated in this research, it is important to consider how the fabric's structure acts. The type of weft, ground warp and pile warp yarns, pile structure, fabric density and treatment process are the main parameters that can be used to design fabrics with the required quality. Hence two effects were studied:

- impregnation conditions for treating terry fabrics,
- structural effect of terry fabric with respect to bending rigidity.

For the last effect it is important to discuss the factors influencing the values of bending rigidity as this property is diverse, having in the mind that terry textile for clothing, towels, sauna/bathrobes, headgears, etc. could be preferable as soft ones with a tender handle or as stiff ones with massage features.

The aim of this paper was to evaluate different concentrations of binder applied for treating terry fabric with microcapsules containing aroma oil, as well as to analyse the effect of the fabric structure, and to perform a prognosis for the fabric's bending rigidity in relation to the fabric structure and binder concentration.

Experimental

Ramie (pile warp: 67 tex)-cotton (ground warp: 25 tex x 2, ground weft: 50 tex) terry fabrics of 8, 10, 12, 14 & 16 weft/cm yarn density (fabric variants: RC8, RC10, RC12, RC14, RC16, respectively) and 25 pile and ground warp/cm were specially woven for this experiment. The pile height of the terry fabrics was 6 mm. Grey terry fabrics were investigated (without any finishing) and then after impregnation. Commercial MCs containing essential oil of Eucalyptus (LJ Specialities, UK) were used for the treatment. ITOBINDER AG (LJ Specialities, UK) was used to bond MCs to the fabric with varied concentrations: 20, 35, 50, 65, 80 and 95 g/dm^3. MCs of 30 g/dm^3 was also applied. The producer gives the general approximate characteristics of MCs: solid content – 50%, pH – 6-7, and destruction of the capsules follows mechanical impacts such as rubbing and scrubbing. The properties of ITOBINDER AG are as follows: main ingredient – acrylic copolymer, anionic, pH ~ 6-8, solid content ~ 40%, viscosity <100 cps. (at 30 °C, 10 rpm). MCs and ITOBINDER AG can be applied to various fibres.

No finishing was used to promote the adhesion of MCs to terry textile because one of the leading factors in the performance of bio-functional textile is the active agent delivery mechanism, which could be interfered with by the use of additional treatment procedures. Microcapsules were applied to terry fabrics on a laboratory scale by the impregnation method according to the recommendations of the MC supplier as well as reproducing the industrial conditions. The fabrics with MCs were pre-dried at 20±2 °C temperature, then dried at 105-110 °C (for 1 minute) and cured at 150 °C (for 2 minutes) in an oven – SNOL 20/300 LFN (Lithuania).

The conditions of the coated microcapsules and the type of the interface between the binder and microcapsules as well as between the binder and textile were examined by scanning electron microscopy Quanta 200 FEG (USA). SEM micrographs also were used for analysis of the presence, shape, sphericity, size, morphology and distribution of MCs. Each sample of MCs, impregnated ground and terry cover was fixed on a standard sample holder and then examined with accelerating voltage (5.00-20.00 kV) and at a magnification of 500 x or 5000 x. The chemical compositions of the microcapsules and binder were studied using a Fourier transform infrared spectrophotometer – Spectrum GX (Perkin Elmer, USA), with a scanning range between 4000 and 400 cm^{-1}. Before measuring the samples, the background was scanned at a scanning condition resolution of 2 cm^{-1}, with a speed of scanning of 0.2 cm/s and number of scans of 20, in order to eliminate the effect of background absorption. The specimen was then measured under the same scanning conditions as for the background.

The thickness (S) of the fabric was measured according to [24] using a digital indicator – DPT 60 (Germany). Standard loading during the measurement was 0.1 kPa. The area density (A) of the fabric was measured according to [25].

