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An Investigation on Comfort Properties of Dyed Mulberry Silk/Cotton Blended Fabrics

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Abstract: Mulberry silk is one of the well known silk types. Especially, its lustrous appearance and handle properties make this fiber type an important natural source for textiles. Even if its properties let the fiber to be produced by itself, blending with other fiber types can be preferred in order to reduce raw material costs and make it more affordable. Cotton can be a good companion to this fiber type because of its tendency to be textile material. In this study, mulberry silk/combed cotton blended yarns were produced by using siro and ring spinning systems, in three different yarn counts. These yarns were dyed and then knitted in a laboratory type circular knitting machine. The comfort properties of these fabrics were investigated. According to test results, increasing silk content in the blend and using the siro spinning system positively affected the comfort properties of fabrics, in general.

Keywords: Mulberry silk, Combed cotton, Siro spinning system, Blended yarns, Clothing comfort

Introduction

Silk has been one of the most important sources in the world, through history. Even there are different stories about how it was found, China is the birthplace of silk fiber and fabric. It was the most powerful silk producer and importer in the past that words like sericin and sericulture come from the word Sers which was the given name to Chinese at those times [1]. This situation is still the same at the present time. China produced 142000 tonnes of silk in 2017 while the second largest producer India's production was nearly 32000 tonnes [2]. This fiber's importance comes from its unique properties. Mulberry fiber has a specific gravity of 1.25-1.3 g/cm^3 and a triangular shaped cross-section [3]. Unlike the other animal protein fibers, it has no scales on the surface. Its tenacity is 0.38 N/tex and breaking elongation is 23.4 % under the 65 % relative humidity and 20 ^{o}C test conditions and with 1 cm test length, according to the literature [4]. This is more than most of the natural fibers used in the textile industry. However, mulberry silk fiber is mostly known for its appearance, which can be improved by weak acid treatments [5]. Moreover, it was indicated in the literature that silk fabrics have high softness values [6]. As being a scarce source, blending mulberry silk with other fibers is quite preferred, especially when using waste silk. There are studies investigating the effects of blending in the literature. In these studies; effects of blending parameters on fiber migration of silk/cotton blended ring-spun yarns [7] and effects of silk content in the silk/cotton blend on properties of rotor-spun [8] and ring-spun [9] yarns.

It is crucial to know the properties of the end product which will be commercialized. In textile industry, especially for the products for clothing purposes, comfort is a key parameter which was defined as pleasant state of physiological, psychological, neurophysiological and physical harmony between a human being and the environment. by Slater [10], [11]. Clothing comfort has a fundamental meaning for the improvement of the quality of our life. It has four elements as stated by Das and Alagirusamy: thermo-physiological aspect, sensorial or tactile aspect, physiological aspect and body movement comfort. Thermo-physiological comfort, which is the subject of this study, deals with heat, air and moisture transmission [12,13].

Comfort properties of fabrics produced with different raw materials and structures have been the subject of several studies in the last decade [14-20]. Moreover, different silk types have also been subject of some studies about comfort properties, recently. Kamijo *et al*. investigated the comfort of t-shirt type underwear made of spun silk using the Kawabata Evaluation System by comparing with filament silk used fabrics and cotton fabrics. They reached results as: spun silk fabrics had highest thermal conductivity and results between cotton and filament silk fabrics for air permeability and moisture permeability [21]. The comfort properties of Eri silk was also investigated in some studies. Kumar and Ramachandran produced knitted Eri silk fabrics with 4 different knitting structures and evaluated their moisture management properties. They stated that Eri silk fabrics had good comfort properties [22]. They also investigated knitting process parameters on thermal comfort and air permeability properties of Eri silk knitted fabrics and according to them, Eri silk fabrics have better thermal comfort and wicking properties than mulberry silk fabrics [23]. These findings were supported by the study of Pachiyappan and Divya [24]. Verma *et al*. studied tactile, thermal, physiological comfort, and hand values mulberry

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silk waste/wool blended fabrics. They reached good air and water permeability with intimate-blended fabrics and good thermal insulation with union-blended fabrics [25].

It was determined from the literature that the studies about the effects of mulberry silk fibers, especially in blends with cotton, on clothing comfort is limited. For this reason, this fiber type was chosen as raw material and cotton was used - as being one of the most used textile fibers- to investigate for its fabric characteristics in terms of clothing comfort. Yarns with different mulberry silk/cotton blend ratios were produced in the ring and siro spinning systems. In terms of analyzing thermal properties, air permeability, water vapour resistance and moisture transfer capability, single jersey fabrics were knitted and comparatively evaluated.

