ISSN 1300-3356

TEKSTİL VE KONFEKSİYON
TEXTILE & APPAREL

E-ISSN 2602-3075

JULY – SEPTEMBER, 2020

VOLUME 30 ISSUE 3

CONTENTS

ABSTRACTING / INDEXING

Science Citation Index Expanded (SCIE)
Scopus
WOS
EBSCO
TR Dizin
Ulakbim

TYPESETTING AND PRINTING

META Basım Matbaacılık Hizmetleri
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TEKSTİL VE KONFEKSİYON

VOL: 30, NO. 3

DOI: 10.32710tekstilvekonfeksiyon.559324

The Effects of Production Parameters on The Physical Properties of Dual-Core Slub Yarns

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ABSTRACT

Denim is fabric construction which is popular worldwide with its fit, ease and durability and it has evolved significantly in terms of aesthetic and functional properties throughout time to maintain this popularity. Denim fabric manufacturers are in search of different visual and functional properties at all times. In this study, dual-core slub yarns were developed for using as weft yarn in denim fabric structure. Dual-core and slub production techniques were used simultaneously for production of dual-core slub yarns which will use improving elastic and aesthetic features of denim fabrics. Within the scope of the scientific study, firstly dual-core slub yarn samples called Group-I were produced with different core draft values of EME (Elastomultiester-I.core) and elastane (II.core). The effects of cores' draft ratio on the features of dual-core slub yarns such as unevenness, hairiness, tenacity and breaking elongation were investigated with Group-I yarn samples. The breaking elongation values are affected by both EME and elastane core draft factors, while the tenacity is only affected by EME core draft factor. Moreover, in order to examine the effects of slub types, the physical properties of the dual-core slub yarn selected from Group I, were compared with equivalent dual-core yarns (having two different version of basic slub and without slub) which called Group II. The results showed that slub types have statistically insignificant effect on the hairiness, tenacity and breaking elongation values.

ARTICLE HISTORY
Received: 30.04.2019
Accepted: 24.07.2020

KEYWORDS
Dual-core, slub yarn, denim fabric.

1. INTRODUCTION

Core-spun yarn, one of the novel materials, generally use in the direction of weft and/or warp to improve elastic comfort properties of denim fabrics. It is desirable that the elasticity value is high in denim fabrics and the permanent elongation value is low. Using of core-spun yarn, having just an elastane core in fabric, can be caused permanent elongation problem [1]. The permanent elongation that encountered during use of garment, arises as a result of long-term and continual forces and induces bagging problems at some sections of the garments such as knees, pockets, elbows, heel and hips. Furthermore, using as warp of core-spun yarn, having just an elastane core, can also be problematic during weaving processes [2]. Dual-core yarn production method as an advanced version of the core-spun technique was developed in order to overcome these kinds of problems [3]. In dual-core production method, two core filaments (one of them is elastane filament) are fed into the center of sheath fibers [4]. Using of some filaments such as T400®, PBT, PET besides elastane core (as second core), in the dual-core yarns not only prevents some problems that can be occurred during weaving process, but also reduces the permanent elongation values considerably. In another words, using dual-core yarns in denim fabric structures, enables the production of high quality denim fabrics.

Several publications about the dual-core spun yarns have been found out, and the publications have been summarized below. Jabbar et al. [5] concluded that cores with the higher linear densities caused the lower tenacity, lower unevenness

To cite this article: Türksoy HG, Ertek Avcı M, Yıldırım N. 2020. The effects of production parameters on the physical properties of dual-core slub yarns. *Tekstil ve Konfeksiyon*, 30(3), 165-172.

and higher hairiness values of dual-core-spun cotton yarns. In addition, it was founded that increasing of polyester denier had decreasing effect on yarn imperfection.

Ertaş et al. [6] investigated the denim fabrics woven with the dual-core weft yarn (sheath-cotton fiber and cores-polyester and elastane filament) in various densities. They concluded that as weft density increases, elasticity and permanent elongation values decrease.

In the study performed by Babaarslan et al. [7] Co/PET/ Elastane dual core-spun weft yarns with different elastane drafts were produced in order to investigate the effect of fineness of filament and draft of elastane on denim fabric features. At the end of the study, it was reported that they are effective factors on tear force, breaking force, breaking elongation, elastic recovery, water absorption rate and vertical wicking rate.

Tantawy et al. [8] evaluated the effects of different types of weft yarns on the pilling performances of jeans. Core spun yarn, dual-core spun yarn without welding and dual-core spun yarn with welding were produced in the study. It was found that the both dual-core yarn types with higher yarn number have lower pilling values.

The aim of the study performed by Türksoy and Yıldırım [9] was to investigate the effect of some production parameters on the features of dual-core yarns (sheath-cotton fiber, cores-wool fiber and elastane filament). Experimental results showed that unevenness and hairiness values decrease as twist level increases. In addition, it was found that the tenacity values of yarns increase with higher elastane draft and twist level. Furthermore, the study revealed that the elongation values increase when wool draft value of dual-core yarns increases. Furthermore, Türksoy et al. [10] searched the effect of production methods (pretreated dual-core and dual-core yarns) on yarn features.

In the paper performed by Bedez Ute [1], elastane (EL), elastomultiester (EME) and poly butylene terefthalate (PBT) were used as core in dual-core yarns and these dual-core yarns were used as weft yarns in weaving. Then, the effect of the weft yarn composition and weft density on denim fabric properties was examined.

Fancy yarns, which offer the opportunities to designers for creating new fashionable effects and styles, are also used in denim fabric structures. Slub yarns, one of fancy yarn types, can be defined as yarns that has been purposely spun with slubs (thicker sections along the yarn) with the intention of giving the fabric an organic, tactile look and feel. Even though, unevenness of yarns was generally regarded as damaged or of poor quality, using slub yarns as a fancy yarns in denim fabrics became a trend due to the original and aesthetic value of the slub effect. Parameters representing the structure of slub yarns are slub thickness, slub distance (mm), slub length (mm), and count of slubs per unit length (Figure 1).

Modified ring spinning frames in which drafting system can be intermittent accelerated are most commonly machines for the production of different slub yarns. It is possible to examine the slub yarns produced in ring spinning machines in three main groups as basic slub, multi-twist slub and multi-count slub. The basic slub yarns are yarn types that the twist is not changed, but the yarn count is changed at regular intervals (Figure 2a). Opposite to the basic slub yarn, multi-twist slub yarns haven't count variations, but only a twist variation (Figure 2b). On the other hand, in the multi-count slub yarn structures, both yarn count and twist value changes at certain intervals along the length of the yarn (Figure 2c). In addition, the multi-effect slub yarns which are the combination of these three slub types can also be produced.

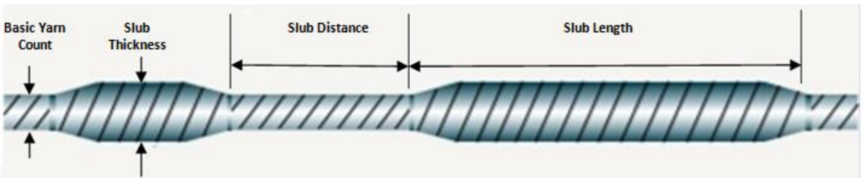


Figure 1. The parameters of slub yarn.

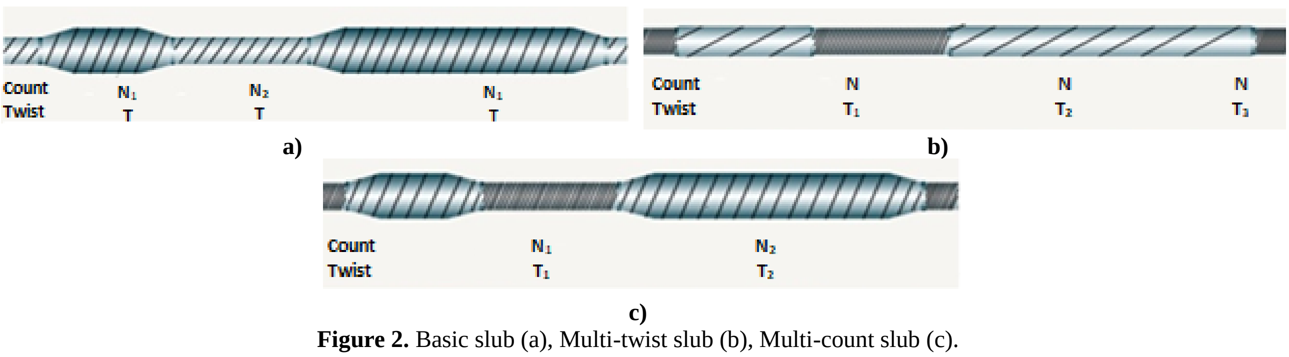


Figure 2. Basic slub (a), Multi-twist slub (b), Multi-count slub (c).

In earlier research on slub yarn, Özgen and Altaş [11] researched the effect of slub yarn structure on air permeability of twill 1/3 fabrics by using Taguchi L9 orthogonal design. It was found that slub distance is the least effective parameter, amplitude of slub is the most important parameter on air permeability value. In addition, they investigated effects of slub yarn parameters such as slub distance, slub length, yarn linear density and slub thickness on the fabric abrasion by using Taguchi L9 orthogonal design. It was concluded that the raise in the slub length and slub thickness raises the abrasion resistance, and slub distance also is a less effective parameter on abrasion of the fabrics [12].

Ilhan et al. [13] studied effects of slub distance, slub multiplier, slub length, yarn count, twist coefficient, ramp time parameters on the elongation and breaking force of slub yarns. It was concluded that while the slub length, slub distance, and base yarn count are statistically significant for the breaking force of slub yarn, the slub multiplier, base yarn count and twist coefficient have an effect on the breaking elongation. Within the scope of this study, dual-core and slub production techniques were used simultaneously for production of innovative dual-core slub yarns which will use improving elastic and aesthetic properties of denim fabrics.

2. MATERIAL AND METHOD

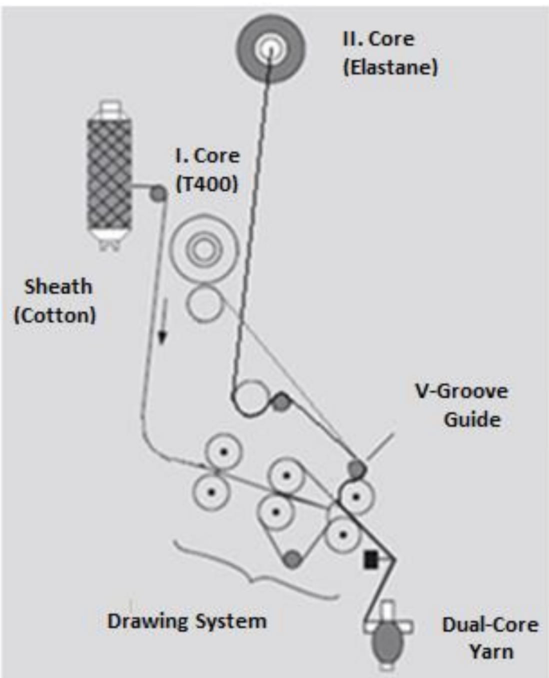
In the study, firstly dual-core slub yarn samples called Group-I were produced with different draft values of EME (Elastomultiester-I.core) and elastane (II.core). The effects of cores' draft ratio on the features of dual-core slub yarns such as unevenness, hairiness, tenacity and breaking elongation were investigated with Group-I yarn samples. Moreover, in order to examine the effects of slub types, the physical properties of the dual-core slub yarn selected from Group I, were compared with equivalent dual-core yarns (having two different version of basic slub and without slub) which called Group II.

2.1 Material

In the present study, eleven different types of dual-core basic slub yarns with different basic slub types, different EME (T400®) draft values and different elastane draft values were produced. Dual-core yarn samples without slub were also produced as a control group. The count of dual-core slub yarn samples was Ne 10,4/1. 55 dtex T400® and 78 dtex elastane were used as core components. Elongation of T400 fibers from elastomultiester fibers with high recovery property used as core in yarn samples, is 15-22% and its tenacity is 4-4.5 gf/denier. Cotton fibers used as sheath fiber have 80.2 uniformity index, 28.19 mm length, 5.8% elongation, fineness of 4.55 microner and 31.27 g/tex tenacity.

2.2 Method

The yarn samples were spun on the Marzoli MDS1 ring spinning machine modified with Pinter dual-core and Marzoli slub system. In the production of dual-core yarns, the core parts are fed to the center of the yarn separately in the modified ring machine. The schematic view of the dual-core manufacturing method and image of ring machine modified for dual-core are showed in Figure 3.



(a)

(b)

Figure 3. Production principle of dual-core yarn (a) and machine image (b).

The production parameters of the yarns are summarized in Table 1. Spindle speed of ring frame is 8500 rpm and the twist coefficient of yarn samples is 4,4 αe. Dual-core basic slub yarns were coded as 'DCS' and dual-core yarns without slub were coded as 'DC'.

In the manufacturing of dual-core basic slub yarn, while spinning the dual-core yarn with certain yarn number and twist level in the ring spinning machine, the speed of rotation of the middle and rear draft shafts are accelerated suddenly at desired time intervals, by unchanging the speed of the front draft shaft. Thus, instant draft is reduced and thicker places are formed in the dual-core yarn. The parameters of basic slub types are seen in Table 2.

The technical visuals (simulative images of fabrics) created with the Amsler WinPK® II EP5000 program of the yarns produced by the ring spinning system were given in Figure 4 in order to see visual effects of these yarns on the fabric surface.

In the study, firstly, samples were conditioned according to TS EN ISO 139 standard. Then, unevenness and hairiness values were measured by Uster Tester 5 device. Furthermore, the tenacity and breaking elongation were measured by Uster Tensorapid 4 Tester, according to relevant standard.

Test results of Group-I yarns were analyzed by using two-way replicated analysis of variance (ANOVA) and test results of Group-II yarns were analyzed by using one-way replicated analysis of variance (ANOVA). The means of results were also contrasted by DUNCAN tests by using SPSS version 13.0.

3. RESULTS AND DISCUSSION

In this part, the various physical properties of Group I and Group II yarns were evaluated. The average test results of Group-I and Group-II yarns are seen in Table 3.

Unevenness values of the Group-I dual-core slub yarns can be seen in Figure 5. According to the ANOVA results; EME draft (p_p=0.16), elastane draft (p_e=0.66) and the intersection of these factors (p_{pxe}=0.21) were found to be statistically insignificant on unevenness values.

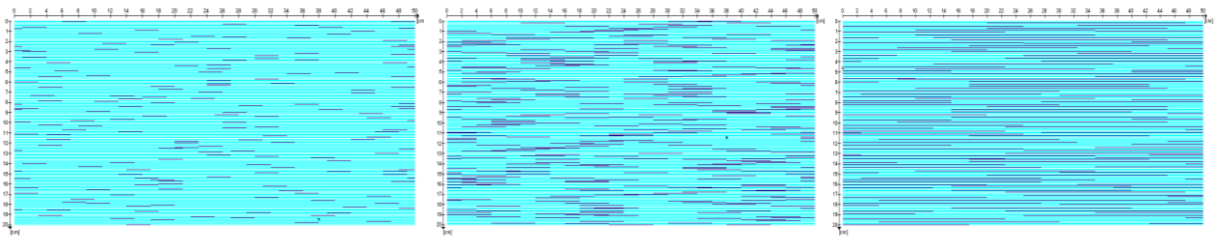
The unevenness values of Group-II yarn samples can be seen in Figure 6. According to the ANOVA results; the slub types have statistically significant effect on unevenness values of Group-II yarn samples (p_s = 0.00).

Table 1. Production parameters of yarn samples.

Yarn Groups	Yarn Samples	I. Component (EME) Draft	II. Component (Elastane) Draft	Type of Slub
Group I	DCSA-1	1.02	3.2	(Slub A)
	DCSA-2	1.02	3.5	
	DCSA-3	1.02	3.8	
	DCSA-4	1.06	3.2	
	DCSA-5	1.06	3.5	
	DCSA-6	1.06	3.8	
	DCSA-7	1.1	3.2	
	DCSA-8	1.1	3.5	
	DCSA-9	1.1	3.8	
Group II	DC	1.06	3.5	-
	DCSB	1.06	3.5	(Slub B)
	DCSC	1.06	3.5	(Slub C)

Table 2. Production parameters of basic slub types.

Parameters	Slub A	Slub B	Slub C
The number of slubs per unit length (100 m)	169 Slub	284 Slub	83 Slub
Slub Length	3 cm	6 cm	25 - 42,5 cm
Slub Thickness	1,35 Layer *Nominal count	1,46 Layer*Nominal count	1,25 and 1,34 Layer* Nominal count
Slub Distance	29 - 80 cm	10 - 50 cm	40 - 140 cm



A B C

Figure 4. Simulative images of fabrics for Slub A, Slub B and Slub C.

Table 3. The average test results of Group-I and Group-II yarns.

Yarn Code	Unevenness (%)	Hairiness (H)	Tenacity (CN/tex)	Breaking Elongation (%)
DCSA-1	13,45	7,5	15,75	7,95
DCSA-2	13,34	7,47	16,42	8,34
DCSA-3	13,49	7,49	16,58	8,5
DCSA-4	13,6	7,41	16,83	8,77
DCSA-5	13,59	7,89	16,96	9,04
DCSA-6	13,9	7,77	16,95	9,36
DCSA-7	13,66	7,72	17,04	9,96
DCSA-8	13,81	7,62	16,93	10,44
DCSA-9	13,73	7,76	17,16	10,4
DC	11,33	8,51	16,48	9,87
DCSB	19,86	9,05	16,03	9,85
DCSC	16,27	8,74	16,17	10,22

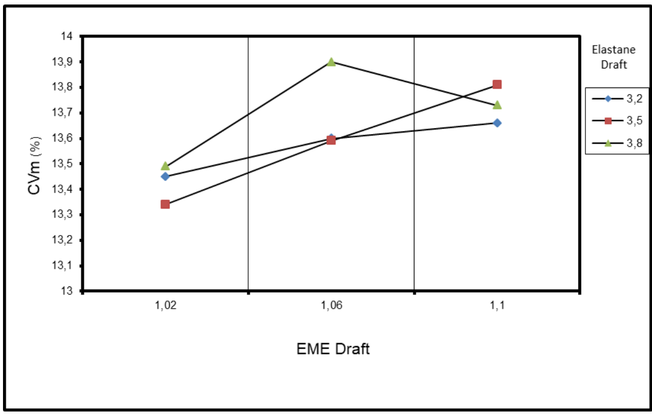


Figure 5. The average unevenness results of Group-I yarn samples.

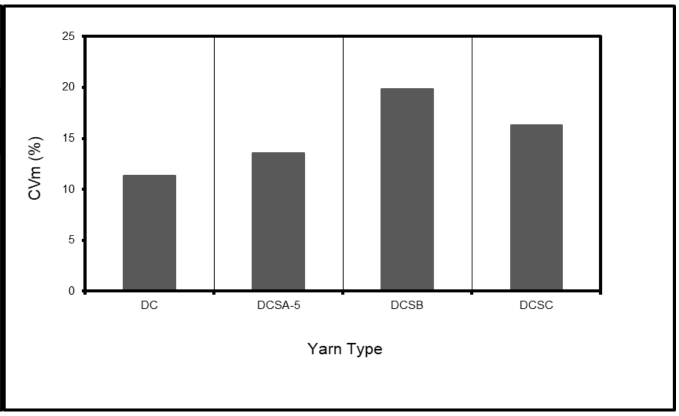


Figure 6. The average unevenness results of Group-II yarn samples.

According to DUNCAN test results showed in Table 4, the difference between unevenness values of yarns for all slub types is statistically significant. When the samples DC and dual-core slub yarns compared in terms of unevenness properties, unevenness values of DC were found to be significantly lower than that of dual-core slub yarns, as expected. Because of the highest slub thickness and the number of slubs per unit length, DCSB yarn type have showed the highest unevenness value.

Hairiness values of the Group-I and Group-II dual-core slub yarns are presented respectively in Figure 7 and 8. When the effect of draft factors on hairiness is examined, according to the ANOVA results; EME draft (p_p=0.27), elastane draft (p_e=0.61) and the intersection of these factors (p_{pxe}=0.51) were found to be statistically insignificant on hairiness values of Group-I yarn samples. Moreover, according to the ANOVA results; the slub types have statistically insignificant effect on hairiness values of Group-II yarn samples (p_s = 0.19). Yarn hairiness correlates a close correlation with unevenness and slub parts show more hairiness than base yarn, because there are more fibers in its cross section. [14]. However, in this study, while slub type has a statistically significant effect on unevenness, it have an insignificant effect on hairiness.

The tenacity values of Group-I yarn samples can be seen in Figure 9. According to the ANOVA results; EME draft values have statistically significant on the tenacity values of Group-I yarn samples (p_p=0.01), while elastane draft values (p_e=0.40) and the intersection of factors (p_{pxe}=0.71) were found to be statistically insignificant on tenacity values of Group-I yarn samples.

In DUNCAN test results showed in Table 5, it is seen that the difference between tenacity values for 1.02 EME draft and the other EME drafts is statistically significant. It is found out that tenacity values of yarn samples have an increasing trend, while EME draft is increasing.

Table 4. DUNCAN test results for unevenness values of Group-II yarn samples.

Process	S	Subset			
Yarn Type		**1**	**2**	**3**	**4**
DC	5	11.33			
DCSA-5	5		13.87		
DCSC	5			16.27	
DCSB	5				19.86
Sig.		1.00	1.00	1.00	1.00

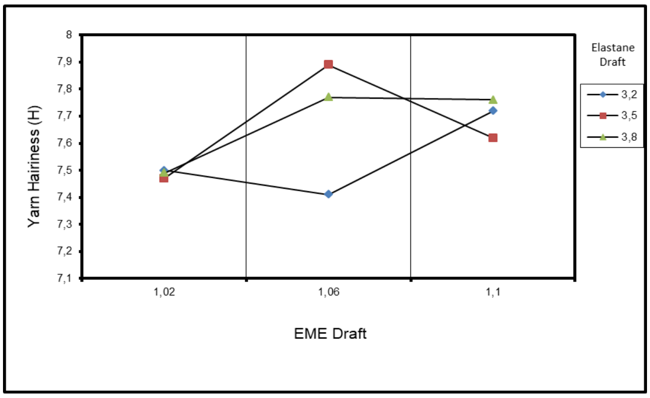


Figure 7. The average hairiness results of Group-I yarn samples.

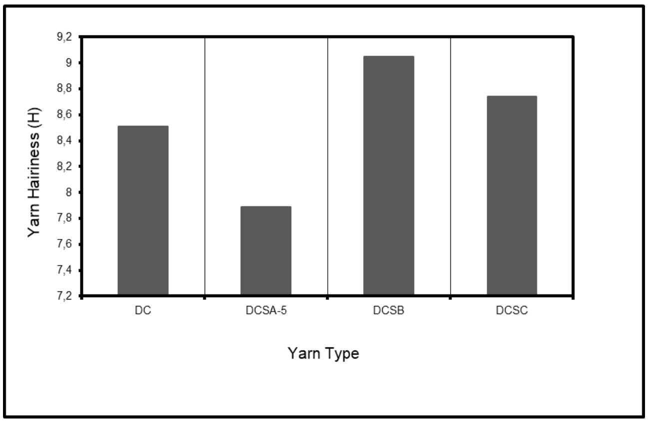


Figure 8 . The average hairiness results of Group-II yarn samples.

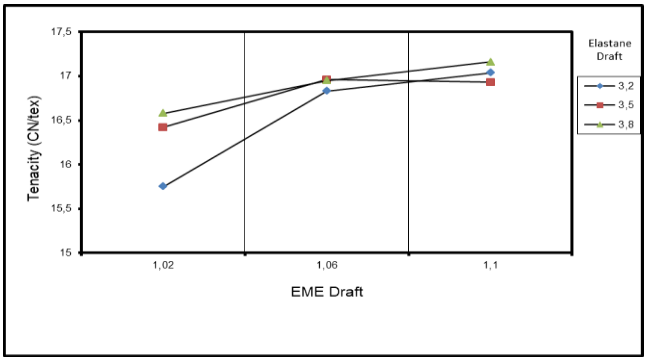


Figure 9. The average tenacity results of Group-I yarn samples.

The tenacity values of Group-II yarn samples can be seen in Figure 10. The weak points which may occur at the beginning or end of slubs, have an reducing effect on slub yarn strength [13]. However, when the effect of slub types on tenacity is examined, according to the ANOVA results; slub types were found to be statistically insignificant on tenacity values of Group-II yarn samples (p_s=0.53).

Table 5. DUNCAN test results for tenacity values of Group-I yarn samples.

Process	S	Subset	
EME Draft		1	2
1.02	15	16.25	
1.06	15		16.91
1.1	15		17.04
Sig.		1.00	0.63

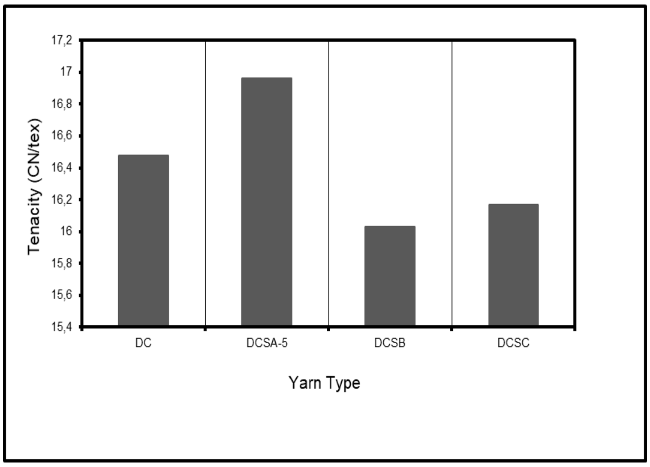


Figure 10. The average tenacity results of Group-II yarn samples.

The breaking elongation values of Group-I dual-core slub yarns can be seen in Figure 11. According to the ANOVA results; EME (p_p=0.00) and elastane draft (p_e=0.00) values were found to be statistically significant on breaking elongation values of Group-I yarns, and intersection of these factors was found to be statistically insignificant on the breaking elongation values (p_{pxe} = 0.79).

According to DUNCAN test results given in Table 6; the difference between of the breaking elongation values of the Group-I yarns produced with different EME draft was found to be statistically significant. It is seen that the breaking elongation values of yarns increase, as the EME draft is increasing. The difference between breaking elongation for 3.2 and the other elastane draft was found to be statistically significant. It is seen that the breaking elongation values of yarn samples have an increasing trend, while elastane draft is increasing, as stated in previous studies [7,15,16]. This case can be explained by increased the amount of staple fibers, having more slippage properties relative to the filament, in yarn structure [17].

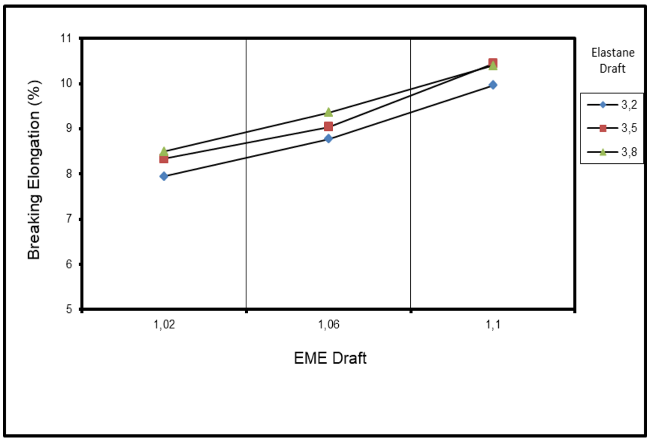


Figure 11. The average breaking elongation results of Group-I yarns.

The breaking elongation values of Group-II dual-core slub yarns can be seen in Figure 12. When the effect of slub types on breaking elongation is examined, according to the ANOVA results; slub types were found to be statistically insignificant on breaking elongation values of Group-II yarn samples (p_s=0.65).

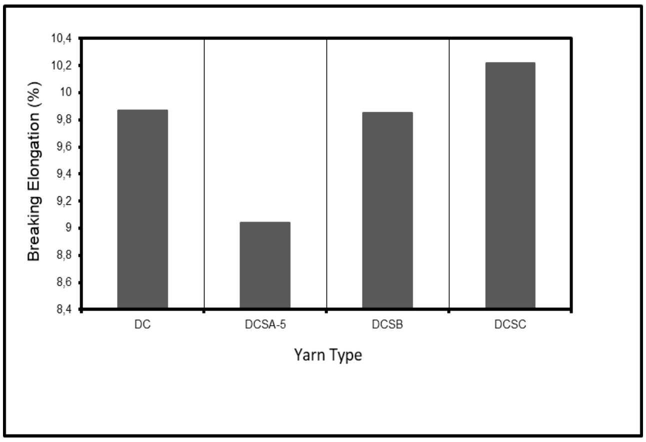


Figure 12. The average breaking elongation results of Group-II yarns.

Table 6. DUNCAN results for breaking elongation values of Group-I yarns.

Process	S	Subset		
EME Draft		**1**	**2**	**3**
1.02	15	8.26		
1.06	15		9.06	
1.1	15			10.27
Sig.		1.00	1.00	1.00
Elastane Draft				
3.2	15	8.89		
3.5	15		9.28	
3.8	15		9.42	
Sig.		1.00	0.22	

4. CONCLUSION

In this study, dual-core slub yarns produced with different EME (Elastomultiester-I. core) draft and elastane (II.core) draft values are called Group-I. The influences of EME and elastane draft on the features such as hairiness, unevenness, breaking elongation and tenacity of yarns were investigated with these yarn samples. Moreover, in order to examine the effects of slub types, the physical features of the dual-core slub yarn type selected from Group I were evaluated comparatively with equivalent dual-core yarns (having two different version of basic slub and without slub) which called Group II.

When physical properties of dual-core basic slub yarns (Group-I) produced with different elastane draft and EME draft values were examined; it was observed that draft values were have statistically insignificant effect on unevenness and hairiness. While the tenacity values of yarns are only affected by EME draft factor, the breaking elongation of yarns are affected by EME draft and elastane draft factors. In addition, it is seen that the breaking elongation values of yarns increase with increase in the EME draft value.

Basic slub types were found to be significant on the only unevenness values, when properties of dual-core slub yarns (Group-II) produced with different basic slub types were investigated. According to statistical analysis; a significant difference between the unevenness values for all types of yarns was found, and unevenness values of dual-core yarns without slub were found to be significantly lower than that of the others, as expected. The hairiness, tenacity and breaking elongation values of the dual-core slub yarns produced in the study do not differ statistically, compared with dual-core yarn the samples without slub. In the light of these results, it is thought that innovative dual-core slub yarns can be used in denim fabrics construction, like dual-core yarns without slub.

In present study, dual-core and slub production techniques were used simultaneously for production of dual-core slub yarns which will use improving elastic and aesthetic properties of denim fabrics and properties of these yarns is investigated. In addition to this work, it is planned that the detailed studies on the performances of the dual-core slub yarns as weft yarn in denim fabric can be conducted in the future.

REFERENCES

1. Ute, T. B., 2018. Analysis of mechanical and dimensional properties of the denim fabrics produced with double-core and core-spun weft yarns with different weft densities. *The Journal of The Textile Institute*, DOI: 10.1080/00405000.2018.1470451.
2. Özdil, N., 2008. Stretch and bagging properties of denim fabrics containing different rates of spandex. *Fibres & Textiles in Eastern Europe*, 16(66), 63–67.
3. Zhang, H., Xue, Y., Wang, S., 2006. Effect of filament over-feed ratio on surface structure of rotor-spun composite yarns. *Textile Research Journal*, 76(12), 922–923.
4. Paul, R. . (Ed.), 2015. *Denim manufacture, finishing and applications*, The Textile Institute Woodhead Publishing Limited, Cambridge, UK.
5. Jabbar, A., Tariq, U., Hussain, T., Basit, A., Hai, A., and Zubair, M., 2018. Effect of polyester and elastane linear density on the physical and mechanical properties of dual-core-spun cotton yarns, *Journal of Natural Fibers*, DOI: 10.1080/15440478.2018.1500338.
6. Ertaş O.G., Zervent Ünal B., Çelik N., 2016. Analyzing the effect of the elastane-containing dual-core weft yarn density on the denim fabric performance properties, *The Journal of The Textile Institute*,107(1),116–126.
7. Babaarslan O., Sarioğlu E., Çelik H.İ, Ertek Avcı, M., 2018. Denim fabrics woven with dual core-spun yarns, In book: Engineered Fabrics.
8. Tantawy, S.E., Sabry, M. and Bakry, M. 2017. The effect of different weft yarn production technique on the pilling property of jeans fabrics, *International Design Journal*, 7(3),161–169.
9. Türksoy, H.G., Yıldırım, N., 2018. Effect of process variables on the properties of dual-core yarns containing wool/elastane, *Industria Textile*, 69 (5), 352-356.
10. Türksoy H.G, Kılıç G., Üstüntağ S., Yılmaz D., 2018. A comparative study on properties of dual-core yarns, *The Journal of The Textile Institute*, doi: 10.1080/00405000.2018.1534541.

11. Özgen, B., Altaş, S., 2017. Evaluation of air permeability of fabrics woven with slub yarns, *Tekstil ve Konfeksiyon*, 27(2), 126-130.

12. Altaş, S., Ozgen, B., 2015. The effect of slub yarn descriptive parameters and yarn linear density on upholstery fabric abrasion resistance, *The Journal of The Textile Institute*, 107:10, 1232-1239, DOI: 10.1080/00405000.2015.1100414.

13. İlhan İ, Babaarslan O, Vuruşkan D. 2012. Effect of descriptive parameters of slub yarn on strength and elongation properties, *Fibres & Textiles in Eastern Europe*, 3(92): 33-38.

14. Mahmood, N., Arshad, M., Iftikhar, M., and Mahmood, T., 2009. Technological study of ring and compact spinning systems for the manufacturing of slub fancy yarn under multiple slub variations and its effect on woven fabric, *Pakistan Journal of Agricultural Sciences*, 46(2):124-129.

15. Kakvan A., Najar SS., Saidi RG., Namil M., (2007). Effects of draw ratio and elastic core yarn positioning on physical properties of elastic wool/polyester core-spun ring yarns. Journal of the Textile Institute, vol. 98, 57-63. DOI: 10.1533/joti.2005.0194.

16. Dhouib AB., El-Ghezal S., Cheikhrouhou M., 2006. A study of the impact of elastane ratio on mechanical properties of cotton wrapped elastane-core spun yarns, *Journal of the Textile Institute*, vol. 97, 167-172. DOI: 10.1533/joti.2005.0121.7.

17. Gharahaghaji , AA., Zargar, E.N., Ghane, M., and Hossaini, A., 2009. Cluster-spun yarn – A new concept in composite yarn spinning, *Textile Research Journal*, 80(1): 19–24 DOI: 10.1177/0040517508099916.

TEKSTİL VE KONFEKSİYON

VOL: 30, NO. 3

DOI: 10.32710tekstilvekonfeksiyon.570895

A Research of Applicability of Ozone Bleaching Process for 100% Cotton Fabrics at Jigger Machine

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ABSTRACT

In the present study, applicability of ozone bleaching process at the jigger machine and effects of chosen ozonation parameters on the whiteness degrees of 100% cotton woven fabrics were investigated. For this aim, effects of ozone gas on the bleaching degrees of the samples in terms of ozonation conditions (in the air with dry and moist fabrics, and in the water), ozonation time (number of the passage), production capacity of the ozone generator (6 g/h, 12 g/h, 18 g/h) and method of ozone feeding to the jigger (via rubber diffuser or stone diffuser) were researched. In addition, in order to examine effect of rinsing process on the whiteness degree of the samples, the rinsing process was applied after ozonation applications. At the end of the study, whiteness degrees (as Berger) of the samples were measured and compared with conventional hydrogen peroxide bleaching. In addition, statistical analysis was carried out in order to research the effects of the investigated parameters on the output. The results showed that it was possible to apply the ozone bleaching process at the jigger and all of the investigated ozonation parameters had effect on the results at different levels. The best bleaching effect was obtained at the longest ozonation time and the highest production capacity of the ozone generator for ozone application in the water.

ARTICLE HISTORY
Received: 28.05.2019
Accepted: 25.06.2020

KEYWORDS

Ozone, Bleaching, Jigger machine, Whiteness, Rinsing

1. INTRODUCTION

Recently, every branch of industry has taken precautions in order to use the nature sources more beneficial and go towards to the clean technologies due to the problems of environmental pollution, limited water sources, and wasting of energy, etc. [1-3]. Textile industry is a water intensive industry which causes big problem on the global water resource. The increasing concern about the textile wet processing industry is arisen from high water consumption, huge amount of wastewater discharge and high pollution potential [3-5].