Bending rigidity (B) was investigated [26] using a standard non-contact device. The tester measured the fabric strain under its own weight (gravitation method). This method uses the determination of the bending length as a measure of the interaction between fabric weight and stiffness. There are many test methods known for measuring textile bending rigidity [27], but the gravitation method was more proper for terry textile because of its simplicity and widespread nature. This test method applies to most fabrics including woven and various treated ones. With the purpose of receiving more exact results, the number of experiments was increased till 7 (according to the standard [26], the number of the samples is 5). The samples were conditioned for 24 hours and all the experiments per-

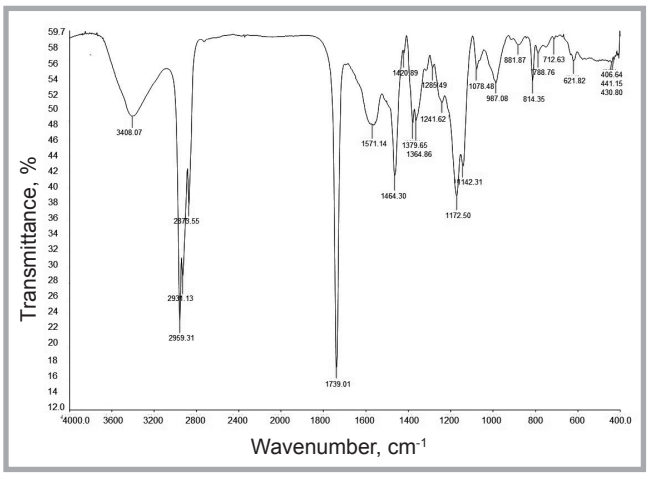

Figure 2. *FTIR spectra of Eucalyptus MCs.*

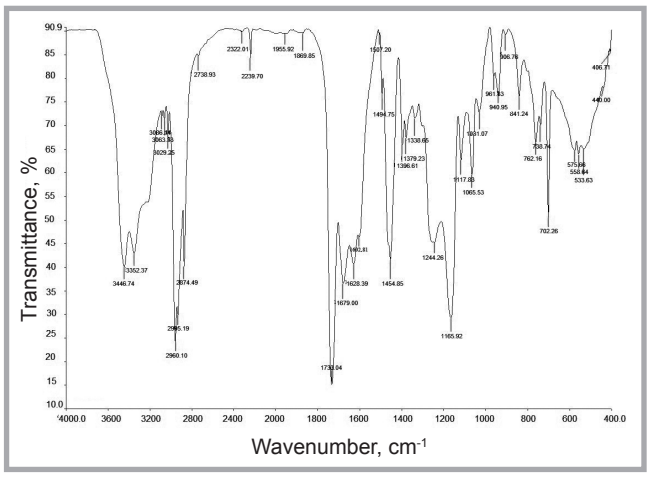

Figure 3. *FTIR spectra of binder ITOBINDER AG.*

formed under normal values: 20±2 °C for the temperature and 65±4 % for the relative humidity [28].

All statistical analysis for the experiments was performed using a standard Microsoft Excel Analysis Tool Pack.

Results and discussion

Terry fabrics with loop pile on one or both sides are the most popular textile for towels, children's clothes, bath-room and sauna textiles: robes, headgears, and slippers, as well as for hygiene products, etc. The benefits of eucalyptus oil include well-known qualities: skin regeneration and healing, antiseptic, deodorant, refreshing, and reviving. Thus in this study microcapsules with eucalyptus essential oil were used for terry fabrics.

Analysis of the shape and distribution of the particle size was performed analysing SEM images. Such analysis as well as the characterizations of the interface binder/microcapsules and binder/textile were effective in other studies [29, 30]. We noticed that the Eucalyptus microcapsules obtained were similar in morphology (***Figure 1***), where they all had a spherical shape. No destruction of the microcapsule shells was perceived. A distribution of the particle size was observed, showing many particles with a particle size generally of 0.1-4.0 µm. The largest amount of MCs (24.4%) was of 0.4-0.7 µm. The small particle sizes facilitate them not only to adhere and cover the surface of the fabric, but also to penetrate and attach to the fibre surfaces, as well as to fill the gaps between fibres and the amorphous area of fibres. MCs larger than 4.0 µm diameter comprised only 5.7%. The composition of microcapsules and ITOBINDER AG were characterised by FTIR. ***Figures 2*** and ***3*** illustrate the FTIR spectra of Eucalyptus MCs and the binder, respectively. The spectra of Eucalyptus MCs illustrated characteristic peaks at 2959 cm^{-1}, 2931 cm^{-1} and 2873 cm^{-1} with respect to the functional group of C–H, as well as strong peak at 1739 cm^{-1}, which was assigned to the stretching vibration of the C=O group. Spectra of the binder illustrated characteristic peaks at 2960 cm^{-1}, 2935 cm^{-1} & 2874 cm^{-1}, which could be assigned to the stretching vibration of C-H as well as the peaks at 1733 cm^{-1}, (C=O), 1165 cm^{-1} (C–O) and 3446 cm^{-1} (N–H and O–H). ITOBINDER AG is suitable for the application of MCs to the composition of terry fabrics selected.