Experimental

In this study, mulberry silk and combed cotton fibers were used as raw materials for spinning blended yarns. The properties of these fibers are given in Table 1. These properties were gathered by using Uster HVI for cotton fibers and FAVIGRAPH for silk fibers.

Initially, mulberry silk and combed cotton slivers were blended in Rieter RSB-D 35 drawframe. Three blending ratios were used in these blends, which were: 15 % silk-85 % cotton, 30 % silk-70 % cotton and 45 % silk-55 % cotton. After drawframe, the final sliver count was 5 ktex. After blending in drawframe, blended slivers were used for producing rovings (Ne 1.5) in Ingolstadt roving frame.

Ring and siro spinning systems were used in yarn productions. Ne 20, Ne 30 and Ne 40 ring spun and Ne 30 siro-spun yarns were produced with α_e 3.8 twist coefficient. G30 ring spinning frame was used for spinning. In order to spin siro yarns, the drafting system of the machine was equipped with suitable parts. 4 mm strand spacing was used for siro-spun yarns. For both spinning systems, 10000 rpm spindle speed and ISO 80, ISO 45 and ISO 31.5 travellers were used for Ne 20, Ne 30 and Ne 40 yarns, respectively. Properties of these yarns obtained by tests carried out using Uster Tester 5 and Uster Tensorapid are given in Table 2.

In dyeing of blended yarns or fabrics, structural characteristics of used fiber types should be kept in mind. In terms of silk/cellulosic fiber blends, which is the subject of this study, two methods of dyeing were suggested by Teli. The first method includes direct and acidic dyeing, and the second one includes direct and 1:2 metal complex dyeing with a specific reserving agent [26]. After spinning, yarns were dyed in two steps, as mentioned: cotton was dyed with direct dyestuff and silk was dyed using acidic dyeing method. Yarns were also treated according to available methods. Subsequently, K/S values of these fabrics were obtained, just to have an idea about the colour properties of these blends. Table 3 presents the K/S values of dyed fabrics at 540 nm wavelength.

Single jersey fabrics were knitted by dyed mulberry silk/cotton yarns on Mesdan Lab Knitter and air permeability, water vapour resistance, moisture management and thermal properties of these 12 fabric types were tested according to the related standards to evaluate thermal comfort.

Statistical analyses were performed using SPSS statistics

Table 1. Fiber properties

	Silk	Cotton
Mean length (mm)	52.0	28.6
Fineness (dtex)	0.93	1.85
Tensile strength (gr/tex)	47.94	31.7
Breaking elongation (%)	13.85	4.1

Table 2. Yarn properties

Spinning system	Yarn count (Ne)	Silk content (%)	Tensile strength (cN/tex)	Uster %CV	Thin places (-50 %)	Thick places (+50 %)	Neps (+200 %)	Hairiness (H)	Diameter (mm)
Ring	20	15	16.78	16.12	9	81	68	7.98	0.26
		30	19.33	16.13	4	29	34	7.71	0.26
		45	24.26	18.87	5	139	85	7.70	0.26
	30	15	21.61	15.74	5	116	156	6.58	0.22
		30	22.39	16.45	5	80	101	6.73	0.22
		45	24.58	16.59	32	353	251	6.96	0.22
	40	15	18.48	16.43	13	147	188	5.72	0.18
		30	20.11	17.26	6	130	234	5.60	0.18
		45	23.85	17.52	15	230	315	5.98	0.18
Siro	30	15	22.12	13.34	4	64	65	4.88	0.21
		30	22.42	13.87	0	67	77	4.93	0.21
		45	25.25	15.09	0	93	163	5.18	0.21

Table 3. K-S values of the fabrics

Spinning system	Yarn count (Ne)	Silk content (%)	K-S value (540 nm)
Ring	20	15	10.58
		30	10.89
		45	11.61
	30	15	10.09
		30	11.12
		45	12.89
	40	15	10.71
		30	11.85
		45	11.98
Siro	30	15	11.63
		30	11.90
		45	14.05

Table 4. Testing methods and standards

Test types	Testing methods and standards
Air permeability	Textest FX 3300, EN ISO 9237
Water vapour permeability	Sensora Permetest, EN ISO 11092
Thermal resistance	Sensora Alambeta
Moisture management ability	SDL Atlas MMT, AATCC 195

software at a significance level of 0.05. Tests were carried out according to two different designs: First, results of ring-spun yarns with yarn counts of Ne 20, Ne 30 and Ne 40 were analysed for evaluating the effect of silk content and yarn count on silk/cotton blended fabrics with one-way ANOVA. Then, the of ring-spun Ne 30 yarns and siro-spun yarns with same yarn count were analyzed using paired sample t test for each fabric feature for understanding the effects of the spinning system on fabric properties.