The environmental impacts of the textile industry can be substantially reduced via using advanced techniques and technologies, which help to decrease wasting of energy and water, and cut emissions [6,7]. Through the advanced technologies, ozone application has had high popularity for many years [2,8,9].

Ozone has the most extremely strong oxidizing character known after the fluorine [2,5,10-13,21-23]. It can participate in many chemical reactions with inorganic and organic substances because of strong oxidizing property [7,12,23]. Besides, it self-decomposed in an aqueous solution to form hydroxyl free radicals which have stronger oxidizing ability. Therefore, ozone has been widely accepted as a forceful disinfectant and a chemical oxidant [14-17,21]. It has been used as an eco-friendly alternative process in order to prevent environmental pollution in many

To cite this article: Paksoy N, Balcı O, Sancar Beşen B. 2020. A research of applicability of ozone bleaching process for 100% cotton fabrics at jigger machine. *Tekstil ve Konfeksiyon*, 30(3), 173-183.

branch of industry such as food, agriculture, textile, automotive, etc., because it can readily decay to oxygen after treatments [7,18].

Ozone gas having decolorization property [2,19] has been commonly used at the bleaching process of the cellulosic fabrics as an eco-friendly agent [4,7,9,12,13,24,25] since bleaching of cellulosic fabrics with hydrogen peroxide is required high alkali pH, high temperature and some auxiliaries [25,26]. Cotton fabrics can be bleached with ozone in very short time at the room temperature, and without using any harsh chemicals [26]. Besides, according to researchers, cotton fabric uses less water when ozone is employed for bleaching agent [7,25,26]. In addition, Harreem et.al (2019) concluded that it was possible to reuse the effluent of ozone bleaching bathat least five times with no treatment or adjustment required, and it did not affect the fabric whiteness and discharged effluent which is cleaner compared to the hydrogen peroxide bleaching [26].

When the literature was investigated in detail, it was concluded that the bleaching effect of the textile surfaces changed depending on the ozone concentration, ozonation time, moisture content of the sample, application way of the ozone gas to the samples, etc. [20]. In the present study, usability of the ozone gas at the jigger machine as bleaching material that could be defined as a novel wet process and effects of the ozonation parameters on the whiteness degrees of 100% cotton woven fabrics were investigated. For this aim, the effects of the ozone gas on the bleaching degrees of the fabric samples in terms of the ozonation condition (in the air and in the water), ozonation time, production capacity of the ozone generator and method of ozone feeding to the jigger were researched.

2. MATERIAL AND METHOD

2.1. Material

In the study, amylase enzyme (Rucolase HPZ, Rudolf Duraner), pectinase enzyme (Rucolase PTZ, Rudolf Duraner), catalase enzyme (Rucolase CAP, Rudolf Duraner), hydrogen peroxide (Tekkim Chemistry), sodium carbonate (Tekkim Chemistry), wetting agent (Rucowet RKB, Rudolf Duraner), sodium hydroxide (Tekkim Chemistry), organic stabilizer (Ruco-Stab OKM, Rudolf Duraner) were used.100% cotton woven fabric (weft: Ne 30/1 compact, warp: Ne 30/1 ring yarn, 3/1 S twill, 167 g/m^2) having starch sizing on the warp yarns was also used for experiments.

In the ozone applications, ozone generators having capacity of 6 g/h and 12 g/h were used. 18 g/h ozone capacity was also obtained by connecting in series of two ozone generators' outputs. The applications were carried out at the laboratory type jigger machine (ATAÇ) of which technical drawing was given in Figure 1.

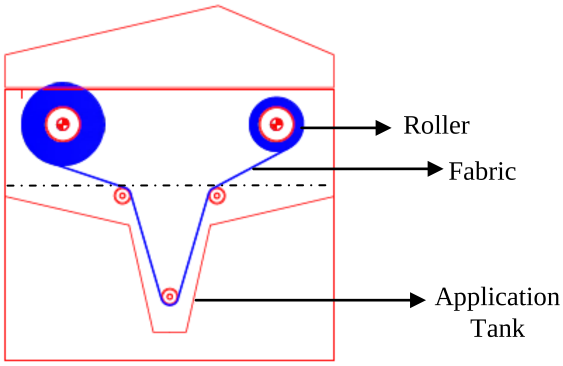

Figure 1. The technical drawing of the jigger machine [20]

Two different diffusers which were rubber (RD, material: rubber + plastic; outlet diameter*inner diameter 0.35*0.27 cm) and stone (SD, material: mineral+plastic; outlet connector diameter: 6 mm/0.24 inch; stone length: 20 cm/8 inch)were placed in the jigger machine in order to transfer the ozone gas to the inner of the machine. Although the rubber diffusor was not compatible for ozone gas, it was used in order to examine the results. In this sense, it regularly deformed, the deformation was followed and it was changed with new one in a way that does not affect the results. The rubber diffuser was placed at the bottom of the application tank (under the drive roller) while the stone one was placed out of the tank (Figure 2). The ozone gas was directly applied to the samples in the machine.

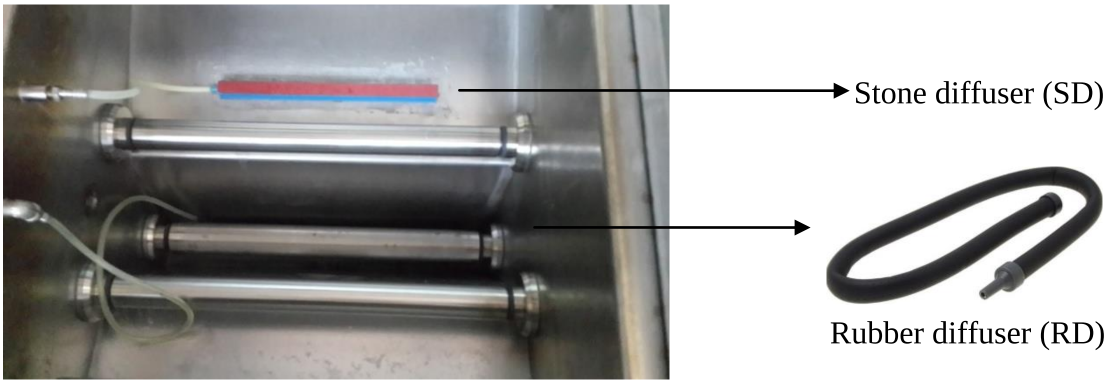

Figure 2. The settlement of the diffusers transferring the ozone gas [20]

2.2. Method

2.2.1. Desizing and bioscouring processes

The fabric samples were prepared to ozone applications by desizing and bioscourig processes which were applied simultaneously. The process was carried out by using 1 g/l amylase, 3 g/l pectinase and 2 g/l wetting agent at 60˚C during 30 minutes (pH 8-8.5 with sodium carbonate). After the process, the fabric was rinsed with hot water (at 90˚C) during 20 minutes.

2.2.2. Conventional bleaching process

In order to compare the ozone with the conventional applications, hydrogen peroxide bleaching was also carried out in the jigger machine. The bleaching was applied by using 3 g/l H_2O_2, 2 g/l NaOH, 1 g/l wetting agent and 0.5 g/l stabilizer at 90˚C during an hour. After bleaching, 0.2 g/l catalase enzyme (pH 6-6.5) was applied to the fabric at 50˚C during 15 minutes.

2.2.3. Ozone bleaching process

Ozone bleaching processes were applied to pretreated fabric samples at the different ozonation conditions (in the air with dry and moist fabrics, and in the water), ozonation time (number of passage), production capacity of the ozone generator and method of ozone feeding. Ozone applications in the water (at pH 6-6.5) were carried out in the water-filled jigger application tank. Besides, applications in the air were applied at two conditions as moist and dry fabrics. In order to obtain moist fabrics, dry fabrics were immersed into the water (at pH 6.5)in the jigger and squeezed directly up to 60% pick up. After those applications, the samples had limited water and defined as moist fabrics. In addition, applications in the air were repeated with dry fabrics which were not contacted any solutions.

The ozone gas produced by two different generators was transferred to the diffusers by different eight methods as shown in Figure 3 and Table 1.

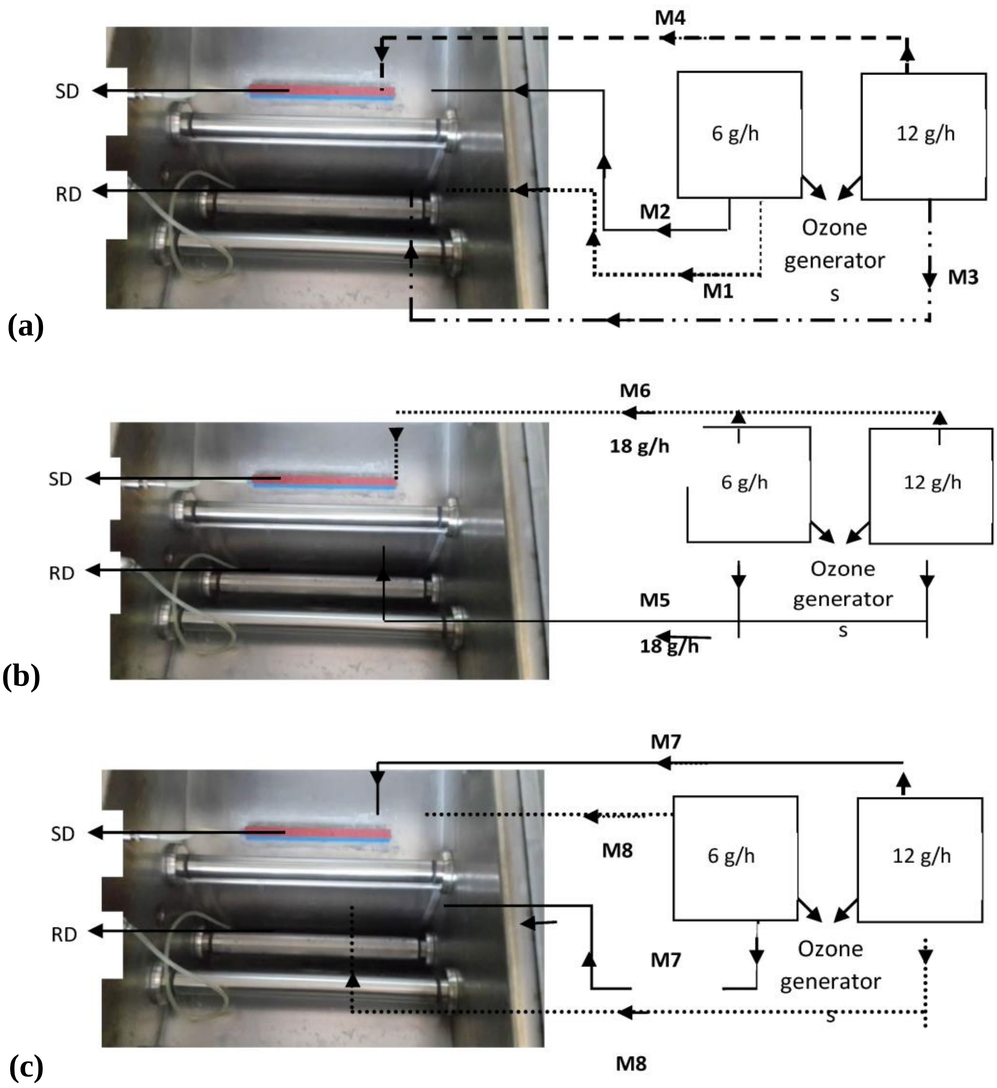

Figure 3. The methods of the ozone feeding to the jigger

Table 1. The methods of the ozone feeding to the jigger

Method	The capacity of the ozone generator-The diffuser used in the transfer
M1	6g/h-RD
M2	6g/h-SD
M3	12g/h-RD
M4	12g/h-SD
M5	18g/h-RD
M6	18g/h-SD
M7	6g/h-RD + 12g/h-SD
M8	12g/h-RD + 6g/h-SD

As seen in Figure 3and Table 1, produced ozone gas having capacities of 6 g/h, 12 g/h and 18 g/h was transferred to the jigger via either stone diffuser or rubber diffuser (M1-M6) since the diffuser type had crucial effect on the solubility of the ozone in the water. In addition, the ozone applications with the capacity of 18 g/h were applied by using both stone diffuser and rubber diffuser, together. In those applications, two ozone generators were not connected in series and ozone gas produced by the ozone generators (capacity of 6 g/h and 12 g/h) was transferred via two different diffusers, separately (M7 and M8). Thus, there was obtained totally ozone capacity of 18 g/h in the jigger machine. Besides, in the study, the application time was also wanted to be researched and different eight passage number was chosen as other variable.

All of the experiments were carried out at the room temperature (ca. 25̊ C). Experimental plan of the ozone bleaching was given in Table 2.

The study about the rinsing process after ozone bleaching showed that the rinsing process had had positive effect on the whiteness degree of the samples [13]. Based on that study, in the present study, the whiteness degrees of the fabric samples were also investigated before and after the rinsing processes.

The whiteness degrees of the fabric samples after bleaching processes were measured as Berger value under D65 daylight and 10 degrees viewing angle via Minolta 3600 A spectrophotometer. Whole measurements were carried out for three times from different locations of the fabric samples (thus, the whiteness homogeneity of the fabrics was also examined) and average of the results was calculated. At the end of the study, the statistical analysis was performed using the results of the whiteness degrees of the fabric samples in order to determine the effect of the investigated working parameters (input) on the results (output) by one-way ANOVA via Design Expert 7.0 Trial Version. The results were evaluated at 5% significance level. While the ANOVA results were being made, it was focused on F and p values. While the significance contribution of the investigated factors on the variance increases, F and p values increase and decrease, respectively. In particular, p values must be less than 0.05 in order to define a factor as statistically significant.

3. RESULTS

3.1. The whiteness results

After the ozone applications, Berger values of the fabric samples before and after rinsing process were measured and given via graphs. In the graphs, experimental number 1 described desizing and bioscouring process while the experimental number 2 defined conventional bleaching process (reference bleaching).

Berger results of the ozone applications in the water were given in Figure 4-7.

Table2. Experimental plan of the ozone bleaching [20]

Exp. number (in the water)-A	Exp. number (in the air-moist)-B	Exp. number (in the air-dry)-C	Passage Number	Method of ozone feeding (Table 1)
1A-**9A**-17A-**25A**-33A-**41A**-49A-**57A**	1B-**9B**-17B-**25B**-33B-**41B**-49B-**57B**	1C-**9C**-17C-**25C**-33C-**41C**-49C-**57C**	50	M1-**M2**-M3-**M4**-M5-**M6**-M7-**M8**
2A-**10A**-18A-**26A**-34A-**42A**-50A-**58A**	2B-**10B**-18B-**26B**-34B-**42B**-50B-**58B**	2C-**10C**-18C-**26C**-34C-**42C**-50C-**58C**	60	M1-**M2**-M3-**M4**-M5-**M6**-M7-**M8**
3A-**11A**-19A-**27A**-35A-**43A**-51A-**59A**	3B-**11B**-19B-**27B**-35B-**43B**-51B-**59B**	3C-**11C**-19C-**27C**-35C-**43C**-51C-**59C**	70	M1-**M2**-M3-**M4**-M5-**M6**-M7-**M8**
4A-**12A**-20A-**28A**-36A-**44A**-52A-**60A**	4B-**12B**-20B-**28B**-36B-**44B**-52B-**60B**	4C-**12C**-20C-**28C**-36C-**44C**-52C-**60C**	80	M1-**M2**-M3-**M4**-M5-**M6**-M7-**M8**
5A-**13A**-21A-**29A**-37A-**45A**-53A-**61A**	5B-**13B**-21B-**29B**-37B-**45B**-53B-**61B**	5C-**13C**-21C-**29C**-37C-**45C**-53C-**61C**	90	M1-**M2**-M3-**M4**-M5-**M6**-M7-**M8**
6A-**14A**-22A-**30A**-38A-**46A**-54A-**62A**	6B-**14B**-22B-**30B**-38B-**46B**-54B-**62B**	6C-**14C**-22C-**30C**-38C-**46C**-54C-**62C**	100	M1-**M2**-M3-**M4**-M5-**M6**-M7-**M8**
7A-**15A**-23A-**31A**-39A-**47A**-55A-**63A**	7B-**15B**-23B-**31B**-39B-**47B**-55B-**63B**	7C-**15C**-23C-**31C**-39C-**47C**-55C-**63C**	110	M1-**M2**-M3-**M4**-M5-**M6**-M7-**M8**
8A-**16A**-24A-**32A**-40A-**48A**-56A-**64A**	8B-**16B**-24B-**32B**-40B-**48B**-56B-**64B**	8C-**16C**-24C-**32C**-40C-**48C**-56C-**64C**	120	M1-**M2**-M3-**M4**-M5-**M6**-M7-**M8**

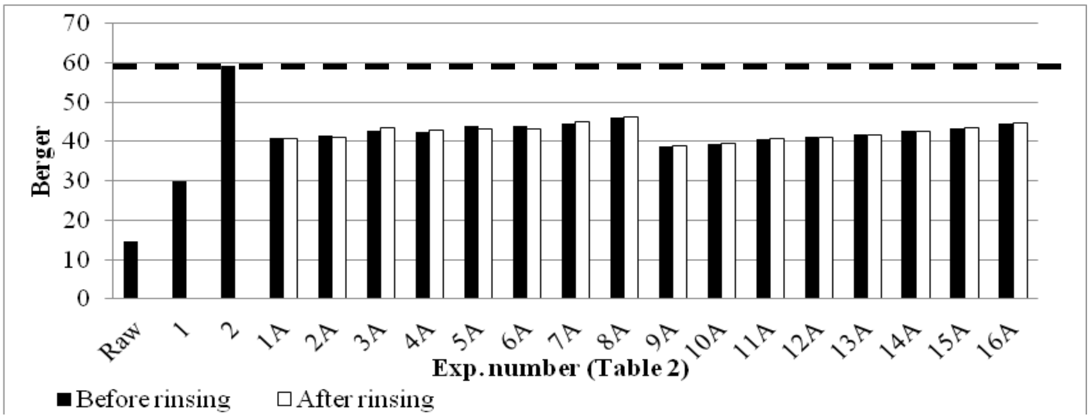

Figure 4. Berger results of the ozone applications in the water with M1 and M2

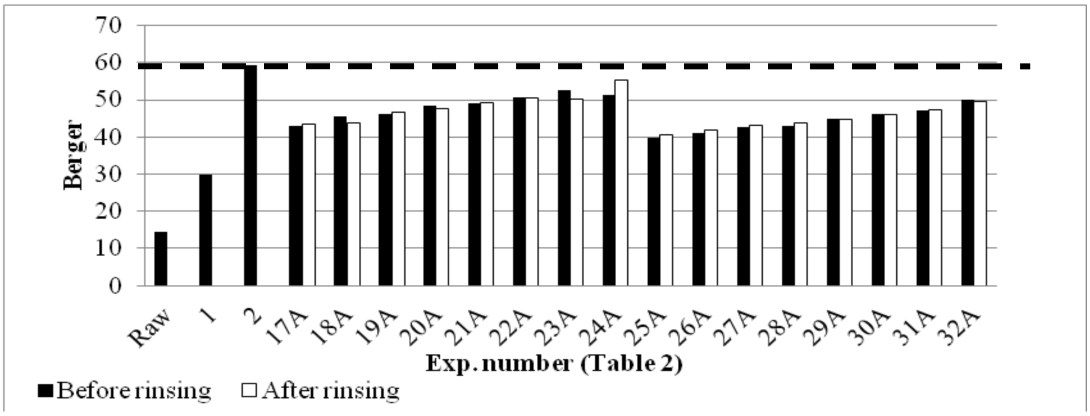

Figure 5. Berger results of the ozone applications in the water with M3 and M4

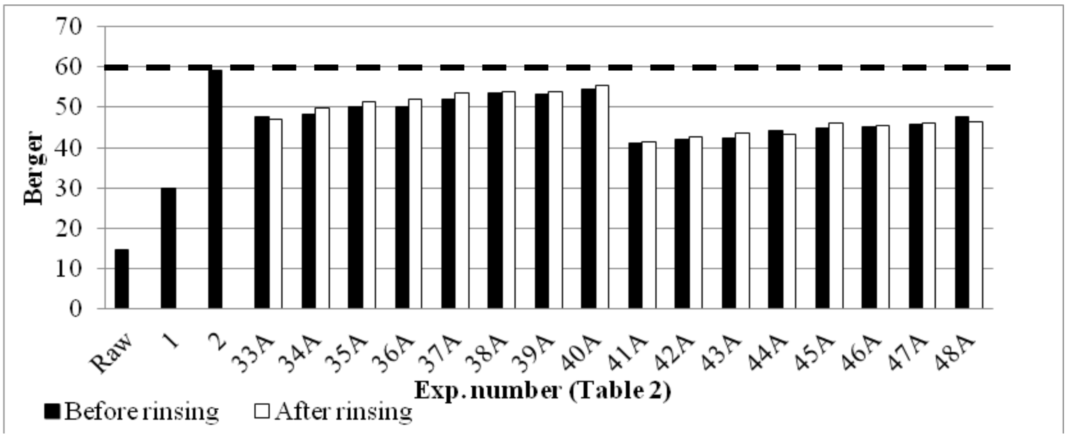

Figure 6. Berger results of the ozone applications in the water with M5 and M6

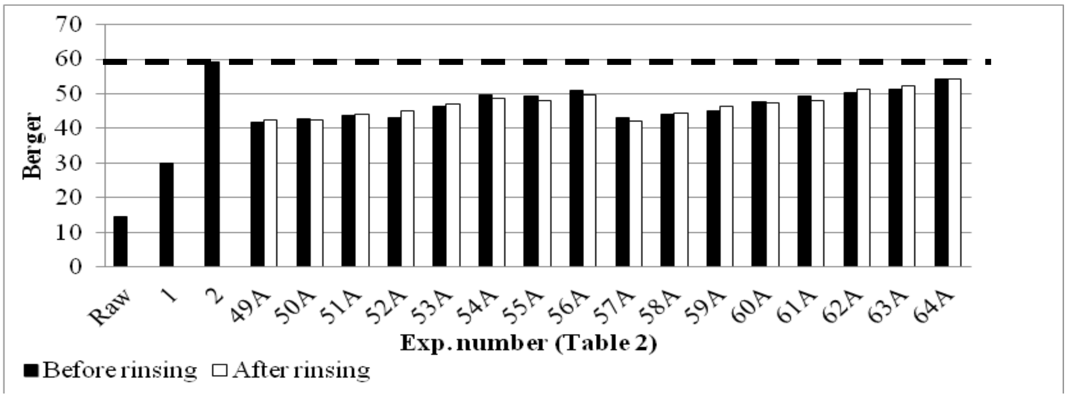

Figure 7. Berger results of the ozone applications in the water with M7 and M8

When Figure 4-7 were investigated, it was clearly seen that Berger value of reference bleaching was 59.27 and higher than all of the ozone applications in the water. Increments at the ozonation time (number of passage) and production capacity of the ozone gas were approached Berger values of the samples to the reference bleaching. When the applications of 50 passage and 120 passage were compared, almost 20% improvement at the whiteness was achieved depending on the capacity and method of the feeding of the ozone gas. In all applications, the method of feeding of the ozone gas affected the results because itchanged the solubility of the ozone gas, and the size and homogeneity of the ozone bubbles. Generally, Berger values of the applications with rubber diffuser were higher than stone one. While the highest Berger value was obtained as 55.48 with rubber diffuser, it was 49.88 with stone diffuser. It was thought to be concluded from position of the diffusers. The rubber diffuser was placed at the bottom of the application tank while the stone one was placed out of the tank. For this reason, there were more ozone bubbles that dissolved in the water while working with rubber diffusor. In addition, rinsing process had not crucial effect on the results. When the results of applications with different combinations of the ozone capacity of 6 g/h and 12 g/h (Figure 8 and Figure 9) were investigated, it was possible to say that Berger results of the applications with the ozone capacity of 18 g/h by using single diffuser was higher.

Berger results of the ozone applications in the air to the moist fabric samples were given in Figure 8-11.

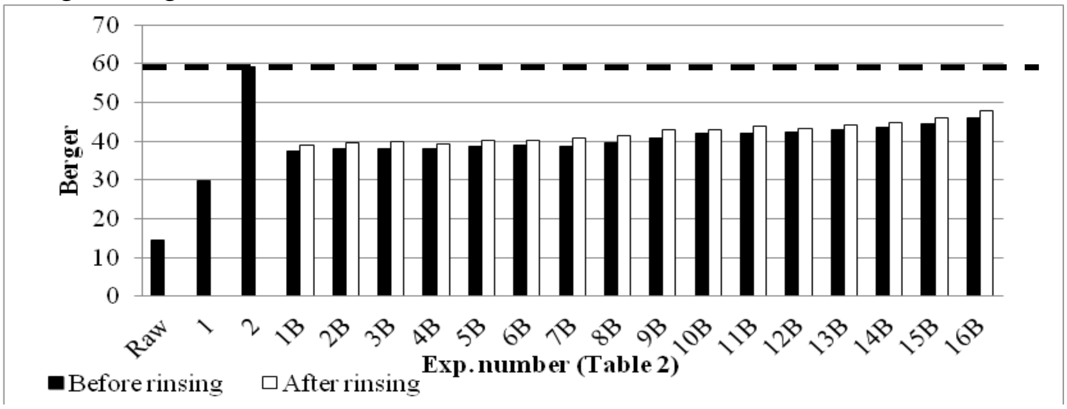

Figure 8. Berger results of the ozone applications in the air to the moist samples with M1 and M2

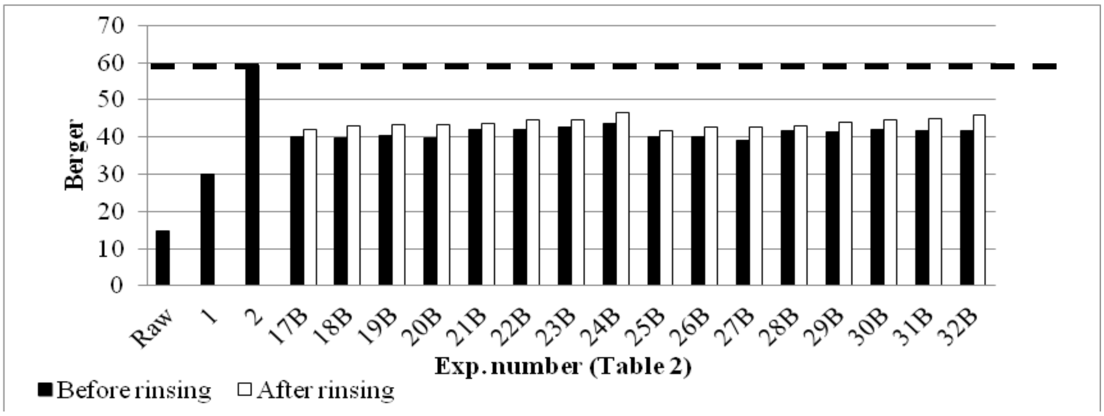

Figure 9. Berger results of the ozone applications in the air to the moist samples with M3 and M4

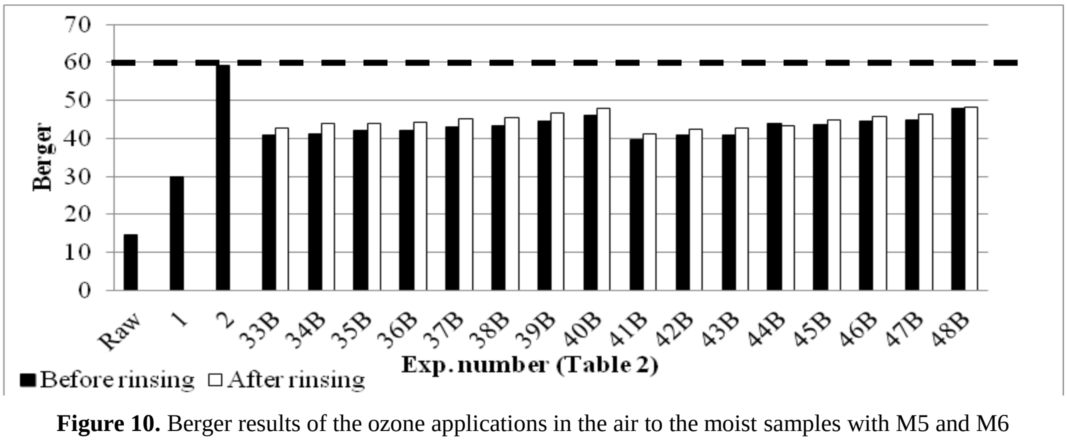

Figure 10. Berger results of the ozone applications in the air to the moist samples with M5 and M6

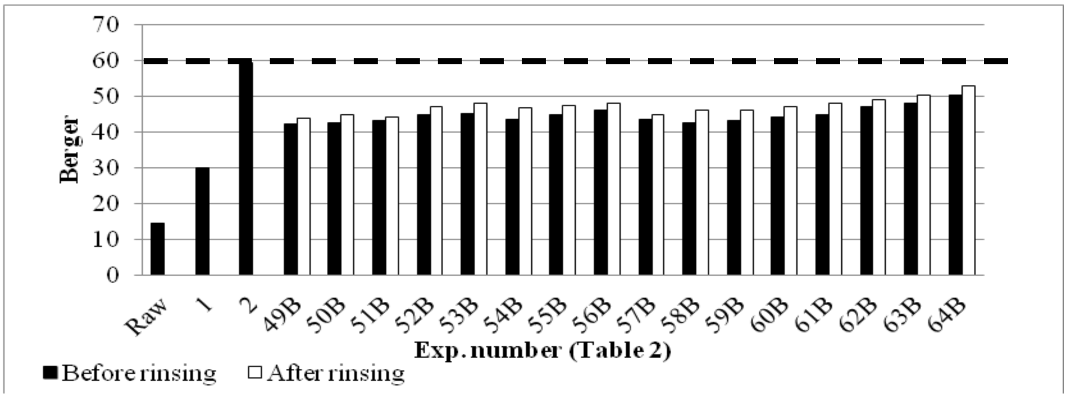

Figure 11. Berger results of the ozone applications in the air to the moist samples with M7 and M8

Figure 8-11 showed that Berger value of reference bleaching was higher than the ozone applications in the air to the moist samples. Similar with the applications in the water, increment in the number of passage and ozone capacity enhanced the whiteness degrees. Generally, Berger results of the moist ozone applications remained lower than in water ones. In those applications, the highest whiteness degree was obtained as 52.75 Berger and rinsing process had positive effect on the whiteness of the samples. In addition, there were not crucial whiteness differences between usage of the rubber diffuser and stone diffuser. It was possible to say that since there was not solubility situation of the ozone gas in the water for the applications in the air, the way of ozone feeding to the medium was not important.

Berger results of the ozone applications in the air to the dry fabric samples were given in Figure 12-15.

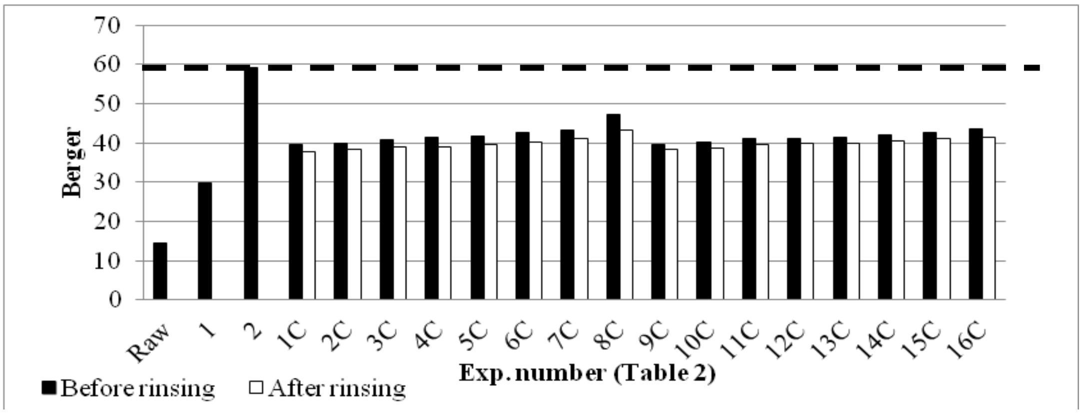

Figure 12. Berger results of the ozone applications in the air to the dry fabric samples with M1 and M2

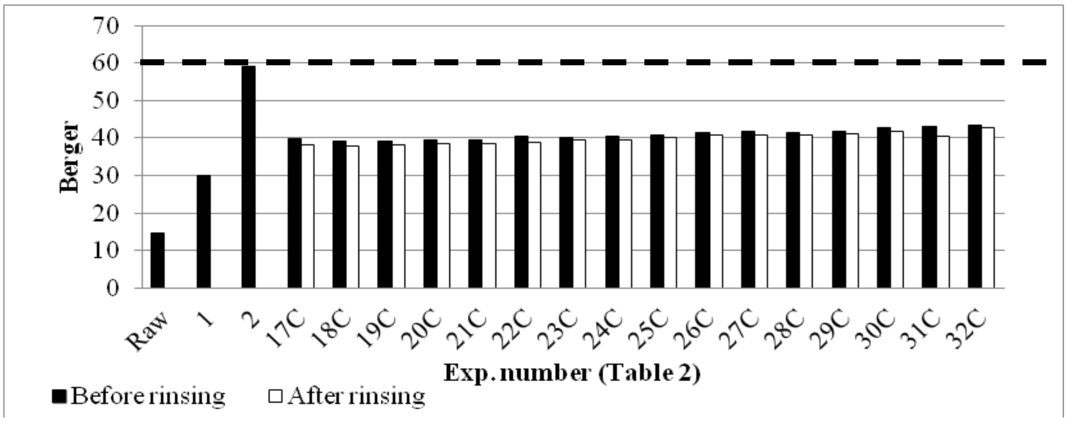

Figure 13. Berger results of the ozone applications in the air to the dry fabric samples with M3 and M4

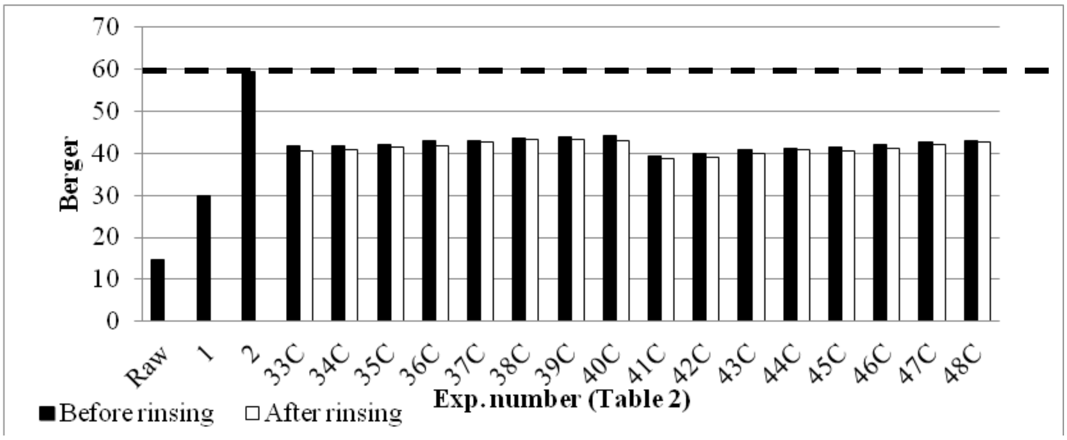

Figure 14. Berger results of the ozone applications in the air to the dry fabric samples with M5 and M6

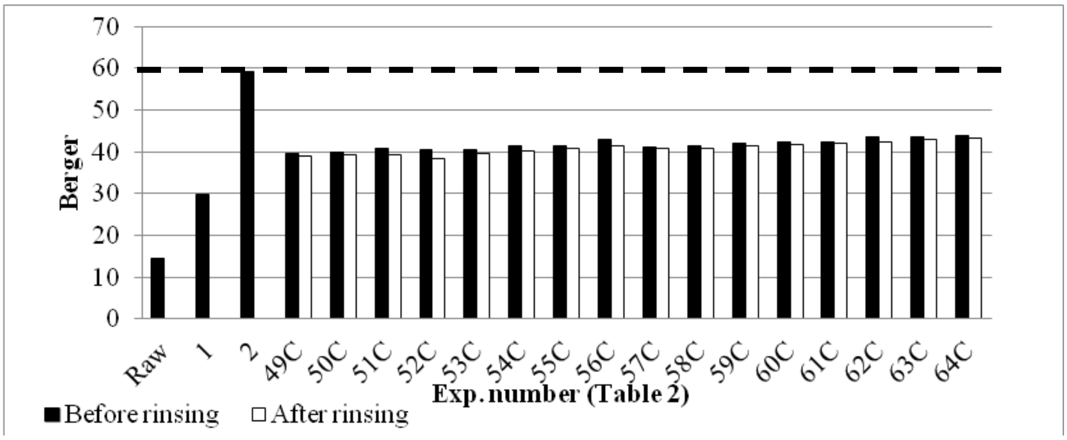

Figure 15. Berger results of the ozone applications in the air to the dry fabric samples with M7 and M8

As seen in Figure 12-15, Berger results of the ozone applications in the air to the dry fabric samples were lower than both in water and moist ones. In those applications, the highest Berger value was achieved as 43.4 Berger. The results were thought to be concluded from the low penetration of the ozone gas on the dry fabric surface. Similar with the ozone applications to the moist samples, the way of ozone feeding was also not important for dry ones. Therefore, it could be said that the feeding method of ozone gas was not important for the ozone applications in the air.