Terry textiles from ramie and cotton yarns were woven for further experiments. Such a fibre composition was selected because of the popularity of cotton fibre and the well known advantages of ramie fibre: its resistance to bacteria and mildew, extremely absorbent, increases in strength when wet, withstands high temperatures during treatment and care, keeps the shape, and does not shrink.

The presence of microcapsules with fine dispersion in impregnated ramie and cotton fibre of terry fabric was obvious. SEM micrographs also confirmed the spherical morphology of the particles (***Figure 4***). Although in many SEM micrographs we observed a good wrapping of the binder around the textile, the behaviour of the binder on the ramie and cotton fibres varied. On the cotton, the binder tended to coat the sockets and fill twilling parts. Meanwhile, on the ramie, the binder wrapped the fibres more homogeneously inside the core of the yarns. Furthermore the microcapsules were linked to the surface of the fibres by being completely enwrapped by the binder, or by creating a linkage with the binder between cotton or ramie fibres. The significance of the structure of textile for the adhesion of microcapsules was also confirmed by other researchers [31]. They stated that in comparison with the plain weave structure and 2/1 right twill structure, the honeycomb fabric structure

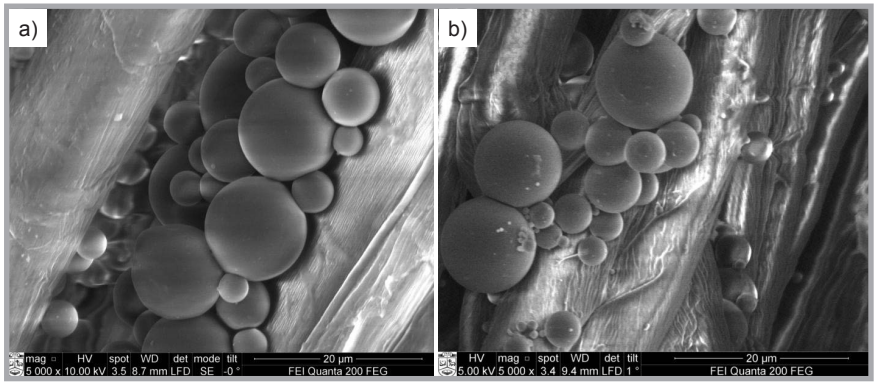

Figure 4. *Presence of microcapsules (binder concentration 80 g/dm³, 150 °C thermo-fixing temperature) on a) ramie fibre, 5000x magnification & b) cotton fibre, 5000 x magnification.*

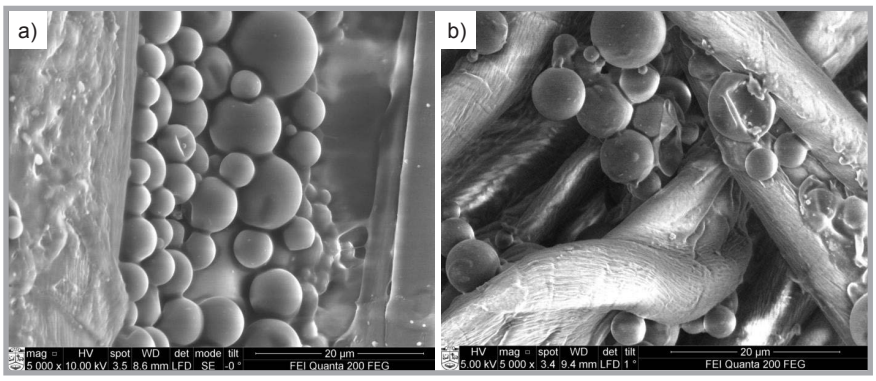

Figure 5. *SEM images of yarns after treating at 160 °C thermo-fixing temperature (binder concentration 80 g/dm³): a) ramie fibre, 5000 x magnification, b) cotton fibre, 5000 x magnification.*