Results and Discussion

Yarn properties were given in Table 2. According to these results, it was found that higher silk content in the yarns allowed yarns with higher tensile strength but also higher unevenness and more IPI faults, generally. These properties and the effects of mulberry silk fibers were discussed in previous studies and our findings collaborated with them [8], [9]. The hairiness values of the yarns also increased with increasing silk content as it was indicated in the literature [27]. Siro-spun silk-cotton blended yarns had higher tensile strength, lower unevenness, fewer IPI faults, and lower hairiness values than ring-spun blended yarns as expected [28,29]. Moreover, the diameters of the yarns spun with the siro system were found to be lower than ring-spun yarns in the same yarn count. Before studying comfort properties, these yarns were initially treated and dyed using the same prescription and then fabrics were knitted with the same machine adjustment.

Test results of air permeability, water vapour and thermal resistance are given in Table 5. The air permeability results showed that using siro-spun yarns in the fabrics allowed easy airflow through them. Kullmann *et al*. mentioned that that air permeability values of yarns are highly affected by yarn and structure [30]. So, these air permeability differences could be caused by siro-spun yarns having less hairiness values and less bulky structure compared to ring-spun yarns. Hairiness and the bulky structure of yarns used in the fabric decrease the air permeability of fabrics as mentioned in different studies [31-33]. It was also indicated that higher silk content in blend caused lower air permeability due to the increasing yarn hairiness (see Table 2). Additionally, the effect of yarn count on permeability results was determined.

Table 5. Air permeability, water vapour resistance and thermal resistance values of the fabrics

Spinning system	Yarn count (Ne)	Silk content (%)	Air permeability (l/m^2/s)	Water vapour resistance (Pa m^2/W)	Thermal resistance (K m^2/W)
Ring	20	15	1334	3.62	0.0162
		30	1334	3.60	0.0179
		45	1102	3.70	0.0190
	30	15	2424	3.55	0.0154
		30	2082	3.45	0.0155
		45	2002	3.36	0.0172
	40	15	3956	3.05	0.0151
		30	3366	3.20	0.0163
		45	2908	3.23	0.0165
Siro	30	15	2454	3.21	0.0139
		30	2372	3.14	0.0150
		45	2328	3.29	0.0172

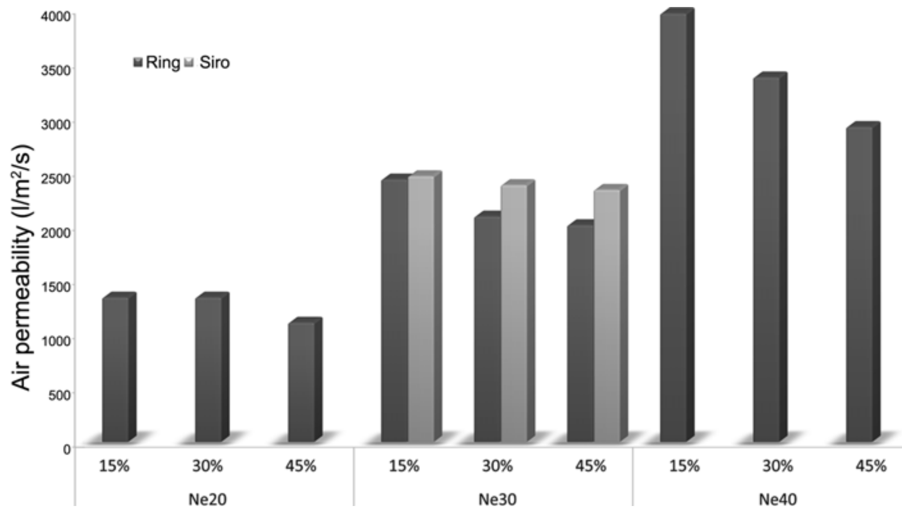

Figure 1. Air permeability of the fabrics.