3.2. ANOVA results

After whole applications, statistical analysis was carried out by using Berger results of the fabric samples as outputs. Codes given to the input parameters (given in the Table 2) were showed in Table 3. The results of the established model were given in Table 4.

Table 3. The inputs for ANOVA

Parameter A: Ozonation condition	Parameter B: Number of the passage	Parameter C: Method of ozone feeding	Parameter D: Rinsing process
- In water - In the air to the moist sample - In the air to the dry sample	-50 -60 -70 -80 -90 -100 -110 -120	-M1 -M2 -M3 -M4 -M5 -M6 -M7 -M8	-Present -Absent

Table 4. ANOVA results

Parameter		F value	p value	State
Model		102,3114	< 0,0001	Significant
A	Main factors	2964,626	< 0,0001	Significant
B		621,8602	< 0,0001	Significant
C		601,2135	< 0,0001	Significant
D		55,34082	< 0,0001	Significant
AB	Interactions	43,76634	< 0,0001	Significant
AC		258,9987	< 0,0001	Significant
AD		360,0317	< 0,0001	Significant
BC		3,785274	< 0,0001	Significant
CD		6,331554	< 0,0001	Significant
ABC		5,485473	< 0,0001	Significant

The R^2 of this analysis was calculated as 0.99 and it was possible to say that the established model was significant. According to Table 4, it could be said that both investigated main factors and double interactions of them had effect on the output. The effect of main factors on the results could be prioritized as the ozonation condition, number of the passage, capacity of the ozone gas, and way of feeding, respectively. The rinsing process had also effect on the results, but its individual contribution was quite low. When the interactions were investigated in detail, it was seen that the most effective one was "AD" interaction. Thus, it was possible to say that while rinsing process had low effect on the whiteness degrees of the fabric samples, individually, it was quite efficient depending on the ozonation conditions. The result could be explained by the ozone residual on the samples depending on the ozonation conditions.

Normal probability diagnostic of the analysis can be seen in Figure 16. The normal probability indicates whether the residuals follow a normal distribution, in which the points will follow a straight line. This plot consists of the number of standard deviations of the actual values from their respective predicted values. Ideally, it should be straight line, indicating no abnormalities [15]. According to Figure 16, it could be said that there was no problem on any plots and it was also good signal for reliability of the experimental results.

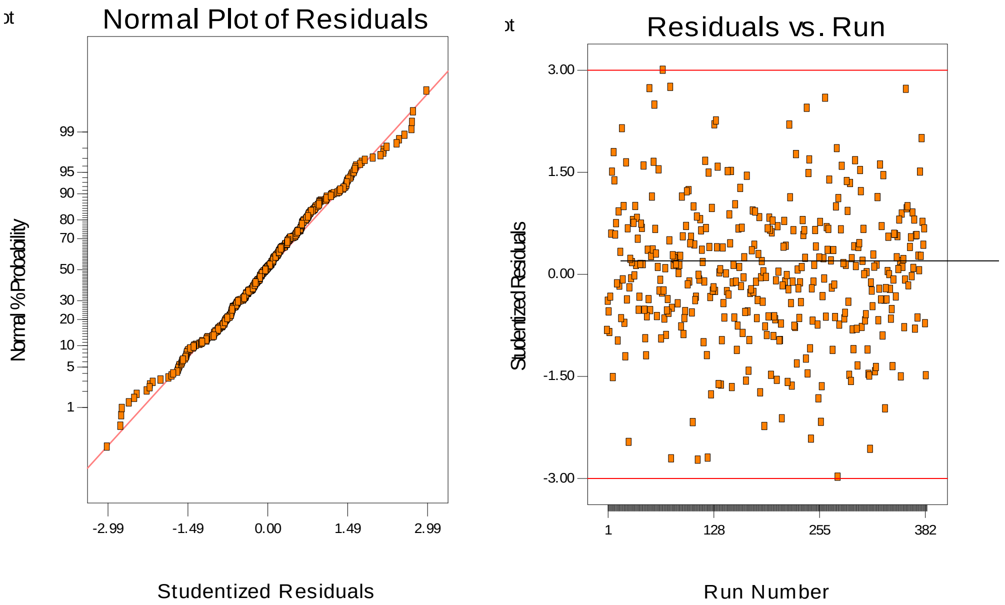

Figure 16. The normal probability diagnostic of the analysis

4. CONCLUSION

In this study, usability of the ozone gas at the jigger wet process machine as bleaching material and the effects of the ozonation parameters on the whiteness degrees of 100% cotton woven fabrics were investigated. For this purpose, effects of ozone bleaching on the whiteness degrees of fabric samples in terms of ozonation condition, ozonation time, production capacity of the ozone gas, and method of ozone feeding were researched. The ozonation conditions were determined as in the water and in the air (moist and dry fabrics). The production capacity of the ozone gas was chosen as 6 g/h, 12 g/h, and 18 g/h while the ozone gas was fed through either rubber diffuser or stone diffuser to the jigger. In addition, ozone applications with the capacity of 18 g/h were applied by using both stone diffuser and rubber diffuser. After the ozonation processes, Berger values of the fabric samples after and before rinsing process were measured and the results were compared with the result of conventional hydrogen peroxide bleaching (reference bleaching). The results could be summarized as followings.

- Ozone bleaching process could be applied at the jigger machine.
- Berger values of the samples bleached with ozone gas were measured lower than conventional bleaching.
- Increment in the ozonation time and production capacity of the ozone gas were approached Berger values of the samples to the reference bleaching.
- Highest whiteness results were obtained for ozone applications in the water while the lowest ones were for ozone conditions in the air to the dry fabrics. The result could be explained by not being able to penetrate the ozone gas on the dry fabric surface.
- Way of ozone feeding was crucial for the ozone applications in the water while it was not important for ozone applications in the air. At the applications in the water, the method of feeding of ozone gas affected the results because of the effects on solubility of the ozone gas, and size and homogeneity of the ozone bubbles. Generally, higher Berger values measured for the applications with rubber diffuser than stone one which result was probably concluded from position of the diffusers.
- When the results of applications with different combinations of ozone capacity of 6 g/h and 12 g/h were focused, it could be said that Berger results of the applications with ozone capacity of 18 g/h by using single diffuser was higher.
- Effect of rinsing process differed depending on the ozonation conditions. It had positive effect on the results of the samples for ozone applications in the air.
- According to ANOVA results, all of the investigated main factors had effects on Berger results, statistically. While the most effective main factor on the results was ozonation condition, the lowest one was rinsing process. However, individual effect of rinsing process on the result was low, its double interaction with ozonation condition was quite important. That could be clarified by the ozone residual on the fabric samples depending on the ozonation conditions.

As a conclusion, it is possible to use ozone gas in the jigger machine as a bleaching material and it can be reached conventional bleaching results through appropriate working conditions. If it is wanted to achieve high whiteness effect, applications should be carried out in the water with high ozone capacity (18 g/h) and ozonation time (120 passage) via using rubber diffuser. This study should be enhanced by measuring ozone concentrations in the reaction tank via probe measuring in the water and air.

5. ACKNOWLEDGEMENT

This work was supported by the Ministry of Science, Industry and Technology, project number: 01426. STZ. 2012-1. The authors would like to thank the Ministry for its financial support.

REFERENCES

1. Gülümser, T., Akça, C., & Bahtiyari, M.İ., (2009). Investigation of the Effects of Ozone on Whiteness Degree in Wool Finishing. *Textile and Apparel* 1, 52-55.
2. Sancar Beşen, B., (2012). Improving of Sustainable, Economic and Innovative Processes with Ozone Applications for Textile Finishing. (Master's Thesis). Kahramanmaraş Sütçü İmam University, Graduate School of Natural and Applied Sciences, Kahramanmaraş.
3. Hussain, T. & Wahab, A., (2018). A Critical Review of the Current Water Conservation Practices in Textile Wet Processing, *Journal of Cleaner Production*, 198, 806–819.
4. Eren, H.A. & Eren, S., (2017). Ozone Bleaching of Cellulose, *IOP Conference Series: Materials Science and Engineering*, 254(8), 1-3.
5. Körlü, A., (2018). Use of Ozone in the Textile Industry. *Textile Industry and Environment*, DOI: http://dx.doi.org/10.5772/ intechopen.81774.
6. Kaşıkara Pazarlıoğlu, N., Sarıışık, M., &Telefoncu, A., (2005). Laccase: Production by Trametes Versicolor and Application to Denim Washing. *Process Biochemistry* 40, 1673-1678.
7. Perincek, S., Duran K., Körlü Ekmekçi, A., &Bahtiyari, İ., (2007). An Investigation in the Use of Ozone Gas in the Bleaching of Cotton Fabrics. *Ozone: Science&Engineering* 29(5), 325-333.
8. Arooj, F., Ahmed, N. & Shaikh, I.A., (2019). Application of Ozone in Stripping of Cotton Fabric Dyed with Reactive Dyes, *Ozone: Science & Engineering*, DOI:10.1080/01919512.2019.1667750
9. Turhan, Y., Soydaş, Ş., (2018). The Effects of Ozone Bleaching and Ozone Desizing Method on Whiteness and Water Absorption of 100% Cotton Terry Fabrics. *International Journal of Materials Science and Applications*, 7(3), 85-94.

10. Maqsood, H.S., Bashir, U., Wiener, J., Puchalski, M., Sztajnowski, S. & Militky, J., (2017). Ozone Treatment of Jute Fibers, *Cellulose*, 24(3), 1543–1553.

11. Erdem, A. & İbrahim Bahtiyari, M., (2018). Ultrasonic-Bioscouring and Ozone Based Bleaching of Cotton Slivers and Coloration of them with Natural Dye Sources, *Journal of Cleaner Production*, 188, 670–677.

12. Benli, H. & Bahtiyari, M.I., (2015). Combination of Ozone and Ultrasound in Pretreatment of Cotton Fabrics Prior to Natural Dyeing, *Journal of Cleaner Production*, 89, 116–124.

13. Dereli Perincek, S., (2006). An Investigation on the Applicability of Ultrasound, Ultraviolet, Ozone, and Combination of These Technologies as a Pretreatment Process. (Master's Thesis). Ege University, Graduate School of Natural and Applied Sciences, İzmir.

14. Hsu Y, Chen J-T, Yang H., &Chen J-T., (2001). Decolorization of dyes using ozone in a gas-induced reactor. *AIChe Journal* 47(1), 169–176.

15. Sancar, B., & Balcı, O., (2013). Decolorization of Different Reactive Dye Wastewaters by O_3 And O_3/Ultrasound Alternatives Depending on Different Working Parameters. *Textile Research Journal* 83(6), 574-590.

16. Perincek, S., Bahtiyari, İ., Ekmekçi Körlü, A., &Duran, K., (2009). New Techniques in Cotton Finishing. *Textile Research Journal*, 79(2), 121-128.

17. Öztürk, D. &Eren, H.A., (2010). The Use of Ozone in Textile Finishing. *Journal of Uludağ University Faculty of Engineering and Architecture*, 15(2), 37-51.

18. Sancar Beşen, B., and Balcı, O., (2016). Fading of Cotton Colored with C.I. Vat Blue I (Indigo Dye) via Ozone Application. *Ozone:Science&Engineering* 38(5), 395-409.

19. Perincek, S., Duran, K., &Korlu, A.E., (2013). Combination of Ozonation and Hydrogen Peroxide Bleaching for Linen Fabrics: Optimization of the Process Using Experimental Design Technique, Ozone *Science&Engineering.* 35, 316-327.

20. Paksoy, N., (2014). The Applicability of the Pretreatment and Dyeing Processes at Jigger Machine by Using Ozone Gas.(Master's Thesis). Kahramanmaraş Sütçü İmam University, Graduate School of Natural and Applied Sciences, Kahramanmaraş.

21. Xu, P., Janex, M., Savoye, P., Cockx, A., &Lazarova, V., (2002). Wastewater Disinfection by Ozone: Main Parameters for Process Design, *Water Research.* 36, 1043-1055.

22. Cardoso, J. C., Bessegato, G. G.& Zanoni, M. V. B., (2016). Efficiency Comparison of Ozonation, Photolysis, Photocatalysis and Photoelectrocatalysis Methods in Real Textile Wastewater Decolorization, *Water Research*. 98, 39-46

23. Prabaharan, M.,&Rao, J., V., (2001). Study On Ozone Bleaching of Cotton Fabric –Process Optimization, Dyeing and Finishing Properties, *Coloration Technology*. 117, 93-103

24. Bahtiyari, M.I & Benli, H., (2016). Ozone bleaching of cotton fabrics with the aid of ultrasonic humidifier, *Cellulose*. 23, 2715–2725

25. Eren, S. & Yetişir, İ., (2018). Ozone bleaching of woven cotton fabric, *Pamukkale Univ Muh Bilim Derg,* 24(7), 1245-1248.

26. Hareem, T., Arooj, F., Kashif, S.R. & Zubair Farooq, (2019). Economic Viability of Pilot-Scale Application of Ozone in Cotton Bleaching with Multiple Reuse of Water, *Ozone: Science & Engineering,* 41(2), 197-203

TEKSTİL VE KONFEKSİYON

VOL: 30, NO. 3

DOI: 10.32710tekstilvekonfeksiyon.622826

Investigation of Antibacterial Activity of Footwear Leather Obtained from Different Tanning

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ABSTRACT

In present study, antibacterial properties of leathers prepared by different tanning processes such as chromium, vegetable (mimosa and quebracho) and wet-white (modified glutaraldehyde) processes were analyzed by qualitative and quantitative tests. Staphylococcus aureus ATCC 33862 and Bacillus cereus NRRL-B-3711 as a representative of Gram-positive, Escherichia coli ATCC 25922 as a representative of Gram-negative were used in our study. The best inhibition effect was achieved against S. aureus by disc diffusion method. According to the bacterial reduction performance of leathers, the antibacterial property of vegetable tanned samples was higher than that of chrome and wet-white tanned samples against E. coli. The surface morphology of the leathers was also examined by scanning electron microscopy (SEM). In SEM analysis, the pores of chrome tanned leather were found to be larger than those of vegetable and wet white tanned leather, and these results were verified by the imagej program. We considered that the antibacterial properties of leathers can be improved by various plant extracts.

ARTICLE HISTORY

Received: 20.09.2019

Accepted: 11.08.2020

KEYWORDS

Antibacterial activity, Leather, Chromium, Vegetable, Wet-white

1. INTRODUCTION

The production of the leather removes unwanted substances from the raw material, makes it durable by tanning, and gains the desired properties in the product with post-tanning and finishing processes. The exact definition of the tanning is the conversion of an organic substance that can be degraded by bacteria into durable [1]. The types of tanning are mainly divided into three classes: (a) mineral, (b) vegetable, and (c) aldehyde [2].

Finished products of leather such as bags, clothes and shoes have been mostly being the essential requirements in people's lives. Especially in footwear, being in contact with foot very long periods of time can be promote proliferation of microorganisms such as molds, yeasts and bacteria, because of inadequate ventilation, suitable humidity and temperature conditions for microbial growth [3,4]. These developing microorganisms have a great problem in terms of the chemical structure of the leather [5]. Loss of elasticity, spots on surface, and unpleasant odor occurs in the leather because of microorganisms' enzymatic activity. Moreover, many microorganisms, such as *Corynebacterium spp*., *Clostridium spp*., *Staphylococcus spp*., *Pseudomonas spp*, *Enterobacter spp*., *E. coli* and *Candida albicans* can be pathogenic to humans [6,7,8]. Diabetics are more sensitive to bacteria and bacteria can stimulate the risk of foot ulceration [9]. For this reason, the prevention of the microorganism's growth on the leather products is important [10]. Many researchers have been coated of leather with different nanoparticles for inhibition of microorganisms' growth. For example, these nanoparticles including zinc oxide [11,12], gold [13], silver [4,8,14] have been studied in numerous researches. Silver nanoparticles as well as other nanoparticles might create positive and negative effects. For instance, some nanoparticles have a potential of entrance in the blood-brain barrier preserved the brain from hazardous chemicals in the blood [15]. Also, the antimicrobial properties of leathers coated with plant extracts was analysed by some researchers [5,13,16,17].

To cite this article: İnanç L, Mercan Doğan N. 2020. Investigation of Antibacterial Activity of Footwear Leather Obtained from Different Tanning. *Tekstil ve Konfeksiyon*, 30(3), 184-189.

The present study was aimed to investigate the antibacterial activity of leathers obtained from different tanning process. The surface morphologies of leather samples were also analyzed by SEM.

2. MATERIAL AND METHODS

2.1. Leather Materials

The nine pieces of dry salted hides which compose the raw material of the study were belonged to the domestic male bovine of the angus race. Hides were divided into two from the neck towards the tail through the belly line and eighteen sides of the hides were obtained. These sides were tanned with chrome, vegetable and wet-white conventional processed accordingly for upper leather. The conventional finishing chemicals were used in the leather finishing processes.

2.2. Test Bacteria and Growth Medium

Staphylococcus aureus ATCC 33862, *Bacillus cereus* NRRL-B-3711 and *Escherichia coli* ATCC 25922 were used. Bacteria were obtained from Bacteriology Laboratory of Biology Department, Pamukkale University. Tryptic Soy Broth and Tryptic Soy Agar (Merck) was used as growth media in study. The culture suspensions were prepared, according to the turbidity of a 0.5 McFarland standard.

2.3. Antibacterial Activity

The inhibitory effect of leathers was detected on solid medium. Leathers are degraded at high temperature. First, the leather materials were cut into 6 mm diameter discs and the surface sterilization of the leathers was done with ethyl alcohol (70% w/v) for 4 hours in sterile conditions. After then, they sterilized in autoclave at 90°C for 5 minutes. Sterile leather discs were placed on solid medium with bacteria. After incubation 24 h, the inhibition zone diameter around the leather discs was measured in mm. All manipulations were duplicated in our study [18].

Antibacterial activity of the leather materials was evaluated by using gram-negative *E. coli* and gram-positive *S. aureus* and *B. subtilis*. The colony counting method was used and the antibacterial activity was called as the percentage of cell reduction [10]. For this purpose, bacteria were grown to get the logarithmic phase in Tryptic soy broth (TSB) at 37°C and diluted in medium to obtain a concentration of 1×10^8 colony-forming units per milliliter; CFU/ml. The cell suspension was seeded into glass tubes in the presence of leathers (6 mm diameter discs) and incubated at 37 ˚C for 24 h. For estimating the number of viable bacteria remaining in the medium, the serial dilutions were prepared and 100 µl of dilution were spread on solid agar medium. After incubation for 24 h at 37 ˚C, the colonies on solid medium were counted and the colony-forming unit (CFU) values were determined. The bacterial suspensions without leather discs were tested under the same conditions as the negative control. The reduction rate (%) was calculated according to the following formula:

$$\% \text{ Reduction} = [(A-B)/A] \times 100$$

A: the colony counting in the tube without leathers

B: the colony counting in the tube with leathers

2.4. Scanning Electron Microscope (SEM) Analysis of Leathers

SEM images were performed on gold-coated samples using a Carl Zeiss Supra 40 VP Field Emission Scanning Electron Microscope (FE-SEM) at the Pamukkale University (Denizli, Turkey). Also, the surface of leather samples was analyzed based on the photographs using software, ImageJ 1.49b.

3. RESULTS AND DISCUSSION

3.1. Antibacterial Properties of Leathers

S. aureus, E. coli and B. cereus are common human pathogens and they cause a wide range of clinical infections such as skin and soft tissue, bacteremia, infective endocarditis and device-related infections [19-25]. The bacterial infections of the skin are among the most common infections in the community. Being in contact with the foot for a long time in poorly ventilated environment, humidity and temperature conditions cause the proliferation of pathogens in leather shoes. The population of foot bacterial flora decreases and the risk of skin colonization by human pathogens increase [3,4,26]. That's why, the use of leathers with antimicrobial properties in the manufacture of shoes, garment leather, etc. is important for human health and hygiene [27].

In our study, the antibacterial properties of leathers treated with the chromium, vegetable and wet-white was analyzed by qualitative and quantitative tests against *S. aureus, E. coli* and *B. cereus*. Table 1 has shown the results of the inhibition zones (mm) of leather discs. In general, the leather samples showed the different inhibition zones. It was found that *Bacillus cereus* NRRL-B-3711 and *Escherichia coli* ATCC 25922 were resistant than *S. aureus* ATCC 33862. On the other hands, the leather samples were more effective against *S. aureus*. Furthermore, there were bacterial colonies under the leather discs for *E. coli* and *B. cereus* while the inhibition zone wasn't seen around and beneath some leather samples for *S. aureus.* The antibacterial properties of the leathers tanned with vegetable (7.4-15.4 mm) was found to be more effective than that of wet-white (4.75-10 mm) and chromium (5.75-10.1 mm). In our opinion, the using different bacterial species or different tanned leathers caused the different inhibition zones.

The antimicrobial and physical properties of leathers coated with plant extracts was reported by some researchers. According to the findings of López et al. (2015), the leathers with *Aloe vera* extract had a powerful antibacterial effect against *S. aureus, B. subtilis, E. coli* and *K. pneumonia* [3]. Raji et al. (2019) verified that the combinations of tannins from *Cassia alata* plant with chromium were improved the properties of leathers such as tensile and tear strength, shrinkage temperature and thickness [16]. In other study, the inhibition effect of raw skin and chrome-tanned leather samples treated with the acetone and chloroform extracts of *Pseudevernia furfuracea* lichens were detected against some bacteria, fungus and yeast species [17]**.**

Table 1. The inhibition zone diameter of leathers (mm)

DYED CRUST LEATHER	*E. coli* ATCC 25922	*S. aureus* ATCC 33862	*B. cereus* NRRL-B-3711	FINISHED LEATHER	*E. coli* ATCC 25922	*S. aureus* ATCC 33862	*B. cereus* NRRL-B-3711
CCL-1	b	a	6.0 ± 0	**CFL-1**	b	a	5.75 ± 0.75
CCL-2	b	a	b	**CFL-2**	b	a	b
CCL-3	b	10.1 ± 0.1	b	**CFL-3**	b	9.15 ± 0.15	b
VCL-4	b	11.3 ± 0.7	b	**VFL**-4	b	15.4 ± 1.8	b
VCL-5	9 mm ± 0	a	b	**VFL**-5	7.4 ± 0.2	8.5 ± 0.5	b
VCL-6	b	13 ± 1	b	**VFL**-6	b	12 ± 2	b
WCL-7	b	a	b	**WFL**-7	b	a	b
WCL-8	b	10 ± 0	b	**WFL**-8	b	7.5 ± 0.5	b
WCL-9	b	4.75 ±0.25	b	**WFL**-9	5.5 ± 0.5	a	b

a: No inhibition zone and no cell growth beneath the leather discs; b: No inhibition zone and cell growth beneath the leather discs;
CCL: chromium crust leather, CFL: Chromium finished leather, VCL: Vegetable crust leather VFL: Vegetable finished leather, WCL: Wet white crust leather, WFL: Wet white finished leather

Velmurugan et al. prepared the green synthesis of silver nanoparticles (AgNPs) by *Erigeron annuus* flower extract as reducing and capping agent and determined the antibacterial properties of cotton fabrics and tanned leather samples against *Brevibacterium linens* and *Staphylococcus epidermidis*. In their study, the maximum inhibition zone was obtained from the cotton fabrics embedded with blend of flower extract and AgNPs against *B. linens* [13]. In a similar study on the antimicrobial performance of leather materials, the quantitative test results showed that leather samples coated with nAg reached the highest antibacterial activity against *E. coli* with 99.25% and against *S. aureus* with 99.91% [4]. In our study, the antibacterial performance of the vegetable-tanned leathers was found to be higher than that of wet-white and chromium-tanned leathers (Table 2). The chromium finished leather (CFL-1) inhibited only the growth of *B. cereus* (47.08%) among all leather samples. The maximum bacterial reduction rate was reached with the vegetable-tanned leather samples (92.33% and 84.66% for *E. coli* and 51.52%, 81.54% and 51.40% for *S. aureus*). In detailed, the vegetable-tanned crust leather (VCL-5) and finished leather (VFL-5) demonstrated good percentage reduction against *E. coli* of 84.66% and 92.33%, respectively. While the percentage reduction rate of all leathers was less for *S. aureus*, only VCL-5 reached good reduction rate (81.54%). The applicability of wet blue leathers obtained by using *Origanum* sp and *Schinus molle* essential oils as bactericide against *S. aureus*, *B. cereus* and *E. coli* was investigated and the antibacterial activity of oregano essential oil for *B. cereus* and *S. aureus* was reported by authors [28]. We thought that this situation was due to the specificity of plant extract-microorganisms.

3.2. Sample Imaging by Scanning Electron Microscopy (SEM)

Scanning electron micrographs showing the grain surface of the leathers tanned with chromium (a-d), vegetable (e-h) and wet-white (i-l) at a magnification of 150 and 500 are shown in Figure 1, respectively. The grain surface and the hair pores of leather samples were seem to be visible. It was found that chromium tanned leathers have a small number of large pores as shown in Fig. 1a-d, while vegetable and wet-white tanned leathers have many small pores (Figure 1e-h and Figure 1i-l). The higher magnification (×500) of scanning electron micrographs confirmed the lower magnification observation and where the hair follicles look clean without any foreign materials in all cases, as shown in Figure 1b, d, f, h, j and l. Also it was examined SEM graphs of all finished leather samples and it was observed that the dimensions of pores were reduced with the finishing of the leather. These graphs were good findings of the appearance of dyed crust and finished leathers according to different types of tanning. The large pores in chromium tanned leathers may be due to the fact that the properties of chrome affinity are less than that of vegetable tanning agents (mimosa and quebracho) and modified glutaraldehyde. Moreover, large pores provide a healthy product because it increases the air permeability of the leather. Contrary of chromium tanned leather; the vegetable tanned leathers had small and numerous pores. Herewith, an excess of pores may also be an advantage for a healthy leather product. In present study, the electron micrographs of all leather samples were analyzed by ImageJ software and the total area of surface and pores were measured. The results on ImageJ of leather samples are illustrated in Table 4. From these data, the efficiency of tanning agent was, in increasing order: chromium > vegetable > wet-white. The area of pore was to be 18.1% (for chromium tanned leather), 7.7% (for vegetable tanned leather) and 7.6% (for wet-white tanned leather). These results were in good agreement with the SEM images as given in Figure 1.

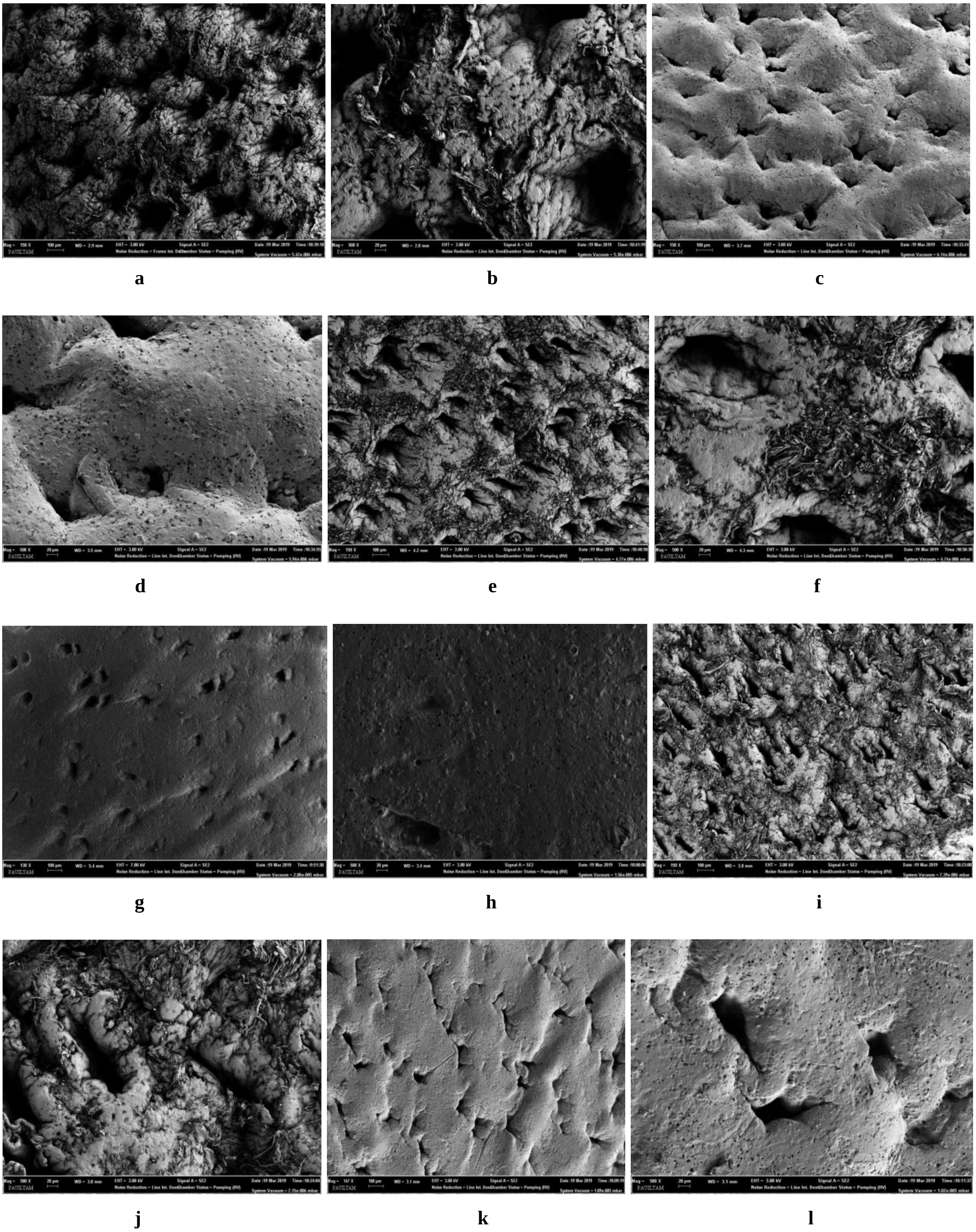

Figure 1. a-b) SEM images for the leathers chromium tanned dyed crust (sample1), c-d) SEM images for the leathers chromium tanned finished (sample10), e-f) SEM images for the leathers vegetable tanned dyed crust (sample4), g-h) SEM images for the leathers vegetable tanned finished (sample13), i-j) SEM images for the leathers wet-white tanned dyed crust (sample7), k-l) SEM images for the leathers wet-white tanned finished (sample16)

Table 2. Bacterial reduction rate (%)

Leather samples	*E. coli* ATCC 25922	*B. cereus* NRRL-B-3711	*S. aureus* ATCC 33862
CCL-1	-	-	-
CCL-2	-	-	-
CCL-3	-	-	25±2,0
CFL-1	-	47.08±0.08	-
CFL-2	-	-	-
CFL-3	-	-	7.69±0.00
VCL-4	-	-	51.52±0.5
VCL-5	84.66±0.00	-	81.54±0.5
VCL-6	-	-	9.98±0.00
VFL-4	-	-	43.38±1.03
VFL-5	92.33±0.91	-	30.46±2.00
VFL-6	-	-	51.40±0.00
WCL-7	-	-	36.15±5.98
WCL-8	-	-	9.23±0.00
WCL-9	-	-	32.65±2.5
WFL-7	-	-	20±1.00
WFL-8	-	-	12.31±0.00
WFL-9	15.14±0.04	-	21.23±1.01

-: No reduction

Table 3. The results of imagej processing software

	Chromium		Vegetable		Wet-White	
	Dyed Crust Leather	Finished Leather	Dyed Crust Leather	Finished Leather	Dyed Crust Leather	Finished Leather
Total pore area (μm^2)	521.725.365	173.502.000	222.410.338	112.235.434	226.081.533	120.627.690
Surface area (μm^2)	2.364.859.518	2.710.890.000	2.650.095.788	3.782.699.168	2.734.773.891	2.811.634.414
Total leather area (μm^2)	2.886.584.883	2.884.392.000	2.872.506.126	3.894.934.602	2.960.855.424	2.932.262.104
Total pore Area (%)	18.1	6.0	7.7	2.9	7.6	4.1

4. CONCLUSION

In summary, we investigated the antibacterial properties of leathers prepared by different tanning methods such as chromium, vegetable (mimosa and quebracho) and wet-white (modified glutaraldehyde). In general, leather samples showed a more specific effect on *S. aureus* compared to *E. coli* and *B. cereus*. Nevertheless, the reduction rates of the vegetable-tanned crust and finished leathers (VCL-5 and VFL-5) were significant for *E. coli*. Especially, the leathers tanned vegetable showed better antibacterial activity than leathers tanned chromium and wet-white. The leathers tanned with chromium have got unique properties. The antibacterial activity of leather tanned with vegetable is better than the leather tanned with chromium. The antibacterial properties of plant extracts are well known. In other words, the mimosa and quebracho may be providing a good antibacterial property to leather. Also, the surface morphology and pores of leather samples were sighted by SEM. The total pore, surface and leather area were confirmed by imagej program. According to our findings, the interaction of leathers-bacteria should also investigate in detailed. Besides, we considered that the antibacterial properties of leathers can be developed with different plants extract.

ACKNOWLEDGEMENT

The authors thank to Dr. Semih Tan (Pamukkale University, Faculty of Medicine, Department of Histology and Embriology) for providing software, ImageJ 1.49b.