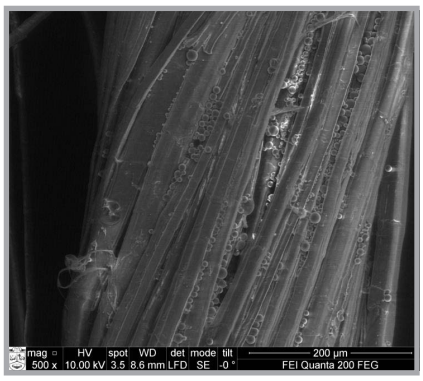

Figure 6. *SEM micrograph of ramie impregnated with microcapsules at binder concentration 80 g/dm³, 500 x magnification.*

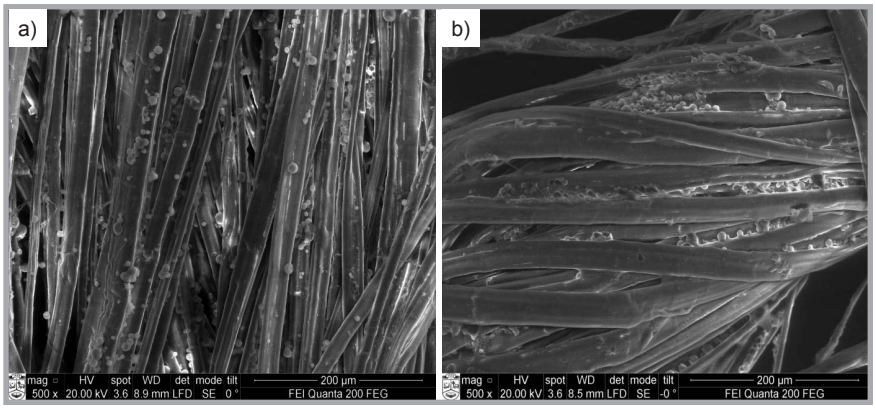

Figure 7. *SEM micrographs (500 x magnification) of ramie fibre of treated terry fabric with weft density of 8 cm⁻¹ and different binder concentrations: a) 20 g/dm³, b) 95 g/dm³.*

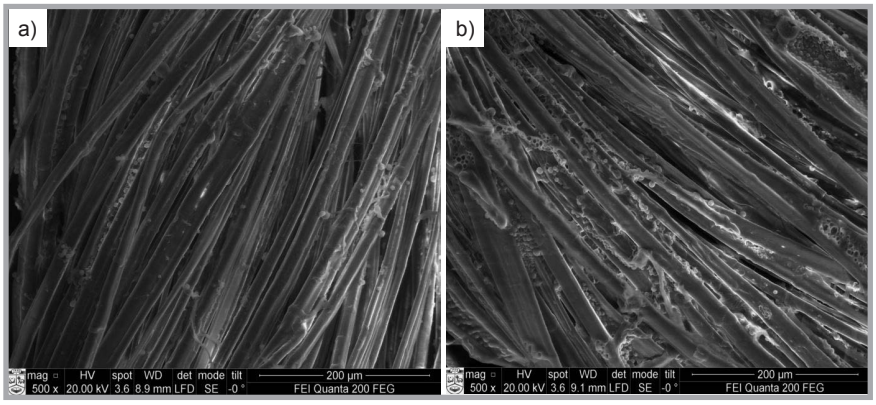

Figure 8. *SEM micrographs (500 x magnification) of ramie fibre of treated terry fabric with weft density of 16 cm⁻¹ and different binder concentrations: a) 20 g/dm³, b) 95 g/dm³.*

is better for carrying microcapsules. In addition, the weft yarn density and weft yarn count also affect the loading capability of woven fabrics. Yarn density and linear density determine the number of yarns in a unit length and the number of fibres in a unit area, respectively. As a result, although high yarn density and linear density may cause a decrease in voids between yarns and fibres, the number of microcapsules embedded on yarns and fibres dramatically increases.