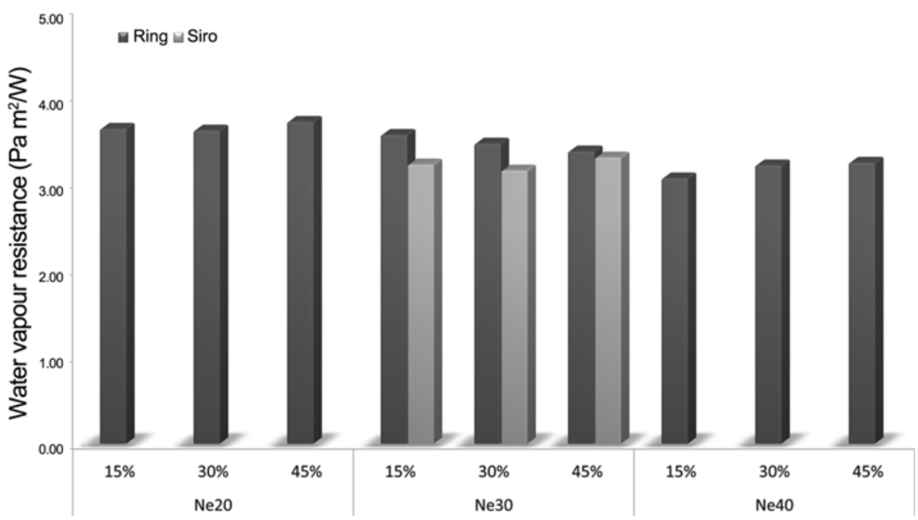

Figure 2. Water vapour resistance of the fabrics.

All samples were produced by the same knitting parameters. Therefore, the yarns with the lowest diameter achieved the highest airflow speed because of the highest inter-yarn porosity (Figure 1). Differences for yarn counts, silk fiber ratios and spinning systems were found to be statistically significant ($p<0.05$).

According to the results of water vapour resistance, there was not any statistical difference between the samples knitted by different blend ratio. On the other hand, the spinning method and yarn count significantly affected water vapour transfer. Similar to air permeability, finer yarns provided higher water vapour permeability (Figure 2). Besides, fabrics produced by siro-spun yarns had better permeability than fabrics produced by ring-spun yarns. This is because of less hairy yarns and a more compact structure which can create greater inter-yarn spaces [34].

Thermal resistance refers to the ability of a system to resist heat flow, whereas thermal conductivity is a property of a material. At this point, the amount of fiber and air gaps in the fabric structure are the most important factors determining the thermal insulation. Thermal resistance results revealed that silk blend ratio and yarn count were the most effective factors. Increasing of silk amount enhanced the resistance skills by higher hairiness and more entrapped air within the structure. Furthermore, the lower thermal conductivity of silk material also can make it available for better insulation [35]. According to the yarn count evaluation, Ne20 yarns showed the highest resistance values with their bulky fabric structure (Figure 3). Differences for yarn counts, silk fiber ratios and spinning systems were found to be statistically significant ($p<0.05$).

Within the scope of this study, moisture management

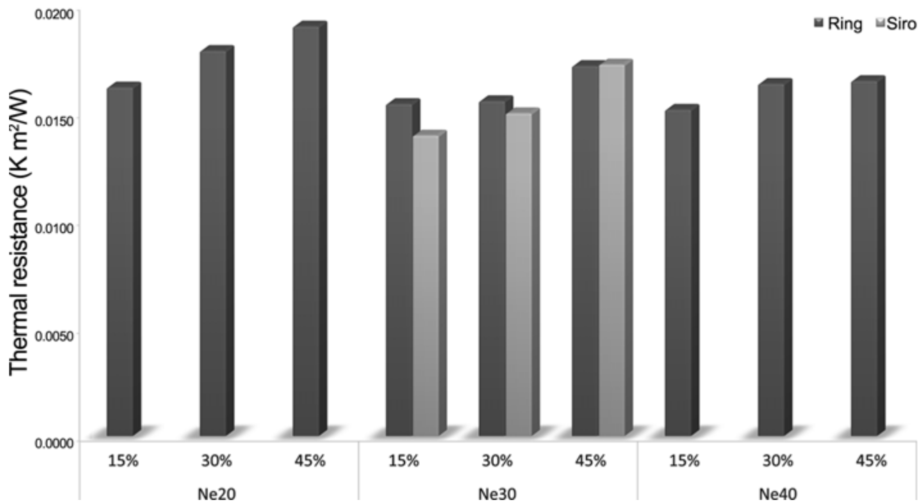

Figure 3. Thermal resistance of the fabrics.