REFERENCES

1. Covington T. 2009. *Tanning chemistry. The Science of Leather*. The University of Northampton, Northampton, UK: RSC publishing.
2. Sreeram KJ, T Ramasami. 2003. Sustaining tanning process through conservation, recovery and better utilization of chromium. *Resources, Conservation and Recycling* 38(3), 185-212.
3. Maestre-López IM, Payà-Nohales FJ, Cuesta-Garrote N, Arán-Ais F, Martínez-Sánchez MA, Orgiles-Barceló C, Bertazzo M. 2015. Antimicrobial effect of coated leather based on silver nanoparticles and nanocomposites: synthesis, characterisation and microbiological evaluation. *Journal of Biotechnology and Biomaterials* 5(1), 1-10.
4. Lkhagvajav N, Koizhaiganova M, Yasa I, Celik E, Sari O. 2015. Characterization and antimicrobial performance of nano silver coatings on leather materials. *Brazilian Journal of Microbiology* 46(1), 41–48.
5. Chirila C, Berechet MD, Deselnicu V. 2016. Thyme essential oil as natural leather preservative against fungi. *ICAMS*
6. Gutarowska B. 2013. Niszczenie materiałów technicznych przez drobnoustroje. *LAB Laboratoria, Badania* 18(2), 10-14. (in Polish)
7. Vouga M, Greub G. 2015. Emerging bacterial pathogens: the past and beyond. *Clinical Microbiology and Infection* 22, 12–21.
8. Bielak E, Sygula-Cholewinska J. 2017. Antimicrobial effect of lining leather fatliquored with the addition of essential oils. *Biotechnology and Food Science* 81(2), 149–157.
9. Jeffcoate WJ, Harding KG. 2003. Diabetic foot ulcers. *The Lancet* 361, 1545-1551.
10. Luo Q, Gao H, Peng L, Liu G, Zhang Z. 2016. Synthesis of PEGylated chitosan copolymers as efficiently antimicrobial coatings for leather. *Journal of Applied Polymer Science* 133(22), 1–7.
11. Gunalan S, Sivaraj R, Rajendran V. 2012. Green synthesized ZnO nanoparticles against bacterial and fungal pathogens. *Progress in Natural Science: Materials International* 22(6), 693–700.
12. Gaidau C, Ignat M, Iordache O, Popescu LM, Piticescu RM, Ditu LM, Ionescu M. 2018. ZnO nanoparticles for antimicrobial treatment of leather surface. *Revista De Chimie* 69(4), 767–771.
13. Velmurugan P, Shim J, Bang KS, Oh BT. 2016. Gold nanoparticles mediated coloring of fabrics and leather for antibacterial activity. *Journal of Photochemistry and Photobiology* 160, 102–109.
14. Majidnia Z, Idris A, Valipour P. 2013. Evaluation of antibacterial properties of leather treated with silver nanoparticles. *Jurnal Teknologi* 60, 5-8.
15. John F, Sargent Jr. 2016. Nanotechnology: A policy primer. *Congressional Research Service*
16. Raji P, Samrot AV, Bhavya KS, Sharan M, Priya S, Paulraj P. 2019. Greener approach for leather tanning using less chrome with plant tannins and tannins mediated nanoparticles. *Journal of Cluster Science* 30 (6), 1533-1543.
17. Türkan MF, Aslan A, Yapici AN, Meriçli Yapici B, Bilgi ST. 2013. Assessment of antimicrobial activity of natural leathers treated with *Pseudevernia furfuracea* (L.) Zopf extracts. *Tekstil ve Konfeksiyon* 23(2), 176-180.
18. Kivrak I, Duru ME, Öztürk M, Mercan N, Harmandar M, Topçu G. 2009. Antioxidant, anticholinesterase and antimicrobial constituents from the essential oil and ethanol extract of *Salvia potentillifolia*. *Food Chemistry* 116, 470–479.
19. Wertheim HF, Melles DC, Vos MC, van Leeuwen W, van Belkum A, Verbrugh HA, Nouwen JL. 2005. The role of nasal carriage in *Staphylococcus aureus* infections. *The Lancet Infectious Diseases* 5, 751–762.
20. Coates R, Moran J, Horsburgh MJ. 2014. Staphylococci: colonizers and pathogens of human skin. *Future Microbiology* 9, 75–91.
21. Tong SYC, Davis JS, Eichenberger E, Holland TL, Fowler VG Jr. 2015. *Staphylococcus aureus* infections: epidemiology, pathophysiology, clinical manifestations, and management. *Clinical Microbiology Reviews* 28(3), 603-661.
22. Dryden MS. 2010. Complicated skin and soft tissue infection. *Journal of Antimicrobial Chemotherapy* 65 Suppl 3, iii35–44.
23. Olszewski WL, Jamal S, Manokaran G, Pani S, Kumaraswami V, Kubicka U, Lukomska B, Dworczynski A, Swoboda E, Meisel-Mikolajczyk F. 1997. Bacteriologic studies of skin, tissue fluid, lymph, and lymph nodes in patients with filarial lymphedema. *The American Journal of Tropical Medicine and Hygiene* 57(1), 7–15.
24. Lee YL, Shih SD, Weng YJ, Chen C, Liu CE. 2010. Fatal spontaneous bacterial peritonitis and necrotizing fasciitis with bacteraemia caused by *Bacillus cereus* in a patient with cirrhosis. *Journal of Medical Microbiology* 59 (Pt 2), 242–244.
25. Ikeda M, Yagihara Y, Tatsuno K, Okazaki M, Okugawa S, Moriya K. 2015. Clinical characteristics and antimicrobial susceptibility of *Bacillus cereus* blood stream infections. *Annals of Clinical Microbiology and Antimicrobials* 14(43), 1-7.
26. Domenico EGD, Cavallo I, Capitanio B, Ascenzioni F, Pimpinelli F, Morrone A, Ensoli F. 2019. *Staphylococcus aureus* and the Cutaneous Microbiota Biofilms in the Pathogenesis of Atopic Dermatitis. *Microorganisms* 7(301), 1-22.
27. Koizhaiganova M, Yas I, Gülümser G. 2015. Assessment of antibacterial activity of lining leather treated with silver doped hydroxyapatite. *International Biodeterioration & Biodegradation* 105, 262-267.
28. Bayramoğlu EE, Gülümser G, Karaboz İ. The investigation of antibacterial activities od some essential oils in wet blue leather. IJNES, 2(1), 33-36.

TEKSTİL VE KONFEKSİYON

VOL: 30, NO. 3

DOI: 10.32710tekstilvekonfeksiyon.672312

Prioritization of Key Activities on Establishment of BPM Practice in Apparel Organizations

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ABSTRACT

The initial assumption within this paper is that successful implementation of business process management (BPM) practice in the apparel industry organizations depends on a set of priority steps and activities shaped by the specific characteristics of the apparel industry. The apparel industry is considered to be particularly specific because it has a labor-intensive and creative character, it is necessary to acquire certain professional knowledge and skills, the female workforce force is dominant, and micro, small and medium-sized enterprises (MSMEs) are present in the largest number. The aim of this paper is to perform prioritization and categorization of BPM practice establishment activities, based on the highlighted specifics, by integrating analytic hierarchy process (AHP), weighted aggregates sum product assessment and ABC analysis. The result showed that group A consists of 12 key activities, the first of which is the definition of process roles and responsibilities.

ARTICLE HISTORY

Received: 08.01.2020

Accepted: 12.06.2020

KEYWORDS

Business process management (BPM), apparel industry specifics, AHP method, WASPAS, ABC analysis

1. INTRODUCTION

The contemporary business sets a demand for organizations to implement adequate changes and to modernize their processes to maintain their position in the market, function in a stable manner, and establish the basis for continuous improvement. It is important to focus on business processes because they represent a set of business activities coordinated to ensure business goals achievement [1]. Business process management as a method of documenting, analyzing, modeling and simulating, functioning, and monitoring continuous changes of business processes from initial to final activities is a way for organizations to meet the requirements of contemporary business [2,3]. The way of carrying out activities within business processes is presented through a process model, which can be regarded from different perspectives, namely control flow, resource, data, time, and function perspective [4,5]. Comprehensive business process insights deliver value through the end-to-end process [6].

The way BPM practice is applied varies across different business environments [7]. This paper focuses specifically on the apparel industry and the separation of primary activities to establish BPM in accordance with specific aspects of the industry. This research idea is the product of knowledge about the functioning of the apparel industry in Serbia and the region. The main products of the textile industry in Serbia nowadays are clothing (dresses, skirts, T-shirts, scarves, sweaters, socks, lingerie, pajamas, nightgowns, etc.), fashion details (bags, purses, wallets, belts, jackets, caps and other articles of leather), knits and yarns [8]. About 85% of textile products in North Macedonia are made by the garment industry [9]. The southwestern region of Bulgaria is characterized by the highest concentration of jobs in the textile and apparel industries [10]. Labor-intensive character with a predominantly female workforce and the need to educate

To cite this article: Dobrosavljević A, Urošević S. 2020. Prioritization of key activities on establishment of bpm practice in apparel organizations. *Tekstil ve Konfeksiyon*, 30(3), 190-199.

professional staff through the cooperation of vocational schools and businesses, the seasonality of collections and creativity, are reflected in the business processes themselves. So, it can be stated that it is necessary to establish a BPM practice, and to adapt the business to the specified industry particularities [11,12]. This practice should be aimed at continuous improvement of business processes while monitoring the business trends of the market. As the success of an organization depends on the developed business model and its orientation [13], the need to form a framework for evaluation and adaptation of BPM practice, under the specific aspects of the industry, is observed within this paper. Business processes have a special role in the analysis and design of an organization, as well as creation of business system behavior patterns [14].

In line with the above mentioned, the aim of this paper is to evaluate and prioritize activities for adequate establishment of BPM in apparel industry organizations according to the specific aspects that determine the business within this industry. The structure of the paper is such that the theoretical part presents a literature review of the current research. The activities and apparel industry specifics, as a subject of research, are individually discussed in detail within the theoretical part of the paper. Within the research part of this paper, BPM activities are ranked, taking into account the estimated impact of specific aspects of the apparel industry. The Analytic Hierarchy Process (AHP) and Weighted Aggregates Sum Product Assessment (WASPAS) methods are performed, to assess the priority of the activities. The classification into the priority groups is managed using the ABC method, and a graphical representation of the classification is made using the Pareto diagram.

2. ESTABLISHMENT OF BPM PRACTICE IN APPAREL ORGANIZATIONS

To survive in the market, organizations need to coordinate and make changes in their production processes [15]. Adequate application of BPM ensures the achievement of flexibility and agility of the organization [16]. BPM is established with the aim to model processes and support their functioning with monitoring, audit, and analysis [17]. This practice drives the process of building a solution in an existing business environment [18].

BPM practices should be adaptable to the nature of business processes within a particular business system. Business systems within the apparel industry are characterized by several specifics, among which is the work intensity of the production process. Production of apparel products consists of a series of related labor-intensive manual operations [19]. The apparel industry can be described as a creative industry, dominated by a number of micro, small and medium-sized enterprises (MSMEs), and the growth of their competitiveness depends on the active acquisition and application of knowledge [20].

Kokeza and Urosevic [21] see the future development of the Serbian textile and apparel industry in the production of higher value-added products. The statement of these authors is consistent with the need to establish a business practice that is focused on delivering value-added results by managing processes that shape the result. Based on the stated findings, further elaboration of the prominent specifics of the clothing industry and activities relevant to the establishment of BPM practice continues.

2.1 Specifics of the apparel industry

Business processes that take place in the manufacturing organizations of the apparel industry include tailoring, sewing, button or zipper placement, ironing, quality control, packaging and shipping of goods to distributors and end consumers [14]. Work intensity, as one of the primary specifics of the apparel industry, is most clearly visualized within the process of assembling products, because the sewing line within this process contains a large number of operations [22]. Although the manufacturing process tends to be modernized and simplified by machines using CNC technology, the tailoring process is still performed manually in many companies [23].

Among apparel industry specifics arises the need for expertise and skills. Workforce productivity can be enhanced through training and the acquisition of effective skills [24]. Besides, learning how to produce something by hand is a particular type of talent or skill [25]. In the process of apparel production, it is necessary to know the techniques of sewing, but also to understand the material properties, the functioning of the sewing machines and what other equipment is necessary to perform the tasks in the process [26]. Urosevic et al. [27] state that the ability to integrate textile technology knowledge with other areas of business, the use of modern engineering tools, skills and techniques in practice, inventiveness and innovation in work, flexibility in behavior and similar, are the requirements for professional staff.

Another of the specifics of the apparel industry is creativity, which occurs in the process of the apparel product design. The highest level of creativity is attributed to the early stages of the design process, within which design principles such as harmony, rhythm, contrast, highlight, and proportion are combined and altered by the ideas that the designer develops [28].

There is a dominant share of the female workforce in labor-intensive activities [29]. Especially in the apparel and textile industries where 70% of employed women are exposed to different types of risk [30].

Dallas and Wynn [31] consider establishing BPM in small organizations. In doing so, they highlight the characteristics of small businesses that can affect the level of BPM practice adoption. These characteristics are: limited human and financial resources, time pressure, narrow integration of activities, strong work ethics, and decision-making agility. Because a significant number of micro and SMEs operate within the apparel industry, these characteristics can influence the level of adoption of BPM practice in them. Chong [32] states that the role of BPM in SMEs is reflected in improving customer service, automating workflows and processes that already exist in the organization, informing employees of the activities they are in charge of with timely and accurate information on necessary measures, enabling the monitoring and optimization of business processes and the integration of tools for managing them.

2.2 Activities according to key dimensions of BPM establishment

Within the research conducted by Škrinjar and Trkman [33], elements related to the establishment of each of the dimensions concerning the functioning of BPM practices within organizations emerge. These authors present a range of activities applicable to the analysis of the process maturity of organizations operating within different industries [34]. A series of activities stems from the view that BPM is necessary to be addressed from a holistic perspective [35-37]. A holistic perspective on BPM encompasses organizational aspects such as human resource management, information systems, structure, sustainability, risk, decision-making, and knowledge along with alignment with business strategies [38].

Concerning human resources in an organization that implements BPM, employee knowledge and skills are considered essential resources for improving business processes, and learning is considered to be an important tool [32]. Börner et al. [39] emphasize the need to develop effective learning and training solutions with the intention of engaging employees to participate in process improvement initiatives. In doing so, they propose simulation as a training instrument because it provides a high degree of interaction between training participants with a realistic experience. Paul-Majumder and Begum [40] find that all jobs in the apparel industry require some level of education. One of the specifics of the apparel industry relates to the gender gap in employee education [41]. The textile industry in Serbia is faces a shortage of workforce that has the necessary skills and knowledge to complete tasks that certain jobs require [2]. Also, there is a gap in the application of theoretical and practical knowledge and skills of employees, a lack of knowledge of new technologies and a quality system, which makes education a necessary precondition for improving performance and productivity [42]. Training is a continuous process whereby an optimal combination of people, machines and materials occurs as the ultimate goal [43]. Not all work tasks, in the entire production process, can be automated, however, with the automatization of the tailoring processes, there is a need to acquire the practical skills and knowledge of handling new machines [44,45]. The innovative behavior of employees is closely linked to their creativity, but unlike creativity, it produces some kind of benefit [46]. Accordingly, stimulation for actors within creatively intensive processes should not be absent [47].

Operational activities related to BPM are often described as a lifecycle model. Starting with process identification where the process map is designed, then process discovery, analysis, and redesign, so that dedicated process-aware information systems can be implemented to support the execution of business processes. These information systems provide continuous process control and periodic control [48]. In the case of process-oriented information and communication technologies, it is more difficult to show the flow of information between all actors within the process as well as their responsibilities [49]. Organizations need a system to fulfill a few requirements. Among these requirements are a process-focused measurement system and a measurement system that would provide the measurement of quantitative and qualitative aspects of performance [50]. The flexibility of information systems is important because it provides support for the dynamic changes in processes [51]. The use of the internet and digital technologies ensures the collection and processing of data and information from customers, with the opportunity to develop strategies based on customer relationship management [52].

The focus on consumers as a dimension of BPM is significant, given the fact that the ultimate goal of managing business processes is to improve the process while optimizing value creation for customers [53]. The consumer-oriented business provides a continuous practice of creating value for customers based on the researched, expressed and hidden needs and desires of customers by applying different research techniques and methods [54]. Melcher [55] states that product complexity is subject to correction only by monitoring the external environment of the organization within which it comes to learn about different individual customer expectations and competitors' activities. If product development is based on consumer feedback, consumer satisfaction after the purchase can have a positive impact on repeated shopping in the future and the creation of a loyal customer base [56-58].

Process jobs refer to tasks and roles that occur in a process-oriented organization. Multidimensionality and a frequent need to solve problems and a constant need for learning characterize them. Responsibilities are allocated horizontally in the structure, and the role of the owner over the whole process is assumed [59,60].

Establishing a performance measurement system in an organization is carried out based on three basic steps that include definition, introduction to business and use of performance measures [61]. The organizations themselves are responsible for evaluating the organization's core and support processes and determining performance targets for each of them [62]. Employees, of organizations that apply BPM, become process participants with a broader range of responsibilities, perform the necessary activities and are tasked with performing multidimensional process tasks and must be familiar with targeted process performance [63,60]. Dobrosavljević and Urosević [64] find that establishing process improvement practices is the result of the experience organizations gain in business.

Min et al. [65] state that cooperation between a particular organization and a supplier is manifested in the form of inter-organizational business processes and as the basis of inter-organizational links. Legner and Wende [66] emphasize the need to coordinate inter-organizational business, and that even after coordination activities, additional challenges may arise concerning the interoperability of multiple business processes.

The use of process terminologies, such as input, process, output, or process owner, in daily communication between employees, results from the adoption of a process organizational culture within an organization [67]. Changes in business require a shift in the way people think. Those who adopt the process view more often work with people from other departments. This way of thinking characterizes information sharing, learning, and teamwork. It is necessary to create space for a culture of cooperation and an orientation towards meeting consumer needs [60].

Management activities include customer acceptance of orders, prototype modeling, customer approval, procurement of required fabrics and materials, production planning, organization resource management, employee performance management, and manufacturing management activities [14]. Production strategies should be subject to constant changes in line with changes in the business environment, but also in response to market needs due to the seasonality of collections [68].

In order to manage the business process at all, it is necessary to define it [69]. The definition of business processes is done by identifying and explaining the segments, or sets of activities, that make the functioning of the whole process possible. Cross-functional teams are designed to define the structure for managing processes and their implementation at the strategic level [70]. The description uses a standardized methodology that all employees should be familiar with in order to fulfill the requirements of the process functioning.

3. MATERIAL AND METHOD

3.1. Material

There is a different set of specific business aspects that characterizes each industry. The process orientation of an organization reflects through the different business dimensions and activities within each of them. An process-oriented organization, which operates in a specific business environment, has to find the optimal way to establish a BPM practice. With that in mind, the need to generate a set of key activities for establishment of BPM pratice, taking into account the apparel industry specifics, arises. That is why the main elements of this research are apparel industry specifics and activities for establishment of BPM practice presented in the Figure 1. The specific aspects of the apparel industry, taken into consideration, are labor-intensive and creative character, professional skills development, the dominant presence of female workforce in the production process, and a large number of micro and SMEs. It is assumed that specifics shape the way of doing business and that one universal set of activities will not produce successful results in all manufacturing and business systems. The specifics of the apparel industry may affect the priority of certain activities for the establishment of BPM practice. There are 39 recognized activities that might help establishment of BPM practice in described business environment listed in the Figure 1.

Each of the given activities for establishment of BPM practice, and the specifics of the apparel industry are evaluated by experts from the textile and apparel industry. Twenty-four experts from Serbia, North Macedonia, and Bulgaria participated in this research. Campagne et al. [71] disscuss the appropriate size of expert panel for reliablility of results. They state that the minimal number of experts should be between 10 and 15, and they find that including 30 experts in the evaluation provides a stable mean. Consistent with these findings, it is considered that the number of 24 experts in the panel might provide reliable prioritization of the key activities for establishment of the BPM practice in apparel industry. The expertise of the experts is established on the basis of years of their experience in the production of textile and apparel and in educational institutions. Experts were asked to assess the impact of the apparel industry specifics having in mind impact on process input, process functioning, and process output, and then evaluate the importance of 39 activities for the establishment of BPM practice. Their estimates represent the input data of this research.

3.2. Method

Within this research the integration of the analytical hierarchy process (AHP) and weighted aggregated sum product assessment (WASPAS) was performed for prioritization of activities for the establishment of BPM practice. Weight coefficients of the apparel industry specifics were determined using the AHP method. This method is widely spread and useful in many decision-making problems [72]. In this case, it is used for calculation of weight coefficients of apparel industry specifics. Experts expressed preferences over specifics using the Saaty's nine point scale, where grade 1 stands for equal impact of two compared specifics, and 9 stands for absolute impact of one of two comapred specifics [73]. AHP allows the problem to be decomposed into levels of the decision-making hierarchy and uses pairwise comparisons for criteria and alternative evaluations, as well as weighitng cofficients computation [74,75]. As Fedrizzi and Brunelli [76] state, by the matrix of construction $A=(a_{ij})_{nxn}$ the relationship between the intensities of the alternatives of alternatives x_i and x_j is evaluated. Thereby, it is possible to assess the degree of consistency of the experts' responses. To do this, it is necessary to calculate a consistency index (CI) using the formula:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (1)$$

Then, the degree of consistency is determined by the formula:

$$CR = \frac{CI}{RI}, \quad (2)$$

where RI is a Random Index (RI) that depends on the number of rows in the matrix denoted by n. The CR value should not be higher than 0.1 (10%) for the responses to be considered consistent [77]. The random index is read from Table 1.

After the calculation of the weight coefficients in the described manner, the third phase continues by application of Weighted Aggregates Sum Product Assesment (WASPAS) method. Chakraborty and Zavadskas [78] apply this method to decision making in production. The basic idea behind applying this method is in integration of *weighted sum* (WS) and *weighted product* (WP) approach to determine the significance of alternatives, or activities in this case. Activities were evaluated using a seven point scale, where grade 1 represents the lowest level of influence, i.e. insufficient significance, and grade 7 indicates the highest level of influence, ie absolute significance according to the defined elements of the research. Within WASPAS method the experts' ratings of activities and weight coefficients, generated by AHP method in previous research step, are combined to perform prioritization of activities for establishment of BPM practice according to evaluated impact of specifics. It is carried out in five steps. The first step is to determine the optimal level of performance with respect to each criterion by finding the maximum or minimum value according to the criterion under consideration. The second step is to normalize the decision matrix by the formula:

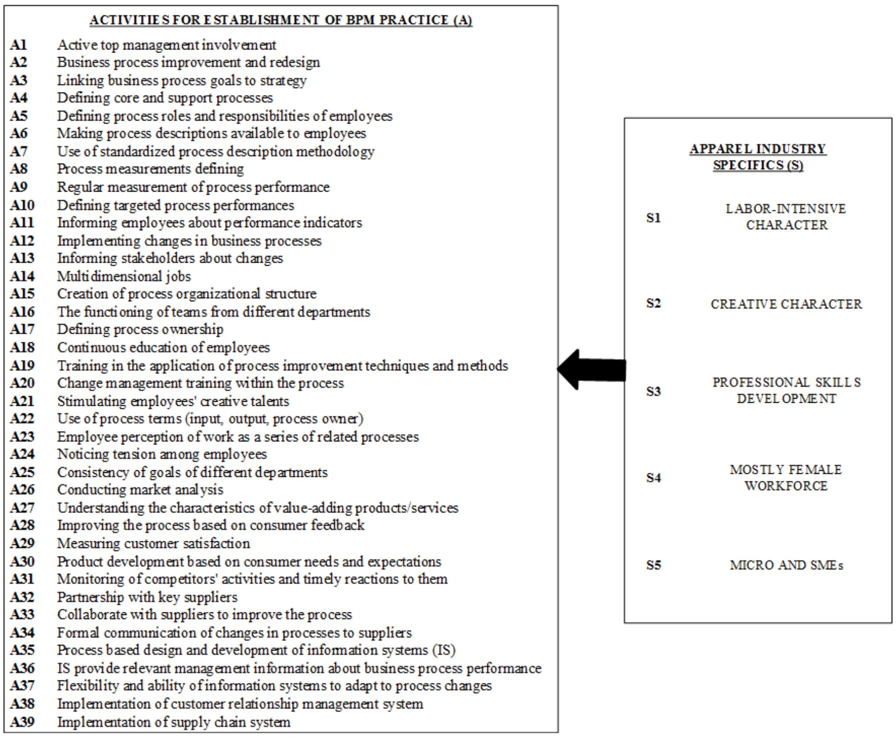

Figure 1. List of activities for establishing BPM practice and specifics of the apparel industry

Table 1. Random Index RI Values [77]

N	1	2	3	4	5	6	7
RI	0	0	0.58	0.90	1.12	1.24	1.32

$$r_{ij} = \begin{cases} \dfrac{x_{ij}}{x_{0j}}; & j \in \Omega_{max} \\ \dfrac{x_{0j}}{x_{ij}}; & j \in \Omega_{min} \end{cases} \quad (3)$$

The third step is to calculate the relative importance $Q_i^{(1)}$ using the WS approach, while within the fourth step, the relative importance of the alternatives $Q_i^{(2)}$ is calculated using the WP approach according to the following formulas:

$$Q_i^{(1)} = \sum_{j=1}^{n} w_j \, r_{ij} \quad (4)$$

$$Q_i^{(2)} = \prod_{j=1}^{n} r_{ij}^{w_j} \quad (5)$$

Finally, the fifth step considers the overall relative importance obtained by applying the formula:

$$Q_i = \lambda Q_i^{(1)} + (1-\lambda) Q_i^{(2)}, \quad (6)$$

where the value of the coefficient is λ= 0.5 [79].

After prioritization, ABC analysis was applied to classify key activities for establishing BPM practice, and the situational presentation of the performed classification was presented in a Pareto diagram. More recent literature provides an example of the use of ABC chart analysis in ranking SME performance indicators as important data in the decision-making process [80]. This analysis is useful in the decision-making process because it enables the most influential elements to be highlighted and the elements with the least level of influence discarded, which contributes to the decision-making of the steps to be taken [32]. According to this analysis, the classification of research elements into ABC groups is most often done on the basis of one criterion, namely the value criterion [81].

The described methodology and the research flow within this paper is illustrated in Figure 2.

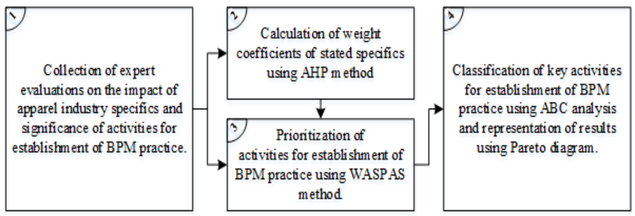

Figure 2. Research methodology and research flow

4. RESULTS AND DISCUSSION

Under the assumption that the business environment of the apparel industry is specific, research on providing the key set of priority activities for the establishment of continuous, efficient, and effective BPM practice is conducted. For this to be possible, data were collected based on the opinions of 24 experts, experienced in tasks related to production process management in business systems of different sizes and within educational and research institutions. Specific aspects were identified based on the generally known characteristics of the apparel industry, and experts had the opportunity to express their preferences about their impact. The mean scores of their responses on the significance of each specific aspect are presented in Table 2.

Table 2. Mean values of expert assessments of specifics

Apparel industry specifics	Mean values
S1 – Labor-intensive character	6.250
S2 – Creative character	4.458
S3 – Pofessional skills development	5.583
S4 – Mostly female workforce	5.083
S5 – Micro and SMEs	2.625

The labor-intensive character was evaluated as a criterion of very strong significance in the functioning of the apparel industry processes, as core processes are the ones characterized by labor intensity. According to the expressed preferences of the experts from the presented mean values, the criteria are arranged in descending order, namely: S1 - S3 - S4 - S2 - S5. In order to effectively evaluate and prioritize activities, which in such a specific environment will accelerate the adoption of BPM principles and ensure business success, the weight coefficients of specific aspects are determined. For determination of weight coefficients of specifics, a decision-making hierarchy, within the AHP method, is defined. The goal is to calculate weight coefficients of apparel industry specifics, the first level considers the criteria of impact on process input, process functioning, and process output, and the specifics are evaluated in the second level of the decision-making hierarchy. According to the described procedure, pairwise comparison at both hierarchy levels was applied.

The pairwise comparison matrix shown in Table 3. Represents the expressed preferences of experts at the second level. The diagonal is a value of 1, which indicates equal significance when comparing the same specific aspect.

Table 3. Pairwise comparison matrix at second level of decision-making hierarchy and calculated weights of apparel industry specifics

	S1	S3	S4	S2	S5	Weights
S1	1	0.67	1.17	1.79	3.63	0.258
S3	1.50	1	0.50	1.13	2.63	0.223
S4	0.86	2	1	0.63	2.46	0.232
S2	0.56	0.89	1.60	1	1.83	0.202
S5	0.28	0.38	0.41	0.55	1	0.085
CR = 0.06						

The estimated consistency ratio (CR) in the responses of experts, based on the application of formulas (2) and (3) in the first level is 0.003 or 0.3%, and in the second level is 0.06, or 6%, which are less than the recommended value of 0.1, or 10%, respectively. Based on which it is concluded that consistency in the experts' answers, that is, a certain degree of agreement in the assessments of a group of experts, has been achieved. The criterion of labor intensity appears as one of the most influential among the specifics. The lowest rated aspect is the size of organizations operating in the apparel industry. The dominant presence of SMEs is characteristic of other industries as well. Starting with the assumption that the character of an industry can be reflected in the business processes, the prioritization of activities in the next step of the research is approached. Evaluated specifics are further treated as criteria in the research.

Based on the obtained weight coefficients and expert evaluations of each activity against the set criteria, the WASPAS method is implemented according to the described procedure. The final level of performance and the degree of utility of the considered activities were obtained by applying formula (6), which is shown in Table 4.

The degree of utility provides insight into the significance of each activity. The activity of the priority importance, according to the ranking result, is to define process roles and responsibilities. This activity is considered to be an initial activity in the characteristic business environment of the apparel industry.

ABC analysis was applied, as a final step. It provides the classification of ranked activities into the activity sets with a priority of the application. However, a graphical representation can provide a better insight into the order and impact of the activity, so the classification result is shown on the Pareto diagram in Figure 3.

Table 4. The resulting level of performance and the degree of utility of the considered activities

Activity	$Qi^{(1)}$	$Qi^{(2)}$	Qi	Rank	Activity	$Qi^{(1)}$	$Qi^{(2)}$	Qi	Rank
A1	0.807	0.685	0.746	**4**	A21	0.386	0.360	0.373	**25**
A2	0.387	0.307	0.347	**31**	A22	0.396	0.317	0.356	**28**
A3	0.390	0.372	0.381	**21**	A23	0.421	0.417	0.419	**18**
A4	0.674	0.609	0.641	**10**	A24	0.387	0.363	0.375	**24**
A5	0.832	0.698	0.765	**1**	A25	0.399	0.320	0.359	**26**
A6	0.378	0.296	0.337	**34**	A26	0.384	0.303	0.344	**32**
A7	0.366	0.282	0.324	**38**	A27	0.394	0.378	0.386	**20**
A8	0.739	0.638	0.689	**8**	A28	0.427	0.423	0.425	**17**
A9	0.507	0.495	0.501	**15**	A29	0.399	0.320	0.359	**27**
A10	0.665	0.603	0.634	**12**	A30	0.389	0.369	0.379	**22**
A11	0.525	0.508	0.516	**13**	A31	0.393	0.313	0.353	**29**
A12	0.375	0.293	0.334	**35**	A32	0.415	0.410	0.412	**19**
A13	0.372	0.289	0.331	**36**	A33	0.516	0.501	0.509	**14**
A14	0.360	0.274	0.317	**39**	A34	0.372	0.289	0.331	**36**
A15	0.498	0.488	0.493	**16**	A35	0.679	0.612	0.645	**9**
A16	0.388	0.366	0.377	**23**	A36	0.802	0.682	0.742	**5**
A17	0.827	0.695	0.761	**2**	A37	0.812	0.687	0.750	**3**
A18	0.669	0.606	0.638	**11**	A38	0.390	0.310	0.350	**30**
A19	0.749	0.644	0.696	**7**	A39	0.381	0.300	0.340	**33**
A20	0.757	0.648	0.702	**6**					

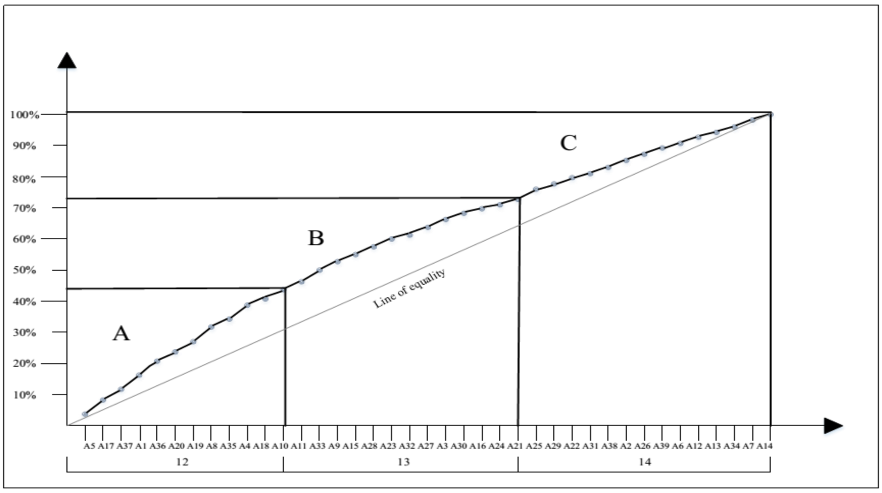

Figure 3. Situational presentation of the classification of key activities using the Pareto diagram

The rule according to which elements are classified A, B, and C, in most cases applied in inventory management cases, is 80-20. This means that 20% of items contribute to a business result with 80% of the value [82,83]. However, in this case, it is not a matter of monetary value. The activities were evaluated based on experts' assessments, and their value is an expression of opinion on potential impact or significance. The ranked values are approximate, although different. The Pareto diagram presents an equality line, which would indicate perfect equality of influence of the considered elements of the analysis, to notice the presence in the difference of activity influence compared to it [84]. In this case, the first 12 activities contribute with 44.88%, according to the rule that the A group contains the lowest number of elements with the highest percentage of contributions, and it is not possible to adhere to the same rule used in inventory management cases, the line is underlined here and these elements are classified as elements of group A. This is a group of key activities that should be implemented for successful establishment of BPM practice. Therefore, in addition to defining process roles and responsibilities, activities that define process ownership (A17) are included here. These are followed by the flexibility and ability of information systems to adapt to process changes (A37), actively engaging top management (A1), obtaining relevant managerial information on process performance through information systems (A36), conducting training for change management within the process (A20), conducting training in the application of process improvement techniques and methods (A19), defining process measures (A8), designing and developing a process-based information system (A35), defining core and support processes (A4), continuous employee education (A18), and defining targeted process performances (A10). It can be seen from the presented that the primary activities are focused on the definition of business process management systems, the functioning of information systems to support the realization of processes, employees, and the development of their skills and knowledge and setting goals related to process performance.

5. CONCLUSION

In the search for best business practice, one can come across models that can be successful within some business systems. But it doesn't necessarily mean that they are universally applicable and equally successful everywhere. Consideration of apparel industry specifics may contribute to the adaptation of activities for best business practice implementation. Taking into account the specific aspects of the business environment in the apparel industry, within this paper, the procedure for establishing BPM practice was explored. Accordingly, 39 activities that influence the establishment of this practice were ranked on the basis of specific aspects by integrating methods AHP and WASPAS. Final categorization of key activities for establishment of BPM practice in the apparel industry organizations was done using ABC analysis. The final result of the extracting a set of 12 activities was presented using Pareto diagram. Based on this procedure, group A consists of a series of activities related to defining the responsibility, knowledge, and skills of employees, defining targeted process performance and forming a functional information system to support the process realization. Following the state of the business environment in the industry can provide information for the selection of adequate activities not only for implementation but also for management and improvement efforts. Future research will focus on a more detailed analysis of the priority activities, that were prioritized in this research. Also, taking into account the responses from employees in the apparel industry, the model that contributes to establishing sound business process management in the apparel industry, and improving overall business performance based on process improvements will be developed.

REFERENCES

1. Awad A, Weidlich M, Weske M. 2011. Visually specifying compliance rules and explaining their violations for business processes. *Journal of Visual Languages & Computing* 22(1), 30-55.
2. Pardanjac M, Jokić S, Stanisavljev S, Zubanov V, Tasić I, Milanov D. 2017. Preconditions for Setting up E-training for SME Textile Companies in Serbia, Chapter 3. In Katalinic, B. (Ed.), *DAAAM International Scientific Book*. Vienna, Austria: DAAAM International, 029-042.
3. Bitkowska A. 2016. Knowledge management vs business process management in contemporary enterprises. *Ekonomia i Zarzadzanie 8*(2), 31-37.
4. Cayoglu U, Dijkman R, Dumas M, Fettke P, García-Bañuelos L, Hake P, ... Mendling J. 2013. August. The process model matching contest 2013. In Lohmann, N, Song, M, Wohed, P. (Eds.), Proceedings of the 11th International Conference on Business Process Management (442-463). Beijing, China.
5. Aalst W. 2013. Business process management: a comprehensive survey. *ISRN Software Engineering*, 1-37.
6. Lambert D. M. 2010. Customer relationship management as a business process. *Journal of Business & Industrial Marketing* 25(1), 4-17.
7. Bucher T, Winter R. 2010. Taxonomy of business process management approaches. In vom Brocke J., Rosemann M. (Eds.), *Handbook on Business Process Management 2*. Springer Berlin, Heidelberg, 93-114.
8. Jordeva S, Tomovska E, Trajković D, Zafirova K. 2015. Current state of pre-consumer apparel waste management in Macedonia. *Fibres & Textiles in Eastern Europe*, 23, 1(109), 13-16.
9. Mladenova G. 2016. Marketing strategy of apparel and textile cluster in southwest region of Bulgaria. *Acta Universitatis Lodziensis. Folia Oeconomica* 2(320), 65-74.
10. Kabukcu E. 2015. Creativity process in innovation oriented entrepreneurship: The case of Vakko. *Procedia-Social and Behavioral Sciences* 195, 1321-1329.

11. Vinčić A. 2018. U Varaždinu održan Okrugli stol: Potreba za obrazovanjem u sektoru tekstil/odjeća/koža/obuća u sjeverozapadnoj Hrvatskoj. *Tekstil: časopis za tekstilnu tehnologiju i konfekciju* 67(5-6), 155-159.