As high temperatures can cause damage to MCs, the thermo-fixing temperatures suitable for MCs with Eucalyptus essential oil were examined. SEM analysis showed that with heating up to 160-170 °C, surface damage to MCs was noted, being a typical appearance in many cases. This confirms that some MCs lost their active agent and deflated or became empty (***Figure 5***). Other authors [32] also confirmed the importance of the curing temperature while investigating microcapsules with lavender fragrance applied on cotton fabrics. They stated that as the fabrics were cured at 150 °C a greater number of MCs remained on the surface than for those without any curing.

It was found that the general tendency that mostly small in diameter MCs remained in the fabric is more certain. Such a phenomenon, but concerning the washing effect, also was detected by other authors [33], confirming that after five washing cycles, only small microcapsules remained fastened to knits and were located between fibres. Additionally we noticed that during the impregnation process of terry fabrics, some MCs tended to agglomerate, but these collections are purely single ones. Besides, SEM analysis proved that MCs not only coated the surface of ramie fibres but were also fixed in the spacing of the yarn (***Figure 6***). Therefore we can conclude that there are differences in the spreading of MCs regarding the weft density of terry fabric and binder concentration (***Figures 7, 8***). In the case of the low weft density of terry fabric (8 cm⁻¹), the coating is more homogeneous, with MCs being distributed between fibres and their inner layers, wrapping them smoothly, and almost without agglomerations. In the case of high weft density (16 cm⁻¹) and binder concentration (95 g/dm³), the coating is not very uniform, where some agglomerations could be observed.

The thickness and area density of the terry fabrics investigated are presented in ***Table 1***. The thickness of grey terry fabrics varied by 2.09-3.43 mm, whereas for the treated ones, this index ranged from 2.87 to 4.57 mm depending on the weft density and binder concentration. The area density of fabrics with MCs increased by 14.7% (for the RC8 variant, binder

Table 1. *Area density and thickness of terry fabric: A and S – mean of area density and thickness, respectively, Δ – absolute error.*

Fabric variant	Test index	Area density and thickness of terry fabric					
		Grey fabric	Treated fabric, when binder concentration equaled:				
			20 g/dm³	35 g/dm³	50 g/dm³	65 g/dm³	80 g/dm³	95 g/dm³
RC8	A±Δ, g/m²	240.7±12.9	282.9±4.7	286.0±10.6	276.2±20.7	292.7±5.8	286.2±15.4	292.6±20.3
	S±Δ,mm	2.09±0.04	2.87±0.10	2.95±0.08	3.02±0.09	2.95±0.12	3.01±0.09	3.10±0.03
RC10	A±Δ, g/m²	299.7±14.8	328.5±16.2	342.0±15.3	325.0±11.6	337.5±22.3	342.3±9.3	335.4±18.7
	S±Δ,mm	2.46±0.07	3.11±0.08	3.28±0.15	3.46±0.13	3.35±0.09	3.68±0.15	3.76±0.19
RC12	A±Δ, g/m²	289.6±16.0	325.3±22.5	313.2±39.8	328.2±43.2	330.4±19.8	330.8±23.1	350.5±22.3
	S±Δ,mm	2.59±0.10	3.14±0.11	3.46±0.05	3.42±0.22	3.52±0.06	3.43±0.11	3.54±0.10
RC14	A±Δ, g/m²	398.9±19.7	453.0±24.8	472.4±25.8	467.0±34.2	461.6±16.0	491.0±36.7	507.1±24.6
	S±Δ,mm	3.18±0.02	3.75±0.13	3.84±0.14	3.99±0.14	4.01±0.09	4.03±0.13	4.06±0.16
RC16	A±Δ, g/m²	431.2±23.6	486.3±20.0	475.4±21.2	481.0±25.8	504.9±23.1	485.0±35.4	510.3±16.7
	S±Δ,mm	3.43±0.06	3.83±0.06	3.88±0.12	3.99±0.10	4.35±0.17	4.44±0.11	4.57±0.15

concentration 50 g/dm³) – 18.3% (for the RC16 variant, concentration 95 g/dm³) compared with grey ones, and varied from 276.2 to 510.3 g/m². The relative error of the area density of grey and treated terry fabrics did not exceed 7.5%, except for single cases, where it was till 13.2%. The relative error of the thickness of grey and treated terry fabrics varied by 0.6-6.4%.