Table 6. Moisture management properties of the fabrics

Spinning system	Yarn count (Ne)	Silk content (%)	Top absorption rate (%/sec)	Bottom absorption rate (%/sec)	Top max wetted radius (mm)	Bottom max wetted radius (mm)	Overall moisture management capacity
Ring	20	15	63.51	73.71	25	20	0.58
		30	59.46	72.66	20	20	0.62
		45	83.47	96.65	20	20	0.57
	30	15	75.27	88.42	25	25	0.62
		30	74.72	83.99	25	25	0.59
		45	74.01	86.38	25	25	0.63
	40	15	72.38	89.2	30	30	0.62
		30	81.69	92.8	30	30	0.63
		45	96.67	111.09	30	30	0.66
Siro	30	15	73.97	85.56	30	30	0.60
		30	78.96	89.39	25	25	0.54
		45	79.16	90.13	25	25	0.63

capability was also determined in terms of drying behaviour (Table 6). The evaluations revealed that all tested samples were in the category of very good, except the fabrics knitted using Ne20 yarns, when compared with the grading scale given by the manufacturing company (0-0.2: very poor, 0.2-0.4: poor, 0.4-0.6: good, 0.6-0.8: very good, >0.8: excellent) [36]. Besides, higher silk ratio provided higher absorption rates. As it known, silk fibers have high moisture absorption capacity, which is up to 30 % of its weight with a dry feeling [1]. On the other hand, the results represented that finer yarn counts increased the maximum wetted radius since the finer yarns decrease the thickness of the fabric [37]. Thus, fabrics can quickly dry [38]. Additionally, the siro spinning method did not create a significant difference in moisture management properties.

Conclusion

This study was aimed to investigate thermo-physiological comfort properties; such as air permeability, water vapour resistance, moisture management capability and thermal resistance of mulberry silk/cotton blended dyed fabrics. For this purpose, mulberry silk/cotton blended yarns were produced by using ring and siro spinning system (siro system was only used in Ne 30 yarn production) in three different yarn counts and with three different silk content values.

According to the results, increasing of silk ratio in the blend provided better thermal resistance and moisture management properties, while causing lower air permeability. Due to the elegant characteristics of mulberry silk fiber, such as thermal insulation and moisture absorption, it is possible to develop fabrics with good comfort properties by using high amounts of silk within the structure. Besides, using finer yarns enhanced permeability properties and moisture transfer capacity of the fabrics. The siro spinning method contributed to fabric porosity with its compact yarn structure. This resulted with higher air and water vapour permeability of fabrics than ring spun yarns used fabrics.

According to these results, it has been proved that innovative products, such as high performance sportswear, can be generated by adding mulberry silk fibers, having superior properties, to the fabric structure. These special garments will be different from conventional textile products with high added value and comfort satisfactory. Positive effects can be improved by increasing the mulberry silk ratio and using finer and qualified yarns. Moreover, the siro spinning system is known for producing yarns with high the physical and mechanical properties. For that reason, it would be beneficial for silk/cotton blended fabrics as demonstrated in this study.