12. Patora-Wysocka Z. 2015. Inhibitors of restructuring change in Textile and apparel enterprises. *Fibres & Textiles in Eastern Europe* 5 (113), 8-12.

13. Böhnlein M, Ulbrich-vom Ende A. 2000. Business process oriented development of data warehouse structures. In Jung, R, Winter, R. (Eds.), *Data Warehousing 2000*. Physica, Heidelberg, 3-21.

14. Gökalp E, Gökalp MO, Eren PE. 2018. Industry 4.0 Revolution in Clothing and Apparel Factories: Apparel 4.0. *Içinde Industry* 4, 169-183.

15. Kansul DS, Karabay G. 2019. Increasing the process cycle efficiency of men’s trousers assembly line. *Tekstil ve Konfeksiyon* 29(3), 253-262.

16. Gong, Y, Janssen, M. 2012. From policy implementation to business process management: Principles for creating flexibility and agility. *Government Information Quarterly* 29, 61-71.

17. Fantinato M, Gimenes IDS, Toledo MB. 2010. Product line in the business process management domain. *Applied software product line engineering*, 497-530.

18. Matejaš M, Fertalj K. 2018. Building a BPM Application in an SOA-Based Legacy Environment. *Computer Science and Information Systems* 16(1), 45-74.

19. Hassler M. 2003. The global clothing production system: commodity chains and business networks. *Global networks* 3(4), 513-531.

20. Urošević S, Dobrosavljević A. 2019. Conditions of development of small and medium enterprises in clothing industry, In Mihajlović, I. (Ed.), *Monography: How to prevent SMEs failure (Actions based on comparative analysis in Višegrad countries and Serbia)*, University of Belgrade, Technical Faculty in Bor, Engineering Management Department (EMD), 583 - 627.

21. Kokeza G, Urošević S. 2018. Strateški pravci razvoja tekstilne i odevne industrije u Republici Srbiji, *Tekstilna industrija* 66(4), 69-78.

22. Rajput D, Kakde M, Chandurkar P, Raichurkar PP. 2018. Enhancing Efficiency and Productivity of Garment Industry by Using Different Techniques. *International Journal on Textile Engineering and Processes* 4(1), 5-8.

23. Şen Kılıç A. 2019. Comparison of Cad and Manual System Efficiency In Pre-Production Preparation Process. *Tekstil ve Konfeksiyon* 29 (1), 67-77.

24. Jain D, Jain P. 2012. November. Sustainable Business Practices– Enablers & Barriers in the Indian Apparel Industry. In Conference proceeding of the National conference on Paradigm for Sustainable Business: People, Planet and Profit held at DOMS, IIT Roorkee.

25. Goodman E, Rosner D. 2011. May. From garments to gardens: negotiating material relationships online and'by hand'. In Tan D (Ed.), *Proceedings of the CHI’11: CHI Conference on Human Factors in Computing Systems*, Vancouver, Canada: Association for Computing Machinery, New York, United States, 2257-2266.

26. Cole J, Czachor S. 2014. *Professional sewing techniques for designers.* A&C Black

27. Urošević S, Cvijanović JM, Đorđević D. 2008. Unapređenje obrazovnog nivoa zaposlenih u tekstilnoj industriji Srbije. *Industrija* 36(3), 79-105.

28. Lee JS, Jirousek C. 2015. The development of design ideas in the early apparel design process: a pilot study. *International Journal of Fashion Design, Technology and Education* 8(2), 151-161.

29. Kucera D, Tejani S. 2014. Feminization, defeminization, and structural change in manufacturing. *World Development* 64, 569-582.

30. Stefanović V, Urošević S, Mladenović-Ranisavljević I, Stojilković P. 2019. Multi-criteria ranking of workplaces from the aspect of risk assessment in the production processes in which women are employed. *Safety science* 116, 116-126.

31. Dallas I, Wynn MT. 2014. Business process management in small business: a case study. In Devos J, et al. (Eds.), *Information Systems for Small and Medium-sized Enterprises*. Springer, Berlin, Heidelberg, 25-46.

32. Chong S. 2014. Business process management for SMEs: an exploratory study of implementation factors for the Australian wine industry. *Journal of Information Systems and Small Business* 1(1-2), 41-58.

33. Škrinjar R, Trkman P. 2013. Increasing process orientation with business process management: Critical practices’. *International Journal of Information Management* 33(1), 48-60.

34. Glavan LM, Vukšić VB. 2017. Examining the impact of business process orientation on organizational performance: the case of Croatia. *Croatian Operational Research Review* 8(1), 137-165.

35. Vugec DS, Vukšić VB, Glavan LM. 2017. Social Business Process Management and Business Process Management Maturity. *International Journal of Economics and Management Engineering* 11(5), 1122-1126.

36. Rosemann M., de Bruin T. 2005. Application of a holistic model for determining BPM maturity. *BP Trends* 2, 1-21.

37. Karagiannis D. 2012. June. Business process management: A holistic management approach. In Mayr HC, Kop C, Liddle S, Ginige A. (Eds.) Information Systems: Methods, Models, and Applications. UNISCON 2012. Lecture Notes in Business Information Processing, vol 137. Springer, Berlin, Heidelberg, 1-12.

38. Seethamraju R. 2012. Business process management: a missing link in business education. *Business Process Management Journal* 18(3), 532-547.

39. Börner R, Moormann J, Wang M. 2012. Staff training for business process improvement: The benefit of role-plays in the case of KreditSim. *Journal of Workplace Learning* 24(3), 200-225.

40. Paul-Majumder P, Begum, A. 2000. The gender imbalances in the export oriented garment industry in Bangladesh (Working Paper Series No. 12). Washington, DC: World Bank, Development Research Group/Poverty Reduction and Economic Management Network.

41. Hossain MA, Tisdell CA. 2005. Closing the gender gap in Bangladesh: inequality in education, employment and earnings. *International Journal of Social Economics* 32(5), 439-453.

42. Đorđević D, Urošević S, Cvijanović JM. 2010. Uloga klastera u unapređivanju konkuretnosti tekstilne i odevne industrije u Republici Srbiji. *Industrija* 38(2), 177-198.

43. Srivastava NA, Chatterjii A. 2014. Skills requirement analysis at the production floor in ready-made garment industry. *Asian journal of management sciences & education* 3(1), 23-34.

44. Sundstrup E, Jakobsen MD, Andersen CH, Jay K, Persson R, Aagaard P, Andersen, LL. 2013. Participatory ergonomic intervention versus strength training on chronic pain and work disability in slaughterhouse workers: study protocol for a single-blind, randomized controlled trial. *BMC musculoskeletal disorders* 14(1), 67.

45. Nemeša I. 2019. Organizacija radnih procesa u krojačnici uz pomoć automatizovanih sistema menadžmenta, *Tekstilna industrija* 67(2), 45-49.

46. De Jong JP, Den Hartog DN. 2007. How leaders influence employees' innovative behaviour. *European Journal of innovation management* 10(1), 41-64.

47. Seidel S, Shortland K, Elzinga D. 2010. Managing creativity-intensive processes: learning from film and visual effects production. In vom Brocke J, Rosemann M. (Eds.), *Handbook on Business Process Management 2*, Springer, Berlin, Heidelberg, 515-538.

48. Malinova M, Mendling J. 2018. Identifying do’s and don’ts using the integrated business process management framework. *Business Process Management Journal* 24(4), 882-899.

49. Berg M, Toussaint P. 2003. The mantra of modeling and the forgotten powers of paper: a sociotechnical view on the development of process-oriented ICT in health care. *International journal of medical informatics* 69(2-3), 223-234.

50. Kueng P. 2000. Process performance measurement system: a tool to support process-based organizations. *Total Quality Management* 11(1), 67-85.

51. Reichert M, Weber B. 2012. *Enabling flexibility in process-aware information systems: challenges, methods, technologies*. Springer Science & Business Media.

52. Arrigo E. 2018. Customer Relationships and Supply Chain Management in the Fast Fashion Industry. In Lee I (Ed.), *Diverse Methods in Customer Relationship Marketing and Management*. IGI Global, 1-16.

53. Conger S. 2015. Six sigma and business process management. In Rosemann M (Ed.), *Handbook on Business Process Management 1*. Springer, Berlin, Heidelberg, 127-146.

54. Alam I, Perry C. 2002. A customer-oriented new service development process. *Journal of services Marketing* 16(6), 515-534.

55. Melcher J. 2014. *Process measurement in business process management: Theoretical framework and analysis of several aspects*. KIT Scientific Publishing.

56. Irani N, Hanzaee KH. 2011. The effects of variety-seeking buying tendency and price sensitivity on utilitarian and hedonic value in apparel shopping satisfaction. *International Journal of Marketing Studies* 3(3), 89.

57. Parrish ED, Cassill NL, Oxenham W. 2006. Niche market strategy in the textile and apparel industry. *Journal of Fashion Marketing and Management: An International Journal* 10(4), 420-432.

58. Kaulio MA. 1998. Customer, consumer and user involvement in product development: A framework and a review of selected methods. *Total quality management* 9(1), 141-149.

59. Mijoska M, Levkov N. 2015. May. Business process orientation construct analysis in companies in the Republic of Macedonia. In Biljanović P, et al. (Eds.). Proceedings of the 38th International Convention on Information and Communication, Technology, Electronics and Microelectronics, MIPRO 2015 (1829-1834). Opatija, Croatia.

60. Eicker S, Kochbeck J, Schuler PM. 2008. May. Employee competencies for business process management. In Abramowicz W (Ed.), Proceedings of the 11th International Conference Business Information Systems, BIS 2008 (251-262). Innsbruck, Austria.

61. Bourne M, Mills J, Wilcox M, Neely A, Platts K. 2000. Designing, implementing and updating performance measurement systems. *International journal of operations & production management* 20(7), 754-771.

62. Amaratunga D, Baldry D, Sarshar M. 2001. Process improvement through performance measurement: the balanced scorecard methodology, *Work study* 50(5), 179-189.

63. Weske M. (2012). Business process management architectures. In Weske M (Ed.), *Business Process Management*. Springer, Berlin, Heidelberg, 333-371.

64. Dobrosavljević AU, Urošević SM. 2019. Evaluation of orientation on performances and process improvements in manufacturing organizations. *Tehnika* 74(2), 287-294.

65. Min S, Roath AS, Daugherty PJ, Genchev SE, Chen H, Arndt AD, Glenn Richey R. 2005. Supply chain collaboration: what's happening?. *The international journal of logistics management* 16(2), 237-256.

66. Legner C, Wende K. 2007. June. The challenges of inter-organizational business process design-a research agenda. In Proceedings of the European Conference on Information Systems, ECIS 2007, (106-118). St Gallen, Switzerland.

67. McCormack K, Willems J, Van den Bergh J, Deschoolmeester D, Willaert P, Indihar Štemberger M, ... Bosilj Vuksic V. 2009. A global investigation of key turning points in business process maturity. *Business Process Management Journal* 15(5), 792-815.

68. Lin SH, Moore MA, Kincade DH, Avery C. 2002. Dimensions of apparel manufacturing strategy and production management. *International Journal of Clothing Science and Technology* 14(1), 46-60.

69. Chang JF. 2016. *Business process management systems: strategy and implementation*. Auerbach Publications.

70. Lambert DM, García-Dastugue SJ, Croxton KL. 2005. An evaluation of process-oriented supply chain management frameworks. *Journal of business Logistics* 26(1), 25-51.

71. Campagne CS, Roche P, Gosselin F, Tschanz L, Tatoni T. 2017. Expert-based ecosystem services capacity matrices: Dealing with scoring variability. *Ecological Indicators*, 79, 63-72.

72. Ishizaka A, Pearman C, Nemery P. 2012. AHPSort: an AHP-based method for sorting problems. *International Journal of Production Research*, 50(17), 4767-4784.

73. Guh YY, Po RW, Lou KR. 2009. An additive scale model for the analytic hierarchy process. *International journal of information and management sciences*, 20(1), 71-88.

74. Dulange SR, Pundir AK, Ganapathy L. 2014. Prioritization of factors impacting on performance of power looms using AHP. *Journal of Industrial Engineering International*, 10(4), 217-227.

75. Cavallo B, D'Apuzzo L. 2009. A general unified framework for pairwise comparison matrices in multicriterial methods. *International Journal of Intelligent Systems* 24(4), 377-398.

76. Fedrizzi M, Brunelli M. 2010. On the priority vector associated with a reciprocal relation and a pairwise comparison matrix. *Soft Computing* 14(6), 639-645.

77. Franek J, Kresta A. 2014. Judgment scales and consistency measure in AHP. *Procedia Economics and Finance* 12, 164-173.

78. Chakraborty S, Zavadskas EK. 2014. Applications of WASPAS method in manufacturing decision making. *Informatica* 25(1), 1-20.

79. Stanujkić D, Karabašević D. 2018. An extension of the WASPAS method for decision-making problems with intuitionistic fuzzy numbers: A case of website evaluation. *Operational Research in Engineering Sciences: Theory and Applications* 1(1), 29-39.

80. Gawlik R. 2019. Ranking of company performance indicators for managerial decision making purposes with application of the Delphi method. *Studia i Materiały Wydziału Zarządzania i Administracji Wyższej Szkoły Pedagogicznej im. Jana Kochanowskiego w Kielcach "Miscellanea Oeconomicae"* , 1 (23), 177-188.

81. Boukili A, Fri M, El Hammoumi M, Belmajdoub F. 2016. Elaboration of a new method in the science of decision. *International Journal of Scientific and Engineering Researc* 7(4), 1334-1338.

82. Flores BE, Whybark DC. 1987. Implementing multiple criteria ABC analysis. *Journal of Operations Management* 7(1-2), 79-85.

83. Stojanović M, Regodić D. 2017. The Significance of the Integrated Multicriteria ABC-XYZ Method for the Inventory Management Process. *Acta Polytechnica Hungarica* 14(5), 29-48.

84. Dunford R, Su Q, Tamang E. 2014. The Pareto Principle. *The Plymouth Student Scientist* 7(1), 140-148.

TEKSTİL VE KONFEKSİYON

VOL: 30, NO. 3

DOI: 10.32710tekstilvekonfeksiyon.674867

On the Design and Specifications of Fibrous Wadding Materials for Maintaining Human Body Comfort at Different Room Temperatures

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ABSTRACT

In the present work, we propose a simple method of obtaining the optimal weight of wadding for cold protective clothing to maintain human thermal comfort. Using the self-developed testing device, we established the experimental relation between the thickness and thermal conductivity of the fibrous wadding materials. Then, according to the distribution of the thermal insulation of a multi-layer clothing system, we derived the relationship between the engineering thickness and the effective insulation of the fibrous wadding, which is subsequently used to obtain the analytical expression for the weight of wadding as a function of the effective insulation of fibrous wadding material. Eventually, we deduced the analytical expression for the optimal weight of wadding as a function of temperature, which keeps the human body under the thermal equilibrium condition at different temperature environments. As such, we developed a scheme to rationally design fibrous wadding materials for cold protective clothing to maintain human body comfort.

ARTICLE HISTORY

Received: 14.01.2020

Accepted: 30.06.2020

KEYWORDS

Multi-layer clothing; thermal conductivity; engineering thickness; the weight of wadding; thermal comfort

1. INTRODUCTION

There is an increasing demand for thermal comfort at different temperature environments since clothing that is poorly insulated from the cold or too warm can cause discomfort. This is especially crucial at low temperatures when clothing is expected to properly balance the heat generated by normal metabolism to maintain the body's thermal balance[1, 2]. Fibrous wadding material is one of the major fibril assemblies used as thermal insulation materials for cold protective clothing. The heat transfer in fibrous wadding occurs through conduction, convection and radiation[3, 4]. At low wind velocity, the heat transfer through convection is negligible; therefore, the conductivity is the primary heat transfer mechanism in fibrous wadding materials[5]. For fibrous wadding materials, a large amount of air is trapped inside the pores between fibers, providing a natural barrier to the cold environment. For example, the conductivity coefficients of cotton and wool are 0.071-0.073 (W/m·°C) and 0.052-0.055 (W/m·°C), respectively, which are much smaller than that of the immobile air; therefore, the amount of air trapped inside the fibrous wadding materials determines the thermal comfort of cold protective clothing, which is associated with weight of wadding. The greater the weight of wadding is, the less air is contained in fibrous wadding.

According to national (GB/T24254-2009) and international (ISO11079-2007) standards, the thermal insulation of the clothing system in different indoor environments is

To cite this article: Ciu P, Xue Y, Wang F. 2020 On the design and specifications of fibrous wadding materials for maintaining human body comfort at different room temperatures. *Tekstil ve Konfeksiyon*, 30(3), 200-207.

essential for human body comfort. Cold-protective clothing prevents heat loss from the human body and makes the person feel comfortable for as long as possible in low-temperature environments. There are a number of studies that examine the relation between thermal insulation of clothing system and temperature environments[6-10]. Meinander et al. [7] reported that the thermal insulation values measured by thermal manikins need to be corrected at -25℃. Wang et al. [6] found that the moisture management property of multi-layer clothing ensembles shows a significant influence on moisture diffusion and temperature distributions in the clothing system. These research works provide the necessary grounding for engineering clothing system that provides the specifications for cold-protective clothing.

On the other hand, cold-protective clothing increases the physical workload by increasing metabolic energy consumption. In particular, the weight of clothing has the greatest influence on energy consumption, and the stiffness of clothing is the second most important influential factor. Dorman and Havenith found that metabolic energy consumption is increased by 2.7% per clothing kilogram[11]. In addition, the friction between clothing layers hinders the extremity movement of a person, which further increases the physical workload. Therefore, lightweight and bulky clothing materials are beneficial for reducing the weight of clothing while still providing sufficient protection against cold. Fibrous wadding is a material having such merits. However, it is labor-intensive and costly to manufacture fibrous waddings due to the unknown thermal resistances of waddings at the specific ambient temperature. Under such circumstances, we may need several trials to adjust the weights of waddings in the production line before finalizing the specifications for a particular temperature environment. For each trial production, the waddings are made into clothing that is subsequently tested with a thermal manikin to obtain the thermal insulation values.

In the past two decades, the theoretical researches on the thermal properties of fibrous assemblies have mainly focused on establishing and improving the theoretical model to accurately describe the heat transfer inside fibrous assemblies[12-15], whereas the experimental researches have primarily focused on blending different types of fibers to achieve a better thermal insulation performance for fibrous material[20-23]. In our previous work[15, 19], we presented combined experimental and theoretical studies on thermal physical properties of fibrous materials, in which we derived an analytical model which significantly improves the accuracy of calculated thermal conductivity of fibrous material. However, there have been very few literature reports on the relationship of occupants' comfort and insulation of clothing, especially regarding the specifications of fibrous materials that meet the requirement of the thermal comfort of the human body at different temperature environments.

In the present study, we measured the heat flows through down wadding and kapok/down blended wadding in different thicknesses using the self-developed device. Based on the relationship between engineering thickness and effective insulation of fibrous wadding, as well as the relationship between the weight and the engineering thickness of fibrous wadding, we derived an analytical expression of the weight of wadding as a function of effective insulation. Furthermore, by applying the national (GB/T24254 – 2009) standard, we obtain the optimal weight of wadding that meets the requirements of human thermal comfort in different temperature environments.

2. MATERIAL AND METHOD

2.1 Theoretical Model

2.1.1 Thermal insulation in a multi-layer clothing system

In general, there are three types of insulation that can be found in the literature[20], i.e., the total insulation, the effective insulation and the basic insulation.

The total insulation refers to the thermal insulation from the skin surface to the environment, which is written as[21]

$$I_t = \frac{(t_s - t_a)}{K_{clo} \cdot Q} \tag{1}$$

where I_t is the total insulation (clo); Q is the heat loss per square meter of skin surface area (W/m^2); t_s is the average skin temperature; t_a is the ambient temperature (℃); K_{clo} is a constant, 0.155 (m^2·℃/W·clo). The Q, t_s and t_a can be measured by the thermal manikin. Subsequently the I_t is calculated.

The effective insulation refers to the thermal insulation from the skin surface to the outer surface of clothing without excluding the influence of increasing body surface area after dressing, which is written as follows[21]:

$$I_{cle} = I_t - I_a = \frac{(t_s - t_a)}{(K_{clo} \cdot Q)} - I_a \tag{2}$$

where I_{cle} is the effective insulation of clothing (clo); I_a is the impedance of the boundary air layer on the thermal insulation of dressed human body surface (clo); The basic insulation refers to the thermal insulation from the skin surface to the outer surface of clothing [21], which can be written as follows:

$I_a = \left[0.61\left((t_a + 273)/298\right)^3 + 1.9\sqrt{v_a}\left((t_a + 273)/298\right) \right]^{-1}$ [20], v_a is the wind speed (m/s).

$$I_{cl} = I_t - \frac{I_a}{f_{cl}} = \frac{t_s - t_a}{K_{clo} \cdot Q} - \frac{I_a}{f_{cl}} \tag{3}$$

where I_{cl} is the basic insulation of clothing (clo); f_{cl} is the clothing area factor (no unit). According to ISO 7730-1994 standard, f_{cl} can be written as follows:

$$f_{cl} = 1.0 + 0.25 I_{cl} \tag{4}$$

Both I_t and I_a can be evaluated with a thermal manikin. Therefore, we can calculate the effective insulation I_{cle} and the basic insulation I_{cl} according to Equations (1) to (4).

It is well known that the relationship between the thermal resistance R ($m^2\cdot°C/W$), the thickness d (m) and the thermal conductivity λ ($W/(m\cdot°C)$) is $R=d/\lambda$. The relationship between the insulation value I and the thermal resistance R is $I=R/K_{clo}$. Therefore, the relationship between effective insulation I_{cle} and thickness d can be expressed as follows:

$$d = \lambda \cdot R = \lambda \cdot K_{clo} \cdot I_{cle} \tag{5}$$

Here, the clothing is a multi-layer system composed of the inner wears, the fabric cover, the fibrous wadding and the coat. The basic insulation of inner wears can be directly evaluated by using a thermal manikin, according to Equations (1) – (4). The thermal conductivity of fabric cover can be measured by using a KES-F7 instrument[22]; subsequently, the effective thermal insulation can be obtained by using Equation (5). Therefore, only the effective insulations of fibrous wadding and coat are to be solved.

The insulation distribution formula of multi-layer clothing system in the reference [20] is used to calculate the basic insulation of clothing system, which is shown as follows:

$$I_{cl} = 0.835 \sum I_{clei} + 0.161 \tag{6}$$

where I_{cl} is the basic insulation of a multi-layer clothing system (clo), I_{clei} is the effective insulation of a single layer of clothing system (clo).

We substitute the basic insulation of the multi-layer clothing system into the left side of Equation (6), and the effective insulations of inner wears, the fabric cover and the fibrous wadding into the right side of Equation (6). Since only the effective insulation of the fibrous wadding is unknown in the equation, it can be solved. In the same way, after obtaining the effective insulation of fibrous wadding, we substitute the basic insulation of the clothing system into the left side of Equation (6), and the effective insulations of the inner wears, fabric cover, fibrous wadding and coat into the right side of Equation (6) to calculate the effective insulation of the coat.

2.1.2 Relationship between the insulation and engineering thickness

The thickness of fibrous wadding is severely affected by external pressure. Under the normal wearing condition, the thickness of fibrous wadding is smaller than its original thickness during the compression, i.e., the engineering thickness. This paper assumes that the engineering thickness of the wadding material is proportional to the weight of wadding, which is generally applicable to the fibrous material s[23], and the relationship between the engineering thickness and the weight of wadding is established accordingly.

Replacing d and λ in Equation (5) with the engineering thickness engineering and the thermal conductivity $\lambda_{engineering}$ at the corresponding thickness, respectively, we get:

$$d_{engineering} = \lambda_{engineering} \cdot K_{clo} \cdot I_{cle} \tag{7}$$

where the physical meanings of K_{clo} and I_{cle} are the same as in Equation (5). According to the discussion above, the effective insulations of the fibrous wadding material can be evaluated using a thermal manikin, while the engineering thickness and thermal conductivity remain unknown. Therefore, we establish the experimental relationship between the engineering thickness and the thermal conductivity under that thickness.

2.1.3 Experimental relationship between engineering thicknesses and thermal conductivities of fibrous wadding

The heat flows of two wadding materials in different compressed thicknesses are measured by the KES-F7 instrument in conjunction with a height-adjustable system, as shall be demonstrated below. For evaluating the thermal conductivities of two wadding materials, a more accurate formula of the thermal conductivity of the fibrous assembly established by our group is adopted herein[15, 19]. The thermal conductivities of two wadding materials in different thicknesses are shown in Figure 1.

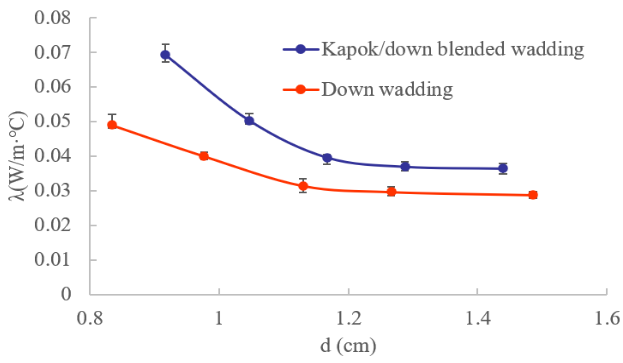

Figure 1. The thermal conductivities of two wadding materials in various thicknesses

According to the test data in Figure 1, the statistical relationships between the thicknesses of the two wadding materials and their thermal conductivities are obtained by performing the nonlinear regression fitting procedures, as shown in Equations (8) and (9).

Substituting Equations (8) and (9) into Equation (7), respectively, the engineering thicknesses of the two wadding materials can be solved. Subsequently, the engineering thickness is expressed as a function of the weight of wadding based on the assumption that the engineering thickness is proportional to the weight of wadding. The general relationships between the weights and the engineering thicknesses of the kapok/down blended wadding and down wadding are as follows:

Obviously, with the same weight, the engineering thickness of kapok/down blended wadding is greater than that of down wadding, because the down wadding can be compressed to a smaller thickness under a certain pressure due to its unique structure [16].

2.1.4 Relationship between weight and effective insulation of fibrous wadding

The relationship between the thermal conductivity λ and the weight G of the kapok/down blended wadding and down wadding can be obtained by combining Equations (8) to (11), as shown in Equations (12) and (13), respectively

$$\lambda_{Kapok/down} = -0.3341d^3 + 1.3781d^2 - 1.9121d + 0.9208, \qquad R = 0.9998 \tag{8}$$

$$\lambda_{down} = -0.0678d^3 + 1.3050d^2 - 0.4587d + 0.2585, \qquad R = 0.9997 \tag{9}$$

$$d_{kapok/down} = 0.009474G \tag{10}$$

$$d_{down} = 0.007207G \tag{11}$$

$$\lambda_{kapok/down} = -0.3313 \times (0.0095G)^3 + 1.3781 \times (0.0095G)^2 - 1.9121 \times 0.0095G + 0.9208 \tag{12}$$

$$\lambda_{down} = -0.0678 \times (0.0072G)^3 + 0.3050 \times (0.0072G)^2 - 0.4587 \times 0.0072G + 0.2585 \tag{13}$$

$$I_{cle} = \frac{6.1275G}{-2.8405 \times 10^{-3}G^3 + 1.2437G^2 - 1.8165 \times 10^2G + 9208} \tag{14}$$

$$I_{cle} = \frac{4.644G}{-2.5306 \times 10^{-4}G^3 + 0.1581G^2 - 33.0264G + 2585} \tag{15}$$

Substituting Equations (12) and (13) into Equation (7), we can get Equations (14) and (15).

2.2 Methods

2.2.1 Clothing

To explore the specifications of wadding materials required in different low-temperature environments, two types of cold protective clothing with the same specifications were made with kapok/down blended wadding and down wadding, respectively. The cold protective clothing consists of a heat-insulating lining and a detachable fabric sheet. The structure of the thermal insulation lining is shown in Figure 2.

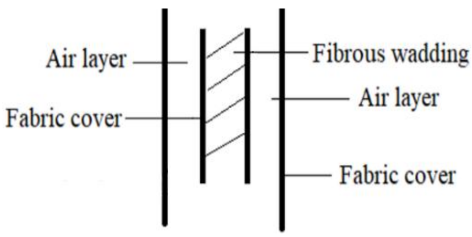

Figure 2. The schematic diagram illustrating the thermal insulation lining

The thermal insulation lining is made of the kapok/down blended wadding or down wadding, wrapped around by a polyester fabric cover. The composition of kapok/down blended wadding is 40% duck down + 20% kapok + 40% polyester, and the weight of wadding is 85.5g/m^2. The down wadding is made up of 90% duck down and 10% silk with a weight of wadding of 88.8g/m^2. The two fabric covers are made of the same materials.

The specifications of customized clothing systems are shown in Table 1. In line with the permitted working conditions of the thermal manikin and the customized combination of clothing in winter, the inner wears consist of stocking cap, shirt, sweater, knitted cotton trousers, outer pants, and cotton socks. The thermal insulation value of each garment is listed in table 2. Coat A and B are made of the same materials with the same styles, the length of which reaches to the middle of the thighs of the thermal manikin, and are equivalent to a windbreaker with lining in it. The coat consists of two sub-layers: the inner one is woven nylon fabric, and the other layer is waterproof polyester fabric. The detailed information of fabrics is shown in table 3. A layer of cotton is sandwiched in the hat of the suit, and the length of the detachable thermal insulation lining is 5cm shorter than that of the coat.

Table 1. Customized clothing systems with five different configurations

Serial number	Configuration
1#	Inner wears
2#	Inner wears + kapok/down lining + fabric cover
3#	Inner wears + down lining + fabric cover
4#	Inner wears + kapok/down lining + fabric cover + coat A
5#	Inner wears + down lining + fabric cover + coat B

Table 2. Thermal insulation for individual garment

Garment description	Thermal insulation (clo)
stocking cap	0.050±0.003
shirt	0.086±0.005
sweater	0.170±0.01
knitted cotton trousers	0.070±0.001
outer pants	0.165±0.01
cotton socks	0.020±0.004

Table 3. Physical properties of fabrics

Layer	Fabric cover	The inner layer of the coat	The outer layer of the coat
Materials	Woven polyester	Woven nylon	Wool-cotton blend
Thickness (mm) at 0.6 kPa	0.860±0.01	0.442±0.01	0.993±0.01
Weight (g/m^2)	110.1±10.2	70.8±0.5	304.9±5.9
Thermal conductivity(W/m·℃)	0.1613±0.002	0.10±0.004	0.068±0.006
Air permeability (mm·s^{-1})	2.30±0.01	25.3±0.6	63.4±3.2

2.2.2 Climate

All experiments were conducted in a climate chamber at an ambient temperature of 3±0.5 °C. The wind speed was 0.4 m/s. The relative humidity was 50 ± 5%. The average skin temperature of the thermal manikin was 33 °C.

2.2.3 Measurements

To evaluate the thermal insulation performance, the KES-F7 instrument[18] was used to measure the thermal conductivities of down wadding, kapok/down blended wadding and fabric cover, as shown in Figure 3 (a). To measure the thermal conductivities of fibrous wadding materials at different thicknesses, a height-adjustable system is employed to adjust the height of the hot plate, as shown in Figure 3 (b). The details of the test system can be found in our previous work[14].

For thermal manikin testing, the body core temperature of thermal manikin was 37±0.5℃[24]. The skin temperature is the mean value of temperatures measured at different surface body area. The skin temperatures were measured by attaching thirty-two PT100 patch sensors all over the surface area of the manikin. The actual skin temperature may vary from 32 to 36℃[24], depending on the amounts of clothing ensembles worn by the manikin.

3. RESULTS AND DISCUSSION

Table 4 shows the calculated total, effective and basic insulations and clothing area factors for the as-prepared clothing systems. The effects of conduction, convection and radiation are included in the calculated insulations. However, the experimental studies show that the effect of convection is very small for a multi-layer clothing system[23]. In particular, the temperatures of the air layers between each layer of clothing is mildly decreased from the body surface to the surrounding environment, which means the temperature difference between the two sides of the fibrous wadding material is so small that the radiation has a negligible effect on heat transfer. Therefore, the thermal conductivity of fibrous wadding material is the main factor contributing to the thermal comfort of the human body.

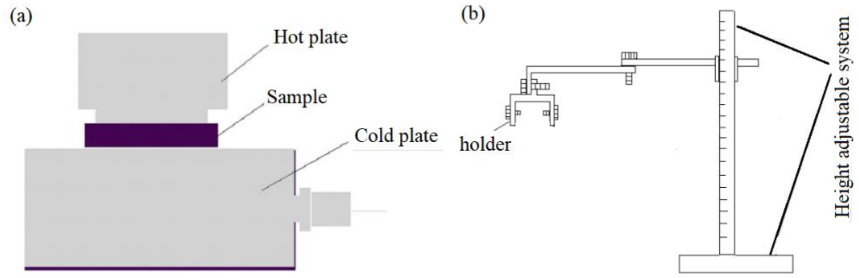

Figure 3. Schematic diagram illustrating (a) KES-F7 instrument and (b) height-adjustable system

Table 4. The total, effective and basic insulations and clothing area factor for each clothing system

	1#	2#	3#	4#	5#
I_t	1.626±0.02	1.991±0.01	1.989±0.01	2.552±0.02	2.715±0.01
I_a	0.626±0.001	0.626±0.001	0.626±0.001	0.626±0.001	0.626±0.001
I_{cle}	1.000±0.01	1.365±0.02	1.363±0.01	1.926±0.01	2.089±0.02
f_{cl}	1.285±0.03	1.378±0.02	1.384±0.02	1.536±0.01	1.580±0.01
I_{cl}	1.139±0.02	1.512±0.01	1.537±0.01	2.144±0.02	2.319±0.02

Table 5 shows the calculated effective insulation of each layer in the customized clothing system. The calculated engineering thicknesses of the kapok/down blended wadding and down wadding are listed in Table 6. As can be seen from Table 5, the effective insulations of coat A and B are much higher than those of the others. There may be two reasons accounting for the higher effective insulations of the coat A and B. Firstly, the cuff and neckline of the coat are fastened during the test, and the manikin is put on the hood of the jacket, which has a layer of cotton in it; secondly, these two coats are equivalent to the windbreaker with lining since it reaches to the middle of the thigh, which leads to a more excellent insulation of the coat. The effective insulation of coat B is slightly higher than that of coat A because the thermal insulation lining of coat B is made by filling the down manually, resulting in a bread-like structure, as shown in Figure 4. The bread-like structure contains still air at the suture after the lining is added with the coat, resulting in greater effective insulation of coat B.

The effective insulations corresponding to different wadding densities are calculated according to eqn. (14) and (15), as shown in Figure 5. By the data in Figure 5, the relationships between the effective insulations of the two wadding materials and the wadding densities are obtained, as shown in Equations (16) and (17).

When the effective insulation of the wadding material is less than 3.12 clo, the required weight of wadding for kapok/down blended wadding is less than that of down wadding. This is because the certain air can be stored by the closed hollow structure of the kapok fiber in the kapok/down blended wadding, while the interior of the fiber assembly is divided into numerous small spaces for air storing by the kapok fiber. Since conductivity is the most important form of heat transfer in wadding[16,25], the hollow structure of kapok benefits the heat preservation of the clothing system due to the conductivity of immobile air is much smaller than those of fibers[16]. Such a unique structure of kapok fiber provides better thermal insulation for kapok/down wadding. In contrast, when the effective insulation of the inner lining material is greater than 3.12 clo, the required weight of wadding of kapok/down blended wadding is greater than that of down wadding, which indicates that, with a mounting increase in demand for warmth, the heat preservation of kapok fibers is gradually exceeded by that of down fiber with the same weight of wadding. This is because the down possesses a superb thermal insulation capacity due to its unique structural characteristics [26]. The down cluster is made of a large number of subunits composed of small fibrils with divergent branch structures[26]. With the increase of the weight of wadding, the large number of subunits of the down fiber helps to maintain a great loftiness and low volume fraction for thermal insulation purposes [26], which ultimately makes heat preservation of down cluster higher than that of the kapok fiber assembly.