Table 2. *Bending rigidity of grey terry fabrics: B – mean, Δ – absolute error, δ – relative error, SD – standard deviation.*

Fabric direction	Test index	Fabric variant				
		RC8	RC10	RC12	RC14	RC16
Warp direction	B±Δ, Nm²	0.65±0.09	0.68±0.05	1.09±0.08	1.33±0.18	1.03±0.07
	δ, %	13.8	7.4	7.3	13.5	6.8
	SD, Nm²	0.09	0.05	0.09	0.20	0.08
Weft direction	B±Δ, Nm²	0.46±0.04	0.65±0.05	0.49±0.06	0.84±0.11	1.16±0.13
	δ, %	8.7	7.7	12.2	13.1	11.2
	SD, Nm²	0.05	0.06	0.06	0.12	0.14

The surface morphology of the fabric was extensively changed by the microcapsule treatment. This alteration also affected the stiffness of the textile. The binder coverage and penetration to the terry fabric surface govern the extent of bending rigidity. The bending rigidity of the grey and treated terry fabrics and statistical indices regarding the binder concentration and weft density are presented in ***Tables 2*** and ***3***. It is obvious that after the treatment procedure all the samples showed an increase in bending rigidity compared to the grey ones, arising from the specific structure of terry fabric, distinctive for its abundant loop cover and bulk appearance, with plenty of emptiness and hollow cavities. It was found that the bending rigidity of grey terry fabrics varied from 0.65 to 1.33 Nm² when analysing the warp direction and from 0.46 to 1.16 Nm² for the weft direction regarding all intervals of weft density investigated. Meanwhile for the samples treated it was found that the bending rigidity increased from 5.57 (RC10 variant, binder concentration 20 g/dm³) to 12.94 Nm² (RC14 variant, binder concentration 95 g/dm³) when analysing the warp direction and from 2.35 (RC8 variant, binder concentration 50 g/dm³) to 10.78 Nm² (RC14 variant, binder concentration 95 g/dm³) when analysing the weft direction. As the binder filled the voids, interstitial cavities, inter-fibre and inter-yarn spaces, sealing the pores of the fabric, the textile became rigid. Besides this, the bending rigidity increased by 5.3-14.0 times for the warp direction and by 5.1-12.8 times for the weft direction when varying the binder concentration at all intervals investigated compared with grey fabrics. It means that the terry fabrics tended to be considerably more resistant against bending due to the treatment with microcapsules and binder. Also other authors [34] found that cross-linking improved the dimensional stability but affected the softness of cotton, which further increased the stiffness of the fabric treated. ***Figure 9*** shows the bending rigidity in the weft direction of the terry fabrics treated in relation to the weft density, showing a good relation between the parameters investigated. While a very clear trend was not seen analysing bending rigidity in the weft direction in dependence on the binder concentration. Statistical analysis showed that all the changes in bending rigidity for the weft direction were statistically significant when comparing the minimum and higher values, i.e. 8.0 cm^{-1} and 14-16 cm^{-1} of the weft density examined. All differences in the changes in binding rigidity when comparing the fabric before treatment and with MCs were statistically significant for all binder concentrations and all weft densities investigated. The high values of relative error of binding rigidity were conditioned by the high irregularities of the terry structure itself.