References

1. R. Currie in "Silk, Mohair, Cashmere and Other Luxury Fibers" (R. R. Franck Ed.), pp.1-67, Woodhead Publishing Ltd., 2001.
2. International Sericultural Commission (Inserco), "Statistics | International Sericultural Commission", Available: http://inserco.org/en/statistics (Accessed August 29, 2018).
3. H. L. Needles, "Textile Fibers, Dyes, Finishes and Processes, A Concise Guide", Noyes Publications, 1986.
4. W. E. Morton and J. W. S. Hearle, "Physical Properties of Textile Fibres", pp.274-321, Woodhead Publishing, 2008.
5. N. V. Padaki, B. Das, and A. Basu, "Advances in Silk Science and Technology" (A. Basu Ed.), pp.3-16, Woodhead Publishing Ltd., 2015.
6. M. Matsudaira and S. Kawabata, *J. Text. Inst.*, **79**, 458 (1988).
7. R. Chollakup, J. F. Osselin, A. Sinoimeri, and J. Y. Drean, *Text. Res. J.*, **78**, 361 (2008).
8. E. Akbaş and P. Çelik, *Tekst. ve Konfeksiyon*, **26**, 221 (2016).
9. M. B. Üzümcü and H. Kadoğlu, *Tekst. ve Konfeksiyon*, **26**, 244 (2016).
10. A. K. Roy Choudhury, P. K. Majumdar, and C. Datta, "Improving Comfort in Clothing" (G. Song Ed.), pp.3-60, Woodhead Publishing, 2011.
11. K. Slater, "Human Comfort", C.C. Thomas, 1985.
12. A. Das and R. Alagirusamy, "Science in Clothing Comfort", Woodhead Publishing India Pvt. Ltd., 2010.
13. Y. Li, *Text. Prog.*, **31**, 1 (2001).
14. N. Oglakcioglu, P. Celik, T. B. Ute, A. Marmarali, and H. Kadoglu, *Text. Res. J.*, **79**, 888 (2009).
15. G. Süpüren Mengüç, *Tekst. ve Konfeksiyon*, **26**, 40 (2016).
16. D. Tester, B. A. Mcgregor, L. Staynes, and X. Wang, *Text. Res. J.*, **85**, 1181 (2015).
17. R. F. Mahbub, L. Wang, L. Arnold, S. Kaneslingam, and R. Padhye, *Text. Res. J.*, **84**, 2094 (2014).
18. T. Bedez Ute, P. Celik, H. Kadoglu, B. Uzumcu, G. Ertekin, and A. Marmarali, *Tekst. ve Mühendis*, **25**, 335 (2018).
19. E. Onofrei, A. M. Rocha, and A. Catarino, *J. Eng. Fibres Fabr.*, **6**, 10 (2011).
20. N. Özdil, A. Marmarali, and S. D. Kretzschmar, *Int. J. Therm. Sci.*, **46**, 1318 (2007).
21. M. Kamijo, T. Uemae, E. Kwon, Y. Horiba, H. Yoshida, and Y. Shimizu, Proceedings - 2009 International Conference on Biometrics and Kansei Engineering, ICBAKE 2009, pp.100-105, 2009.
22. B. Senthil Kumar and T. Ramachandran, International Conference on Systems, Science, Control, Communication, Engineering and Technology 2016, pp.968-972, 2016.
23. B. Senthil Kumar and T. Ramachandran, *Fibres Text. East. Eur.*, **26**, 47 (2018).
24. K. M. Pachiyappan and R. Divya, *Int. J. Res. Eng. Appl. Manag.*, **4**, 28 (2018).
25. N. Verma, N. Grewal, and S. Bains, *J. Nat. Fibers*, **13**, 277 (2016).
26. M. D. Teli, "Advances in Silk Science and Technology" (A. Basu Ed.), pp.55-79, Woodhead Publishing, 2015.
27. R. Chollakup, A. Sinoimeri, F. Philippe, L. Schacher, and D. Adolphe, *Int. J. Cloth. Sci. Technol.*, **16**, 132 (2004).
28. P. Soltani and M. S. Johari, *J. Text. Inst.*, **103**, 921 (2012).
29. M. N. Sun and K. P. S. Cheng, *Text. Res. J.*, **70**, 261 (2000).
30. R. M. H. Kullman, C. O. Graham, and G. F. Ruppenicker, *Text. Res. J.*, **51**, 781 (1981).
31. S. L. Paek, *J. Text. Inst.*, **86**, 581 (1995).
32. B. K. Behera, S. M. Ishtiaque, and S. Chand, *J. Text. Inst.*, **88**, 255 (1997).
33. R. T. Ogulata and S. Mavruz, *Fibres Text. East. Eur.*, **82**, 71 (2010).
34. G. K. Tyagi, G. Krishna, S. Bhatlacharya, and P. Kumar, *Indian J. Fibre Text. Res.*, **34**, 137 (2009).
35. J. W. S. Hearle and W. E. Morton, "Physical Properties of Textile Fibres", Woodhead Publishing, pp.168-177, 2008.
36. "SDL Atlas MMT User Manual", 2009.
37. N. Ozdil, G. Süpüren, G. Ozçelik, and J. Pruchova, *Tekst. ve Konfeksiyon*, **19**, 218 (2009).
38. A. Çay, *Tekst. ve Konfeksiyon*, **27**, 373 (2017).