Table 5. The effective insulation of each layer in a multi-layer clothing system

	Fabric cover	Kapok/down blended wadding	Down wadding	Coat A	Coat B
I_{clei}	0.034±0.001	0.550±0.02	0.580±0.02	0.757±0.02	0.936±0.01

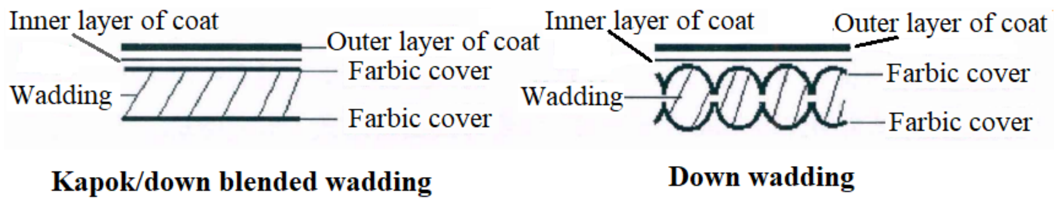

Figure 4. Schematic drawings summarizing the overall features of the clothing systems made of kapok/down blended wadding and down wadding, respectively

Table 6. The calculated engineering thicknesses and measured actual thicknesses of kapok/down blended wadding and down wadding

Fibrous wadding	G (g/m²)	$d_{engineering}$ (cm)	d (cm)
Kapok/down blended wadding	85.5±1.2	0.81±0.003	1.43±0.02
Down wadding	88.8±2.2	0.64±0.002	1.48±0.01

$$G_{\frac{kapok}{down}} = 8.9253 I_{cle}^3 - 39.606 I_{cle}^2 + 80.82 I_{cle} + 51.249, \quad R^2 = 0.9991 \qquad (16)$$

$$G_{down} = 4.3468 I_{cle}^3 - 25.949 I_{cle}^2 + 83.796 I_{cle} + 48.79, \quad R^2 = 1 \qquad (17)$$

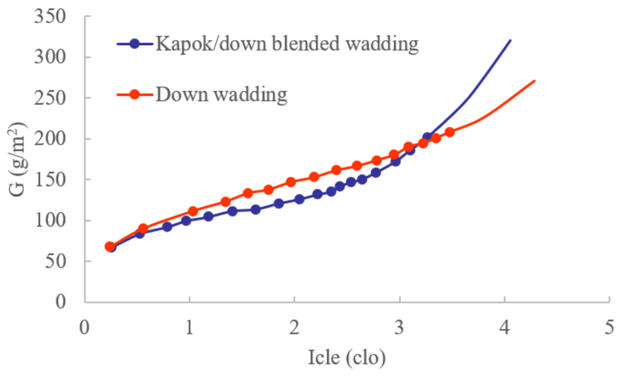

Figure 5. The nonlinear regression fitting of the weight of wadding as a function of effective insulation

Based on the research above, we propose a method of quickly and efficiently obtaining the optimal weight of the wadding of fibrous wadding materials required to maintain human thermal comfort at different temperatures in this paper. In the following, we use an example to illustrate our algorithm. The way of wearing is as clothing system 4#, coat A is adopted as the outfit, and the airflow rate is assumed to be 0.4m/s.

(1) According to GB/T24254 – 2009 standard, the metabolic rate of physical labor is found to be 90W/m². When the ambient temperature is t, the basic insulation of the clothing required to maintain the thermal comfort of the human body is:

$$I_{cl} = -0.087t + 2.46 \qquad (18)$$

(2) Based on Equation (6), i.e., I_{cl}=0.835×(I_{cle}(inner wears) +I_{clex}+2×I_{cle}(fabric cover)+I_{cle}(coat))+0.161, the relationship between the basic insulation of the clothing system and the effective insulation required by the wadding material is obtained:

$$I_{cleX} = 1.198 I_{cl} - 2.018 \qquad (19)$$

(3) Substituting Equation (19) into Equation (18), we can get the relationship between the effective insulation of wadding materials and the ambient temperature:

$$I_{cleX} = -0.104t + 0.929 \qquad (20)$$

(4) The effective insulation of wadding material I_{cleX} is substituted into Equations (16) and (17) to obtain the wadding densities corresponding to the effective insulation, i.e., the optimal amount of wadding filled in the thermal insulation lining to maintain human thermal comfort at the temperature of t, as shown in Equations (21) and (22).

Several temperatures are selected as examples to illustrate the relationship between the ambient temperature and the optimal weight of wadding of the fibrous wadding in the required lining materials, as shown in Figure 6.

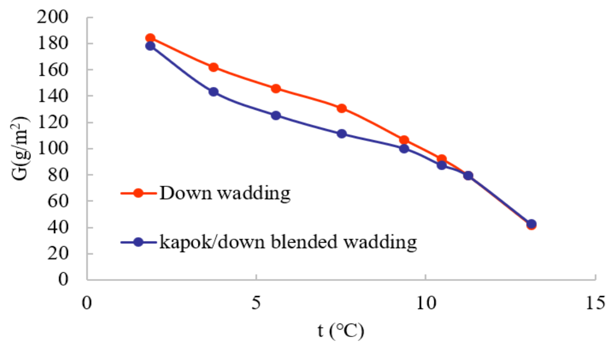

Figure 6. The optimal wadding densities in different temperatures

According to the actual production data[27] provided by Zhejiang Sanhong international feather Co Ltd, the weight of wadding of the filled duck down in the thermal insulation lining sold to Shanghai is 100g/m², while the weight of wadding of the filled duck down in the thermal insulation lining sold to the north is 140g/m², which is consistent with the weight of wadding of the down wadding in Figure 6, thus verifying the accuracy of the relationship between the ambient temperature and the optimal weight of wadding required to maintain human thermal comfort obtained in this study. In addition, under the same temperature, the weight of wadding of down wadding is generally larger than that of kapok/down wadding, suggesting that adding kapok fiber into the fibrous wadding can reduce the weight of cold-protective clothing while maintaining the same thermal insulation performance, which is consistent with our previous work[14].

$$G_{\frac{Kapok}{down}} = 8.9253 \times (1.024 - 0.101t)^3 - 39.606 \times (1.024 - 0.101t)^2 + 80.82 \times (1.024 - 0.101t) + 51.249 \qquad (21)$$

$$G_{down} = 4.3468 \times (1.024 - 0.101t)^3 - 25.949 \times (1.024 - 0.101t)^2 + 83.796 \times (1.024 - 0.101t) + 48.79 \qquad (22)$$

4. CONCLUSION

In this work, we proposed an intelligent prediction algorithm in which one can easily acquire the specifications of fibrous wadding at different temperatures by studying the relationship between the thermal comfort of the human body and the thermal insulation of clothing. In particular, we derived the analytical expression for the weight of wadding as a function of effective insulation, which is achieved by establishing the experimental relationship between the thermal conductivity and the thickness. The thermal conductivities of fibrous wadding under different thicknesses were measured with the KES-F7 instrument in conjunction with a height-adjustable system. Following the national standard, we obtain the optimal weights of kapok/down wadding and down wadding required to maintain the thermal comfort of the human body at the specified temperatures. We found that the thermal insulation of kapok/down blended wadding is generally better than that of down wadding due to the hollow structure of kapok fiber; however, with the increase of weight of wadding, the three-dimensional skeleton structure of down fiber divides the fiber assembly into numerous small spaces, which stores more still air than does the hollow structure of kapok fiber, leading to a better insulation performance of down wadding than that of kapok/down blended wadding.

Acknowledgement

This work is supported by“the Fundamental Research Funds for the Central Universities” under Grant “JUSRP12029” and “JUSRP52007A”.

REFERENCES

1. SHRAE Standard 55 - Thermal Environment Conditions forHuman Occupancy. 1992. *American Society of Heating Ventilating andAir-conditioning Engineers*, Atlanta, USA.
2. Lin Z, Deng S. 2008. A study on the thermal comfort in sleeping environments in the subtropics—developing a thermal comfort model for sleeping environments, *Building and Environment* 43 (1), 70-81.
3. Hearle JW, Morton WE. 2008. *Physical properties of textile fibres*, Sawston, Cambridge: Woodhead Publishing.
4. Incropera F, DeWitt D. 1985. *Introduction to heat transfer*, New York, NY (USA): John Wiley and Sons Inc.
5. Sukigara S, Yokura H, Niwa MJ. 1994. Non-recovery of futon padding after repeated compression, *International Journal of Clothing Science and Technology* 6 (2/3), 51-56.
6. Wang S, Li Y, Tokura H, Hu J, Han Y, Kwok Y, Au R. 2007. Effect of moisture management on functional performance of cold protective clothing, *Textile Research Journal 77* (12), 968-980.
7. Meinander H, Anttonen H, Bartels V, Holmér I, Reinertsen RE, Soltynski K, Varieras S. 2004. Manikin measurements versus wear trials of cold protective clothing (Subzero project). *European journal of applied physiology* 92 (6), 619-621.
8. Tanaka M, Tqchihara Y, Yamazaki S, Ohnaka T, Yoshida K. 1983. Thermal reaction and manual performance during cold exposure while wearing cold-protective clothing. *Ergonomics* 26 (2), 141-149.
9. Nilsson HO, Anttonen H, Holmér I. 2000. New algorithms for prediction of wind effects on cold protective clothing. *ARBETE OCH HALSA VETENSKAPLIG SKRIFTSERIE* 5 (8), 17-20.
10. Meinander H, Hellsten M. 2004. The influence of sweating on the heat transmission properties of cold protective clothing studied with a sweating thermal manikin. *International Journal of Occupational Safety and Ergonomics* 10 (3), 263-269.
11. Dorman LE, Havenith, G. 2009. The effects of protective clothing on energy consumption during different activities. *European journal of applied physiology* 105 (3), 463-470.
12. Bankvall C. 1973. Heat transfer in fibrous materials, *Journal of Testing and Evaluation* 1 (3), 235-243.
13. Dent RW, Donovan JG, Skelton J, Fossey S. 1984. Development of Synthetic Down Alternatives (Technical Report Natick/TR-86 L). US Army Natick RD&E Center.
14. Cui P, Wang FM. 2009. An investigation of heat flow through kapok insulating material, *Tekstil ve Konfeksiyon* 19 (2), 88-92.
15. Cui P, Wang FM, Liang ZY. 2010. Study on the measured error of thermal conductivity of fibrous porous materials. Part I. Error analysis, *Industria Textila* 61 (6), 276-282.
16. Cui P, Wang FM, Wei AJ, Zhao KW. 2010, The performance of kapok/down blended wadding, *Textile research journal* 80 (6), 516-523.
17. Bajaj P. 2011. *Thermally sensitive materials, Smart Fibres, Fabrics and Clothing*, Cambridge, England: Woodhead publishing Ltd.
18. Mao N. 2019. Textile Materials for Protective Textiles, *High Performance Technical Textiles* 22 (3), 107-157.
19. Cui P, Wang FM, Liang ZY. 2011. Study on the measured error of thermal conductivity of fibrous porous materials. Part II. Improved calculating formula, *Industria Textila* 62(2), 88.
20. Candas V. 2000. Techniques de l’Ingénieur, traité Génie énergétique, *Doc. BE* 9, 085.
21. Fanger P. 1970. Thermal Comfort, Copenhagen, Denmark: Danish Technical Press.
22. Operating Instruction, F7: Manual for KES-F7 Thermo Labo II (Precise and Prompt Thermal Prosperity Measurement Instrument). 1998. Kato Tech Co. Ltd., Japan.
23. Sampson WW, Urquhart SJ. 2008. The contribution of out-of-plane pore dimensions to the pore size distribution of paper and stochastic fibrous materials, *Journal of Porous Materials* 15 (4), 411-417.
24. Fan J, Chen Y. 2002. Measurement of clothing thermal insulation and moisture vapour resistance using a novel perspiring fabric thermal manikin. *Measurement Science and Technology* 13 (7), 1115.
25. Hearle J W, Morton WE. 2008. Physical properties of textile fibres: Elsevier.
26. Gao J, Yu W, Pan N. 2007. Structures and properties of the goose down as a material for thermal insulation. *Textile Research Journal* 77 (8), 617-626.
27. Cui P. 2011. The Principle and Application of Test of Warm Performance of High Buoyancy Firbous Porous Materials (doctor disseration), Retrieved from cnki.net, Donghua University, Shanghai, China.

TEKSTİL VE KONFEKSİYON

VOL: 30, NO. 3

DOI: 10.32710tekstilvekonfeksiyon.695487

Statistical Process Control Methods For Determining Defects of Denim Washing Process: A Textile Case From Turkey

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ABSTRACT

The denim garments, which are made with many different sewing patterns, are given the final appearance by applying industrial washing processes and these are turned into high value-added fashion products. In this study, denim fabric control performed in a textile company, washing department after weaving for one month was investigated and as a result, washing defects are examined by using statistical methods. Pareto analysis, cause and effect diagram, and P control graphs, which are statistical process control methods, were used to classify the defects seen as a result of quality control. In Pareto analysis, chemical repair (20, 52 %), blue floor (19, 86 %), chemical intensive (19, 56 %), light floor (10, 71 %), deep floor (7, 95%) are in first five places among 53 defects and account for 78, 6 % of total number of defects. Of the 53 defects encountered during the washing process, it is found that only five of these defects could be prevented during the washing process, thus reducing the total waste by about 80%. In cause and effect diagram, washing defects are divided into categories as chemical, foreground, intensity, repair, tinctorial and processual and sub-dimensions as causes are determined. In the Laney P control chart, all processes are determined under control.

ARTICLE HISTORY

Received: 27.02.2020

Accepted: 10.07.2020

KEYWORDS

Denim Washing Defects in Process, Statistical Process Control, Pareto Chart, P-Chart, Cause and Effect Diagram

1. INTRODUCTION

The textile sector is one of the traditional industries, providing employment opportunities and in terms of the value-added creating during the production process, from past to present is a sector that affects the economy of Turkey significantly. As the most important part of the textile sector, denim garments, and clothing made of this fabric, which is one of the oldest fabric types in the world, can always remain young, but as a result of the intensive product development efforts that have been going on for years, it is a family-wearable type that can be worn in the wardrobe of people of all ages and has become textile and apparel products which are perceived as high fashion clothes by some circles [1]. Denim garments are produced from denim fabrics, which is one of the oldest fabric types in the world and can always remain young as a result of years of intensive product development activities. In ready-made clothing, especially in types of denim, one color can be used, and contrasting colors, shades of the same color, and neighboring colors can be preferred [2]. The denim products which can be worn after the garments are delivered either to the customer in a dry state (without washing) or according to the fashion demands, or subjected to various washing processes that were applied in the 1970s and which create a distinct fashion today. Today, the share of dry denim products that meet the customer without washing does not exceed 3% of total denim product production. For this reason, denim washing has a very important place today. When the 2018 January and December period, the product groups based on Turkey's

To cite this article: Ata S, Yıldız MS, Durak İ. 2020. Statistical process control methods for determınıng defects of denım washıng process: a textıle case from Turkey. *Tekstil ve Konfeksiyon*, 30(3), 208-219.

special yarn and fabric exports is observed that the most important product group in denim fabric exports valued at 341 million dollars, and this value constitutes 51.2% of the total special yarn and fabric exports [3]. One of the important operations for denim fabric products is washing operation. Washing is seen as the final process in denim production and is the base of denim finishing [4]. The washing process is the process of washing the sewn denim garment in special washing machines according to certain prescriptions and techniques, removing the sizing on it, and giving it different colors and touches. Denim washing technology aims to create new color tones and effects on consumer demands and the effect of fashion. The main feature of denim is that it is dyed with indigo dye which is discolored as it is washed [5]. Washing of denim products can be

carried out either as a garment or as a fabric. The purpose of the washing process in the form of fabric before the garment is to lighten the denim fabrics, to provide a tensile strength in the fabric, and to remove the hard attitude in the raw fabric. Washing in the form of garments takes place in the form of washing of the finished textile products in a rotary drum garment machine according to various principles [6]. The purpose of this study and the most important difference that emphasizes the study is to determine what are the most common defects during and after denim washing with statistical methods and to test whether these defects are controlled in terms of quality. In the following sections of the study, denim washing process will be evaluated in a general framework, the findings and results obtained by statistical process control methods will be discussed and some suggestions will be made.

2. OVERVIEW OF DENIM WASHING PROCESS

Denim washing is a process with too much input. Therefore, many parameters influence color. These parameters can be extended from the property of the fiber and yarn to the product stage. In conventional washing, it is aimed that the color difference between the boilers is tolerable in the washing of the finished products with the same prescription. The results obtained in the intermediate-wash controls and post-wash final controls are compared with the customer request [7]. The washing steps of denim can be categorized as follows [8]:

Desizing refers to a leaving starch denim garments is to provide amylase enzyme. This material can break down long molecular (water-insoluble) starch chains into shorter (water-soluble) molecules that can be washed away more quickly. *Rinsing* has only one aim for wash and it is to make the garment wearable. During the construction of denim fabric, starch is applied to strengthen the warp. This makes the fabric stiff and harsh to the skin. In rinse wash the garment is desized and some softening agent is applied to improve the hand feel of the garment. *Denim abrasion* with enzymes provides a high color-contrast finish, high color pull and a low degree of back-staining, reduces equipment wear and tear compared to washing with pumice stones and It is also available for temperatures as low as 30°C and combined de-sizing and abrasion (single process step). *Softening* is the process that gives a soft touch to denim products, washing machines are softened. In industrial denim washing 3 types of softeners are used: Cationic softeners: All soft products except white products have a soft touch. They provide white and light-colored products that cause yellowing. Non-ionic softeners: They are used to soften white and light-colored products. Their effects are less than cationic softeners because they do not infiltrate into the product they remain on the surface. Silicones: They give the product softness as well as lubricity [1]. *The drying time* affects the hand feel. After washing, denim garments are hydroextracted to remove 80% of water content before drying. During drying, the number of denim garments in the dryer should not be too great. Too many denim garments in the dryer need a longer drying time which increases the contact between the garments leading to back staining. The denim garments are dried and *packed* for delivery [6]. Industrial washing processes of denim products are divided into two groups as dry processes and wet processes. Dry operations are sanding, whisker effect, damage, swift, and laser operations. Wet processes are resin spray, permanganate spray, pigment spray, desizing, stone washing, crinkle, enzyme washing, bleaching, tint, softening, and other special processes. The purpose of the *sanding* process is to give locally worn effect to certain areas of the denim garment. Standard metal sanders with 180 to 600 tines per square inch are used for this process. In the process, the operator abrades the indigo dye that covers only the outer part of the warp thread by applying the suitably sanded product to the desired color removal section of the product. The product to be sanded is dressed on horizontal mannequins (chamber) inflated by air pressure. Abrasion is applied with sandpaper according to the target product. However, because they cause the disease slikosis among employees, Republic of Turkey Ministry of Health issued a circular in 2009, and in all kinds of denim and fabric applied to the spraying process, the use of sand, silica powder or any substance containing silica crystals had been banned [9]. The purpose of the *whisker process* is to obtain worn and worn-looking lines resulting from creases and wrinkles in the garment used for a long time [10]. The purpose of the destruction (damage) process is based on the principle of shredding warp yarns in certain areas of denim products to reveal only weft yarns and simulate the long-term wear of the products. Therefore, this effect is called the destruction (damage). *Laser operations* are the process of giving effect by burning the denim fabric from the areas where the laser touches on the laser machine. Denim fabric can be made in the most open laser process or as a finished product. *Swift technique* is made in the raw state of denim products. Plastic blades are punched to the desired area with the machine designed for this application. The purpose of the application is to ensure that the stapled areas do not receive the washing effect applied during the washing. When these blades are removed after washing, the desired effect is obtained on the product [11]. *Resin spray* is generally applied as the first process in wet processes. It is made by a spray gun or by dipping method. It is used to keep the color dark in case of very dark washing. For example, when a process consisting of only 10 minutes of prewash is made to the resinous fabric, the color remains darker than the non-resinous one. It is made for better results in sanding areas. The dipping resin is mostly used for wrinkles or hard touches.

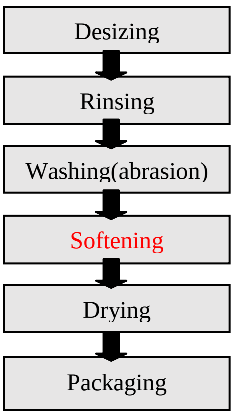

Figure 1. Denim Washing Process [8]

The effect of the resin leads to contrast images, especially in crosswise stitches, pocket stitches, and waist. Resinated clothing has a more fragile structure. Bleaching with *permanganate* is mainly used in local processes (such as spraying with guns) and in bleaching fabrics containing elastane and a mixture of fibers damaged under the influence of temperature and hypochlorite, and after bleaching, neutralization with peroxide or bisulfite should be performed. The large size of the permanganate molecules makes the color bleaching process more controlled and slower. However, in large stitched regions, the large molecule is disadvantageous and in these regions, the color remains dark [12]. *Pigment sprays* are applied only to color the outer parts of the products. In the *stone washing* process, freshly painted jeans are loaded into the large washing machine and rotated with a soft hand and a pumice stone or volcanic rock to achieve the desired appearance. Composition types, hardness, size shape, and porosity make this stone multifunctional. The process is very expensive and requires high capital investment. Pumice stone abrades the denim surface, such as sandpaper, creating a faded or worn appearance and removing some paint particles from the surfaces of the yarn. *Crinkle* is called the application of the desired effect on the product to the desired region by fixing the crushing effect with special chemicals in the oven at high temperatures. Wrinkle - crinkle effect is obtained in the product after application. This effect will not disappear even if the product is washed again. An *enzyme* is a kind of protein, has been used in the textile industry in recent years, and has come to the forefront in the washing sector because of its ability to break down starch and cellulose. The ground color of the products is tried to be captured by enzymes used according to different species and temperatures. *Bleaching* is the process of fading the color of denim products. It is effective in cotton products. This is a kind of reduction reaction. This is done using potassium permanganate or sodium hypochlorite. After capillary pumice overflow impregnation of reducing chemicals, only stone and product are treated in a washing machine. *Tint (Dirty) washing* is a type of washing that is done by applying special dyes of different colors and features in hot water. It is applied to give the product a dirty or antique appearance [13]. Finally, in the *softening* process, the final image of the fabric is captured. Most often cationic softeners are applied to the fabric in a weak acid environment. These ammonium-based substances contain chemically oil-containing groups, depending on the nature of these groups, called silicon or normal emollients. While only a soft touch can be obtained with normal softeners, a silky touch is obtained with silicon softeners [14]. In the manufacturing sector, there may be defects in every stage of production and in the textile sector; the formation of a defect in the denim washing processes is inevitable.

In denim washing and use, chemical defects such as back dyeing yellowing, inability to achieve regional color and nuance shift in the product, inability to achieve color fastening due to bleaching, color changes due to softener and resin, green in nuance, lack of gray or blue tone, inadequate blue, and white contrast, excessive bleaching may occur. Further, mechanical defects such as fractures, tears, wear caused by garments, dry process based on defects, accessory welded defects may occur. Further, heat-induced defects such as excessive drying and combustion may emerge [1].

2.1. Literature Review

According to literature review, in one [15] study related to the influence of denim washing, as industrial properties and washing on fabric properties, the structural features, shrinkage, air permeability, bending rigidity, extensibility, breaking force and elongation, shear rigidity has been determined. Additionally, [16] in other study researchers define mechanical properties of denim garments after enzymatic bio-machine washing processes and it is found that treatment of denim with different enzymes and stones may cause different effects. In the research about the effect of different washing processes on various performance and surface properties of denim fabrics were examined and for this purpose, 3 different types of fabrics (1/1 plain, 2/2 twill, and 3/1 twill constructions) were produced from 100% cotton yarn, and 4 different types of washing processes (rinse, enzyme, stone, and stone+bleach) were applied [17]. The effect of woven structure and washing processes on denim fabrics performance properties like dimensional stability, breaking strength, tearing strength, bending rigidity, surface views examination, and colorimetric valuation were investigated statistically. At the end of the washing process, when the surface appearance and color values of samples combined with the mechanical effect, chemical applications (stone+bleach) of fabric made significant changes on denim color values. In real concept analyzing quality control in garment company and aiming to determine the application of quality control by using statistical tools which can be convenient to control the level of disability products in the company, know the type of disability dominant, and provide solutions for problems facing by the company in other studies[18]. The result of their Pareto analysis diagram showed that major types of rejected products were the defected clothes (31.53%), broken (28.40%), and disability accessories (20.98%), nevertheless, the dominant type of defect was the defect in fabric. Based on the analysis of the control u map, it

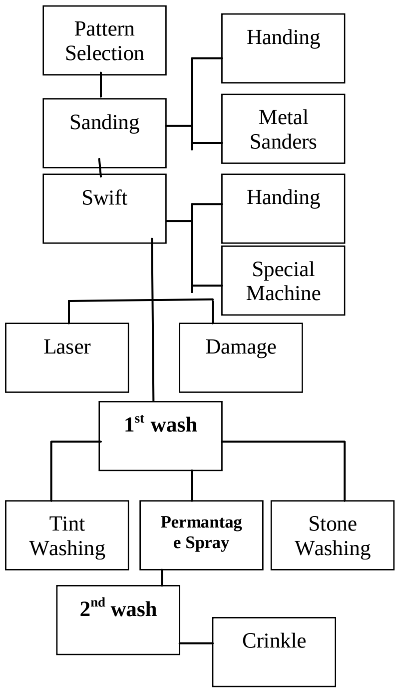

Figure 2. An alternative Flowchart for denim washing process

showed that there were still samples outside the control limits. From the analysis of the causal diagram, it can be concluded that disability products were derived from working systems, human/labor, materials/raw materials, and machinery. To augment, the perceptible raw materials become the main factor causing the fabric defect in the study. To determine the quality control on finished jeans and in the quality control segment, one study referred to the possible defects like strength loss, shading, stains, yellowing, and seaming that influence marketability or serviceability of denim garments are discussed and the possible solutions are suggested. The results obtained after dry and wet processes are a combined effect of mechanical abrasion, color dissolution, and destructive processes [19]. To enhance observations of the effects of Pareto analysis and Cause and Effect diagram, it is mentioned in the garment sector in Bangladesh that minimizing defects percentage and applied these methods. It is found that 6 top defect positions (Uncut Thread, 23.72%; Spot, 20.70%; Waist Belt,11.67%; Bottom Hem, 10.04%; Side Seam, 6.30%; Waist Belt Top Stitch, 6.14%) are identified where 78.56% defects occur. On those top positions, further Pareto Analysis is performed to identify the top defect types. It is resulted in a total of 115 regarding areas where 71.40% defects arise, which should be the foremost concerning areas to lessen defect percentage [20]. In other study, investigation is about the chemical oxygen demand (COD) and color removal efficiency and specific energy consumption during batch electrochemical treatment of synthetic textile wastewater and containing yellow-brown acrylic dye and found that COD (0.8815), color (0.9494), and specific energy consumption (0.9331, 0.8805) by Pareto chart. It shows that chemical oxygen demand brought the wastewater problem into the forefront [21].

3. MATERIALS AND METHODS

The statistical process control that forms the core of the method of this study is a quality control method used to continuously control a process and to control the variability in the process. Statistical process control is the use of various statistical techniques to ensure a product that is produced in the most economical and most useful way, to target its defective variability produced at this point [22]. According to Professor K. Ishikawa, 95% of the problems encountered in the industry can be solved with seven basic techniques. These techniques are flow diagram, check sheets, Pareto analysis, cause and effect diagram, histogram, scatter diagram, and control cards [23].

In this study, the defects encountered in the washing process in a denim factory are identified and designated, and the most common defects are examined using statistical process control methods, Pareto analysis, cause and effect diagram, and *P* control graph. During the washing process, it is not possible to prevent all defects detected over quality control. With the Pareto analysis technique, many defect types are listed according to importance. Thus, the most important washing process defects are identified. The results of quality control are examined with *P* control charts. In this way, it is aimed to present the necessary regulations to control the continuity of the quality level, to control the process, and to achieve the targeted product quality.

3.1. An Overview of Pareto Chart, Cause-and-Effect Diagrams and *P* Control Chart

Pareto analysis is called as ABC analysis or sometimes (20/80) rule. According to this principle, the majority of nonconformities are based on many reasons, and the identification of these causes plays a key role in solving the problems. In economics, 80% of the outputs, 20% of the inputs; 80% of the results will arise from the basis of 20%

of the reasons and the 80/20 rule, which is expressed as Pareto, is based on the idea that 80% of problems can be solved by eliminating the causes accounting 20% of all problems [24].

The reason for using the Pareto analysis technique in this study is that there are many flaws encountered in the washing process, but not all of them affect the whole process. If the main defects affecting the whole process are eliminated, the process can be continued even if there are other defects. After determining the problem to be investigated in the drawing of the Pareto diagram, the information collected with the appropriate data schedule is used. The collected data is sorted in descending order according to the unit quantities. The others are placed in the last row, regardless of size. The cause-effect diagram is prepared to reveal the relationship between a particular result and possible causes, and thus the causes of defects, and is drawn to show the connections of factors that affect a process. A detailed diagram is in the form of fishbone, developed by the Japanese Ishikawa, often referred to as the Ishikawa Diagram. When the diagram is drawn, the problem is identified, and possible causes are written in the main categories [25]. When the main reason is considered as washing process errors, all the reasons causing will be identified and categorized in the diagram. To change from a monitoring-based system to a prevention-based system, it is necessary to see and control the variation in process output over time. Thanks to the *p* control graphs showing the changes over time, the measured values obtained from the samples taken at certain and equal time intervals from production; It is recognized that the changes in the process are caused by natural or unnatural reasons [26]. Sampling for *P* control chart includes the yes / no decision. The process output may be defective or not defective. Statistical distribution is based upon the binomial distribution. The number of products controlled in the enterprise examined varies. In enterprises where 100% inspection is performed or the number of products controlled in proportion to the production amount varies, the control chart will have variable sample sizes. The approach that can be followed in such cases is to set separate control limits for each sample. In case the sample size is n_i and the standards are determined, the midline, upper, and lower control limits are calculated by the following formula [27]:

3.2. Methodology

The study was conducted in Turkey on a production company engaged in the production of denim in Düzce. Within the scope of the research, Pareto diagram, *P* control chart, and cause and effect diagrams were formed over the defects that occurred during the washing process.

3.3. Data Collection and Analysis

Data were obtained through interviews in a production company, by a production manager and director of the washing department. The data in the department only include working days of November 2019 and weekends (Saturday and Sunday or Sunday only) are not included. So the data consist of 25 days. There are two shifts in the shape of day and night in washing section as the same in all production process. In data set obtained, 53 defects are classified as chemical repair, blue floor, rinsing, green floor, press, retouch, chemical intensive, light floor, deep floor, neutral repair, hard touching, panel difference, flaw, local repair, stained works, lycra eccentric, chemical above green, coating repair, branch flaw, yellow floor, downy works, rope cut, blue above whisker, being blown out, chemical above yellow, pigment repair, red floor, grey floor, moiré works, random repair, straight floor, stripe defect, resin intensive, resin broken, over effect, resin stain, fray repair, coating line, washing repair, orange floor, chemical segregation, fabric difference, whisker repair, fray off, and fabric tear. Business employees have some ideas about the potential causes of defects. Although several attempts have been made previously, no registered studies have been found. In previous studies available in the enterprise, no research on the prevention of washing defects was found. This situation makes this study more important.

4. FINDINGS IN PROCESS AND STATISTICAL EVALUATION

Table 1 was prepared with the purpose of checking the distribution of defects. Total defects are found and reported as 176240 washing process defects as a result of the control of 759259 denim in 25 days. In the total part, the number of each error recorded in the control cards in 759259 units is given. When controlling the column of total numbers, it is ranged as first chemical repair (36382 defects) and last and the lowest fabric tear (9 defects).

$$UCL = \bar{p} + 3\sqrt{\left(\frac{\bar{p}(1-\bar{p})}{n_i}\right)} \quad CL = \bar{p} = \frac{\sum p_i}{\sum n_i} \quad LCL = \bar{p} - 3\sqrt{\left(\frac{p(1-\bar{p})}{n_i}\right)}$$

Table 1. Defects Tracking Report

Defects/Days	1	2	4	..	28	29	30	Total
Chemical Repair	1460	546	1992	..	2279	2437	1275	36382
Blue Floor	1565	427	1422	..	2568	2028	1281	35216
Chemical Intensive	1123	1592	1239	..	1152	662	534	34674
Light Floor	289	588	193	..	1202	391	574	18984
Deep Floor	1130	920	1036	..	242	636	257	14099
Neutral Repair	6	0	417	..	0	0	207	5526
Chm. Above Yellow	0	117	0	..	245	164	240	5197
Pigment Repair	0	275	48	..	0	87	100	4720
Retouch	500	13	0	..	192	138	50	3570
Rinsing	118	856	110	..	102	0	121	3324
Yellow Floor	0	30	130	..	144	12	182	1715
Green Floor	20	453	0	..	14	200	0	1713
Press	200	0	65	..	192	0	0	1322
Local Repair	0	0	380	..	0	28	50	1316
Resin Broken	0	0	0	..	0	0	0	1134
Panel Differ.	44	72	0	..	94	10	0	964
Stained Works	0	0	0	..	0	0	0	814
Red Floor	0	50	0	..	0	0	0	583
Straight Floor	0	0	0	..	224	0	0	579
Lycra Eccentric	0	0	0	..	0	500	66	566
Grey Floor	0	50	27	..	0	0	0	552
Chemical Burnt	0	0	0	..	236	0	0	505
Random Intensive	0	0	0	..	0	0	0	483
Stripe Defect	0	0	293	..	0	0	0	403
Downy Works	0	0	0	..	101	0	0	340
Random Repair	0	0	0	..	0	0	0	260
Random Stain	0	0	0	..	0	0	0	249
Washing Repair	0	0	0	..	0	0	0	248
Resin Stain	0	0	0	..	0	0	0	219
Moiré Works	0	67	0	..	0	0	0	134
Fray Repair	0	0	0	..	11	20	0	131
Coating Line	0	0	0	..	0	0	0	122
Orange Floor	0	0	0	..	0	0	0	121
Mesh Intensive	0	0	0	..	0	0	0	100
Whisper Repair	0	0	0	..	0	20	71	91
Blue Whisker	0	89	0	..	0	0	0	89
Flaw	48	0	0	..	0		0	86
Dye Slump	0	0	0	..	0	0	0	85
Chemical Segregat.	0	0	0	..	79	0	0	79
Chemical Light	0	0	0	..	0	0	0	74
Fray Off	0	0	0	..	0	0	74	74
Be. Blown Out	0	57	0	..	0	0	0	57
Over Effect	0	0	0	..	0	0	0	53
Coating Repair	0	48	0	..	0	0	0	48
Fabric Dif.	0	0	0	..	43	0	0	43
Local Blue	0	0	0	..	0	0	0	40
Resin Intensive	0	0	18	..	0	0	0	37
Hard Touching	34	0	0	..	0	0	0	34
Chemical Green	0	25	0	..	0	0	0	25
Branch Flaw	0	23	0	..	0	0	0	23
Rope Cut	0	0	0	..	19	0	0	19
Leg Conversion	0	0	0	..	0	0	0	11
Fabric Tear	0	0	0	..	0	0	9	9
Denim Cont.	**34791**	**29293**	**39561**	**..**	**32374**	**28659**	**15426**	**759259**
Total Defects	**6437**	**6298**	**7370**	**..**	**9139**	**7333**	**5088**	**176240**

With the intention of preliminary preparation for Pareto analysis, Table 2 was comprised by calculating the defect percentages and cumulative percentages by ordering the total number of washing process defects in the defect tracking report from large to small. According to table of number of defects observed during washing process respectively chemical repair (20,52 %), blue floor (19,86 %), chemical intensive (19,56 %), light floor (10,71 %), and deep floor (7,95 %) have great impact on increasing % of defects when checking cumulative percentage.

Among the 53 washing defects examined, the Pareto diagram in Figure 1 was created by using the data in Table 2 to determine the defects that comprise 80% of the total defects. In Pareto analysis formed, chemical repair (20,52 %), blue floor (19,86 %), chemical intensive (19, 56 %), light floor (10, 71 %), deep floor (7,95%) are in first five places among 53 defects and account for 78,6 % of the total number of defects. (See Table 2, See Figure 3).

In this study, the reason for using Pareto diagram in this study shown in Figure 3 is to is to guide the quality control staff in determining the types of defects, to ensure that their efforts are concentrated in the most productive fields and that the necessary measures are taken by making accurate decisions. Of the 53 defects encountered during the washing process, it was found that only five of these defects could be prevented during the washing process, thus reducing the total waste by about 80%.