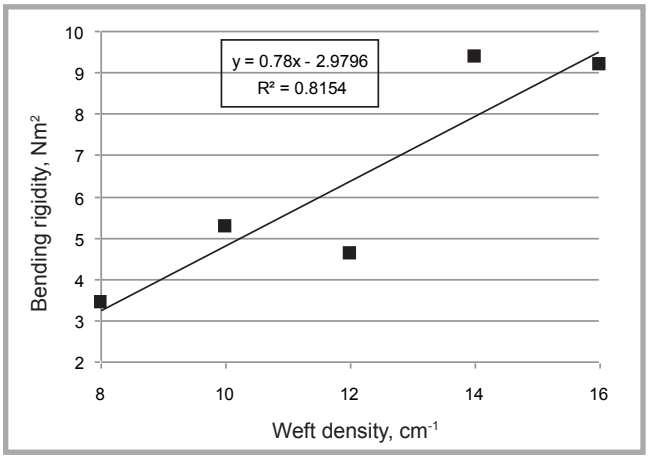

Figure 9. *Bending rigidity in weft direction of treated terry fabrics in relation to weft density.*

Table 3. *Bending rigidity of treated terry fabrics: B – mean, Δ – absolute error, δ – relative error, SD – standard deviation.*

Fabric variant	Fabric direction	Test index	Binder concentration					
			20 g/dm³	35 g/dm³	50 g/dm³	65 g/dm³	80 g/dm³	95 g/dm³
RC8	Warp direction	B±Δ, Nm²	8.32±1.02	8.24±0.78	7.30±0.87	7.02±0.91	6.44±0.53	9.09±1.29
		δ, %	12.3	9.5	11.9	13.0	8.2	14.2
		SD, Nm²	0.82	0.63	0.70	0.73	0.42	1.04
	Weft direction	B±Δ, Nm²	2.86±0.31	3.40±0.24	2.35±0.10	2.46±0.27	3.45±0.49	3.54±0.37
		δ, %	10.8	7.1	4.3	11.0	14.2	10.5
		SD, Nm²	0.25	0.19	0.08	0.21	0.40	0.30
RC10	Warp direction	B±Δ, Nm²	5.57±0.57	6.03±0.37	6.13±0.53	7.13±0.92	6.47±0.61	6.84±0.72
		δ, %	10.2	6.1	8.6	12.9	9.4	10.5
		SD, Nm²	0.46	0.29	0.43	0.74	0.49	0.58
	Weft direction	B±Δ, Nm²	3.43±0.23	3.93±0.46	4.20±0.46	4.89±0.54	5.26±0.25	5.95±0.60
		δ, %	6.7	11.7	11.0	11.0	4.8	10.1
		SD, Nm²	0.18	0.37	0.37	0.43	0.20	0.48
RC12	Warp direction	B±Δ, Nm²	5.93±0.61	8.31±0.91	8.46±1.05	8.67±0.45	6.95±0.56	8.47±1.04
		δ, %	10.3	11.0	12.4	5.2	8.1	12.3
		SD, Nm²	0.49	0.73	0.84	0.36	0.45	0.84
	Weft direction	B±Δ, Nm²	5.85±0.75	3.70±0.50	5.15±0.62	5.25±0.28	4.63±0.57	6.16±0.56
		δ, %	12.8	13.5	12.0	5.3	12.3	9.1
		SD, Nm²	0.60	0.41	0.50	0.23	0.46	0.45
RC14	Warp direction	B±Δ, Nm²	7.05±0.39	8.48±1.21	8.89±1.15	8.27±0.89	11.04±1.67	12.94±1.36
		δ, %	5.5	14.3	12.9	10.8	15.1	10.5
		SD, Nm²	0.32	0.98	0.93	0.71	1.34	1.10
	Weft direction	B±Δ, Nm²	7.06±0.92	6.84±0.95	8.54±1.20	8.85±0.70	9.39±1.14	10.78±1.51
		δ, %	13.0	13.9	14.1	7.9	12.1	14.0
		SD, Nm²	0.74	0.76	0.97	0.56	0.92	1.21
RC16	Warp direction	B±Δ, Nm²	9.17±0.93	10.74±1.39	9.20±1.56	9.49±0.97	10.69±1.27	10.79±1.43
		δ, %	10.1	12.9	17.0	10.2	11.9	13.3
		SD, Nm²	0.75	1.12	1.26	0.78	1.03	1.15
	Weft direction	B±Δ, Nm²	9.93±0.46	9.43±1.58	8.18±1.01	8.49±0.72	9.18±0.99	8.85±0.81
		δ, %	4.6	16.8	12.3	8.5	10.8	9.2
		SD, Nm²	0.37	1.27	0.81	0.58	0.80	0.65