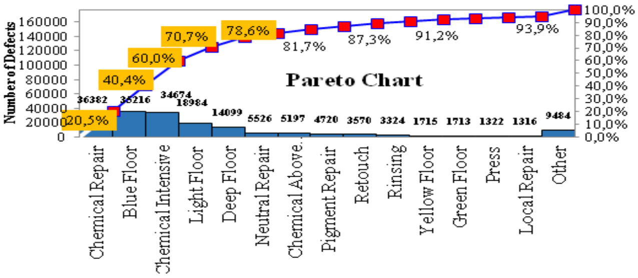

Figure 3: Pareto Chart for Denim Washing Defects

Table 2: Number of Defects Observed During Washing Process

Defect Name	Number of Defects	% of Defect	Cum %	Defect Name	Number of Defects	% of Defect	Cum %
1.Chemical Repair	36382	20,52	20,52	28.Washing Repair	248	0,14	99,06
Blue Floor	35216	19,86	40,38	Resin Stain	219	0,12	99,18
Chemical Intensive	34674	19,56	59,94	Moiré Works	134	0,07	99,25
Light Floor	18984	10,71	70,65	Fray Repair	131	0,07	99,32
Deep Floor	14099	7,95	78,6	Coating Line	122	0,06	99,38
Neutral Repair	5526	3,11	81,71	Orange Floor	121	0,06	99,44
Chemical Above Yellow	5197	2,93	84,64	Mesh Intensive	100	0,05	99,49
Pigment Repair	4720	2,66	87,3	Whisper Repair	91	0,05	99,54
Retouch	3570	2,01	89,31	Blue Above Whisker	89	0,05	99,59
10.Rinsing	3324	1,82	91,13	Flaw	86	0,04	99,63
Yellow Floor	1715	0,96	92,09	Dye Slump	85	0,04	99,67
Green Floor	1713	0,96	93,05	Chemical Segregation	79	0,04	99,71
Press	1322	0,84	93,89	40.Chemical Light	74	0,04	99,75
Local Repair	1316	0,83	94,72	Fray Off	74	0,04	99,79
Resin Broken	1134	0,71	95,43	Being Blown Out	57	0,03	99,82
Panel Difference	964	0,54	95,97	Over Effect	53	0,03	99,85
Stained Works	814	0,45	96,42	Coating Repair	48	0,03	99,88
Red Floor	583	0,32	96,74	Fabric Difference	43	0,02	99,90
Straight Floor	579	0,32	97,06	Local Blue	40	0,02	99,92
20.Lycra Eccentric	566	0,31	97,37	Resin Intensive	37	0,02	99,94
Grey Floor	552	0,31	97,68	Hard Touching	34	0,02	99,96
Chemical Burnt	505	0,28	97,96	Chemical Above Green	25	0,01	99,97
Random Intensive	483	0,27	98,23	Branch Flaw	23	0,01	99,98
Stripe Defect	403	0,22	98,41	Rope Cut	19	0,01	99,99
Downy Works	340	0,19	98,64	Leg Conversion	11	0,005	99,99
Random Repair	260	0,14	98,78	53.Fabric Tear	9	0,005	100,0
Random Stain	249	0,14	98,92				

Chemical repair, which constitutes 20.52% of the total defect in the washing process, includes parts of the denim in the washing process that can be repaired after exposure to the chemical. 19, 56% of the total defects are the chemical intensive, that denim is included non-repairable products as a result of exposure to excess chemical. The first of the chemicals used in the washing process; desizing enzymes is the process, that make the starch contained in the sizing water-soluble, prewash process, and the nonfoaming-hard water having a pH of 6-7. If the enzyme does not remove the dye and scalp homogeneously, a fracture will occur in these areas [28]. This causes irreparable damage. The sizing material is usually based on starch or modified starch, although some wetting chemicals and emollients are also present in the sizing recipe. These chemicals should be removed from the fabric as it reduces the effects of chemicals to be used in washing operations to be made on denim garments. Unless a proper desizing is done, the possibility of abraj formation in the fabric is quite high. A desizing process that cannot be done sufficiently will cause unnecessary consumption as it will reduce the effect of chemicals to be given to the fabric in the next stages.

Other chemical processes that increase the light fastness of denim fabric optic whiteners, disintegrated dyes or indigos by dispersing the fabric to reduce the permeability of the fabric, washing the enzyme to keep the dye to help enzyme to reduce the effect of sunlight, and shine under the brightening phosphorus brighteners used to obtain the appearance of bright jeans, cationic or silicone-based softeners used for softening purposes are included in the process [29]. The second most common problem is blue floor defect which accounts for 19, 86 % of the total defect. At the end of washing process control, blue, light, or dark color appears on the floor. These products are divided into repair as insufficient or intensive local permanganant and insufficient and intensive pigment locally. The background color becomes blue due to back-staining and during the back-staining process the indigo dyestuff precipitates on the floor. With this collapse, white weft yarns are contaminated. Back staining is solved by ozone and this increases energy costs. Processes to be performed in industrial washing machines and spray sections bring extra energy, chemical, and labor costs [29]. Another problem identified is the light floor which constitutes 10.71% of the defects. The light color of the products is tried to be caught with enzymes according to different species and temperatures. When the undesirable light floor color emerges in the washing process, any dyestuff used in the product itself can be driven, or the dyestuff in a different color is reduced and soiled by machine exhaustion. Besides, preventive softeners are also used to prevent open floor problems.

In order to avoid undergoing further processes and to prevent stains and irregularities before other processes, it is necessary to resolve the softener in the washing process. Another problem is dark ground and constitutes 7.95% of the total defect. Since the ground color is dark, denim products that are deemed defective are controlled in color until they reach the desired surface and the parameters such as temperature, time, and concentration are adjusted according to the target sample. In the washing process, sodium hypochlorite or potassium permanganant bleaching process, neutralization and rinsing are performed respectively for products with dark ground defects. Another factor in the dark color of the background is the inadequate abrasion effect. As the defect correcting process, additional abrasion and rinsing are carried out and drying is started [29].

For the purpose of sighting and controlling the variation in the process output, the defect rate control chart is prepared using the data that recorded the defects seen in the washing process. The daily controlled product amounts are different for the period in which Laney P chart is prepared. To prepare the chart, values that were found by using formula [27] and Z_i that was calculated for each day can be seen in Table 3. Z_i reflects deviations from upper control limits (UCL) lower control limits (LCL), and centerline scores of these both UCL and LCL. Formula for Z_i is[27] :

$$Z_i: \frac{pi - \bar{p}}{\sqrt{\left(\frac{\bar{p}(1-\bar{p})}{n_i}\right)}}$$

Depending on the production per unit time, the control charts will have variable sample sizes in the enterprises where the controlled quantity varies. So Laney P control chart, which is widely used in quality monitoring that has a very large sample size [30], will be useful for this study. Because it is not possible to control the processes spontaneously, the controlling graphics used are very important to eliminate identifiable causes, to reduce variability in the process, and to maintain process performance. For this purpose, the fact that all points in the Laney P control chart are within the control limits and it indicates that the process is kept under control. If the values exceeding the upper control limits were found, special factors should be studied and necessary corrections should be made. The fact that the majority of the dots are under the midline may mean an improvement in quality. (See Figure 4 and dates: 1.11-6.11; 8.11-14.11; 25.11). Moreover, dots between 14.11 and 22.11 as subgroup numbers are almost with average values and this shows that the process is under control.

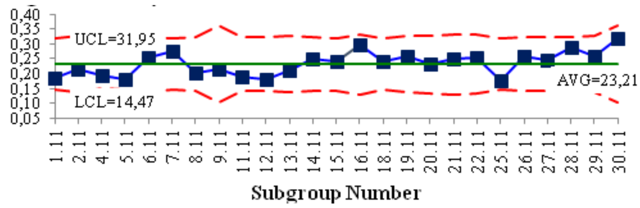

Figure 4. Laney P'Chart

Values below the lower control limit indicate that the defect rate was very low in this period. In these cases, the reasons for these improvements need to be investigated.

Table 3. Defect Rate *P* Control Chart Data

Sample Numbers Date)	Cont. Numbers	Number of Defects	Defects Ratio(*p*)	Center -	UCL	LCL	Z_i
01.11.19	34791	6447	0,19	0,23	0,2389	0,2253	0,1852
02.11.19	29293	6298	0,22	0,23	0,2395	0,2247	0,2149
04.11.19	39561	7720	0,20	0,23	0,2384	0,2257	0,1951
05.11.19	34696	6265	0,18	0,23	0,2389	0,2253	0,1805
06.11.19	30812	7877	0,26	0,23	0,2393	0,2249	0,2556
07.11.19	35456	9776	0,28	0,23	0,2388	0,2253	0,2757
08.11.19	33032	6661	0,20	0,23	0,2390	0,2251	0,2016
09.11.19	15513	3332	0,21	0,23	0,2422	0,2219	0,2147
11.11.19	33133	6306	0,19	0,23	0,2390	0,2251	0,1903
12.11.19	32915	5983	0,18	0,23	0,2391	0,2251	0,1817
13.11.19	28708	6074	0,21	0,23	0,2395	0,2246	0,2115
14.11.19	31664	7936	0,25	0,23	0,2392	0,2250	0,2506
15.11.19	33360	8103	0,24	0,23	0,2390	0,2251	0,2428
16.11.19	25873	7675	0,30	0,23	0,2399	0,2242	0,2966
18.11.19	36361	8844	0,24	0,23	0,2387	0,2254	0,2432
19.11.19	28729	7410	0,26	0,23	0,2395	0,2246	0,2579
20.11.19	28040	6537	0,23	0,23	0,2396	0,2245	0,2331
21.11.19	25664	6385	0,25	0,23	0,2400	0,2242	0,2487
22.11.19	26355	6728	0,26	0,23	0,2399	0,2243	0,2552
25.11.19	35557	6196	0,17	0,23	0,2388	0,2254	0,1742
26.11.19	32187	8385	0,26	0,23	0,2391	0,2250	0,2604
27.11.19	31100	7702	0,25	0,23	0,2393	0,2249	0,2476
28.11.19	32374	9300	0,29	0,23	0,2391	0,2250	0,2872
29.11.19	28659	7386	0,26	0,23	0,2396	0,2246	0,2577
30.11.19	15426	4914	0,32	0,23	0,2423	0,2219	0,3185
Total	759259	176240					

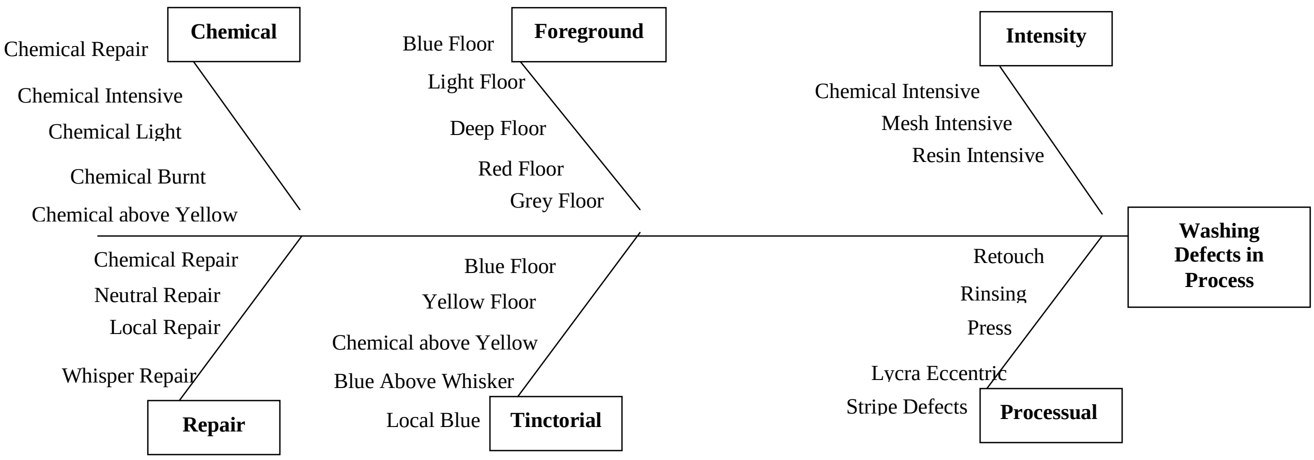

Figure 5. Cause and Effect Diagram

The cause-and-effect diagram for washing defects in the process is illustrated in Figure 5. In the cause-and-effect diagram, washing defects in the process are categorized into chemical, foreground, intensity, repair, tinctorial, and processual. The reason for the washing defects to be collected in the categories is that they are interdependent and interact as a result of being similar to each other. For example, the majority of tinctional flaws emerge with the nuanced differences between the colors experienced on the floor and the desired colors after washing in denim fabric. Moreover, chemical defects could be associated with defects in the color category.

5. CONCLUSION

After identifying and analyzing cause and effect diagrams washing defects in the process could be reduced by taking corrective actions given in Table 4.

Washing in the process has been causing some losses and the appropriate identification of washing defects in the process is exact noteworthy for taking helpful actions before other steps in denim production. Washing defects in the process in table 2 are analyzed by Pareto chart. It is revealed that chemical repair constitutes 20.52%, blue floor defect accounts for 19, 86 %, chemical intensive accounts for (19, 56 %), light floor constitutes 10.71% and deep floor constitutes 7.95%. Here these 5 major defects comprised of 78, 6 % of the total number of defects. Washing process defects are undesirable on the product that has not passed the ending stage.

As a result of the defects in the washing process, products are either sent for repair or the product is removed from the production stage before the final control of the product that is about to be finished and separated as waste. If any washing defect on the finished product is not noticed and the dyeing stage is passed and the finished product reaches the customer in this state, bigger problems arise, and the trust of the customer is shaken. Considering that almost 80% of the defects encountered and eventually analyzed by Pareto chart and Cause and Effect diagram are chemical and color-based ground defects, it would be the best way to prevent these defects before occurring. In this study, the number of defects detected during and after the washing process of the raw fabrics produced in a denim production facility for 25 days, and quality controls were examined by statistical methods. Data containing 25 days of washing process defects seen as a result of fabric control made by the control staff in the washing section were collected. It is not possible to take measures for all 53 error classes in the defect tracking report and to prevent these defects from occurring. Therefore, the detected defects are listed in order of importance by the Pareto analysis technique. Since the defects in the washing processes cannot be controlled automatically, control cards are used in this study. Laney *P* control chart was used in this study because the amount of denim that is controlled daily and the defect is different. In this study, the process is under control since all points are within the control limits.

Table 4: Recommended Corrective Actions for Washing Defects in Process.

	Defect Type	Causes	Corrective Actions
1	Chemical Defects	Desizing enzymes, homogeneity (exceeding Ph 6-7)	Dispersing Indigos, Using cationic or silicone for softening
2	Ground Defects	insufficient or intensive local permanganant and pigment,	Back staining by ozone,
3	Intensity Problem	After the type of washing, as a result of the narrowing in the width and neck of the fabric and the increase of weft and warp frequencies	Investigations should be made on rins, enzymes, and stone and stony bleach wash recipes. Time, temperature and stone used in washing recipes, enzyme and bleach, weight, dimensional stability
4		Reasons for repairs are wet processes and operational errors due to spray.	Faulty products with tone difference are light or dark color on the floor, permanganate at local insufficient or dense
5	Tinctorial	parameters such as temperature, duration and concentration	Sodium hypochlorite or potassium permanganant bleaching process, neutralization and rinsing
6	Processual	Failure to rinse with soft water. The problem that the rinse water is not cold. Failure to remove peroxide. Hard water causes problems in dyeing due to the high rate of lime it contains.	Acetic acid and peroxide killer are added. In addition to these, soft water is added and the temperature is raised to 50 degrees and kept for 15 minutes. If peroxide is 0 and ph = 7, it means that suitable environment is provided for dyeing.

Although the process is seen under control, taking into account the rate of defects encountered and the points of concentration, corrective actions should be taken by taking some precautions to prevent errors encountered in the washing process. Some of these corrective actions are presented with the Cause and Effect diagram, and some number of other suggestions can be submitted to the business. The personnel in the washing department to prevent 80% of the defects should be gained experience and manual records should be made more systematic and processed on the control cards to ensure that the defects can be observed more clearly and clearly. Detection of defects in the washing process is mostly carried out before proceeding with the rinsing and dyeing process. As seen in Figure 2, according to the alternative flowchart created, when the defect occurs as a result of each process in washing, the next process should not be started, and each process should be gained from the customers' perspective of the previous process. At this point, control charts will be of great help. Thanks to the control charts used to control the continuity of the captured quality level; the reasons for the defects can be investigated and the necessary arrangements can be seen to reach the targeted product quality. Thanks to the decrease in faulty production, operating costs will be significantly reduced in addition to achieving the desired product quality. To clarify the result in one study it is similarly found and addressed that it is essential to control the washing processes and take every stage to minimize industry wastes and environmental pollution by employing different applications such as statistical process control methods with learned restrictions on the products and washing processes. To control it recommends the use of bio-degradable enzymes in place of detrimental chemicals. In case of preventing environmental pollution, fully acquiescence to legal requirements and regulations inducements high priority. In denim washing, usage of chemicals and enzymes, washing conditions, etc. are essential and main factors to reduce costs [31].

The research addressed in the existing paper could be practical to different companies in the textile industry. The result of the research may diverge in concerned companies reliant on the level of preventive/corrective actions thanks to Cause and Effect diagrams and we consider that the research methodology could simply be monitored in other industries for identifying and preventing defects in washing and other processes. In future studies it is advised to be studied control charts and diagrams before controlling the process and after controlling the process.

REFERENCES

1. Karagöz, G.2009. Denim Yıkama İşlemlerinde Ortaya Çıkan Zararlar Nedenleri ve Çözüm Olanakları, Ege Üniversitesi, Fen Bilimleri Enstitüsü, Tekstil Mühendisliği Ana bilim dalı, Yüksek Lisans Tezi, İzmir.
2. Öcel Y., Arslan H.M. 2018. Hazır Giyim Ürünlerinde Tüketicilerin Demografik Özellikleri İle Renk Algılarının Değerlendirilmesi. Business & Management Studies: *An International Journal* 6 (3), 154-170.
3. İstanbul Tekstil ve Hammaddeleri İhracatçıları Birliği (ITHIB) 2018 Raporu. Erişim: https://www.ithib.org.tr/tr/bilgi-merkezi-raporlar-aylik-ihracat-degerlendirme-bilgi-notlari-2018.html
4. Zhao, W.B.2008. Common denim washing technologies (in Chinese). Dyeing Finish. 34 (7), 34–36.
5. Dindar, D., Yavuz, B., 2001. 2000-2001 Moda Trendleri ve Kot Pantolon-Mont Üretimi, Marmara Üniversitesi Teknik Eğitim Fakültesi Tekstil Eğitimi Bölümü, Yüksek Lisans Tezi, İstanbul.
6. Kan, C. W. 2015. Washing techniques for denim jeans. In *Denim* (pp. 313-356). Woodhead Publishing.
7. Pal, S. 2010. Technology of Denim Production: Part-VI (Washing Techniques of Denim). San Blue Enterprises Pvt. Ltd, India.
8. Li, Z.J., Liu, S. 2013. Denim Production Techniques (in Chinese). Donghua University Press Ltd., China
9. Akkurt, İ. (2015). Silikozis. Mesleki Sağlık ve Güvenlik Dergisi (MSG), 9(32).
10. Yi, C.M. 2011. Effect of Washing on Tensile Strength of Denim Fabric, A Thesis Degree of Bachelor of Arts (Honours) Scheme in Institute of Textiles & Clothing, The Hong Kong Polytechnic University. Hong Kong.
11. Matthews, K. 2018. *Encyclopaedic Dictionary of Textile Terms: Volume 3*. WPI Publishing.
12. Arjun, Dakurı., Hiranmayee, J., & Farheen, M. N. 2013. Technology of industrial denim washing. *International Journal of Industrial Engineering & Technology*, *3*(4), 25-34.
13. Choudhury, A. K. R. 2017. Environmental impacts of denim washing. In *Sustainability in Denim* (pp. 49-81). Woodhead Publishing.
14. Sweeney, D. 2002. Way To Go Indigo–Using Cellulase To Soften & Lighten Denim. *The American biology teacher*, *64*(3), 202-208.
15. Jucienė, M., Dobilaitė, V., & Kazlauskaitė, G. 2006. Influence of industrial washing on denim properties. *materials science*, *12*(4), 355.
16. Mir, S., Hossain, M., Biswas, P., Hossain, A., & Idris, M. A.2014. Evaluation of mechanical properties of denim garments after enzymatic bio-washing. *World Applied Sciences Journal*, *31*(9), 1661-1665.
17. Mezarcıöz, S., & Toksöz, M. 2014. Investıgatıon Of Effect Of Specıal Washıng Processes On Denım Fabrıcsr17; Propertıes. Tekstil Ve Konfeksiyon, 24(1), 86-95.
18. Mayang, N., Koeswandi, T. A., & Yulianti, S. 2016. August). The Analysis of Quality Control in Garment Company Using Statistic in Controling Product. In *2016 Global Conference on Business, Management and Entrepreneurship*. Atlantis Press.
19. Paul, R. (Ed.). 2015. Denim: manufacture, finishing and applications. Elsevier.
20. Ahmed, T., Acharjee, R. N., Rahim, M. A., Sikder, N., Akther, T., Khan, M. R., ... & Saha, A. 2013. An Application of Pareto Analysis and Cause-Effect Diagram for Minimizing Defect Percentage in Sewing Section of a Garment Factory in Bangladesh. *International Journal of Modern Engineering Research, Bangladesh*.
21. Bhatnagar, R., Joshi, H., Mall, I. D., & Srivastava, V. C. 2014. Electrochemical treatment of acrylic dye-bearing textile wastewater: optimization of operating parameters. *Desalination and Water Treatment*, *52*(1-3), 111-122.

22. MacGregor, J. F., & Kourti, T. 1995. Statistical process control of multivariate processes. *Control Engineering Practice*, *3*(3), 403-414.
23. Patır S. 2009 "İstatistiksel Proses Kontrol Teknikleri ve Kontrol Grafiklerinin Malatya'daki Bir Tekstil (İplik Dokuma) İşletmesinde Bobin Sarım Kontrolüne Uygulanması". *Sosyal ve Ekonomik Araştırmalar Dergisi*, 12(18), 231-249.
24. Koch, R. 1999. The 80/20 Principle: the secret to achieving more with less, Crown Business, ISBN: 0385491743.
25. Suárez-Barraza, M. F., & Rodríguez-González, F. G. 2019. Cornerstone root causes through the analysis of the Ishikawa diagram, is it possible to find them?. *International Journal of Quality and Service Sciences*.
26. Bircan H, Gedik H. 2003. "Tekstil Sektöründe İstatistiksel Proses Kontrol Teknikleri Uygulaması Üzerine Bir Deneme". *Çukurova Üniversitesi İktisadi ve İdari Bilimler Dergisi*, 4(2), 69-79.
27. Shah, S., Shridhar, P., & Gohil, D. 2014. Control chart: A statistical process control tool in pharmacy. *Asian Journal of Pharmaceutics (AJP): Free full text articles from Asian J Pharm*, *4*(3).
28. Kunt, A. G. 2004. *Denim Kumaşlarda Konfeksiyon Sonrası Yapılan İşlemlerin Kumaş Mekaniği Üzerine Etkisi* (Doctoral dissertation, Fen Bilimleri Enstitüsü).
29. Köksal, F. 2015. *Denim Yıkamada Renk Varyasyonlarının Neden-lerinin İncelenmesi* (Master's Thesis, Namık Kemal Üniversitesi).
30. Ahsan, M., Mashuri, M., & Khusna, H. 2017. Evaluation of Laney p'Chart Performance. *International Journal of Applied Engineering Research*, *12*(24), 14208-14217.
31. Wickramasinghe, T. 2011. Process improvement in denim washing.

TEKSTİL VE KONFEKSİYON

VOL: 30, NO. 3

DOI: 10.32710tekstilvekonfeksiyon.752956

Assessing Water-Related Comfort Performance of Knitted Fabrics made of Rayon Microfibers and Lyocell Fibers for Intimate Wear

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ABSTRACT

Comfort properties of knitted fabrics used for intimate wear is an important matter to be dealt with. Hence, the comfort issue of the knitted fabrics made of micro-rayon and lyocell fibers were examined in the current study after they were separately treated with the antibacterial and wicking finishes. Moreover, the effect of spandex was investigated. The fabric samples were analyzed in terms of vertical wicking capacity, transfer wicking, water vapor permeability and drying rate. According to the results, spandex incorporation and process history were found to be influential on the vertical wicking capacity of the fabric samples whereas, spandex incorporation was found as the main affecting parameter for the transfer wicking. Moreover, fiber type and spandex incorporation were both found to have significant effects on the water vapor permeability of the fabric samples. The best fabric option from its alternatives for intimate wear was chosen by the hybrid AHP-TOPSIS approach.

ARTICLE HISTORY

Received: 15.06.2020

Accepted: 11.08.2020

KEYWORDS

Comfort, finishing treatments, lyocell, rayon microfibers, multi-criteria decision approach

1. INTRODUCTION

Intimate wear is the most important clothing layer since it acts as human's second skin. It requires the comfort issue to be maintained perpetually than that of outerwear due to the contact to the skin directly [1]. Comfort for intimate wear is multidimensional and can be examined with regard to several aspects such as sensorial, thermal, motion, aesthetical and hygienic all of which are interrelated. Intimate wear is an inner layer worn between the skin and the outerwear allowing perspiration, transmission of body heat and excessive wetness from the skin to the atmosphere for staying dry. Therefore, its thermal comfort in terms of moisture management is very important. Transferring moisture from the clothing to the environment through diffusion, wicking, sorption and evaporation is regulated by the thickness of the fabric, tightness of the fabric construction and hygroscopicity of the fiber kind. Since the wet skin is much more easily irritated than the dry skin, specific care should be taken to provide better skin comfort [1, 2]. As the intimate wear contacts the skin directly, its hygienic comfort becomes also an important issue. If satisfactory hygiene is not provided, health problems (prophylaxis and infections) and the incidence of bacteria and fungi propagation, as a result of which malodor formation and decomposition of textiles due to microbial corrosion can readily occur. Therefore, the antimicrobial finishing consisting of the antimicrobial agents can be used for the protection of the human skin health [1, 3-13].

Wearing intimate clothes consisting of irritating or allergic substances can induce skin reaction so that the tactile comfort which can be defined as the tactile sensations of softness and smoothness becomes the most important issue (Yu, 2011). A pleasing sensation of feeling soft and smooth on the skin is required to be achieved in intimate wear since it is worn directly in contact with the skin. The fabrics made of rayon microfibers and lyocell fibers wrap the body

To cite this article: Cimilli Duru S, Göcek İ. 2020. Assessing water-related comfort performance of knitted fabrics made of rayon microfibers and lyocell fibers for intimate wear. *Tekstil ve Konfeksiyon*, 30(3), 220-230.

with a touch of lightness and soft feeling twice as cotton. Because of their smooth structures, the fabrics made of these fibers become particularly silky and gentle on the skin preventing skin irritations, which makes them a perfect choice for the intimate wear [14]. However, there is a limited number of studies regarding the comfort properties of the knitted fabrics consisting of rayon microfibers and lyocell fibers [1, 2, 15, 16]. Therefore, in this study, some water-related comfort properties of the seamless fabrics for intimate wear made of lyocell fibers and rayon microfibers such as vertical wicking capacity, transfer wicking, water vapor permeability and drying rate were investigated. For outwear garments, drape and silhouette should be acquired. On the other hand, the intimate wear, which is a stretch garment in contact with the skin requires particular fabric tension resulting in a certain degree of fitting by the help of spandex to provide the wearer with a sense of support and security [1, 2]. Thus, spandex was used in the fabric structure to investigate its effect on comfort. Additionally, even though hygiene and dry feel are the unignorable factors for the intimate wear to feel comfortable, there are lack of studies taking the antibacterial efficacy and wicking finishing treatment of the fabrics made of lyocell fibers and rayon microfibers into consideration [17-20]. For that reason, antibacterial and wicking finishes were applied on the fabrics and their effects on the water-related comfort were examined.

2. MATERIAL AND METHOD

2.1 Material

The fabric samples were produced on an E28 13’’ Merz Mbs seamless knitting machine with identical machine settings. The purpose of selecting the seamless knitting technology was that it is a common technique for the production of intimate wear as well as functional knits. Half of the fabric samples was knitted only with the main yarns, while the remaining part was produced with both the main yarns and spandex (Lycra®, 100% spandex multifilament fibers by Lycra Company) with the help of the plaiting technique. By doing so, the effect of spandex on the water-related comfort properties of the seamless samples was investigated. In the production, Ne 50/1 yarns made of cellulosic fibers, micro rayon (MicroModal® by Lenzing Ag) and lyocell were used as the main yarns while 33 dtex spandex fibers were utilized as the plaiting yarn.

Since micro rayon and lyocell are regenerated cellulosic fibers they do not have any natural color as cotton has. Therefore, they do not need bleaching however; as a pretreatment, mild scouring helps decontamination of fabric samples from spin finish, dirt and dust existing sticked over the surface of the fibers. Because of this, initially, fabric samples were separately washed with water by using ECE detergent in a conventional washing machine at 60°C for 30 min. to remove industrial contaminations remaining in the fabric structure. Then, in order to be rinsed, all of them were separately washed five times in succession with water without utilizing any detergent in a conventional washing machine at 60°C for 15 min. Finally, they were flat-dried at ambient temperature under atmospheric conditions. After the fabric samples were decontaminated from industrial residuals, dyeing process was conducted on all of the fabric samples under identical conditions in ATC-DYE HT01F lab-type exhaust dyeing machine using black reactive dye (SETAZOL Black MMS), salt and soda ash at 60°C for 60 min with a liquor ratio of 1:10. In a conventional washing machine, the dyed fabric samples were washed off with water utilizing ECE detergent at 60°C for 15 min. and rinsed with water at 60°C for 15 min. without using any detergent.

Afterwards, one third of the samples, a control group were not treated with any finishing applications, while the rest of them were treated with the wicking (one third of the samples) or antibacterial finishing applications (one third of the samples). The wicking finish (Ultraphil® PA by Huntsman Textile Effects) was applied at 400°C for 20 minutes however; (Ultrafresh Silpure® FBR by Thomson Research Associates) was used at 600°C for 30 minutes as an antibacterial finish. The factors chosen for the full-factorial experimental study were “fiber type” including lyocell and micro rayon as levels, “spandex content” including with and without spandex as levels and “process history” including none, wicking and antibacterial as levels. Properties of the seamless samples are shown in Table 1. The samples were coded such that the first letter shows the fibre type (L-Lyocell, M-Micro rayon), the second letter refers to the spandex (W-Without spandex, S-With spandex), and finally the last one stands for the process history (N-None, A- Antibacterial, W- Wicking).

2.2 Method

Water vapor permeability (WVP), fabric weight and fabric thickness were tested in accordance with the standards ASTM E96/E96M-16, TS EN 12127 and TS 7128 EN ISO 5084, respectively. The overall porosity defined as the ratio of the open space to the total volume of the porous material was calculated from the measured thickness and the weight per unit area values according to the equations previously reported [21]. The moisture regain of the samples were obtained according to ASTM D2495-07 standard using the “wet” and “dry” weights. The test regarding the measurement of the transfer wicking (TW) was based on Zhuang et. al.’s method with a modification in the method that the pressure applied was kept constant at 15.6 kg/m^2 [22]. According to the method, samples were prepared as 74.5 mm diameter circles. The sample to be wetted out was dipped in distilled water and then, drained with a drying paper for the removal of excess water. Dry fabric sample was put over the wet fabric sample. For the samples placed horizontally, a 74.5 mm diameter dish was put over the top

Table 1. The properties of the seamless samples

			Weight (g/m^2)	Thickness (mm)	Stitch Density (loops/cm^2)	Porosity (%)	Moisture Regain (R)
Micro rayon	Without spandex	MWN	92.5	0.428	144	85.78	8.6
		MWA	89.8	0.426	153	86.13	9.6
		MWW	92.2	0.466	153	86.98	10.0
	With spandex	MSN	395.0	1.249	189	79.19	9.9
		MSA	378.4	1.212	189	79.46	10.3
		MSW	376.7	1.289	198	80.77	10.0
Lyocell	Without spandex	LWN	85.0	0.476	153	86.26	8.3
		LWA	83.3	0.407	153	84.26	9.9
		LWW	78.4	0.446	180	86.48	10.0
	With spandex	LSN	344.8	1.250	198	78.78	8.8
		LSA	315.9	1.178	216	79.37	9.1
		LSW	338.6	1.257	216	79.28	9.6

layer however; the vertically placed samples were put in between two 74.5 mm diameter dishes. After that, external pressure was applied and water was allowed to be transferred for a specific time period. Later on, dry fabric sample was weighed to determine the amount of water transferred from the wet sample. For repetitions of the tests, the fabric sample water was transferred to was dried to its initial state and wet fabric sample was dipped in distilled water. To conduct the tests at the same conditions, weights of the dry and wet fabric samples were initially determined. Each sample was tested for 5, 10, 15, 20, 25, and 30 min. For testing the vertical wicking capacity (VWC), DIN 53924 standard was used. The drying rates (DR) of the fabric samples were determined according to the Coplan and Fourt methods [23, 24]. According to the method, the fabric was cut into 8 cm x 16 cm samples and weighed. The samples were wet-out upon immersion in distilled water for 1 h. They were taken out of water and held suspended in a vertical position for 15 s. Each side of the samples were subsequently held placed flat on drying paper for 2 min to be drained for the removal of excess water. Each of the samples were weighed following the procedure and the values were considered as the maximum water content of the samples for simple drainage. Later on, the samples were hung on a drying rack to be dried in the laboratory under standard atmospheric conditions (65%±2% R.H. and 20°±2 °C). Weights were measured at one hour intervals during the course of drying process to determine the moisture regain as a percentage. The samples were considered as dry at 1% moisture regain and the time corresponding to the duration of the process in which the samples became dry was considered as the drying time. All of the tests were conducted three times. The statistical evaluation of the data obtained from the experimental work was performed using the Minitab 17 and SPSS 18 package programs. The factors were considered to be significant at a level of 95%.

Additionally, the multi-criteria decision approach was utilized for the selection of the best option from the existing alternatives examined in this study. Multi criteria decision making is a branch of Operations Research (OR) which deals with the selection problems under the presence of finite number of decision criteria and alternatives [25]. TOPSIS, a type of multi-criteria method is based on a simple and intuitive concept enabling consistent and systematic criteria based on the selection of the best alternative with the shortest distance from the ideal solution and the furthest distance from the negative ideal solution [25-27]. The ideal solution is regarded as the maximal benefits solution, which includes taking the best value of the alternative however, the negative ideal solution is treated as the minimal benefits solution which is composed of all the worst value of the alternatives and the alternatives are ranked according to the relative closeness to the ideal solutions. AHP is a powerful and flexible multi-criteria decision-making tool structuring a complicated decision problem hierarchically at several different levels, where both the qualitative and quantitative aspects need to be considered [27]. TOPSIS is a more efficient method for handling the tangible attributes and no limit exists in terms of the number of the criteria or alternatives [25]. Therefore, the combination of AHP and TOPSIS can be used for the determination of the liquid transfer properties of garments. In the case of the hybid AHP-TOPSIS method, the pair-wise comparison method of AHP is combined with the other steps of TOPSIS and the procedure of the hybrid AHP-TOPSIS method is explained elsewhere [25-27].

3. RESULTS AND DISCUSSION

3.1 Vertical Wicking Capacity

As can be seen from Figure 1i, MWA samples gave the highest wicking capacity values whilst LSN samples yielded the lowest ones. All the VWC results (Figure 1i) of full-factorial trials were statistically analyzed using the Minitab® package program. It is known that a high R2 value close to 1.0000 with a low standard deviation is the representative of a good statistical model. According to the Minitab analysis, process history was the most effective factor among those studied, which was followed by spandex incorporation to the fabric structure with an R2 value of 0.7500 and a standard deviation of 5.86, respectively. However, two-way interaction effect between these parameters did not exist.

As can be seen from Figure 1iia, the VWC values of the fabric samples made of rayon microfibers without spandex were slightly higher than those of the ones made of lyocell. When a fabric is immersed into a liquid, water enters the space in between the fibers in the yarns and in between the yarns in the fabric [28]. It is reported that the water transport is suppressed as the number of fibers in the yarn decreases [29, 30]. Therefore, based on the literature survey, it is suggested that the higher number of fibers in the micro rayon yarns may be the reason of the higher wicking capacity values. However, after the incorporation of spandex to the fabric, the fabric samples made of both of these fibers performed almost the same and their wicking capacity decreased to approximately the same level. The flow of the liquid through the textiles is caused by the fiber–liquid molecular attraction at the surface of the fiber, which is mainly determined by the surface tension and effective capillary pathways and pore distribution [31, 32]. As stated in a study, the amount of water taken up by a fibrous material is dependent on the porosity of the material such that as the porosity increases, water entrapment by the pores increases accordingly [33]. Hence, the decrease in the porosity of the structure having spandex contributed to a decrease in the wicking capacity of the fabric samples made of both rayon microfibers and lyocell fibers. Furthermore, the utilization of spandex may cause some problems by reducing the thermophysiological wear comfort since spandex is non hygroscopic, however, hydrophobic. Therefore, it is hard for spandex to absorb moisture in its structure and also it cannot be wettable by liquid sweat [2]. The paired t-test supported this result that spandex became an important parameter on the wicking capacity of the sample (t(36)=2.903 p=.006).

As can be seen from Figure 1iib, both of the finishing treatments improved the wicking capacity values of the fabric samples made of lyocell fibers and rayon microfibers which gave the similar tendency meaning that the antibacterial finishing treatment was much more effective on the wicking capacity values than the wicking finishing treatment. Moreover, at the beginning, although the wicking capacity values of the lyocell fabric samples were lower than the micromodal fabric samples, after the finishing applications, they increased to nearly the same level. In other words, these antibacterial or wicking finishing treatments can provide better water-related comfort by removing excessive liquid from the body. With the finishing applications, surface characteristics of cellulosic fibers are expected to change, i.e. the fiber surface becomes rougher and some cracks and damages are

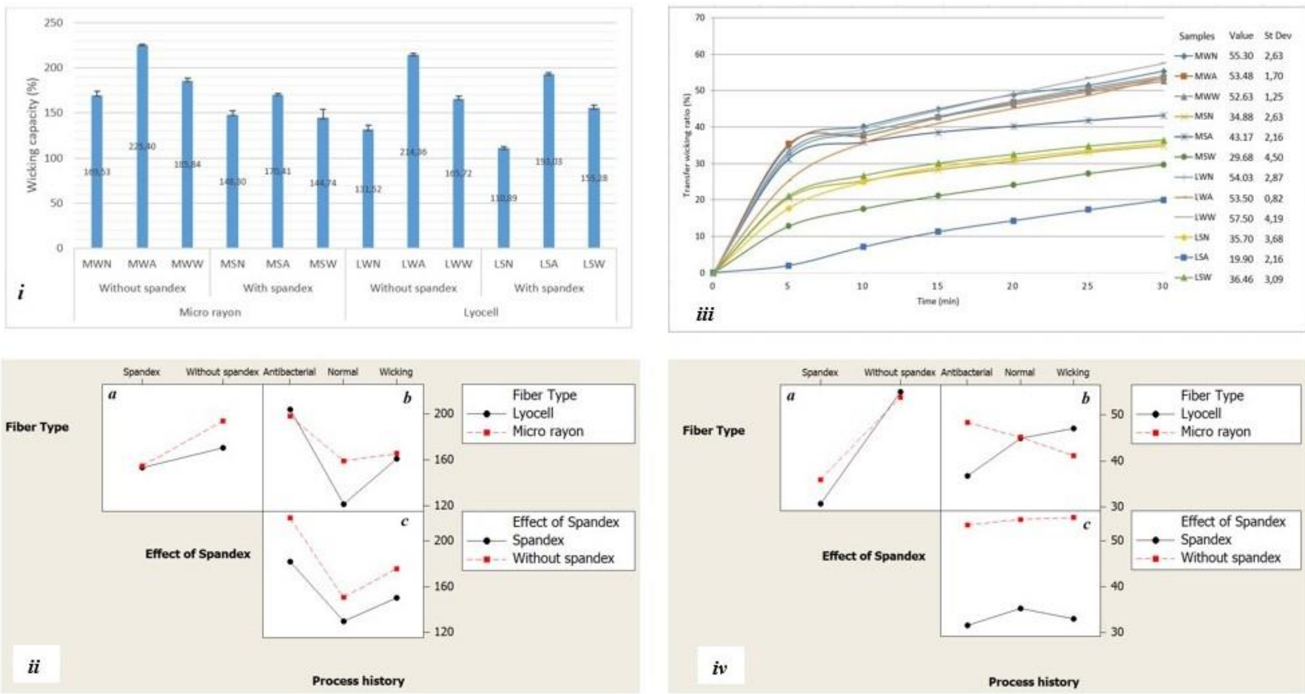

Figure 1. Wicking properties of the fabric samples i) VWC ii) Interaction plot for VWC iii) TW ratios versus time iv) Interaction plot for TW

observed on the surface, which might be caused due to the highly acidic padding bath in the application [34]. Presence of the crosslinkers in the finishing bath decreases acidity which leads to cracks caused by the damage of the cellulosic fibers through the acid hydrolysis of glycosidic linkages [34]. These possible cracks and damages on the surface of the lyocell fibers and rayon microfibers may have created some kind of capillary effect leading to the increase in the wicking capacity values. According to the independent t-test, the finishing treatments influenced the wicking capacity values of the fabric samples ($t(36)=-4.616$ $p=.000$) and also the ANOVA evaluation implied that the wicking capacity values of the fabric samples differed for the three conditions ($F(2,33)=27.274$ $p=.000$).

In addition to this, considering the process history, the wicking capacity of the fabric samples with spandex was lower than that of the ones without spandex for the three different conditions (Figure 1iic). Both of the finishing treatments enhanced the wicking capacity values of the fabric samples with and without spandex with the same trend. However, the antibacterial finishing treatment was observed to be much more influential on the wicking capacity values than the wicking finishing treatment.

3.2 Transfer Wicking

In the first minutes of the test, the TW had a steep increase for all the samples and then became more gradual. Also, as seen from Figure 1iii, among all of the fabric samples, LWW fabric sample had the highest TW ratio, while the LSA one gave the lowest value for the same period. According to the Minitab ® package program results, the presence of spandex in the fabric samples was the main effecting parameter on the TW ratios of the investigated fabric samples with an R2 value of 0.7806 and a standard deviation of 5.23, respectively.

The TW ratios of the samples made of rayon microfibers and lyocell fibers without spandex were almost the same. After the incorporation of spandex to the fabric structure (Figure 1iva), the TW ratios of the samples for both of the fiber types decreased. However, the effect of spandex was found to be slightly more influential on the lyocell ones. Moreover, the difference in the TW ratios of the fiber samples were not statistically significant according to the paired t-test ($t(36)=1.498$ $p=.6$). The reason of the decrease in the TW ratios of the samples after utilizing spandex may be the fabric samples with spandex initially held less water due to not only the hydrophobic structure of spandex but also the reduction of both the amount of pores and pore sizes of the fabric where water fills in, and thus, less amount of water was transferred which is compatible with the literature survey [2, 22, 35]. Also the paired t-test results suggested that spandex was a highly significant factor on the TW ratios of the seamless samples made of not only lyocell fiber but also rayon microfiber (95 % significant level lyocell $t(18)= 11.872$ $p=.000$ and micro rayon $t(18)=8.782$ $p=.000$).

When it comes to the interaction between the fiber type and process history (Figure 1ivb), it was observed that the finishing treatments applied influenced the fabric samples made of lyocell fiber and rayon microfiber differently; such that for the lyocell fabric samples, the TW ratio slightly increased with the wicking finishing treatment, while it slightly decreased with the antibacterial finishing treatment. However, for the fabric samples made of rayon microfibers, the TW ratio slightly increased with the antibacterial finishing treatment, while it slightly decreased with the wicking finishing treatment. According to the literature, porosity and thickness of a fabric are the factors that mainly influence the TW ratio [1, 22, 36, 37]. Fabric thickness and porosity values of the samples with and without any finishing treatments were approximately same hence, no significant difference was expected to occur between the TW ratios of the lyocell and micro-modal fabric samples with and without finishing treatments. Moreover, the independent t-test also implied that the decrease of the TW ratios of the fabric samples were not significant ($t(36)=0.391$ $p=.698$) and the ANOVA statistical evaluation showed there was no significant difference between the TW ratios of the samples for the three cases of the process history ($F(2,33)=0.123$ $p=.885$). On the other hand, these incidents of slight decrease or increase in the TW ratios of the fabric samples with the wicking or antibacterial finishing treatments might be attributed to the cracks thereby, some level of roughness and porosity, occuring on the fiber surface due to the acidic medium in the finishing applications [34, 38]. Since silver particles in antibacterial finishing solution can be incorporated to the fiber structure by the help of the polymer inside the antibacterial finishing receipt because of the bonding mechanism of the finishing agent of the antibacterial finish application on the fiber surface, the surface of the fibers may have been coated effectively and to a high degree with nano-scaled silver particles [39]. Therefore, it may also be attributed to the change in the contact angle of the surface which might have happened by the nanoscaled surface roughness on the fibers. Finally, the interaction plot given for the process history and spandex presence (Figure 1ivc) demonstrated that the TW ratio of the fabric samples with spandex was lower than that of the ones without spandex for the three cases i.e. non-treated, antibacterial and wicking finishes applied. The fabric samples without spandex were more hydrophilic compared to the ones consisting of spandex, because of this, antibacterial and wicking finishes were incorporated more to the structure of these fabric samples leading to some level of increase in the TW. Since thickness and porosity values were approximately same, as expected, the finishing applications did not change TW ratio of the fabric samples without spandex while they slightly decreased TW ratio of the ones incorporated with spandex.

3.3 Water Vapor Permeability

Relative WVP is the rate of water vapor transmission through a material and from Figure 2i, it is apparent that the fabric sample MWN had the highest WVP value, while LSW exhibited the lowest value. The Minitab® program was used to statistically analyze the data in Figure 2i. It was found that when only single effects were considered, the effect of spandex was the most effective factor among those studied in terms of their effects on the resultant WVP values of the fabric samples. Fiber type and process history followed it respectively. Fiber type* spandex incorporation was the two-way deterministic effect (R2=0.9831 and σ=5.14).

Water vapor transfer is the ability of a fabric to transfer perspiration in the form of moisture vapor through its structure and it is measured by the amount of water vapor passing through a square meter of a fabric per day. WVP depends on the construction characteristics of yarns as well as fibers and fabric structure. Thickness and surface characteristics are the other affecting parameters on the WVP of fabrics [33, 40]. As can be seen from Table 1, the mean thickness and porosity values of the fabric samples made of lyocell fibers and rayon microfibers were almost the same. However, since the fiber fineness of the rayon microfiber was smaller than that of the lyocell one, the amount of the free air spaces between the fibers and the yarns for water vapor to flow were higher for the fabric samples made of rayon microfibers without spandex than that of the lyocell ones without spandex. Thus, the WVP values of the fabric samples made of rayon microfibers without spandex were higher as presented in Figure 2iia. Also, the paired t-test showed a significant difference between the vapor permeability values of the fabric samples made of lyocell fibers and rayon microfibers (t(36)=1.876 p=.047). On the other hand, the fabric samples made of both of these fibers performed similarly with the addition of spandex to the production, which resulted in a steep decrease of the WVP values. The decrease was much more effective for the fabric samples made of rayon microfibers; after the spandex incorporation, WVP of the micro rayon and lyocell fabric samples became nearly the same. Both the thickness and porosity of textiles have strong effect on water-vapor diffusion or breathability [29, 35]. When the effect of spandex was considered, the fabric samples produced with spandex fibers were found to have less porous structure and higher thickness as can be seen in Table 1. It was reported that to some extent, the fabric thickness determines WVP with a thicker path facing higher frictional forces during the vapor passage through the fabric [40, 41]. Also, when free spaces in the fabric structure increase, this provides easy passage for water vapor transfer hence, higher moisture transfer occurs through fabric [40, 41]. Because of these reasons, the WVP values of the fabric samples were higher when spandex was not utilized in the production (Figure 2iia). Also, the paired t-test showed that the WVP values of the fabric samples having spandex decreased irrespective of the process history and the fiber type (t(36)=11.514 p=.000).

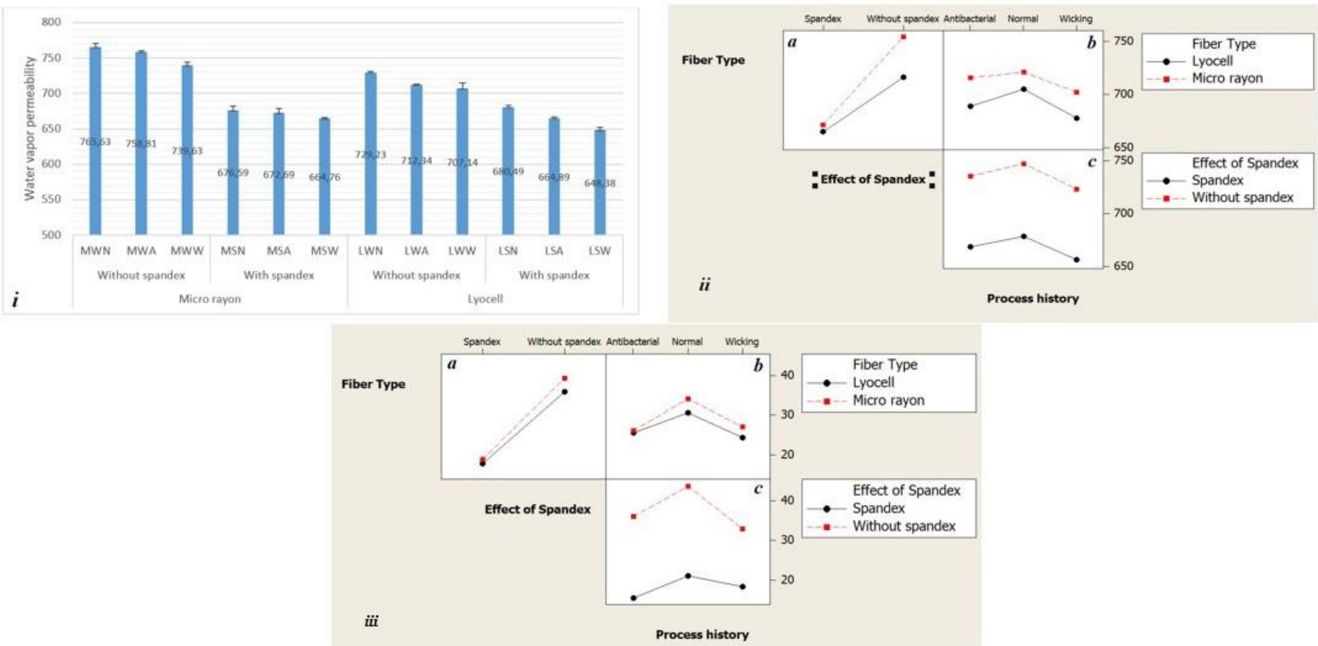

Figure 2. WVP and DRs of the fabric samples i) WVP ii) Interaction plot for MVTR iii) Interaction plot for DR

For the fabrics with higher WVP values, it is easier for water vapor to pass through the fabric to the environment resulting in drier skin thereby, improving water-related comfort. According to the results in Figure 2iib, it was found that the lycocell fabric samples had lower WVP values for the three cases of the process history compared to the micro rayon ones and the finishing treatments slightly reduced the WVP of lyocell and micro rayon fabric samples. Cracks obtained due to the acidic medium in the finishing applications alter the surface characteristics of fibers creating fiber-like structures on the fiber surface, which block the space in between the fibers and as well as the yarns in the fabric structure leading to a decrease in the WVP of fabrics [34, 38]. However, according to the statistical analysis, this reduction was not significant ($t(36)=1.257$ $p=.217$). The ANOVA evaluation showed that there was no significant difference between the WVP values of these three cases of process history irrespective of the fiber type and the spandex incorporation ($F(2,33)=1.085$ $p=.349$). In addition to this, considering the interaction between the process history and the spandex incorporation (Figure 2iic), the WVP of the fabric samples with spandex was lower than that of the ones without spandex for all the cases of treatments due to less porosity in the fabric structure and higher fabric thickness values (Table 1). Moreover, with both of the finishing applications, the WVP of the fabric samples with or without spandex both slightly decreased.

Differently from all of the above findings, the moisture regain, hence the fabric humidity, is an important phenomenon in WVP of fabrics. Thus, in the study, the effect of moisture regain on WVP was also investigated. At the condition of less than or equal to 23% of moisture regain, the major mechanism of moisture transport can be identified as diffusion in fabrics [42]. Moisture regain of all the fabrics of the study were found below 11%. Therefore, in our study, moisture transport mainly took place through the diffusion of water vapor into the fibers leading to fiber swell. As water vapor diffuses in the fiber structure, besides swelling, fiber gets closer to its saturity which reduces the water vapor transfer rate. On the other hand, micro modal and lyocell are hydrophilic fibers which can easily retain water molecules due to their cellulosic structures, so that they can swell resulting in reduction in the porosity of fabrics [40, 43]. All of these mean that as the water vapor transport into the fiber structure (moisture regain) via diffusion increases, fibers get saturated with water. They swell more and end up with a decrease in the fabric porosity. These result in lower fabric water vapor permeability. Therefore, the highest water vapor transfer rate of the hydrophilic fabrics can be also explained by the lowest moisture regain as it was demonstrated in the literature [16].

3.3 Drying Rate

The DRs of the fabric samples were investigated and the results were summarized in Table 2. As can be seen from the table, the MWN samples gave the highest DR whilst the MSA and LSA samples performed the worst ones. The results obtained from the statistical analysis performed by the Minitab® program showed that the spandex incorporation was the main affecting parameter with an R2 value of 0.9298 on the DRs of the investigated fabric samples.

Table 2. Drying properties of samples

Fiber	Spandex	Fabric code	Dry fabric weight (g)	Initial wet-out fabric weight (g)	Initial water amount (g)	Drying rate, $g/h/m^2$	Drying time, h	Standard deviation of drying rate
Micro rayon	Without spandex	MWN	1,313	6,902	5,589	46,67	4,23	1,70
		MWA	1,293	6,798	5,505	36,90	3,39	2,62
		MWW	1,302	6,575	5,273	34,27	3,29	3,84
	Spandex	MSN	5,234	6,931	1,697	21,58	7,52	1,25
		MSA	5,298	6,583	1,285	15,14	7,42	3,09
		MSW	5,443	6,947	1,504	19,67	7,99	1,25
Lyocell	Without spandex	LWN	1,173	6,43	5,257	40,83	3,93	0,82
		LWA	1,25	6,034	4,784	35,33	3,74	2,62
		LWW	1,182	5,852	4,67	31,66	3,43	4,50
	Spandex	LSN	4,895	6,433	1,538	20,40	7,89	1,70
		LSA	4,72	6,141	1,421	15,84	6,68	2,62
		LSW	4,87	6,37	1,5	16,91	6,73	2,16

The interaction plot presented in Figure 2iiia showed that the fabric samples made of rayon microfibers and lyocell fibers with spandex had almost the same DR values however, for the case without spandex incorporation, the micro rayon fabric samples had slightly higher DRs than the lyocell ones. Since DR is defined as the rate of initial wet weight to drying time per unit area of fabric, the DR would be higher when the fabric dries quickly after absorbing high amount of water. As can be seen from Table 2, the DRs of the micro rayon seamless samples without spandex incorporation were higher although they had higher initial water amount. Therefore, it can be concluded that the fabric samples made of rayon microfibers had slightly higher DRs than the ones made of lyocell fibers due to the higher surface area to volume ratio of rayon microfibers and hence higher water evaporation rate. But the paired t-test conducted between the DRs of these fibers showed that the difference was not so meaningful ($t(36)=0.545$ $p=.590$). The data given in Table 2 and Figure 2iiia demonstrated that the spandex incorporation was an important and influential parameter on the drying properties of the fabric samples; such that the DRs of the fabric samples having spandex were seriously lower for both the micro rayon and lyocell seamless samples. Total volume of liquid a material can hold is positively correlated with its thickness [44]. As it is commonly known that the increase in the thickness of a fabric causes higher water absorption [23, 24, 44-46]. In this study, as given in Table 1, the fabric samples having spandex fibers were thicker than those made of only main yarn such as lyocell fiber and rayon microfiber. However, by the incorporation of spandex into the fabric structure, while the thickness increased, the initial water amount did not increase due to both the lower water absorption capability of spandex and the lower porosity as well as the alteration in the interconnectivity of the pores in the fabric structure. According to the results of this study, as a factor, the porosity was more dominant than the fabric thickness. On the other hand, according to the literature, fabric drying-time mainly depends on the amount of liquid it initially takes up into its structure such that lower the initial amount of liquid in the fabric structure higher the DR [16]. Contrarily, although the fabric samples with spandex had lower initial water amount, they had lower DRs. Moreover, in the literature it was also reported that higher VW ability and higher moisture permeability are other factors that increase the DRs of fabrics [16, 22-24, 44, 46]. Therefore, since the VWC and the WVP of the fabric samples with spandex incorporation were both lower than the ones without spandex incorporation, the DR of the fabric samples with spandex incorporation was lower. According to the results of this study, as a factor, the VWC and the WVP were more dominant than the initial water amount in the fabric structure. The t-test supported this result that the effect of spandex on the DRs of the fabric samples was significant at 95% confidence level ($t(36)=-17.771$ $p=.000$).

When the effect of process history was evaluated, after the seamless samples were treated with either antibacterial or wicking finishes, the tendency was similar for both fiber types that the DRs of the seamless samples decreased (Figure 2iiib). If crosslinking ratio is increased, crystallinity of the fibers may be decreased resulting in higher water absorbency. In between the cellulose chains inside the fiber structure, crosslinking may cause voids to which water molecules can easily penetrate. However, if effective three dimensional polymer network cannot be created by crosslinking, this might result in lower water absorbency. When the crosslinking density is increased, more three dimensional polymer network occurs causing the water absorbency to increase, however, if the crosslinking density gets too high, at that time the space in between the polymer chains gets really low causing a decrease in the water absorbency. This means that optimum crosslinking should be obtained for high water absorbency values. Therefore, numerous voids, free spaces and capillaries caused by the crosslinking obtained after these finishing applications can constitute new paths for water to penetrate inside [47-49]. With both of the finishing applications, the water absorbency values of the fabric samples were found to get lower. This may be caused by the highly cross-linked structure of the cellulosic fibers obtained after the finishing applications resulting in a denser structure. Also, this result was supported with the independent t-test that the difference between the untreated and the treated fabric samples was statistically significant ($t(36)=2.961$ $p=.0343$). On the other hand, although, as aforementioned, the initial amount of water in the fabric structure decreased for all of the fabric samples after both of the finishing applications compared to the ones without finishing treatments, their DRs were found to slightly decrease. However, according to the ANOVA evaluation, the DRs of the fabric samples did not vary with the different finishing treatments and the fabric samples behaved in the same manner ($F(2,33)=0.457$ $p=.657$). When it comes to the interaction between the process history and the spandex incorporation to the fabric structure, the DRs of the fabric samples decreased after both of the finishing treatments however, the effect was much more prominent for the ones without spandex (Figure 2iiic). Moreover, the fabric samples without spandex were found to have higher DRs than the ones with spandex for the three cases of the process history.

3.5. Hybrid AHP-TOPSIS Approach

The analytic hierarchy process was employed to find out the relative weights of four decision criteria in terms of their relative importance for the liquid characteristics of the seamless knitted fabrics. The DR, VWC, TW and WVP are the parameters that are important and effective on the liquid transfer characteristics of the fabrics. Therefore, they were taken as criteria and the normalized weights were calculated. The pair-wise comparison matrix of the four decision criteria in terms of their importance level can be seen in Table 3.

Casual and leisure wear apparels are less likely to become soaked with sweat and do not need to dry so rapidly. Consequently, the drying time is less significant for the comfort of the casual and leisure clothing. However, it is not the case for the intimate wear.

For the measurement of the consistency of the judgement, the original matrix is multiplied by the weight vector to acquire the product. λmax was obtained as 4.25073. Since the value of CR is below 0.1 in Equation (1), the comparison matrix remains coherent.

After the identification of the positive (A+) and the negative ideal solutions (A-), the separation of each alternative from the ideal solution was calculated. The relative closeness of the alternatives (Rj) to the ideal solution (Aj) was defined in terms of A+. Based on the closeness of the coefficient to the ideal solution (Rj value), the ranking of the preference order of all the alternatives in descending order is displayed in Table 4. With reference to Table 4, the MWA fabric samples appeared to be the best alternatives whereas the MSW fabric samples were the ones which gave the worst performance.

Table 3. Pair-wise comparison matrix of criteria with the objective and codes

	Transfer Wicking	Wicking Capacity	Drying Rates	Water Vapor Permeability	Normalized Weights	Codes
Transfer wicking	1	1	3	1/3	0.222	C1
Wicking capacity	1	1	3	1/3	0.222	C2
Drying rates	1/3	1/3	1	1/7	0.112	C3
Water vapor permeability	3	3	7	1	0.444	C4

$$CI = \frac{4.25073 - 4}{4 - 1} = 0.083591 \qquad CR = \frac{CI}{RCI} = \frac{0.083591}{0.9} = 0.092879 < 0.1 \qquad \text{(Equation 1)}$$

Table 4. Preference order for the samples

Reference order				
Fabrics	**Pos Ideal (d+)**	**Pos Ideal (d-)**	**Relative Closeness (Rj)**	**Rank**
MWA	0.01	0.07	0.85	1
LWA	0.02	0.07	0.79	2
MWN	0.02	0.07	0.76	3
MWW	0.02	0.06	0.74	4
LWW	0.03	0.06	0.67	5
LWN	0.04	0.06	0.61	6
MSA	0.05	0.04	0.45	7
LSW	0.06	0.03	0.34	8
MSN	0.05	0.03	0.33	9
LSA	0.07	0.03	0.32	10
LSN	0.06	0.02	0.28	11
MSW	0.06	0.02	0.24	12

4. CONCLUSION

According to the results of the study, spandex incorporation to the fabric structure and the process history were all proven to be effective on the VWC values of the seamless samples. For the TW, while the spandex incorporation to the fabric structure was found as the main affecting parameter, the fiber type and process history were both exhibited to have no significant effect. The process history was shown to have no significant effect, whereas the fiber type and spandex incorporation to the fabric structure were found to have significant effects on the WVP. When the DR was considered, according to the findings, both the fiber type and process history had no significant effect, while spandex was the main affecting parameter. While the MWA fabric was the best choice, MSW was the worst according to the AHP-TOPSIS approach. In the futurework, assessment of water-related comfort of the knitted fabrics will be conducted after employing both of the finishing agents simultaneously, as both hygiene and dry feel are very important for comfort of intimate wear. Moreover, fabrics made of synthetic-based and natural-based fibers will be compared with each other in terms of their water-related comfort properties after simultaneous application of these finishes, since it is assumed that the effect of finishing agents will be realized more clearly on the comfort of the fabrics made of the fibers from different origin than similar origin.

REFERENCES

1. Yu W. 2011. Achieving comfort in intimate apparel. Song, G. (Ed.), Improving Comfort in Clothing. Woodhead Publishing Limited, Cambridge UK, 427-448.
2. Bartels VT. 2005. Physiological comfort of sportswear. Shishoo R. (Ed.), Textiles in sports. Woodhead Publishing Limited, Cambridge UK, 177-203.
3. Akaydın M, Gül R. 2014. A survey of comfort properties of socks produced from cellulose-based fibers. *Tekstil ve Konfeksiyon* 24 (1), 37-46.
4. Renzi AI, Carfagna C, Persico P. 2010. Thermoregulated natural leather using phase change materials: An example of bioinspiration. *Applied Thermal Engineering* 30, 1369-1376.
5. Bedek G, Salaün F, Martinkovska Z, Devaux E, Dupont D. 2011. Evaluation of thermal and moisture management properties on knitted fabrics and comparison with a physiological model in warm conditions. *Applied Ergonomics* 42, 792-800.
6. Song G, Cao W, Cloud RM. 2011. Medical textiles and thermal comfort. Bartels VT. (Ed), Handbook of Medical Textiles, Woodhead Publishing Limited, Cambridge UK, 198-218.
7. Rossi RM. 2013. Characterizing comfort properties of flame-resistant fabrics and garments. Kilinc, FS. (Ed.), Handbook of Fire-Resistant Textiles, Woodhead Publishing Limited, Cambridge England, 415-433.
8. Küklane K. 2013. Footwear for cold weather conditions. Luximon A. (Ed.), Handbook of Footwear Design and Manufacture, Woodhead Publishing Ltd, Cambridge UK, 283-317.
9. Pavlidou S, Paul R. 2015. Moisture management and soil release finishes for textiles. Paul R. (Ed.), Functional Finishes for Textiles: Improving Comfort, Performance and Protection, Woodhead Publishing Limited, Cambridge UK, 99-121.
10. Makinen H, Jussila K. 2014. Cold-protective clothing: types, design and standards. Wang F. & Gao C. (Ed.), Protective Clothing: Managing Thermal Stress, Woodhead Publishing Limited, Cambridge England, 3-38.
11. Ravandi SAH, Valizadeh M. 2011. Properties of fibers and fabrics that contribute to human comfort. Song G. (Ed.), Improving Comfort in Clothing, Woodhead Publishing Limited, Cambridge UK, 61-78.
12. Bartels VT. 2011. Improving comfort in sports and leisure wear. Song G. (Ed.), Improving Comfort in Clothing, Woodhead Publishing Limited, Cambridge UK, 385-411.
13. Hunter L, Fan J. 2015. Improving the comfort of garments. Sinclair R. (Ed.), Textiles and Fashion: Materials, Design and Technology, Woodhead Publishing Limited, Cambridge UK, 739-761.
14. Kongdee A, Bechtold T, Burtscher E, Scheinecker M. 2004. The influence of wet/dry treatment on pore structure-the correlation of pore parameters, water retention and moisture regain values. *Carbohydrate Polymers* 57 (1), 39-44.
15. Okubayashi S, Griesser UJ, Bechtold T. 2004. A kinetic study of moisture sorption and desorption on lyocell fibers. *Carbohydrate Polymers* 58 (3), 293-299.
16. Cimilli S, Nergis BU, Candan C, Özdemir M. 2010. Comparative study of some comfort-related properties of socks of different fiber types. *Textile Research Journal* 80 (10), 948-957.
17. Pluut OA, Bianco C, Jakasa I, Visser MJ, Krystek P, Larese-Filon F, Rustemeyer T, Kezic S. 2015. Percutaneous penetration of silver from a silver containing garment in healthy volunteers and patients with atopic dermatitis. *Toxicology Letters* 235 (2), 116-122.
18. Emam HE, Manian AP, Siroka B, Duelli H, Redl B, Pipal A, Bechtold T. 2013. Treatments to impart antimicrobial activity to clothing and household cellulosic-textiles–why “Nano”-silver?. *Journal of Cleaner Production* 39. 17-23.
19. Li R, He M, Li T, Zhang L. 2015. Preparation and properties of cellulose/silver nanocomposite fibers. *Carbohydrate Polymers* 115, 269-275.
20. Emam HE, Manian AP, Siroka B, Duelli H, Merschak P, Redl B, Bechtold T. 2014. Copper(I)oxide surface modified cellulose fibers—Synthesis, characterization and antimicrobial properties. *Surface and Coatings Technology* 254, 344-351.
21. Mukhopadhyay A, Ishtiaque SM, Uttam D. 2011. Impact of structural variations in hollow yarn on heat and moisture transport properties of fabrics. *The Journal of the Textile Institute* 102 (8), 700–712.
22. Zhuang Q, Harlock SC, Brook DB. 2002. Transfer wicking mechanism of knitted fabric used as under garments for outdoor activities. *Textile Research Journal* 72 (8), 727–734.
23. Coplan MJ. 1953. Some moisture relations of wool and several synthetic fibers and blends. *Textile Research Journal* 23, 897–916.
24. Fourt L, Sookne A, Frishman MD, Harris M. 1951. The rate of drying of fabrics. *Textile Research Journal* 21, 26–32.
25. Majumbar A, Sarkar B, Majumbar PK. 2005. Determination of quality value of cotton fibre using hybrid AHP-TOPSIS method of multi-criteria decision-making. *The Journal of the Textile Institute* 96 (5), 303-309.
26. Moghassem AR, Bahramzadeh H. 2010. Application of multi-criteria analysis for parameters selection problem in rotor spinning. *Textile Research Journal* 80 (20), 2176-2187.
27. Shyjith K, Ilangkumaran M, Kumanan S. 2008. Multi-criteria decision making approach to evaluate optimum maintenance strategy in textile industry. *Journal of Quality in Maintance Engineering* 14 (4), 375-386.
28. Prahsarn C. 2001. Factors influencing liquid and moisture vapor transport in knit fabrics (PhD thesis), NCSU, Raleigh, USA.
29. Gun AD. 2011. Dimensional, Physical and Thermal Properties of Plain Knitted Fabrics Made from 50/50 Blend of Modal Viscose Fiber in Microfiber Form with Cotton Fiber. *Fibers and Polymers* 12 (8), 1083-1090.
30. Ito H, Muraoka Y. 1993. Water Transport Along Textile Fibers as Measured by an Electrical Capacitance Technique. *Textile Research Journal* 63 (7), 414 – 420.
31. Hsieh YL. 1995. Liquid transport in fabric structures. *Textile Research Journal* 65 (5), 299-307.
32. Zhu Q, Li Y. 2003. Effects of pore size distribution and fiber diameter on the coupled heat and liquid moisture transfer in porous textiles. *International Journal of Heat and Mass Transfer* 46, 5099–5111.
33. Das B, Das A, Kothari V, Fanguiero R, Araujo MD. 2009. Moisture Flow through Blended Fabrics – Effect of Hydrophilicity. *Journal of Engineered Fibers and Fabrics* 4 (4), 20-28.
34. Poon CK, Kan CW. 2015. Effects of TiO_2 and curing temperatures on flame retardant finishing of cotton. *Carbohydrate Polymers* 121, 457–467.
35. Gun AD. 2011. Dimensional, physical and thermal comfort properties of plain knitted fabrics made from modal viscose yarns having microfibers and conventional fibers. *Fibers and Polymers* 12 (2), 258-267.

36. Nyoni AB, Brook D. 2006. Wicking mechanisms in yarns—the key to fabric wicking performance. *Journal of the Textile Institute* 97 (2), 119-128.

37. Ramachandran T, Kesavaraja N. 2004. A study on influencing factors for wetting and wicking behavior. *IE(I) Journal –TX* 84, 37-41.

38. Simoncic B, Klemencic D. 2016. Preparation and performance of silver as an antimicrobial agent for textiles: A review. *Textile Research Journal* 86 (2), 210–223.

39. Ghosh S, Yadav S, Reynolds N. 2010. Antibacterial properties of cotton fabric treated with silver nanoparticles. Journal of the Textile Institute, 101 (10), 917–924.

40. Prahsarn C, Barker RL, Gupta BS. 2005. Moisture Vapor Transport Behavior of Polyester Knit Fabrics. *Textile Research Journal* 75 (4), 346-351.

41. Ozdil N, Marmarali A, Kretzchmar SD. 2007. Effect of yarn properties on thermal comfort of knitted fabrics. *International Journal of Thermal Sciences* 46 (12), 1318-1322.

42. Adler MM, Walsh WK. 1984. Mechanisms of Transient Moisture Transport between Fabrics. *Textile Research Journal* 54 (5), 334-343.

43. Yoo HS, Hu YS, Kim EA. 2000. Effects of Heat and Moisture Transport in Fabrics and Garments Determined with a Vertical Plate Sweating Skin Model. *Textile Research Journal* 70 (6), 542–549.

44. Crow RM, Osczevski RJ. 1998. The interaction of water with fabrics. *Textile Research Journal* 68 (4), 280-288.

45. Li Y. 2001. The science of clothing comfort. *Textile Progress* 31 (1-2), 1-135.

46. Benltoufa S, Fayala F, Nasrallah SB. 2008. Capillary rise in macro and micro pores of jersey knitting structure. *Journal of Engineered Fibers and Fabrics* 3 (3), 47-54.

47. El-Shafei A, ElShemy M, Abou-Okeil A. 2015. Eco-friendly finishing agent for cotton fabrics to improve flame retardant and antibacterial properties. *Carbohydrate Polymers* 118, 83–90.

48. Popescu V, Vasluianu E, Popescu G. 2014. Quantitative analysis of the multifunctional finishing of cotton fabric with non-formaldehyde agents. *Carbohydrate Polymers* 111, 870–882.

49. Lai SL, Yu JF, Wang JL, Chen YS. 2016. Preparation and Properties of Sepiolite Clay-based Superabsorbent Resin under Microwave Irradiation. In Y Liu & Y Peng (Ed.). Proceedings of the 2015 International Conference on Advanced Material Engineering (pp. 150-158). World Scientific Publishing Co. Pte. Ltd., Singapore.