Table 4. *Coefficient of anisotropy (K_C) of terry fabrics.*

Fabric variant	K_C of grey fabrics	K_C of treated fabrics when binder concentration equalled:					
		20 g/dm³	35 g/dm³	50 g/dm³	65 g/dm³	80 g/dm³	95 g/dm³
RC8	1.42	2.91	2.42	3.11	2.85	1.87	2.57
RC10	1.04	1.62	1.53	1.46	1.46	1.23	1.15
RC12	2.22	1.01	2.25	1.46	1.65	1.50	1.38
RC14	1.58	1.00	1.24	1.04	0.93	1.18	1.20
RC16	0.89	0.92	1.14	1.12	1.12	1.16	1.22

Other researchers [22] found the effect of microcapsule concentration on bending properties. According to their investigation, the bending rigidity for untreated PES fabrics was 0.00048 N·cm²/cm, while it was 0.00250 and 0.00276 N·cm²/cm, respectively, for 5% and 40% microcapsule concentrations. While other experiments showed that after dyeing and microcapsule treatments, the stiffness (resistance to bending) of cotton fabrics increased very slightly [19]. The drop in the total handle value [35] generated in relation to the tensile property, shearing property, bending property, surface property and compression property of the fabric was believed to be largely attributed to the increases in surface friction after embedding MCs on the cotton fabric.

The deformation of the textile material in space is also influenced by the anisotropy of bending rigidity, which is the value of bending rigidity determined in different directions of the fabric. The effect of weft density and binder concentration on the anisotropy coefficient (K_C) of grey and treated terry fabrics was also assessed. Analysis of the coefficient of anisotropy (see ***Table 4***) showed that before treating terry fabric, K_C varied from 0.89 to 2.22. The tendency of a decrease in the anisotropy coefficient with an increase in the weft density of terry fabrics was determined, but a direct trend was not seen. Generally maximum values of the anisotropy coefficient (1.87-3.11) were determined for the treated RC8 fabric variant.

Conslusions

1. The observation of microcapsules with Eucalyptus essential oil by SEM showed a spherical morphology. The particle size distribution of microcapsules demonstrated a non – uniform size distribution in volume, with the largest amount of particle sizes in the interval of 0.4-0.7 μm. Because of their small size, the microcapsules can penetrate into the spacing of fibres of ramie/cotton terry fabric and cover the fibres as well. SEM micrographs confirmed the spherical morphology and size of MC in the impregnated fabrics.
2. It was observed that the dense structure of terry fabric and high binder concentration led to a secure coating of MCs on the surface of terry fabric, but the coating is not uniform and presents some agglomerations. Mean-

while with a less dense structure, the binder wrapped the fibres homogeneously between the loops and inside them up to the base of fabric, which ensured good impregnation.

3. It was determined that the difference between the bending rigidity of terry fabrics before treating and after treatment was significant, i.e. by 5.1-14.0 times. The bending rigidity of the terry fabrics treated in the warp direction was 5.57-12.94 Nm^2, whereas in the weft direction it varied from 2.35 to 10.78 Nm^2.
4. Results of the analysis show that generally the bending rigidity in the warp direction of the fabrics treated with a binder concentration of 20 g/dm^3 was lowest (till 5.57-9.17 Nm^2) when the weft density varied by 10.0-16.0 cm^{-1}, except the fabric with a weft density of 8.0 cm^{-1} and binder concentration of 80 g/dm^3. Whereas for the weft direction, the binder concentration till 50 g/dm^3 conditioned the lowest values of binding rigidity (2.35-8.18 Nm^2), whose values increased constantly with an increase in weft density from 8.0 till 16.0 cm^{-1}.
5. The bending rigidity in the weft direction of terry fabrics treated with microcapsules in relation to the weft density can be described by a linear equation with determination coefficient $R^2 = 0{,}8154$.

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